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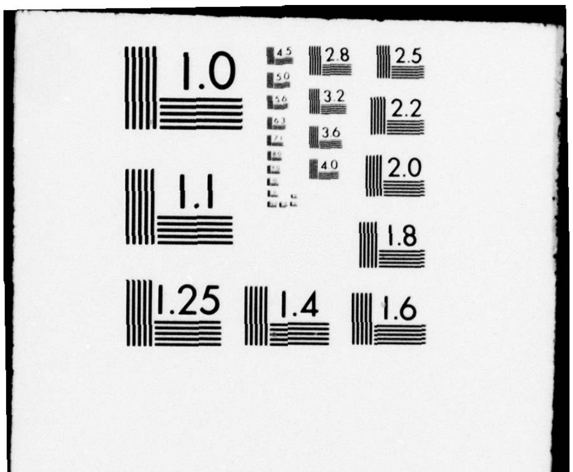

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Volume 18 1976 Numbers 1, 2, 3

LEVEL II

Fire Research Abstracts and Reviews

National Academy of Sciences

FIRE RESEARCH ABSTRACTS AND REVIEWS

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

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FOREWORD

We regret to announce that, with the inactivation of the Committee on Fire Research, this will be the final issue of FIRE RESEARCH ABSTRACTS AND REVIEWS.

Your editor expresses his thanks to the members of the Committee, both past and present, for their support and advice. Over the past 20 years the Committee has acted as a catalyst and national focal point for the efforts to apply rational scientific and engineering principles to the mitigation of the nation's fire problems. The members are to be congratulated on their vision and steadfastness. The Committee would not have existed except for the support of a number of governmental agencies. The agencies were represented by managers who saw the national fire problem as a part of their public charge and believed enough in the effort to struggle for its support. They deserve the thanks of the fire research community and of the country at large.

FIRE RESEARCH ABSTRACTS AND REVIEWS has been a labor of love of a small group who believed in its objectives and usefulness. You will find their names on the inside cover of each issue and compiled below. The names have changed through the years, but these are real people who have dedicated their efforts toward mitigating our national fire problem. These colleagues have made FIRE RESEARCH ABSTRACTS AND REVIEWS a unique reality. Finally, we thank the contributors, the abstractors, and you, the readers who have used the information. We hope that this publication has assisted you and wish you success in the coming years.

ROBERT M. FRISTROM
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BOOKS

MEETINGS

NEW JOURNALS

DETECTION AND SMOKE PROPERTIES*

ROBERT LEVINE

National Bureau of Standards
Gaithersburg, Maryland

INTRODUCTION

In this paper I will first briefly review the state-of-the-art capabilities of different kinds of detectors, then discuss smoke research that is relevant to properties that should be measured to make detectors more reliable and sensitive to real fires, and free of false alarms. We shall consider primarily detectors used in residences and, secondarily, commercial establishments and care institutions (hospitals and nursing homes). Factories, mines, etc., present special problems which I do not plan to discuss. This choice is justified by the fact that in the U.S. the vast majority of the fires and of the fire deaths take place in residences. Over two million smoke detectors were sold in the U.S. last year, and some local governments soon will require their use in new and resold residences.

STATE OF ART OF DETECTORS

There are five generic kinds of detectors in use today. I will briefly review the state-of-the-art and the strong points and the deficiencies of each type.

HEAT DETECTORS

This is the oldest kind of detector. It may include a thermostatic switch that closes at a fixed temperature, say 70° C, or a rate-of-rise sensitive switch, or both. These detectors are usually reliable in operation, easily tested, the external circuit easily tested, and they are free of false alarms. The only trouble is that the people may be dead before the alarm activates. The reason is that most deaths in residences and institutions are due to toxic gases and smoke, and the heat detector activates only late in the development of the fire. So detectors are needed that will activate earlier and be sensitive to smoke particulates, oxidizable gases, or radiation that arise from fires.

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*Prepared for the 2nd Joint Meeting, U.S.-Japan Panel on Fire Research and Safety, UJNR, Tokyo, October 19-22, 1976.

IONIZATION DETECTORS

One kind of detector that is sensitive to particulates is the ionization detector. This kind is currently the most popular in the U.S. for residences. A very small radioactive source provides alpha particulates to ionize air in a chamber, and a sensitive solid-state electrical circuit senses the ion current. When particulates enter the chamber they reduce the ion current, and the alarm is triggered. Recent models of this device, whether battery powered or line-powered, retain a fairly constant sensitivity with time and, of course, are easily tested with a match or cigarette. One additional factor, both an advantage and a disadvantage, is that the detector is sensitive to sub-micron aerosols (0.005 microns and above) as well as to visible smoke (0.5 microns and above). These sub-micron aerosols are released from many heated fuels at temperatures as much as 50°C below the temperature at which the material releases visible smoke. So the ionization detector gives early warning when certain types of ignition occur — for instance, overheating due to a poor electrical connection. But the detector is also sensitive to the aerosols produced in cooking and other household activities, and may cause false alarms. Since the average incidence of fire in residences in the U.S. is once per 50 to 100 years, even one false alarm per year will give 50 false alarms per each real fire. This causes a serious problem in detector credibility, and probably precludes using this type of detector to furnish a signal automatically to the fire department for fires in residences.

A second problem with this detector, and also other kinds of detectors, is the placing of them where the air currents that normally exist in the structure will carry the aerosols to the detector and through it. Remember that for early warning we cannot always wait for the buoyancy-driven air circulation from a hot fire to transport the smoke to the detector, and that under some weather conditions stagnant air may be present in the house (neither the heating or air conditioning operating). Current thought is to install at least one detector at each level (story) of the house. Since heat from the sun can cause a stagnant hot layer of air next to the ceiling of the top story, the detector in that story possibly should be mounted on a sidewall about 15 to 30 cm below the ceiling. Recent tests in houses show that one detector on each level will give almost a 90% probability of a warning at least 3 minutes before the escape path becomes unpassable.[4]

An advanced version of the ionization, developed for the space shuttle vehicle, avoids false alarms by a combination of particulate separation and intelligence.[1] An 11 watt fan pumps air through the unit and the air that enters the sensitive ion chamber previously passes through a channel that deposits particles larger than ½ micron. This prevents false readings due to dust. The output voltage is digitalized and feeds a micro-computer that looks at intensity and duration. The computer is programmed to ignore some signals, alert the crew to others, and signal "fire" if the signal is strong and long enough. This system is not economic for residences, but is said to be applicable for systems with greater than 30 detectors.

COMBUSTIBLE GAS DETECTORS (TAGUCHI)

This detector uses a semiconductor device, kept hot by an electrical current, whose resistance changes when it is in contact with an oxidizable gas such as CO or a hydrocarbon. The device is not sensitive to smoke particles, either in the submicron or micron range. Nor is it sensitive to the gases from small fires if the fires are clean-burning and hence to do not produce oxidizable vapors. The sensitivity to CO may be small in some models. For these reasons, the Taguchi detector may not warn of a fire as early as the ionization detector.

Taguchi detectors are also subject to false alarms, since they are sensitive to various organic vapors used about the house (rubbing alcohol, for example), and to quick changes in relative humidity, such as steam from a shower bath. So, although they are considered better than a heat detector as a reliable safety device, the NBS Center for Fire Research has issued a critical report.[3] Not all parties in the U.S. agree with this negative assessment. We understand that the Factory Mutual System has approved 12 versions of this device.

PHOTOELECTRIC DETECTORS

This kind of detector is sensitive to visible smoke, but not to the smaller aerosols that are generated earlier in the pyrolysis process. There are several modes of operation. One depends on light scattered at an angle onto a photosensitive surface from a parent beam of light. Another senses light obscuration. In the case of installation where the light beam traverses a long path to protect an extended region, refractive index gradients caused by local heating of the air can deflect the beam, resulting in a lessened signal or a signal from an off-axis detector. This makes it possible to detect fires over an extended region. In practice, the most characteristic attribute of a fire distinguishing it from other heat sources is a 40-80 hz flutter of the photocell output.[8]

Until now, it has been necessary to equip photoelectric systems with a way of testing for light source and circuit integrity, since a failure of either would destroy the system but not result in an alarm or otherwise alert the user. One of the most common problems is the burning-out of the light source. The advent of long lived light emitting diodes and internal compensation for dirt collecting in the light paths promise rapid improvement in photoelectric detector. Versions using LED's are already commercially available in the U.S. One advantage of these photoelectric detectors is that they are less subject to false alarms than the other sensitive detector systems.

INFRA-RED AND/OR ULTRA-VIOLET DETECTORS

The smoldering stage of a fire has little infra-red or ultra-violet light emission, but a diffusion flame is characterized by both. Further, diffusion flames emit a strong 1-10 hz flicker in the infra-red, and sunlight generally does not, so detection systems can be designed that are sensitive only to the fire, and not to sunlight or other sources, whether direct or reflected. Amplifiers and electrical filters that are sensitive to flicker in the 1-10 hz range are used. (Illumination and other infra-red sources may flicker at the electrical supply frequency.) Sunlight does have some modulation due to atmospheric scintillation, so it is sometimes necessary to use photocells and filters that look simultaneously at two different wavelengths, as well as amplifiers that are sensitive only in the flicker frequency range. Since the sun approximates a 6000° K black body, and sooty flames approximate a 1500° K black body, the ratio of the signal at short wavelength to that at long wavelength will be larger for sunlight than for a diffusion flame. Detectors using this system are generally not used for residences, since they are more expensive than other types and are not sensitive to smoke. They are generally designed for the particular optical field of view and the sensitivity required in the given special purpose application.

One advanced detection system developed for aircraft use by the U.S. Air Force requires simultaneous signals from two detectors to signal a fire. One of these senses flicker in the infra-red, the other senses ultra-violet light at wavelengths shorter than 270 nanometers. The ultra-violet in the sun's spectra at these short wavelengths is filtered out by stratospheric ozone, so its presence in an aircraft is a reliable indiction of fire, at least at altitudes below about 25 km. Note the use of two separate tests to confirm fire to avoid false alarms. In aircraft, false alarms are serious in that the action the pilot may take, believing he has a fire, may hazard his aircraft and his passengers.

NEEDED RESEARCH

We see from the above that we have four sensitive inexpensive detectors that are reliable enough for use in residences and institutions, but are subject to false alarms. We also have sophisticated systems that are sensitive to fires and resistant to false alarms, but these are definitely not inexpensive. So a need exists for an inexpensive way to incorporate fire/no-fire discrimination into inexpensive detectors. Only with this improvement will it be possible to automatically energize an extinguishment system or to notify the Fire Department. This is one reason we are carrying out research on the properties of smoke derived from various fires and of particulates from various other sources. Another reason for research is to improve our ability to measure the sensitivity and change in sensitivity of fire detectors — important if there is to be an agreed upon standard test. The research described in the following section is carried on at NBS, the University of Minnesota (Prof. Liu) and at Georgia Institute of Technology (Prof. Ben Zinn).

SMOKE RESEARCH

INTRODUCTION

The objectives of the Smoke Research Projects in the U.S. include providing basic data on the physical properties of fire-generated and ambient smokes. These include smoke generation rate from materials, particle size-distributions, light scattering and absorption; mobility and aging of fire smokes.

SMOKE GENERATION RATE FROM MATERIALS AND PARTICLE SIZE

At the Georgia Institute of Technology,[10] Prof. Zinn and coworkers have evolved a Combustion Products Test Chamber that pyrolyzes materials in a horizontal or vertical position, at a selected radiant flux, flaming or non-flaming, and at air temperatures from room temperature to 650°C. All of these parameters may have significant influence on the smoke properties from a given material, as shown in Figures 1, 2, 3, and 4. The abscissa shows time during the test, not aging of the smoke. The apparatus is partly described in Reference 9. An elaborate system of radiators and heaters using quartz lamps and baffles has been added.

During flaming combustion, particle sizes are generally smaller and particulate mass fractions are lower than under non-flaming conditions at comparable weight loss rates. Zinn[10] states that at low temperatures the effects of changes in atmospheric composition are relatively insignificant (10 to 21% oxygen) on the particles produced with both flaming and non-flaming combustion. These results are generally confirmed at NBS. Pyrolysis of some polymeric materials shows that smoke generation rate is less sensitive to temperature change than with cellulose. In many cases, an increase in air temperature not only increases the generation rate but also the particle size. After the ignition temperature is reached, there may be a large increase in generation rate, in contrast to the cellulose case.

PARTICULATE ANALYSIS

Reference [9] and also NBS analyze the smoke for particle size, etc., with a variety of instruments.* At Georgia Tech the sample is first passed through an Andersen Sampler (Model 21-000) to measure particle size distribution in the range of 0.43 to 11 microns. A second sample is measured by a Whitby Electrical Aerosol Analyzer (Thermal Systems Inc., Model 3030) for the range 0.01 to 1.0 microns. The latter gives a complete distribution each 1.5 minutes while the Andersen analyzer (a cascade impactor) gives only one distribution per test, but the material collected can be subjected to chemical analysis after the test.

LIGHT SCATTERING PROPERTY OF SMOKE

Mie scattering intensity at various scattering angles and beam polarization depends on the size distribution, refractive index, and shape of the particles. Thus smoke identification may be based on differences of refractive index and size by measuring the scattering intensities at several angles located at two planes — one parallel and one perpendicular to the polarization plane of a polarized light beam.

Figure 5 shows a small laser arranged to demonstrate that different aerosols scatter polarized light differently. The light from the laser passes through two glass cylinders, one containing cigarette smoke and the other smoke from pyrolyzed rubber carpet backing. A mirror is located so that one can see light scattered 90° relative to the beam in two planes from both cylinders. Figure 6 shows that the

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*The use of trade names is for identification only and does not imply approval or disapproval of the instruments by NBS.

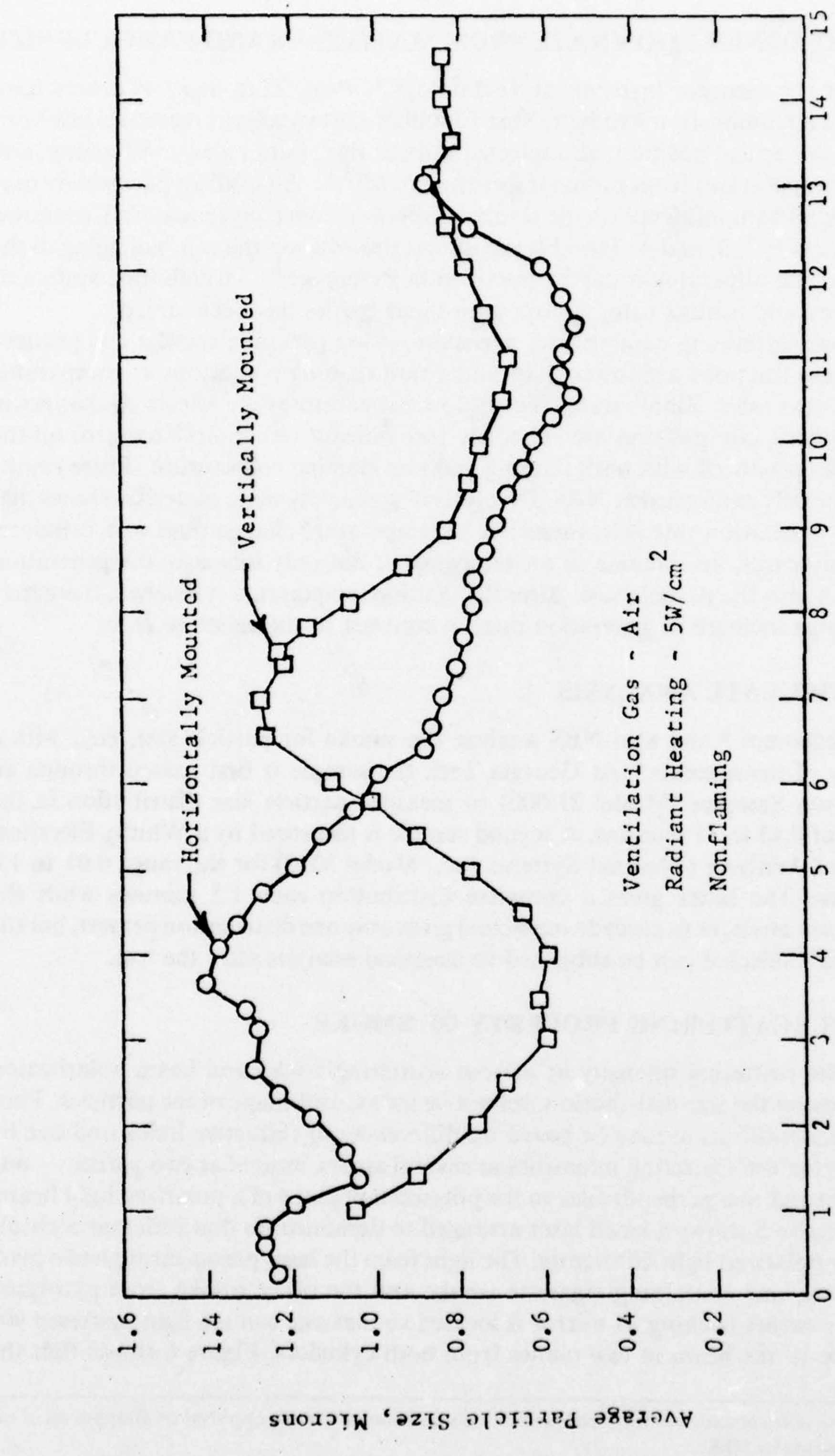


FIGURE 1 Comparison of smoke particle sizes for wood samples in horizontal and vertical orientations. (Reference 10)

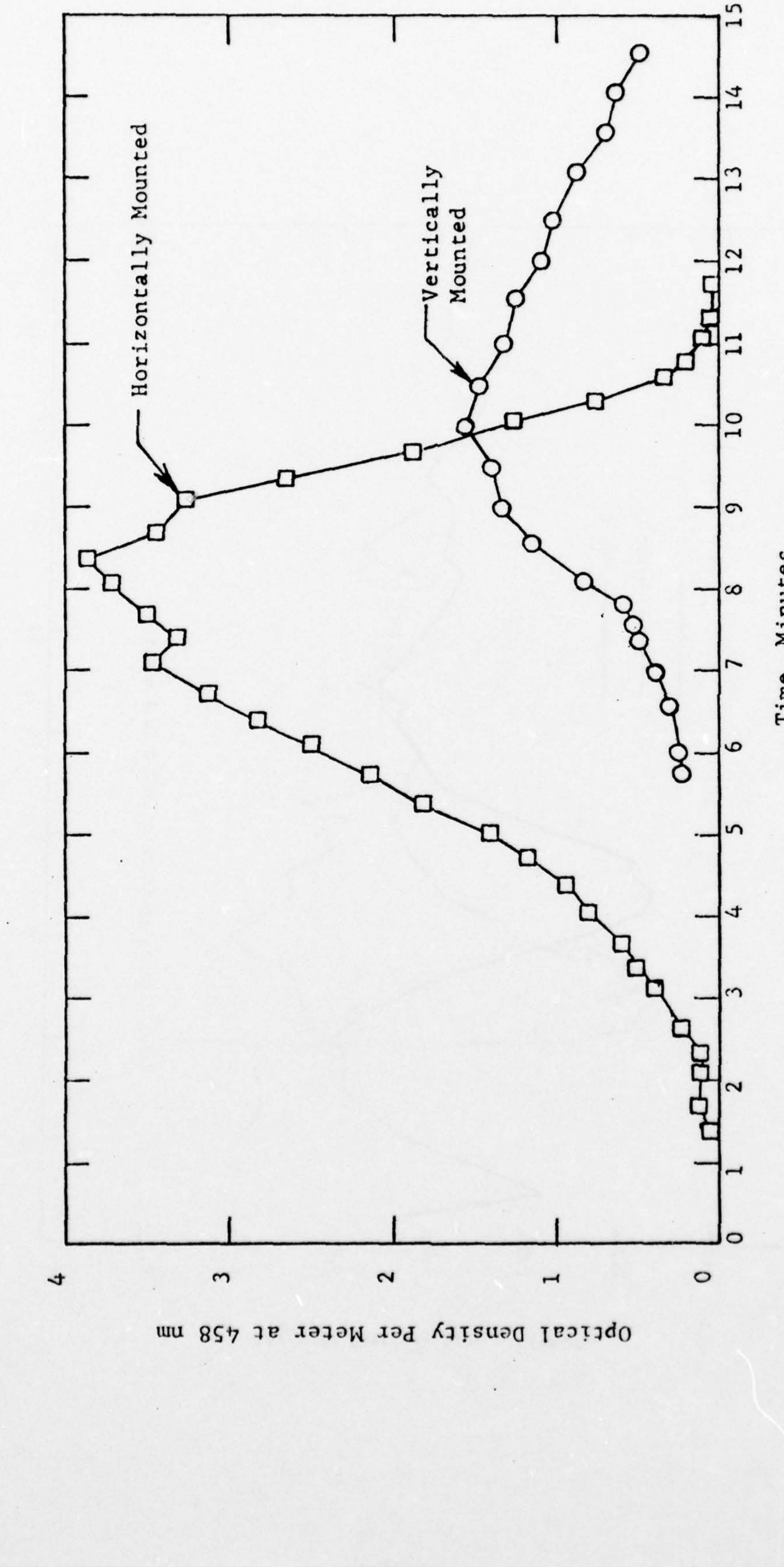


FIGURE 2 Comparison of smoke optical density for wood samples in horizontal and vertical orientations. (Reference 10)

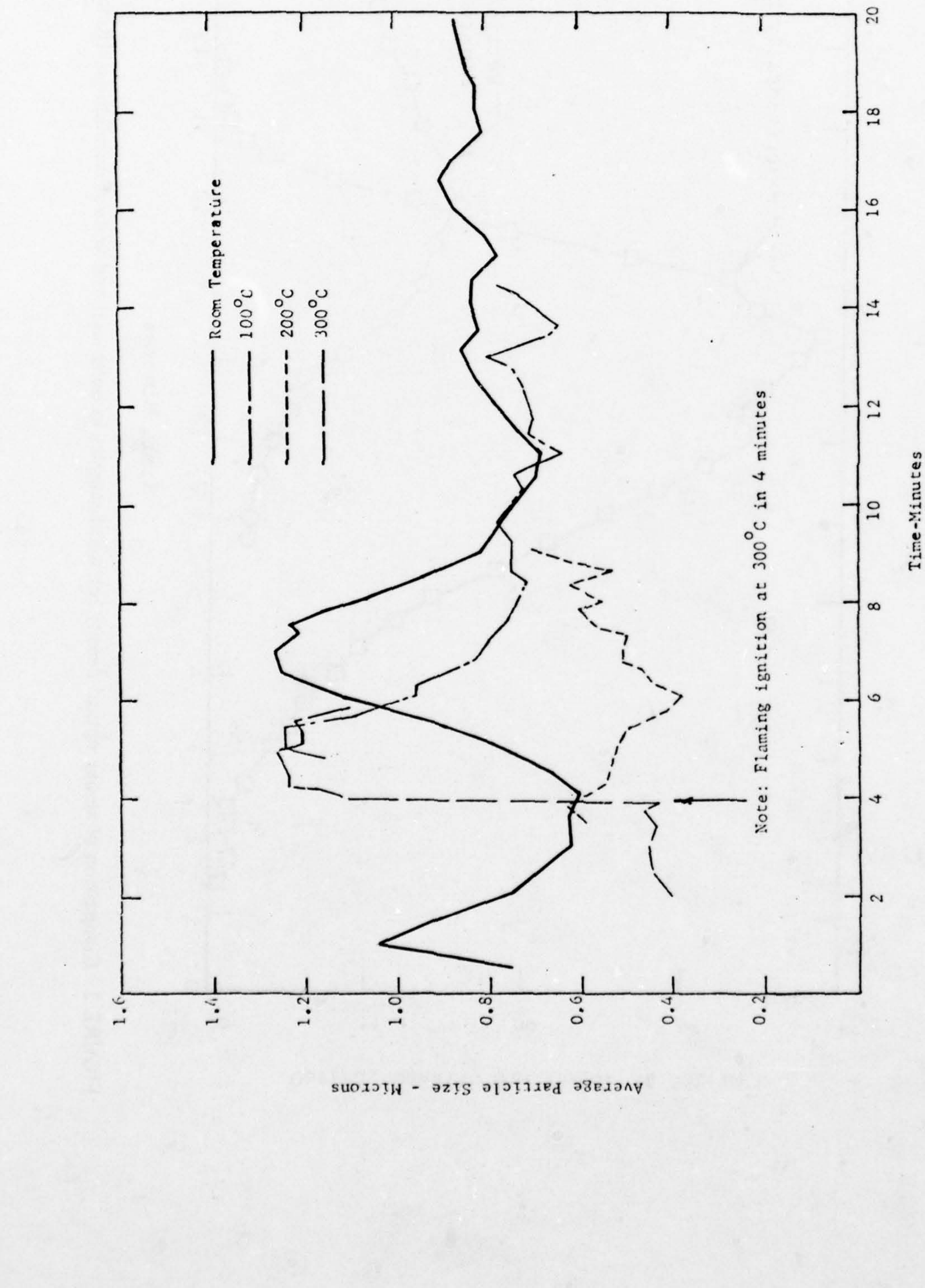


FIGURE 3 Particle size variations for smoldering wood in air at different temperatures. (Reference 10)

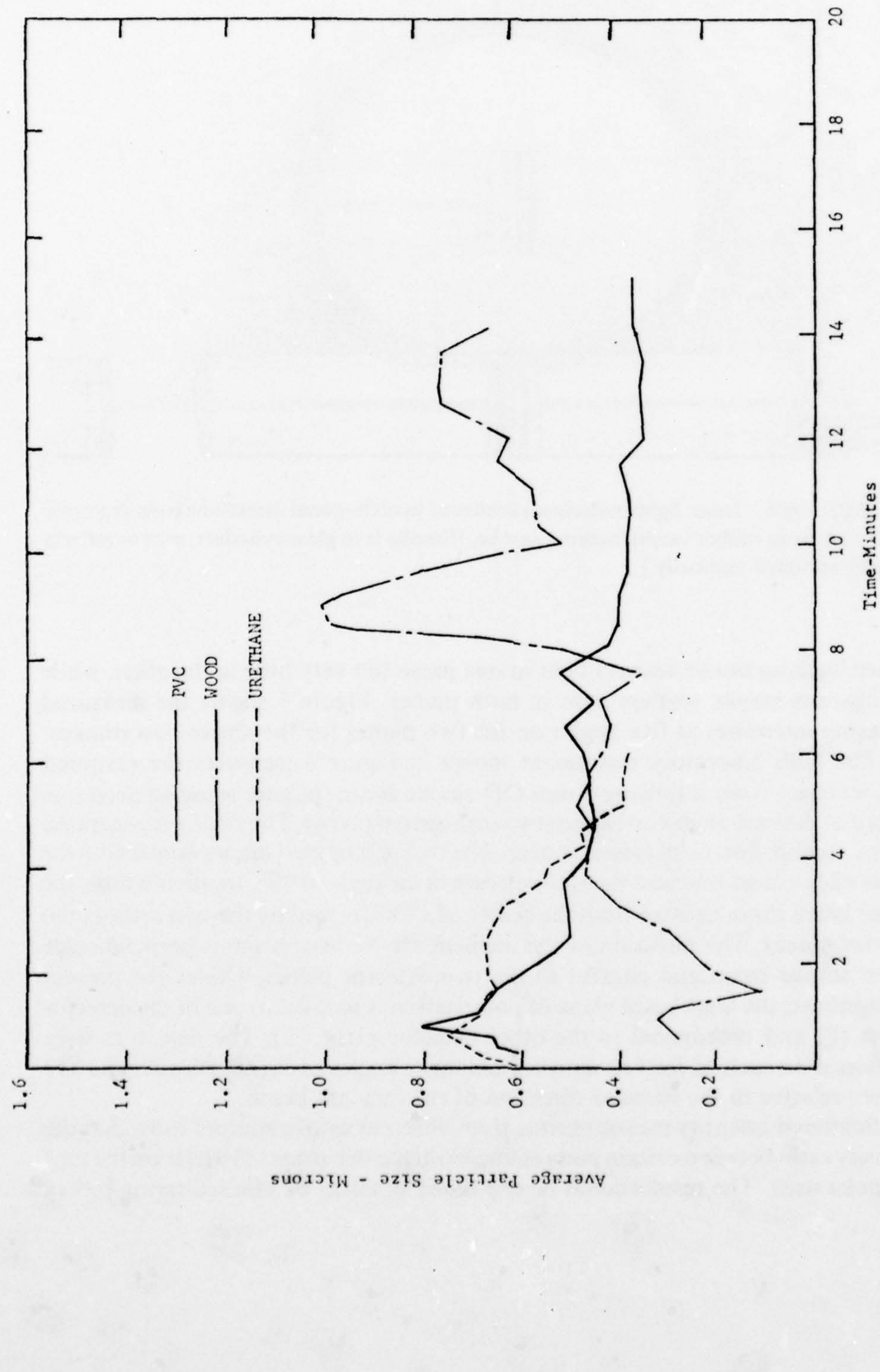
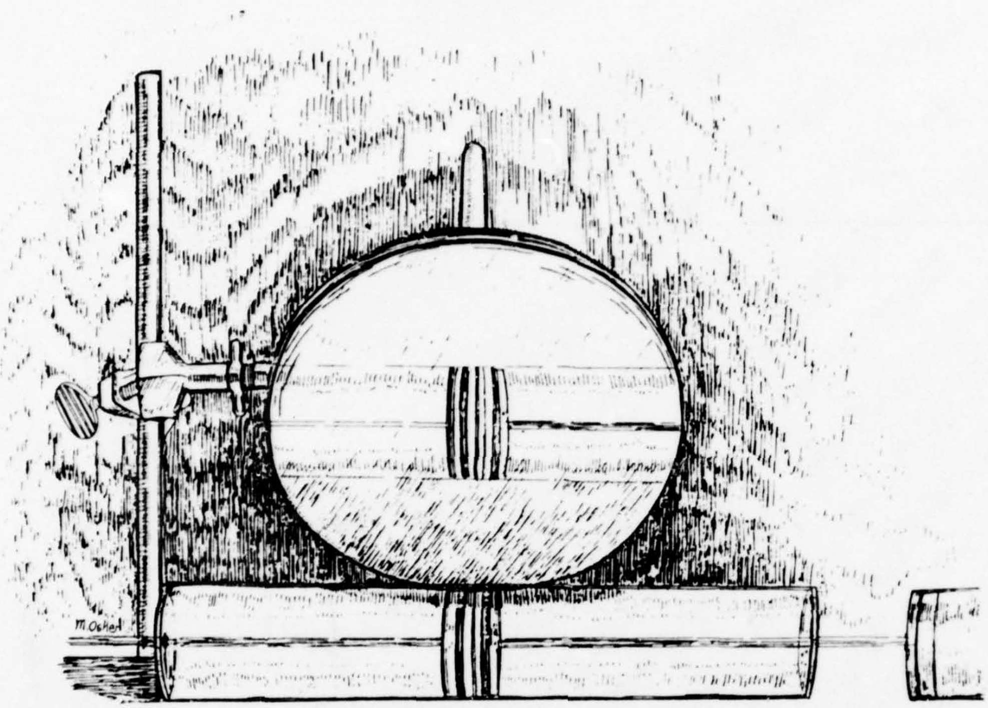


FIGURE 4 Particle size variations during flaming combustion in air. (Zinn, Reference 10)



FIGURES 5 & 6 *Laser light (polarized) scattered in orthogonal directions from cigarette smoke and from rubber carpet backing smoke. (Smoke is in glass cylinders, mirror reflects the light scattered vertically.)*

rubber-backing smoke scatters light in one plane but very little in the other, while the cigarette smoke scatters light in both planes. Figure 7 shows the measured scattering intensities at five angles on the two planes for the above two smokes.

The NBS laboratory instrument shown in Figure 8 measures the scattered light intensity from a flowing 5-mm OD smoke beam (plume) using 10 detectors located at discrete angles on each of two orthogonal planes. The smoke is generated from a combustion or pyrolysis source. The two orthogonal planes containing the banks of detectors intersect the smoke beam at an angle of 45°. In other words, the smoke beam flows upward from the center of a "V" formed by the two orthogonal detector planes. The direction of the incident He-Ne laser beam is perpendicular to the smoke beam and parallel to the two detector planes. Under the present arrangement, the laser beam plane of polarization is parallel to one of the detector planes ($\|$) and orthogonal to the other detector plane ($\perp$). The detectors were positioned on each of the two detector planes at angles of 30, 60, 90, 120, and 150 degrees relative to the forward direction of the incident beam.

Scattered intensity measurements from different smoke sources show that the intensity ratio between certain pairs of angles on the two planes depends on the type of smoke used. The results could be explained in terms of Mie scattering theory

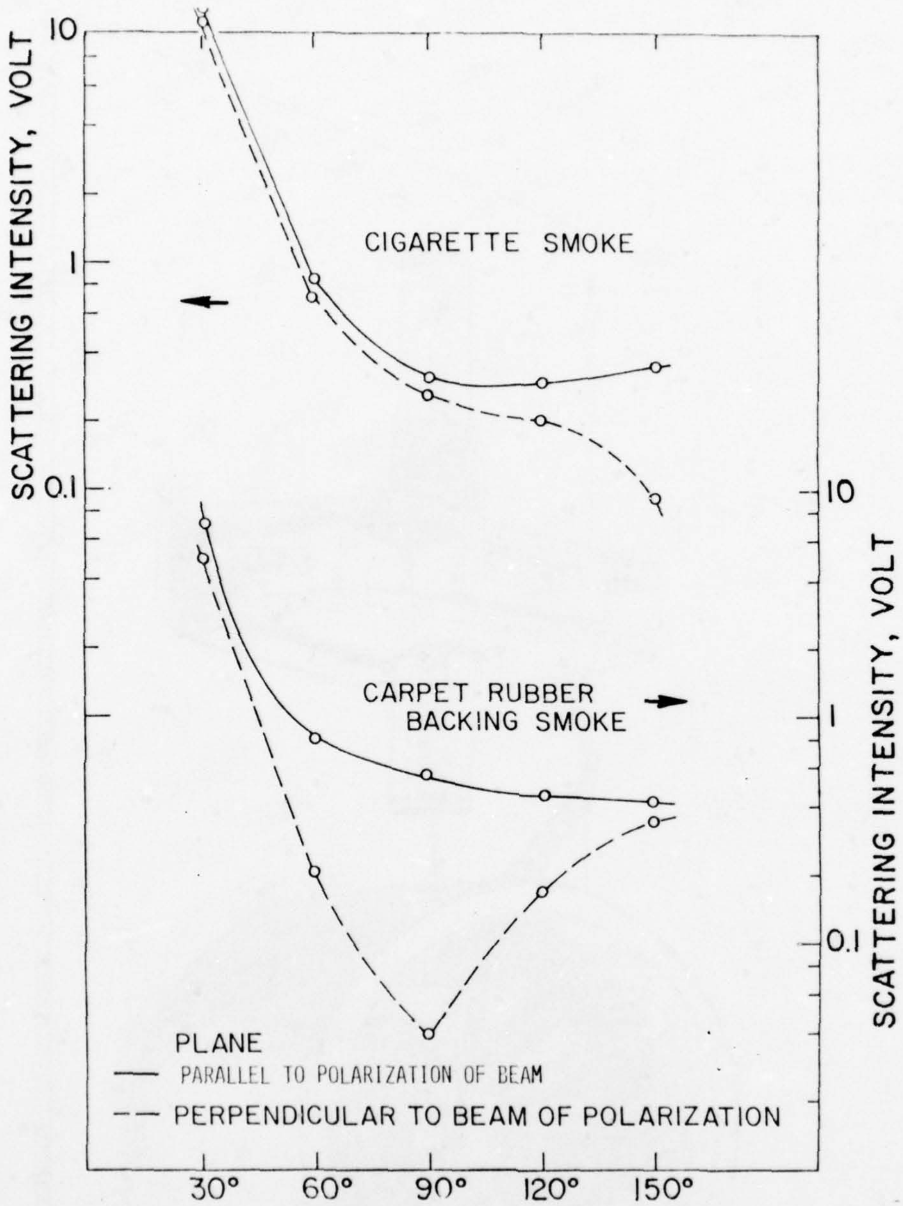


FIGURE 7 Scattering intensity, volt.

which attributes such differences to variation of refractive index, especially the imaginary part, and the particle size distribution of different smokes.

Data plotted in Figure 9 show the ratios of scattered intensities of 30° ⊥ and 150° ⊥ versus 90° || and 150° ⊥ for some smokes, and the effect of aging. Scattering ratios of highly opaque smoke (lower left, Figure 9) are not sensitive to aging. The concentration of the smoke used was in the order of 10^6 particles/cc; comparable

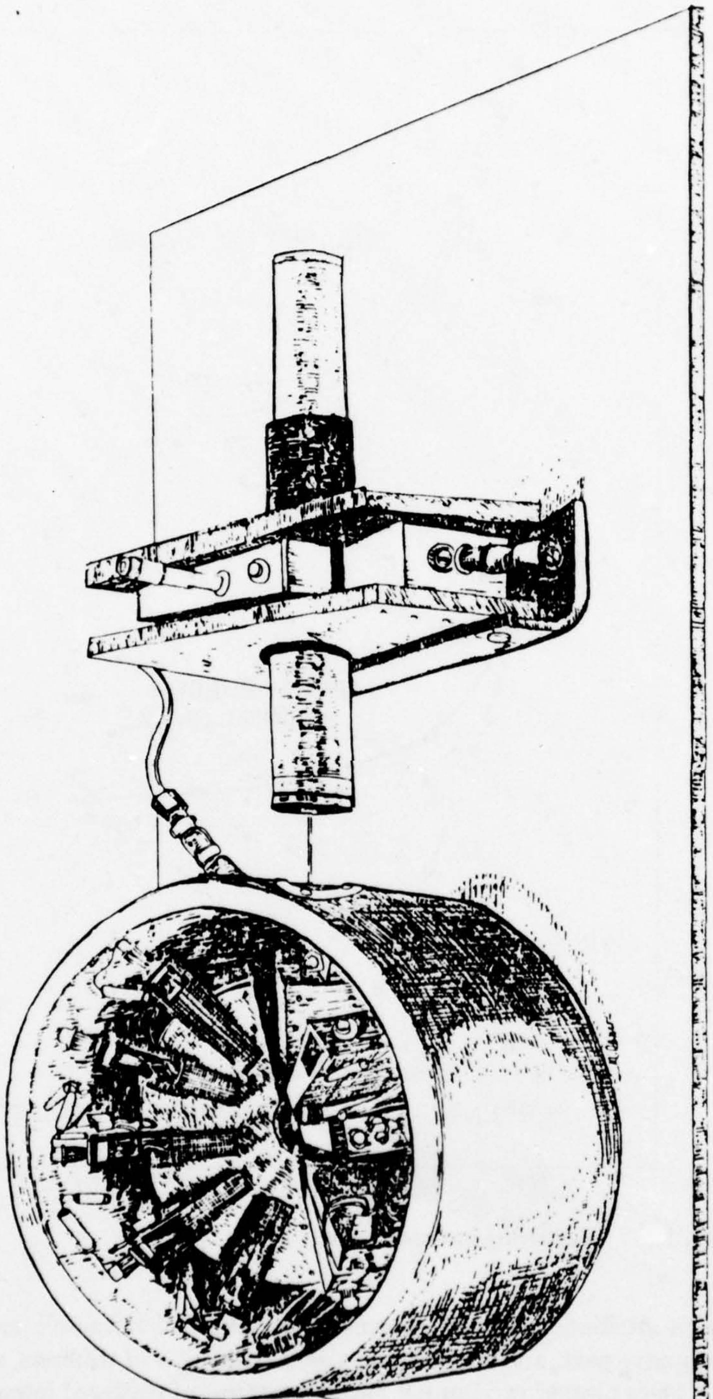


FIGURE 8 NBS laboratory instrument for measuring light scattered from smoke.

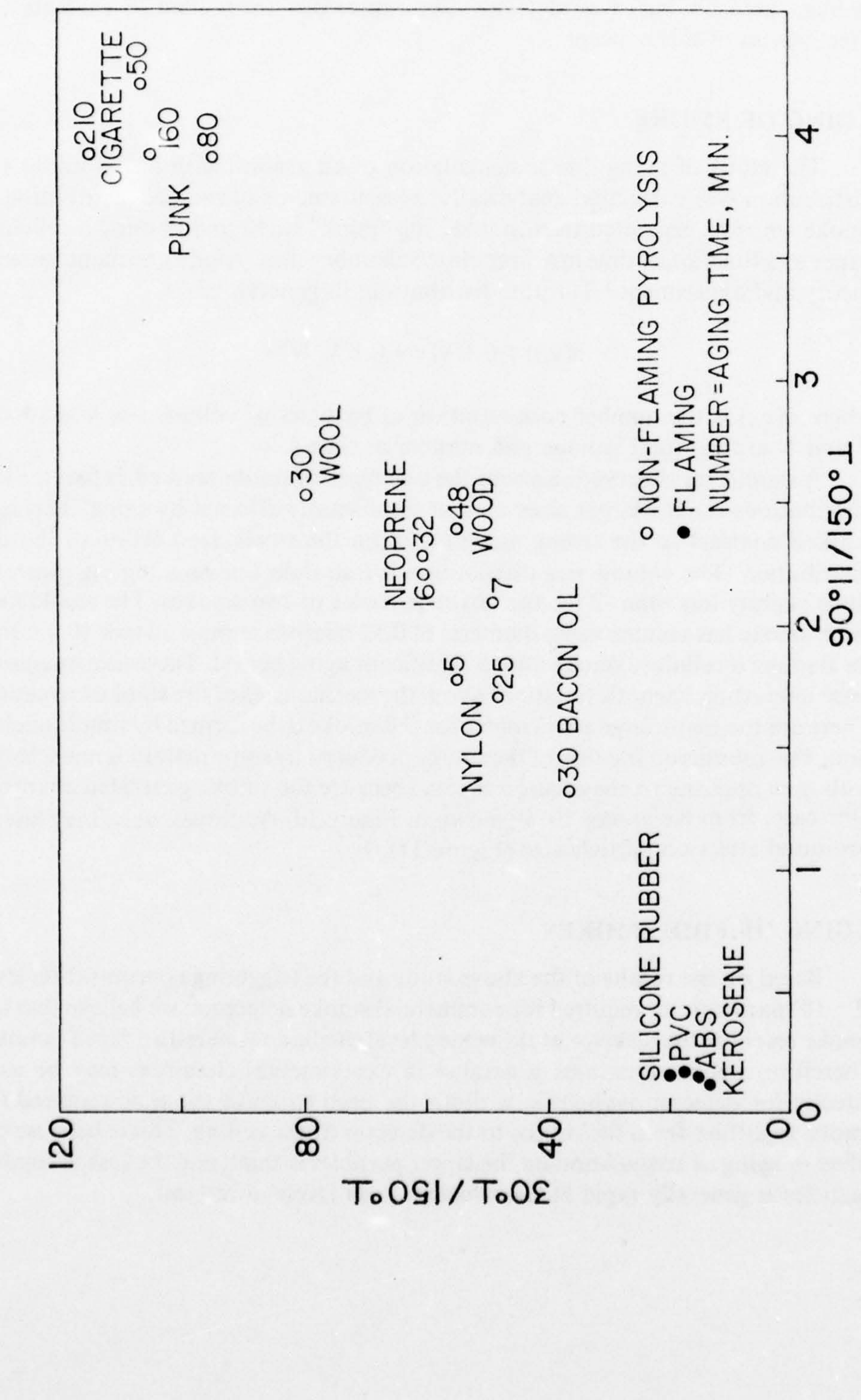


FIGURE 9 Scattering intensity ratios of smokes

to the triggering level of common commercial detectors. Laser output was 3 mW. Some other combinations of angles may also be effective in delineating the smokes. Better discrimination may also be possible if the present view angle of 3° in each detector is reduced. This method, if further refined, might be a basis for detectors which can discriminate various types of smokes if programmed to trigger on certain discrete ratio values. However much more detailed information on the nature of ambient aerosols based on detector-user experience are needed to evaluate the effectiveness of this concept.

AGING OF SMOKE

The effect of aging due to coagulation of an aerosol with broad initial size distribution was calculated analytically. Measurements of the size distribution of smoke aerosols generated from smoldering "punk" sticks and flaming α cellulose paper as a function of time in a large closed chamber show good agreement between theory and experiment.[7] The size distribution, in general, is:

$$n(v,t) = 0.1\ V[v + 0.1\ V/N]^{-2}$$

where n(v,t) is the number concentration of particles of volume size v at time t. V and N are the total volume and number at time t.

A significant observation about the two types of smoke studied, is that the size distributions for the larger sizes are not significantly affected by aging. This is in marked contrast to the strong aging affect on the small size portion of the size distribution. The volume size distribution is a straight line on a log-log plot with slope slightly less than -2 for the larger particles of two smokes. The smoldering punk smoke has volume mean diameter of 0.32 microns compared to 0.10 microns for flaming α cellulose smoke after a significant aging period. These measurements raise interesting scientific questions about the mechanisms of fire smoke formation. There are too many large particulates for the smoke to be formed by simple nucleation. The submicron fraction of the smoke produced by some materials may change with time opposite to coagulation theory (because the smoke generated changes). One case, from Reference 10, is shown in Figure 10. Additives, also, may have a profound effect on particle size (Figure 11).[10]

AGING OF FIRE SMOKES

Based on the results of the above study and the triggering concentration level of $\sim 10^6$ particle/cm^3 required for commercial smoke detectors, we believe that the smoke reaching the detector at the ceiling level can be considered an "aged" smoke. Therefore, smoke signatures generated in experimental chambers may be used directly for detector evaluation without the need to know the time required for smoke to diffuse from the source to the detector at the ceiling. This is because the effect of aging or coagulation on the larger particles is small and the loss of smaller particles is generally rapid at the concentration levels of interest.

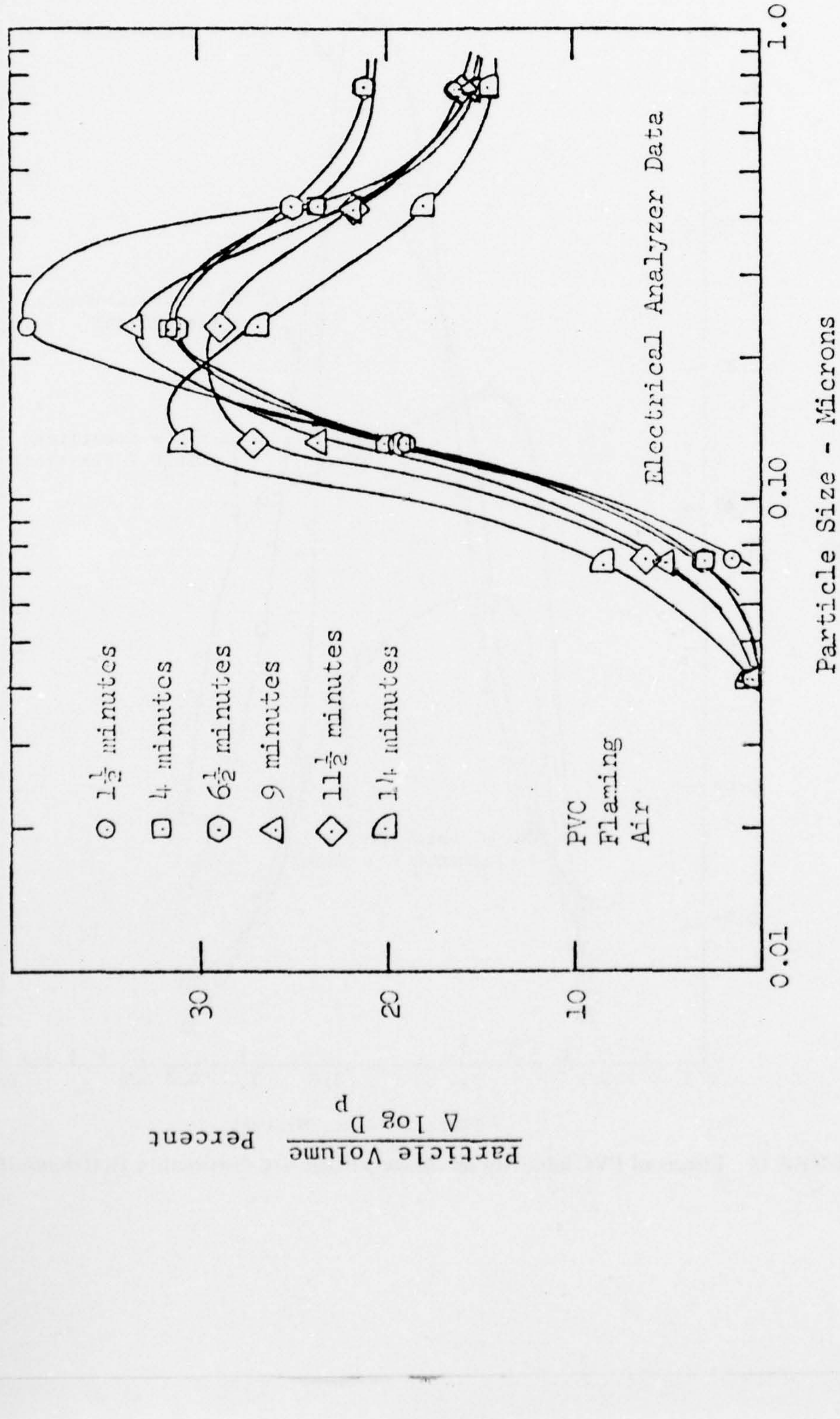


FIGURE 10 Time resolved particle volume distribution for PVC smoke particles less than 1.0 micron — flaming air. (Reference 10)

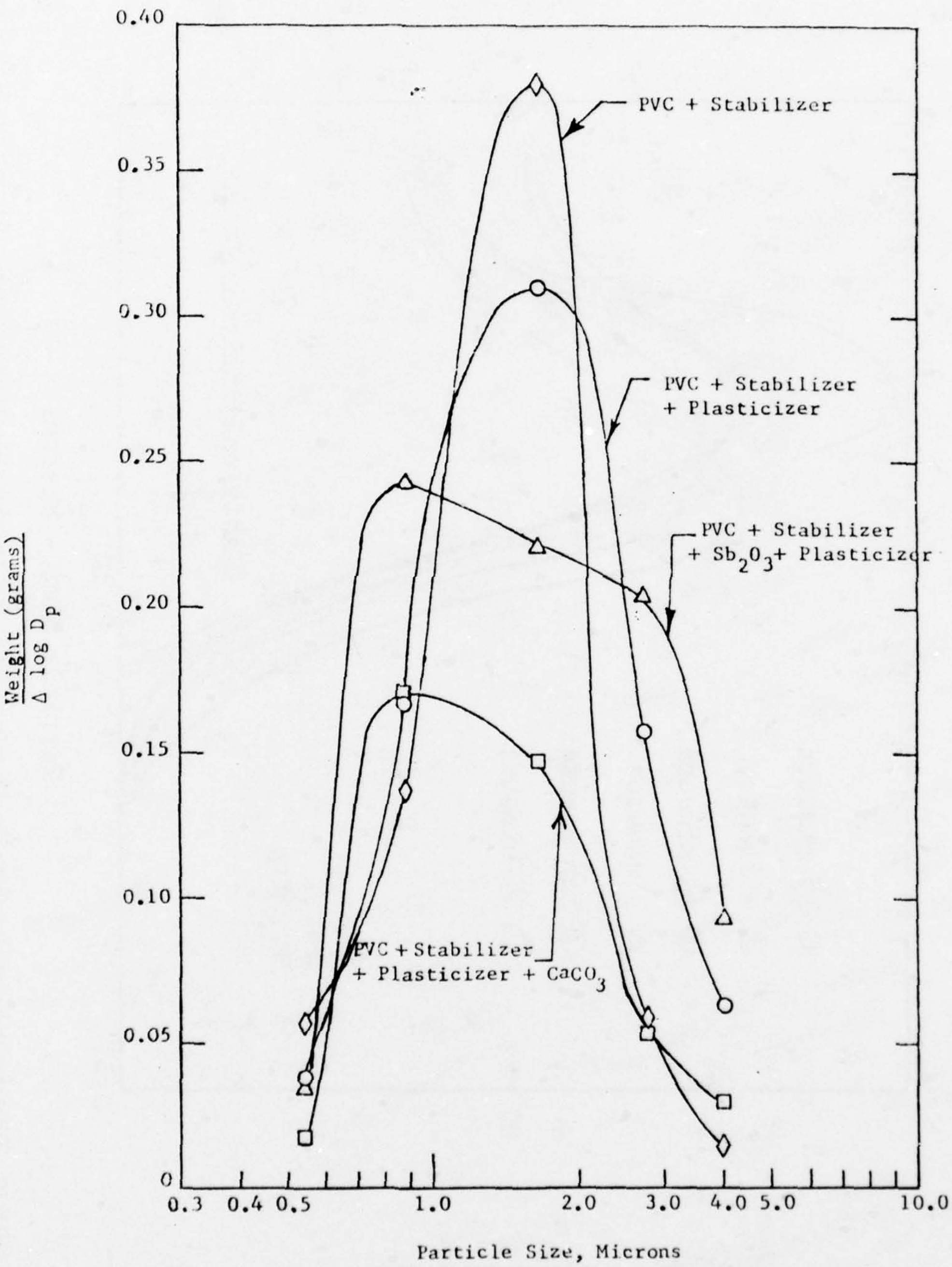


FIGURE 11 Effects of PVC additives on smoke particle size distribution. (Reference 10)

CHEMICAL ANALYSIS OF FIRE SMOKES

High pressure liquid chromatography and gas chromatography are being applied to the analysis of smoke aerosols by one investigator.[10] They find that PVC smoke consists of over 50 compounds, (Table 1 and Figure 12), most of which are polynuclear aromatic compounds. Some of these are known carcinogens. Smoke scrapings from surfaces at the scene of real fires have been compared chemically with material isolated from the tracheobronchial trees of fire victims.[5] Both contain a surprisingly large amount of inorganic metals. Large quantities of HCl and other species are undoubtedly adsorbed on the soot (see Table 1 of Reference 5).

LOOKING AHEAD

Only very limited data are available in the literature on the response of ionization and light scattering type detectors as a function of well-defined monodisperse aerosols from 0.005 to 5 microns. We have shown, for example, that the detector voltage output of a commercial photoelectric detector can increase by a factor of 9 merely by changing the particle size diameter from 0.2 to 0.3 micron using a monodisperse aerosol at the concentration of 10^5 particles/cm^3. Some data are shown in Figure 13. We are currently measuring detector sensitivity as a function of aerosol concentration and particle size with techniques of much higher precision than those used by others in the past.

It has been suggested that coincidence of two fire signatures be used to verify a fire and reduce false alarms. We have mentioned the possible use of scattering of polarized light. The use of CO concentration has also been suggested. In connection with this we are currently measuring CO concentration in some of our experiments on smoke generation of materials. Full scale detection tests[2] on variety of materials showed that CO levels between 20-50 ppm are found in smoke which would trigger commercial detectors. A gas detector cell to measure these CO levels, if added to the present detectors, might increase its cost by about 50-100%. Therefore, coincidence detection possibly will be commercially feasible. More detailed information based on the experience of detector users on the nature of ambient aerosols that cause false alarms is urgently needed to solve the false alarm problem effectively.

TABLE 1*

Chemical Analyses of PVC Smoke (Particulates)
(Generated under Nonflaming Conditions)

Peak No.	Compound	MW	Formula	Peak No.	Compound	MW	Formula
1	Unidentified			17	Naphthalene	128	$C_{10}H_8$
2	Acetophenone	120	C_8H_8O	18	α-Methylnaphthalene	142	$C_{11}H_{10}$
3	Trimethylbenzene	120	C_9H_{12}	19	β-Methylnaphthalene	142	$C_{11}H_{10}$
4	Isomer of Trimethylbenzene	120	C_9H_{12}	20	Dimethylnaphthalene	156	$C_{12}H_{12}$
5	Cumene	120	C_9H_{12}	21	2,5-Di-T-Butylfuran	180	$C_{12}H_{20}O$
6	Sec-Butylbenzene	134	$C_{10}H_{14}$	22	2,6-Di-T-Butyl-P-Benzoquinone	220	$C_{14}H_{20}O$
7	P-Cymene	134	$C_{10}H_{14}$	23	2,6-Di-T-Butyl-4-Methylphenol	220	$C_{15}H_{24}O$
8	Dimethylethylbenzene	134	$C_{10}H_{14}$	24	Trimethylnaphthalene	170	$C_{13}H_{14}$
9	Isomer of Dimethylethylbenzene	134	$C_{10}H_{14}$	25	Isomer of Trimethylnaphthalene	170	$C_{13}H_{14}$
10	Methylisopropylbenzene	134	$C_{10}H_{14}$	26	Isopropylnaphthalene	170	$C_{13}H_{14}$
11	Isomer of Methylisopropylbenzene	134	$C_{10}H_{14}$	27	Isomer of Trimethylnaphthalene	170	$C_{13}H_{14}$
12	5-Methylphthalide	148	$C_9H_8O_2$	28	Isomer of Trimethylnaphthalene	170	$C_{13}H_{14}$
13	P-Tolyl-2-Butane	148	$C_{11}H_{16}$	29	2-Methyl-1-Propylnaphthalene	184	$C_{14}H_{16}$
14	αα-Diethyltoluene	148	$C_{11}H_{16}$	30	Fluorene	166	$C_{13}H_{10}$
15	Trimethylethylbenzene	148	$C_{11}H_{16}$	31	2-Methylbiphenyl or Dihydrofluorene	168	$C_{13}H_{12}$
16	Isomer of Trimethylethylbenzene	148	$C_{11}H_{16}$	32	2-Ethylbiphenyl	182	$C_{14}H_{14}$

33	α,α′-Dimethylbiphenyl	182	$C_{14}H_{14}$
34	Unidentified		
35	1,1-Diphenylethane	182	$C_{14}H_{14}$
36	3,4-Dimethylbiphenyl or Isomer of 2-Ethylbiphenyl	182	$C_{14}H_{14}$
37	1,2-Diphenylethane	182	$C_{14}H_{14}$
38	Anthrone	194	$C_{14}H_{10}O$
39	Phenanthrene and/or Anthracene	178	$C_{14}H_{10}$
40	Unidentified		
41	2-Phenyl-(2,3-Dihydroindene)	194	$C_{15}H_{14}$
42	Unidentified		
43	Methylphenanthrene or Methylanthracene	192	$C_{15}H_{12}$
44	Isomer of Methylphenanthrene or Methylanthracene	192	$C_{15}H_{12}$
45	Unidentified		
46	Phenylnaphthalene	204	$C_{16}H_{12}$
47	3,6-Dimethylphenanthrene or Ethylphenanthrene	206	$C_{16}H_{14}$
48	Trimethylphenanthrene	220	$C_{17}H_{16}$
49	Pyrene	202	$C_{16}H_{10}$
50	Dihydropyrene or Dihydrofluoanthene	204	$C_{16}H_{12}$
51	Unidentified		
52	Methylpyrene	216	$C_{17}H_{12}$
53	Unidentified		
54	2-Benzylnaphthalene	218	$C_{17}H_{14}$
55	2,3-Benzofluorene	216	$C_{17}H_{12}$
56	o-Terphenyl	230	$C_{18}H_{14}$
57	m-Terphenyl	230	$C_{18}H_{14}$
58	p-Terphenyl	230	$C_{18}H_{14}$
59	Alkylphthalate		
60	Triphenylene or Isomer of Chrysene	228	$C_{18}H_{12}$
61	Chrysene	228	$C_{18}H_{12}$
62	Methylchrysene	242	$C_{19}H_{14}$

*Reference 10

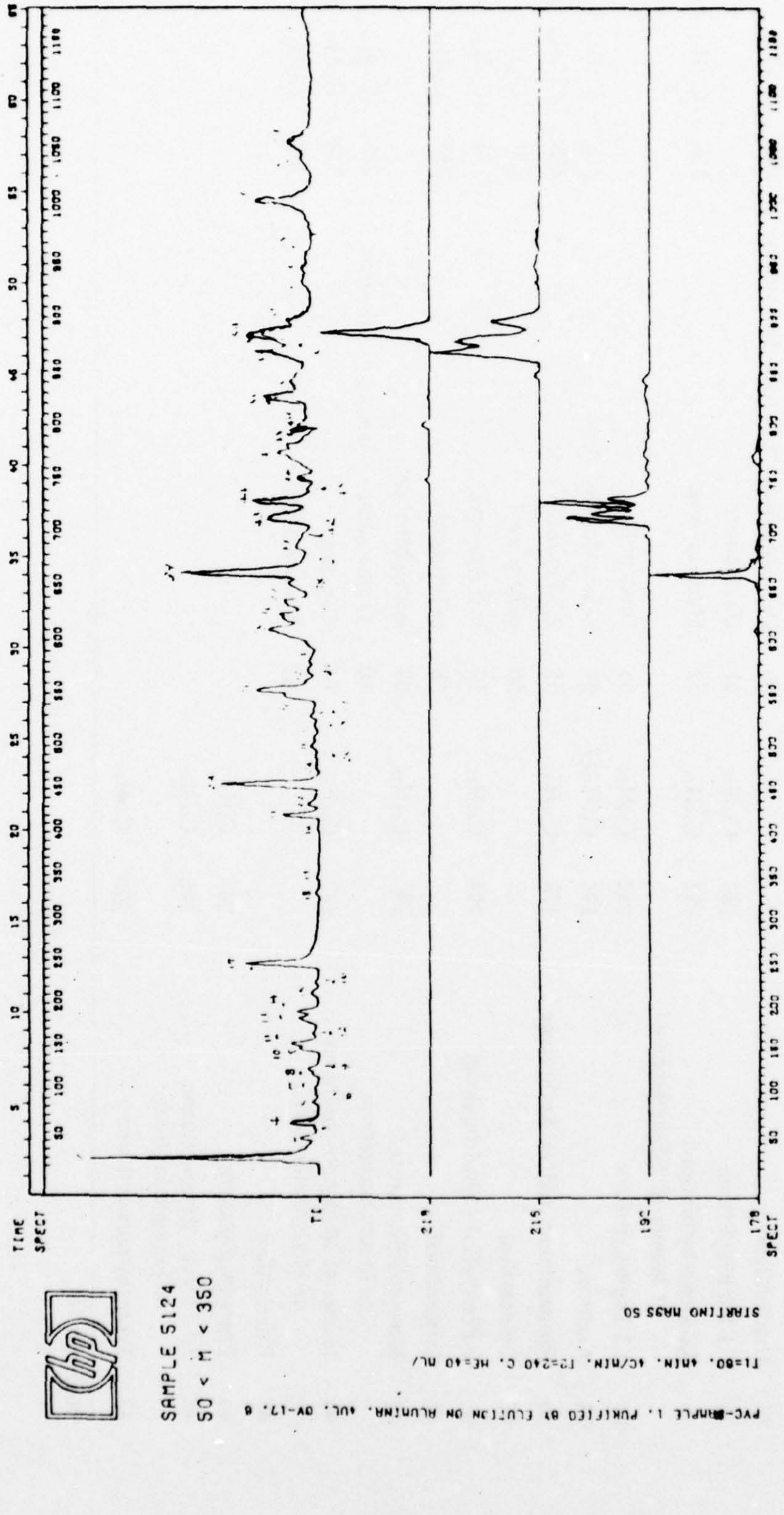


FIGURE 12 Gas chromatogram of PVC smoke. (Reference 10)

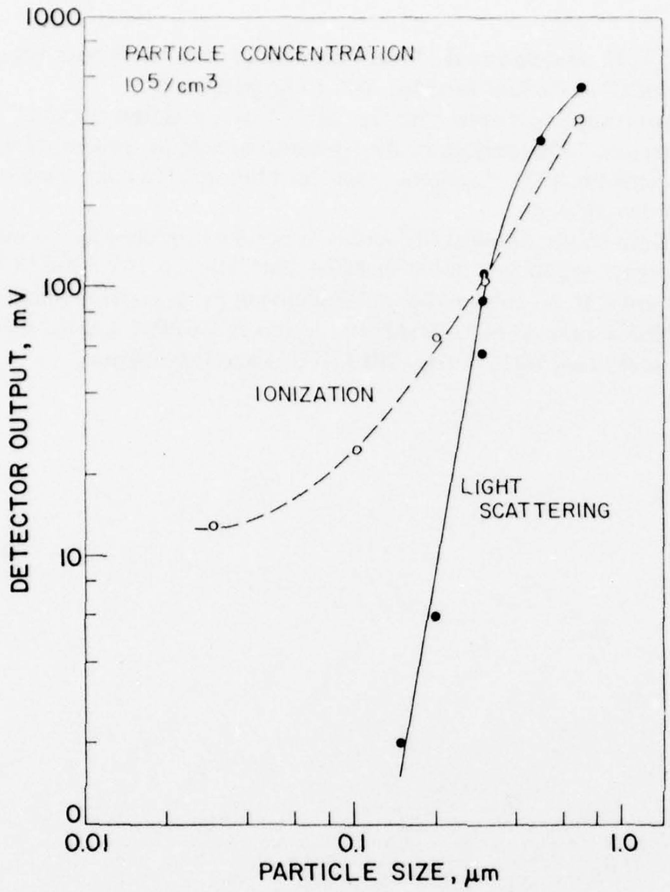


FIGURE 13 Response of two commercial smoke detectors.

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RESEARCH IN JAPAN ON TOXICITIES OF COMBUSTION GASES PRODUCED DURING FIRE*

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INTRODUCTION

The number of fatalities due to fires in Japan, although less than in the preceding year, during the two years 1971 and 1974, has generally shown a rising trend, and in the past decade has increased by 50 percent. Figure 1 shows the trend in building fires during a 10-year period normalized to 1965 as 100. In spite of the number of people killed, indicating a characteristic rapid increase, the number of fire outbreaks and the floor space destroyed have not increased proportionately. That sharp increase in the number of fire and area burned are not seen, even though the number and floor area of buildings have increased, may be considered to be due to the contributions made by improvements in fire protection and fire resistance of building materials and structures. Consequently, the increase in fatalities implies that in spite of the improvements in fire protection and resistance performances, individual fires which take the lives of many people at once have been increasing. In other words, it may be said that measures to ensure the safety of human lives during fire are still insufficient. Table 1 lists examples of fires in recent years in which large numbers of people have been killed, the buildings in these cases all being large-scale structures of fire-resistant construction, and these fires were so-called "building fires." Detection of outbreak of fires in large-sized fire-resistant buildings are delayed, while department stores and hotels are occupied by large numbers of unfamiliarized and unspecific persons, which may be said to be responsible for the mass fatalities. Since the trend is for buildings to become even more large-sized, highrise and complex, it may be considered that the risk of fires causing large numbers of deaths will be increased.

Table 2 gives the breakdown of causes of death for those killed in recent fires. Carbon monoxide poisoning, asphyxiation, and burning comprise 80 percent of the fatalities. The matter of grave concern here is that, of those counted as burning to death, in a fairly large number of cases carbon monoxide poisoning

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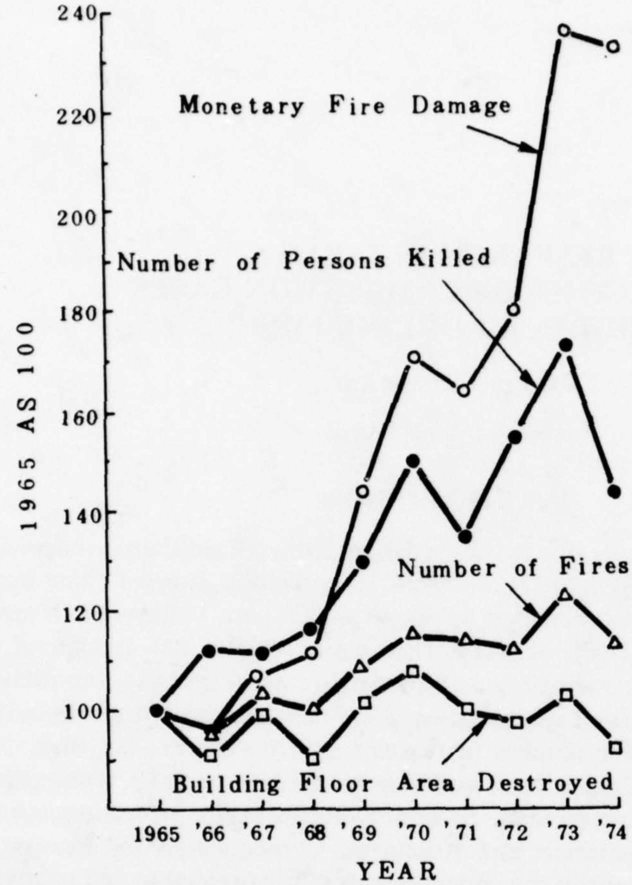

FIGURE 1 Trend in building fires.[1]

was actually the cause of the deaths, or there were deaths by burning because of incapacitation due to carbon monoxide poisoning.[1] According to an investigation[2] of carbon monoxide-hemoglobin concentrations of people killed in fires (death by carbon monoxide poisoning is said to occur when CO-Hb concentration exceeds 70 ~ 80 percent), CO-Hb concentrations of 50 percent or more comprised 50 percent of the total, while those of 70 percent or more comprised at least 22 percent. Furthermore, those of negative CO-Hb concentrations were 13 percent of the whole. Today, when large quantities of high polymer materials exist inside buildings as interior finish materials, or as furnishings, it may be considered that large amounts of toxic gases other than carbon monoxide are produced during a fire. Based on these facts, it may be surmised that during a fire people are hindered from carrying out early evacuation activities due to carbon monoxide and other toxic gases generated from the various materials, and at times are subjected to

TABLE I

Fires in Japan Resulting in Mass Deaths

Occurrence	Building	Building Structure, Size	Dead
Nov. 1968	Ikenobo Mangetsujo (Kobe City)	RC, 2B, 4F Floor space 11,258 m^2	31
Feb. 1969	Banko Hotel (Koriyama City)	RC, 4F Floor space 15,511 m^2	30
May 1972	Sennichi Department Store (Osaka City)	SRC, 1B, 7F Floor space 25,924 m^2	118
Nov. 1972	Japanese National Railways train (Hokuriku Tunnel)	1 electric locomotive, 15 passenger cars	30
Mar. 1973	Saiseikai Yahata Hospital (Kitakyushu City)	RC, B1, 5F Floor space 6,270 m^2	13
Nov. 1973	Taiyo Department Store (Kumamoto City)	SRC, B1, F9	103

injury which may even be fatal. Particularly, since detection of fire tends to be delayed in large buildings, it is presumable that by the time evacuation is started toxic gases at corridors and stairways have already reached dangerous levels of concentration. Such cases can easily result in the loss of many lives in one fire.

This report describes the present state of studies concerned with toxicities of combustion gases, selected from research being carried out in Japan regarding fires. Papers closely relevant to this theme are classified herein according to the three groups below.

I. Research on components of gases generated from materials during fire and quantities generated.
II. Full-sized fire experiments (including animal tests or gas analysis tests).
III. Research on toxicities of gases produced from materials during fire.

The papers quoted range over such fields as architecture, chemistry, and medicine as this problem is indeed an interdisciplinary one. This point must be kept in mind in handling, proceeding with, and evaluating any research to be done hereafter.

I. RESEARCH ON COMPONENTS OF GASES GENERATED FROM MATERIALS DURING FIRE AND QUANTITIES GENERATED

Research work on gases produced through combustion and thermal decomposition of materials is to be found in particularly large numbers in the field of chemistry. Many of these are on thermal decomposition in high vacuum or in inert gases, such as nitrogen and helium. There are considerable differences due to com-

TABLE 2

Fire Fatalities in Japan by Cause

Year	Total	CO Poisoning, Asphyxiation	Burns	Contusion, Fracture, Etc.	Suicide	Unknown	Other	Osaka Gas Explosion	Ship Collision Fire
1968	1160 (100)	685 (59.1)	346 (29.8)	14 (1.2)	94 (8.1)	4 (0.3)	17 (1.5)		
1969	1334 (100)	793 (59.4)	372 (27.9)	16 (1.2)	126 (9.5)	4 (0.3)	23 (1.7)		
1970	1595 (100)	785 (49.2)	541 (33.9)	8 (0.5)	145 (9.1)	10 (0.7)	32 (2.0)	74 (4.6)	
1971	1483 (100)	654 (44.1)	521 (35.1)	16 (1.1)	220 (14.8)	8 (0.6)	64 (4.3)		
1972	1672 (100)	625 (37.4)	790 (47.2)	16 (1.0)	201 (12.0)	4 (0.2)	36 (2.2)		
1973	1870 (100)	684 (36.6)	866 (46.3)	14 (0.3)	284 (15.2)	7 (0.4)	15 (0.8)		
1974	1646 (100)	465 (28.3)	787 (47.8)	4 (0.2)	323 (19.6)	4 (0.9)	20 (1.2)		23 (2.0)

Note: Figures in parentheses indicate percentages.

bustion conditions of materials in actual fires. In recent years, however, there has been an increase in research efforts made in various quarters which are applicable to fires. It is being established that materials produce toxic gases peculiar to the kinds of elements they respectively contain.

H. Nagao, *et al.*,[3,4] heated 1 gram each of polyacrylonitrile "Orlon (Type 42)", wool, and silk at 200 to 350°C in test tubes in air or nitrogen atmospheres with the following results. All of the materials produced HCN and ammonia. Quantities produced were larger the higher the temperature, with HCN quantities being larger in air and ammonia larger in nitrogen. Polyacrylonitrile produced HCN at 180°C and higher and ammonia at 200°C and higher. In heating at 350°C the quantity of HCN produced was largest with "Orlon," followed in order by silk and wool, whereas the quantity of ammonia produced was largest with wool followed by silk and "Orlon." The production of hydrogen sulfide was seen in the case of wool.

H. Kanbe and Y. Shibasaki[5,6] caused thermal decomposition of polyethylene and polystyrene by heating them in air and in vacuum at approximately 320°C, and obtained the following results. The products of polyethylene did not differ according to the atmosphere, producing principally hydrocarbons which are liquid at room temperature, *n*-paraffin and *n*-olefin of 7 to 9 carbon atoms being relatively large in quantity. With polystyrene, the rates of production of styrene monomers did not differ greatly whether in vacuum or in air, and were approximately 60%.

N. Hara and Y. Matsumura[7] took 1 gram each of nitrogen-containing adhesives (7 varieties based on urea, melamine, isocyanate, cyanoacrylate, polyamide, nitrile rubber, and urethane), heated them in a quartz tube while passing air through, measured the amounts of HCN produced, and obtained the following results. None of the adhesives produced HCN at 250°C and below, but on exceeding 300°C, HCN production from nitrile rubber and urea base adhesives began and increased with rising temperature. At 400°C, there was production from isocyanate and acrylate base adhesives. HCN production was not observed below 400°C with melamine, polyamide, and urethane base adhesives.

T. Morikawa[8] inserted small amounts of various nitrogen-containing, high polymer and low molecular weight materials divided into small increments in a quartz tube heated in an electric furnace and, while passing air or nitrogen through, caused combustion and thermal decomposition to occur. He measured the quantities of HCN produced and obtained the following results. Nitrogen-containing organic compounds (excluding nitro compounds) all produced HCN without fail at temperatures of 600°C and above, and in particular, polyacrylonitrile produced HCN even at 300 to 400°C. Organic materials, even though not containing nitrogen, produced HCN at 600°C and higher when ammonia or a substance readily releasing ammonia coexisted. The quantity of HCN produced generally was larger the higher the temperature and the poorer the supply of air. Polyacrylonitrile and "Nylon 6" showed increases in quantities of HCN produced up to a certain air supply velocity, but beyond that velocity the production contrarily decreased. This was because of the decomposition and combustion of HCN due to oxygen. The quantities of HCN produced by the resins, urea, melamine, and urethane were not very much influenced by air supply velocity. With urea and melamine resins the quantities of HCN produced decreased at 800° C. This was because at 800° C both of these resins broke out in flames and combustion of HCN took place. The nitrogen contents and HCN production quantities of the various resins are roughly proportional.

T. Morimoto[9] heated various materials to 700° C in a quartz container in an air or nitrogen atmosphere and obtained the following results on analyzing the gases produced. With Japanese cedar, the rate of carbon dioxide production was higher and the rate of carbon monoxide production lower the larger the amount of air supplied (the greater the oxidizing property of the atmosphere). In thermal decomposition in nitrogen gas of materials having nitrogen as a component, all but polyurethane produced ammonia. However, in combustion in air, "Nylon 66," polyacrylic amide, and melamine resin produced ammonia. The quantities of ammonia produced by thermal decomposition in nitrogen gas were larger than those in combustion, while in combustion the ammonia quantity was larger the smaller the quantity of air. Nitrogen oxides were detected in the cases of melamine and urea resins. The greater part (approximately 70%) of the sulfur content of the sulfur-containing polymer, polyphenylene sulfide, became sulfur dioxide. In vulcanized natural rubber, sulfur dioxide was detected in the way of a sulfur compound. A considerable amount of ethylene monomer (C_2H_4) was produced with polyethylene.

The author and K. Nakamura[10] examined the compositions of combustion and thermal decomposition gases generated from typical materials, and particularly, the kinds of toxic gases, based on published research reports and their own experiments. As a result, the following conclusions were reached. In general, organic materials produce carbon monoxide and carbon dioxide during combustion. If the supply of air is large, the quantity of carbon dioxide produced is large, whereas if the supply is small, the quantity of carbon monoxide produced is large. Cellulose base materials chiefly produce carbon monoxide and carbon dioxide, but during smoldering combustion aldehydes and acids are produced. Materials containing chlorine in their chemical structures produce carbon monoxide, carbon dioxide, and hydrogen chloride, while materials containing nitrogen produce carbon monoxide, carbon dioxide, HCN, and ammonia. In general, plastic materials produce large quantities of various monomers and hydrocarbons, especially at low temperature and when air supply is low.

Morikawa with S. Yamashika[11] also caused combustion and thermal decomposition of various natural and synthetic high polymer materials to occur in a quartz tube to investigate the quantities of lower fatty acids and formaldehyde among irritative components produced to arrive at the following conclusions. Both lower fatty acids and formaldehyde are generally produced in large quantities during smoldering combustion. Materials producing large quantities during smoldering are cellulose base substances such as wood, polyethylene, and polypropylene. In case of synthetic high polymer substances such as plastics, aliphatic materials produce far more than aromatic materials. Formaldehydes generated from polyethylene and polypropylene are several times larger in quantity than lower fatty acids, and their toxicities are strong and thus they are extremely hazardous.

Still further, Morikawa[12] measured the quantities of acrolein produced during combustion or thermal decomposition of various substances by the same method as used in his previous work.[11] He caused smoldering combustion to occur simulating actual conditions with materials found in ordinary residential buildings and which are prone to smoldering combustion, and on investigation of the quantities of acrolein and formaldehyde produced, discussed their toxicities. His conclusions are as described below. In many cases, the maximum quantities of acrolein generation are seen when various organic substances smolder at 350 to 450° C. Of the substances used in the experiments, large quantities of acrolein were generated from polyethylene, polypropylene, vinylon, and cellulose. The quantity of acrolein generated was approximately 1/10 of the quantity of formaldehyde. However, since the toxic intensity is 20 times stronger, the generation of acrolein may be said to be more dangerous with respect to toxicity than the generation of formaldehyde. The quantities of acrolein and formaldehyde generated in actual smoldering combustion of cellulose base substances, were ½ to ⅓ compared with the maximum quantities generated in electric furnace experiments.

Based on the above reports, the following may be said regarding research on the components and quantities generated of combustion and thermal decomposition products carried out in Japan up to the present. In general, organic materials produce at least both carbon monoxide and carbon dioxide during combustion. The generation of these two is closely related to the quantity of air supplied during heating, with the quantity of carbon dioxide being large when air supply is large, while the quantity of carbon monoxide produced is large when air supply is small. The principal combustion gases produced from cellulose base materials are carbon monoxide and carbon dioxide, while during smoldering combustion, aldehydes, acrolein, and acids are generated. The generation of carbon monoxide and carbon dioxide starts at 300 to 400°C. Plastics, besides carbon monoxide and carbon dioxide, generate toxic gases peculiar to the materials depending on the types of elements contained. Materials containing chlorine in their chemical structures generate hydrogen chloride from low temperatures of around 300°C until high temperatures at the heights of fires. The chlorine in these materials is almost entirely converted to hydrogen chloride unaffected by variations in heating temperature and air supply quantity. Materials containing nitrogen in their chemical compositions generate HCN at 400 to 500° C, and generally, the higher the temperature and the greater the shortage of air, the larger is the quantity produced. Polyacrylonitrile produces HCN even at 200 to 300° C. The quantity of HCN produced is roughly proportional to the nitrogen content. Furthermore, these materials generate ammonia, the quantity being inversely proportional to the supply of air. Materials containing sulfur generate sulfur dioxide and hydrogen sulfide. Generally speaking, plastics generate large quantities of various monomers and hydrocarbons, especially at low temperatures and with shortages of air. Polyethylene and polypropylene produce aldehydes, acrolein, and lower fatty acids during smoldering combustion.

When the above results are examined and applied to situations during fires, judging by the quantities of materials contained inside buildings and the degrees of toxicities of gases, those which would particularly pose problems in a fire may be considered to be carbon monoxide, carbon dioxide, hydrogen chloride, HCN, aldehydes, and acrolein accompanied with a lack of oxygen. Of these, the toxicity of HCN is especially strong and materials containing nitrogen in their chemical structures will require caution. The quantities of these gases generated under varying conditions of air supply in the temperature range (approximately 300 to 800°C) at the early stage of fire, which coincides with the evacuation period, have not necessarily been clarified. In order to evaluate the harmful natures of the products of combustion of materials, it will be necessary to arrive at a general conclusion regarding the gas producing properties of materials and the quantities of representative toxic gases produced under various temperature and air supply conditions.

II. FULL-SIZED FIRE EXPERIMENTS (INCLUDING ANIMAL TESTS OR GAS ANALYSIS TESTS)

It is of extreme importance in considering safety during fire to know how the atmosphere inside a building changes while burning, parenthetically, the states of lowering of oxygen concentration and the generation of carbon monoxide, carbon dioxide, and other harmful gases. This knowledge is also indispensable in establishing harmful gas reference concentrations for quantification of toxicity in high-concentration, short-time exposure to harmful gases.

There are a number of full-sized building fire experiments conducted up to the present in which the components of air inside the buildings have been analyzed, while further, medical investigations have been made by planting test animals in the buildings and studying the effects on the living bodies.

Y. Uchida, *et al.*,[13] used one second-floor unit of a three-storied reinforced concrete apartment building to conduct a fire experiment and obtained the following results regarding indoor air composition. With windows closed, oxygen concentrations averaged 18.1 to 19.2%, carbon dioxide generation averaged 0.73 to 1.22%, and carbon monoxide generation averaged 0.18 to 0.23%. With windows open, oxygen was reduced successively from the bottom layers to the top layers of the rooms while carbon dioxide was increased, and at the middle layers, the concentrations of carbon monoxide were especially high. Oxygen concentrations averaged 11.4%, carbon dioxide generation averaged 6.44%, and carbon monoxide generation averaged 0.46%. The quantity of carbon monoxide generated was larger with windows opened than closed, but the ratio to the quantity of carbon dioxide generated was extremely small.

Y. Uchida[14] used two wooden houses, both with 4 rooms on the first floor and 2 rooms on the second floor, to carry out fire experiments and obtained the following results. The oxygen concentrations in a room on fire were 6.6 to 19.2% carbon dioxide concentrations 0.6 to 12.0%, and carbon monoxide concentrations 0.03 to 0.3%. When this is seen from the aspect of time, from about 5 minutes after the force of the fire in a room has become strong, the condition of the air gradually worsens. About the time gas in the room becomes very hazardous flames will have become extremely strong and in such a condition flames and smoke rather than gas are to be feared. However, at or near rooms above or below the burning room there is possibility of poisoning from gas occurring even though danger from flames does not exist.

The Tokyo Fire Department,[15] in a fire experiment on a reinforced concrete office building (4 stories, 1 basement), dispersed 100 mice throughout the building and measured carbon monoxide-hemoglobin levels in the blood of the mice. The results are described below. A dead end such as the end of a corridor, when near the room on fire, is hazardous. Stairways are generally hazardous, and especially, places in the top story where hot air accumulates or outlets from which hot air escapes are hazardous. As for each individual story, danger from carbon monoxide is greater the closer to the ceiling. Next to the story on fire, the top story is the most hazardous, and it is estimated that this is followed by the succeeding stories below. At the individual stories, places that are dead ends are hazardous and rooms opening out to corridors are also hazardous.

The Japan Housing Corporation Committee on Fire Experiments[16] conducted a fire experiment using one second-floor unit of a five-storied reinforced concrete apartment house building. At this time, changes in air components in the unit on fire and at staircases were investigated. Mice were placed at various locations throughout the building and the carbon monoxide-hemoglobin levels in the blood of mice surviving after the experimental fire were measured. The results of the experiment were the following. Changes in the components of air were closely related to the condition of progress of the fire. The time at which the greatest change occurred in the air components came approximately 5 minutes earlier than the time at which air reached its highest temperature during the fire. The air components indicated a maximum change 25 minutes after ignition, the composition at this time being nitrogen gas 70.49%, oxygen 2.27%, carbon dioxide 15%, carbon monoxide 5.61%, hydrogen 3.65%, methane 1.90%, and other hydrocarbons 0.69%. Of mice recovered from the unit on fire 16 minutes after ignition, those at the ceiling were burned to death, those from 1.5 m above floor level were in critical condition (CO-Hb, 8 ~ 11%), and those from on the floor were lightly afflicted (CO-Hb, 5 ~ 7%). Mice recovered after the fire were all found to have been burned black. Mice which had been placed at an open staircase at the second story near the unit on fire were burned to death directly by fire, while mice at higher stories of the same staircase were alive but damage due to carbon monoxide was prominent.

The Committee on Measures for Fire Prevention of the Tokyo Fire Department[17] carried out various fire experiments using a seven-storied steel and reinforced concrete office building. Of these experiments, two used mice and rabbits to study the effects on living bodies. The principal results were the following. Corridors were fairly high in degree of hazard in consideration of carbon monoxide concentrations. Both carbon monoxide and carbon dioxide concentrations were higher at the corridor just in front of a staircase at a distance from the room on fire rather than at adjoining rooms. At the corridor in front of a staircase approximately 42 m away from the burning room there was a high concentration of carbon monoxide, sufficient for a human being to be killed within one minute. The carbon monoxide-hemoglobin levels of mice placed at the fourth to seventh stories were higher than 20% in a considerable number of cases with the maximum being 44%.

There was a group of mice which survived in spite of being exposed to extremely dense smoke for a period of 50 minutes, while there were mice found dead in a room sealed so that entrance of smoke was limited to a very small amount. Autopsies on the six rabbits killed from among those placed at the fourth story revealed hyperemia and stagnation in hearts, lungs, tracheae, and larynges.

M. Yamaga, *et al.*,[18] examined the medical effects on firemen engaged in evacuation, rescue, and fire fighting activities and test animals (Wistar strain rats) during a fire experiment on a fire-resistant building (1 basement, 2 stories). They used polyurethane and apparel as fire sources and placed the test animals at various locations inside the building. Their conclusions were reported as follows. With regard to animal tests, since the physiochemical conditions of the fire experiment were extremely violent, the only difference in particular, depending on the kind of material burned, was the higher carbon monoxide-hemoglobin levels of rats at the second story in combustion of urethane. In the cases of both materials burned, compared with the fatality rates of rats placed at 1.5 m above the floor and 0.4 m below the ceiling, the fatality rate of rats 0.5 m above the floor was lower. Although the generation of cyanides during combustion of urethane foam has been feared, within the scope of the method of measurement selected for the experiments, it was not possible to confirm the existence of cyanides in the blood of the rats. Prominent medical effects due to violent activity were not recognized in the participating firemen, but there were high degrees of tension, and it was considered there was a kind of hindrance to intellectual functioning because of this psychological background.

The Yokohama City Fire Department[19] conducted an experiment assuming the textile products floor as being the floor from which fire originated using a four-storied fire-resistant department store building. The first story was taken to be the source of the fire with mice, rats, and rabbits placed at the fourth story to investigate the influences of gas, smoke, and heat. The following results were obtained regarding the animal experiments. The carbon monoxide-hemoglobin concentrations of mice killed were between 15.5 and 37%. The CO-Hb concentrations of rats were between 37.5 and 44.5%. The hydrogen cyanide levels in blood of rabbits were 0.007 to 0.35 μg/ml.

The Committee on Fire Experiments on the Central Railway Hospital[20] conducted fire experiments on a four-storied fire-resistant building. They used rooms at the second and third stories as the fire sources and placed mice at the third and fourth stories to investigate the effects of the fire. The results obtained were as follows. An extreme reduction in oxygen concentration was measured at the fourth-story corridor. The number of mice killed was larger at the third story than at the fourth story.

Based on the above reports the following may be said regarding full-sized fire experiments.

As can be perceived from the reports up to this time regarding analyses of the components of air inside buildings on which fire experiments were conducted, almost all were on carbon monoxide, carbon dioxide, and oxygen only. In view of the present situation in which various plastics are being used, it must be considered that many toxic gases other than the above are generated. On looking at carbon monoxide, carbon dioxide, and oxygen, the concentrations of carbon monoxide and carbon dioxide increase in accordance with reduction in oxygen concentration, while temperature and smoke concentration are also increased. The quantities of carbon monoxide and carbon dioxide produced are larger when windows are open than when windows are closed. This is because more combustion of materials occurs. However, compared with carbon dioxide, there is a much larger proportion of carbon monoxide produced with windows closed than with windows open. The conditions in the room on fire and its vicinity are extremely severe for human beings, with carbon monoxide and carbon dioxide being as much as 5 to 6% and 15%, respectively, while oxygen concentration is reduced to as low as 2 to 3%. However, since the temperature may be considered to have risen to 700 to 800° C at such time, the toxicities of gases are hardly a problem when compared with the effects of heat from fire.

This problem lies in the fact that concentrations of toxic gases, for example, carbon monoxide, are raised at places fairly distant from the room on fire where there is almost no effect of heat. There is a case of a corridor at a distance from the room on fire, where in spite of the fact that temperature measured at 1.5 m above the floor was normal temperature and concentration of smoke was extremely low, carbon monoxide concentration was as much as about 1.5% and carbon dioxide concentration 5%. It is thought that at such times there would be many cases in which people lose freedom of movement due to carbon monoxide poisoning and being unable to escape either burn to death or die directly due to poisoning. Such a situation can easily arise especially in a large building since perception of fire is delayed. However, even in small residential buildings, there are cases of fires breaking out on the first floors with danger from carbon monoxide preceding danger from oxygen deficiency or flames at second-floor rooms. When toxic gases other than carbon monoxide are also generated the conditions for human occupants will be even more severe.

A characteristic common to the reports on animal experiments is that carbon monoxide is given as the cause of deaths of the test animals. Lack of oxygen and heat can be considered as other causes. There are no cases of the effect of carbon dioxide being considered and this is due to the low toxicity of carbon dioxide. Although conditions of fire may differ considerably, it is clearly seen that carbon monoxide is the principal cause of harm. Other than carbon monoxide, there are many reports pointing out the harmful nature of oxygen deficiency and it may be assumed that lack of oxygen aggravates the problem of carbon monoxide toxicity. It is conceivable that other than carbon monoxide and oxygen deficiency, there are numerous toxic gases which exert influences in a complex manner, but there are very few reports in this regard and the situation is not clear. It is difficult to draw general conclusions for this type of research since the conditions to which test animals were exposed were not consistent. However, these animal experiments are exceedingly useful in that the hazards during fire can be investigated to some degree directly using living bodies.

III. RESEARCH ON TOXICITIES OF GASES PRODUCED FROM MATERIALS DURING FIRE

The toxicities of combustion products of materials may be estimated to an extent by clarifying the components and compositions of the combustion products generated under various heating temperature and air supply conditions, particularly the quantities of toxic components, and comparing these quantities produced with data on the toxicities of these components to human beings. However, in practice, it is difficult to completely analyze the combustion products due to their complex compositions, while data on the toxicities of these harmful components to humans are also inadequate. For these reasons, it is thought the surest method of investigating the harmful natures of combustion products is to cause test animals to directly inhale the combustion products in toto and study the effects.

K. Hattori and M. Ooka[21] investigated the effects of toxicities of carbon monoxide, carbon dioxide, and oxygen deficiency on rats and obtained the following results. The carbon monoxide concentration at which rats died was approximately 0.4% and the carbon monoxide-hemoglobin concentrations in blood at such times were around 65%. The lethal concentration of carbon dioxide was approximately 30%. When rats were placed in pure nitrogen gas, 12 minutes were required until respiration stopped. When 5% of oxygen was mixed in the nitrogen gas, rats did not die even when 2½ hours had elapsed. Hattori and the others next caused rats to inhale gases produced in fire experiments on two wooden houses to investigate toxicities and arrived at the following conclusions. Toxicity of gas generated during fire is mainly attributable to carbon monoxide. The CO-Hb levels when rats show difficulty in walking are 40 to 45% and the levels when the rats die are 48 to 83%.

T. Sotoyama and H. Sakurai[22] drew the combustion products of various textiles into an exposure chamber containing mice to investigate the acute toxicities of the products and arrived at the following conclusions. Cotton and silk, and wool and acrylic fiber, respectively, pose hazards of the same degree. The toxicities are far lower for combustion than for smoldering combustion. The cause of mice fatality is carbon monoxide in case of cotton. Ammonia plays a role in deaths in the cases of wool and silk. HCN and nitrogen dioxide may be excluded as causes of death. Grounds for considering combustion gas of acrylic fibers to be more hazadous than combustion gases of natural fibers are said not to have been found, but based on the author's studies and data, there is reason to question this conclusion.

The author[23] heated materials assuming temperature conditions at the early stages of fire, caused mice to inhale the combustion products generated, and investigated the toxicities by electrocardiograms and carbon monoxide-hemoglobin levels in blood. First, pure carbon monoxide gas was used to establish carbon monoxide-hemoglobin levels at the times at which mice die and a range of 33 to 44% was obtained. Next, various materials were tested and as a result the following conclusions were obtained. The carbon monoxide-hemoglobin concentrations in the blood of mice averaged higher than 20% with all of the materials tested, and although there may have been differences in degree, carbon monoxide was the greatest factor in toxicity and this must be taken into consideration without fail in any case. The toxicities of materials such as wood, cement-excelsior board, fire retardant-treated plywood, melamine resin-coated board, and acrylic resin are all due to carbon monoxide. Fatalities in the case of polyvinyl chloride and polyurethane are due to effects of some other toxic gas in addition to carbon monoxide. Prominent changes in electrocardiograms were noticed at the early stage of heating in case of all materials.

K. Yamamoto and S. Horiuchi[24] burned various textiles with an electric hot plate and drew the combustion products into an exposure chamber containing rats or mice, to investigate the toxicities. Their conclusions were as follows. Results obtained with incapacitation of rats to act as an index were substantiated by the results of lethal experiments on mice. The index of incapacitation of activity according to visual observation can adequately be used as a criterion for judging toxicity. Of the samples tested, the most hazardous are acrylic fibers, the toxicities of which are due to HCN. Silk also produces HCN. It is thought that poly(vinyl chloride) and poly(vinylidene chloride) definitely cause sequellae in rats.

F. Saito[25,26] investigated the effects on mice of pure gases and the combustion products of various materials. He detected the states of activity of mice through revolutions or vibrations of cages into which the mice were put. The following results concerning toxicities of pure gases were obtained. Expressing toxicity of carbon monoxide as the product of concentration and the period of exposure until death, the result was 4.0%·min, but when mice were placed in revolving cages this became 1.35%·min due to the increased amounts of movement of the mice. Mice resisted dying when oxygen concentration was 10% or higher, but died suddenly when the concentration fell to 8%. Times of fatality were prolonged when hydrogen chloride gas was mixed in other gases. Saito also heated various materials by gas flame or electric furnace and investigated toxicities by causing mice to inhale the combustion products. Proposing a "specific toxicity, T_s," for evaluation of toxicity and adjusting his data employing this, he obtained the following results. It was difficult to judge toxicity of a combustion product based only on carbon monoxide. The value of T_s was considered to indicate the toxic characteristics of a material. Of the materials tested, the toxicities of acrylic fiber and wool were strongest. Poly(vinyl chloride) fibers showed weak toxicities under the determination method of the experiments.

The author and K. Nakamura[27] heated various materials at temperatures of 350, 500, and 750°C and caused mice to inhale the combustion products generated to investigate their toxicities. The mice were placed on a vibration plate equipped with a vibration sensor and the conditions of the mice such as convulsion, falling over, and cessation of breathing were detected. The following conclusions were reached. The principal factor in toxicities of cellulose materials is carbon monoxide. Fire retardant-treated plywood and cement-excelsior board involve great danger from carbon monoxide at 500°C and higher. Chlorine base materials such as poly(vinyl chloride) generate hydrogen chloride leaving irrecoverable damage to the lungs of mice and there are cases of mice succumbing after a day or two. The toxicities of chlorine base materials are mainly due to hydrogen chloride at low temperatures with carbon monoxide being added at 500° C and higher. Nitrogen base materials are high in toxic effects due to HCN. There is high danger of HCN with polyacrylonitrile, polyamide, silk, and wool at 750° C and with polyurethane at 500° C. With polyethylene and polypropylene, the effects of some other products appear strongly along with those of carbon monoxide at 350° C and 500° C. The mice are subject to irrecoverable damage due to monomers and hydrocarbons and die within one week. In general, the physiological effects of smoke are small compared with the effects of toxic gases.

Based on the above reports, the following may be said about research in Japan on the toxicities of combustion products. The methods of testing are generally those of either introducing a constant flow of combustion products to a chamber in which test animals have been placed and causing the animals to inhale the products, or of diffusing the combustion products to a given volume and causing test animals to inhale them. Mice and rats are used as test animals in most cases. Although there is a report which asserts that reliable judgments of the states of activity of test animals can be made by visual observations, since there are cases when observations cannot be made due to smoke or some other factor, and in order to make more objective evaluations, there are various electrical detecting methods being tried.

That the toxicities of combustion products of organic materials are due mainly to carbon dioxide in many cases is beyond doubt, and in order to make judgments, the carbon monoxide-hemoglobin concentrations in the blood of test animals are measured. It has been proposed that the CO-Hb levels of mice and rats killed by pure carbon monoxide are 34 to 44% and 65% respectively.

The following may be said in general regarding the toxicities of combustion products of various materials. The toxicities of combustion products of cellulose base materials such as cotton, rayon, and wood are chiefly due to carbon monoxide. The toxicities of combustion products of materials containing chlorine such as poly(vinyl chloride) and poly(vinylidene chloride) are due to carbon monoxide and hydrogen chloride in the products. Hydrogen chloride in these products cause pulmonary hemorrhaging and pulmonary edema in living bodies to inflict irrecoverable damage. The toxicities of combustion products of materials containing nitrogen such as polyacrylonitrile, polyurethane, wool, and silk are principally due to carbon monoxide and HCN. In relative comparisons between various materials the toxicities of acrylic fiber combustion products are especially strong.

The harmful nature of combustion products depends on such factors as type of material, heating temperature, quantity of air supply, kind of test animal, and exposure conditions. When these factors vary, the harmful nature of the combustion products naturally varies. Hereafter, it will be necessary to use various combinations of these factors to accumulate data and clarify the toxicities of combustion products in a more comprehensive manner.

SUMMARY

The following may be said of research conducted in Japan up to this time on the toxicities of combustion products generated during fire.

Regarding combustion gases of materials: Organic materials produce at least

carbon monoxide and carbon dioxide, while it is becoming clear that plastics among these materials produce toxic gases peculiar to each kind of plastic in accordance with chemical composition.

Regarding building fire experiments: It may be considered that, at places distant from the rooms on fire in buildings of large size, danger from carbon monoxide precedes danger from heat, smoke, and oxygen deficiency in many cases. The principal reasons for the harmful properties to be lethal are carbon monoxide, oxygen deficiency, and heat, while the physiological effects of carbon dioxide and smoke may be considered to be small.

Regarding toxicities of combustion products: Carbon monoxide poisoning may be evaluated by carbon monoxide-hemoglobin concentrations. The concentrations in the blood of mice and rats killed are 34 to 44% and approximately 65%, respectively. The major causes of toxicities of combustion products according to materials are carbon monoxide in the case of cellulose base materials, carbon monoxide and hydrogen chloride in the case of materials containing chlorine, carbon monoxide and HCN in the case of materials containing nitrogen, and carbon monoxide, monomers and hydrocarbons in the case of hydrocarbon base materials. Hydrogen chloride and monomers inflict irrecoverable damage to living bodies.

An outline of research in Japan on the toxicities of combustion gases produced during fire has been reported in the foregoing. The subject is extremely difficult and there are many problems which must be considered such as comparisons with real fires and the theory of safety in connection with experimentation techniques, analyses, and evaluations. Cooperation between researchers in many disciplines will be required more than ever.

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RESEARCH AT THE FIRE RESEARCH STATION – BOREHAMWOOD, ENGLAND

BUILDING DESIGN AND FIRE

Anyone who designs, maintains or runs a building is vitally concerned with its safety in a fire — how quickly would a fire be detected and put out, would the occupants be able to escape, how would the building itself withstand the fire, what is the most economic and efficient method of fire protection? The aim of fire research is to provide the answers to these questions and to try to reduce the annual toll in human life and material damage caused by fires.

Last year there were over 300,000 fires in Britain, causing about 1,000 deaths, 6,000 serious injuries and doing £230m worth of damage. Only about 40 per cent of the fires take place in buildings, but these account for a high proportion of the casualties and most of the material damage. The total loss due to fire in the UK is now more than 1 per cent of the GNP.

Before the second World War most buildings were constructed using established methods and materials which provided considerable inherent fire resistance, and were in general comparatively small and simple in plan. Thus fire protection of buildings did not present many problems. Post-war changes in design concepts such as tower blocks, central area developments, bulk warehouses and leisure centres, and the introduction of new materials and construction techniques, have created a series of new fire problems.

Work at the Fire Research Station covers these and many other aspects of fire from basic physics to the formulation of international standards for fire-fighting equipment. It is organised in three roughly equal divisions: Statistics and Operational Research, Fire Protection, and Building and Structures. Many problems cut across these broad boundaries; the fire behaviour of plastics materials, increasingly used in buildings, furniture and fittings is probably the most important of these. Study of this problem currently absorbs more than 10 per cent of the Station's resources.

The total strength at FRS is currently just over 200, of which about half are professional staff. Most of the research is carried out at Borehamwood, but the Station also has the long-term use of one of the two disused airship sheds at Cardington (see page 60) where large-scale experimental fires can be studied with a minimum of inconvenience to others. In addition to work in the laboratory, the staff visit the scene of actual fires to investigate first-hand the development of the fire and to study the fire behaviour of the structure of the building and its contents.

The Fire Research Station is unique among government research establishments because it is owned and run jointly by a partnership between government and the insurance industry — the Joint Fire Research Organisation. It was set up in 1947 to formalise a close liaison between the then DSIR and the Fire Offices' Committee (FOC), an association of companies underwriting fire risks. The aim was to conduct research into all aspects of fire, and to continue and develop the testing work which the FOC had been doing since the early 1900s. Following a policy decision that government research establishments should no longer undertake routine tests, it has been agreed that this side of FRS work should pass back to the insurance industry. The Fire Industry's Research and Testing Organisation (FIRTO), in which FOC, other companies and Lloyds are involved, is therefore being set up for this purpose, on the same site at Borehamwood. FRS will then be wholly government financed.

FIRE STATISTICS

Accurate data are the starting point in deciding the research programme. The UK has an extremely comprehensive system for producing these, based on reports rendered by every fire brigade on every fire it attends. The data is coded and collated at FRS into various tables, which are published annually, and held in a data bank from which it can be retrieved using the FRS computer. The responsibility for producing UK fire statistics lies with the Home Office for which FRS have acted as agents. The Home Office has recently assigned a statistician to FRS to assume direct local responsibility for this work.

Analysis of the data provides information on such aspects as frequencies, causes and effects of fire, incidence of casualties and fire losses. This shows up new hazards and probable causes of damage and life loss and the need for further research, legislation or technical development.

BUILDING MATERIALS

Knowledge of the behaviour of materials at high temperatures is still relatively limited, making it difficult to predict the fire resistance of the structural elements of a building or the potential hazard of any new material. FRS is studying the fire behaviour of concrete, steel and wood, and the flammability of a wide range of plastics materials.

BUILDING COMPONENTS

Investigations are in progress of the fire behaviour both of the individual elements of a building — beams, columns, floors, walls and doors — and also the performance of assemblies of one or more of these. Although structural design is based to a large extent on the concept of interaction between building elements, there is little knowledge at present of the effect of these interactions on the fire performance of the whole building.

The test procedure for measuring the fire resistance of insulated steel beams and columns is both expensive and time-consuming. Studies have started of methods of calculating this numerically, with the aim of developing simple design aids for computing fire resistance.

The problem of fire spreading through ducts and cavities was highlighted by the fire in the Fairfield old peoples' home and by many of the fires in schools investigated by FRS. Building regulations lay down a requirement for fire barriers to subdivide extensive cavities, and FRS is studying the best ways to design and construct these. Recent fires have also shown the importance of workmanship: bad workmanship on a satisfactory design can contribute to fire spread in various ways.

STANDARDS AND BUILDING REGULATIONS

Agreement between countries on standards for fire tests will obviously benefit trade, and international activity on the preparation of standards has increased considerably in recent years. FRS is collaborating with research organisations within the UK and in other countries in designing realistic and mutually acceptable tests. The Station also analyzes research data for use in structural codes in concrete, steel and wood being prepared by both national and international organisations.

EFFECTS OF FIRE IN BUILDINGS

To extend the usefulness of laboratory work and to increase confidence in the results in practice, the behaviour of buildings in which there have been fires is being studied. A major project on school fires was completed last year, and another on domestic house fires is now in progress.

SAFETY REQUIREMENTS

In designing a building, safety aspects are assessed either against a standard or against what is considered to be an acceptable threshold for risk. FRS is trying to arrive at an objective basis for criteria for fire protection. Mathematical and computer models which simulate fires in buildings are being developed, using both experimental and statistical data.

FIRE RESISTANCE

An essential part of designing a building is to establish the optimum fire resistance necessary to avoid collapse and to prevent rapid fire spread. FRS is building up a statistical picture of the fire severity which can be expected in different types of building, making it possible to estimate the optimum level of fire protection required.

GAS EXPLOSIONS

Following the Ronan Point disaster, research was started on the development of explosions in buildings and the extent to which the pressures could be relieved by venting. Experiments in a single compartment were carried out at Cardington, and work is beginning there on the propagation of an explosion through a series of full-scale compartments.

FIRE SAFETY

MOVEMENT AND CONTROL OF SMOKE

In traditional buildings, methods of safeguarding the occupants from smoke and combustion products are based on limiting smoke travel by self-closing doors and providing protected staircases as the means of escape. In the light of quantitative knowledge about smoke spread and behaviour, these methods can now be rationalised. High-rise buildings and complexes such as covered shopping malls present a new problem and entirely new methods must be developed. FRS is studying the factors affecting smoke flow and developing techniques for controlling the smoke movement.

BEHAVIOUR AND SPREAD OF FIRE

The way a fire behaves and spreads within the various parts of a building is governed by many complex factors, interacting together. By studying the basic mechanisms of fire spread, both experimentally and with the use of mathematical models, FRS is trying to quantify these interactions. Laboratory work includes the effect of different lining materials on the early stages of fire growth, and vertical fire spread up building facades. On the theoretical side, mathematical models are being developed to study the economics of different forms of control and of compartmentation of buildings.

BEHAVIOUR OF PEOPLE

To design effective fire protection systems and means of escape, more information is needed about people's behaviour in a fire, and the influence of their attitudes and knowledge. Work at FRS is mainly on the problems of evacuating people from fires, particularly old people or hospital patients; more general problems of behaviour in fires are being studied at Surrey University under an extra-mural contract.

PLASTICS IN FIRE AND DOMESTIC HAZARDS

More than half the people who die in fires are overcome by gas or smoke. This is partly due to the increasing use of plastics, which can burn more rapidly and can produce more smoke and toxic gases than traditional materials. Laboratory studies are being made of the toxic products and burning behaviour of a range of plastics particularly pvc, phenol formaldehyde laminates and polyurethane foams. Full-scale fire tests on materials used in actual building contents are carried out at Cardington in a rig which represents a room attached to an escape route. A number of extra-mural contracts in this field include a major three-year study by the Rubber and Plastics Research Association of the ignition properties and fire spread in

FIGURE 1 The size of the problem: devastation by fire.

modern furniture. Hazards in the home can also be caused by portable heaters using both traditional and new fuels, and FRS is closely involved in standards and design.

DETECTION, EXTINCTION AND PROTECTION

DETECTION

If a fire is discovered early, the loss of life and property is minimised and the task of the fire brigade is much easier. In designing automatic fire detectors, a major problem is to predict how effective they will be in responding to small fires. FRS is looking at the properties of small, growing fires and the response to them of heat and smoke detectors. A large-scale survey is in progress of the ambient conditions in the various types of situations where detectors are installed to find out what variations occur in normal circumstances. At the moment 30 to 40 per cent of false alarms in automatic detection systems are believed to be due to unusual ambient conditions near the detector heads.

EXTINCTION

Ways of improving the efficiency of water jets for fire fighting are being studied, including the use of chemical additives to increase the flow of water by reducing drag, and careful design of the nozzle shape to give a better throw of the jet. Foams for extinguishing flammable liquids had in the past to be tested against large fires. Extensive research has enabled these fires to be scaled down to laboratory size, and new Defence Standards based on them are being issued this year.

PROTECTION

FRS has developed a zoned sprinkler system to protect goods stored in high racks in modern warehouses, where very great losses can occur in a fire. Two prototype systems have been produced and tested at Cardington. The Station has also been experimenting to find an effective foam sprinkler installation for use against oil spillage fires on North Sea oil rigs (*BRE News* 33).

TESTS AND STANDARDS

Tests of fire-fighting materials and equipment have been carried out for many years by FRS, and the results are used in compiling national and international standards and specifications to improve the quality of equipment. The actual testing work will be taken over by FIRTO, though FRS will retain responsibility for government input to standards committees.

PROTECTION AGAINST EXPLOSIONS

In industry there is a risk of fire and explosion arising from ignition of vapour-air mixtures, from dust clouds of finely divided materials, and from flammable gases and dusts. The Station is studying the use of flame arresters to protect electrical equipment in hazardous atmospheres, and collaborating with the Property Services Agency of DOE on the use of explosimeters for the protection of personnel during maintenance of oil storage tanks.

PLASTICS IN BUILDING CONSTRUCTION

P. L. Hinkley and Mrs. B. F. W. Rogowski

In the past the main combustible materials likely to be encountered in buildings were basically cellulosic ie timber, wood products or cotton, although the contents probably included some protein fibres such as wool and possibly some synthetic fibres. This is no longer true. The contents of a building may contain a large amount of synthetic fibres and plastics foams and sheets, while plastics — a term which covers a very wide range of materials with widely varying physical and chemical properties — are being increasingly incorporated into the building structure itself.

The possible hazards of plastics contents and their combustion products are discussed on page 12. Any increase in the severity of fires involving the contents of a building may, of course, have repercussions on structural fire requirements. The emphasis in this article, however, is on the behaviour of plastics when used in the building structure. These will be considered under four main headings: constructional, decorative, services and insulation.

CONSTRUCTIONAL USES

Plastics may be used for weatherproof cladding, for glazing panels, rooflights or translucent domed structures. Sandwich panels consisting of a core of low density foamed material with facings of, for example, glass reinforced polyester resin, aluminum or sheet steel, are being increasingly used for such purposes as fascia panels, window and door frames or storey height external wall panels. FRS has investigated the fire behaviour of plastics in many of these applications, often at the request of manufacturers, and this is continuing.

Experiments to determine the minimum spacing between plastics dome lights necessary to prevent rapid spread of fire showed that the distance depends not only on the material of the dome light but also on its shape and whether it is on an upstand (Figure 2). The presence of an upstand may lead to increased mixing between the flammable gases evolved from the lower surface of the burning dome light and the air beneath, so shortening the flames and decreasing the chance of ignition of an adjacent dome light. This finding has led to some relaxation in fire requirements for rooflights in a recent amendment to the Building Regulations.

Other work has been concerned with the possible fire hazards of emergency housing for disaster areas. Shelters which can be quickly fabricated on site from foamed polyurethane or similar materials have significant advantages as temporary housing for families following an emergency. Tests were made of the time taken for polyurethane shelters to ignite and the way in which they would subsequently burn. The application of a suitable flame retardant finish extended the time before ignition, but once ignited the building burned rapidly. Recommendations have been made on the spacing required between these shelters to reduce the risk of fire spread from one to another.

DECORATIVE USES

Decorative uses of plastics include wall panels; thin films which can be stuck to walls or ceilings; paints and finishes; and translucent ceiling panels and membranes. Where the material used for a decorative finish adheres to the surface and does not fall away when heated, the behaviour can be characterised, as appropriate

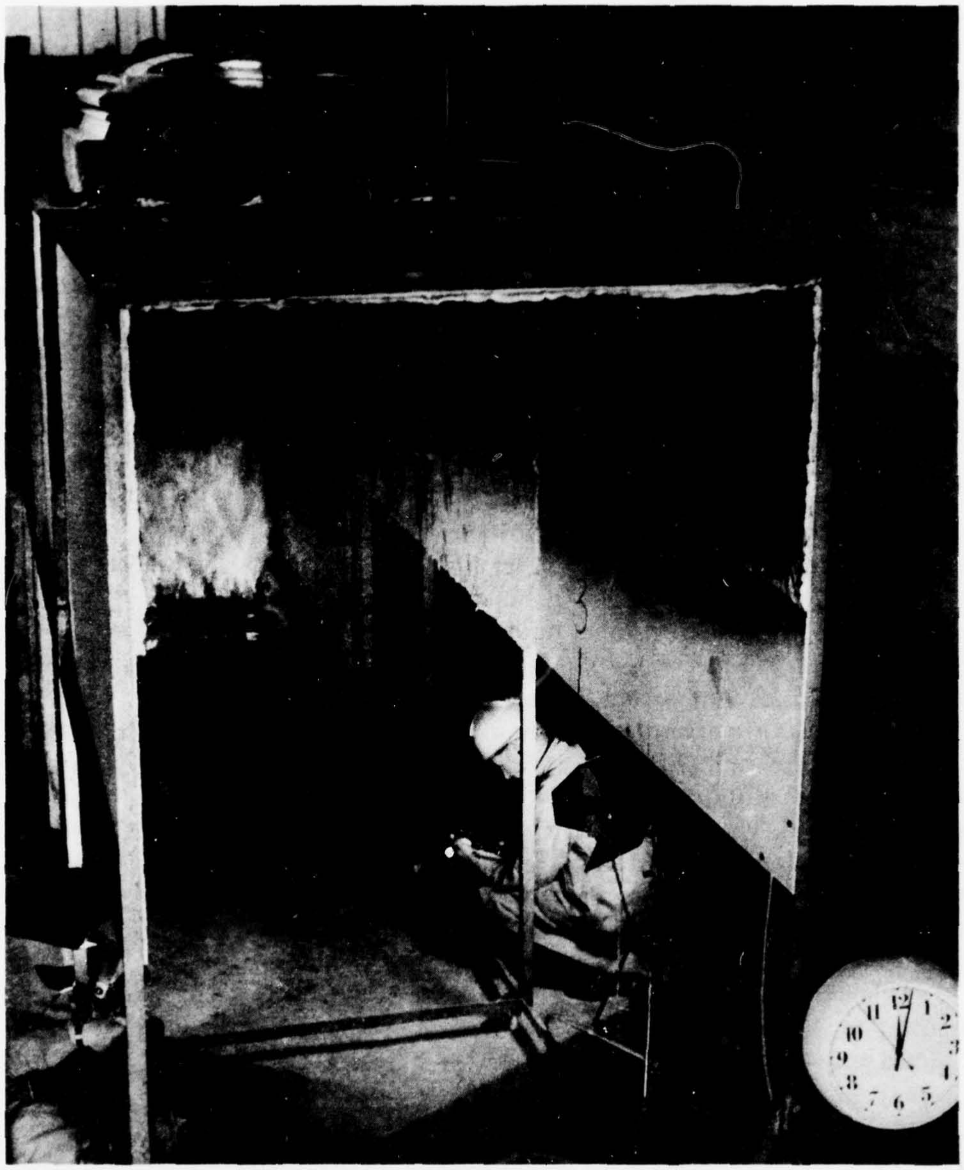

FIGURE 2 Fire test on an acrylic domelight.

by the Spread of Flame Test of BS 476, Part 7 or the Fire Propagation Test of BS 476, Part 6. The results of tests on many proprietary materials are included in the recently published catalogue of spread of flame test results[1] and in a catalogue of fire propagation test results to be published soon. These results are only applicable when the same type of backing material and method of fixing are used as were employed in the test.

There is some difficulty when there is a possibility of melting of plastics material located away from the source of heat. The behaviour of translucent plastics ceiling panels and light fittings has been investigated by the Rubber and Plastics Research Association under a contract placed by FRS. This has shown that the provisions in the Building Regulations allowing the use of thermoplastics sheet materials with some limitations are generally adequate to avoid spread of fire over the surface of the ceiling. The limitations on the materials are in terms of the ease with which they are ignited by a small flame and their softening temperatures, and fixing methods are stipulated which allow the material to fall out before ignition from a large source of heat.

PLASTICS SERVICES

Conduits and cable insulation are now most frequently made of pvc which has also found wide application in pipes and gutterings for rainwater and waste systems, although other plastics may be used. The Station has studied the danger of fire spread from one compartment to another through soil and waste systems. As a result of this work, the Building Regulations now allow the use of unplasticised pvc systems, with appropriate protection, up to 100 mm diameter in many standard situations and, more exceptionally, up to 150 mm in diameter.

PLASTICS INSULATION

The ability of some plastics to be foamed to give low density insulating products, and particularly the feasibility of in situ foaming, provides one of the most attractive features of these materials and with increased requirements for thermal insulation of buildings, the use of foamed plastics for this purpose will continue to rise. FRS has started work on the spread of fire in ductwork due to the presence of a foamed plastics lining, and the programme has been extended to include the use of foamed plastics in domestic lofts and as cavity fill.

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COMPUTING FIRE RESISTANCE

R. BALDWIN AND G. M. E. COOKE

Research into the fire resistance requirements of buildings has been carried out at FRS over a number of years, involving extensive co-operation with research laboratories in other countries.[1] The long term objectives of the work are to examine the general validity of the fire resistance requirements; to examine the possibility of more flexible requirements, for example, by supplementing present regulation fire gradings by an optional calculation procedure, as in the current Swedish

Building Regulations; and to formulate the technical basis for rules which will allow trade-off between active and passive fire defence measures.

In the short term, the results of the research are being applied to buildings where conditions or the method of construction are exceptional, for example, where external structural elements are involved, while analytical work on the heat transfer of insulating materials will help to complete and extend the range of construction specifications included in regulation schedules of fire resistance currently under revision. This article describes the more important aspects of research into these problems being carried out at FRS.

Following an extensive series of internationally-conducted model tests and a number of full-scale tests, it is now possible to predict the fire resistance of a compartment or building to survive a burnout, knowing the fire load of the contents, floor area, window opening, and area of walls and ceilings.

One outcome of this work is recognition of the importance of ventilation and compartment shape in addition to fire load density and this is reflected in the varied rate of burning of ventilation-controlled compartment fires. Rate of burning data enable computations of fire severity outside building compartments to be made so that the safety of external structural elements can be assured. The size of flames emerging from windows and their temperature and duration are estimated, from which it is possible to compute whether or not the external structure needs additional fire protection.

Another important aspect of work by FRS involves the prediciton, using heat transfer principles, of temperature rise of protected steel elements such as columns and beams. Provided that the method of fixing the protection is satisfactory the fire resistance of structural steel elements can be predicted using the well known 'critical temperature' criterion: namely that properly designed elements fail in the BS 476: Part 8 test for fire resistance when the steel temperature reaches a critical value which for mild steel is around 550° C. The development of a computer model for predicting how long it takes for different steel sections to reach critical temperature when protected with the wide range of commercial encasement materials now available is of clear importance. A number of empirical methods have been assessed and their range of application has been determined. The preferred method uses a finite element technique, which requires the use of a computer, and a skeleton programme has been written. Sub-routines are being prepared so as to take account of temperature dependent properties of insulating materials ie thermal conductivity, specific heat, density and moisture content.

COST EFFECTIVENESS STUDIES

The practical application of calculations and experiments in determining the best level of fire protection for a given type of building presents new operational problems. It is necessary to take into account not only the different frequency of fires associated with different activities, but also as described above, the type and quantity of fuel, ventilation and building layout and a variety of other factors.

Last, but not least, fire protection must give good value for money, that is, the resultant reduced risk must justify the cost of the protection.

The problem is that because of uncertainty and the inherent variability of buildings and fires and the circumstances in which they occur, it is impossible to guarantee absolute safety. No matter what level of protection is specified, within a practical range, there is always a degree of risk that it will prove inadequate in the event of a fire. Increasing fire protection will reduce the risk and hence the expected losses, but it will also increase the costs of protection until ultimately it is no longer economically viable. Ideally, fire protection should be chosen so that the total cost of fire, ie the sum of losses and costs of protection is as small as possible.

A mathematical model has been formulated to solve this problem.[2] Fire severity has been estimated by studying surveys of fire loads and ventilation in buildings, leading to a statistical distribution from which a probability of failure of the fire protection can be estimated.[3] It is estimated, for example, that in office buildings approximately 7 per cent of rooms would require a fire resistance in excess of 1 hour to survive a burnout. Use of our extensive data bank, including all fires attended by the brigades in the UK, has enabled us to estimate the probability of fires occurring, and shown also that most fires are put out *before* they damage the building fabric. Costs of various levels of structural protection have been estimated and the results show that current levels of structural protection, at least in buildings studied so far, are not unreasonable.

The techniques described above have also been applied to study the important question of the economic use of sprinklers in buildings to partly or completely replace passive measures,[2] mainly structural. Sprinklers have the advantage that

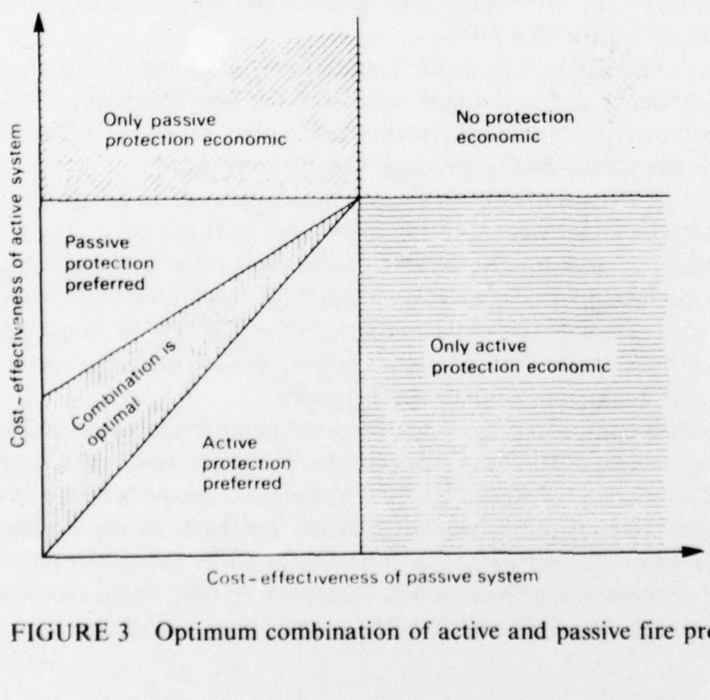

FIGURE 3 Optimum combination of active and passive fire protection measures.

they detect and control fires, resulting in less property damage, but they sometimes fail (usually because they have been turned off for maintenance). The resulting financial benefits with the additional risk have been incorporated into the economic model. The results show (Figure 3) that, depending on the balance of costs and expected damage, active protection (sprinklers) sometimes provide a more economic solution to protecting the structure, and in some circumstances a combination of structural and active protection is best.

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INVESTIGATING FIRES IN BUILDINGS

A. SILCOCK

While work in the laboratory is the backbone of fire research, there is a limit to the size and scope of experimental fires and laboratory conditions cannot always simulate a real fire situation. It is therefore necessary to provide a two-way link between theory and practice by investigating actual fires and the FRS Field Investigations Section was set up for this purpose.

The survey team normally arrives at the scene shortly after the fire has been extinguished. From evidence of fire damage, and from the first hand accounts of fire brigade personnel, occupants and others, they assess the origin and behaviour of the fire and the performance of the building and its components.

The investigation of a series of fires in similar buildings enables comparative analysis of the results to be made and this is the main work of the Section. The first investigation was of fires in modern schools and a report was published earlier this year.[1] The Section's current project is an investigation of residential fires, which account for the majority of fire deaths and casualties in the UK. About 10 per cent of the Section's effort is used for investigations of individual fires of special interest to FRS, to government departments or to fire brigades.

The results provide a continuous feedback of information for research and for the monitoring and up-dating of Building Regulations. However, major fire tragedies at Summerland in the Isle of Man and the Fairfield old people's home have highlighted the serious lack of published information available to the building industry and professions on the performance of buildings under actual fire conditions. The published reports of the Section will substantially help to fill this need and will also be of interest to anyone who staffs or maintains buildings.

FIRES IN SCHOOLS

Over the last decade, the number of fires in schools increased sharply, rising from 900 in the early 1960s to nearly 1900 in 1972, with an eightfold increase in malicious ignition. School building is controlled by DES Schools Bulletin No. 7 which gives measures for life safety. The purpose of the FRS project was to indicate what additional measures could be taken to reduce the extent of fire spread, material damage (£6m in 1973) and consequent disruption to education. Over 20 fires were investigated and an analysis of 14 — all in schools of modern construction with suspended ceilings — was given in detail in the report.[1] A number of important conclusions were drawn:

1. It was known at the outset that undivided ceiling voids were a major factor in fire spread, but the investigation showed that the extent of the spread was greatly influenced by the airtightness of the void and the materials enclosing it. Other means of fire spread, mainly due to weakness in constructional details, were also identified. While these were often overshadowed by firespread in ceiling voids, their correction would be important in buildings in which the problem of firespread in voids has been solved.
2. Certain suspended ceilings did not behave as well in practice as the results of fire resistance tests suggested. There were wide differences between the furnace test conditions and the more complex situation in actual buildings.
3. Poor maintenance or misuse of the building by the occupants was shown to nullify fire protection measures completely.
4. Fortuitous ventilation, mainly through roofs and windows, was the main factor (apart from fire brigade action) in preventing further fire spread, and the report indicated how this factor might be exploited in future designs. This, combined with proposed improvements in detailing and layout, could make the complete destruction of a school very unlikely.

FIRES IN HOUSES

In the vast majority of residential fires, the people who die have been in contact with the material first ignited, usually clothes or bedding. Thus, in only a minority of cases could the building be a contributory factor to death. However, modern materials and forms of construction have less inherent fire resistance than traditional buildings and it is essential to monitor their performance to assess new hazards which may arise and to up-date Building Regulations. Furthermore, higher living standards, with their associated greater use of electrical equipment and other energy-consuming appliances, have increased the sources of ignition, and furniture and personal possessions tend to be more numerous and more flammable. Statistical analysis has shown that 40 per cent of the deaths in house fires are from fires which started in furniture or furnishings and the fire hazard due to furniture within a room has been studied at FRS.

A major interest of the Field Investigation Section is in the spread of the fire beyond the room of origin, and in relating daytime and night-time hazard to the

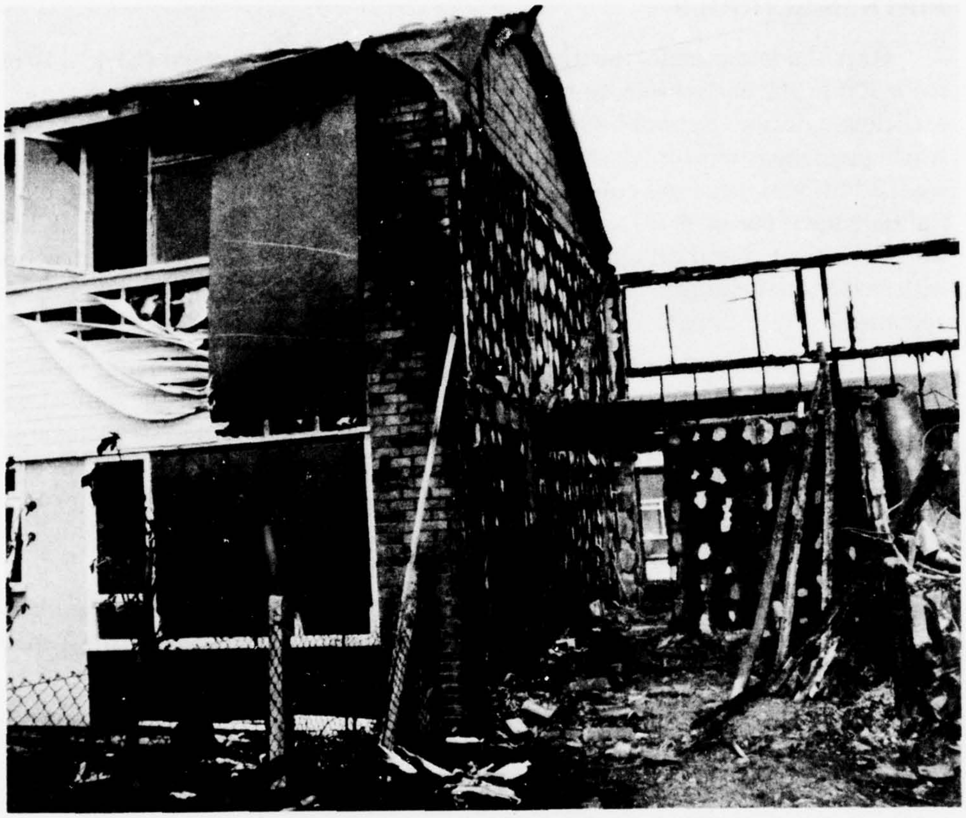

FIGURE 4 Complete destruction of a house in a daytime fire, with severe damage to the adjoining house.

occupants, to the contents, construction and plan layout of the building. The project is the first stage in a longer-term programme investigating actual fires in multi-storey buildings. Houses are the smallest and perhaps the simplest example of a multi-storey building, but the lessons will be applicable to many larger buildings such as blocks of flats, hotels and hospitals.

So far, 25 residential fires in which there were either casualties or an escape problem have been investigated. Problems associated with lightweight industrialised building materials and the effect of do-it-yourself activities are being studied. Two fires involving polyurethane foam ceiling boards have been investigated. In both of them the ceilings failed rapidly, allowing the fire to enter the roof space above and involve the roof structure.

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WORKMANSHIP AND FIRE HAZARD

A. SILCOCK AND P. L. HINKLEY

It is essential that those concerned with the construction and maintenance of buildings have a clear understanding of the purpose of the fire protection provisions and of the possible consequences of their failure due to poor workmanship. With traditional construction, even a brick left out of a separating wall in a roof space may allow firespread to the adjoining roof. On the other hand many modern buildings are constructed wholly, or in part, of lightweight forms of construction which have little inherent fire resistance. Since modern buildings are often larger, more complex, and have more sophisticated services than traditional buildings, they are potentially more hazardous should constructional faults or deviations from agreed standards occur.

In a number of school fires investigated it was found that fire-resisting suspended ceilings with 'lay in' panels performed badly in actual fires because the erection details differed from and were generally more complex than those used for the standard for resistance test. Such ceilings can contribute to the fire resistance of the floor above and thus early failure of the ceiling can seriously lessen the fire resistance of the construction.

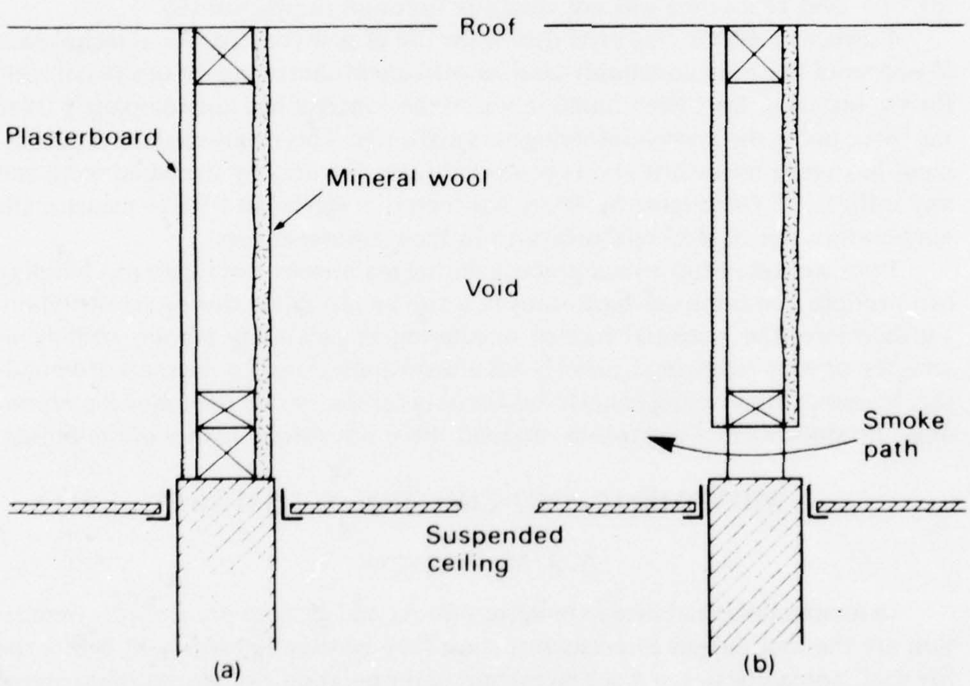

FIGURE 5

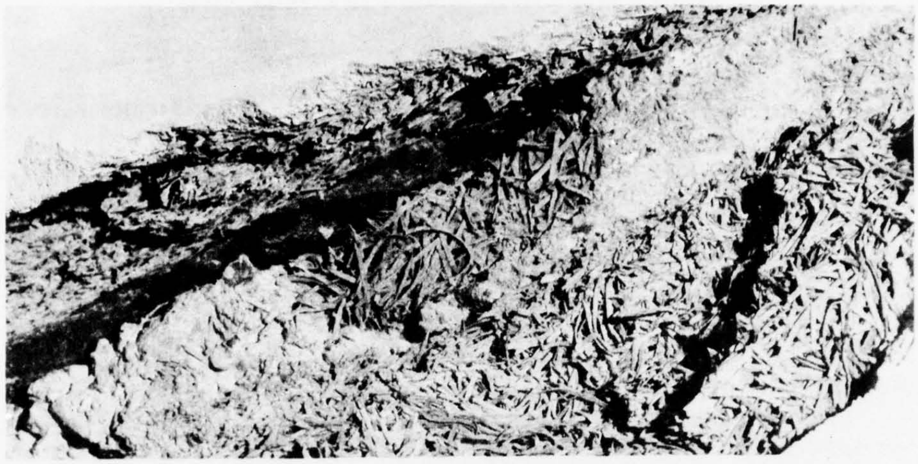

FIGURE 6

Failure to provide adequate fire stopping to services passing through fire resisting constructions can completely nullify provisions for fire compartmentation. Fire rising up through the floor around a flue pipe ignited the casing to the flue and spread to part of the contents of the room above. In Figure 5 the agreed detailing of a void barrier (a) was not carefully followed in practice (b).

Further problems may arise due to the use of new constructional techniques. Wood wool has been commonly used as permanent shuttering for in situ concrete floors. Instances have been found in which the concrete has not completely filled the space under the lower reinforcing bars in the ribs. This means that the reinforcement has voids beneath it and is protected from fire only by the wood wool and any soffit finish (see Figure 6). Work has therefore started at FRS to measure the temperature rise of steel reinforcement in these circumstances.

Poor workmanship or bad practice during maintenance or repair of a building can produce conditions as hazardous in a fire as can faults during construction. Furthermore, the potential hazard of altering the planning layout, routing of services, or even removing a panel is not always appreciated by the users of a building. By removing a ceiling panel to make room for the crest of their model pteranodon, the students in a classroom negated the fire resisting quality of the ceiling.

MOVEMENT AND CONTROL OF SMOKE

A. J. M. HESELDEN

In many substantial fires in buildings smoke and gaseous products of combustion are the first danger to occupants since they become hazards well before the fire itself, spreading over a much larger part of the building. Smoke particles carried by the combustion products from the fire can obscure escape routes and therefore delay or prevent escape. The toxic constituents of these products, aggravated by irritant constituents and by heat, can then endanger occupants. Buildings should be so planned and constructed that in the event of fire all the occupants can readily escape and the fire brigade can reach the fire and extinguish it; in most buildings measures to obstruct the flow of smoke are needed.

Fires may release very large quantities of energy in the form of heat and in many cases it is largely this energy which moves smoke within a building, by expansion as the gases are heated and by the buoyancy forces generated by the low density of the hot gases. Smoke movement can also be caused by those factors which cause air to circulate for ventilation during normal occupation of the building — wind generated pressures and suctions, 'stack' effects and mechanical ventilation systems.

Methods employing permanent ventilation and openable windows are recommended in current Codes of Practice to prevent undue build-up of smoke on protected, ie properly enclosed stairways — an all-important part of the escape route in multi-storey buildings. The recently developed 'pressurisation' method is also gaining wider acceptance, in which air is injected into enclosed staircases and/or lobbies to raise their pressure slightly and thus oppose the entry of smoke. Other methods have been proposed and used in America and on the continent, for example air-lock systems with smoke extraction and air injection. A computer program which predicts the smoke flow in buildings has been developed at FRS and will be used to explore the relative merits of these systems for various applications, and to obtain design information.

For buildings like factories and enclosed shopping complexes, with large, open spaces, smoke control measures can make use of the fact that in most cases the smoke forms a layer under the ceiling. The smoke can therefore be collected in ceiling reservoirs from which it can be efficiently extracted, its horizontal movement can be restricted, and tolerable conditions for fire fighters and escaping occupants can be maintained beneath the smoke.

SHOPPING MALLS

Roof venting systems primarily for factories were studied by P. L. Hinkley and P. H. Thomas in the early 1960s. More recently natural, ie buoyancy-operated, venting and also mechanical extraction systems for enclosed shopping complexes have been studied at the Fire Research Station.[1] Many such complexes have been built in the UK in recent years. They usually consist of one or two storeys of shops fronting extensive covered pedestrian malls, often connected via tall 'squares' to other, similar, malls. Without safeguards they would present special dangers because smoke generated by a fire would be channelled along the malls to impede escape and endanger occupants.

Among the safety measures recommended are the installation of automatic sprinklers, which limit the size of fire and therefore the amount of smoke produced, and the provision of smoke control measures incorporating smoke reservoirs, smoke venting or the mechanical extraction of smoke, and, to replace the smoke leaving the building, provision for inlet air.

For single storey malls natural venting is often satisfactory because the quantity of smoke is not too large and the smoke layer developed is hot enough to have sufficient buoyancy. Special difficulty arises in malls having two inter-connected shopping storeys and this situation is being studied at FRS using a 1/10th scale model. This work has shown that because of the large quantity of air entrained into the rising plume of smoke it would be all too easy for a fire on the ground floor to rapidly fill the upper storey with smoke down to floor level.

The model work has indicated that smoke-logging on the upper floor could be reduced by the following measures:

First of all, the horizontal travel of smoke under the ceiling of the lower floow should be drastically curtailed. The ideal is for the rising smoke plume to form as small a perimeter as possible. This can be achieved by restraining the sideways travel of the smoke leaving a shop by means of ceiling screen leading it directly to the balcony edge (Figure 7). Screens permanently in position would not usually be acceptable to developers, but systems in which the screen are held horizontally so that they can swing down after fire detection may be feasible.

For all systems it is advantageous for the replacement air to enter on both upper and lower floors, otherwise stagnant areas are formed which can fill with cool smoke. The incoming jets of air should be allowed to expand and slow down before meeting the smoke layer, to reduce the downward pull on the smoke layer.

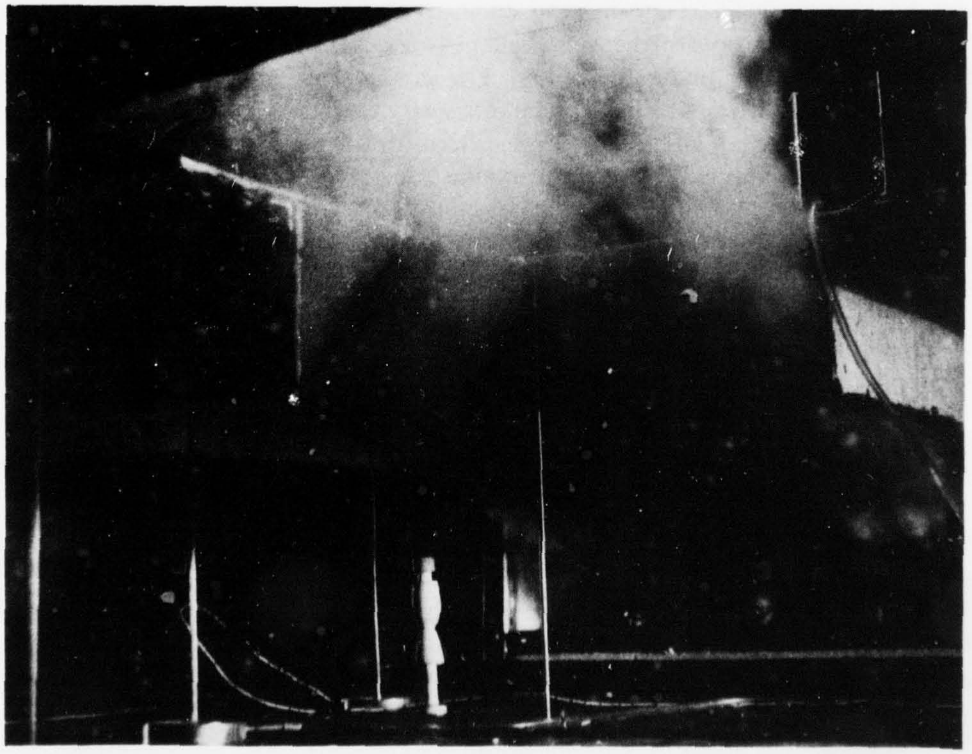

FIGURE 7 Smoke from a model fire confined by ceiling screens to form a compact plume.

This can be arranged by having, for example, a roof screen placed a few metres from the air entry point; this also serves to reduce disturbances due to wind. This provision is especially important on the upper floor of a two-storey mall because here the smoke layer may not be very buoyant.

Smoke reservoirs on the upper floor should be deep and sufficient extraction should be provided by natural or mechanical venting.[2] To prevent inefficient extraction due to the drawing-up of air from below the smoke layer, smoke should be extracted from a number of points distributed over the reservoir.[1]

Venting outlets should not be sited near the base of tower blocks as adverse pressures opposing the venting may be developed by winds. Outlets in outward-facing vertical surfaces should be avoided because of the possibility of wind interference.

In view of the low buoyancy of the smoke, mechanical extraction systems are likely to be especially suitable for two-storey malls, particularly where the presence of tower blocks makes the siting of outlets for natural venting difficult.

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BEHAVIOUR OF PEOPLE IN FIRE

I. C. APPLETON

The fire requirements of the Building Regulations seek to ensure the safety of occupants by limiting the effects of fire, usually by structural means, and by providing adequate means of escape. In doing so, some assumptions about human behaviour are made, most particularly what people actually do in fires, the manner in which they move, and the circumstances in which panic is likely to occur. The traditional sources of information are common sense and experience but, today, the speed of change of building form and novelty of design make these traditional sources insufficient. We need to improve our understanding and our ability to predict human behaviour.

PATTERNS OF BEHAVIOUR

The first attempt to make a systematic investigation of the behaviour of people in fire was made by Wood, under contract from FRS.[1] Using a questionnaire approach, Wood obtained data from about 1,000 fires. His main aim was to ascertain the sequence of actions of the occupants and to relate these to a number of key variables which were identified as recognition, perception, familiarity, training, experience, age, sex, and social environment. Some general patterns of behaviour emerge as well as some interesting features, namely (1) there is little evidence of panic, (2) fire fighting by the occupants happens more frequently than previously thought and is not related to training, and (3) people are prepared to move fair distances through smoke. The results were largely unstructured and are unconfirmed, and they high-lighted the problems of conducting and analysing such work.

Building on the experience of Wood, FRS initiated a further research programme. The initial stage reviewed current knowledge about the behaviour of people in fires and the behavioural assumptions and data used in the drafting of existing regulations. In the light of this review the problem was structured using psychological methods and hence a strategy for future programmes using available methodology could be suggested. Canter and Matthews report this stage of the work in reference 2.

Fire regulations are designed to assist escape, whereas escape is only one part of people's overall response to fire. This leads to the concept of behaviour being multi-dimensional and the need to develop an index of effectiveness of behaviour by giving weighted scores to particular actions which, in turn, involves attaching values to particular consequences.

The current phase in the programme is to develop a predictive model of behaviour based on psychological characteristics, to find out how this is modified by the building form and fire safety provisions, and how the people involved respond to various fire and non-fire stimuli.

A team of psychologists at Surrey University are engaged in data collection: they are visiting fires and studying a selection of them in depth, interviewing firemen and people involved in fires, in order to search for patterns of behaviour and the effectiveness of patterns. In addition, a comprehensive survey of existing records is being made to collate all the known behavioural data.

EVACUATION STUDIES

In parallel with this work, FRS is making studies of evacuation from buildings on fire. Many modern buildings are large and are occupied by several hundred people. It is therefore important to know how quickly people can be evacuated from a building or part of a building in an emergency. Published data on crowd movement in non-fire situations have been reviewed and used for calculating the flow rates along corridors, through exits and on staircases. These flow rates have formed the basis of a simple model which has been compared with evacuation exercises conducted in tall office blocks and is generally in good agreement.[3]

The data on crowd movement related to normal healthy people, but the evacuation of a hospital ward is a special case because of the immobility of bedbound patients. By visiting hospitals where there had been an evacuation and by attending evacuation drills, an overall picture is being built of the circumstances in which evacuations are attempted. The aim is to develop models of the evacaution process, so that predictions can be made of the likely course of events in varying circumstances. Such models require a numerical data base and to establish this a series of evacuation experiments was filmed at Hackney Hospital,[4] in which 30

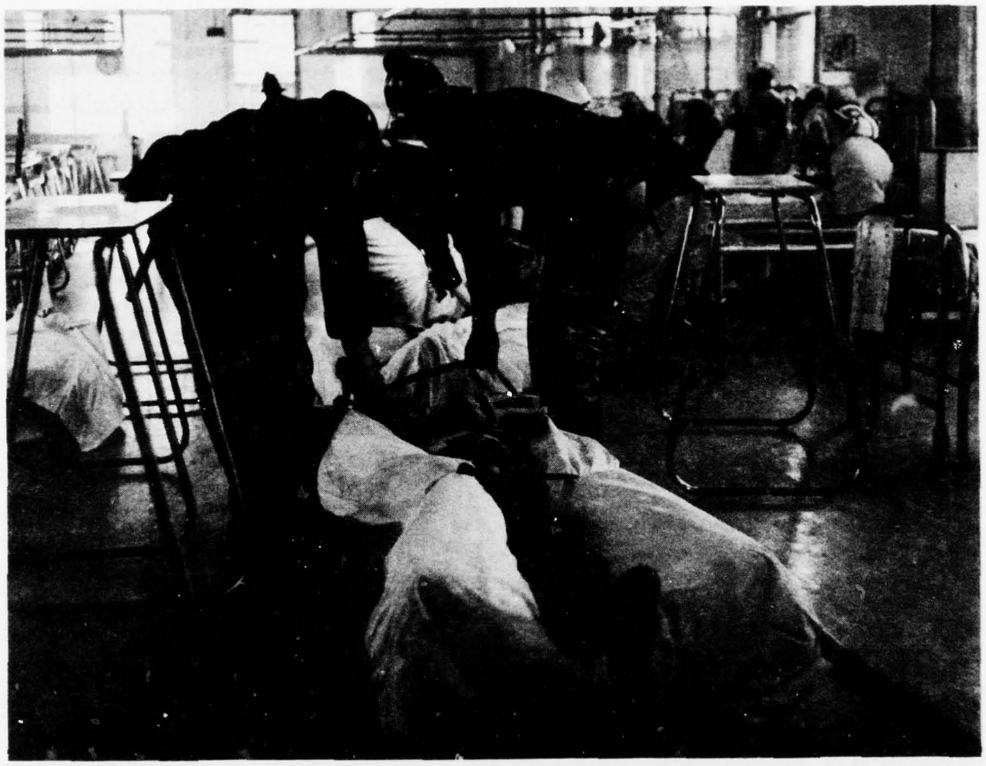

FIGURE 8 Study of evacuation problems in a mock fire at Hackney hospital, with actors playing the "patients."

actors working as 'patients' were moved by hospital staff from a second floor ward down an external fire escape (see Figure 8).

In addition to the work described FRS has placed a contract to survey attitudes to risk. The questionnaire approach to the collection of behavioural information and the necessary statistical methods for data handling are being developed at Surrey University. In addition a study of the ability of hospital staff to use first aid fire fighting equipment is envisaged.

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LARGE-SCALE TESTS AT CARDINGTON

In the vast airship shed at Cardington, the Fire Research Station has experimental facilities which are unique in Europe and probably in the world. The 240 m long, 80 m wide, 60 m high shed (Figure 9), birthplace of the R101, provides weatherproof conditions for large-scale fires and explosion tests which would normally have to be performed in the open air. The still atmosphere in the hangar allows accurate measurements of air speeds and smoke movements which would be impossible outside, while smoke and other combustion gases are quickly diluted, rise safely into the roof, and can be dispersed gradually. Some of the test rigs installed in the shed are described in these pages.

CORRIDOR RIG (Figure 10)

This is designed to represent a room connected to an escape route, a situation common to many buildings. Made of 150 mm thick, low density concrete blocks, it

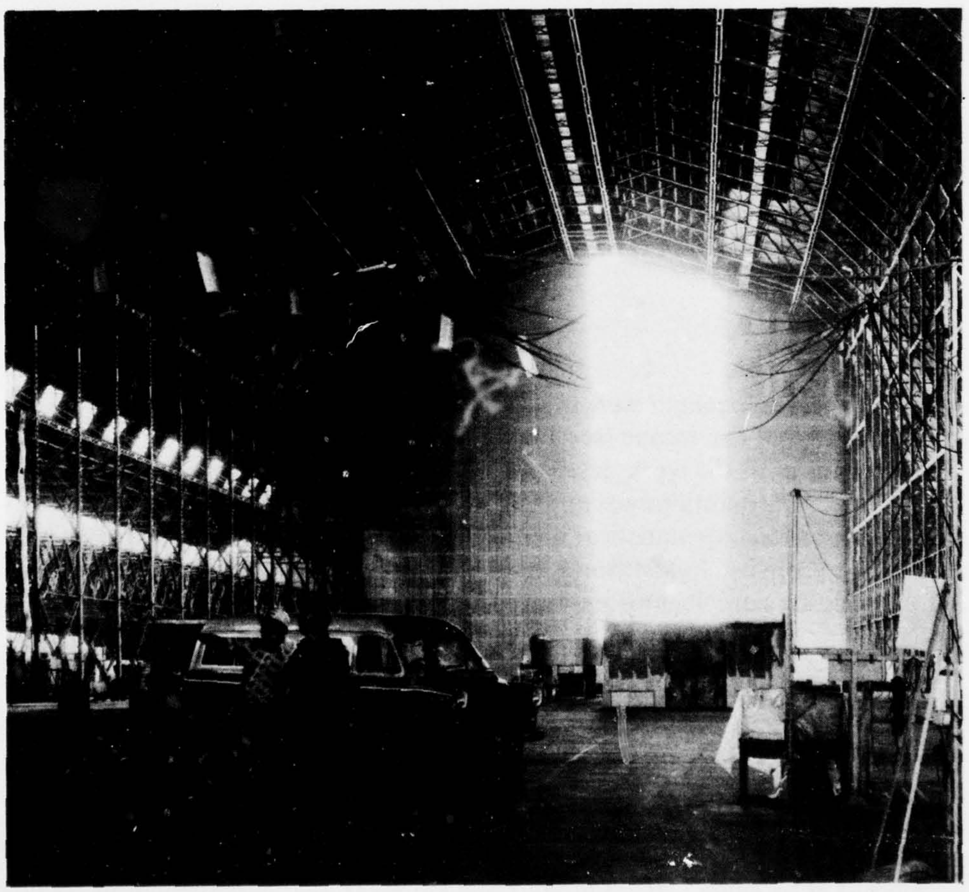

FIGURE 9

FIGURE 10 Corridor rig.

consists of a 3 × 3.3 × 2.4 m high room opening into the middle of a 22 m long corridor and is capable of withstanding temperatures up to 1,200°C. The rig is being used to study at full scale the fire behaviour of different materials used in buildings. Measurements are taken in a separate pressurised cabin of burning behaviour, smoke release, and production of various toxic gases.

EXPLOSION CELLS (Figure 11)

Gas explosions are one of the main causes of building damage, and two test cells have been built at Cardington to study the problem. The single 28 m^3 cell shown in the photograph has been used to measure the effectiveness of different types of relief vent. Work has also started with a complex cell representing full-scale interconnected rooms or compartments. The progress of a gas explosion through the structure will be monitored, and in particular the effects of turbulence on the severity of an explosion.

The concentration in the gas layers as the cell fills is measured with the aid of a sampling probe developed in the services section at FRS. This is remotely operated from the control room, and gives digital read-out of the probe position. The multiple cell will also have a mini-computer system, designed by the systems section at

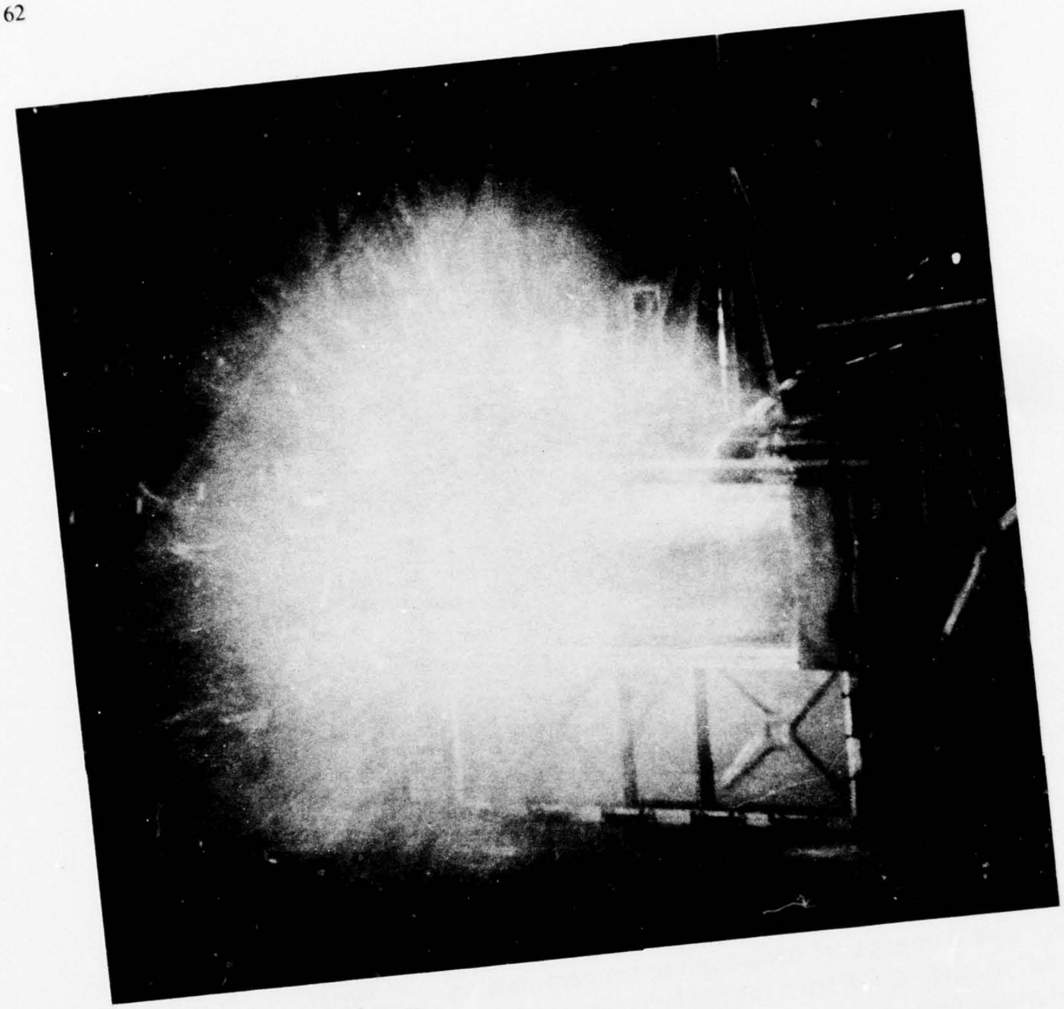

FIGURE 11 Explosion cells.

BRS, Garston, which will control the gas sampling and analysis equipment and give an immediate printed read-out of the gas concentration in each sample.

DETECTOR TUNNEL (Figure 12)

The 25 m long detector tunnel was built initially to study the problem of detecting a fire in a cable tunnel. A series of experiments was carried out for the Central Electricity Generating Board on the response of automatic detectors to the different types of fire which might occur.

IMPROVING WATER JETS (Figure 13)

The still air conditions of the hangar are ideal for studying the throw of water jets from fire-fighting hoses, and the effects of different shapes of nozzle and of additives in the water. Photographs are used to record the shape of the jet.

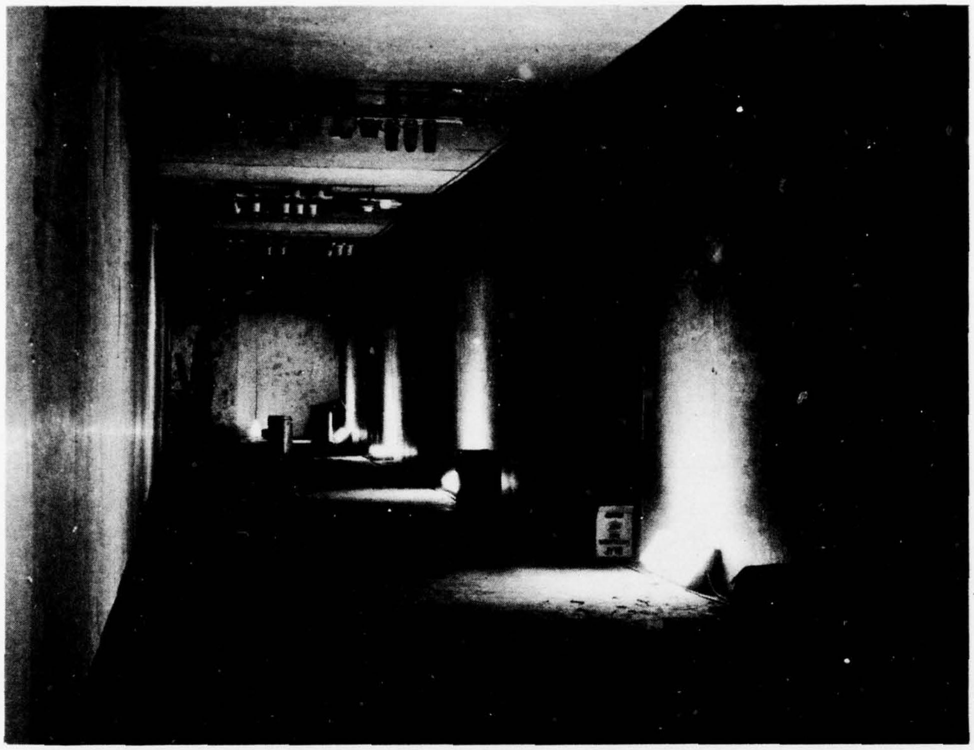

FIGURE 12 Detector tunnel.

ROOF CONSTRUCTION TEST (Figure 14)

One of the problems highlighted by the survey of fires in schools was fire spread within ceiling voids. At the request of the Department of Education and Science and the education building consortia, tests are being carried out in this rig to assess whether the materials and construction of the roof contribute to the spread of fire. Materials tested include expanded polystyrene foam under three-layer felt, fibre board with three-layer felt and with asphalt, and rigid polyurethane. A standard suspended ceiling of mineral fibre tiles was used for each test. The effect of a fire barrier in the void is also being investigated.

HIGH RACK STORAGE (Figure 15)

A fire in a modern warehouse, where goods are stored in racks up to 12 or 15 m high, can cause enormous damage very rapidly. Controlling the fire is difficult because it quickly spreads upwards through the cells of a stack (15a), and the sprinklers in a conventional system generally do not operate until the flames have passed above them.

FRS has developed a zoned sprinkler system in which groups of sprinklers

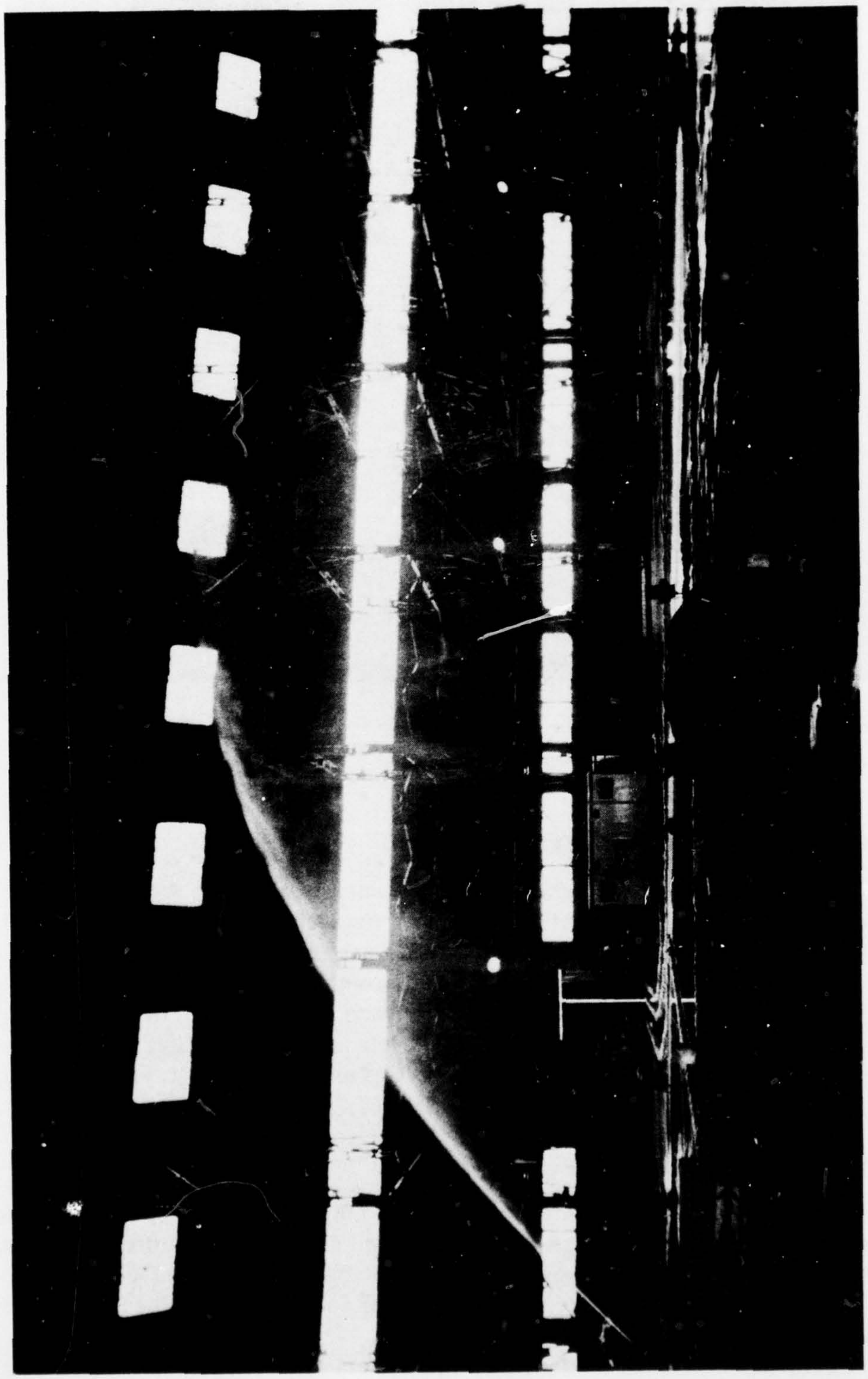

FIGURE 13 Improving water jets.

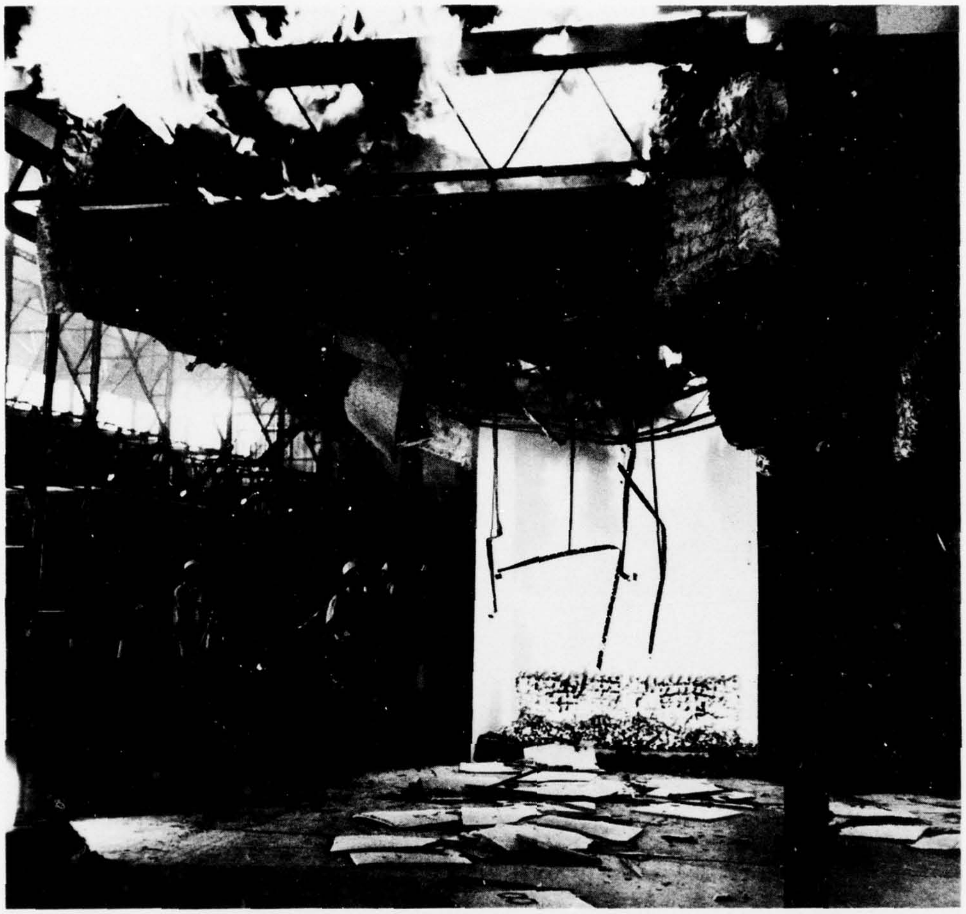

FIGURE 14 Roof construction test.

are operated together so that if a fire starts in one cell, the sprinklers in the surrounding cells also start to operate, damping down the packages in advance of the fire (15b). The system employs a heat-sensitive line detector distributed round the racking, ensuring that a fire is detected in its early stages wherever it occurs.

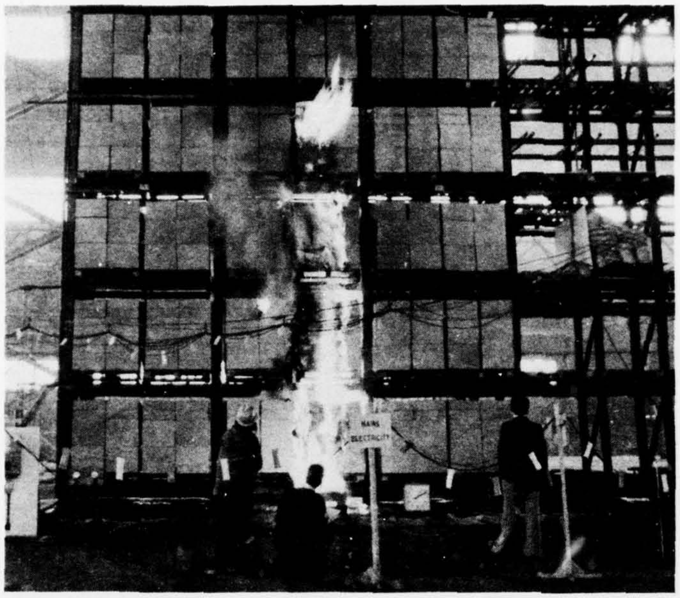

FIGURE 15a

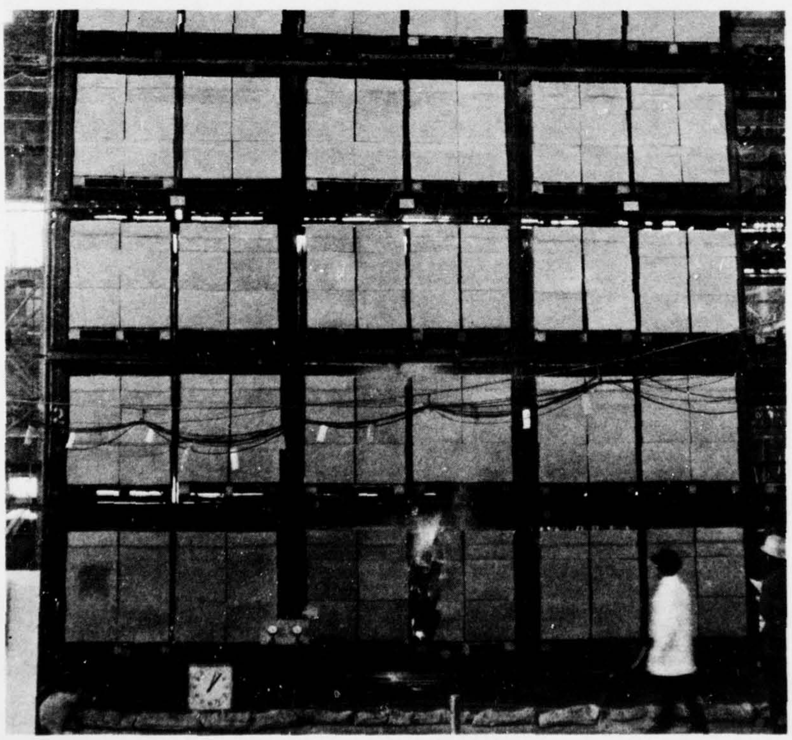

FIGURE 15b

PLASTICS IN FIRES AND TOXIC HAZARDS

W. D. WOOLLEY AND K. N. PALMER

The majority of deaths in fires in the UK occur in domestic premises and the proportion due to smoke and toxic gases has increased markedly over the last 20 years, now accounting for over half of all fatalities. With fires involving furniture the proportion of deaths attributed to smoke and gases is between 60 and 70 per cent.

There is a temptation to assume that this increase is due wholly to the increased use of synthetic polymers but other changes have also taken place within buildings over this period which may have contributed.

It is difficult to assess quantitatively the changing pattern of real fires over a number of years. Nevertheless the subjective evidence, mainly from fire brigades, shows that modern fires are relatively intense, usually of short duration and produce large quantities of smoke and gases.

The main research programmes related to plastics, particularly to the release of smoke and toxic gases, include:

Laboratory Decompositions

Small samples of plastics are decomposed in a furnace in air or in an oxygen-depleted atmosphere at temperatures up to 1,000°C to simulate the broad decomposition conditions likely to be encountered in fires. The decomposition products are analysed by gas chromatography and mass spectrometry which provides information about the way in which various products are formed and highlights the products which need to be monitored during real fires.

Laboratory Combustion

Many primary products of combustion themselves burn and a special burner is used to study the final products of materials known to be released during decomposition experiments. Important information about the destruction of cyanides and formation of oxides of nitrogen by flames has been obtained in this way.

Full-Scale Fires

Full-scale fire tests are carried out in a structure designed to represent a room attached to an escape route. The rig is instrumented for measuring temperatures and smoke and gas production, and is currently being used to assess the fire hazard of furniture and beds as part of a collaborative programme with the DOE Property Services Agency.

RESULTS OF TESTS

Considerable effort has been directed to studies of the general decomposition processes and fire behaviour of various plastics, and particularly pvc and polyurethane foams.

With pvc, upwards of 75 different products have been detected during thermal degradation consisting mainly of hydrocarbons which are formed during and following the dehydrochlorination. The main toxic products appear to be hydrogen chloride and carbon monoxide. The release of hydrogen chloride (a severe irritant at about 50 ppm and hazardous in a short exposure at about 1,500 ppm) occurs at a relatively low temperature (200-300° C) and about one-half of the weight of a rigid (unplasticised) pvc can be released as hydrogen chloride.

The overall risk from hydrogen chloride depends upon the amount of pvc in a room, its location, and particularly the ventilation. The ventilation controls the temperature build-up in the compartment and also the release of carbon monoxide. For example, in a room with a high degree of ventilation the fire develops rapidly and carbon monoxide in the fire gases is relatively low, but hydrogen chloride is released relatively early and copiously.

Considerable work has been carried out to study the decomposition behaviour of the flexible polyurethane foams used in furniture and bedding. These foams decompose at a relatively low temperature (200-300°C) to produce the original polyol with the release of the tolylene diisocyanate part as a polymeric 'smoke'. The decomposition of this smoke at high temperature produces hydrogen cyanide and other organic nitriles. Fire tests with the flexible foams have shown that the cyanide risk can be significant (in comparison with the carbon monoxide) in the very high temperatures encountered during industrial fires, but less significant during domestic fires.

More recently a study has been made of the thermal decomposition behaviour of rigid polyurethane and poly isocyanurate foams, particularly those containing phosphorus-based flame retardants, because of the possible release of a highly toxic bicyclic phosphorus ester termed TMPP.

A series of fire tests has recently been carried out in collaboration with the Property Services Agency of DOE to study the fire behaviour of domestic beds (see *BRE News* 36). The work has shown that the mattress cover plays a very important role in the overall development of fire, particularly with polyurethane foam mattresses. A very rapid rate of fire development can occur with polyurethane foam enclosed in a proofed nylon cover, which is a very commonly used combination of materials.

EXTRAMURAL CONTRACT WORK

Experiments to study the physiological behaviour of fire gases and known decomposition products are being carried out at the Chemical Defence Establishment and at the Huntingdon Research Centre. This work gives support to the analytical programmes and explores toxicological problems which might influence people's escape from fires.

A three-year contract has been completed at the Rubber and Plastics Research Association to establish the fire properties of furniture and furnishings in both laboratory and full-scale tests. The work has shown that, in general, chairs and settees upholstered with modern materials were ignited by flame considerably more easily than their traditional equivalents, whereas the traditional materials were more prone to smouldering from cigarettes. Modern upholstered furniture burnt rapidly whereas the traditional equivalent burnt more slowly.

In a sequence of fires in a fully-furnished sitting room, traditional material was relatively difficult to ignite with a small flame and underwent a period of smouldering; when flames re-established themselves the fire developed slowly. Four tests involving the progressive substitution of less flammable fabrics and foams and the use of inter-linings has shown that the flammability of a modern suite was reduced to resemble that of traditional furniture.

IMPROVING METHODS OF DETECTION

P. E. BURRY

The first known patent for a fire detection system was granted shortly after the Great Fire of London, and the art of detection might be said to have started at about that date. Scientifically, however, little progress was made before the 1939-45 war; since then research has gone on at an increasing rate, both in this country and abroad, with FRS taking a leading part.

Detectors already help considerably in reducing fire losses, but it has been estimated that introduction of detectors into all premises in the UK might save 400 lives and reduce fire losses by £50m a year. In practice such an overall introduction would be extremely expensive, and it would be more economical to start by installing detectors in premises in which the maximum of benefits is obtained for the minimum of cost. FRS work is aimed at identifying the types of premises in which this would be so.

Part of the cost of running a detector installation lies in the false alarms raised, with the consequent disruption of work and the attendance of the fire brigade. A survey carried out by FRS in 1968 showed that detectors raised more than 10 false alarms for every real fire detected, and this figure was confirmed in a survey carried out by the relevant trade organisation in 1971. If detectors are to go into more widespread use this number must clearly be reduced appreciably.

The causes of false alarms fall mainly into three broad classes: human interference, mechanical or electrical faults, and environmental effects. The first two classes are primarily the responsibility of the user, the installer and the manufacturer, but there is little that they can do about the third class without a much better knowledge of the environment in which fire detectors exist. To obtain this knowledge the detector section has started a long-term survey of the conditions in a variety of locations in which detectors might be installed. A pilot survey, started at the end of 1974 in an office at FRS, was intended to provide data for the development of analysis techniques; however, the data obtained on temperatures, smoke densities and air velocities has already thrown new light on the ways in which extreme conditions might occur in practice.

There is, of course, no point in making a detector which gives no false alarms if its sensitivity has been so far reduced that it is no longer able to give a real alarm.

In parallel with the work on environment the Section is therefore studying the early stages of fire, and hopes to develop techniques of predicting the size of fire which can be detected by different types of detector in various types of building fires. The Section has been particularly concerned with growing fires, and the development of the fire plume and the ceiling layer of fire gases. This work will also cover studies of optimum siting of detectors to obtain the best cost/benefit ratio.

The primary application of FRS work is through the medium of British and International Standards, and a considerable part of the effort is taken up in their formulation and in the development of test techniques. One item in particular is worthy of mention; the standard method of test for smoke detectors and for heat detectors involves the use of a wind tunnel, and for some time there has been considerable variation between results obtained in different laboratories, largely due to poor control of the airflow in the wind tunnels used. A new testing tunnel has therefore been developed in which much greater care has been given to the airflow, and it is hoped that this will reduce inter-laboratory differences.

TOWARDS INTERNATIONAL STANDARDS

H. L. MALHOTRA

Every country interested in structural fire protection has gradually developed standardised methods of conducting fire resistance tests, and has used the data to evolve design codes for structures which provide a specified fire resistance. Over the years various attempts have been made to harmonise procedures, but effective steps were not taken until 1961 when the International Organization for Standardization (ISO) set up a technical committee (TC 92) to prepare specifications for fire tests. It has so far produced five recommendations for standards of which the most important are on fire resistance tests for elements of building construction (ISO/834) and on fire doors and shutters (ISO/3008).

The test specifications are apparatus-related and consequently differences can exist between various laboratories. A number of leading laboratories in Europe joined together to form an association known as Inter-Laboratory Data Acceptance Association (ILDA), with the objective of achieving improved uniformity of procedures and specifications, and the mutual acceptance of data. The Fire Research Station has played a leading role in its activities.

The Internal Market Directorate of the Commission of the European Communities (DG XI of CEC) is concerned with the removal of barriers to trade between the nine European countries. It has been asked to harmonise the methods of fire tests so that products tested in one country do not need to be retested in another to comply with national requirements. The Commission appointed ILDA as a technical adviser and has prepared a draft directive on fire resistance tests. On approval and adoption the directive will enable automatic acceptance of test data between the member countries. Future activities of the Commission will deal with tests on doors and 'reaction to fire' tests, ie tests to measure ignitability, flammability, flame spread, heat release and smoke production.

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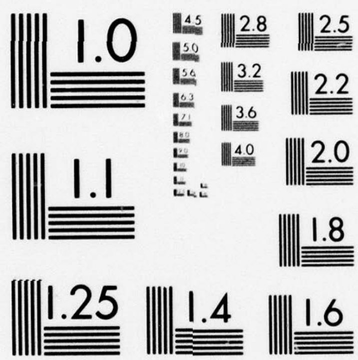

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Concurrent with the activity in the testing field, discussions are also progressing on the preparation of codes and guides to assess the fire conditions to which structures will be subjected and the computation of their fire resistance. Following international agreement between civil engineering associations, the main liaison is being provided by a CIB Commission (W14 on fire research), which has set up a code advisory panel (CAP). Various international organisations have been preparing material codes over the past few years, and another directorate of the CEC (DG III) has been seeking ways of providing common codes and regulations on requirements for structural safety in buildings.

The activities of CEC-DG XI and CAP have been linked in such a way that the experts in the field can provide technical data on various aspects of structural behaviour on a common basis. With the CAP providing the necessary guideline for harmonization, the following five subject areas are under active consideration: principles of fire safety; levels of protection for building safety; design of concrete, steel and wood structures.

FRS is contributing actively to these discussions at a technical level as well as in the co-ordination aspects. It is hoped that the production of unified standards for fire tests and common methods of estimating levels of fire safety and the performance of structures will lead to the unification of building regulations in the European countries. This move towards harmonisation exists not only in the EEC but also the rest of Europe through the activities of ECE and internationally through CIB.

THE SCIENCE AND ENGINEERING OF HOSTILE FIRES

A. MURTY KANURY

University of Notre Dame

INTRODUCTION

In this modern society destructive fires play a role far greater than realized individually by most of us. In the U.S. alone, over 1% of the G.N.P. is destroyed by fires every year; more importantly, over 12,000 lives per year are lost in fires and many thousands more are left with scars for life. The need for an introductory article on hostile fires is clear if one notes the recent rapidly increasing interest on the topic.

So much as the fire phenomenon involves a host of interacting physical and chemical processes, an individual interested in its study is expected to be fairly conversant with a variety of engineering science disciplines. To a scientist, the problem of fire is interesting, for it is composed of a multitude of competing processes; many exciting limiting cases of idealized fires evolve to challenge his creativity. To an engineer, the fire protection field opens up a fresh, new, wide arena in which he is called to demonstrate his traditional skills of dimensional analysis, "similarity" studies and testing; after all, these are the very skills which made it possible for him to design, test, and build ships, dams, bridges, propulsion engines, reactors, as well as artificial organs for the human body — all to function under quite adverse circumstances. To the historian, the great fires served as the milestones of time. To the economist, the dollar-destruction caused by fire has serious implications. To the conservationist, the possibly preventable waste of wild-land and wild-life due to conflagratory forest fires is a true tragedy. To the sociologist, fire and poverty almost always seem to go hand in hand. In this paper, I shall cover fire with only the viewpoint of an engineering scientist who is enough of a historian, enough of an economist, enough of a conservationist, and enough of a sociologist to appreciate the relevance of his work.*

SCOPE OF THIS WORK

The goal of this work is to postulate, on the basis of the available experimental and theoretical models, the conditions required (a) to initiate a fire (i.e., ignition), (b) to render persistence to the initiated fire (i.e., propagation and spread), and (c) to foster a persistent flame to grow into a destructive killer of a fire (i.e., growth).

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*These words, in fact, belong to Prof. P. L. Blackshear of University of Minnesota.

Extrapolating this postulation, we shall consider the processes of control and extinction. Due to the inherently necessary conciseness, no single review of the present kind can claim to be complete and comprehensive — particularly so in a rapidly growing field of research such as Fire. In the framework of the quite arbitrary topical organization chosen here, I hope to summarize what I believe are the salient points of progress and promise.

WHAT IS A FIRE?

A fire may be defined as a chemical reaction between a "fuel" and an "oxidizer" (which is usually the ambient air), the result of such a reaction being release of energy (mostly, thermal) and production of such inert and noxious chemical species as CO_2, CO, H_2O, soot, smoke, . . . etc. All too frequently, considerable amount of the energy release also occurs in the form of visible light and invisible infrared radiation. A fire may be flaming (i.e., the exothermic reactions are predominately in the gas phase), glowing (i.e., the reaction is heterogeneous, confined to the surfaces) or smoldering (i.e., the reaction is heterogeneous in the subsurface layers of a porous fuel bed). Examples of flaming combustion are many (candle flame, cooking range flame, etc.) whereas those of glowing are relatively fewer (glowing embers in a fireplace, coals in a grill, etc.). Smoldering occurs in porous fuel arrays such as mattresses, haystacks, etc. In the present work we deal, in the main, with flaming fires.

For flaming to occur, the "fuel" is required to be in gaseous state. If the fuel is present in solid or liquid state, it has first to be gasified by either destructive distillation (i.e., pyrolysis) or purely physical vaporization. Upon their production in this manner, the fuel vapors convect and diffuse outwards into the ambient air to form a reacting mixture. It is clear by this brief description that diffusion, convection, mixing, and chemical kinetics are a few of the important processes generally involved in fire problems. In most fire situations, usually, even the slowest of the chemical kinetics steps are extremely fast when compared to the physical transport processes of flow, diffusion and mixing; the resultant reacting fluid flow is consequently "diffusion controlled."

It is now possible to state qualitatively the conditions required to make a fire start, persist, and grow. To initiate, the conventional fire triangle [of fuel (vapor), oxidant, and the all-important heat] has to be fulfilled. For persistence, the initiated fire must produce heat at a rate sufficient to exceed the loss rate (due to combined conduction, convection and radiation in addition to any other extraneous heat loss mechanisms). In order to grow, the persistent fire must feed heat back to the fuel yet to be burned; the larger this feedback, the greater the growth rate.

Cut down the feedback, one cuts down the fire growth rate. Enhance the heat losses or inhibit the heat generation rate, one disables the fire to self-sustain. Break the fire triangle (by removing any of its sides), one eliminates the incidence of fire. So much as a nonexistent fire is also a nonpersistent and nongrowing fire, breaking the fire triangle trivially eliminates the need to consider the energy balance and feedback rate aspects of the problem. Similarly, so much as a nonpersistent fire is also a nongrowing fire, increasing the heat losses or decreasing energy production will automatically remove the need for the feedback rate considerations in the problem. Brief quantification of these thoughts with reviews on some of the scientific advances in various areas of fire constitute the remainder of this paper.

SMOLDERING IGNITION

Due to slow oxidation reactions, heat is known to be generated in such porous solids as sawdust, food grains and flours, cotton linters, fiberboard, foam rubbers, oily rags, etc. If this generation rate is large enough to exceed the rate of dissipation through the solid boundary, the temperature in the body is expected to build up gradually to a sufficiently high level where the oxidation reactions are accelerated to what is widely known as "self-ignition." Large volume to surface ratio of the body, low conductivity of the solid, high ambient temperature, etc., are the factors which reduce the heat loss rate; high reactivity and heat of oxidation are among those factors which increase the generation rate; these are some of the effects encouraging the self-ignition.

Mathematically, the self-ignition problem is governed by the following coupled energy and kinetic equations.

$$K\left[\frac{\partial^2 T}{\partial x^2} + \frac{j}{x}\frac{\partial T}{\partial x}\right] + \Delta H\dot{c} = \rho C\frac{\partial T}{\partial t} \qquad (1)$$

$$\dot{c} = -\,kc^n \exp(-E/RT) \qquad (2)$$

[K, ρ, and C, respectively, are the solid thermal conductivity, density, and specific heat. T is temperature and t is time. x is the position from the plane (j=0), line (j=1), or point (j=2) of symmetry in a body of thickness 2ℓ. ΔH is heat of reaction. $\dot{c}$ is reaction rate, c being the reactant concentration. k is the pre-exponential factor, n is the reaction order, E/R is the activation temperature.]

The problem is to solve for T(x,t) and c(x,t). Assuming that the reactant consumption in the pre-self-ignition period is negligible, the reactant concentration, c, may be set equal to its initial value making Equation (2) unnecessary and the second term of Equation (1) purely temperature dependent. With the boundary conditions

$$t = 0,\ T = T_o,\ \text{all } x \qquad \text{(initial)}$$

$$x = 0,\ \partial T/\partial x = 0,\ \text{all } t \geq 0 \qquad \text{(symmetry)}$$

$$x = \pm\ell,\ T = t_o\ (\text{or } \partial T/\partial x = \text{a constant}),\ \text{all } t \geq 0 \qquad \text{(exposure)}$$

introduction of the nondimensional definitions, $\xi \equiv x/\ell$, $\tau \equiv Kt/\rho C\ell^2$, $\Theta \equiv E(T-T_o)/RT^2$, and

$$\delta \equiv \frac{\Delta H k c_o^n \exp(-E/RT_o) E \ell^2}{KRT_o^2}, \qquad (3)$$

with the usual approximation $\exp(-E/RT) = \exp(-E/RT_o[1+(T-T_o)/T_o]) \approx \exp(-E[1-(T-T_o)/T_o]/RT_o) = (\exp \Theta) \cdot \exp(-E/RT_o)$ transforms Equation (1) to the form

$$\frac{\partial^2\Theta}{\partial\xi^2} + \frac{j}{\xi}\frac{\partial\Theta}{\partial\xi} + \delta \exp \Theta = \frac{\partial\Theta}{\partial\tau} \qquad (4)$$

with the initial and boundary conditions: $\tau = 0$, all ξ, $\Theta = 0$; $\tau > 0$, $\xi = 0$, $\partial\Theta/\partial\xi = 0$; and finally, $\tau > 0$, $\xi = \pm 1$, $\Theta = 0$ (or $\partial\Theta/\partial\xi =$ constant). This non-linear equation has been solved only approximately. Semenov's approximate solution[1] assumes that the temperature is spatially uniform everywhere except near the boundary and follows the progress of the reaction with time according to Equation (4) to obtain the solution $\Theta = \Theta(\delta,\tau;j)$. At the critical condition of a thermal run-away one finds that $\Theta_c = 1$, $\delta_c = \tau_c^{-1} = j + 1$.

Frank-Kamanetski's approximate solution[2] considers Equation (4) in its steady state form to obtain solutions (numerically) of the form $\Theta = \Theta(\xi, \delta,;j)$. The maximum temperature occurs at $\xi = 0$. For values of δ greater than a critical value $\delta_c(j)$, steady solutions are physically impossible due to the non-negligibility of $\partial\Theta/\partial\tau$. This critical δ_c corresponds, once again, to the self-ignition. The results of these two analyses are summarized below.

	j=0		j=1		j=2	
Approximation due to	δ_c	Θ_c	δ_c	Θ_c	δ_c	Θ_c
Frank-Kamanetski	0.88	1.20	2.00	1.37	3.32	1.60
Semenov	1.00	1.00	2.00	1.00	3.00	1.00

Solutions considering the reactant depletion delaying the self-ignition are available in the literature (C. F. Thomas[3]).

Another phenomenon, somewhat related to self-heating and self-ignition, is that of smolder spread. It is a related phenomenon, for it too occurs with the absence of a gas phase flame. Smolder spread is poorly defined in the literature but is very common in residential fires. For example, materials which are extremely porous and spongy (such as a mattress, a bed of pine needles, a layer of not-so-dry autumn leaves, etc.) are known to support a self-propagating combustion wave in their interior, once a nonflaming ignition occurred at a localized spot due to a source such as a cigar butt. Clearly, the wave propagation rate is determined by some sort of a conspiracy between heat transfer and chemical reaction processes. So far as the heat transfer is concerned, radiation and conduction probably suffice. Among the chemical reactions, at least one endothermic (i.e., decomposition) and one exothermic (i.e., oxidation) processes seem to need consideration. What precise mechanism governs the smolder spread and hence which variables influence is not known at present.[4]

It is perhaps correct to speculate that greater toxicity hazard is posed by self-ignition and smolder spread than by gas phase combustion because of the slowness of the oxidation process and incompleteness of the pyrolysis gas combustion. (Recall here the popular last words: the fire that killed is the fire that is invisible and undetected!) Thus toxicity investigations perhaps should consider the smoldering fires without fail. Furthermore, it is widely acknowledged that when cellulosic (and some synthetic) solids are "inhibited" by trace inorganic additives, the tendency of flaming is greatly discouraged whereas that of glowing and smoldering is drastically enhanced. Investigations into this behavior seem to be needed to cope with the toxicity problem effectively.

IGNITION

Ignition of cellulosic solids (ex: wood, cardboard, paper, cotton, etc.) subjected to radiative and/ or convective heating received much investigatory attention in the last two decades. This work is useful in understanding how a fire "jumps" from one combustible object to another. It is also pertinent to the biomedical problem of burn protection and fireman's apparel design.

As the solid is heated, charring ensues; progressively deeper layers pyrolyze in a time-dependent manner. (The chemistry of this pyrolysis and the associated kinetics and energetics are quite extensively studied even though the results of most of these studies seem to be of little help in interpreting various practically relevant overall features such as the gross mass-loss rate of solid bodies burning in air.) A small fraction of some of the condensibles produced in the pyrolysis of solid layers near its exposed surface are known to diffuse into the cooler interior regions modifying the simple transient conductive heat transfer; most of the pyrolysates, however, transpire out of the solid into the gas phase to mix with air in the adjacent *transient (free convective) boundary layer yielding a transient composition mixture* in it. If the resultant mixture is within the so-called flammability limits, it may be ignited by means of a small localized pilot flame, heating coil, or a glowing ember. In the absence of a pilot heat source, the mixture requires additional heating to spontaneously ignite. Attainment of about 600° C by the exposed surface of the cellulosic body is known to ensure spontaneous ignition. (This critical temperature is near 350° C for piloted ignition.) The area of exposure, uniformity of exposure, drafts in the room, exposure intensity, composition and total pressure of the oxygen-bearing gas phase, surface absorptivity, the solid initial temperature, pyrolysis characteristics, diathermancy, thermal conductivity, specific heat, density, moisture content, thickness, homogeneity, etc., are the variables influencing the time required to realize ignition. Figure 1 shows the delineation of various regimes of spontaneous ignition of radiantly heated cellulosic solids as presented by Martin in his historic contribution on this subject in 1964. Simple transient conduction solutions can predict[5] the essentials of Martin's delineation as shown in Figure 2. (In Figures 1 and 2, K, ρ, and C are the solid thermal conductivity, density, and specific heat respectively. ℓ is half-thickness of the solid. I is the exposure heat flux. T^* and T_o are respectively the ignition and initial temperature; t^* is the time to ignition. h is the convective heat loss coefficient.)

In order to establish the mechanism of ignition, Alvares and Martin[7] measured spontaneous ignition times (due to radiant heating) by varying the atmospheric total pressure, oxygen partial pressure, and the nature of the gas-phase inert species. An examination of various possible thermal and chemical mechanisms of

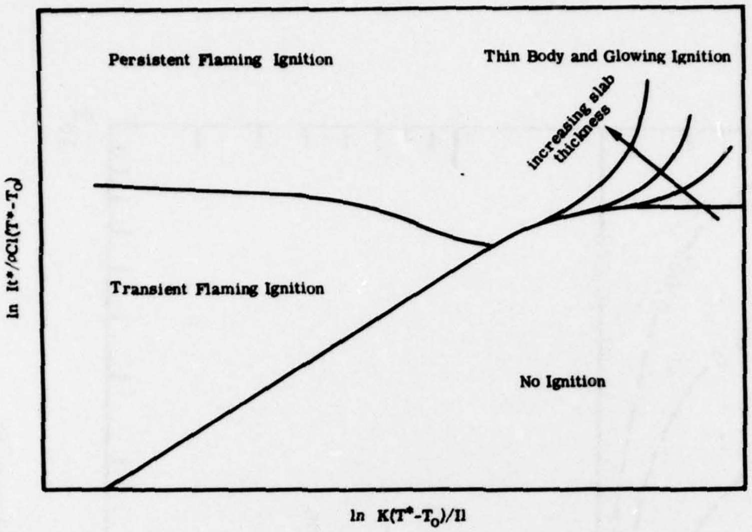

FIGURE 1 Martin's ignition Map (From Reference 6)

ignition leads one to suspect that ignition is most probably the result of a thermal imbalance in the reactive boundary layer in which heat is generated by the preignition oxidation reactions at a rate exceeding the heat loss rate. By a theoretical model of this mechanism closed form predictions shown in Figure 3 may be obtained.[8] (In this figure, τ^* is nondimensional ignition time proportional to: the square of absorbed radiation, the time to ignition, and the inverse square of the solid's thermal responsivity. ω is the ratio of the heat generation rate to the heat conduction rate across the reactive gas phase boundary layer. It is proportional to: the heat of oxidation, the oxygen partial pressure, the square of the total pressure, the square of the plate height, and the inverse gas phase thermal conductivity. λ is essentially the ratio of the solid phase and gas phase thermal diffusivities. ϵ is the nondimensional activation energy of the preignition oxidation reaction.) Work reported by Welker[9] and his collaborators at the University of Oklahoma on the ignition of a variety of common plastics suggests that the ignition mechanism of these abundant modern fuels may not be too different from that of cellulose.

To establish the mechanism of ignition of a wide assortment of common fuels seems to be important in view of fire prevention; after all, the safest fire is the one which did not start at all! Considerable amount of experimentation still remains to be done with both radiative and convective heating on both cellulosic and non-cellulosic fuels to verify the postulated mechanisms. Of particular importance in elucidating these mechanisms are the limiting cases of extremely low and extremely high heating rates. At the low heating rates, perhaps the role played by the condensed phase pyrolysis/vaporization process overwhelms and perhaps even self-heating phenomena enter the picture. In the other extreme case of high heating

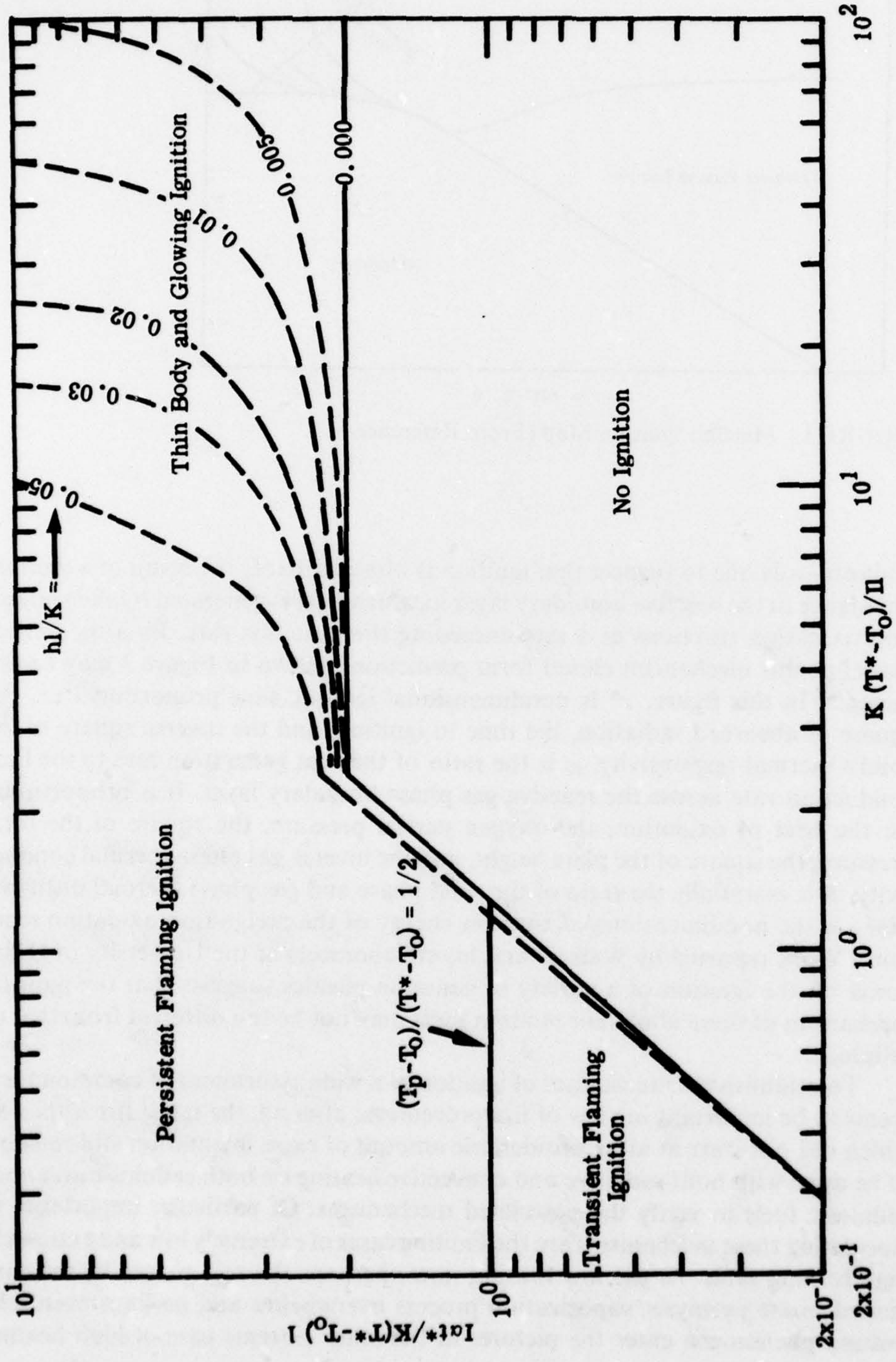

FIGURE 2 Martin's map obtained from transient conduction considerations. (From Reference 5)

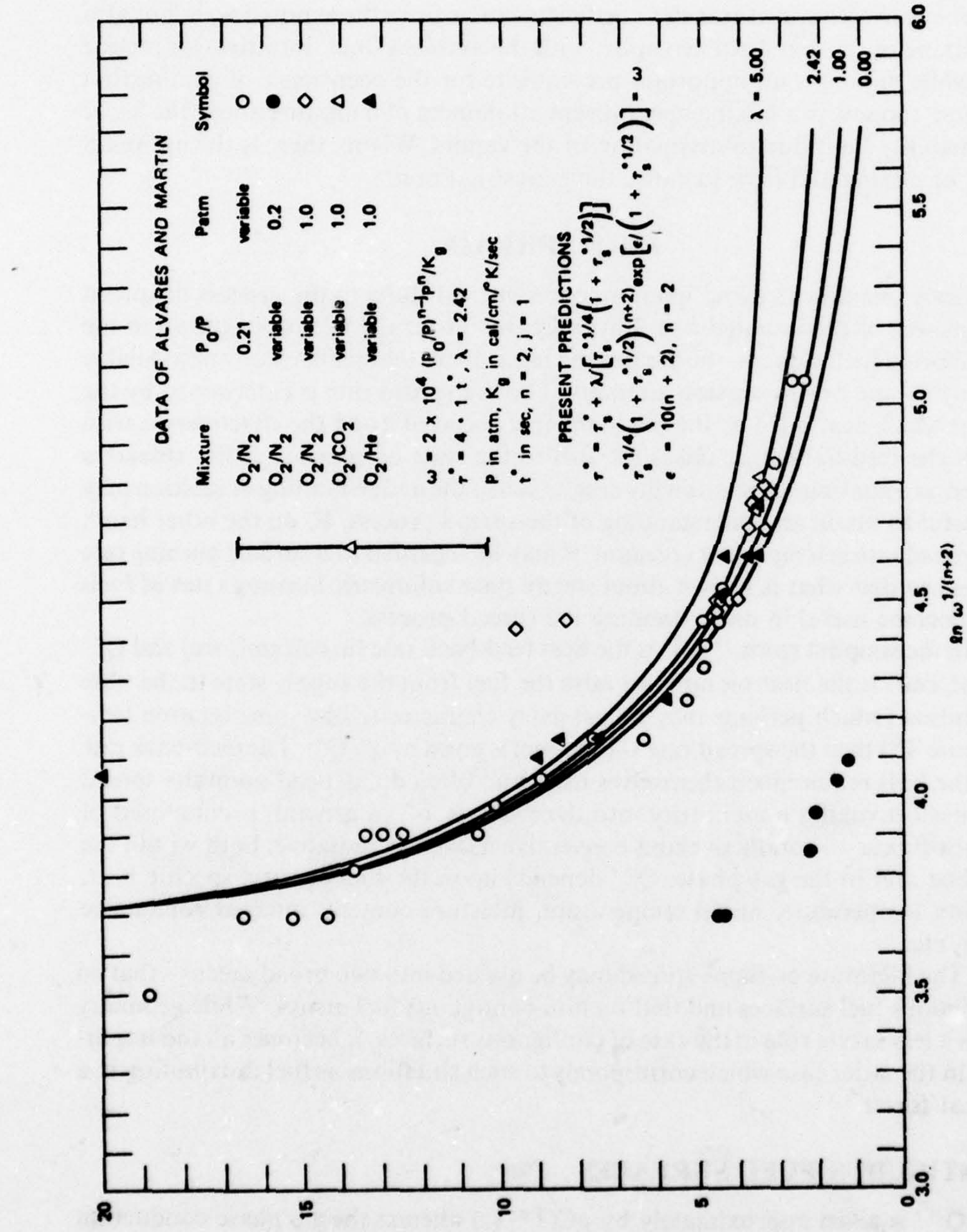

FIGURE 3 Comparison of ignition predictions with the measurements of Alvares and Martin (From References 7 and 8)

rates, it is quite possible that phenomena such as ablation, erosion, sputtering, and flash boiling complicate the basic ignition process.

A thorough understanding of the ignition mechanism should also lead to compromise and mutually relate the multitude of passive ignition criteria[10] presently prevalent in the literature; then, questions related to the size of the exposed area and the external flow arise. For example, the flow is expected to affect not only the convective heat transfer coefficients to or from the exposed wall, but also the mixing of the combustible vapors with the ambient fluid. Intuitively,it is clear that while mixing is an important prerequisite for the occurrence of combustion reaction, too severe a mixing may prevent attainment of a mixture above the lower flammability limit due to dissipation of the vapors. Where, then, is the optimum point of mixing and flow to cause the easiest ignition?

FIRE SPREAD

Once one fails to avoid ignition, one's interest shifts to the process of spread and growth of the initiated fire. Naturally, the faster the fire propagation to the neighboring fuel surfaces, the greater the hazard and the smaller the time available for any escape or suppression attempts. The fire spread rate is determined by the rate at which heat is fed by the fire to the fuel ahead of it and the effectiveness with which the feed-back heat raises the fuel to the state of ignition. If fire spread is viewed as a continuous ignition process, much of the understanding of ignition may be useful to attain an understanding of the spread process. If, on the other hand, the spread rate is temporally constant, it may be regarded as a surface burning rate process so that what is known about steady state volumetric burning rates of fuels may become useful in understanding the spread process.

In the simplest spirit,[11] if $\dot{q}''$ is the heat feed-back rate (in cal/cm^2/sec) and Q''' (in cal/cm^3) is the heat required to raise the fuel from the supply state to the state of ignition (which perhaps may be passively characterized by some ignition temperature T^*) then the spread rate U (cm/sec) is given by $\dot{q}''/Q'''$. The feed-back rate and the heat requirement themselves may, and often do, depend upon the spread rate itself invoking nonlinearity into the analysis. $\dot{q}''$, in general, is composed of various fluxes — conductive and conventive as well as radiative, both within the fuel bed and in the gas phase. Q''' depends upon the fuel density, specific heat, ignition temperature, initial temperature, moisture content, internal conductive drain, etc.

The literature on flame spread may be divided into two broad areas — that on contiguous fuel surfaces and that on non-contiguous fuel arrays. While geometry plays a less severe role in the case of contiguous surfaces, it becomes all too important in the latter case which corresponds to such situations as fuel distribution in a typical forest.

CONTIGUOUS FUEL SURFACES

Q''' is given approximately by $\rho C(T^*-T_o)$ whereas the gas phase conduction is given approximately by $\dot{q}'' \approx K_g(T_f-T^*)/\Delta$ where Δ is some sort of a gas phase conduction thickness. [ρ and C are respectively the density and specific heat of the solid phase. K_g is gas phase conductivity. T^*, T_f, and T_o are respectively the ignition state, flame, and initial fuel (ambient) temperatures.] The flame spread rate is given by $U \approx K_g(T_f-T^*)/[\Delta\rho c(T^*-T_o)]$. Assuming infinitely fast gas phase reactions, constant gas phase density, and transport properties, de Ris[12] solved the detailed mathematical problem to arrive at the following results.

$$\Delta \approx \frac{\ell}{\sqrt{2}} \quad \text{for thermally thin fuels} \tag{5a}$$

$$\Delta \approx \frac{K(T^*-T_\infty)}{\dot{q}''_{in}} \quad \text{for thermally thick fuels} \tag{5b}$$

ℓ, as before, is the half-thickness of the fuel bed. $\dot{q}''_{in}$ is the convective heat flux associated with the induced flow given by $\rho_g C_g(T_f-T^*)(g\alpha_g\beta\Delta T)^{1/3}$ where α_g is the gas phase thermal diffusivity and $\beta\Delta T \equiv (T_f-T_\infty)/T_\infty$. Δ is of the order of the fuel bed half-thickness, ℓ, in the thin fuel case and is of the order of the thermal conduction penetration depth in the thick fuel case. These predictions agree well with the extensive experimental measurements made by McAlevy's associates at the Stevens Institute of Technology.[13] The past six International Combustion Symposia and the latest critical reviews of Williams[11] and of Sirignano[14] are recommended to bring the reader up-to-date on this topic relevant to the fires in structures.

In a real room fire situation, the spread of fire involves its jumping from one piece of furniture to another one. While the studies of spread on contiguous fuel surfaces are quite advanced to-date, they cannot at this time tell us much about the "jumping spread" process. Obviously one needs to invoke the ignition process to deal with this matter. Most of the presently available spread studies remain to be adapted to the jumping spread process.

NON-CONTIGUOUS FUEL ARRAYS

Turning one's attention to the problem of fire spread on non-contiguous fuel arrays, the research done by Williams and Vogel[15] on a model forest built out of match-stick arrays is to be noted.

A model of a fire in the forest, in which the radiative heating alone is considered to be the governing mode of feed-back, is proposed by Emmons[16] in a historic paper. [See his Tenth (International) Combustion Symposium paper[17] for a brief review of this and other fundamental problems of the free burning fire.] One of the most significant contributions made by Emmons in this paper is to demonstrate the utility of scientific methods in designing such relevant and extremely practical concepts as a firebreak. It is also worth noting in this connection the pioneering 1944 paper of Fons[18] in which he emphasizes the need to place on a systematic basis such forest fire control practices as rating the fire danger, determining the proper size of the suppression crews, speed of attack, and planning a suppression strategy under various circumstances of the forest cover, its moisture content, weather, and topography. He considers all three modes of heat transfer to predict the fire spread rate as a function of the wind velocity (and direction), fuel thickness, fuel compactness (i.e., the fineness and crowdedness of the forest), fuel temperature, density, moisture, slope of the terrain, time after ignition, etc.

Many questions such as the following arise. What special characteristics of the convective fire plume over a spreading forest fire affect the spread rate? How do the topographic details tamper with these effects? What circumstances of weather and topography lead to the evolution of a fire devil (a phenomenon somewhat similar and analogous to dust devils, tornadoes, and inverted bath tub vortices) which is often noticed in forest fires? How do these fire devils influence the burning/spread rates and suppression activities? What combination of conditions culminates in the "blow-up," a phenomenon mortally feared by the forest fire fighters? How are the fire brands produced and transported? What sort of trajectories and ranges of flight of these brands may be expected? Is there a way to retard production of the brands? How best are the firebreaks designed and maintained today? Are there any weed-killing chemicals usable here without adversely affecting the forest and environment? Do fire suppressant chemicals do their job in aerial fighting of forest fires? While the literature shows some progress in answering a multitude of questions like these, much work waits to be done.

FLASHOVER

Once the fire is started and is allowed to spread in a fuel-loaded confinement such as a typical room, a time will soon ensue when something peculiar and unexpected happens. Known as "flashover," the fire spread abruptly increases to extremely fast speed to engulf the entire room in flames. Prior to the flashover, fuel surfaces ahead of the slowly propagating fire front release visible vapors due mainly perhaps to the radiative heating. As the surfaces get hotter, augmentation of the radiant energy exchange between various surfaces occurs while the relatively localized fire continues to release the combustion energy at a gradually but measurably increasing rate. The feed-back to the unburnt fuel is no longer solely from the propagating fire alone, but all the enclosing surfaces contribute radiatively. Finally, the intuitively unexpected event of flashover is in order.

Kawagoe[20], Gross, and Robertson[21] and others more recently, discussed the dependency of time history of burning and characteristic temperature on such variables as the fuel content of the room and the window size. In certain special regimes of these variables, prevalent in the modern architecture, the fires described by the word "flashy" arise leading to very high temperatures and nonconstant burning rates. It may be suspected that these "flashy" fires are the result of "flashover." In view of life safety in fires, flashover is obviously a process of utmost importance.[22] To date only preliminary models are available[22,23] on this important phenomenon. As international cooperative program (known as C.I.B.) was organized by Philip Thomas[24,25] to obtain a host of systematic measurements on the issue of flashover.

BURNING OF SOLIDS AND LIQUIDS

All too many fires involve natural and synthetic solid fuels. Most of the natural solids belong to the cellulosic family. Synthetics proliferated in the last decade in this modern society due to their low cost, manufacturing versatility, light weight, and aesthetic qualities. Concerning their response to the intense thermal environments arising in and around a fire, on the other hand, the synthetics, perhaps, leave much to be desired; they are suspected to ignite much too easily, support fast spread, yield relatively higher heat release rates and toxic gas concentrations, and present complexities due to melting, dripping, etc.

Irrespective of the nature of the fuel, the initiation of a fire, if unattended, is usually followed by spread, flashover, and then the fully involved "steady state" phase of burning. The heat source strength due to this steady maximum burning is an important characteristic not only intrinsically but also in view of the events in progress in the vicinity. Intrinsically, the radiation emitted by the flame augments the self-burning rate. Extrinsically, the energy release rate is significant in at least two ways: (a) the radiation emitted by the flame outwards contributes to the further flame spread and growth; (b) one of the most important factors influencing the convective flow, heat, and mass transfer patterns in the enclosure is the heat release rate. The burning rate also determines the time at which structural failure occurs. It is this rate that also determines the minimum extinguishant application rate for suppressing the fire.

That the problem of predicting the behavior of a fire may be divided into two parts is obvious.[26,27] The "internal" (or "pyrolysis" of "vaporization" or "fuel-phase") problem addresses itself to the determination of the distribution of composition (i.e., quality of combustibility) and rate of generation (i.e., quantity) of the fuel vapors issuing out of the surface for a given distribution history of the surface heat flux. That is, determination of the thermochemical (or physical) vaporization response of the fuel as a function of the surface heat flux constitutes the internal problem. The "external" (or "combustion" or "gas-phase") problem addresses itself to the determination of the shape, size, and intensity of the flame in the boundary layer and heat transfer from this flame to the fuel surface for a given quality and quantity of fuel vapor transpiring into the boundary layer. That is, determination of the gas-phase combustion and heat-transfer response as a function of the surface emission of the fuel vapor constitutes the external problem.

For a simple liquid fuel and a subliming or melting (e.g., chain scission type polymers) solid fuel, the internal problem is greatly simplified since the vaporization (and pyrolysis, if any) is confined to a rather thin layer of the fuel body near its surface. Characteristics of the fire then are deduced from the solution of the external problem. The fuel-specimen thickness exerts only a secondary influence on this problem.

On the other hand, as frequently encountered in practice, if the fuel under consideration is complex (such as wood and other natural or synthetic charring polymers), the internal problem assumes as much importance as the external problem in determining the characteristics of a fire because of the complexity of the chemical degradation and transient conduction processes. The thickness of a charring specimen strongly affects the quality and quantity of the combustibles for various reasons. The problem of predicting the burning behavior of fuel is perhaps best handled by first studying the boundary layer combustion process associated with the simple fuels whose internal problem is simpler and then by applying this knowledge to solve the internal problem of complex fuels with the assumption that the boundary layer behavior is independent of the manner in which the fuel vapor is produced.

Spalding[28] has shown that in the convectively controlled diffusion flame problem, the fluid dynamic part may be separated from the thermodynamic part. The burning rate may then be written as the product of a mass transfer coefficient and a function of the mass transfer number.

$$\dot{m}'' = \frac{h^\circ}{c_g} \cdot f(B) \tag{8}$$

h° is the heat transfer coefficient pertaining to the geometry and flow situation (considered with vanishing interfacial velocity). It is obtainable from the well-known dependence of Nussett number on the Grashof (or Reynolds) and Prandtl numbers. Figure 4 shows the pattern of burning[27] of a liquid fuel (methanol) on a flat plate wick (6″ in size) in different orientations; the boundary layer type burning feature is quite clear from these photographs.

The thermodynamic function, f(B), may be safely assumed as $f(B) = \ell n(B+1)$ where the mass transfer driving force, B, is defined as

$$B \equiv \frac{fY_{o\infty}\,\Delta H + c_g(T_\infty - T_w)}{Q} \tag{9}$$

Q is the effective heat of vaporization of the fuel (defined as the ratio of heat flow across the exposed surface to the resultant mass flow). In its definition, Q contains the latent heat of vaporization in addition to the sensible enthalpy rise and extraneous losses per unit mass transferred. Naturally, for wood burning, one of the factors contributing to the loss term in Q is the internal transient conductive drain which is higher for thicker solids. Consequently a high Q results in a low B which in its own turn leads to lower burning rates of thicker bodies. If the fuel were one which physically melts and vaporizes, a steady state internal temperature distribution is soon established to yield a constant Q and hence a constant B.

The power of B to describe the steady burning intensity of a variety of fuels is quite significant in the so called "flammability" considerations. Questions, however, remain to be answered as to the effect of radiant heating (from the flame as well as from the fuel surface), dripping, popping, and spattering of plastics, etc. That the B number isolates the chemistry and thermodynamics of the problem from the fluid dynamics and that it thus can serve as a convenient comparative flammability index is evident in the pool and vertical wall burning data presented in Figures 5 and 6 where we composed much of the currently available literature together on a variety of solid and liquid fuels. Noteworthy in these figures is the point that while the low Grashof number fires may be adequately predicted by the rules of

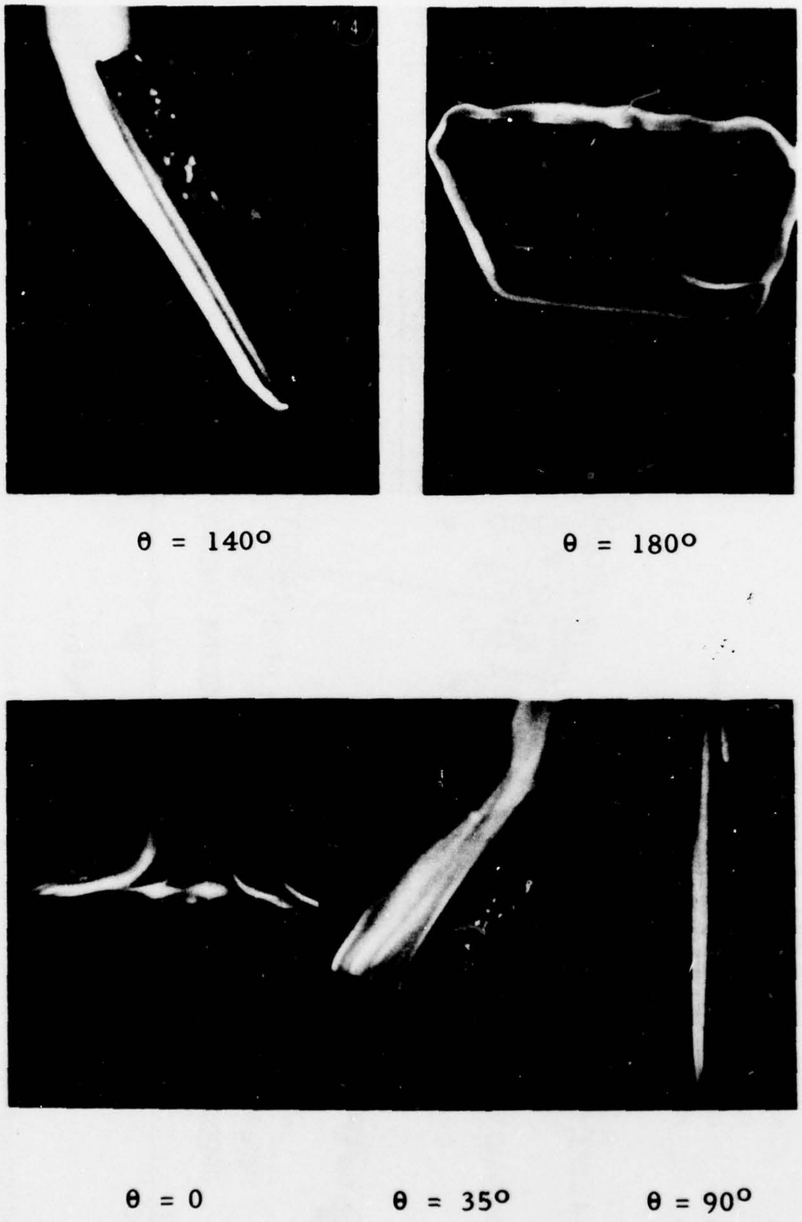

FIGURE 4 Alcohol burning on a 4″ ceramic wick. (From Reference 27)

laminar free convective heat transfer, larger fires are strongly affected by radiation – particularly so if the geometry of the fuel is in a pool configuration. This observation leads to the issue of radiation in fires – radiation from the fire to the fuel surface supporting it and radiation from the fire to its surroundings.[29, 30]

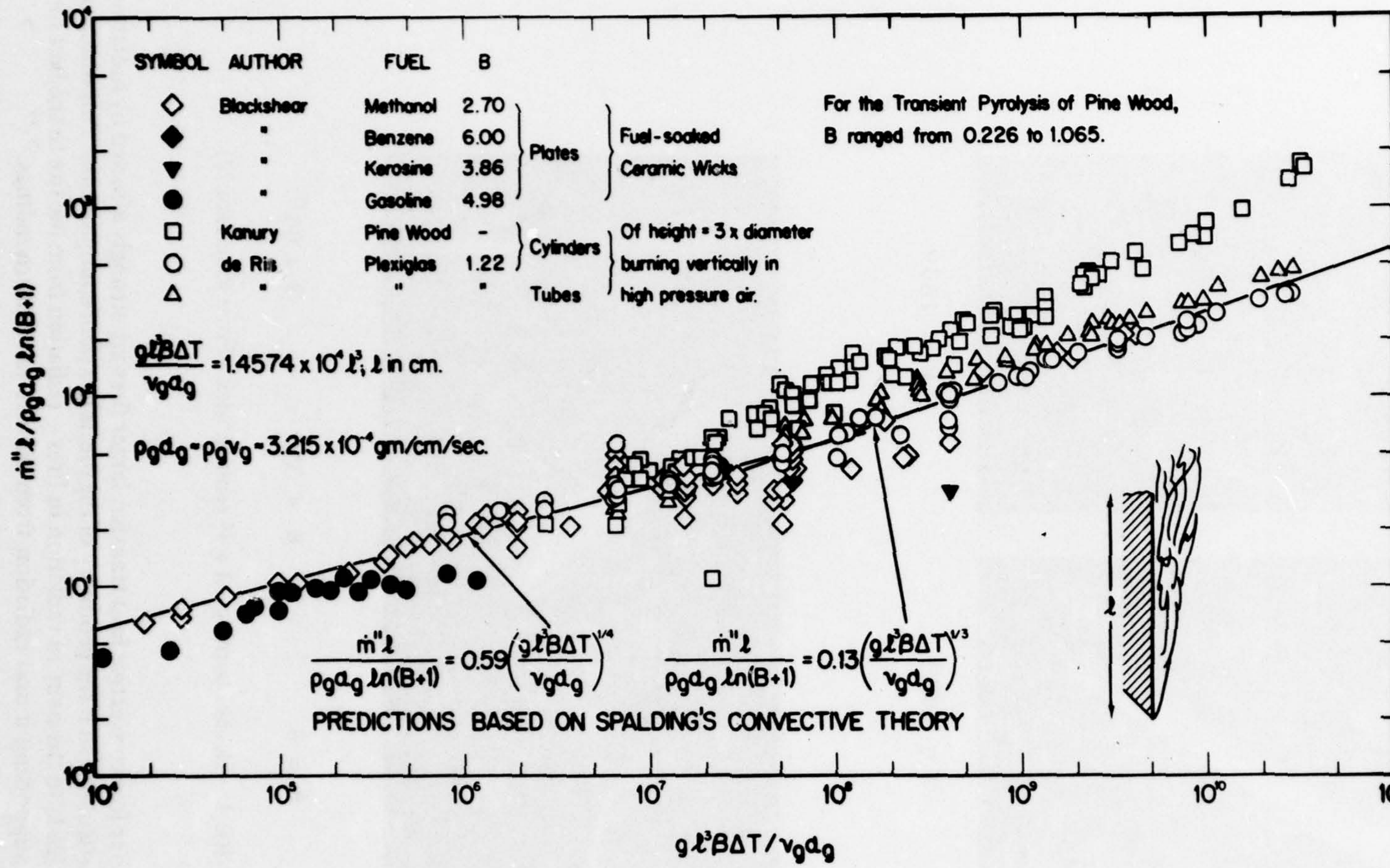

FIGURE 5 Laminar and turbulent free convective burning of liquid and solid vertical walls.

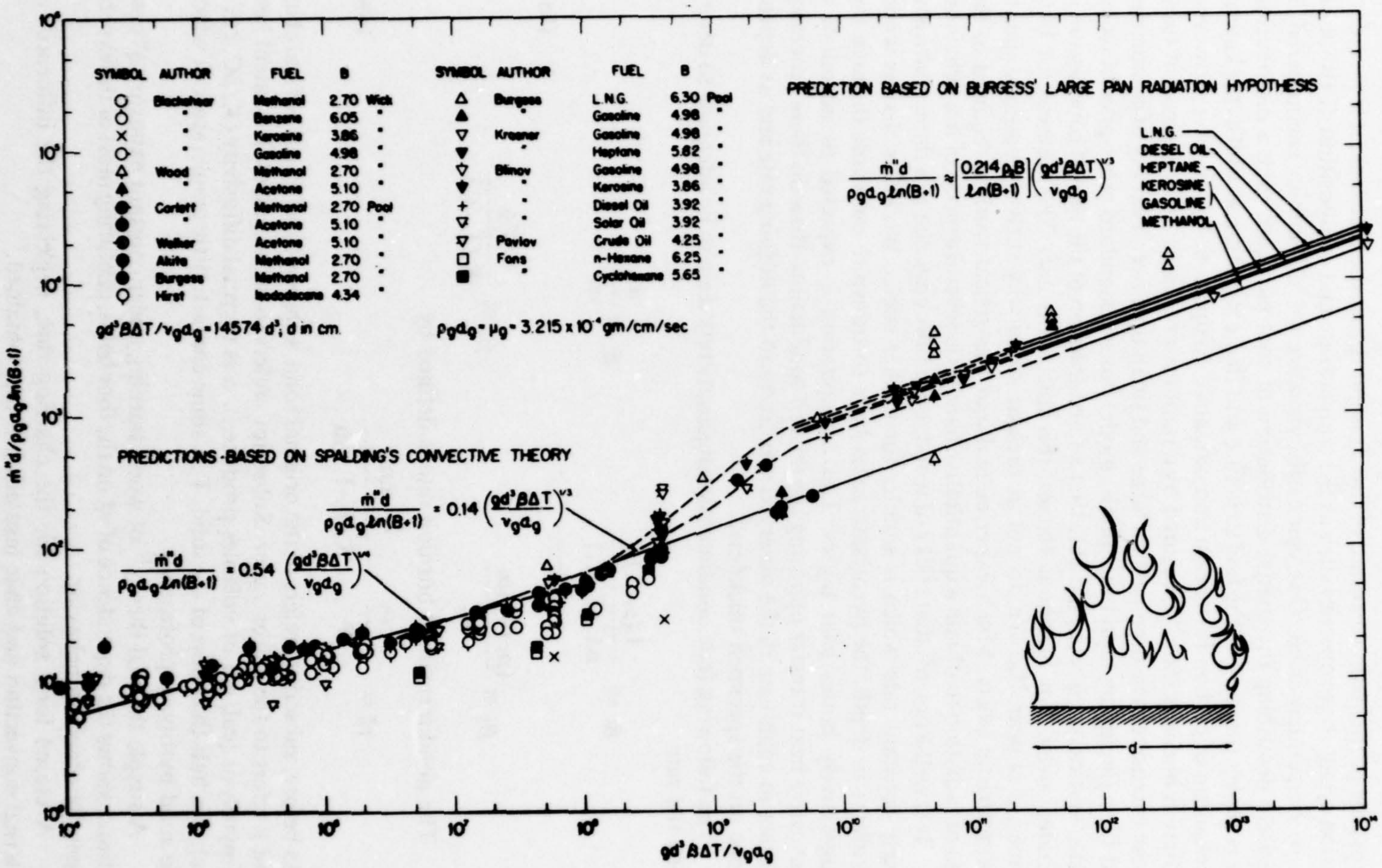

FIGURE 6 Laminar and turbulent free convective burning of horizontal pools of liquids.

We do not at present know how best to compute the radiation characteristics across the participating medium of fire. It is not the method we lack; it is the information about the properties such as the temperature and composition distribution we so desperately need. One can easily visualize the difficulties encountered in precisely describing the spatial distribution of soot particles; such a distribution is a complex function of the fuel structure and flame structure as well as the kinetic mechanism of carbon formation and oxidative dissipation. We do have, however, radiation intensity data[31] measured by a radiometer located in the vicinity of fires. These extensive measurements on large and small fires over a variety of geometries and fuels (including liquid fuel pools, model houses, standard cross-piles of wood sticks, vertical walls, etc.) indicate that a fixed fraction of the heat of combustion is radiated away. For luminous flames, this fraction is near 20% whereas for blue flames, it is near 5%. We do not at present know why such a seemingly simple characteristic exists. Much experimental and theoretical work is required in the area of radiation to obtain a quantitative handle on several aspects of fire behavior.

It is well-known[32] that sticks of wood, once fully engulfed in a flame, burn at a nearly constant rate which is smaller for thicker sticks. We know that as wood pyrolyzes in depth, the pyrolysate gases have to transpire outwards through the progressively hotter char layers. This transpiration is expected to introduce a convective heat transfer opposing the inward conduction. How do these processes interact to culminate in the observed steadiness of the burning rate and its dependence on the specimen thickness?

The following four nondimensional parameters seem to be adequate to determine the rate.

$$\beta_1 \equiv \frac{L(\rho_s-\rho_c)}{\rho_s C_s(T_p-T_o)} \qquad \beta_2 \equiv \frac{\alpha_s}{\alpha_c}$$

$$\beta_3 \equiv \frac{(\rho_s-\rho_c)c_g\alpha_s}{K_c} \qquad \beta_4 \equiv \frac{\dot{q}''\ell}{K_s(T_p-T_o)} \tag{6a}$$

The nondimensional burning rate is defined by

$$\tau_p^* = \frac{\rho_s-\rho_c}{\rho_s} \quad \frac{\dot{q}''^2\alpha_s m_o}{K_s^2(T_p-T_o)^2\dot{m}} \tag{6b}$$

[As before, subscript $_s$ refers to the original solid, subscript $_c$ refers to the final char, and g refers to the gas or vapor. Subscript $_o$ refers to initial values. L is latent heat of pyrolysis (cal/gm of volatiles produced), α is thermal diffusivity ($K/\rho C$, cm^2/sec), ℓ is half-thickness of the solid. T_p is some characteristic temperature at which the solid pyrolyzes profusely.]

A simple thermal theory[32] of wood burning under constant exposure $\dot{q}''$ conditions, shows the dependence of τ_p^* on the four betas, capturing most of the experimentally observed behavior.

A closed form solution for the charring rate, neglecting the influences of internal convection and char insulation is also obtained.[33]

$$\tau_p^* \approx \frac{2}{(j+1)} \beta_4^2 \left[\frac{1+(j+3)\beta_1/2}{(j+1)\beta_4} + \frac{1}{2(j+3)} \right] \qquad (7)$$

The predictions of this solution are in excellent agreement with the numerical calculations of the simple thermal theory.

A comment here is in order regarding the exposure heat flux $\dot{q}''$. In general, it is not a constant with respect to time and location on the exposed surface. It is most often quite strongly dependent upon the external fluid mechanics. Modeling of fires involves in essence, as discussed in a latter section, modeling of $\dot{q}''$ as influenced by the flow and fluid properties.

EXTINCTION

Any suppressive action taken against a roaring fire involves depriving it of its requirements to grow, to continue, and to subsist.[34] This would mean reducing (or eliminating) the feedback, rendering the heat balance negative, and taking away the fuel, oxygen or heat.

Feedback is reduced by altering the geometry of the fuel array, diverting the hot gases away from the fuel yet to be involved in the fire, etc. The heat balance may be made non-positive by increasing the loss rate or by decreasing the generation rate. Increase in heat loss rate may be brought about by such means as sprinkling water on the fire, applying a high heat capacity inert gas to the environment or by some other technique of extracting heat from the fire. Heat generation rate may be reduced by inerting the atmosphere (*to eliminate the oxygen availability*), blanketing the fuel by a foam or by a surfactant film, killing the reactive species of all sorts in the gas phase by the use of reaction inhibitors, modifying the fuel chemically to reduce its vaporization rate (by increasing Q), etc. The manner in which these suppressive activities reflect in the fire intensity may be described as below.

When the rate of application of the extinguishing agent is low, an increase in this rate causes a minor decrease in the burning rate (or spread rate) of the fire. Then abruptly, at a certain critical application rate, (and the corresponding critical burning or spread rate) the fire is extinguished. Beyond this critical application rate, the higher the application rate, the quicker the fire dies. Obviously, as Emmons muses in his Tenth Symposium paper,[17] "the fire in a burning building would be immediately quenched if the building could be picked up and dunked in the ocean."

Extinguishment of fires with water sprays, carbon dioxide, dry chemicals, foams, etc., is so commonly practiced that a mention here would sound trite. These agents perform their intended duty of suppressing the fire by the deprivation tactics described earlier in this section. The most important question to be asked is, how effectively can a given agent put out a given fire? To answer this, experimental investigation is needed to answer the following preliminary questions: (a) What is the best manner of application of the extinguishant? (b) What is the critical minimum extinguishant application rate to ensure an end to the fire? (c) What factors determine the fraction of delivered extinguishant reaching the fuel and fire? (d) Is there any quantitative meaning to the critical rate of heat (or active species) removal by the extinguishant? (e) What exactly is the mechanism by which a fire is suppressed? (While it is expected that this aspect is probably the inverse of the ignition mechanism, hysteresis effects are also expected in the response of the fire to the starting and stopping impulses.)

Questions such as the above have to be tackled to suppress a fire most effectively with the least amount of the agent applied, with the least effort, and with least delay. "Here too," as Berl[35] rightly points out, "the scientist is confronted by more questions than he can answer with confidence."

FLAMMABILITY

Flammability is a term used in assessing the response of a given material to a given fire exposure. Even the so-called experts often use this term loosely as though it were an intrinsic property of the material under consideration to arrive at such unscientific and unquantitative measures as "noncombustible," "nonburning," "very slow burning," "slow burning," "self-extinguishing," "flameproof," "flame-retarded," etc. It is perhaps well to remember Setchkin's words[36] "an incombustible material means to the user of the word a material which will not burn under conditions of exposure which he has in mind. It will not necessarily have the same meaning to others unless those conditions are defined." Alas, how many times the misused words resulted in fires violent enough to kill! To obtain a quantitative handle at the techniques of assessing the fire hazard of a given situation we must possess an understanding of the behavior of fires. Since nearly all materials degrade when subjected to severe enough thermal environments, the description of the fire-environment-exposure-conditions becomes part and parcel of the flammability ratings. If there exists a typical range of typical exposure conditions arising in a typical fire situation, then perhaps one might be justified in using the term flammability as the property solely of the material under scrutiny. The level of our understanding, however, is still so primitive that only recently we began identifying its component processes. Basic research into the scientific nature of fire seems, therefore, to be a prerequisite to soundly formulate the fire hazard assessment techniques.

When one attempts to evaluate quantitatively the degree of fire hazard posed by a given end-use situation, the following questions arise. (1) How easily is ignition possible? (2) How fast does the fire spread, grow, and lead to a flashover? (3) How intensely does the "fully developed" fire burn? [This intensity is perhaps describable in terms of (a) burning rate, (b) heat release rate, (c) emission of radiation, (d) flame temperature, etc.] (4) How hard is the fire to extinguish? (5) What is the nature of the chemical species produced in the fire at various stages of its growth? (6) How fast and how much of each of these species is produced in relation to the ventilation in the structure? (7) What is the degree of opacity to transmission of light and obscuration of vision caused by smoke? (8) What is the influence of heat and chemical species on life and on mechanical strength and integrity of the structure? How does synergism mutilate these influences?

Properties such as the thermal conductivity, specific heat, density, ignition temperature, thermal distortion temperature, burning rate, spread rate, heat of combustion, etc., of the materials define only the nature of the materials. Flammability should concern more than the material; it is the virtue of the end-use situation in which the material is used. If we know that a given end use situation requires a material of high ignition temperature or low burning rate, then the knowledge of the material properties would enable one to either accept or reject it.[37] The use determines the hazard; hazard is an aspect of culture; safety is a decidedly relative concept; people will tolerate a certain level of hazard to obtain the degree of freedom, comfort, and convenience. Obviously, all our questions about incorporating fire safety in the design of man's environment are raised because the flammability of man himself leaves much to be desired. The more we know about a material and

TABLE 1

Nondimensional Numbers of a Fire

Independent Numbers		Property Numbers		Dependent Numbers	
*Froude	$\Delta\rho g\ell/\rho_g V_g^2$	Prandtl	$K_g/C_g\mu_g$	*Nussels	$\dot{q}''\ell/K_g\Delta T$
*Reynolds	$\rho_g V_g \ell/\mu_g$	Schmidt	$\rho_g D/\mu_g$	*Sherwood	$\dot{m}''\ell/\rho_g D\Delta Y$
*Grashof	$(g\ell^3\rho_g^2/\mu_g^2)(\Delta\rho/\rho_g)$	Lewis	$\rho_g C_g D/K_g$	Stanton	$\dot{q}''/\rho_g V_g C_g \Delta T$
*Fourier	$K_s t/\rho_s C_s \ell^2$			Peclet	$\dot{m}'' C_g \ell/K_g$
*Geometry	L/d, shape			*Radiation Number	
Peclet	$\rho_g V_g C_g \ell/K_g$				
Damkohler	$V_g/\ell k$, $K_g/k\rho_g C_g \ell^2$				
Mass Transfer Number					
Stoichiometric Fuel/Oxygen Ratio					
Flame Temperature					
Unsteadiness of Flow					
Thin Body Heat Losses					
Specific Heats					
Turbulence Criteria					
Heats of Reactions					
Equilibria					
Activation Energies					
And Others					

*Asterisks denote numbers adequate for most of the usual fires.

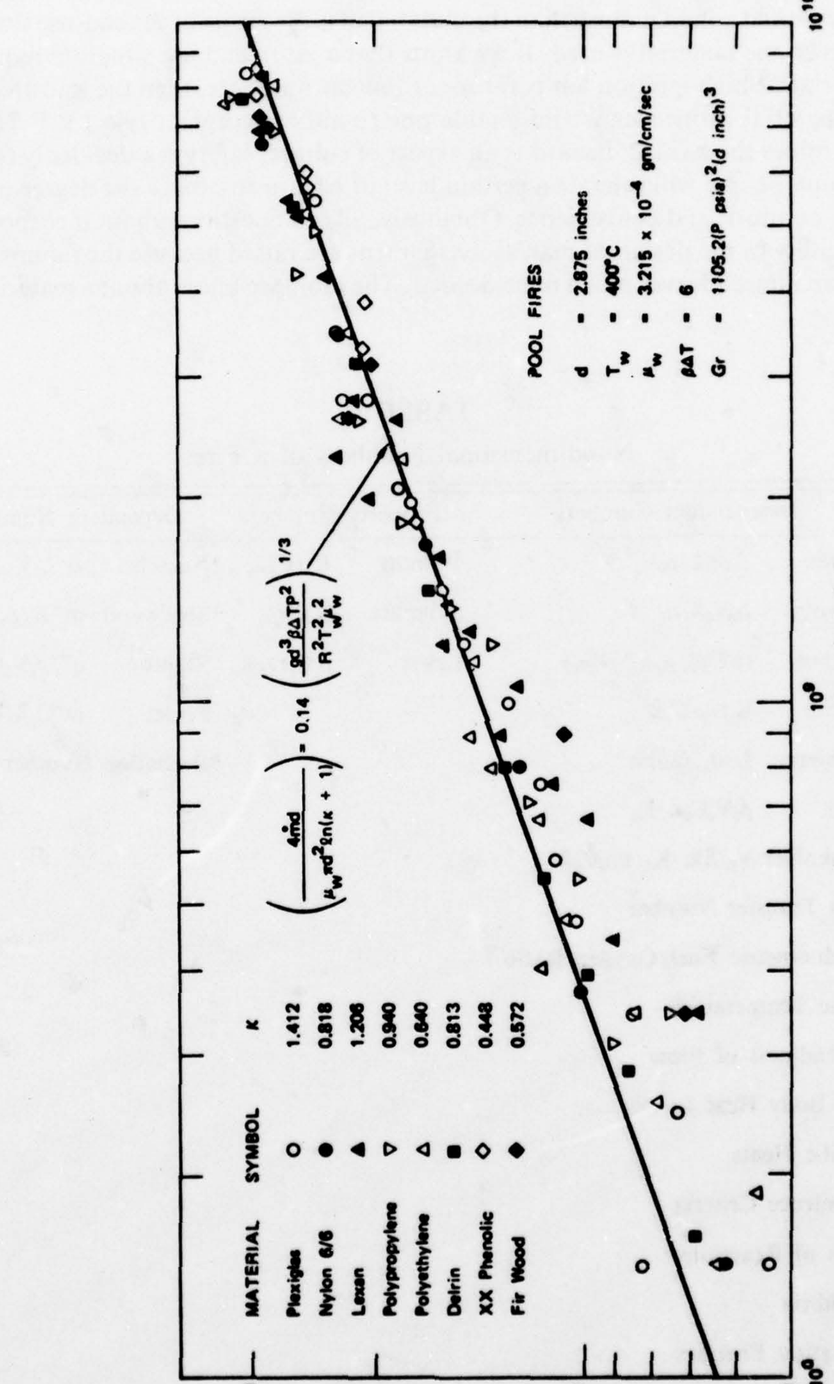

FIGURE 7 Turbulent free convective burning of various plastics in pool fire configuration. (From Reference 31)

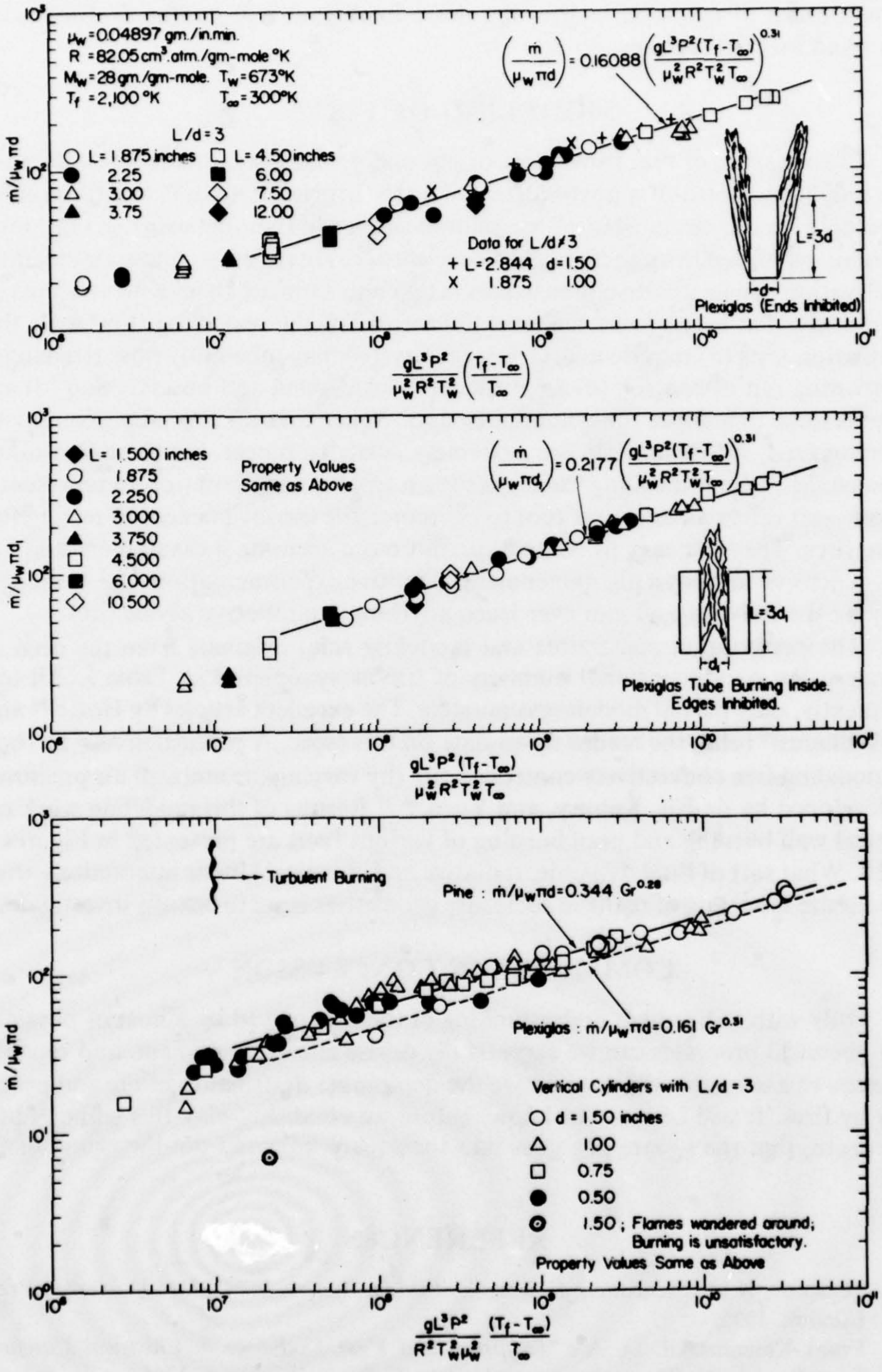

FIGURE 8 Turbulent free convective burning of solids in vertical wall configuration. (From Reference 40)

its properties of response to fire, the more intelligent will be our decision with regard to its possible uses.

MODELING OF FIRES

Examination of real fires, their origin and growth, was made a few decades ago only in the spirit of a post-mortem. To the surprise of no one, two fires under seemingly similar circumstances are seldom similar in their behavior so that post-mortems rarely led to any generalizable conclusions. In order to conduct systematic observations on destructive fires, resort is taken to simulate them with attempts to reproduce what is felt to be the essential picture of the real thing. Full scale fire simulation tests (a) require a large test facility, (b) may inherently pose the danger of growing out of control, (c) are difficult to instrument and observe, and (d) are cumbersome to analyze the voluminous data. When and if a crucial measurement is recognized, full scale tests are extremely costly to repeat, for these and other reasons. Modeling (meaning merely testing a smaller configuration to represent a larger one) offers an excellent tool to overcome the inconveniences of testing full scale fires. They are easy to control, permit more accurate measurement and are less expensive to study a phenomenon by repetitive experimentation. Use of models may be the only way we can ever learn anything quantitative about fires.

The prescription constraints and modeling rules originate from the need to preserve the nondimensional numbers of fire as synopsized in Table I. All too frequently, only partial modeling is possible. The excellent articles by Hottel[38] and by Williams[39] bring the reader up-to-date on this topic. A promising new method to modeling free convectively controlled fire (by varying the ambient air pressure) is developed by de Ris, Kanury, and Yuen.[40,31] Results of this modeling work on vertical wall burning and pool burning of various fuels are presented in Figures 7 and 8. What sort of fluid dynamic, radiative and chemical kinetic interactions arise in pressure modeling of realistic enclosure geometries is yet to be fully investigated.

COMMENTS IN CONCLUSION

Only with a thorough understanding of the role played by a host of physical and chemical processes can we successfully devise effective, efficient, and reliable schemes to assess, avoid, or minimize the deplorable destruction of life and property by fires. It will be nicer to know, before we childishly play this game of life and death, that the square peg goes into the square hole and not the round one?

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ABSTRACTS AND REVIEWS

A. Prevention of Fires, Safety Measures, and Retardants

Abbott, N. J. and Schulman, S. "Protection from Fire: Nonflammable Clothing - A Review," *Fire Technology 12* (3) 204 (1976)

Subject: Nonflammable clothing

Journal Abstract

Fiber, such as Durette (modified Nomex), Rhovel (a polyvinyl chloride), polymide fibers, HT-4 (an aramid), and PBI (modified polybenzimidazole) with limiting oxygen index values of 35 to 40 are considered to be truly nonflammable, even under fairly extreme conditions, but are of interest for specialized applications where the need justifies the cost. The insulating value of protective clothing must be sufficient to prevent skin burns by heat transfer. The requirements of nonflammability, insulation, and heat reflection tend to make the protective garment heavy, bulky, and stiff, which may be acceptable to fire fighters.

Albini, F. A. (Intermountain Forest and Range Experimental Station, Ogden, Utah) "An Attempt to Correlate Duff Removal and Slash Fire Heat," *U.S. Department of Agriculture Forest Service General Technical Report INT-24* (1975)

Subjects: Slash; Duff; Heat release; Broadcast burning; Fuel loading; Fuel sampling

Author's Abstract

Describes an attempt (and failure) to correlate duff removal to the quantity of heat released by the burning of slash in Douglas-fir/larch clearcuts in western Montana.

Albini, F. A. (Intermountain Forest and Range Experiment Station, Ogden, Utah) "Estimating Wildfire Behavior and Effects," *U.S. Department of Agriculture Forest Service General Technical Report INT-30* (1976)

Subjects: Fire control; Fire behavior model

Author's Abstract

This paper presents a brief survey of the research literature on wildfire behavior and effects and assembles formulae and graphical computation aids based on selected theoretical and empirical models. The uses of mathematical fire behavior models are discussed, and the general capabilities and limitations of currently available models are outlined.

Babrauskas, V. and Williamson, R. B. (University of California, Berkeley, California) "Post—Flashover Compartment Fires," *Fire Research Group Report No. UCB FRG 75-1,* University of California (December 1975)

Subjects: Post-flashover fires; Compartment fires; Fires, post-flashover

Author's Abstract

The requirements for fire resistance in buildings are examined. An historical background is given for the current building code requirements governing fire endurance tests. Relevant aspects of compartment combustion theory are set forth. Salient shortcomings, mainly in the area of fuel pyrolysis rates, are pointed out. Use of rationally calculated time-temperature curves for design and analysis is illustrated and discussed. A new design methodology is outlined which allows conservative, rationally based simplifications to be made. This approach, termed "pessimization," allows gas time-temperature curves to be produced that are applicable to a multiplicity of design conditions by letting certain variables always assume those values which would produce the highest temperatures. Finally, improvements offered by such a method over existing code design provisions are noted.

Barry, T. J. and Newman, B. "Some Problems of Synthetic Polymers at Elevated Temperatures," *Fire Technology 12* (3) 186-192 (August 1976)

Subjects: Synthetic polymers, elevated temperatures; Temperature effects on synthetic polymers

Safety in Mines Abstracts 25 No. 1224
Safety in Mines Research Establishment

While research has been conducted of flammability, thermal effects, and the toxicity of gaseous products from the pyrolysis of various synthetic polymers, little if any research has been conducted on any synergistic interactions.

Beaufait, W. R., Hardy, C. E., and Fischer, W. C. (Intermountain Forest and Range Experiment Station, Ogden, Utah) "Broadcast Burning in Larch Fir Clearcuts: The Miller Creek Newman Ridge Study," *U.S.D.A. Forest Service Research Paper INT-175* (1975)

Subjects: Fuel reduction; Fire effects; Prescribed fire; Broadcast burning

Author's Abstract

Describes a major study of broadcast burning for hazard reducation and site preparation in western Montana larch-fir clearcuts and the effects of such prescribed fires on soil, air, water, wildlife, and tree regeneration. The study area is described and prefire fuel conditions documented. Results of attempts to quantitatively evaluate the experimental burns in terms of duff reduction and fuel loss as well as attempts to characterize fires according to relative intensity are provided.

Brenden, J. J. (U.S. Forest Products Laboratory, Madison, Wisconsin) "How Nine Inorganic Salts Affected Smoke Yield from Douglas-Fir Plywood," *U.S.D.A. Forest Service Research Paper FPL-249* (1975)

Subjects: Smoke chamber measurements; Inorganic salt retardants; Flammability of plywood

Author's Abstract

Reports smoke yield in a smoke chamber apparatus after treated and untreated Douglas-fir was exposed to flaming and nonflaming conditions.

Brown, J. K. and Marsden, M. A. (Northern Forest Fire Laboratory, Missoula, Montana) "Estimating Fuel Weights of Grasses, Forbs, and Small Woody Plants," *U.S.D.A. Forest Service Research Note INT-210* 11 pp. (1976)

Subjects: Forest fuels; Weights of forest fuels

Author's Abstract

Equations were developed for estimating fuel loading (g/m^2) of grasses, narrow-leaved forbs, broad-leaved forbs, and small woody plants common to western Montana and north Idaho. Independent variables were plant height and percentage of ground covered. R^2 for the equations ranged from 0.30 to 0.91. The equations provide reasonable estimates for vegetation similar to that sampled in this study; however, accuracy could decrease significantly if the equations are applied to dissimilar vegetation. Differences in ocular estimates of ground cover between observers averaged 5.8 percentage points.

Budnick, E. K. and Klein, D. P. (National Bureau of Standards, Washington, D.C.) "Evaluation of the Fire Hazard in a Mobile Home Resulting from an Ignition on the Kitchen Range," *Interim Report NBSIR 75-788*, National Bureau of Standards for the Department of Housing and Urban Development (February 1976)

Subjects: Mobile home fire tests; Fire tests, mobile home; Kitchen range fire tests

Authors' Abstract

A series of fire tests was conducted in a typical mobile home to evaluate the potential fire hazard resulting from an accidental ignition from cooking on the kitchen range. Specific attention was directed to (a) ease of ignition of the kitchen cabinets as a function of the clearance between the range and the underside of the cabinets with and without the presence of a metal hood and (b) flame spread following the ignition. The tests, which used a preheated pan of cooking oil as an ignition source, were conducted in a mobile home kitchen area. The materials tested were printed lauan plywood, printed particle board, and molded polystyrene, representative of materials used in kitchen cabinet construction in mobile homes. Under the test conditions employed, it was found that ignition of the kitchen cabinets occurred in all cases in which a metal hood was not used. The time to ignition of the materials was only slightly affected by the clearance between the specimen (cabinet bottom) and the range. A significant time delay or no ignition resulted from the installation of a metal range hood. An additional problem area revealed by the tests was the ignition and burn-through of the partition directly behind the range. Specific design recommendations based on test results are presented along with suggestions for further investigation.

Chaiken, J. M., Ignall, E. J., and Walker, W. E. (The New York City Rand Institute) "A Training Course in Deployment of Emergency Services: Student's Manual," *The Rand Corporation*, R-1784/2-HUD (September 1975)

Subjects: Emergency service deployment; Deployment of emergency services

Authors' Preface

The development, documentation, and field presentation of this course was performed under a contract with the Office of Policy Development and Research of the U.S. Department of Housing and Urban Development (HUD)—"Contract for the Development, Field Testing, and Documentation of Management Methods for Emergency Services for Local Agencies." This contract and earlier contracts between HUD and The New York City-Rand Institute involved work with city agencies designed to improve the deployment of their emergency service units. Prior to beginning such work, a training course was often presented to agency and city officials, and to local analysts. This manual provides lecture notes, visual aids, and references for such a course, to be used by students whose instructor is teaching from the companion volume:

R-1784/1-HUD, *A Training Course in Deployment of Emergency Services: Instructor's Manual.*

This student's manual is not designed for self-directed study. The companion instructor's manual is more suitable for this purpose.

Corrie, J. C. (Joint Fire Research Organization, Borehamwood, Herts., England) "The Effect of Foam Liquid Concentrates on Fire Performance on Laboratory Fires," *Fire Research Note No. 1047,* Joint Fire Research Organization (January 1976)

Subjects: Fluoroprotein foam; Fluorochemical foam; Fire tests of fluoronated foams

Author's Summary

The effect of deterioration of foaming solutions of fluoroprotein and fluorochemical liquids has been simulated by dilution, and the consequent change in performance has been measured by means of the new 0.25 m^2 test fire described in FR Note No. 1007. The results obtained are compared with earlier ones on the Defence Standard 42-3 fire of 0.28 m^2 area, over which the new fire is shown to have advantages.

Damant, G. H. (Flammability Research Laboratory, State of California, Sacramento, California) "The Effects of Aging on Fire Retardant Flexible Polyurethane Foams Commonly Used in Upholstered Furniture," *Department of Consumer Affairs, Bureau of Home Furnishings Laboratory Report SP-76-7, State of California* (October 1976)

Subjects: Polyurethane foam, fire retarded; Fire retarded polyurethane foam; Upholstered furniture, polyurethane in; Aging effect on fire retarded urethane foam

Author's Summary

In past years the development of flexible urethanes with reduced flammability has encountered numerous problems including odor, poor aging, toxicity, increased smoke production and permanence. However, recent developments claim to have surmounted many of these difficulties. This paper reports on the correlation between a short term laboratory procedure for determining permanence of flame retardance in flexible urethane foams and long term shelf life exposure conditions. Significant correlation of 150° F/14 day aging with 24 month shelf-life aging conditions was obtained in this study for flame retardant flexible urethanes. On the basis of pass/fail considerations, using California Technical Bulletin 117 criteria, all 18 F.R. Foams and 6 of 9 H.R. Foams gave identical pass/fail classifications under both 150° F/14 day and 24 month shelf-life aging conditions.

Ferguson, R. S. "The Separation of Legal and Technical Functions in Building Regulations," *Fire Journal 70* (1) 74 (1976)

Subjects: Fire codes; Fire regulations; Safety standards

Fire Technology Abstract 76-19

Technology and law are characteristically different. The technologist says, "The minimum safe condition is . . . ," while the lawmaker says, "The minimum conditions that you may create or allow shall be . . . " The appropriate combination of technology and law embraces the statements of both the technologist and the lawmaker. A building code should be understandable to those who adminster it. Legal statements must be understandable to the legal profession. Technical statements should not be expressed in legal form, nor should they be part of the law. Separate legal and technical statements are necessary. Laws should be written by lawyers and technical codes by technologists.

Foehl, J. M. "In Quest of an Economical Automatic Fire Suppression System for Multi-Family Residential Complexes," *Fire Journal 70* (1) 48 (1976)

Subjects: Sprinkler systems, low cost; Fire suppression systems

Fire Technology Abstract 76-18

Based on an adaptation of the domestic cold water mains and risers to automatic fire sprinkler use, price reductions of 16% resulted from the combined system approach as compared to systems of conventional design. One installation in an eight-story condominium using copper fittings cost $420 per dwelling unit, $53 per sprinkler, and 62 cents per square foot of protected area compared to estimates for conventional systems of $491 per dwelling unit and 74 cents per square foot of protected area. A demand flow of 150 gallons is provided with a minimum orifice pressure of 15 psi at the most remote operating sprinkler. A vertical constant pressure pump delivers 160 gpm at a discharge pressure of 105 psi.

George, C. W., Blakely, A. D., and Johnson, G. M. (Intermountain Forest and Range Experiment Station, Ogden, Utah) "Forest Fire Retardant Research: A Status Report," *U.S.D.A. Forest Service General Technical Report INT-31* (1976)

Subjects: Forest fire retardants; Retardants for forest fires

Authors' Abstract

Forest fire retardant research was divided into five different study areas: (1) retardant effectiveness; (2) retardant physical properties; (3) retardant delivery systems; (4) retardant-caused corrosion; and (5) retardant environmental impact. Past research is reviewed for each study area; current and future research needs are described.

George, C. W. and Johnson, C. W. (Northern Forest Fire Laboratory, Missoula, Montana) "Revised Marsh Funnel Calibrations for Measuring Fire Retardant Viscosity," *U.S.D.A. Forest Service Research Note INT-205* (1976)

Subjects: Aerial fire suppression; Chemical fire retardants; Fire retardant quality control

Authors' Abstract

Updates data (Research Note INT-91) for measuring viscosity of fire retardants in the field by means of the Marsh Funnel. New data cover Tenogum and gum thickened Fire-Trol 931. Data for Gelgard (no longer available) have been dropped.

Haines, D. A., Johnson, V. J., and Main, W. A.(North Central Forest Experiment Station, Saint Paul, Minnesota) "An Assessment of Three Measures of Long Term Moisture Deficiency Before Critical Fire Periods," *U.S.D.A. Forest Service Research Paper NC-131* (1976)

Subjects: Fire period, moisture assessment; Moisture deficiency assessment

Authors' Abstract

Values of the Palmer Drought Index, the Keetch-Byram Drought Index, and a Buildup Index are calculated for twenty-six critical fire situations in the north central and northeastern states. The paper examines the response characteristics of these indices, representative of different moisture regimes, relative to fire danger.

Hall, C. "Chemistry and Construction," *Chemistry in Britain 12* (10) 713-720 (October 1976) See Section H.

Harmathy, T. Z. (Division of Building Research, National Research Council of Canada, Ottawa) "Creep Deflection of Metal Beams in Transient Heating Processes with Particular Reference to Fire," *Canadian Journal of civil Engineering 3* (2) 219 (June 1976)

Subjects: Beam creep in fires; Deflection of beams in fires; Creep of beams in fires

Author's Abstract

A new numerical technique is described by which the process of creep bending under transient heating conditions can be predicted. It utilizes a convenient creep model, proposed by Dorn and expanded by this author.

The computer simulation of the behavior of three protected steel beams during standard fire tests is discussed. The close agreement between the experimental and computed midspan deflection histories is regarded as the proof for the accuracy of the technique as well as of the creep model employed.

Harmathy, T. Z. "Design of Buildings for Fire Safety, Part 1," *Fire Technology 12* (2) 95-108 (1976)

Subjects: Fire safety; Building design; Fire protection; Fire spread

Journal Abstract

Fire safety provided by conventional fire resistant compartmentation of buildings is largely illusory. Both mathematically and experimentally, it was found that maximum fire temperatures occur at relatively low levels of ventilation (ship, basement, and theatre fires). Well-ventilated fires burn at lower temperatures and are very short. Wall, floor, or building collapse usually occurs after the spread of fire to adjacent spaces; collapse is the result of fire spread, not the cause. In multistoried buildings, fire spread on upper floors will be toward outside boundaries; while on the lower floors, fire spread is toward the shafts. Noxious combustion products are carried through the shafts to the upper floors.

Harmathy, T. Z. "Design of Buildings for Life Safety, Part II," Fire Technology 12 (3) 219 (1976)

Subjects: Life safety; Building design

Journal Abstract

The destructive potential in a fire cell (space on fire) may be minimized by proper dimensioning of the compartment (large windows and low ceiling). Fire isolation may be accomplished by self-closing doors, continuous balconies, open corridors, and flame deflectors on windows. For the drainage method, applicable to poorly compartmented high-rise buildings, the energy of the fire is exploited by drawing air into the fire cell in quantities that produce a fuel-surface-controlled condition, i.e., short duration at relatively low temperatures, also by maintaining pressure in the fire cell below the pressure in neighboring spaces, and by removing flames and smoke from the fire cell.

Hayashi, T., Shibata, M., Yamaguchi, H., Sakurai, H., and Kanehara, K. "Research on Air Shutters for Fire Protection (2)," *Bulletin of the Japanese Association of Fire Science and Engineering 26* (1) 15 (1976) (in Japanese)

Subjects: Fire protection; Air shutter research

Authors' Abstract

The push-pull type air shutter is suggested as a new type equipment for fire protection, and is effective and well-directed both for protection from fire and smoke and for escape.

The method is described in the preceding paper on an assumption that the shutter ought to shut off smoke and toxic gases perfectly. From a different point of view, for reducing the initial and running costs of equipment, the exhaust flow rate of the air shutter can be decreased permitting a little smoke and gases to leak through the air shutter. Nevertheless, as people in the safety zone should be kept secure, there should be a limit to the reduction in exhaust flow rate.

In order to determine the limit values, an air shutter model on the scale of 1/60 is used. The equation to determine the volume rate of pull flow Q_3 on push-pull

type air shutter is given as follows[1]:

$$Q_3 = Q_1(1 + m \cdot K_B) \qquad (1)$$

where, Q_1 is volume rate of push flow, m is the break safety factor, and K_B is the break limit flow ratio determined by the shape ratio of air shutter and the side flow velocity ratio V_o/V_1. Equation (1) is changed to a dimensionless form:

$$Q_3 Q_1 = 1 + m \cdot K_B \qquad (2)$$

The experiment is run varying the push-pull flow ratio Q_3/Q_1 and the side flow velocity ratio v_o/v_1 to obtain the "smoke leak ratio" with the following results.

(1) The aims of a push-pull type air shutter for fire protection are, first, to protect people from smoke and gases at an early stage of fire outbreak; second, to exhaust smoke and prevent fire extension, and, third, to make fire fighting easy. Therefore, the value of the smoke leak ratio ought to be zero and the value of m in equation (1) has to be larger than 1.

(2) When the value of m is smaller than 1 and interception of the shutter is imperfect, even if the value of smoke leak ratio is small, the permissible time for escape is very short. Once the smoke begins to leak toward the safety zone, concentration in the zone increases and bad visibility makes escape difficult.

Hayashi, T., Shibata, M., Yamaguchi, H., Sakurai, H., and Kanehara, K. "Research on Air Shutters for Fire Protection (3)," *Bulletin of the Japanese Association of Fire Science and Engineering 26* (2) 17 (1976) (in Japanese)

Subjects: Fire protection; Air shutter research

Authors' Abstract

In this report it is mentioned how side flows with nonuniform velocity distributions, as in fires, influence the flow characteristics of air shutters, and next how to design them.

Then, assuming push flow, pull one, and side one to be two dimensional potential flow, the three flows are combined theoretically.

The results are as follows:

(1) The mode of push-pull flow of the shutter varies according to the velocity distribution pattern of side flow, even if each volume flow rate is constant.

(2) In such cases, the nearer the position of the point where the velocity of side flow shows a maximum at the suction side of the shutter, the stabler the flow becomes. In other words, the position of center of gravity of side flow influences to a great extent, the stability of push-pull flow.

(3) Furthermore, the smaller the maximum velocity of side flow, the stabler the push-pull flow becomes, under the conditions that the mean velocity and distance of center of gravity of side flow from the pull side of air shutter are constant.

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1) T. Hayashi *et al.*; Characteristics of Push-pull Hoods and Their Design (1)-(5), Bulls. of Presentations of the Society of Heating, Air-Conditions and Sanitary Engineers of Japan, 1970-1974.

Next, in order to confirm the conclusions described above, the experiment on the practical flow was performed by employing a model and the results coincide well with conclusions (1)—(3).

Therefore, the design of air shutters for fire protection should consider the following:

(1) Since the side flow of smoke near the ceiling is faster than near the floor, therefore, the shutter ought to be designed so that the flow is inhaled at the ceiling. Also, this is affirmed by the fact that smoke has a buoyancy because of its temperature.

(2) The volume rate of flow, Q_3, can be calculated by "Flow Ratio Method"

$$Q_3 = Q_1(1 + m \cdot K_{BUNI})$$

where, Q_1: Volume rate of push flow, m^3/min

m: Break safety factor determined according to the velocity distribution pattern of side flow

K_{BUNI}: Break limit flow ratio calculated by employing the mean velocity of side flow

Hinkley, P. L. (Building Research Establishment, Borehamwood, Herts., England) "Work Done by the Fire Research Station on the Control of Smoke in Covered Shopping Centers," *Building Research Establishment Current Paper 83-75*, Fire Research Station (September 1975)

Subjects: Smoke control; Shopping centers, smoke hazards in

Author's Abstract

Shopping centres with covered malls can present a hazard in the event of a fire because smoke and combustion products could spread throughout the centre. The Fire Research Station has studied the rate of production of smoke by a fire, the rate at which it can spread and methods of restricting its spread. Extensive experiments have been carried out both on models and on full scale, including work in a building representing part of a shopping centre, and on the rate of flow of smoke from fires in a railway tunnel in Glasgow.

The rate of production of smoke depends on the area of the fire and the height of the shop or mall while the density of the smoke depends on the materials burning and the rate of burning of the fire. The smoke forms a layer beneath the ceiling which may move sufficiently fast to overtake people on escape routes. Beneath the outward flowing layer of smoke and hot gases air flows back towards the fire; smoke will mix into this return flow of air, particularly when the layer of hot gases has reached an obstruction or the open end of a mall, so that the mall can become completely filled with smoke.

If shop fronts are fire resisting, hot smoky gases may be confined to the shops of origin. Otherwise the size of the fire and hence the rate of production of hot smoky gases must be limited (preferably by sprinklers) and it is then possible to confine the hot smoky gases to a stratified layer beneath the ceiling while the air beneath

them is relatively cool and clear. The extent of the layer is limited by dividing the space beneath the ceiling into smoke reservoirs by screens extending part of the way towards the floor. Arrangements must be made to extract smoke from the reservoirs as fast as it flows into them while fresh air must be introduced or allowed to flow into the building to replace the extracted hot gases. Such a system is satisfactory for single-storey malls. The requirements of both natural and powered systems for extracting smoke from the smoke reservoirs are considered; natural venting systems are liable to be adversely affected by the wind whereas forced extraction systems can overcome wind effects, but is difficult to obtain fans which will handle the large volumes of hot gases involved.

Jin, T., Shimada, H., and Takemoto, A. (Fire Research Institute of Japan, Tokyo, Japan) "Experiment on Smoke in Pressurized Staircase," *Report of the Fire Research Institute of Japan No. 40,* 35-42 (1975) (in Japanese)

Subjects: Smoke measurement; Pressurized staircase

Authors' Abstract

The purpose of this experiment was to determine the minimum amount of air supply required to prevent smoke invasion into a staircase under various opening conditions. One room (floor area: 225m^2) on the second floor was selected as a fire compartment. The combustibles in the fire compartment consisted of 2 tons of woods and 2 tons of clothes (20 kg/m^2). The air was supplied into the staircase by a fan (capacity 1000 m^3/min., 100 mm Aq) installed on the first floor. The effectiveness of pressurizing the staircase to prevent smoke invasion through the swing door of the 2nd floor was studied. The effectiveness was studied under several conditions in which the rate of air supply and the opening conditions of the swing door of the 2nd floor and the entrance door of the fifth floor. The experimental results agreed with theoretical pressure values.

King, R. M. and Furman, R. W. (Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado) "Fire Danger Rating Network Density," *U.S.D.A. Forest Service Research Paper RM-177* (1976)

Subjects: Forest fire control; Forest fire danger rating

Authors' Abstract

Conventional statistical techniques are used to answer the question, "What is the necessary station density for a fire danger network?" The Burning Index of the National Fire Danger Rating System is used as an indicator of fire danger. Results are presented as station spacing in tabular form for each of the six regions in the western United States.

Kisilyakhov, E. K. and Konev, E. V. (Forest and Wood Institutes, Siberian Section, Academy of Sciences USSR, Krasnoyarkh) "Evaluation of the Fire Extinguishing and Fire Retarding Efficiency of Chemical Agents," *Fizika Goreniya Vzryva 12* (6) 497-502 (1976) (in Russian)

Subjects: Fire retardants; Fire extinguishing chemicals; Chemical fire retardants; Chemical extinguishants

Abstracted by L. Holtschlag

A method is described which makes it possible to determine the fire retarding, fire extinguishing, and, if necessary, the cool extinguishing properties of chemical agents on combustible forest materials. The principle of the method consists in applying an agent to a characteristic particle of the combustible material and then measuring the rate of flame spread over this particle. A decrease in the flame spread rate per 1% of agent relative to the weight of the dry material characterizes the fire retarding properties of the agent. If, as the quantity of agent is steadily increased, a limit is reached when combusiton or smoldering of the particle becomes impossible, the corresponding content of the agent characterizes its fire and cool extinguishing properties in the passive extinguishing mode. The most effective agents can be determined by intercomparison. The fire extinguishing effectiveness of twenty agents, among them water, ammonium bromide, sodium carbonate (powder and crystals), sodium bicarbonate, ammonium chloride, etc., is given in a table with pine needles as the combustible material. The effectiveness of the different agents was related to that of water which turned out to be the most effective.

Lathrop, J. K. "Two Die in High-Rise Senior Citizens Home, Albany, New York," *Fire Journal 69* (5) 60-62 (September 1975)

Subjects: High-rise buildings; Fire safety

Fire Technology Abstract

Although two residents died in a fire on the eleventh floor of a fourteen-story apartment for senior citizens in Albany, New York, a more serious loss of life was averted by the presence of self-closing, fire-rated, apartment entry doors and a firesafety education program. There was lateral fire penetration through a plywood pipe enclosure, which allowed smoke to spread to an adjacent apartment and cause the death of the occupant. The other victim was found in the remains of a bed in the apartment of origin. With a heat or smoke detector in the apartment of origin, the fire could have been discovered much sooner.

Lyon, L. J. (Intermountain Forest and Range Experiment Station, Ogden, Utah) "Vegetal Development on the Sleeping Child Burn in Western Montana, 1961 to 1973," *U.S.D.A. Forest Service Research Paper INT-184* (1976)

Subjects: Forest fire; Forest succession; Herbicide side effects

Author's Abstract

In the year following the 1961 Sleeping Child forest fire on the Bitterroot National Forest, Montana, 11 permanent transects were established within the burn. Vegetation development was recorded through 1973, but only four transects were considered indicative of seral forest succession independent of superimposed management activities including salvage logging, cattle grazing, and chemical thinning of tree seedlings. Major modifications in plant community structure resulted from management activities, but none of the existing communities are considered completely atypical.

Miller, D. A. "A Computerized Planning System for Bureau Inspectors," *Fire Technology 12* (3) 237 (1976)

Subjects: Fire prevention; Inspections; Computer planning

Journal Abstract

A computerized system, developed for the Atlanta Fire Prevention Bureau to help use its full-time inspectors in the most effective and efficient manner, is described. The system is concerned with how often to conduct routine planned inspections in all public and commercial buildings in the city, how to set up territorial responsibility for each inspector, and when to conduct each routine, planned inspection. Man-hours available for inspections can be more effectively used, and here is a potential for reduction in the number of supervisors. By better balanced districts, there will be more equality in work loads, leading to better morale. More compact inspection districts permit reduction of travel time.

Morgan, H. P., Marshall, N. R., and Goldstone, B. M. (Building Research Establishment, Borehamwood, Herts., England) "Smoke Hazard in Covered Multilevel Shopping Malls: Some Studies Using a Model Two Storey Mall," *Building Research Establishment Current Paper 45/76* Fire Research Station (1976)

Subjects: Smoke hazard; Covered shopping malls, smoke in

Authors' Abstract

A 1/10 scale model shopping mall was used to investigate quantitatively the effects of a number of structural features of the mall on certain variables: these included the smoke extraction rate, and the optical density (and hence visibility) at head height. The optical density was studied using a tracer-gas modelling technique. Other variables studied were the vent area, air inlet area and the size of the openings (voids) passing smoke between levels. Conclusions are drawn concerning the optimum values for these variables. Further modifications are shown to be necessary to achieve maximum visibility on upper levels of the mall. It is shown that the lateral spread of smoke below the upper deck should be minimised, as should the perimeter of the rising smoke plume. Fresh air entering the upper mall should move at a low velocity when it first encounters smoke.

Nash, P. (Building Research Establishment, Borehamwood, Herts,. England) "Portable and Installed Fire-Fighting Equipment in Buildings," *Building Research Establishment Current Paper 3/77*, Fire Research Station (1977)

Subjects: Firefighting equipment; Building firefighting equipment

Author's Abstract

This note describes the range of portable and installed first-aid fire-fighting equipment in buildings, for the use of the occupants in case of emergency. It gives a guide to the fire-fighting capability and most likely usage of each type of equipment.

Nash, P. (Building Research Establishment, Borehamwood, Herts., England) "The Essentials of Sprinkler and Other Water Spray Fire Protection Systems," *Fire Prevention No. 108*, 15-26 (1975)

Subjects: Sprinklers; Fire protection by sprinklers

Author's Abstract

This paper describes the three protective systems which discharge water: sprinkler systems, water-spray systems and deluge systems. These systems can be designed and used for the extinction or control of solid-fuel fires, flammable-liquid fires, or mixtures of the two.

Nash, P. and Young, R. A. (Building Research Establishment, Borehamwood, Herts., England) "Sprinkler Systems for Special Risks," *Building Research Establishment Current Paper 52/76*, Fire Research Station (1976)

Subjects: Sprinkler systems; Special risk sprinkler systems

Authors' Summary

This article describes and discusses those risks not covered by existing rules and codes for sprinkler systems and the methods which are being used to protect them. Special risks discussed are: aircraft maintenance hangers, computer suites, cold storages, paper storages, carpet storages, and offshore drilling platforms and terminals.

Nash, P. and Young, R. A. (Building Research Establishment, Borehamwood, Herts., England) "The Performance of the Sprinkler in Detecting Fire," *Building Research Establishment Current Paper 29-75*, Fire Research Station (1975)

Subjects: Sprinklers; Fire detection by sprinklers

Authors' Abstract

It is shown that the response of sprinklers to a fire situation does not only depend upon the sprinkler itself, but also upon many characteristics of the building and the

fire-load concerned. A proper study of all the factors can greatly help in deciding the design parameters of a system in order to make it as effective as possible in a specific application.

Palmer, K. N. "Industrial Dust Explosions and Fires," *Archiwum Thermodynamiki i Spalania* 7 (1) 22-39 (1976)

Subjects: Dust explosions; Explosions' dusts; Fires from dust explosions

Safety in Mines Abstracts 25 No. 1213
Safety in Mines Research Establishment

A brief description is given of the occurrence of explosions and fires due to dusts in industry as obtained from fire brigade reports. The chemical industry is given particular consideration and the most frequent source of ignition was electricity. Other frequent causes were mechanical heat and sparks, smoking materials and spontaneous combustion. Solid chemicals figure prominently and taken together with materials specifically manufactured as dusts or powders they clearly represent an important risk. Two extreme cases of the burning of dusts are considered in detail; dust explosions and smouldering fires. Dust explosions are rapid processes involving suspensions of dust in air, burning with flame and generating pressure. Discussion is given of the characteristics of dust explosions, the types of plant frequently involved and the available tests. The protection of industrial plant against dust explosions either involves control of the explosion pressure to a safe level by relief venting or prevention of the development of an explosion by automatic suppression or by the use of inert gas. Principal attention was given to relief venting because it is likely to be considered every time a new plant which needs protection is designed. Smouldering fires are slow, in deposits of dust, and involve combustion without flame. Attention is given to smouldering rates, the transition to flaming, the effects of air flows, and smouldering within dust deposits. Consideration is given to the extinguishing of fires in dusts.

Palmer, K. N., Taylor, W., and Paul, K. T. (Building Research Establishment, Borehamwood, Herts., England) "Fire Hazards of Plastics in Furniture and Furnishings: Fires in Furnished Rooms," *Building Research Establishment Current Paper 21-76*, Fire Research Station (1976)

Subjects: Fire hazards of polymer furnishings; Furniture fire hazards; Room fire hazards

Authors' Abstract

The final phase of a 3-year contract on the fire hazards of plastics in furniture and furnishings is described. The third year's work was mainly on the burning of furnished rooms; measurements were made of temperature, smoke density, and composition of fire gases as the fire proceeded. A sequence of well-ventilated fires involving sitting/dining-room furniture, showed that traditional furniture was relatively difficult to ignite with a small flame and underwent a period of smouldering; when flames re-established themselves the fire developed slowly producing less smoke than furniture containing rubber or polyether foams. Modern sitting/dining-room furniture was readily ignited and burned rapidly evolving considerable quantities of smoke. Its flammability could, however, be reduced by improved covering and filling materials and by the provision of a flame-retardant interlining between the foam and the upholstery fabric. In a sequence of four tests involving the progressive substitution of less flammable fabrics and foams, and the use of interlining, the flammability of a modern suite was reduced and resembled that of traditional furniture. The implications of these findings are discussed.

In bedroom fires modern furnishings burned more rapidly than traditional but could be improved by the careful selection of bedding materials. A fire in a bed-sitting room, furnished in a modern style, developed rapidly with considerable production of smoke. Fire-spread was probably assisted by there being a great deal of furniture in the room, so that when a piece of furniture caught fire it could quickly set the pieces next to it alight. A similar pattern was found in a hotel bar fire where the number and close proximity of seats and small tables enabled fire to spread rapidly. Modern office furniture burned more rapidly than the traditional, and the use of structural foams in furniture gave rise to a severe smoke problem even after the fire temperature had decreased considerably. At their present state of development, structural foams in furniture could hinder the escape of occupants in the event of a fire. Polypropylene upholstery fabrics gave no protection against fire, were readily ignited, and should be regarded as a hazardous upholstery fabric.

Pineau, J., Giltaire, M., and Dangreaux, J. "Vent Efficiency. Study of Dust Explosion in Containers of 1, 10, and 100 m^3; Effects of Dust Type and the Presence of a Tube Forming an Extension to the Vent," *Cah. Not. Docum. No. 82, Note No. 1005-83-76*, pp. 191-202 (1976) (in French)

Subjects: Dust explosions; Explosions, dusts; Vent efficiency

Safety in Mines Abstracts 25 No. 1214
Safety in Mines Research Establishment

This data sheet is a follow-on to data sheet no. 881-74-74. However, the present one is original in that it treats explosion tests that have been carried out on full-scale equipment. In the first part, the characteristics of the dusts used are described and details are given of the changes in the experimental procedure by comparison with the tests described in the first data sheet. In the second part, experimental results are given for the variation of the maximum explosion overpressure as a function of the venting coefficient and dust type. In the third part, the effects of a conduit forming an extension to the vent are examined. In the fourth and last part, the limitations on the application and extrapolation of the results obtained are discussed.

Pusey, J. C., Prater, D., and Corrie, J. C. (Joint Fire Research Organization, Borehamwood, Herts., England) "An Evaluation of Hand Portable Foam Type Fire Extinguishers," *Fire Research Note No. 1049,* Joint Fire Research Organization (March 1976)

Subjects: Fire extinguisher; Chemical foam extinguisher; Fluoroprotein foam extinguisher

Authors' Summary

Chemical and mechanical type foam extinguishers were compared using four different liquid fuels and six sizes of tray fires. Three different foam liquids were used in the mechnical type extinguishers. Mechanical type extinguishers gave quicker fire control and extinction than did the chemical type. Using the mechnical type extinguishers significant differences in control and extinction times were obtained when different foam liquids were used.

Rodgers, S. P. (Joint Fire Research Organization, Borehamwood, Herts, England) "Preliminary Experimentation on the Sprinkler Protection of Carpets in Storage," *Fire Research Note No. 1061*, Joint Fire Research Organization (November 1976)

Subjects: Sprinkler protection; Storage sprinkler protection; Fire protection of carpets in storage

Author's Summary

With the increasing concern shown by carpet manufacturers and insurance companies on the fire protection of rolled carpets in storage, a series of experiments were carried out by the Fire Research Station (FRS). The initial small scale work on a selection of rolled carpet samples, enabled the least and most flammable carpets to be selected for simulated full scale experiments in an open rack, to study the effectiveness of sprinklers in controlling the fire. These experiments showed that conventional in-rack sprinklers with a sufficiently high rate of water application would probably only prevent damage to building and racking.

The fire hazard presented by the two carpets varied to such an extent that further work is necessary, to enable a relationship to be established between the rate of water application ("water density") required, to the types of carpet stored. This would then allow sufficient sprinkler protection to be given to the type of carpet, and ensure maximum fire control. Further work is also required on simulated full scale closed racks to study the burning characteristics of the carpets and the sprinkler protection required in this type of storage.

Schneider, U. (Technical University, Braunschweig, West Germany) "Behavior of Concrete Under Thermal Steady State and Non-steady State Conditions," *Fire and Materials 1* 103-115 (1976)

Subjects: Concrete under thermal conditions; Temperature effects on concrete

Author's Abstract

Stress-strain behaviour of concrete at elevated temperatures is extremely complex and is not completely understood up to now. The creep properties of concrete at temperatures up to 300°C thus need to be determined, as well as the thermal stability of concrete during repeated cycles of heating and cooling. In this report the results of recent high temperature experiments with normal concrete specimens are presented. The main objectives of the tests were to investigate the dependence of strength and elasticity on temperature and to study the creep and deformation characteristics of concrete at temperatures up to 450°C. Transient creep data, i.e. data derived under transient temperature conditions, are compared with creep data which were measured at constant elevated temperatures. The results suggest that transient creep values and steady state creep values in some cases may be of the same magnitude.

The creep measurements appear to be in good agreement with data presented by other workers. However, the scatter in all data increases significantly with increasing temperature and differences of more than 100% can be observed. When loaded concrete specimens were cooled down to ambient temperature extraordinarily large compressive strains can be observed. The experiments indicate clearly the considerable strain capacity of normal structural concrete at elevated temperatures. The measurements suggest that in certain cases normal structural concrete can be used at temperatures higher than 100°C. In areas of high stress concentrations a considerable reduction of stress peaks may occur due to the greater ductility of concrete at elevated temperatures. On the other hand, with respect to the whole structure it is necessary to limit the deformations. For a constant maximum temperature this can only be done by limiting the admissible stresses. The test results permit an initial estimation of maximum permissible stress and temperature values.

Silcock, A. and Tucker, D. M. (Building Research Establishment, Borehamwood, Herts., England) "Fires in Schools: An Investigation of Actual Fire Development and Building Performance," *Building Research Establishment Current Paper 4/76,* Fire Research Station (1976)

Subjects: Fires in schools; School fires; Fire development in buildings

Authors' Abstract

The number of fires in schools is increasing, owing mainly to malicious ignition, and the high cost of reinstatement requries consideration of measures to reduce the extent of damage. The Field Investigations Section of the Fire Research Station has carried out detailed investigations of a number of school fires in co-operation with the Department of Education and Science to assess the performance of school buildings under fire conditions. The immediate aim was to make proposals for possible revisions of structural fire requirements and to point the way to further improvements.

The report gives a detailed study of 14 of the incidents investigated. The functions

of various elements of a building in a fire are explained and assessments of actual performance in the particular fires are given. The major single factor affecting fire-spread was the presence of undivided ceiling voids, but other means of spread were also important. The extent of spread and consequent fire damage was considerably influenced by the construction and the nature of materials used. The results of the investigation indicate that those who design, build, staff and maintain buildings do not appreciate fully the fire hazards involved in the use of non-traditional construction and materials. Suggestions are put forward for earlier discovery by automatic and human detection, and for the limitation of damage by smoke and fire. The latter involves considerations of general planning and site layout, sub-division of ceiling voids, fire venting through roofs and windows, the fire resistance of doors and partitions, fire-spread through vertical cavities and ducts, and maintenance.

Skinner, G. A., Parker, L. E. and Marshall, P. J. (Kingston Polytech, Kingston, Surrey, England) "Flame Retardant Synergism Between Molybdenum and Halogen Containing Compounds in Unsaturated Polyesters," *Fire and Materials 1* (4) 154-159 (1976)

Subjects: Molybdenum halogen flame retardency; Flame retardant, molybdenum-halogen

Authors' Abstract

Oxygen index results for a series of unsaturated polyesters, containing molybdenum oxide and various halogenated compounds, have provided definite evidence for some form of flame retardant synergistic effect between molybdenum and halogen. With the halogenated compounds used, the magnitude of the effect was greater in the presence of bromine but was dependent on the type of compound. When dibromoneopentyl glycol was used as the bromine source, the synergistic effect exhibited by molybdenum oxide was comparable to that shown by antimony oxide. Since molybdenum oxide also acts as a smoke suppressant, it could offer a useful alternative to antimony oxide particularly in the light of probable changes in standards and regulatory control regarding smoke emission.

"Standards Governing Explosion Proof Protective Enclosures," *Italian Electrochemical Committee,* National Research Council of Italy, 31-1, 51 pp. (1969)

Subjects: Explosion-proof enclosures; Standards for explosion-proof enclosures

Safety in Mines Abstracts 25 No. 1249
Safety in Mines Research Establishment

Compiled by Sub-Committee 31 on Flameproof Materials. The draft contains the regulations governing the construction and testing of AD-PE enclosures for atmospheres in which a mixture of air and flammable vapour or gas could form. The regulations do not cover acetylene or carbon sulphide or any other gases with which there are similar difficulties in preventing flame propagation outside enclosures in which joints are used.

Stoicheci, C. "Explosion and Fire Prevention with Air Compressors," *Paza Contra Incendiilor 47* (1) 10 (1975) (in Romanian)

Subjects: Explosion prevention, air compressors; Fire prevention, air compressors, Air compressors, explosion and fire

Safety in Mines Abstracts 25 No. 1210
Safety in Mines Research Establishment

The article shows that the part most prone to explosion and fire is the zone of air pressure and compression. The abnormal rise in air temperature leads to the oxidation and carbonization of the compressor-lubricating oil, which determines, owing to the existing oxygen, the conditions favourable to explosion and fire bearing.

Takahashi, S. (Fire Research Institute of Japan, Tokyo, Japan) "Development of an Oxygen Generating Breathing Apparatus. I. The Reactive Characteristics of Potassium Superoxide Mainly with Exhaled Breath," *Report of the Fire Research Institute of Japan No. 41*, 33-48, (1976) See Section K.

Taylor, W. "Assessment of Fire Hazard of Foam," *Conference on Urethanes and the Environment, Hayes, September 21-22, 1976, F1 - F9*, London, Plastics and Rubber Institute, (1976)

Subjects: Foam fire hazard; Fire hazard of foam

Safety in Mines Abstracts 25 No. 1228
Safety in Mines Research Establishment

The problems of assessing the fire hazard of foams are examined against recent experience in examining furniture and furnishings. The factors which are important as regards room contents are examined, and the most important measures to prevent such fires are discussed. Control of ignitability of components is considered to be the most central issue to a safer environment.

Watanabe, Y. (Fire Research Institute of Japan, Tokyo, Japan) "A Study of Voice Guidance for Evacuation," *Report of the Fire Research Institute of Japan No. 41*, 1-7 (1976) See Section K.

Woolley, W. D. and Ames, S. A. (Building Research Establishment, Borehamwood, Herts., England) "The Explosion Risk of Stored Foamed Rubber," *Building Research Establishment Current Paper 36-75*, Fire Research Station (1975)

Subjects: Explosion of foamed rubber, Foamed rubber explosion; Rubber, foamed, explosion of

Authors' Abstract

A fire occurred recently in a store room containing foamed rubber mattresses which led to an explosion of a hitherto unknown type which caused two deaths and some serious injuries. The incident was investigated as a matter of urgency at the Fire Research Station and this report describes experimental work which has been carried out to study the flammability and explosibility of the products from the burning and smoldering of foamed rubber. The work has shown that a serious explosion risk exists when the flammable smoke and vapors from the smoldering of foamed rubber are allowed to collect in an enclosed space.

Yamashika, S., Mirikawa, T., and Kurimoto, H. (Fire Research Institute of Japan, Tokyo, Japan) "Effectiveness of Halon 2402 as Incipient Fire Suppressant for Floating Roof Petroleum Tank," *Report of the Fire Research Institute of Japan No. 40,* 30-34 (1975) (in Japanese)

Subjects: Halon 2402; Petroleum tank; Fire suppression

Authors' Abstract

A series of tests was conducted to examine the effectiveness of halon 2402 for suppressing the incipient stage of fire within the weather seal space of the floating roof petroleum tank. The actual weather seal space was simulated by a long rectangular steel vessel, 30 cm wide and 16 m long, provided with slated roof plates, which were partly or totally removable. With model fires of burning gasoline in this vessel under various opening conditions of roof plates, the halon was applied through a fixed array of nozzles either of sprinkler-head type or fog-discharge type. In every run of the tests, halon 2402 could successfully extinguish the fire. As regards the types of nozzles tested, the fog-discharge nozzles compared favorably with the sprinkler heads by affording more reproducible extinction time and less consumption of the halon.

B. Ignition of Fires

Annamalai, K. (Center for Fluid Dynamics, Brown University, Providence, Rhode Island) and **Durbetaki, P.** (Georgia Institute of Technology, Atlanta, Georgia) "Ignition of Thermally Thin Porous Pyrolyzing Solids Under Normally Impinging Flames," *Combustion and Flame 27* 253-266 (1976)

Subjects: Fabric ignition model; Cellulose fabric ignition

Authors' Abstract

Prediction of the fire hazard for a piece of garment exposed to a flaming heat-

ing source requires the development of a fabric ignition model which provides an accurate description of the flame-fabric interaction. Ignition times have been measured earier on single fabrics by exposing them to a time invariant convective source. A theoretical correlation of these results has been carried out utilizing a new ignition criterion. For a porous, thermally thin material exposed to a normally impinging flame, quasi-steady conservation equations for species, energy and momentum have been formulated for the gas phase, and the transient effects have been accounted for through the variation of the fabric temperature with time. The predicted cellulosic fabric ignition times, under varied exposure conditions and including the effects of porosity, deviate from the measured ignition times by no more than 42%. Accounting for convective heat loss from the fabric improves the predicted results by about 5%. Porosity effects on ignition time are found to be small for the fabrics tested here. Pyrolysis appears to be the dominant process which controls the ignition time.

Bright, R. G. (National Bureau of Standards, Washington, D.C.) "Report of Fire Tests on Eight TGS Semiconductor Gas Sensor Residential Fire Smoke Detectors," *Final Report NBSIR 76-990,* National Bureau of Standards for the Consumer Products Safety Commission (April 1976)

Subjects: Detectors; Fire detector; Gas detectors; Smoke detector; Taguchi gas sensors

Author's Abstract

At the request of the Bureau of Engineering Sciences Consumer Product Safety Commission, twenty-four Taguchi gas sensor (TGS) detectors, representing eight manufacturers were tested to the requirements of Section 22 (base sensitivity tests) and Section 24 (full-scale fire tests) of Underwriters' Laboratories Standard No. 217, "Standard for Single and Multiple Station Smoke Detectors." Two conventional single-station smoke detectors, one an ionization chamber type and the other a photoelectric type, were included in the test series for comparison. Only one of the TGS detectors was able to meet the requirements of Section 22, base sensitivity tests. None of the TGS detectors were able to meet the requirements of Section 24, full-scale fire tests. The two conventional smoke detectors met the requirements of Section 22 and 24.

Detz, C. M. (Union Carbide Corporation, Tarrytown, New York) "Threshold Conditions for the Ignition of Acetylene Gas by a Heated Wire," *Combustion and Flame 26* 45-55 (1976)

Subjects: Ignition; Acetylene

Author's Abstract

Threshold temperatures for the ignition of the exposive decomposition of pure acetylene gas by a resistively heated wire have been determined over the pressure

range 1.34-21.41 atm. The minimum acetylene pressure at which an explosion can be initiated has been found to lie between 1.34 and 1.68 atm. The ignition temperature increases with decreasing acetylene pressure and also with decreasing ignition wire diameter. The ignition data have been correlated using a simple empirical relationship between gas concentration and ignition temperature.

Gol'dshleger, U. I. and Amosoz, S. D. (Chernogolovka Section of the Physical Chemistry Institute of the Academy of Sciences, USSR) "Two Modes of Ignition and Combustion of Hydrocarbon Fuel Droplets," *Fizika Goreniya Vzryva 12* (6) 854-859 (1976) (in Russian)

Subjects: Ignition of hydrocarbons; Hydrocarbon combustion; Droplet combustion; Combustion of hydrocarbons

Abstracted by L. Holtschlag

In order to obtain a more distinct and complete picture of the physical and chemical processes that take place near the surface of a droplet as it evaporates, it is necessary to measure the temperature and concentration profiles during the ignition and combustion of the droplet. In this paper an attempt is made to measure the gas phase temperature near an evaporating droplet of hydrocarbon fuel (n-heptane and n-decane) in a quiescent air atmosphere. It is shown that there may be two droplet ignition and combustion modes, depending on the temperature of the medium. In the low temperature region the droplet evaporates in the cool flame combustion mode with a combustion temperature close to that of the ambient medium. In the high temperature region droplet ignition is of a two stage nature. The results point up the complex nature and mechanism of the gas phase chemical reaction during the evaporation of a droplet, and therefore certain constraints must be imposed on the class of systems to which the existing ideas on droplet ignition can be applied.

Kono, M., Kumagai, S., and Sakai, T (Univeristy of Tokyo, Japan) "The Optimum Conditions for Ignition of Gases by Composite Sparks," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 757 (1976)

Subjects: Ignition of gases; Gas ignition; Ignition by sparks

Authors' Abstract

To determine the optimum ignition condition for sparks consisting of a capacitance spark followed by a dc- (glow) or ac-discharge (1 MHz), the effects of gap width, electrode configuration, mixture strength, spark duration, and energy distribution between the two components on the minimum ignition energy were investigated, using a quiescent propane-air mixture. The condition in question is conveniently characterized by the optimum spark duration for which the minimum ignition energy is lowest and the corresponding energy value. For a de-discharge spark, the well-defined optimum spark duration varies from about 50 to 300 μsec and the minimum ignition energy for spark durations larger than the optimum increases in different modes, depending on the mixture strength and the quenching effect of spark electrodes. For an ac-discharge spark, the optimum condition for ignition is much the same as for a dc-discharge spark, but the minimum ignition energy and the spark duration are always proportional to each other above the optimum, and therefore the optimum spark duration is easily obtained up to about 5 msec. Flash-schlieren photographic observations of the initial behavior of the spark kernel confirmed that such differences in the mode of minimum ignition energy are related to electrostatic attraction by the negative electrode.

Lay, D. (National Bureau of Standards, Washington, D.C.) "A New Concept for Automatic Detection and Extinction of Fires," *Final Report NBSIR 76-1028,* National Bureau of Standards (March 1976)

Subjects: Automatic sprinklers; Fire detection; Fire extinguishment; Carbon dioxide extinguishment; Flame detection; Heat detection; Smoke detection

Author's Abstract

The use of automatic fire detectors to trigger fire extinguishment systems has gone on for many years. Systems of this type use a variety of extinguishing agents including water, carbon dioxide and, most recently, the halogenated agents. Automatic extinguishing systems with practically an unlimited supply of agent suffer from the fact that these systems often continue in operation long after the fire is out resulting in additional damage. This doesn't occur with those systems having limited supplies such as carbon dioxide systems and the like. However, these systems are only successful if: (1) their original design was correct; (2) no unanticipated changes are made in the area or materials to be protected; and (3) extinguishment commences at a time when successful extinguishment is possible. This paper describes how the disadvantages recommended above can be avoided, to a large extent, with a modified design for permanently-installed, automatic extinguishing systems and how systems can be provided which will only discharge extinguishant at the proper time and in the proper amount.

Masarik, I. (Fire Research Laboratory, Prague, Czechoslovakia), **Rysak, M., Svetlik, J.** (Academy of Sciences, Prague, Czechoslovakia) **and Horak, Z.** (Research Institute of Synthetic Rubber, Kaucuk Kralupy, Czechoslovakia) "The Use of the Setchkin Apparatus — Mass Spectrometry in the Investigation of Ignition and Burning of Flame Retarded Polystyrenes," *Fire and Materials 1* (4) 129-133 (1976)

Subjects: Ignition of polystyrene; Burning of polystyrene; Polystyrenes, fire retarded; Fire retarded polystyrenes

Authors' Abstract

A review is given of the possibilities for the use of the Setchkin apparatus combined with mass spectrometry in the investigation of the gaseous products of the thermo-oxidative decomposition and burning of flame-retarded polystyrenes, with simultaneous determination of the characteristics of ignition. Information on flame retardants in polystyrene, and their effect on the inhibition of burning in the gaseous phase was provided by mass fragmentation analysis of the main components of decomposition and burning.

Miller, B. (Textile Research Institute, Princeton, New Jersey) "The Thermal and Flammability Behavior of Multicomponent Fibrous Polymer Systems," *Final Report, May 1973 - October 1974* under Grant GI-37805, National Science Foundation (1975)

Subjects: Polymer flammability; Flammability of textiles; Textile flammability; Multicomponent fibers, flammability of

Author's Summary

The data presented show decisively that the flammability of blends containing wool and synthetic fibers cannot be predicted from the behavior of the components alone. The trends observed with both the polyester-wool and nylon-wool fabrics are similar in many respects. The unrestrained upward burning rates show a consistent composition dependence with burning rates greater than would be expected. The postignition flammability characteristics obtained with restrained samples show a more complex composition dependence with maxima or minima occurring near 50 and 95% wool for both systems.

Interactions that occur during polymer decomposition may be partly responsible for these results. However, some of the minima and maxima of postignition characteristics occur at compositions which show no corresponding inflections for decomposition behavior. This would seem to indicate that postignition phenomena, either chemical or physical, also are responsible for the observed effects. Further work on these systems is planned which will include more detailed chemical analysis of decomposition products and studies on the heat emission from burning blends.

Nash, P. and Young, R. A. (Building Research Establishment, Borehamwood, Herts., England) "The Performance of the Sprinkler in Detecting Fire," *Building Research Establishment Current Paper 29-75,* Fire Research Station (1975) See Section A.

Stockstad, D. S. (Northern Forest Fire Laboratory, Missoula, Montana) "Spontaneous and Piloted Ignition of Cheatgrass," *U.S.D.A. Forest Service Research Note INT-204* 12 pp. (1976)

Subjects: Forest fuel ignition; Spontaneous ignition forest fuels; Pilot ignition forest fuels; Cheatgrass ignition; Ignition of forest fuels

Author's Abstract

Spontaneous and piloted ignition of cheatgrass (Bromus tectorum L.) stems were investigated in an isothermal atmosphere. Three levels of sample moisture content were tested and minimum heat flux intensities required to produce ignition, times to ignition, and surface temperatures at time of ignition were recorded. Piloted ignition occurred at lower flux intensities and in less time than did spontaneous ignition. A significant difference in delay time to ignition was found to exist for sample moisture contents above 5.4 percent.

Tewarson, A. and Pion, R. F. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Flammability of Plastics, I. Burning Intensity," *Combustion and Flame 26* 85-103 (1976)

Subjects: Flammability of plastics; Plastic flammability; Pyrolysis; Wood

Authors' Abstract

This paper presents the progress of an experimental study to develop a laboratory-scale test to define the burning intensity of various commercial samples of plastics. In the study, a steady state heat balance at the burning surface has been used to derive the burning intensities. An "ideal" burning rate has been defined, which appears to correlate with full-scale fire test data. Conditions for the burning intensities in full-scale fires are postulated. Data for heat of gasification/pyrolysis/depolymerization, heat flux transferred from the flame to the surface, heat flux lost by the surface, and minimum mole fraction of oxygen required for flame extinction are presented for 16 commercial samples of plastics, a wood, and a plywood sample and six organic liquid samples.

Thorne, P. F. (Fire Research Station, Borehamwood, England) "Flash Point of Mixtures of Flammable and Nonflammable Liquids," *Fire and Materials 1* (4) 134-140 (1976)

Subjects: Flash point of liquid mixtures; Liquid mixture flammability

Author's Abstract

A general theory is developed which enables closed-cup flash-points of mixtures of flammable and non-flammable liquids to be predicted from a knowledge of certain properties of a flammability diagram. The theory illustrates, quantitatively, the effect of both the flame inhibiting properties of the vapour of the non-flammable component and the relative volatility of that component. Experimental results for some mixtures of carbon tetrachloride and dichlorodifluoromethane with *n*-hexane, *n*-heptane and *n*-octane are correlated by the theory. The theory also enables a flammability diagram to be partially constructed from standards flashpoint mea-

surements. Such measurements for the *n*-hexane carbon tetrachloride system are in good agreement with a published flammability diagram.

Vilynnov, V. N., Nekkasov, E. A., Baushev, V. S., and Timokhin, A. M. (Applied Mathematics and Mechanics Research Institute, Tomsk State University, USSR) "Characteristics of Spark Ignition and Transition to Steady State Combustion Conditions," *Fizika Goreniya i Vzryva 12* (3) 361-266 (1976) (in Russian)

Subjects: Spark ignition; Combustion, steady state

Abstracted by L. Holtschlag

A numerical method is used to study spark ignition and the transition of combustion to steady state conditions for a broad range of physical and chemical parameters. A system of equations is derived to describe the spark ignition phenomenon. Simulation by a Dirac function of the energy released by the spark is possible only if the time of development of the discharge is much less than the ignition time. The system of equations is solved to find the critical energy (of extinction or ignition), the temperature behavior, and conversion near the ignition limit. Flame propagation is considered to be established when the difference between two consecutive rate values does not exceed a specified value, taken here to be 0.001. A characteristic indicator of ignition is the behavior of the temperature at the point of heat liberation, as it tends toward the adiabatic flame temperature.

C. Detection of Fires

Golovin, V. I. "Computerising Fire Detection and Extinguishing Systems," *Lesnoe Kozyaistvo 4* 70-72 (1973)

Subjects: Analysis of fire protection systems; Forest fire protection, USSR; Fire protection systems in forests

Safety in Mines Abstracts 25 No. 1233
Safety in Mines Research Establishment

Describes calculation procedures carried out on the computer "Minsk 22" to determine optional fire detection and extinguishing systems in USSR forests.

Hertzberg, M. and Litton, C. D. "Multipoint Detection of Products of Combustion with Tube Bundles; Transit Times, Transmissions of Submicrometer Particulates and General Applicability," *U.S. Bureau of Mines Report Investigation 8171* (1976)

Subjects: Combustion products; Detection of combustion products

Safety in Mines Abstracts 25 No. 1350
Safety in Mines Research Establishment

This Bureau of Mines study concerns the use of the tube bundle method as a sensitive and reliable detector of mine fires. The method involves the pneumatic, sequential sampling of many points in a system through branching tube bundles that lead to a single analytic station of high sensitivity, good reliability, and convenient location. Two serious limitations inhibit its use: the relatively slow response times for long lengths of narrow sampling tubes and the wall-diffusion losses for submicrometer smoke particulates. These limitations were quantitatively evaluated by measuring tube transit times and smoke particulate transmissions as a function of tube length, diameter, and pressure drop.

Hill, R. G. (National Aviation Facilities Experimental Center, Atlantic City, New Jersey) "Flight Test of a Self-Generating Overheat Detection System," *Final Report AFAPL-TR-76-1, October 1972 to September 1975,* Contract No. F33615-75-M-6251, Air Force Aero Propulsion Laboratory (January 1976)

Subjects: Fire warning; Aircraft fires; Overheat detection system

Author's Abstract

Flight tests were conducted on two self-generating overheat detection systems installed in the number two nacelle of a Federal Aviation Administration (FAA) Convair CV880. The systems were mounted inboard and outboard in the nacelle paralleling the existing aircraft system. The outboard system logged 722.2 flight hours with no problems reported. The inboard system logged 615.0 flight hours. Shortly after the inboard system was installed, overheat warnings were obtained when the thrust reversers were used. The problem was found in the control box which caused the system to alarm at a lower temperature than was set. The inboard system then operated flawlessly for 585.9 flight hours until another problem in the control box caused the system to cease operating completely. No false alarms were noted, at any time, from electrical noise. It is concluded that the self-generating system tested is an airworthy system which should decrease the false fire warning rate in engine nacelles.

Schnell, M. "Points of View in Testing Flame Detectors," *Verband der Sachversicherer e.V.,* Cologne, 17 pp (1976)

Subjects: Flame detectors; Testing flame detectors

Safety in Mines Abstracts 25 No. 1234
Safety in Mines Research Establishment

The general principles for type testing the fire detectors which are already in use in the assessment of heat and smoke detectors are summarized. These include the so-called basic tests and the trial tests. The trial tests were intended to include all test fires in order to ensure comparability of tested fire detectors. Additional test fires are proposed which are intended to permit differentiated comparison of flame detectors between one another. The main problem in assessing the performance of flame detectors during environmental influences is the selection of a suitable radiation source for reproducibly simulating the characteristic "flame." The requirements that this radiation source must fulfill are dealt with and various realizations involved are discussed. The practical testing of infrared flame detectors to the basic tests is described. In addition, a suggested test apparatus for ultraviolet flame detectors is dealt with.

Wagner, J. P., Fookson, A., and May, M. (Gillette Research Institute, Rockville, Maryland) "Performance Characteristics of Semiconductor Sensors Under Pyrolytic, Flaming, and Smoldering Conditions," *Journal of Fire and Flammability 7* 72-103 (January 1976) See Section N.

D. Propagation of Fires

Alger, R. S., Wiersma, S. J., McKee, R. G., Johnson, W. H., Laughridge, F. I., and Wiltshire, L. L. (Naval Surface Weapons Center, White Oak, Maryland) "Ship Fire Characteristics, Part 1. Sealed Compartments," *Naval Surface Weapons Center Report NSWC/WOL/TR 76-125* (November 1976)

Subjects: Ship fires; Fires in ships

Authors' Abstract

To optimize weight and cost of fire protection for aluminum ships, it is essential to know the characteristics of the fire threat. Fire behavior is a function of the fuel and environment, particularly of ventilation; therefore, fire characteristics are studied as a function of typical conditions aboard Navy ships. This report covers the first part of a series of experiments dealing with various ventilation conditions. Fire characteristics such as burning rate, fuel consumed, temporal and spatial heating patterns, and the O_2, CO_2, and CO concentrations at extinguishment were measured. With all class A and B fuels examined, flaming combustion stopped at oxygen concentrations of 10 to 15%. Factors such as pool size, compartment volume, and fire location had as much effect on the oxygen concentration for self-extinguishment as the oxygen index. Because fuel consumed has been proportional to available oxygen, the heat released and the thermal hazard can be estimated from compartment volume. Sealed compartments offer a simple, light weight form of passive fire protection. The concept of spaces too small to flashover is explored with a simple model. This approach to passive fire protection is applied to the PHM-1 and to components suitable for general use.

Delichatsios, M. A. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Fire Growth Rate in Wood Cribs," *Combustion and Flame 27* 267-278 (1976)

Subjects: Wood crib fires; Fire growth in wood cribs

Author's Abstract

The burning history of a wood crib ignited at the center of its base has been investigated theoretically and experimentally. A simple energy-balance model has proven successful in predicting the radial fire-spread rates and mass burning rates for varying crib geometries with accuracies of $\pm$ 10%. Exceptions to the validity of the model were only noted for very densely packed cribs for which significant lateral spread occurred simultaneously with vertical fire spread. Cribs consisting of sticks with thicknesses of 0.635 cm, 1.905 cm and 3.17 cm were burned in the present experiments. Analysis of pressure modeling experiments has also shown that pressure modeling cannot, in general, model the fire growth rates in wood cribs.

Harmathy, T. A. (National Research Council of Canada, Ottawa) "Fire Resistance Versus Flame Spread Resistance," *Fire Technology 12* (4) 290 (November 1976)

Subjects: Fire resistance; Flame spread resistance

Author's Conclusions

What is usually referred to as the "fire resistance" of compartment boundaries is, in effect, a measure of their ability to prevent the spread of fire by some mechanisms implied by the standard test procedure. In reality, fires spread by different mechanisms and, therefore, compartment boundaries may become exposed to fire on both sides. The results of standard fire tests are not applicable to such situations. The performance of a simple but common structural element of a building has been analyzed under conditions corresponding to two realistic fires. It has been concluded that conventional concrete-steel structures are likely to function satisfactorily in a spreading fire, provided that the "control parameter" characterizing the nature of the fire is higher than a critical value.

Hirano, T., Suzuki, T., and Mashiko, I. (Ibaraki University, Ibaraki, Japan) **and Iwai, K.** (Hitachi Ltd., Ibaraki, Japan) "Flame Propagation Through Mixtures with Concentration Gradient," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1307 (1976)

Subjects: Flame propagation; Concentration gradients

Authors' Abstract

The effect of the concentration gradient on the characteristics of flame propaga-

tion when the direction of flame propagation is normal to that of the concentration gradient was studied. The velocity of flame propagation through a mixture with a known concentration distribution established over methanol or ethanol was measured by using high-speed schlieren photography. The concentration distributions in the combustion chamber were predicted theoretically and confirmed using gas chromatography.

The shape of a propagating flame appeared to depend on the concentration distribution before ignition. The leading flame front usually propagated through a layer where the mixture composition before ignition was closer to that for the maximum flame velocity in a homogeneous mixture. The propagation velocity of the leading flame front was found to decrease as the difference between the mixture composition of the layer along which the leading flame front propagated and the composition for maximum flame velocity in a homogeneous mixture increased, or as the absolute value of the concentration gradient at the layer increased. The experimental results indicate that the product of the height of the combustion chamber and the absolute value of the concentration gradient is an important parameter for characterizing flame propagation through a mixture with concentration gradient. The propagation velocity of the leading flame front decreased as the value of this parameter increased.

Hirano, T. and Tazawa, K. (Ibaraki University, Ibaraki, Japan) "Effect of Thickness on Downward Flame Spread over Paper, *Bulletin of the Japanese Association of Fire Science and Engineering 26* (1) 7 (1976) (in Japanese)

Subjects: Flame spread; Paper flame spread

Authors' Abstract

An experimental study has been conducted to explore the effect of thickness on downward flame spread over thin solid-fuel sheets in an upward air stream. Flame spread rates over paper of four different thicknesses at various air-stream velocities were measured, and the gas velocity and temperature profiles in the vicinity of spreading flames were examined using particle tracer techniques and fine-wire thermocouples. It was confirmed that the spread rate of a stably spreading flame decreased with the increase of the thickness. The gas velocity profile in the vicinity of the leading edge of the preheat zone and the gas temperature profile in the preheat zone were almost independent of the paper thickness. In the case of stable flame spread, the mass burning rate decreased with the increase of the air-stream velocity and increased with the increase of the thickness. The increase of the mass burning rate with the paper thickness was confirmed to be partly due to the heat transfer to the unburned material through solid phase, and mainly due to the existence of the solid-phase temperature difference in the direction normal to the paper surface.

Kaptein, M. and Hermance, C. E. (University of Waterloo, Ontario, Canada) "Horizontal Propagation of Laminar Flames Through Vertically Diffusing

Mixtures Above a Ground Plate," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1295 (1976)

Subjects: Flame propagation; Laminar flame; Diffusion flames

Authors' Abstract

This investigation concerned the propagation of laminar flame fronts through combustible fuel/air mixing layers above a permeable ground plane. The combustible layers were established by upward diffusion of vapors from a liquid fuel which saturated the permeable ground but did not wet the ground/air interface. The experiments were carried out using an open trough approximately 240 cm long, 8 cm wide, and 25 cm deep with a smooth ground plane constructed of 100 micrometer glass beads. Ignition, by hot wire, was at one end of the trough, approximately at the stoichiometric mixture level. The fuels were benzene, hexane, heptane, and methyl alcohol. Flame front propagation speeds were determined cinematographically. Total pressure variations prior to, and through the front were measured by a microphone, and the fuel concentration variation above the ground plane were determined by an IR optical scanning system.

Propagation velocities of some two to four m/sec were observed, depending upon fuel type and thickness of the combustible zone; no precursor blast waves or detonations were observed. The pressure variations through the propagating flame front were found to have the same magnitude as those of a normal laminar flame. A steady state, quasi-one-dimensional flow theory is presented. Predicted values of propagation velocities were in good agreement with experimental values as a function of fuel type and thickness of the combustible region of the mixing layer.

Nash, P. and Theobald, C. R. (Building Research Establishment, Borehamwood, Herts., England) "The Use of Automatic Sprinklers as Fire Sensors in Chemical Plants," *Building Research Establishment Current Paper 50/76,* Fire Research Station (1976)

Subjects: Sprinklers, automatic; Heat response of sprinklers; Chemical plant sprinklers as detectors; Fire detection by sprinklers

Authors' Summary

This paper compares the response of sprinklers to convected heat, and to radiant heating as in a chemical plant.

Norum, R. A. (National Forest Fire Laboratory, Missoula, Montana) "Fire Intensity-Fuel Reduction Relationships Associated with Understory Burning in Larch/Douglas Fir Stands," Proceedings of the Tall Timbers Fire Ecology Conference and Fire and Land Management Symposium No. 14 559-572, Tall Timbers Research Station, Tallahassee, Florida (1976) U.S. Government Printing Office 1977-0-777-023-28

Subjects: Forest fire; Fire intensity fuel relation

Author's Conclusions

Given correct preburn measurements and using proper ignition techniques, it is possible to achieve desired objectives through the use of carefully prescribed fire in standing Douglas-fir and western larch. Otherwise, the stand can be severely damaged. This research was designed to sample a wide range of burning conditions; seemingly that was accomplished. Fuel consumption ranged from zero to near complete, yet complete control of the fires was retained. However, as fuel consumption increases, so does damage to the stand in the form of cambium death and crown scorch.

Nevertheless, reasonable trade offs are possible. Several fires were conducted that consumed as much as 80 percent of the fuel, burning 25 to 35 tons per acre of down dead woody material and killing no more than 10 percent of the trees larger than 5 inches d.b.h. Five fires killed no trees of this size, which shows that significant fuel reduction can be accomplished without undue damage to trees. Estimates of fuel consumption, fire intensity, crown-scorch height, degree of cambium damage and duff depth reduction, and other important fire results can be made from preburn measurement of fuels, burning conditions, and tree characteristics. An acceptable set of tradeoffs in desired objectives will have to be based on such estimates, and the fires conducted accordingly.

Orloff, L., Modak, A. T., and Alpert, R. L. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Burning of Large Scale Vertical Surfaces," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1345 (1976)

Subjects: Vertical surface burning; Burning of vertical surfaces.

Authors' Abstract

Measured burning rates per unit area in a large-scale vertical polymethyl methacrylate (PMMA) wall fire experiment are found to increase nearly linearly with height along the 3.56-m high slab. The radiative heat feedback from the flames to the fuel surface is derived from radiance measurements using a gray flame analysis. Radiative heat transfer accounts for 75 to 87 percent of the total heat feedback to the burning surface. Results for thin and gray flame models are compared, with fuel scale and flame absorption coefficient as parameters. The asymptotic burning rate, where the flame emissivity is unity, may be as high as 123 g/m^{2}s, on the basis of an effective flame radiation temperature of 1367 K for PMMA. Computed PMMA flame transmittance versus radiance characteristics in the radiance range 0 to 1.5 W/cm^{2}sr are shown to be similar to that of turbulent ethane and propane flames.

Pagni, P. J. and Shih, T. M. (University of California, Berkeley, California) "Excess Pyrolyzate," Sixteenth Symposium (International on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1329 (1976)

Subjects: Excess pyrolyzate; Pyrolyzate, excess

Authors' Abstract

The use of synthetic polymers in home furnishings can result in rapid fire spread throughout a structure. This appears to be caused by the generation at the fire origin of excess pyrolyzate, i.e., combustible gases which are not consumed in the flame which produced them. The amount of excess pyrolyzate is predicted quantitatively as a function of the material mass transfer number, B, and mass consumption number, r, and the ambient fluid mechanics for both free standing and flush mounted fuel slabs. Detailed temperature, velocity and mass fraction fields are obtained numerically from Shvab-Zeldovich analyses. Excess pyrolyzate is then found as a fraction of the total pyrolyzate by the simple species between the fuel surface and the flame. Flame heights for both forced and free flow are also predicted using integral analyses to describe combustion downstream of the fuel slab. Results obtained for ten common polymers are in agreement with observations that some synthetic polymers produce significantly more excess pyrolyzate than natural polymers. Applications to compartment fire tests and tunnel tests are discussed.

Schacke, H., Hunter, L. W., Fristrom, R. M., and Grunfelder, C. (Applied Physics Laboratory, The Johns Hopkins University, Laurel, Maryland) "Combustion of Poly(vinyl chloride) Studied by the Moving Wire Technique," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1317 (1976)

Subjects: Poly(vinyl chloride); Combustion of poly(vinyl chloride); Moving wire technique

Authors' Abstract

This paper is a demonstration of the utility of the Moving Wire Technique (MWT) for studying polymer pyrolysis, ignition and burning. The polymer is coated on a support wire and transported at a uniform and controlled speed through a heat or ignition source flame. An advantage of the MWT is that residence time, as seen by an observer moving with the wire, is resolved spatially in laboratory coordinates (residence time is the ratio of distance to wire speed). This allows greater precision in measurements of composition and temperature profiles and makes it easy to obtain samples of the solid phase.

In this study, we compared reagent and commercial grade poly(vinyl chloride) (PVC). Our heat source was the wake of a flat CH_4—O_2—N_2 flame. Excess O_2 for polymer combustion was a part of the flame gases in some experiments but was confined to an adjoining flowing "atmosphere" in others. Ignition in an O_2-rich

source flame required a minimum of about 20% excess O^2. Above this value, the O_2-level had no effect on the critical surface temperatures at ignition, which were $295 \pm 5°C$ for the pure PVC and $370 \pm 10°C$ for two different brands of commercial PVC. Earlier studies with the MWT indicated that critical ignition temperatures appear to be independent of the diameter and heat capacity of the support wire, and the thickness of the polymer coating. Ignition occurred at the first appearance of flammable gas, identified as principally benzene in pyrolysis experiments. Reagent PVC emitted HCl prior to ignition but the commercial PVC did not. Quenched samples of the solid phase were collected for analysis; the quenching was accomplished by rapid cooling with cold He. A long-lived free radical was detected in the burned PVC, which was charred.

Silcock, A. and Tucker, D. M. (Building Research Establishment, Borehamwood, Herts., England) "Fires in Schools: An Investigation of Actual Fire Development and Building Performance," *Building Research Establishment Current Paper 4/76* Fire Research Station (1976) See Section A.

Ubhayakar, S. K. (Avco Everett Research Laboratory, Inc. Everett, Massachusetts) "Burning Characteristics of a Spherical Particle Reacting with Ambient Oxidizing Gas at its Surface," *Combustion and Flame 26* 23-34 (1976)

Subjects: Particles; Extinction; Carbon particles

Author's Abstract

An analytical model is presented to describe the quasi-steady burning and spontaneous extinction of a spherical particle in a quiescent oxidizing gas. In the special case of an exothermic Arrhenius first-order reaction of the oxidant with the surface of the particle, the model yields burning and extinction domains in terms of four dimensionless numbers. For a high activation energy of this reaction an approximation to the heat release rate is made, and this results in a transcendental algebraic equation having the four dimensionless numbers as the parameters. The analytical results are illustrated by choosing the burning of a carbon particle as an example.

E. Suppression of Fires

Brzustowski, T. A., Kaptein, M., and Sullivan, H. F. "The Action of Subsurface Foam in Extinguishing Oil Tank Fires," *Archwm. Termodyn. Spal. 7* (2) 165-174 (1976)

Subjects: Foam extinguishment in oil tanks; Oil tank fires, extinguishment; Extinguishment by foam of oil fires

Safety in Mines Abstracts 25 No. 1235
Safety in Mines Research Establishment

The results of laboratory experiments have been used as the basis for an analysis which predicts the conditions under which foam injection under the liquid surface can extinguish oil burning in a storage tank.

Burford, R. R. "The Use of AFFF in Sprinkler Systems," *Fire Technology 12* (1) 5-17 (February 1976)

Subjects: Aqueous film-forming foam; Automatic sprinklers; Sprinkler systems, foam; Fire tests; Spill fires

Author's Abstract

The Factory Mutual Research Corporation contracted with 3 M to conduct a test program aimed at determining the effectiveness of aqueous film forming foam used in conjunction with a wet-pipe sprinkler system equipped with standard water sprinkler. The results indicate that closed wet-pipe sprinkler systems using AFFF can control flammable liquid spill fires as effectively as, faster than, and using less water and AFFF concentrate than, deluge systems. Densities as low as 0.11 g/min/ft^2 (4.48 l/min/m^2) provide effective control. Tests indicate that, at this discharge density, air temperature does not become high enough to damage structural members.

Corrie, J. G. (Building Research Establishment, Borehamwood, Herts., England) "Experimental Methods for the Study of Fire-Fighting Foams," *Building Research Establishment Current Paper 74/76,* Fire Research Station (1976)

Subjects: Firefighting foams; Foam extinction, liquid fires; Experimental evaluation of foams

Author's Abstract

This paper describes studies on the use of foam in the extinction of flammable liquid fires, and experimental techniques which can be used to evaluate its performance. These include four methods for producing foam in the laboratory, and methods for measuring the expansion, drainage rate and shear stress of the foam produced. Areas in which further knowledge of foam performance are required are suggested, and 24 references are given.

Corrie, J. G. (Joint Fire Research Organization, Borehamwood, Herts., England) "Measuring the Shear Stress of Fire-Fighting Foams," *Fire Research Note No. 1055,* Joint Fire Research Organization (August 1976)

Subjects: Firefighting foam; Shear stress of foams

Author's Summary

Experiments to define the characteristics of torsional vane viscometers when used for measuring the shear stress of foam are described, so that replacement instruments can incorporate improved features. It is shown that shear stress determined by this method is ot a fundamental property of the foam but depends upon the instrument dimensions and the method of operation as well as upon the characteristics of the foam. The significant dimensions and operational procedures are identified, and recommendations are made for their adoption.

Note: For the convenience of those who wish to construct and use a foam viscometer a companion *Fire Research Note No. 1059* provides constructional details and a recommended standard procedure for its use.

Corrie, J. C. (Joint Fire Research Organization, Borehamwood, Herts., England) "The Effect of Foam Liquid Concentrates on Fire Performance on Laboratory Fires," *Fire Research Note No. 1047*, Joint Fire Research Organization (January 1976) See Section A.

Dixon-Lewis, G. and Simpson, R. J. (The University, Leeds, England) "Aspects of Flame Inhibition by Halogen Compounds," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1111 (1976)

Subjects: Flame inhibition; Halogen compound inhibition; Inhibition by halogen compounds

Authors' Abstract

The effects of both hydrogen bromide and hydrogen chloride on the rich flammability limit of hydrogen-air mixtures at atmospheric pressure have been measured. HBr was considerably more efficient than HCl in reducing the flammability range.

Computation of the properties of the HBr inhibited limit flame having the initial composition: $X_{HBr} = 0.0400$, $X_{H2} = 0.5760$, $X_{N2} = 0.3034$ and $X_{O2} = 0.0806$, was carried out using an inhibition mechanism and rate coefficients previously proposed by Day, Stamp, Thompson, and Dixon-Lewis.[5] The results showed that the proposed mechanism was adequate for explaining the observed contraction of the flammability range. In particular, the reaction:

$$H + HBr \rightleftharpoons H_2 + Br \qquad \text{(xxiii)}$$

was effectively equilibrated over virtually the whole of the reaction zone, and the bromine atoms contributed to chain termination. A similar calculation on an HCl inhibited flame showed that the reduced inhibition by HCl was largely connected with the difference in thermodynamic properties between reaction (xxiii) and its chlorine analogue.

The properties of the HBr inhibited flame are also compared with those of an uninhibited H_2-air flame having the same stoichiometric ratio.

Elliott, D. E. and Chiesa, P. J., Jr. "A New Foam Rheometer for Studying Firefighting Foams," *Fire Technology 12* (1) 66-69 (February 1976)

Subjects: Firefighting foams; Rheology; Viscosity; Flow characteristics

Authors' Abstract

The rheology of a foam defines its flow properties. Flow properties of a foam have been characterized by measuring its viscosity, continuous stress, and critical shear stress. The methods used, however, measure sheer stress only at specific times during the lifetime of a foam, require extreme care in calibration, require the operator read a moving pointer, are cumbersome to use, and produce no permanent record of the results. This paper describes a newly developed instrument that overcomes these problems.

Elliott, D. E. and Chiesa, P. J. "Rheological Properties of Fire Fighting Foams," *Fire Technology 12* (2) 141-150 (1976)

Subjects: Firefighting foams; Protein foams; Fluoroprotein foam

Journal Abstract

Foam rheology, which measures the flow characteristics and stiffness of foams, was studied by a newly developed method. The yield stress point of various foams was determined to characterize the fluidity of the foams under investigation. Protein foams had higher yield stress points than AFF foams, while the fluoroprotein stress points were intermediate. Foam expansion did not influence yield stress values of protein foams, but there was a slight correlation for the AFF foams. The equipment used had a significant effect on the quality and yield stress values of the foam produced. No simple correlation was found to exist between foam yield stress points and fire performance.

Fay, J. A. and Lewis, D. H., Jr. (Massachusetts Institute of Technology, Cambridge, Massachusetts) "Unsteady Burning of Unconfined Fuel Vapor Clouds," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1397 (1976) See Section G.

George, C. W., Blakely, A. D., and Johnson, G. M. (Intermountain Forest and Range Experiment Station, Ogden, Utah) "Forest Fire Retardant Research: A Status Report," *U.S.D.A. Forest Service General Technical Report INT-31* (1976) See Section A.

Golovin, V. I. "Computerising Fire Detection and Extinguishing Systems," *Lesnoe Kozyaistvo 4* 70-72 (1973) See Section C.

"Guide to Fabric Flammability" U.S. Consumer Product Safety Commission, Washington, D.C. (Revised June 1976) U.S. Government Printing Office 625-067 (1976)

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Hayashi, T., Shibata, M., Yamaguchi, H., Sakurai, H., and Kanehara, K. "Research on Air Shutter for Fire Protection (2)," *Bulletin of the Japanese Association of Fire Science and Engineering 26* (1) 15 (1976) (in Japanese) See Section A.

Kaskan, W. E. and Reuther, J. J. (State University of New York at Binghamton, New York) "Limiting Equivalence Ratio, Dissociation, and Self-inhibition in Premixed, Quenched, Fuel Rich Hydrocarbon Air Flames," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1083 (1976)

Subjects: Hydrocarbon flames; Equivalence ratio; Dissociation; Self-inhibition; Flames, premixed hydrocarbon air

Authors' Abstract

Radical overshoots have been used to provide a measure of the overall efficiency of dissociation processes in fuel-rich hydrocarbon/air flames. The actual number of dissociations per fuel molecule, N_D/N^o_{HC}, determined at a limiting equivalence ratio, Φ_L, has been determined as a function of pressure.
Net dissociation efficiency (dissociation minus recombinations) was found to be a function of equivalence ratio. Although Φ_L has been proven to represent the fuel-rich composition at which unreacted hydrocarbon fuel firsts persists in a methane flame, no evidence can be provided to show this behavior for the other fuels. For propane/air flames, radical overshoots exist at $\Phi < \Phi_L$, radical equilibrium exists at $\Phi = \Phi_L$, and radical undershoots exist at $\Phi > \Phi_L$. The existence of unreacted fuel and radical undershoots may aid in unburned hydrocarbon pollution control and in elucidation of the mechanism for carbon formation.

It has been demonstrated that hydrocarbon fuels can inhibit their own combustion with the following order of effectiveness: $C_3H_8 > C_2H_6 > C_2H_4 > CH_4$. This trend for self-inhibition is rationalized in terms of the ability of the hydrocarbon to enhance rates of radical recombination. Reduced pressure decreases self-inhibitor effectiveness.

Kisilyakhov, E. K. and Konev, E. V. (Forest and Wood Institutes, Siberian Section, Academy of Sciences USSR, Krasnoyarkh) "Evaluation of Fire Extinguishing and Fire Retarding Efficiency of Chemical Agents," *Fizika Goreniya Vzryva 12* (6) 497-502 (1976) (in Russian) See Section A.

Maneval, D. "Assessment of Latest Technology in Coal Refuse Pile Fire Extinguishment," 1976 Coal Show of the American Mining Congress, Detroit, 10-13 May, Washington American Mining Congress (1976)

Subjects: Coal refuse pile fires; Fire extinguishment of coal refuse piles; Extinguishment of fires in coal refuse piles

Safety in Mines Abstracts 25 No. 1353
Safety in Mines Research Establishment

The disposal of banks of highly carbonaceous waste from all types of coal processes presents health hazards and economic problems. The tippler form of pile construction causes most difficulty as the steep faces and loose nature of the material make sealing nearly impossible and fire control difficult. Random coal waste piling can readily lead to a potentially dangerous situation, embers may smoulder and emit obnoxious gases or there is the possibility of spontaneous combustion. Spontaneous combustion is affected by several factors: temperature, coal rank, presence of pyrite, moisture, voids ratio, and specific surface. Prevention lies in the design and engineering of coal refuse sites. Major factors are: site selection and preparation, geometry of refuse material, disposal practices, particle size for refuse, maintenance of refuse pile, and control of refuse force. Methods of fire extinguishment are detailed; digging, trenching, blanketing, injection, and water. Safety precautions are listed. Extinguishment projects must be technically feasible and economically viable.

Morikawa, T. "An Improved Sodium Carbonate Based Extinguishant for Sodium Fires," *Fire Technology 12* (2) 124-132 (1976)

Subjects: Sodium fires; Extinguishant for sodium fires; Sodium carbonate extinguishant

Journal Abstract

Sodium carbonate was found to be a most suitable material for use as a noncorrosive, sodium fire extinguishant except for its tendency to become wet and sink in molten sodium. A mixture of 90% sodium carbonate, 6% polyarcylonitrile, and 4% magnesium stearate was found to be a satisfactory extinguishant. Under the test conditions, the sodium was maintained at 550° C for 30 minutes with an extingushant thickness of only 1.5 cm. The burning characteristics of sodium are not as dependent on the depth of the extinguishant as is the case with oil fires.

Nash, P. (Building Research Establishment, Borehamwood, Herts., England) "Portable and Installed Fire-Fighting Equipment in Buildings," *Building Research Establishment Current Paper 3/77,* Fire Research Station (1977) See Section A.

Nash, P. (Building Research Establishment, Borehamwood, Herts., England) "Sprinkler and Spray Systems for Maritime Use," *Building Research Establishment Current Paper 1/77,* Fire Research Station (1977)

Subjects: Sprinkler systems; Spray systems; Fire extinguishing systems; Maritime extinguishing systems

Author's Abstract

This paper gives an account of the international regulations and requirements governing the use of automatic sprinklers and water spray systems in ships, and describes some typical marine installations. It also gives an account of the testing procedures for sprinklers and spray systems, pumps and water supplies. Further detailed information may be obtained from the comprehensive list of references.

Nash, P. (Building Research Establishment, Borehamwood, Herts., England) "The Essentials of Sprinkler and Other Water Spray Fire Protection Systems," *Fire Prevention No. 108,* 15-26 (1975) See Section A.

Nash, P. (Building Research Establishment, Borehamwood, Herts., England) "The Extinction of Aircraft Crash Fires," *Building Research Establishment Current Paper 53/76,* Fire Research Station (1976)

Subjects: Aircraft fires; Extinction of aircraft crash fires; Fires from aircraft crash

Author's Summary

This paper discusses one of the most severe fire situations, the aircraft crash fire, its problems and the development of extinguishing agents.

Nash, P. and Theobald, C. R. (Building Research Establishment, Borehamwood, Herts., England) "The Use of Automatic Sprinklers as Fire Sensors in Chemical Plant," *Building Research Establishment Current Paper 50/76,* Fire Research Station (1976) See Section D.

Nash, P. and Young, R. A. (Building Research Establishment, Borehamwood, Herts., England) "Sprinkler Systems for Special Risks," *Building Research Establishment Current Paper 52/76,* Fire Research Station (1976) See Section A.

Nash, P. and Young, R. A. (Building Research Establishment, Borehamwood, Herts., England) "The Performance of the Sprinkler in Detecting Fire," *Building Research Establishment Current Paper 29-75*, Fire Research Station (1975) See Section A.

Rodgers, S. P. (Joint Fire Research Organization, Borehamwood, Herts., England) "Preliminary Experiments on the Sprinkler Protection of Carpets in Storage," *Fire Research Note No. 1061*, Joint Fire Research Organization (November 1976) See Section A.

Schacke, H., Hunter, L. W., Fristrom, R. M., and Grunfelder, C. (Applied Physics Laboratory, The Johns Hopkins University) "Combustion of Poly(vinyl chloride) Studied by the Moving Wire Technique," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1317 (1976) See Section D.

Skinner, G. A., Parker, L. E. and Marshall, P. J. (Kingston Polytech, Kingston, Surrey, England) "Flame Retardant Synergism Between Molybdenum and Halogen Containing Compounds in Unsaturated Polyesters," *Fire and Materials 1* (4) 154-159 (1976) See Section A.

Williamson, H. V. "Halon 1301 Flow in Pipelines," *Fire Technology 11* (4) 18-32 (November 1975)

Subjects: Halogenated extinguishing agents; Halon 1301; Fluid flow of extinguishing agents; Calculation of Halon flow

Author's Abstract

The complete manual calculation of pressure drops in the piping used in a Halon 1301 total flooding fire extinguishing system is not practical. The flow of nitrogen pressurized Halon 1301 is a two phase flow phenomenon involving a mixture of liquid and vapor in which the ratio of vapor to liquid increases as the pressure drops from the friction loss. With two phase flow, the rate of pressure drop increases as the fluid proceeds through the pipeline because the velocity of flow must increase as the volume of fluid expands. Since it is not practical to use a manual method for two phase calculations, a simplified linear approach or a complete calculation by computer is indicated.

Woolley, W. D. and Rodgers, S. P. (Joint Fire Research Organization, Borehamwood, Herts., England) "Performance of Asbestos Fire Blankets," *Fire Research Note No. 1057*, Joint Fire Research Organization (November 1976)

Subjects: Asbestos fire blankets; Fire tests of asbestos blankets

Authors' Summary

Fire tests involving liquid fuels (AVGAS and white spirit), frying oil, wood and clothing have been carried out to evaluate the effectiveness of three different sizes of asbestos blankets. With the AVGAS and white spirit the blankets were tested against fires of increasing size according to the CEN WG/70 Series. With frying oil the blankets were tested against burning oil, (1B, 2B, 3B, and 5B) with oil heated above the spontaneous ignition temperature. Wooden cribs were used for assessing the performance of the blankets against cellulosic type fires and burning cloth used to simulate a clothing fire. The work has shown that the AVGAS tests provide a simple and effective means of assessing the "rating" of the blankets but additional tests involving frying oil, wood and clothing are necessary to ensure that the blankets are suitable for general applications of this kind. The results should provide a useful means of assessing the performance of new types of blankets in comparison with the asbestos types.

Yamashika, S., Morikawa, T., and Kurimoto, H. (Fire Research Institute of Japan, Tokyo, Japan) "Effectiveness of Halon 2402 as Incipient Fire Suppressant for Floating Roof Petroleum Tank," Report of *the Fire Research Institute of Japan No. 40*, 30-34 (1975) (in Japanese) See Section A.

Zuber, K. "LNG Facilities - Engineered Fire Protection Systems," *Fire Technology 12* (1) 41-48 (February 1976)

Subjects: Extinguishment of LNG fires; LNG fires; Test fires LNG, extinguishment; Dry chemical extinguishment; High expansion foams

Author's Abstract

In various types of LNG processing, storage, and transfer facilities, consideration must be given vapor dispersion control, fire control, exposure control, and extinguishment. Tests conducted with LNG spill fires indicate that high expansion foam facilitates vapor dispersal by warming the vapors, making them more buoyant. High expansion foam was shown to be more efficient than water curtains and water sprays in reducing radiant heat flux reaching exposures. Dry chemicals were most effective in extinguishing test fires following the application of a controlling layer of high expansion foam. A foam expansion ratio of 500:1 seemed to be the most satisfactory. In designing automatic fixed dry chemical systems, care must be taken to prevent disturbing the surface of the LNG, which can result in increased burning rate. Manual application requires well-trained personnel and the proper deployment of equipment of suitable capacity to cope with the hazard.

F. Fire Damage and Salvage

Butlin, R. N. (Joint Fire Research Organization, Borehamwood, Herts., England) "Estimation of Maximum Explosion Pressure from Damage to Surrounding Buildings — Explosion at Mersey House, Bootle, August 28, 1975," *Fire Research Note No. 1054,* Joint Fire Research Organization (July 1976)

Subjects: Explosion pressure estimation; Mersey House explosion

An explosion in the ground floor flat of a 16-storey block caused severe damage to the flat, some other parts of the 16-storey block and resulted in the failure of many windows in surrounding prooperty. Calculations based on the decay of pressure with distance, and the dimensions and thickness of glazing broken in nearby buildings, indicate that the peak explosion pressure within the flat was between 46 and 81 kN/m^2 (6.5 and 11.5 lbf/in^2). These pressures are substantially greater than those that would be expected from measurements made from explosions in single, empty, compartments, and are also greater than that calculated from an equation making some allowance for turbulence, and indicate that a high degree of turbulence was generated by the complexity of the compartmentation and the contents of the flat. These findings emphasise the importance of tests to be carried out by the Fire Research Station in a complex array of compartments and corridors and the development of appropriate mathematical expressions for the relationship between vent area and explosion pressure for a given set of conditions.

Butlin, R. N. and Finch, C. P. (Joint Fire Research Organization, Borehamwood, Herts., England) "Gas Explosions in Buildings, Part V. The Measurement of Sound Levels and Pressures Outside a Vented Gas Explosion Chamber," *Fire Research Note No. 988,* Joint Fire Research Organization (May 1976)

Subjects: Gas explosions in buildings; Vented gas explosion chamber; Pressure measurement of gas explosion; Sound measurement of gas explosion

Authors' Summary

The methods of measuring the external pressure and sound levels resulting from vented gas explosions in experiments by the Fire Research Station at Cardington are described, together with the methods of calibration. Examples of the oscilloscope traces for sound and pressure are given.

Crosby, J. S. (North Central Forest Experiment Station, Saint Paul, Minnesota) "A Guide to the Apprisal of Wildfire Damages, Benefits, and Resource Values Protected," *U.S.D.A. Forest Service Research Paper NC-142* (1977)

Subjects: Forest fire damage; Forest fire benefits; Forest fire planning

Author's Abstract

A set of value concepts and methods for appraising both values-at-risk and changes in value resulting from wildfire are presented. Emphasis is placed on the effects of forest fires in terms of their affects on human and organizational goal achievement. Fire effects that help achieve goals are beneficial; those that hinder goal achievement are undesirable and create damage.

Guenther, D. A., McGarry, D. L., Shearer, R. P., and MacCleary, R. C. "Fire Analyses from Mechanical Properties," *Fire Technology 12*(3) 172 (1976) See Section 1.

Lathrop, J. K. "Two Die in High-Rise Senior Citizens Home, Albany, New York," *Fire Journal 69* (5) 60-62 (September 1975) See Section A.

Mainstone, R. J. (Building Research Establishment, Borehamwood, Herts., England) "The Response of Buildings to Accidental Explosions," *Building Research Establishment Current Paper 24-76*, Fire Research Station (1976)

Subjects: Explosion, response of buildings; Building responses to explosions

Author's Abstract

Nine instances of major accidental explosions are described. In each case something is said about the probable loading, and the major features of the structural response are then described. As background there are introductory sections on the character of explosions loadings and the type of response to be expected theoretically. The paper concludes with a listing of six generally valid lessons drawn from inspections of actual responses.

G. Combustion Engineering and Tests

Abbott, N. J. and Schulman, S. "Protection from Fire: Nonflammable Clothing — A Review," *Fire Technology 12* (3) 204 (1976) See Section A.

Bakhman, N. N., Kichin, Yu. S. (Institute of Chemical Physics, Academy of Sciences, Moscow, USSR) **Kolyasov, S. M., and Fogelzang, A. E.** (Mendeleev's Institute for Chemical Technology, Moscow, USSR) "Investigation of the Thermal Structure of the Burning Zone in Condensed Mixtures by Fine Thermocouples," *Combustion and Flame 26* 235-247 (1976)

Subjects: Flame structure; Temperature profiles; Combustion waves in solids; Condensed phase combustion

Authors' Abstract

Temperature profiles through combustion waves in mixtures of ammonium perchlorate (AP) with polymethylmethacrylate (PMM), paraform (PF), and sulphur were obtained by fine W5%Re-W20%Re thermocouples embedded in the strands. The surface temperature, T_g, increased with pressure, p (for $AP + PF$. $\alpha = 1$ mixture-from 460° C at $p = 0.3$ atm to 580° C at $p = 1$ atm) and there was a corresponding rise in the burning rate. In contrast, the addition of a catalyst (Cu_2O) had no effect on T_g despite a considerable (1.7-1.95 times) increase in the burning rate. The slopes of $\ln(T - T_o) = f(x)$ curves reveal a marked increase at $T = T_*$ (where T_* ranges from 200° C to 310° C), probably due to the phase change AP (orthorhombic) → AP (cubic). The departure of T_* from the well-known value 240° C may be ascribed to errors in the thermocouple measurements and to the gasification of PF at $T < T_*$ at low pressures. The profiles $T(x)$ and $\psi(x)$ (where $\psi = dT/dx$) were obtained theoretically from a solution of the heat flow equation for a medium with a phase change. An estimate was obtained for the value of ($\psi_{240°+dT} - \psi_{240°-dT}$) equal to 1.69×10^5 m deg C/cm for the preheat zone in pure AP (where m is mass burning rate). Two maxima of ψ were observed in the gas phase. The first appears when the thermocouple traverses the $NH_3 + HClO_4$ flame. The value $(\psi_{max})_1$ increased with pressure at $p \leqslant 1$ atm (for AP + PMM, $\alpha = 0.75$ mixture—from 2.1×10^5 deg C/cm at $p = 0.34$ atm to 4.9×10^5 deg C/cm at $p = 1$ atm). At $p = 1$ atm $(\psi_{max})_1$ decreased with increasing p, probably due to thermal inertia of the thermocouple. A simple relationship was obtained for the maximum thermal gradient recorded by a thermocouple. The heat balance at the burning surface is considered. For the mixture under investigation the heat production in the condensed phase at $p \leqslant 1$ atm was insignificant. The addition of Cu_2O increased the thermal gradient in the gas phase near the surface and the burning velocity by about the same extent.

Baranov, A. A., Buldakov, V. F., and Shelukhin, G. G. (Leningrad Mechanics Institute, Leningrad, USSR) "Effect of an Electric Field on the Burning Rate of Heterogeneous Condensed Systems," *Fizika Goreniya Vzryva 12* (5) 689-692 (1976) (in Russian)

Subjects: Burning rate, condensed systems; Electric field effect on Combustion; Combustion in electric fields

Abstracted by L. Holtschlag

A study is made of the effect of a longitudinal constant electric field on the burning rate of a heterogeneous condensed system at atmospheric pressure. With increasing field strength, the burning rate first decreases to 65-75% of the unperturbed value, and then increases, exceeding that value. After applictaion of the field, there is an oscillating transient return to the steady state value with a frequency of 1.5 Hz with a decrement of 0.11/sec. The electric field affects the structure and parameters in the combustion region.

Barron, S. "An Investigation of the Effects of High Temperatures Upon Various Industrial Polymers," *Journal of Fire and Flammability* 7 (3) 387-400 (July 1976)

Subjects: Industrial polymers, high temperature effects on; Polymers, high temperature effects on; High temperature effects on polymers

Safety in Mines Abstracts 25 No. 1220
Safety in Mines Research Establishment

The purpose of the paper is to present the results of a laboratory program performed to measure the outgassing or degradation characteristics of a number of industrial polymers when subjected to high temperatures. The results are not necessarily indicative of true service temperature.

Barry, T. J. and Newman, B. "Some Problems of Synthetic Polymers at Elevated Temperatures," *Fire Technology 12* (3) 186 (1976)

Subjects: Polymer flammability; Flammability of polymers

Journal Abstract

Development and standardization of reliable test methods are essential in the determination of synthetic polymer flammability. The test methods should be developed on an individual product and use basis, with the results presented so that they can be integrated for a safety analysis of mixed use potential. In spite of much research on the physiology of thermal stress, methods are not standardized and results are often difficult to reproduce. Little work has been done on the response to oxygen deficient atmospheres at elevated temperatures. The prospect for complete toxicity analysis by computer appears to be excellent.

Becker, H. A. and Yamazaki, S. (Queen's University, Kingston, Ontario, Canada) "Soot Concentration Field of Turbulent Propane — Air Diffusion Flames," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 681 (1976)

Subjects: Soot concentration; Propane-air flames; Turbulent flame; Diffusion flames

Authors' Abstract

A systematic study has been made of soot concentration in free turbulent propane/air diffusion flames. Sampling probes and a lightscatter technique were used; the latter also allowed detection of soot concentration fluctuations. The relative intensity of the fluctuations is very high, while the integral spatial scale is rather small. The behavior of the intensity is essentially as expected from the theory of scalar fluctuations given by one of us at the Fifteenth Symposium. The results as a whole suggest that the soot concentration field is mixing-controlled and the principal aerodynamic performance parameter is the Richardson ratio $Ri_L \equiv \pi / 4 \, g\rho_\infty$

L^3/G_0, where g is acceleration due to gravity, ρ_∞ is air density, L is flame length, and G_0 is the jet source momentum flux. The results span the transition between forced-convection and natural convection flames. Some results are also given on acetylene flames.

Benisek, L. and Phillips, W. A. "Variables in the NBS Smoke Chamber," *Journal of Fire and Flammability* 7 (3) 337-346 (July 1976)

Subjects: NBS smoke chamber; Smoke chamber, NBS

Safety in Mines Abstracts 25 No. 1215
Safety in Mines Research Establishment

Several commercial flame resistant wool fabrics and carpets, a Nomex carpet and a Cordelan fabric were evaluated by the NBS Smoke Chamber under smouldering, Flaming 1 conditions using a six jet inline burner and sample holder without a trough and Flaming 2 conditions-multi-directional burner and specimen holder with a trough. Best reproducibility was observed for smoldering conditions. Flaming 2 conditions gave in most cases significantly less reproducibile and higher smoke emission results than Flaming 1 conditions. Specimen weight loss under Flaming 1 conditions was higher than under Flaming 2 conditions indicating a higher heat flux for Flaming 1. This is connected with the design of the two burners. As heat flux can significantly influence smoke emission, materials should be evaluated under constant heat flux conditions, regardless whether they melt or not, and preferably under various heat fluxes, thus simulating real life conditions.

Benjamin, I. A. and Adams, C. H. "The Flooring Radiant Panel Test and Proposed Criteria," *Fire Journal 70* (2) 63 (1976)

Subjects: Radiant panel test; Flame spread; Fire tests; Hazard analysis

Fire Technololgy Abstract 76-33

The background and history of the Flooring Radiant Panel Test Method is covered from hazard analysis through full-scale tests and qualitative models, to the development of the test in its final form. For flooring in corridors and exitways, an average acceptance criterion of 0.25 watts per square centimeter for residential and commercial occupancies and an average acceptance criterion of 0.5 watts per square centimeter critical radiant flux for institutional occupancies are suggested. These values were derived from experience with floor coverings above and below these values and analysis of measured flux values in corridor experiments. These average values are subject to testing variance and should not be used without a rational sampling plan for testing.

Bilger, R. W. (University of Sydney, Australia) "Reaction Zone Thickness and Formation of Nitric Oxide in Turbulent Diffusion Flames," *Combustion and Flame 26* 115-123 (1976)

Subjects: Turbulent flame; Diffusion flames; Flame structure; NO; Reaction zone thickness

Author's Abstract

The Gibson-Libby formula for the thickness of the reacton zone in a diffusion controlled-reaction is revised to account properly for the concentration gradients that occur in fully turbulent flow. The result is that the reaction zone is thickened considerably. When used to calculate reaction zone thickness in turbulent diffusion flames these are now found to be of the same order as the Kolmogoroff length scale. The presence of a relatively diffuse reaction zone allows the oxygen atom concentration to be above equilibrium over a significant proportion of the flow. For a hydrogen-air flame, O atom concentrations can be calculated from the assumption of equilibrium for the fast radical exchange reactions, with the hydrogen and oxygen molecule concentrations computed from the Kolmogoroff concentration fluctuation scale. With these assumptions nitric oxide formation rates show the Reynolds number dependence and "rich shift" found by Kent and Bilger, and Bilger and Beck.

Biordi, J. C., Lazzara, C. P., and Papp, J. F. (U.S. Bureau of Mines, Pittsburgh, Pennsylvania) "Molecular Beam Mass Spectrometry Applied to Determining the Kinetics of Reactions in Flames II. A Critique of Rate Coefficient Determinations," *Combustion and Flame 26* 57-76 (1976)

Subjects: Molecular beam mass spectrometry; Kinetics; Flame structure; Rate constants

Authors' Abstract

The microstructure of low-pressure methane-oxygen-argon flames has been investigated using modulated molecular beam-mass spectrometry. Profiles of radical and stable species concentration, temperature, and area expansion ratio have been used to calculate rate coefficients as a function of temperature for certain elementary reactions occurring in flames, namely, $H + O_2 \rightarrow OH + O$, $H + CH_4 \rightarrow CH_3 + H_2$, $CO + OH \rightarrow CO_2 + H$, $CH_3 + O \rightarrow H_2CO + H$, and $H + CF_3Br \rightarrow HBr + CF_3$. The profiles have been modified (computationally) to simulate the effect of various perturbations and errors possible in sampling and analyses, and the effect on the rate coefficients is discussed. Detailed consideration is given to date reduction techniques, temperature profile-composition profile alignment, and the possible temperature dependence of mass spectral fragmentation. The rate coefficients are not dramatically sensitive to the imposed perturbations, although the results depend upon the nature of the reaction in question. Rate coefficients determined for high activation energy reactions and for reactions singularly responsible for the chemical behavior of a given stable species are in agreement with values determined by other techniques. Flame structure studies in which all significant radical and stable species are measured by a single technique are judged to be viable sources of high-temperature rate data for elementary reactions, where such reactions have been identified.

Biordi, J. C., Lazzara, C. P., and Papp, J. F. (U.S. Bureau of Mines, Pittsburgh, Pennsylvania) "An Examination of the Partial Equilibrium Hypothesis and Radical Recombination in 1/20 Atm Methane Flames," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1097 (1976)

Subjects: Methane flames; Radical recombination

Authors' Abstract

Slightly lean CH_4—O_2—Ar flames at 0.042 atm with and without small amounts of the inhibitor CH_3Br were probed using molecular beam-mass spectrometric techniques. All the principal radical and stable species concentration profiles and temperature profiles were measured in the primary and part of the secondary zone of these flames. Ratios of product concentrations to reactant concentrations were formed and compared with the equilibrium constant for the following reactions:

$$H + O_2 = OH + O \quad (1)$$

$$O + H_2 = OH + H \quad (2)$$

$$OH + H_2 = H_2O + H \quad (3)$$

$$OH + OH = H_2O + O \quad (4)$$

$$CO + OH = CO_2 + H \quad (5)$$

$$Br + HBr = Br_2 + H \quad (6)$$

$$H + HBr = H_2 + Br \quad (7)$$

in order to determine to what extent they may be considered balanced in various regions of the flame. Although, with the possible exception of reaction (4), none of these reactions are completely balanced until the maximum flame temperature is reached, the order in which the first five reactions become partially equilibrated is (4), (2) and (3), (5), (1). Once these reactions become equilibrated, their balance is maintained as the temperature and radical concentrations fall off in the secondary reaction zone. Reaction (7), in inhibited flames, is balanced at relatively low temperatures, comparable to (4); reaction (6) was found not to balance in either the secondary or primary reaction zones.

The radical decay in the secondary reaction zone is analyzed using the concept of pool decay. The important recombination reactions were judged to be $H + OH + M \rightarrow H_2O + M$ and $H + O_2 + M \rightarrow HO_2 + M$. Assuming equal rate coefficients and chaperon efficiencies for these three reactions, rate coefficients of 2×10^{16} cm^6 mole^{-2} sec^{-1} are calculated for M = the burnt gas mixture of Ar, H_2O, CO_2 and 5×10^{15} cm^6 mole^{-2} sec^{-1} for M = Ar, both for $T = 1750 \pm 150$ K.

Bradley, D. and Mitcheson, A. (University of Leeds, England) "Mathematical solutions for Explosions in Spherical Vessels," *Combustion and Flame 26* 201-217 (1976)

Subjects: Explosions; Flame theory

Authors' Abstract

Equations, assumptions, and previous solutions for central ignition of premixed gases in closed spherical vessels are reviewed. Three new categories of solution are presented: the Approximate Computer Solution (Case 1), the Dimensionless Universal Expression (Case 2), and the Complete Computer Solution (Case 3). Case 3 is the most accurate and shows the importance of accurate values of burning velocity as the unburnt gas is compressed in the course of the explosion. Recommendations are made concerning such values for methane-air mixtures. Case 2 solutions do not require a computer and they appear to be of good accuracy. During the explosions studied, dimensionless pressure, P_r, is proportional to dimensionless time, t, raised to the power 4.5.

Brenden, J. J. (U.S. Forest Products Laboratory, Madison, Wisconsin) "Wood-Base Building Materials: Rate of Heat Release," *Journal Fire and Flammability 6* 275-293 (July 1975)

Subjects: Heat release; Building materials; Wood

Author's Abstract

Rate of heat release data on several types of wood-base materials and constructions were determined under fire exposure in an FPL (Forest Products Laboratory) -developed, gas-fired, water-jacketed furnace. Materials evaluated include Douglas-fir plywood (untreated and fire retardant treated), high-density hardboard, red oak lumber, rigid insulation board, and particleboard. Among the constructions were a plywood-faced polyurethane foam sandwich panel and assemblies of both fire-retardant-treated and untreated Douglas-fir studs and gypsum wallboard facings. Fire-retardant treatment of wood greatly reduced the maximum rate of heat release. Rate of heat release for treated wood studs compared to untreated was reduced when both were protected with a gypsum wallboard facing.

Buckmaster, J. (University of Illinois, Urbana, Illinois) "The Quenching of Deflagration Waves," *Combustion and Flame 26* 151-162 (1976)

Subjects: Quenching; Deflagration waves

Author's Abstract

A simple model of a low Mach number deflagration wave is studied, with emphasis on the effects of a phenomenological heat loss term. It is shown by explicit construction that two quite different solutions, a fast wave and a slow wave, are possible in the adiabatic limit. In both cases the chemical reaction goes to completion and all the fuel is consumed, but for the fast wave the temperature increases from the ambient value to the usual adiabatic flame temperature, whereas the slow wave is isothermal. An analysis for finite heat loss is carried out in the realistic limit of infinite activation energy. In general this leads to a much simplified numerical problem, but for values of the flame speed of greatest physical interest an analytical description is possible. This predicts quenching when the heat loss is too great or the reaction rate too small, and yields simple explicit quenching criteria.

Budnick, E. K. and Klein, D. P. (National Bureau of Standards, Washington, D.C.) "Evaluation of the Fire Hazard in a Mobile Home Resulting from an Ignition on the Kitchen Range," *Interim Report NBSIR 75-788,* National Bureau of Standards for the Department of Housing and Urban Development (February 1976) See Section A.

Bulewicz, E. M. "Some Notes on the Oxygen Index and Inflammability Limits," *Archiwum Thermodynamiki i Spalania 7* (2) 175-190 (1976)

Subjects: Oxygen index; Inflammability limits

Author's Abstract

The oxygen index is a quantity which can be regarded as related, not as was thought previously, to the heat of combustion of the fuel, or the flame temperature, but at least for gases and volatile fuels, to the maximum burning velocity with air. The oxygen index for most solids which do not undergo an irreversible chemical change at temperatures above 200°C, decreases with increasing temperature in the same general manner and is a linear function of T^3 (°K).

Bullen, M. L. "A Comparison of Flashover Times in Small Scale Fires Using Test Data," *Fire and Materials 1* (2) 74-75 (June 1976)

Subjects: Fire tests, flashover times; Flashover in materials tests

Safety in Mines Abstracts 25 No. 1232
Safety in Mines Research Establishment

Reaction to fire standard tests on materials used as lining are not sufficient in themselves to predict the behavior of growing fires. However, flashover times with cellulosic linings have been correlated qualitatively with the British test, but generally there is wide divergence in the test results from different countries. This short paper discusses some aspects of this problem.

Bullen, M. L. (Joint Fire Research Organization, Borehamwood, Herts., England) "A Combined Overall and Surface Energy Balance for Fully Developed Ventilation Controlled Liquid Fuel Fires in Compartments," *Fire Research Note No. 1051,* Joint Fire Research Organization (June 1976)

Subjects: Liquid fuel fires; Energy balance of liquid fuel fires; Controlled liquid fuel fires in compartments

Author's Summary

As part of the research to extend the understanding of fully-developed wood fires to non-cellulosic fuels, the outline of a theoretical energy balance for a liquid fuel fire in a compartment is presented. A computer solution of the heat balance is described and the results of simulated fires are given to illustrate the uses of the model and the limitations of the assumptions made in the theory. The results show systematic departures from the well known assumption of the constancy of the ratio of burning rate to ventilation rate; this can account for some of the scatter commonly found in measurements of this ratio.

Butlin, R. N. (Joint Fire Research Organization, Borehamwood, Herts., England) "Production of Gas Layers for Large Scale Gas Explosion Studies Part 1. Preliminary Investigations," *Fire Research Note No. 1004,* Joint Fire Research Organization (April 1976)

Subjects: Gas explosion studies; Gas layers in explosion studies

Author's Summary

A series of experiments on the formation of roof layers of buoyant flammable gas, using mixtures of natural gas and air and also 100 percent natural gas, is described in which both vertical and horizontal distributions of gas concentrations were determined. Mixing of the introduced flammable gas with air in the explosion chamber was reduced by the adoption of appropriate input conditions. The distribution of gas in horizontal planes in all mixtures was found to be uniform but the vertical distribution of gas indicated the formation of diffuse layers, particularly when introducing 100 percent natural gas. The effects of filling rate and also the change of concentration with time in a quiescent layer are described.

Corrie, J. G. (Building Research Establishment, Borehamwood, Herts., England) "Experimental Methods for the Study of Fire-Fighting Foams," *Building Research Establishment Current Paper 74/74,* Fire Research Station (1976) See Section E.

D'Alessio, A., Di Lorenzo, A., Borghese, A., Beretta, F., and Masi, S. (Universita P., Napoli, Italy) "Study of the Soot Nucleation Zone of Rich Methane-Oxygen Flames," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 695 (1976)

Subjects: Soot nucleation; Methane-oxygen flames

Authors' Abstract

Some aspects of the soot nucleation processes which take place in the reaction zone of an atmospheric pressure premixed flat methane/oxygen flame have been studied using a laser light scattering method and a gas chromatographic technique.

A range of CH_4/O_2 ratios of 0.9 to 1.27 was covered and the temperatures of the flames were varied by altering the inlet flow rate; in some experiments small amounts of ethylene or acetylene were added to the feeding mixtures. The maximum concentration of C_2H_2, C_4H_2, and C_4H_4 is increased when a higher $R = CH_4/O_2$ ratio is used and, for the same R ratio, when the flame has a higher combustion temperature. The addition of C_2H_2 and C_2H_4 to the feeding mixtures increases the concentrations of all the unsaturated hydrocarbons. The angular patterns of the vertically and horizontally polarized components of the scattered light at $\lambda_o = 514.5$ nm were determined at different heights in the flame. It was found that in the reaction zone the vertical $\dot{Q}_{vv}$ polarized components were due both to Rayleigh scattering by gas phase combustion products and to a contribution due to higher molecular weight substances.

Higher combustion temperatures decrease the contribution of soot particles to the measured $\dot{Q}_{vv}$ intensity, which is higher for richer mixtures. The depolarized $\dot{Q}_{Hv}$ component was much higher in the reaction zone than that predicted by the depolarization of the gas phase compounds. The $\dot{Q}_{Hv}/\dot{Q}_{vv}$ ratios pass through a maximum which is more pronounced and displaced toward the burner for higher CH_4/O_2 mixtures. The extinction coefficients at $\lambda_o = 514.5$ nm in the reaction zone have also been measured and compared with the scatter results. The analysis of the experimental results shows that the formation and evolution of C_2, C_3, and C_4 unsaturated hydrocarbons does not appear to be a process which takes place before spot nucleation. A part of the scattered signals in the first reaction zone is due to highly depolarized "anelastic" effects, whereas the depolarization in the burned gas region is due mainly to the anistropy of the soot particles. The minimum particle size observed, determined by the scatter/extinction method, is around 20Å and the initial soot number concentration has a maximum of $10^{13}cm^{-3}$ for the richest flame studied.

Damant, G. H. (Flammability Research Laboratory, State of California, Sacramento, California) "Flammability Aspects of Upholstered Furniture," Department of Consumer Affairs, Bureau of Home Furnishings Laboratory Report SP-76-1, State of California (January 1976)

Subjects: Flammability of upholstered furniture; Upholstered furniture flammability

Author's Conclusions

The improvement in combustion resistance and retardance of furniture composites when substituting flame retardant filling materials for conventional non-flame retardant fillers, is not always as obvious or spectacular as in the illustrated mock-up systems. The cumulative knowledge gained in the multitude of mock-ups evaluated illustrates the importance of obtaining an understanding of the apparent interaction of dissimilar upholstery componants when used in furniture composites.

Results of thousands of ignition studies of furniture componants and mock-up systems have shown that:

1. The use of flame retardant filling materials in place of conventional fillers can:
   (a) Reduce the incidence of cigarette induced smoldering combustion in many furniture systems.
   (b) Reduce the spread of flaming combustion and prevent the involvement of interior filling material.
   (c) Retard the progress of any ongoing large scale combustion in many furniture systems.
2. In many systems the use of flame retardant cotton batting can provide significant increased protection when compared to conventional non F.R. battings This is particularly true when the F.R. cotton is used with fabrics which could be classified as marginal smolderers.
3. Overall, polyester battings perform much better than do cotton battings in cigarette tests.
4. Some flexible polyurethane foams are much more likely to sustain smoldering combustion than others. This characteristic does not appear to be primarily influenced by density, I.L.D. value, filler content, or F.R. chemical additive, but by the basic chemical formulation. There are indications that smoldering tendencies of flexible urethane foams may be critically affected by the choice of polyol.
5. The exterior fabric has an important influence on whether or not a cigarette causes ignition in a furniture system.
6. Cellulosic based fabrics are the most hazardous in terms of cigarette induced smoldering combustion. This hazard increases as the weight of the cellulosic fabric increases.
7. Most thermoplastic fabrics, when of adequate weight, will usually perform well in cigarette tests; that is, they will generally not sustain smoldering combustion, nor will they transfer sufficient heat to interior filling materials to induce smoldering in these materials.
8. Smoldering combustion of thermoplastic fabric covered systems may be induced. This occurs when burning cigarette embers penetrate the melt void of the fabric created by the thermal effects of the cigarette.
9. Vinyl and expanded vinyl fabrics perform well in cigarette tests, often causing cigarettes to extinguish prior to full burn.
10. Flame retardant finishes on cellulosic fabrics are usually not effective in preventing the occurrence of smoldering combustion in the fabric.
11. The choice of welt cord can be critical to the combustion resistance of the system. Synthetic welt cords perform much better than do cellulosic. Cellulose welt cords, typically jute, hemp, or paper, show a strong tendency for "wicking."
12. There is a greater tendency for tight seat construction to ignite from cigarettes than loose cushion construction.
13. The use of heat sinks, in the form of laminated aluminum foils or latex based aluminum powder coated fabrics, shows tremendous promise. Combustion

resistance of all furniture systems can be improved dramatically by the use of such heat barriers. However, many of these products do have a potential flexing problem.

14. It is reasonable to hope that some correlation will exist between mock-up systems and finished upholstered furniture articles of similar shape and construction. Preliminary work with finished furniture pieces does show some correlation. However, there may be limitations in predicting the behavior of furniture that does not correspond to the geometry and orientation of mock-up systems.

Damant, G. H. (Flammability Research Laboratory, State of California, Sacramento, California) "Flammability Aspects of Flexible Polyurethane Foams Commonly Used in Upholstered Furniture," *Department of Consumer Affair, Bureau of Home Furnishings, Laboratory Report SP-76-3,* State of California (May 1976)

Subjects: Flammability flexible polyurethane foams; Polyurethane foams flammability; Upholstered furniture flammability

Author's Summary

This report surveys some of the flammability characteristics of a commonly used upholstery filling material, flexible polyurethane foam. Smoldering tendencies have been investigated using cigarettes, smoldering fabric trips and cigarette/fabric composites. Flaming characteristics to a variety of ignition sources have been evaluated. The flaming ignition protocols used have included methenamine tablet, vertical flame, horizontal flame, 45° incline plane and limiting oxygen index. In addition an attempt has been made to correlate the test data.

Delfosse, L., Spilda, I., and Pavik, J. "Studies of Smoke Emission from Burning Poly(vinyl chloride) Plasticised with Diisooctylphthlalte," *Fire and Materials 1* (2) 43-47 (June 1976)

Subjects: Poly(vinyl chloride); Smoke from poly(vinyl chloride); Diisooctylphthlate plasticised poly(vinyl chloride)

Safety in Mines Abstracts 25 No. 1221
Safety in Mines Research Establishment

Smoke evolved from burning poly(vinyl chloride) plasticised with diisooctylphthlate has been studied using a light absorption method. It has been shown that the quantity of smoke produced depends upon the oxygen concentration of the oxidizing gas as well as on the concentration of diisooctylphthalate present in the polymer. The results of this work have been analysed using an empirical equation proposed by the authors, which correlates the maximum smoke density (σ max) with oxygen concentration. The equations may be written σ max = σ LOI exp -k[(NO_2-LOI)] where NO_2 is the molar concentration of oxygen in the oxidizing gas, and LOI refers to the limiting or critical concentration of oxygen at which the polymer will just burn, as defined by the ASTM test 2863. The effect of various additives, particularly organic iodine compounds, as smoke suppressants has also been investigated.

Dixon-Lewis, G. and Simpson, R. J. (The University, Leeds, England) "Aspects of Flame Inhibition by Halogen Compounds," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1111 (1976) See Section E.

D'yachkov, B. G., Polonskiy, I. Ya., and Klimov, A. S. (Promgaz All Union Research Institute, Moscow, USSR) "Effect of an Electric Field on the Normal Flame Propagation Rate," *Fizika Goreniya i Vzryva 12* (3) 405-410 (1976) (in Russian)

Subjects: *Flame propagation; Combustion in electric fields; Electric field effect on combustion*

Abstracted by L. Holtschlag

The effect of a dc electric field on the normal combustion rate is studied, the effect being conditioned by the governing role of ionic wind. The study was carried out in a mixture of gas (88% C_3H_8, 9% C_4H_{10}, 3% C_2H_6) and air in a quartz tube with a laminar combustion front. The behavior of the internal combustion front in the electric field was studied in a range of potentials up to 8 kV. The increase in combustion rate in the electric field can be attributed to the mechanical effect of positive ions, displaced by the applied field, on the combustion front. The agreement between the experimental and calculated data makes it possible to use this method to determine the concentration of charged particles in the flame front from the known dependence of the normal combustion rate on the electric field strength.

Fay, J. A. and Lewis, D. H. Jr. (Massachusetts Institute of Technology, Cambridge, Massachusetts) "Unsteady Burning of Unconfined Fuel Vapor Clouds," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1397 (1976)

Subjects: *Fuel vapor burning; Burning of fuel vapor*

Authors' Abstract

The rapid accidental escape of a combustible vapor into open surroundings can produce a cloud of gas which can burn as an unsteady, turbulent diffusion flame if ignited at its edge. In such a flame, buoyancy forces induce a mixing of the fuel with air, promoting combustion which ultimately consumes the initial fuel change. This paper considers three principal characteristics of such a combustion process: the flame height, the time to complete combustion, and the maximum diameter of the flame. A simple entrainment model is proposed which leads to the determination of these flame characteristics, to within two unknown parameters to be determined from experiments. The principal consequence of the model is the prediction that the rise height and the maximum diameter of the flame vary as the 1/3 power of the initial volume of vapor cloud, while the combustion time varies as the 1/6 power. Experimental observations of the burning of small (laboratory scale) vapor samples are described. The experimental observations were lognormally distributed about a mean line whose slope conformed with the scaling laws derived from the theoretical model. From the mean line, the unknown parameters were determined. Within the limits of the laboratory experiments, the principal flame characteristics are nearly independent of the initial conditions of the vapor cloud and also of the fuel type, and are adequately correlated by the equations given by the theoretical model.

Fenimore, C. P. (General Electric Company, Schenectady, New York) "Reactions of Fuel Nitrogen in Rich Flame Gases," *Combustion and Flame 26* 249-256 (1976) See Section H.

Fire Problems Program: Quarterly Report, October - December, 1976, Applied Physics Laboratory, The Johns Hopkins University, Laurel, Maryland, APL/JHU FPPQ-2-76, under grant from the National Fire Prevention and Control Administration. Program Director: A. G. Schulz; Principal Investigators: R. M. Fristrom and W. G. Berl, See Section K.

Fiumara, A. and Cardillo, P. (Experimental Station for Combustion, San Donato Milanese, Italy) "Flammability Limits of Ethylene Air Mixtures," *La Rivista dei Combustibili, Vol.. XXIX (11-12)* 459-464 (1975)

Subjects: Flammability limits; Ethylene air mixture flammability; Flammability of ethylene air mixtures

Authors' Summary

The paper reports the flammability limits of ethylene-air mixtures, at atmospheric pressure and temperature up to 250° C, and at room temperature up to 20 atm. Flammability diagrams for the system C_2H_4-O_2N_2 at atmospheric pressure and at 25-100-250° C have been determined; at these temperatures the minimum oxygen concentration necessary to support the combustion of ethylene was calculated. The results obtained are compared with those in the literature; the results of this research define a wider range of ethylene flammability. The differences are due to different operative procedures: almost all of the former Authors charged separately the component gases to the explosion reactor according to their partial pressures; in this research the flow was maintained through the reactor of preformed fuel-air mixtures; by-passing the reactor only when ignition is provided.

Fiumara, A. and Cardillo, P. (Experimental Station for Combustion, San Donato Milanese, Italy) "Influence of Temperature and Pressure on the Flammability Limits of Ethylene," *La Rivista dei Combustibili 30 (9-10)* 296 (September-October 1976)

Subjects: Ethylene flammability limits; Flammability limits of ethylene

Authors' Abstract

The variation of flammability limits of the ternary system ethylene-oxygen-nitrogen was determined as a function of temperature (up to 200° C) and of pressure (up to 20 atm). The flammability field of the system was also determined at room temperature and at different pressures (from 1 to 30 atm). To evaluate the influence of temperature and pressure together, the range 25-250° C and 1-10 atm was explored. From the diagrams drawn, the lowest oxygen concentration for flame propagation in the mixture was obtained.

Frey, A. E., Jr. and T'ien, J. S. (Case Western Reserve University, Cleveland, Ohio) "Near Limit Flame Spread Over Paper Samples," *Combustion and Flame 26* 257-267 (1976)

Subjects: Flame spread; Paper; Limits of combustion

Authors' Abstract

In this study the near-limit characteristics of a spreading flame are considered. Flame spreading rates and temperaure profiles are measured as extinction conditions are approached. The flame is extinguished by increasing the heat loss, reducing the total pressure, or reducing the oxygen mole fraction in the environment. The gas phase temperature profiles are obtained with fine-wire thermocouple probes. The flame spreading results show that the power-law correlations of McAlevy and Magee do not remain valid near the extinction limit. In all cases the slope of the Log (flame spread rate) vs. Log (total pressure) curves increase and approach vertical at extinction. Differences in vertical and horizontal flame spreading are discussed. The flame temperature profiles are examined for a near-limit flame, but the total pressure level is the only parameter changed. In the near-limit flame the maximum flame temperature is reduced slightly, but the flame is enlarged in physical size greatly. It is observed that near the pyrolysis front, heat transfer forward in the gas phase and normal to the fuel surface are of the same order of magnitude.

George, C. W. and Johnson, C. W. (Northern Forest Fire Laboratory, Missoula, Montana) "Revised Marsh Funnel Calibrations for Measuring Fire Retardant Viscosity," *U.S.D.A. Forest Service Research Note INT-205* (1976) See Section A.

Gol'dshleger, U. I. and Amosov, S. D. (Chernogolovka Section of the Physical Chemistry Institute of the Academy of Sciences, USSR) "Two Modes of Ignition and Combustion of Hydrocarbon Fuel Droplets," *Fizika Goreniya Vzryva 12* (6) 854-859 (1976) (in Russian) See Section B.

Graham, S. C. (Shell Research Limited, Chester, England) "The Collisional Growth of Soot Particles at High Temperatures," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 663 (1976)

Subjects: Soot particles, growth; High temperature growth of soot particles

Author's Abstract

Recently, we have shown that the light-scattering behavior of soot aerosols in incident shock flows (duration ~ 3 ms) at ~ 1800° K is consistent with the predictions of free-molecule coagulation theory. However, agreement between theory and experiment is obtained only if it is assumed that the collisions between soot particles are coalescent in that the collision partners fuse completely after each collision to form a new spherical particle. The aim of the present study is to determine as directly as possible, whether the collisions that occur in the first 1-2 milliseconds following nucleation are indeed coalescent or chain forming. This was achieved from observations on soot aerosols generated in cycloheptatriene/argon shock-flows at ~ 1750° K using a laser light-scattering technique in which the polarization of the incident beam was modulated at ~ 20 kHz. The ratios of the absorbances of the aerosol at 488 nm and 3.39 μm were also measured to assess the relative proportions of true soot (I.R. absorbing) and polynuclear aromatics (I.R. transparent) in the condensed phase. The polarization modulation permitted the variation in the ratio of the differential light-scattering cross-sections of the aerosols, for light-scattered perpendicular and parallel respectively to the polarization direction of the linearly polarized incident beam, to be measured during the same shock flow. This ratio was observed to increase throughout the flow, showing that the scattering properties of the particles become more and more like those of isotropic spheres as time proceeds. This behavior is the opposite of that predicted for chain-forming collisions. The small but significant scattering that is observed along the polarization direction of the incident beam is attributed to an intrinsic, rather than a shape anisotrophy, that reflects the highly anisotropic nature of the polynuclear aromatics that are present in the particles.

Granovskiy, E. A., Knorre, V. G., and Tesner, P. A. (All Union Research Institute for Industrial and Natural Gas) "The Role of Soot in the Propagation of a Laminar Acetylene Decomposition Flame," *Fizika Goreniya Vzryva 12* (5) 719-724 (1976) (in Russian)

Subjects: Acetylene flame; Laminar decomposition flame; Flame propagation, role of soot in

Abstracted by L. Holtschlag

The dispersive characteristics of the soot formed in constant pressure laminar acetylene decomposition flames were determined over the 3-7 atmosphere range. An expression was derived for the normal flame propagation velocity, v, assuming that the controlling stage of acetylene decomposition is a heterogeneous reaction

on the surface of the soot particles. Values calculated for v were in satisfactory agreement with experiment. The rate of particle formation and acetylene consumption in the flame front is calculated.

Green, W. and Hurd, R. "Advances in the Fire Performance of Rigid Polyurethane Foams," Conference on Urethanes and Environment, Hayes September 21-22, 1976, D1-D15, London, Plastics and Rubber Institute (1976)

Subjects: Polyurethane foams, fire performance; Rigid polyurethane foams; Fire performance of rigid foams

Safety in Mines Abstracts 25 No. 1225
Safety in Mines Research Establishment

Modifications to the chemistry of polyurethane and other isocyanate based foams which have led to improvements in fire resistance are summarised. It is emphasized, however, that the performance of the foams in true fire situations is greatly dependent upon the composite design and major advances have been made in methods of understanding composite performance. Improved methods of assessing and comparing the toxicity of smoke from natural and synthetic materials are also described.

Gukasyan, P. S., Mantashyan, A. A., and Sayadyan, R. A. "Detection of High Concentrations of Radicals in the Cool Flame Zone in the Propane Oxidation Reaction," *Fizika Goreniya Vzryva 12* (5) 789-792 (1976) (in Russian)

Subjects: Propane oxidation; Radical detection in flames; Cool flame zone, radical in

Abstracted by L. Holtschlag

The mechanism of generation of cool flames, obtained by oxidation of hydrocarbons, has been studied for many years. It is believed that the multistage ignition observed during the oxidation of hydrocarbons is of a chain or thermal nature. In the present paper, in order to study cool flames in the propane oxidation reaction, the kinetic method of freezing out radicals was used for the purpose of detecting the leading active centers in the pre-flame region and directly in the flame zone and also to measure the concentrations of radicals in these two different modes of the process. The experiments were carried out under static and jet conditions with a mixture of $C_3H_8 : O_2 = 1:1$ at $p = 270$ mm Hg and $T = 330°C$.

Hilado, C. J., Smouse, K. Y., Kourtides, D. A., and Parker, J. A. "The Effect of Temperature and Air Flow on the Relative Toxicity of Polymeric Materials by the USF/NASA Toxicity Screening Test Method," *Journal of Combustion Toxicology 3* (3) 305-336 (August 1976)

Subjects: Polymeric materials, toxicity screening; Toxicity screening, USF/NASA method; Toxicity of polymeric materials, temperature effect; Toxicity of polymeric materials, air flow effect

Safety in Mines Abstracts 25 No. 1216
Safety in Mines Research Establishment

A variety of polymeric materials was evaluated using the USF/NASA toxicity screening test method with two levels of pyrolysis temperature and two levels of air flow. The materials evaluated were polyethylene, polycaprolactam (nylon 6), polybismaleimide, polycarbonate, poly(aryl sulfone), poly(ether sulfone), poly (phenylene sulfide), chlorinated poly(vinyl chloride), polychloroprene foam, Douglas fir, red oak, hemlock, and wool fabric. Relative toxicity was highly dependent on pyrolysis temperature, air flow, and choice of toxicity criteria. Under essentially smoldering conditions without air flow, relative toxicity appeared to be highly dependent on the weight pyrolyzed. Under oxidative pyrolysis conditions with relatively high air flow, relative toxicity appeared to be dependent on temperature, rate, and time of pyrolysis. Relative toxicity rankings are highly dependent on selection of test conditions and criteria. It appears possible to select a ranking system which would be applicable over a range of fire situations, even though it would not cover all situations. The rankings obtained at 800°C without air flow seem to have the widest applicability. The poly(ether sulfone) samples were consistently among the less toxic materials in this study.

Hilado, C. J., Smouse, K. Y., and Leon, H. A. "A Large Hemispherical Chamber for Fire Toxicity Tests," *Journal of Combustion Toxicology 3* (3) 284-295 (August 1976)

Subjects: Fire toxicity tests; Toxicity test chamber

Safety in Mines Abstracts 25 No. 1241
Safety in Mines Research Establishment

Small-scale laboratory tests for relative toxicity of pyrolysis and combustion products are limited as to the size and number of animals which can be exposed in each experiment. As a result, several tests are needed on each material to adequately discriminate between materials. An 84-litre hemispherical chamber for fire toxicity tests is described in this paper. It is designed to expose 36 mice, 8 rats, 4 rabbits, or combinations of smaller numbers of two or three species simultaneously to the gaseous products of pyrolysis or combustion. Some test results are presented. The 84-liter chamber does not appear appropriate for screening purposes because its large size introduces operating costs and problems which reduce its cost-effectiveness. It appears to be significantly different in that the concentrations required to obtain mortality were significantly higher than were needed in the 4.2 liter chamber. It is useful for producing large numbers of exposed animals for physiological studies.

Hirano, T., Sato, K., and Tazawa, K. (Department of Mechanical Engineering, Ibaraki University, Ibaraki, Japan) "Instability of Downward Flame Spread Over Paper in an Air Stream," *Combustion and Flame 26* 191-200 (1976)

Subjects: Flame spread; Paper; Downward combustion; Combustion instability

Authors' Abstract

An experimental study has been conducted to elucidate the mechanism causing the instability of downward flame spread in an air stream. Following detailed observations of unstable flame spread phenomena, the flow fields near unstably spreading flames and the temperature profiles across the preheat zones were examined using particle tracer techniques and fine wire thermocouples. When the free-stream velocity was above that of the stable flame-spread limit, a series of local blow offs were observed during the spread. In this case, most leading flame edges were inclined or bended, and the blow offs occurred mainly at the locations where both inclined angle of the leading flame edge from the horizontal surface and curvature of the leading flame edge were small. Measured temperature-time diagrams at a given distance from the paper surface were almost similar if flames spread stably across the thermocouple junction. The flame spread phenomena including blow offs at the burning zone with a straight leading flame edge could be considered to depend mainly on the velocity component of the free-stream normal to the leading flame edge but scarcely on the velocity profile in the boundary layer of the approach flow.

Hwang, C. C., Chaiken, R. F., Singer, J. M., and Chi, D. N. H. (U.S. Bureau of Mines, Pittsburgh, Pennsylvania) "Reverse Stratified Flow in Duct Fires: A Two Dimensional Approach," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1385 (1976)

Subjects: Duct fires; Fires in ducts

Authors' Abstract

In ventilated duct fires, smoke and other combustion products may form a layer near the ceiling and flow in the direction opposite to the ventilation flow. Previous workers have shown that backing of hot combustion products occurs if the ratio of the buoyancy head $H\Delta T/T$ to the velocity head V^2/g is greater than unity. A two-dimensional mathematical model of the phenomenon is developed based upon the interaction of a steady-state fire plume with a cross ventilation flow. The objective of the analysis is to gain some understanding of the behavior of the hot gas layer flow and its response to changes at the fire source and in the ventilation current. Through the present mathematical treatments it appears possible to predict the effects of ventilation speed, duct inclination, mass flux of fire plume, etc., on the critical length of the reverse flow layer. The detailed flow behavior of plumes and gas layers can also be studied with the model.

Kanury, A. M. (University of Notre Dame, Indiana), **Martin, S. G.** (Stanford Research Institute, Menlo Park, California) **and Alvares, N. J.** (Lawrence Livermore Laboratory, Livermore, California) "Theoretical Analysis of Fire and Flammability Tests, I. Precepts," *Fire and Materials 1* (4) 141-146 (1976)

Subjects: Flammability tests; Flammability hazard index

Authors' Abstract

Flammability testing is largely empirical and consists of many confusions, contradictions and unexplained factors. In order to accomplish reliable fire safety prediction and design, the empirical art of flammability testing has to develop into a quantitative engineering science in which rigorous analyses are made of the various fire phenomena as measured by existing tests. A rudimentary examination of the many existing tests shows that only a few of them measure some property of the material(s)-fire interaction which will be sufficiently meaningful or useful to develop a scalable hazard rating system. In this paper we examine the meaning of the word "flammability" to distinguish between the material's response to a fire exposure and its contribution to the fire. The functional components of a versatile flammability hazard index are demonstrated to account for the properties of material, of fire, and — of great importance — of use and of human interaction. The promise of modelling techniques to establish these component functions is examined and the directions which future work should take to resolve the questions of fire safety are indicated.

Kaptein, M., and Hermance, C. E. (University of Waterloo, Ontario, Canada) "Horizontal Propagation of Laminar Flames Through Vertically Diffusing Mixtures Above a Ground Plate," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1295 (1976) See Section D.

Kashiwagi, T. and Newman, D. L. (National Bureau of Standards, Washington, D.C.) "Flame Spread Over an Inclined Thin Fuel Surface," *Combustion and Flame 26* 163-177 (1976)

Subjects: Flame spread; Cellulosic materials; Surface combustion; Inclined combustion

Authors' Abstract

Downward flame spread velocity over a thin α-cellulose sheet was measured from the vertical to the horizontal positions under external radiant fluxes of 0, 0.9, 1.4 and 2.0 W/cm^2. The flame spread velocity had little dependency on the angle of inclination of the sheet with the stable lower flame. When the lower flame became unstable, wavy flames, cellular flames and flame rolls were observed below the lower surface. With these unstable lower flames, the flame spread velocity increased significantly reaching several cm/s. Qualitative analysis based on the Rayleigh instability mechanism describes well the effects of the inclination angle and the external flux on the instability of the lower flame.

Kondrikov, B. N. and Novozhilov, B. V. (The D. I. Mendeleev Institute of Chemical Technology, Moscow, USSR) "Stabilization of Combustion of Condensed Materials," *Fizika Goreniya Vzryva 12* (3) 333-342 (1976)

Subjects: Combustion, condensed materials; Condensed material combustion

Abstracted by L. Holtschlag

A layer of particles on a burning surface can affect the process in various ways, interacting in part with the original substance or with its products, the latter is not considered in this article. Here a layer of inert particles on the surface acts to provide thermal inertia. The heat accumulated in the layer dampens oscillations of the surface temperature, thus expanding the region of stable combustion. The heat damping action of a layer of inert particles is the subject of this article. The principle result consists of the following. A layer of relatively refractory particles (carbon, ashes, inorganic impurities, etc.) can form on the burning surface during the combustion of condensed materials. A theoretical analysis of the stability of the combustion wave within the framework of a Belyaev - Zel'dovich model shows that this layer stabilizes the process, regardless of the nature and chemical activity of the constituent particles: the limits of the stable combustion mode are expanded appreciably. The experiments showed that for a number of secondary explosives (trinitroresorcin, trinitrophloroglucinol, PETN, nitromannite, et al) characterized by considerable thermal instability, a layer of powder on the surface, either specially applied or generated as a result of combustion, greatly increased the stability of the process, leading to combustion under conditions in which combustion could not occur without this layer.

Kovalenko, V. A. and Yarin, L. P. (V. I. Lenin Advanced Naval Engineering Academy, Leningrad, USSR) "Study of the Structure of Compound Turbulent Flames," *Fizika Goreniya Vzryva 12* (6) 493-497 (1976)

Subjects: Turbulent flame; Flame structure

Abstracted by L. Holtschlag

In continuation and expansion of work done previously, an investigation is made of the structure of compound turbulent flames generated during the combustion of a system of flame jets of unmixed gases or of a homogeneous mixture. A brief review is first made of some characteristics of the propagation of compound turbulent jets that demonstrate the specific features of the types of jet flows being considered in this work. These features of compound jets are also characteristic of gas flames. The calculation of compound turbulent flames entails exceptional difficulties connected primarily with the solution of the problem of propagation of a system of interacting turbulent jets. For an approximate calculation of such a flow it is expedient to use the method of the equivalent problem in the theory of thermal conductivity. On the whole, calculation by this method correctly reflects the qualitative pattern of the development of a compound diffusion flame and results in satisfactory agreement with experiment, provided the values of the empirical constants are suitably chosen. The calculation of compound homogeneous flame jets should take into account the presence of appreciable pressure gradients, acceleration of the gas near the flame front, et al. The solution of this problem requires the researcher to resort to more general methods of calculating compound turbulent flows and requires further accumulation of data on the structure of homogeneous flames.

Krishna, C. R. (Brookhaven National Laboratory, Upton, New York) **and Berlad, A.L.** (State University of New York, Stoney Brook, New York) "Stability of Combustion Systems," *Combustion and Flame 26* 133-135 (1976)

Subjects: Flame stability; Combustion stability

This short communication shows the method of Lyapunov functionals to be useful in the stability analysis of inhomogeneous combustion systems.

Law, C. K. (Guggenheim Laboratories, Princeton University, Princeton, New Jersey) "Unsteady Droplet Combustion with Droplet Heating," *Combustion and Flame 26* 17-22 (1976)

Subjects: Droplet combustion; Unsteady droplet combustion

Author's Abstract

Unsteady droplet combustion caused by droplet heating is modelled by assuming quasi-steady gas-phase processes and the droplet temperature being spatially uniform but temporally varying. Results show droplet heating is a significant source for the experimentally observed unsteady combustion phenomena of Okajima and Kumagai.

Law, C. K. (Guggenheim Laboratories, Princeton University, Princeton, New Jersey) "Multicomponent Droplet Combustion with Rapid Internal Mixing," *Combustion and Flame 26* 219-233 (1976)

Subjects: Droplet combustion; Mixtures of fuels; Combustion theory

Author's Abstract

Two models are proposed to describe the gas-phase diffusion-controlled, unsteady combustion of a multicomponent droplet in a stagnant, unbounded atmosphere. The first, termed the Ideal-Mixture Model, assumes that the mixture behaves as an ideal mixture in its phase change characteristics, and that the composition and temperature within the droplet are spatially uniform but temporally varying. Expressions are obtained for the droplet vaporization rate and other quantities of interest. Sample solutions indicate that the components vaporize approximately sequentially in the order of their relative volatilities, and that the vaporization rate is insensitive to the mixture composition during combustion as well as during pure vaporization in hot environments. Available experimental evidence supports the theoretical model. The second model, termed the Shell Model, assumes a shelled distribution of the components such that quasi-steady, single-component vaporization prevails for each shell. Simplified solutions are derived and are shown to closely approximate the bulk vaporization behavior described by the more detailed Ideal-Mixture Model, particularly for the prediction of the total vaporization time.

Lazarev, P. P. and Pleshanov, A. S. (The G. M. Krizhanovskiy National Power Research Institute, Moscow, USSR) "Diffusion Thermal Stability of a Laminar Flame Front," *Fizika Goreniya Vzryva 12* (6) 615-619 (1976)

Subjects: Laminar flame; Diffusion thermal stability

Abstracted by L. Holtschlag

An exact solution of this problem which was obtained for arbitrary perturbation wavelengths leads to the existance of a stability region, one of whose boundaries is determined by the ratio of the diffusion and thermal conductivity coefficients and the dimensionless activation energy of the chemical combustion reaction. The stability region is expanded somewhat by taking into account temperature and concentration discontinuities of the reacting agent in the flame front.

Lee, C. K., Chaiken, R. F., and Singer, J. M. (U.S. Bureau of Mines, Pittsburgh, Pennsylvania) "Charring Pyrolysis of Wood in Fires by Laser Simulation," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1459 (1976)

Subjects: Pyrolysis of wood; Wood pyrolysis; Fires of wood; Laser simulation

Authors' Abstract

Utilizing a 250 watt CO_2-laser radiation source, wood pyrolysis at fire-level surface heat flux was investigated through the measurement of decomposition rates, solid temperatures and thermal properties, pyrolysis gas compositions and pressures, and crack formation. Heats of reaction calculated from these measurements show that at an incident heat flux of 0.76 cal/cm^2-sec applied parallel to the wood grain direction, the pyrolysis layer ($\sim$ 1 cm thick) can be divided into three zones: (i) an endothermic primary decomposition zone at temperatures $T < 250°$C, (ii) an exothermic partial char zone at $250°\text{C} < T < 340°$C, and (iii) an endothermic surface char zone at $340°\text{C} < T < 520°$C. The overall mass weighted effective heat of reaction is endothermic to the extent of -146 cal/g. At 2.0 cal/cm^2-sec applied parallel or perpendicular to grain direction, pyrolysis reaction proceeds as a charring wave of $\sim$ 0.5 cm thickness advancing into the wood. The charring wave ($250°\text{C} < T < 450°$C) is characterized by active overall exothermic reactions accompanied by rapid solid density change. In front of the wave is an endothermic primary decomposition zone, and behind the wave is an exothermic char layer ($T <$

800°C) of relatively constant density. The overall heat of reaction at the higher heat flux is exothermic, being greater for perpendicular heating (260-410 cal/g) than for parallel heating (25-94 cal/g). For parallel heating at both heat fluxes, macroscopic cracks (~ 1mm wide) occur in the pyrolysis region, whereas for perpendicular heating no cracks are observed. Present results show that the wood pyrolysis process is dependent upon the external heating rate, the total time of heating, and the anisotropic properties of wood and char relative to the internal flow of heat and gas.

Lie, T. T. (Division of Building Research, National Research Council of Canada, Ottawa) "A Method for Assessing the Fire Resistance of Laminated Timber Beams and Columns," *Canadian Journal of Civil Engineering 4* (2) 161-169 (June 1977)

Subjects: Fire resistance of laminated timber; Laminated timber, fire resistance of

Author's Abstract

A method for the calculation of the fire resistance of timber beams and columns is described. The method is based partly on the results of theoretical studies and partly on the results of a large number of tests on timber beams and columns. Simple formulas for calculating fire resistance are presented. Comparison with experimental results shows good agreement between calculated and measured fire resistance.

Lloyd, S. A. and Weinberg, F. J. (Imperial College, London, England) "Limits to Energy Release and Utilization from Chemical Fuels," *Nature 257* 367 (1975)

Subjects: Flammability; Low enthalpy burners; Lean limit of combustion; "Swiss Roll" burner

Abstracted by R. M. Fristrom

A new burner design called the "Swiss Roll" Burner which exchanges heat without material allows preheating of low enthalpy mixtures thereby permitting their combustion. The new combustor effectively abolishes limits of flammability. This extends the concept of what is a fuel. By burning very lean mixtures, the burners also minimise pollution and irretrievable energy losses during conversion. The theoretical saving is more than double the proportion currently contributed by all nuclear and other "non-combustion" sources.

Lovachev, L. A. (Physical Chemistry Institute, Academy of Sciences, Moscow, USSR) "Determination of the Microkinetic Characteristics of Flames," *Fizika Gorenita Vzryva 12* (5) 786-789 (1976) (in Russian)

Subjects: Flame microkinetics; Microkinetics of flames

Abstracted by L. Holtschlag

If the rate of heat evolution is related to the combustion temperature, the value of the effective activation energy becomes exaggerated, increasing with true activation energy and increasing finite flame temperature. A determination is made of the flame front temperature by which the true value of the microkinetic activation energy can be found.

Masarik, I. (Fire Research Laboratory, Prague, Czechoslovakia), **Rysak, M., Svetlik, J.** (Academy of Sciences, Prague, Czechoslovakia), **and Horak, Z.** (Research Institute of Synthetic Rubber, Kaucuk Kralupy, Czechoslovakia) "The Use of the Setchkin Apparatus — Mass Spectrometry in the Investigation of Ignition and Burning of Flame Retarded Polystyrenes," *Fire and Materials 1* (4) 129-133 (1976) See Section B.

Massoudi, M. S. "The Burning of Solid Polymeric Particles in a Reactive Environment 1. Wood," *Journal of Fire and Flammability 7* (3) 347-357 (July 1976)

Subjects: Polymeric particle burning; Burning of polymeric particles; Wood burning

Safety in Mines Abstracts 25 No. 1227
Safety in Mines Research Establishment

A mathematical model has been developed to describe the combustion characteristics of polymeric particles and the theoretical results have been compared with experimental findings obtained using wood particles in a stirred reactor. The particles used were between 0.02 and 0.08 cm in diameter and the reaction temperature varied between 400-800° C. The mathematical model incorporates pyrolysis-gasification process of the fuel and subsequent combustion of the char and the produced gases. Different reactive environments have been studied, i.e., air and moist air to determine the effect of water vapor on the burning rate of fuel particles. The overall goal has been to investigate the effect of important parameters such as environment, temperature, particle size, and suspension density on the burning behavior of particles.

Merzhanov, A. G. and Smirnov, L. P. (Chernogolovks Section of the Physical Chemical Institute of the Academy of Sciences, USSR) "Nonisothermal Kinetics of Thermoneutral Polymerization Processes," *Fizika Goreniya Vzryva 12* (5) 659-665 (1976) (in Russian)

Subjects: Thermoneutral polymerization; Kinetics, nonisothermal

Abstracted by L. Holtschlag

The course of a chemical reaction in a periodic reactor without mixing (Frank-Kamenetskiy model) is described by a system of nonlinear partial differential equations, the solution of which can be obtained only by numerical integration. Manelis and Smirnov have published computer derived results of an analysis of the macrokinetic features of the course of a weakly exothermic polymerization process in such a reactor. An approximate analytical solution of the problem is given assuming a thermoneutral chemical reaction and this solution is generalized to the case of small thermal effects.

Moussa, N. A., Toong, T. Y., and Garris, C. A. (Massachusetts Institute of Technology, Cambridge, Massachusetts) "Mechanism of Smoldering of Cellulosic Materials," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1447 (1976)

Subjects: Cellulosic materials; Smoldering of Cellulosic materials

Authors' Abstract

A coordinated theoretical and experimental investigation of the mechanism of smoldering in cellulosic materials has been conducted.

Both steady and transient smoldering have been observed for single cylindrical cellulosic elements, mounted horizontally in quiescent oxygen/nitrogen environments of varying pressures and compositions. An extinguishment limit, separating the steady from transient regions, is observed at well-defined combinations of oxygen mole fraction and partial pressure. In the region of steady smoldering, the measured propagation speed and maximum temperature in the smoldering zone depend on the oxygen partial pressure and mole fraction in the environment. However, independent of the environmental conditions, the speed is uniquely related to the maximum temperature.

It is postulated that cellulose, upon heating, decomposes to yield char and volatiles. The char then reacts with oxygen, diffusing from the surroundings, to provide the heat flux needed to sustain pyrolysis. On the basis of this mechanism, the predicted characteristics of steady smoldering and of the extinguishment limit are found to be in good agreement with the experimental results, thus demonstrating the validity of the proposed mechanism.

Nesterko, N. A. and Taran, E. N. (Dvepropetrovsk State University, USSR) "Spectroscopic and Probe Studies of the Structure of a Flat Low Pressure Diffusion Flame in Opposed Jets," *Fizika Goreniya i Vzryva 12* (6) 837-845 (1976) (in Russian)

Subjects: Diffusion flames; Opposed jet flame; Flame structure

Abstracted by L. Holtschlag

Temperature and ion concentration profiles, as well as profiles of the radiation of C_2, CH, CN, and OH radicals and continuum profiles were measured in acetylene air flames. The effective activation energies of the processes of ionization and excitation of the C_2 and CH radicals were determined in acetylene -, propane -, AD-A064 190 F/G 13/12

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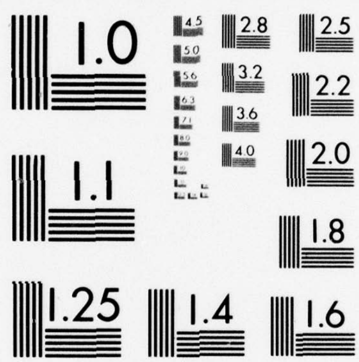

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

and methane - air flames. The electron temperature exceeds the gas temperature of the flame by several hundred degrees. The change of the electron temperature over the height of the flame correlates with the change in OH ($A^2 \Sigma^+$) radiation. The energy exchange between the different degrees of freedom of the flame gas molecules is discussed. Some conclusions are reached as to the mechanism of ionization and excitation of radicals in hydrocarbon flames.

Orloff, D. I. (University of South Carolina, Columbia, South Carolina) **and Matula, R. A.** (Drexel University, Philadelphia, Pennsylvania) "An Experimental Study of the Afterburning Region of Lean Tetrafluoroethylene Oxygen Flames," *Combustion and Flame 26* 141-150 (1976)

Subjects: Flame structure; Tetrafluoroethylene-oxygen

Authors' Abstract

The afterburning region of premixed, lean, one dimensional tetrafluoroethylene-oxygen flames has been studied. Composition and temperature profiles were measured for flames burning near 80 torr on a water cooled porous disk burner. Measured compositions and temperatures were compared to those predicted by thermodynamic equilibrium, and the species CF_4, COF_2, O_2, and CO were found to be in superequilibrium while CO_2 and estimated atomic fluorine were lower than equilibrium predictions. Temperatures in the afterburning region of these flames were found to be between 300-500° K higher than the predicted adiabatic flame temperatures. However, the measured flame temperatures were found to compare favorably with flame temperatures derived from the measured compositions and the first law of thermodynamics. Composition and temperature profiles were used in conjunction with the quasi-one dimensional flame equations to calculate net reaction rate profiles of stable species in the afterburning region of the flames studied. The calculated net reaction rate profiles were found to be independent of uncertainties in temperature measurement and in the case of COF_2 and CF_4 to show a trend away form the calculated equilibrium. These results indicate errors in the thermochemical data associated with species in this system.

Ozerova, G. E. and Stepanov, A. M. (The M. I. Kalinin Polytechnic Institute of Leningrad, USSR) "Flame Propagation Through a Suspension of Hydrocarbon Droplets," *Fizika Goreniya Vzryva 12* (5) 710-718 (1976) (in Russian)

Subjects: Flame propagation; Hydrocarbon flames; Droplet combustion; Mist flames

Abstracted by L. Holtschlag

A brief review of the experimental and theoretical work devoted to the problem of flame propagation through a suspension of hydrocarbon droplets is made. A computational flame model based on a conductive heat transfer mechanism with allowances for combustion both within the bulk of the gas and near individual droplets is proposed. The computations have shown that the dependence of the flame velocity on droplet size can vary (depending on the excess of oxidizer α): at low values of α the flame velocity v increases with decreasing droplet size d, approaching the values of the flame velocity for a homogeneous mixture; at large values of α, the curve of v(d) has a maximum.

Pagni, P. J. and Shih, T. M. (University of California, Berkeley, California) "Excess Pyrolyzate," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1329 (1976) See Section D.

Podlevshikh, N. A. and Tarasyuk, V. A. (National Institute of Applied Chemistry, Leningrad, USSR) "Limits of Combustion Stability in a Laboratory Gas Burner," *Fizika Goreniya Vzryva 12* (6) 885-890 (1976) (in Russian)

Subjects: Combustion stability; Combustion limits

Abstracted by L. Holtschlag

In earlier papers one of the authors (Tarasyuk) proposed a semi-empirical method of evaluating the low frequency stability of gas combustion. In the present paper this method is used to plot the limits of combustion stability in the plane of the mode parameters as a function of the mass flow m, the excess air coefficient x of a real burner device, a laboratory burner. The calculated limits are compared with experimental limits obtained elsewhere. The analysis indicates that there is quantitative agreement between theory and experiment.

Prado, G. P., Lee, M. L., Hites, R. A., Hoult, D. P., and Howard, J. B. (Massachusetts Institute of Technology, Cambridge, Massachusetts) "Soot and Hydrocarbon Formation in a Turbulent Diffusion Flame," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 649 (1976)

Subjects: Soot formation; Hydrocarbon formation; Diffusion flames; Turbulent diffusion flame

Authors' Abstract

Formation and emission of soot and polycyclic aromatic hydrocarbons (PCAH) from a turbulent continuous flow combustor have been studied. Measurements included mass concentration of both soot and PCAH, composition of individual PCAH, and size distribution of soot particles, as a function of mixing intensity, fuel equivalence ratio and type of fuel (kerosene or benzene). Both soot and PCAH concentrations reach maxima early in the flame, after which PCAH decays rapidly and soot decays much slower. The maximum PCAH concentration always preceded that of soot in agreement with the concept that certain PCAH may serve as intermediates in soot formation. An approximate calculation based on the assumptions of local equilibrium with respect to soot formation and a Gaussian distribution of air-fuel mixedness gave satisfactory correlations of the data on soot formation at the higher cold gas velocity. At the lower velocity, the amount of soot and PCAH formed was drastically increased and strongly dependent on fuel atomization.

Powell, D. A. and Martin, K. G. (Division of Building Research CSIRO, Melbourne, Australia) "Smoke and Fire Assessment with the Fire Propagation Test," *Fire and Materials 1* 97-102 (1976) See Section J.

Rogowski, B. F. W. (Building Research Establishment, Borehamwood, Herts., England) "Plastics in Buildings — Fire Problems and Control," *Building Research Establishment Current Paper 39/76,* Fire Research Station (1976)

Subjects: Fire problems of plastic building materials; Plastic building materials in fires

Author's Abstract

This paper reviews the more common applications of plastics in building construction and discusses the effect on their fire performance of factors such as density, thickness and method of use. Test methods appropriate for assessing the probable fire performance of constructional elements or lining materials incorporating plastics are listed and the possibility of different types complying with current Building Regulations requirements is indicated in the tables.

Saito, N. and Yanai, E. (Fire Research Institute of Japan, Tokyo, Japan) "Weight Loss Rates of Polymers Pyrolyzed Isothermally at High Temperatures in Air Flow, Part 1. Cellulose, Rayon, and Polyester Fiber," *Report of the Fire Research Institute of Japan No. 42* 26 (1976) (in Japanese)

Subjects: Polymer pyrolysis at high temperatures; Cellulose pyrolysis; Rayon pyrolysis; Polyester pyrolysis

Authors' Abstract

The isothermal pyrolysis of cellulose, rayon and polyester fiber was carried out in air flow in the temperature range 350-550° C, and the weight loss rates were measured. With every polymer used, it is shown that the logarithm of maximum weight loss rate decreases linearly with the increase in the reciprocal of absolute temperature. At temperatures below 500° C, rayon shows the largest value in the maximum weight loss rate, while polyester fiber the smallest. On the other hand, it is estimated that the above relation is reversed at temperatures above 700° C. With every polymer used, the temperature dependence of the maximum weight loss rate is smaller than expected from the first stage of decomposition in the thermogravimetric analysis in air flow. Reduction of oxygen concentration from 21% to 15% has no influence on the weight loss with cellulose and polyester fiber.

Schacke, H., Hunter, L. W., Fristrom, R. M., and Grunfelder, C. (Applied Physics Laboratory, The Johns Hopkins University) "Combustion of Poly(vinyl chloride) Studied by the Moving Wire Technique," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1317 (1976) See Section D.

Schneider, U. (Technical University, Braunschweig, West Germany) "Behavior of Concrete Under Thermal Steady State and Non-steady State Conditions," *Fire and Materials 1* 103-115 (1976) See Section A.

Sellman, L. G., Ostman, B. A., and Back, E. L. (Swedish Forest Products Laboratory, Stockholm, Sweden) "Methods of Calculating the Physical Action of Flame Retardants," *Fire and Materials 1* 85-89 (1976)

Subjects: Flame retardants; Physical action of retardants

Authors' Abstract

The chemical mechanisms for the action of flame retardants are often mentioned in the literature, but the physical modes of action are seldom discussed. This article presents one way to quantify their efficiency. The technique is based on literature data for the physical and thermal properties of flame retardants for temperatures from 25°C up to 1000°C. The prolongation of the time to ignition by heat absorption by the retardant and the amount of inert gas evolved by the retardant are calculated at a given radiation for a material flame-proofed with a given amount of the flame retardant. The ability to form an insulating surface layer is considered but not quantified. It is assumed that a medium density wood fibre building board is treated with 2 kg of flame retardant per m^2. The flame retardants included are borates, boric acid, phosphates and silicates. The board is assumed to be irradiated with an intensity of 15 kW m^{-2}. Under these conditions an untreated board ignites after 6-7 min. The time to ignition is prolonged by 1-5 min through heat absorption by the different retardants, and the amount of inert gases evolved may be as high as 2.6 m^3 per m^2 board. The importance of inert gases in inhibiting ignition is, of course, very dependent on the ventilation conditions. The formation of an insulating surface layer is more difficult to quantify. The results confirm the importance of the physical modes of action of flame retardants and the technique could form the basis for evaluating materials in simulated fire situations.

Shchetnikov, E. S. (Institute for Problems in Mechanics, Academy of Sciences, Moscow, USSR) "Burning Velocity of a Turbulent Diffusion Flame," *Fizika Goreniya Vzryva 12* (6) 483-493 (1976)

Subjects: Burning velocity; Turbulent flame; Diffusion flames

Abstracted by L. Holtschlag

The aim of this paper is to draw attention of researchers to deficiencies in the development of the theory of gas combustion. In addition, an attempt is made to select a characteristic burning velocity which would be suitable for both homogeneous and diffusion flame jets. The study shows that the rate of traverse expansion of a reduced flow of combustion products can be used as a characteristic rate of diffusion burning, while the width of this flow can be used as a linear dimension characterizing the degree of combustion. The physical principle of a diffusion combustion rate is in agreement with ideas in the literature on the rate of laminar and turbulent diffusion combustion, and it is therefore possible to compare the intensity of these types of combustion. In experimental studies of turbulent homogeneous combustion it is more useful to measure the combustion rate which is uniquely related to the rate of heat evolution rather than the rate of flame propagation with respect to the leading edge of the flame front, as is usually done. A preliminary comparison of the rates of diffusion and homogeneous combustion indicates a considerable decrease in the intensity of heat evolution in a diffusion flame compared to a homogeneous flame, which can be explained by the increasing complexity of the mixing process preceding chemical reaction.

Smith, E. E. "Relation of Performance Tests to Actual Fires," *Fire Technology 12* (1) 49-54 (February 1976)

Subjects: Fire tests; Heat release rate; Fire hazard

Author's Abstract

"Hazard load" calculations have been proposed which use exposed surface area and release rate data for the control of, or to measure, loading. Release rate values can be used to rate and specify materials and products as a function of location in the fire system and the nature of the occupancy. In theory, predictive methods based on the release rate data offer an approach by which the performance of materials and products can be determined under any fire exposure. The advantage of this approach is the ability to look at a number of combustion characteristics, rather than just one attribute, to describe the fire safety of a material. No one characteristic, nor one exposure, can adequately describe the performance of an item in a fire. Release rate data give a more complete evaluation of combustibility characteristics and a more relevant description of a material's or product's performance.

"Smoke Test Methods" *American Society Testing and Materials Standardization News 4* (8) 18 (August 1976)

Subjects: Smoke tests; ASTM smoke tests; Test method for smoke

Article Summary

Smoke is a major hazard in a building fire, not only due to its effect on the safety and rescue of the occupants but also because it hinders fire suppression efforts. All fires produce smoke problems. Therefore, primary design and regulatory efforts should be devoted to control movement of smoke in buildings, including pressurization, venting, detection, and sprinklers.

Since smoke is a complex function of the type of fire and the materials involved, the measurement of smoke generated and the application of the test data should be very carefully considered. A number of test methods have been developed to provide comparative data on smoke development rate and its quantity and quality. These tests employ two general methods of measurement: gravimetric and optical techniques. Five test methods have been selected for primary study by ASTM Committee E-5 on Fire Tests of Building Construction and Materials. These tests can be further classified in accordance with the reaction of the test specimen during test as (1) mass involvement, (2) progressive surface involvement, (3) total surface involvement, or (4) a combination of the above.

All of the methods described provide usable data if applied within the limits necessarily imposed by the test method itself. The test data should only be used with the recognition that materials react differently under the many varied conditions of exposure that can be expected in a fire.

Consideration of any smoke test method results for selection of building construction and furnishing materials should recognize the following:

- Smoke limit requirements for building products should be based on the *quantity* of the product likely to be involved in the fire, recognizing at the same time that the application of the material in use will affect its performance.
- In any application of the results it should be recognized that the values are not fundamental material properties or characteristics. They are specimen properties and representative of the performance of the product in the thickness and assembly nature used and under the test conditions imposed.

Much more research is needed to fully understand the fire process itself and to demonstrate the fallacy of using simplified solutions to a very complex problem. ASTM committees are continuously working to solve these and many other similar problems. All persons who are seriously interested in helping in this tremendous endeavor are encouraged and cordially welcomed to join the committee.

Stark, G. W. V. and Field, P. (Joint Fire Research Organization, Borehamwood, Herts., England) "Toxic Gases and Smoke from Poly(vinyl chloride) in Fires in FRS Full-Scale Test Rig," *Fire Research Note No. 1030,* Joint Fire Research Organization (April 1975) See Section K.

Takeno, T. and Kotani, Y. (University of Tokyo, Japan) "A Study on the Structure of Turbulent Jet Diffusion Flames," *Combustion Science and Technology 10* 45-57 (1975)

Subjects: Flame structure; Turbulent flame; Diffusion flames

Authors' Abstract

The gross structure of turbulent jet diffusion flames developing in a coflowing high temperature vitiated air stream was examined experimentally and theoreti-

cally. The observed radial profiles of total pressure within the flame were similar in all axial positions, while the temperature profile showed a sharp peak at the most luminous position. The measured temperature profiles in the upstream region of flame were found to correlate satisfactory with those of a simplified analysis based on the flame surface approximation and the boundary layer similar solution for the velocity field.

Tewarson, A. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Heat Release Rates from Samples of Poly(methyl methacrylate) and Polystyrene Burning in Normal Air," *Fire and Materials 1* 90-96 (1976)

Subjects: Poly(methyl methacrylate) heat release; Polystyrene heat release; Burning of poly(methyl methacrylate); Burning of polystyrene

Author's Abstract

Results are presented for mass generation rates of major combustion products (CO_2, CO, total hydrocarbons and smoke particulates) and heat release rates from samples of polymethylmethacrylate and polystyrene burning in normal air under varying magnitudes of externally applied radiant heat flux. In the experiments mass generation rates of products and convective heat release rates are measured and, from heat and mass balance, actual and radiative rate of heat release, as well as heat that is not released due to incompleteness of combustion, are calculated. From the data, 99% of the rate of the theoretical heat release for complete combustion can be accounted for. In some cases the experimentally derived heat release rate was less than half that predicted from mass loss rate (assuming complete combustion). This "combustion efficiency" decreased strongly with increasing externally applied radiant flux, and was always much lower for polystyrene than for polymethylmethacrylate. At the "ideal" condition, defined as a condition where heat losses have been compensated and where the mass burning rate of polystyrene is 1.44 times the rate for polymethylmethacrylate, polystyrene generates 6.60 times more CO, 7.83 times more smoke particulates, and the radiative rate of heat release is 1.75 times more than that of polymethylmethacrylate.

Tewarson, A. and Pion, R. F. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Flammability of Plastics I. Burning Intensity," *Combustion and Flame 26* 85-103 (1976) See Section B.

Thorne, P. F. (Fire Research Station, Borehamwood, England) "Flash Point of Mixtures of Flammable and Nonflammable Liquids," *Fire and Materials 1* (4) 134-140 (1976) See Section B.

Ubhayakar, S. K. (Avco Everett Research Laboratory, Everett, Massachusetts) "Burning Characteristics of a Spherical Particle Reacting with Ambient Oxidizing Gas at its Surface," *Combustion and Flame 26* 23-34 (1976) See Section D.

Vilynnov, V. N., Nekkasov, E. A., Baushev, V. S., and Timokhin, A. M. (Applied Mathematics and Mechanics Research Institute, Tomsk State University, USSR) "Characteristics of Spark Ignition and Transition to Steady State Combustion Conditions," *Fizika Goreniya i Vzryva 12* (3) 361-366 (1976) (in Russian) See Section B.

Warner, B. L. "Evaluation of Materials for Protecting Existing Urethane Foam in Mines," U.S. Bureau of Mines OFR 75-76 (PB 254 682) 51 p.

Subjects: Urethane foam in mines, protection of; Protection of urethane foam in mines

Safety in Mines Abstracts 25 No. 1354
Safety in Mines Research Establishment

Evaluation of various coatings for use in preventing flame propagation on urethane foam surfaces in mines. Full-scale tests were conducted in simulated mine passageways, using kerosine pan fires as an ignition source. A test was also conducted on a recently developed fire-resistant foam, without coating, to evaluate its resistance to flame propagation. Test results showed that, of seven coatings tested, four cementitious types were effective in preventing flame spread on the urethane foam used. The test on the uncoated fire-resistant foam showed this foam to effectively inhibit flame propagation without a protective coating being required.

Watts, P. R., edited by Goldstone, B. M. (Joint Fire Research Organization, Borehamwood, Herts., England) "The Assessment of Smoke Production by Building Material in Fires Part 4. Large Scale Tests with Wall Lining Materials," *Fire Research Note No 1013*, Joint Fire Research Organization (June 1976)

Subjects: Smoke from building material fires; Building material fire tests; Fire tests smoke production

Author's Summary

Quantitative measurements have been made of the smoke production in vision obscuring terms of five materials, exposed both in the Fire Propagation Test Apparatus and also in much larger quantities (8 m^2) as the linings of a compartment containing a substantial fire, itself producing little or no smoke.

The range of smoke production was very large, extending over three orders of magnitude. Both methods gave similar values for the smoke production of materials producing much smoke, but for materials producing little smoke the large-scale tests registered less smoke than the Fire Propagation test method. Nevertheless there was a strong correlation between the values of smoke production from the two methods under the conditions examined.

Williams, F. A. (University of California, San Diego, La Jolla, California) "Mechanisms of Fire Spread," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1281 (1976)

Subjects: Fire spread; Mechanisms of fire spread

Author's Abstract

Mechanisms involved in many types of fire spread are described in a manner that sacrifices accuracy for the purpose of emphasizing general aspects of the underlying heat-transfer, fluid-flow and chemical-kinetic phenomena. Consideration is given to conditions for transition from one mode of propagation to another. Research on fire spread has been pursued intensively in recent years, and in the present contribution an attempt is made to provide a framework within which various studies can be placed. Entries to current literature are provided. Areas of apparent important that do not seem to have been emphasized are suggested.

Williamson, R. B. (University of California, Berkeley, California) "Fire Performance Under Full Scale Test Conditions — A State Transition Model," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1357 (1976)

Subjects: Fire performance; Full scale tests; State transition model

Author's Abstract

This paper concerns the measurement of fire performance under experimental fire conditions resembling actual fire conditions. A new method of analyzing and reporting the results of these experiments, a State Transition Model, is introduced.

Distinct states are chosen for the analysis of fire growth experiments and their duration provides a new experimental data. Three pre-flashover states are defined as follows:

J = The period of time from the beginning of the experiment to ignition of the specimen.

K = The period of time from ignition of the specimen until flames touch the ceiling, and

L = The period of time from when the flames first touch the ceiling until full involvement (flashover) occurs.

These states are components of the State Transition Model, and histograms and cumulative distribution functions (CDF) of the state durations then provide a graphical representation of fire performance. Examples are chosen to illustrate the method. Traditional cellulosic and cementitious walls and ceilings are compared to plastic materials in the same configuration.

Wooley, W. D., Ames, S. A., Pitt, A. I., and Murrell, J. V. (Joint Fire Research Organization, Borehamwood, Herts., England) "Fire Behavior of Beds and Bedding Materials," *Fire Research Note No. 1038*, Joint Fire Research Organization (June 1975)

Subjects: Beds and bedding material fires; Fire tests

Authors' Summary

Fire tests with measurements of temperatures, radiation levels, and smoke production have been carried out using domestic beds fitted with full bedding materials in a full-scale compartment-corridor. The tests have included mattresses made of polyurethane of various types, hair, spring interior and foamed rubber with mattress covers of cotton, flame retarded cotton or proofed nylon. Some tests with hair or glass fiber cloth protective interlinings are also recorded.

The study has shown that a rapid development of fire in bed and bedding materials can take place with certain combinations of mattresses and their covers. The type of cover is extremely important in the overall fire development, particularly with polyurethane mattresses. A substantial improvement in the fire behavior of many of the principal types of beds tested can be achieved by a careful selection of bedding materials, such as the type of mattress cover, and in certain cases by the use of protective interlinings.

Yamashika, S. and Kurimoto, H. (Fire Research Institute of Japan, Tokyo, Japan) "Burning Rate of Wood Crib," *Report of the Fire Research Institute of Japan No. 41*, 8-15 (1976) (in Japanese)

Subjects: Wood crib burning; Burning of wood cribs

Authors' Abstract

Burning rate of wood crib was measured in connection with a crib weight, width of stick, lapse of time, and crib porosity. The rate was directly proportional to the weight or the surface area of the crib in the same width of stick as expected. The influence of width of stick on the rate was the same as that of Gross's experiments. As the stick became thinner with the lapse of time, the rate was directly proportional to the square root of remaining crib weight. The rate varied with crib porosity which has influence on inflow rate of air into the crib fires. Then the empirical equation modified for the air inflow was suggested by the authors.

Yuen, W. W. and Tien, C. L. (University of California, Berkeley, California) "A Simple Calculation Scheme for the Luminous Flame Emissivity," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1481 (1976)

Subjects: Luminous flame emissivity; Emissivity of luminous flames

Authors' Abstract

A simple expression for the total emissivity of a luminous flame has been established on the basis of a flame-radiation model that consists of gray soot and nongray gases. The gray-soot approximation is demonstrated to be an accurate characterization of soot emission from both the analytical formulation and the experimental observations. This simple model also allows a comparative analysis of soot

emission characteristics in flames produced by various common solid and gaseous fuels. The present calculations for the luminous-flame emissivity show excellent agreement with existing experimental data and exact analysis.

H. Chemical Aspects of Fires

Baldwin, R. R., Bennett, J. P., and Walker, R. W. (The University, Hull, England) "Rate Constants for Elementary Steps in Hydrocarbon Oxidation," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1041 (1976)

Subjects: Hydrocarbon oxidation; Oxidation of hydrocarbons

Authors' Abstract

A review is given of the four main types of reaction which are important in determining the distribution of products in the oxidation of hydrocarbons:

(a) free-radical attack on the hydrocarbon RH;
(b) decomposition of the radical *R* by C-C homolysis;
(c) reaction of *R* radical with O_2 to form the conjugate alkene;
(d) reaction of *R* radical with O_2 to give O-heterocycles and other oxygenated products.

Rate constants for these types of reaction, obtained from studies of the oxidation of C_2-C_4 hydrocarbons and neopentane, are applied to predict the yields of products in the oxidation of pentane.

Becker, H. A. and Yamazaki, S. (Queen's University, Kingston, Ontario, Canada) "Soot Concentration Field of Turbulent Propane — Air Diffusion Flames," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 681 (1976) See Section G.

Biordi, J. C., Lazzara, C. P., and Papp, J. F. (U.S. Bureau of Mines, Pittsburgh, Pennsylvania) "An Examination of the Partial Equilibrium Hypothesis and Radical Recombination in 1/20 Atmosphere Methane Flames," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1097 (1976) See Section G.

D'Alessio, A., Di Lorenzo, A., Borghese, A., Beretta, F., and Masi, S. (Universita Napoli, Italy) "Study of the Soot Nucleation Zone of Rich Methane-Oxygen Flames," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 695 (1976) See Section G.

Damant, G. H. (Flammability Research Laboratory, State of California, Sacramento, California) "The Effects of Aging on Fire Retardant Flexible Polyurethane Foams Commonly Used in Upholstered Furniture," Department of Consumer Affairs, *Bureau of Home Furnishings Laboratory Report SP-76-7*, State of California (October 1976) See Section A.

Dixon-Lewis, G. and Simpson, R. J. (The University, Leeds, England) "Aspects of Flame Inhibition by Halogen Compounds," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1111 (1976) See Section E.

Dobbs, A. J., Phil, D., and Grant, C. (Building Research Establishment, Princes Risborough, Buckinghamshire, England) "Report on the Burning of Wood Treated with Wood Preservatives Containing Copper, Chromium and Arsenic," *Building Research Establishment Current Paper 63/76*, Princes Risborough Laboratory (1976)

Subjects: Burning of treated wood; Copper wood preservatives; Chromium wood preservatives; Arsenic wood preservatives

Authors' Abstract

Mixtures of copper, chromium and arsenic salts are used extensively in the UK to preserve timber. This report is concerned with the fate of these metals when timber treated with these salts is burned. A large percentage of the arsenic present in the timber is shown to be volatilised during combustion and the potential environmental implications of this are assessed by comparison with the release of arsenic during coal burning. From this assessment it is concluded that burning of treated wood is unlikely to add significantly to the quantity of arsenic present in the atmosphere, although the concentration of arsenic in the discharged flue gases could give rise to local problems. Much of the arsenic and the chromium that remains in the ash is in the water soluble form and the possible implications of this are discussed. Recommendations based on findings reported here have been made to the Directorate General Water Engineering for consideration by the Arsenic Wastes Working Party which will be producing guidelines for the disposal of treated wood under the Control of Pollution Act 1974.

Fenimore, C. P. (General Electric Company, Schenectady, New York) "Reactions of Fuel Nitrogen in Rich Flame Gases," *Combustion and Flame 26* 249-256 (1976)

Subjects: Flame structure; Fuel nitrogen reaction; Kinetics; Rich flame gases

Author's Abstract

Fuel-nitrogen fed as ammonia or as pyridine to rich flames is mainly present in the burnt gas in the forms HCN, NH_3, NO, and N_2. The HCN decays in this region

to form more NH_3, and the NH_3 (or species equilibrated with NH_3) undergoes two types of reactions: an oxidation to NO at rate R_1, reaction with NO to form N_2 at rate R_2. The total remaining fuel-N not yet converted to NO or N_2, i.e. RN = HCN + NH_3, therefore decays in accordance with

$$-d[RN]/dt = R_1 + R_2,$$

and the simultaneous change in NO is

$$d[NO]/dt = R_1 - R_2.$$

Empirically, these rates can be expressed in mole/cm^3 sec as

$$R_1 = \frac{5 \times 10^{12}[H_2O]^2[NH_2]}{[H_2]} \exp(-20 \text{ kcal}/RT)$$

$$R_2 = 9 \times 10^{12}[NO]\,[NH_2].$$

R_1 is not readily interpreted in terms of elementary reactions: R_2 is the rate of $NO + NH_2 \rightarrow N_2 + H_2O$. The findings are not necessarily valid in the primary reaction zone where other processes also occur. To the extent that all the fuel-N added to rich flames attains NO and N_2 in accordance with R_1 and R_2, however, the yield of NO is predictable a priori. The prediction agrees roughly with the yields observed.

Fire Problems Program: Quarterly Report, October - December 1976, Applied Physics Laboratory, The Johns Hopkins University, Laurel, Maryland, APL/JHU FPPQ-2-76, under grant from the National Fire Prevention and Control Administration. Program Director: A. G. Schulz; Principal Investigators: R. M. Fristrom and W. G. Berl, See Section K.

George, C. W., Blakely, A. D., and Johnson, G. M. (Intermountain Forest and Range Experiment Station, Ogden, Utah) "Forest Fire Retardant Research: A Status Report," *U.S.D.A. Forest Service General Technical Report INT-31* (1976) See Section A.

Gonzalez, F. S. and Sandler, S. (University of Toronto, Ontario, Canada) "An Experimental Study of the Oxidation of *n*-Pentane in the High Temperature Pre-Ignition Region," *Combustion and Flame 26* 35-44 (1976)

Subjects: Pentane; Oxidation; Ignition; Kinetics; Pyrolysis

Authors' Abstract

The gas-phase oxidation of *n*-pentane-air mixtures in the high temperature pre-ignition region (500-620°C) was studied at levels of conversion maintained at low values (0.5-6.1%) by using an annular flow reactor and very short residence times. Among the sixteen products identified and quantitatively monitored by gas chromatography and other methods were lower hydrocarbons, aldehydes, ketones

and such cyclic ethers as 2-methyltetrahydrofuran, 2, 4-dimethyloxetan and 2-ethyloxetan. Pentyl and peroxypentyl radicals were judged to be the first intermediates of the reaction and their pyrolysis to account for more than 40% of the *n*-pentane reacted at 520°C and 70% at 620°C. The contribution of the pentyl radical to this pyrolysis increased markedly with temperature. The mechanism proposed for the formation of the products is a relatively simple one involving a series of internal isomerization reactions of the peroxy and alkyl radicals, following a scheme put forward by Fish.

Graham, S. C. (Shell Research Limited, Chester, England) "The Collisional Growth of Soot Particles at High Temperatures," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 663 (1976) See Section G.

Gukasyan, P. S., Mantashyan, A. A., and Sayadyan, R. A. "Detection of High Concentrations of Radicals in the Cool Flame Zone in the Propane Oxidation Reaction," *Fizika Goreniya Vzryva 12* (5) 789-792 (1976) (in Russian) See Section G.

Hall, C. "Chemistry and Construction," *Chemistry in Britain 12* (10) 713-720 (October 1976)

Subjects: Construction fire risk; Fire risk of construction

Safety in Mines Abstracts 25 No. 1230
Safety in Mines Research Establishment

Examines the risk of fire and of structural failure in relation to choice and costs of construction materials.

Kaskan, W. E. and Reuther, J. J. (State University of New York at Binghamton, New York) "Limiting Equivalence Ratio, Dissociation, and Self-Inhibition in Premixed, Quenched, Fuel Rich Hydrocarbon Air Flames," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1083 (1976) See Section E.

Kisilyakhov, E. K. and Konev, E. V. (Forest and Wood Institutes, Siberian Section, Academy of Sciences USSR, Krasnoyarkh) "Evaluation of the Fire Extinguishing and Fire Retarding Efficiency of Chemical Agents," *Fizika Goreniya Vzryva 12* (6) 497-502 (1976) (in Russian) See Section A.

Mach, M. H. "Gas Chromatography-Mass Spectrometry of Simulated Arson Residue Using Gasoline as an Accelerant," *J. Forensic Sci. 22* (2) 348-357 (1977)

Subjects: Arson; Forensic science, gasoline; Gas chromatography; Mass spectrometry; Polyaromatic hydrocarbons

Author's Conclusions and Summary

A number of gasoline residue samples generated under a wide variety of conditions show the presence of specific PAH. Computerized gas chromatography-mass spectrometry with methane chemical ionization has been used to characterize samples of simulated arson residue derived from gasoline by distillation, evaporation, and combustion. The more concentrated samples show the presence of higher PAH not seen in the original gasoline or the early distillation residues. If these materials can be distinguished from compounds derived from wood, plastics, and other fire debris, routine analytical techniques can be developed, based on the presence of these characteristic PAH, to determine whether or not gasoline was used as an accelerant in a suspected arson case.

Manelis, G. B. and Smirnov, L. P. (Chernogolovka Section of the Physical Chemical Institute of the Academy of Sciences, USSR) "Experimental Study of Polymerization Processes under Nonisothermal Conditions," *Fizika Goreniya Vzryva 12* (5) 665-669 (1976)

Subject: Polymerization processes

Abstracted by L. Holtschlag

This paper presents results of an experimental study of polymerization under nonisothermal conditions (the macrokinetics of polymerization) in a periodic reactor without mixing and compares these results with the conclusions of a theory previously developed by the authors.

Masarik, I. (Fire Research Laboratory, Prague, Czechoslovakia), **Rysak, M., Svetlik, J.** (Academy of Sciences, Prague, Czechoslovakia), **and Horak, Z.** (Research Institute of Synthetic Rubber, Kaucuk Kralupy, Czechoslovakia) "The Use of the Setchkin Apparatus — Mass Spectrometry in the Investigation of Ignition and Burning of Flame Retarded Polystyrenes," *Fire and Materials 1* (4) 129-133 (1976) See Section B.

Michal, J. (Ore Research Institute, Praha, Czechoslovakia), **Mitera, J.** (Institute of Chemical Technology, Praha, Czechoslovakia) **and Tardon, S.** (Coal Research Institute, Ostrava-Radvanice, Czechoslovakia) "Toxicity of Thermal Degradation Products of Polyethylene and Polystyrene," *Fire and Materials 1* (4) 160-168 (1976) See Section K.

Morikawa, T. (Fire Research Institute, Mitaka, Tokyo, Japan) "Evolution of Acrolein and Formaldehyde in Smoldering Combustion," *Bulletin of the Japanese Association of Fire Science and Engineering 26* (1) (1976) (in Japanese)

Subjects: Smoldering combustion; Acrolein; Formaldehyde

Author's Abstract

Recently problems of smoke from fires have been of growing concern. The irritative effect of smoke is one of the problems. Acrolein and formaldehyde are considered two of the most irritative materials among combustion products of organic materials which consist only of carbon, hydrogen, and oxygen. The present study concerns the extent of these products evolved from combustion and pyrolysis of synthetic and natural polymers. The evolution of acrolein was the highest at 350-450°C (below the flaming temperature) while air was supplied to the electric cylindrical furnace. However, when nitrogen gas was supplied, while heating oxygen-containing materials, maximum evolution of acrolein occurred at 600°C.

The materials which evolved the maximum amount of acrolein, 0.5-3.5 mol per gram of material, when heated at optimum temperature, were in the order: polyethylene, polypropylene, vinylon, and cellulose. The amount of acrolein is only one tenth of the amount of formaldehyde evolved, but the toxicity of acrolein is only one tenth of the amount of formaldehyde evolved, but the toxicity of acrolein is twenty times greater than formaldehyde. Therefore, the evolution of acrolein can be said to be more dangerous than that of formaldehyde. For materials containing no oxygen, it is considered that oxygen atoms are supplied from the atmosphere. However, in the case of cellulosic materials it is indicated that most of the oxygen atoms contained in acrolein molecules come from cellulosic materials themselves.

Only materials which would continue to smolder in the normal atmosphere were subjected to the smoldering experiments under more practical conditions, where specimen was kept contact with a heated nichrome wire, in order to determine the evolution of acrolein and formaldehyde. The experiment results showed that the amounts of both acrolein and formaldehyde from cellulosic materials were 1/2-1/3 of the greatest amount obtained from the furnace experiments. The figures are still not too small and considered to be at a dangerous level. In order to know the theoretical extent of which the toxic level in an average size room increases with time, the concentrations of acrolein and formaldehyde in a 25 m^3 room versus time were calculated from the smoldering rate of cotton batting and the ventilation rate of the room (1 air change per hour). It was found that a considerably hazardous condition could be reached even before flaming occurs.

Morikawa, T. (Fire Research Institute of Japan, Tokyo, Japan) "Evolution of Irritant Materials from Smoldering Combustion," *Report of the Fire Research Institute of Japan No. 41,* 63-75 (1976) See Section K.

Prado, G. P., Lee, M. L., Hites, R. A., Hoult, D. P., and Howard, J. B. (Massachusetts Institute of Technology, Cambridge, Massachusetts) "Soot and Hydrocarbon Formation in a Turbulent Diffusion Flame," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 649 (1976) See Section G.

Saito, N. and Yanai, E. (Fire Research Institute of Japan, Tokyo, Japan) "Weight Loss Rates of Polymers Pyrolyzed Isothermally at High Temperatures in Air Flow, Part I. Cellulose, Rayon, and Polyester Fiber," *Report of the Fire Research Institute of Japan No. 42* 26 (1976) See Section G.

Skinner, G. A., Parker, L. E. and Marshall, P. J. (Kingston Polytech, Kingston, Surrey, England) "Flame Retardant Synergism Between Molybdenum and Halogen Containing Compounds in Unsaturated Polyesters," *Fire and Materials 1* (4) 154-159 (1976) See Section A.

Smoke and Other Products of Combustion, National Fire Protection Association Publication SPP-41, Boston, Massachusetts (1976) See Section J.

Sumi, K. and Tsuchiya, Y. (National Research Council of Canada, Ottawa) "Evaluating Toxicity of Decomposition Products from Analytical Data," *Division of Building Research Paper No. DBR 711*, National Research Council of Canada (1976) See Section K.

Takahashi, S. (Fire Research Institute of Japan, Tokyo, Japan) "New Wet Method Synthesis of Potassium Superoxide," Report of *the Fire Research Institute of Japan No. 40,* 17-29 (1975) (in Japanese)

Subjects: Potassium superoxide; KO_2

Author's Abstract

A new wet process for the synthesis of potassium superoxide (KO_2) has been investigated on a laboratory scale. This process was successfully expanded to a large scale test for possible commercial production. In order to explain the experienced phenomena of the synthesis, a thermodynamic investigation was also performed experientally as well as theoretically.

1. Synthesis Process

The apparatus used in the synthesis of KO_2 is shown in Figure 1. Potassium hydroxide granules or a paste of potassium hydroxide was reacted with aqueous hydrogen peroxide under reduced pressure to remove water with heat, both harmful for the latter reaction. When boiling had subsided, the temperature of the reaction vessel was maintained as slightly below 40°C to remove H_2O. Next, the temperature of solid $K_2O_2(2 + n)H_2O_2(S)$ ($n \geqq O$) was raised between 50 and 63°C at the rate 2-3°C/min, to bring the whole mass of solid complete dryness and suitable to initiate disproportionation. As a final process, the solid was kept at this temperature for a short time, and was heated locally to initiate disproportionation to form KO_2. A larger scale test for possible industrial application was also performed successfully by the same principle. The photos and the schematic of the reaction chamber are shown in photos and in Figure 2;

The temperature curve from the mixing state to disproportionation is illustrated in Figure 3; and

The relationship between KO_2 yield versus Molar ratio $[H_2O_2]/[KOH]$ is shown in Figure 4.

2. Thermodynamics of Synthesis

The enthalpy ($\triangle H$) of formation and molentropy (S) of $K_2O_2\,(2+n)H_2O_2(S)$ ($n \geqq 0$) was determined theoretically and experimentally to explain the experienced phenomena of the synthesis described above. The theoretical value of enthalpy ($\triangle Ht$) agreed closely with the experimental value of enthalpy ($\triangle He$) as follows.

$$\triangle Ht = -220.7 - 51.35n \text{ (Kcal/mol)}$$
$$\triangle He = -230.8 - 45.8n \text{ (Kcal/mol)}$$

The molentropy was theoretically calculated as,

$$St = 30.86 + 2.43n \text{ (cal/mol.deg)}$$

It is then possible to calculate the necessary concentration of KOH and H_2O_2 from the said enthalpy, and at the same time, explain the experienced phenomena of the heat balance. Furthermore, the disproportionation temperature required to produce KO_2 under reduced pressure was calculated and agreed closely with the experimental data.

Trujillo, D. P. (Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado) "Chemical Properties of Chaparral Fuels Change During Preheating Before Flaming," *U.S.D.A. Forest Service Research Note RM-320* 2 pp (August 1976)

Subjects: Flammability of chaparral fuels; Chaparral fuel flammability

Author's Abstract

Two chaparral species, pointleaf manzanita (*Arctostaphylos pungens* H.B.K.) and shrub live oak (*Quercus turbinella* Greene), were analyzed for certain chemical properties known to influence flammability. Half of each sample was analyzed before heating, and the other half after heating for 5 minutes. The losses of crude fat, heat of combustion, and phosphate-phosphorus were statistically significant.

Tsuchiya, Y. and Sumi, K. (National Research Council of Canada, Ottawa) "Determination of Hydrogen Cyanide in Fire Gases," *Journal of Combustion Toxicology 3* 363-370 (November 1976)

Subjects: Fire gases; Hydrogen cyanide determination

Authors' Abstract

Many of the nitrogen containing polymers produce HCN when involved in fires. Various methods of HCN determination in fire gases are reviewed. The methods discussed are colorimetric tubes, specific ion electrode, wet chemical analysis and

gas chromatography. Two common problems in HCN determination are concentration decrease by absorption and interferring reactions. Authors recommend that at least two different methods be employed in order to avoid errors caused by interference and absorption.

Westley, F. (National Bureau of Standards, Washington, D.C.) "Chemical Kinetics of the Gas Phase Combustion of Fuels: A Bibliography on the Rates and Mechanisms of Oxidation of Aliphatic C_1 to C_{10} Hydrocarbons and Their Oxygenated Derivatives," *Final Report 1902-1975,* National Bureau of Standards NBS SP-449 for the Navy Department and Energy Research and Development Administration (October 1976)

Subjects: Gas phase combustion; Combustion, gas phase; Chemical kinetics; Kinetics of combustion; Hydrocarbon combustion

Author's Abstract

A reaction oriented list of references is provided for papers and reports containing rate data for gas phase reactions of combustion and oxidation of aliphatic saturated or unsaturated C_1 to C_{10} hydrocarbons, alcohols, aldehydes, ketones, ethers, peroxides and their free radicals. The list also includes decomposition, disproportionation, atom transfer and recombination reactions of the oxygen containing species noted above. Pyrolytic reactions of hydrocarbons and their radicals are excluded. All the processes listed here have been reported to occur in the gas phase combustion of fuels. In addition, a list of critical reviews dealing with the reaction kinetics of the above processes and a list of papers dealing with generalized mechanisms of the same reactions are also included. More than 800 papers covering 540 reactions are listed. The period covered extends from 1902 through June 1975.

Woolley, W. D. and Fardell, P. J. (Joint Fire Research Organization, Borehamwood, Herts., England) "Formation of Highly Toxic Organophosphorus Product (TMPP) During the Decomposition of Certain Polyurethane Foams under Laboratory Conditions," *Fire Research Note No. 1060*, Joint Fire Research Organization (November 1976)

Subjects: Polyurethane foam decomposiiton; Decomposition of polyurethane foams; Toxic organophosphorus products

Authors' Summary

Details are given of a method for the decomposition of small quantities of polyurethane foam and the collection and direct analysis of a highly toxic bicyclic phosphorus compound (termed TMPP) produced from the thermal decomposition of foams containing trimethylol propane polyols in combination with phosphorus-containing additives.

A range of typical commercial flexible and rigid polyurethane foams and polyisocyanurates available in the United Kingdom up to and including the period of

1974 to 1975 when the problem was first identified by bioassay tests, have been tested for potential TMPP release. Flexible and rigid polyurethane foams yield zero to 0.004 and zero to 0.003 weight per cent conversion of foam to TMPP respectively at 500°C. The polyisocyanurate foams show two distinct ranges of zero to 0.003 and 0.1 to 0.15 weight per cent conversion.

A detailed study has been carried out with the polyisocyanurate foams which fall in the high yield range to monitor the temperature dependence of TMPP production in both nitrogen and air atmospheres. The optimum temperature of formation is 600°C in nitrogen and 500°C in air. The maximum temperature at which TMPP is released is about 800°C in nitrogen and 700°C in air which is consistent with the thermal stability of TMPP obtained during direct experiments with TMPP alone. This work is of a laboratory nature and supplements other work being carried out internationally to evaluate the overall hazard associated with the release of TMPP from foams under fire situations.

Williams, F. A. (University of California, San Diego, La Jolla, California) "Mechanisms of Fire Spread," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1281 (1976) See Section G.

Zellner, R., Erler, K., and Field, F. (Institute for Physical Chemistry, University of Gottingen, West Germany) "Kinetics of the Recombination Reaction OH+ H + M→ H_2O + M at Low Temperatures," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 939 (1976)

Subjects: Kinetics of recombination; OH and O recombination

Authors' Abstract

A discharge flow resonance fluorescence technique (for the detection of OH) was used to determine the absolute rate of the reaction (1) OH + H + M → H_2O + M for M = He (in the range T = 230-300° K) and for M = Ar, N_2 and CO_2 (at 300° K). At total pressures between 3-11 torr reaction (1) is in its third-order regime, where it can be separated from the second-order (heterogeneous) recombination reaction (2) OH + H → H_2O. Specific rate constants, k_1 at 300° K (in units of 10^{-31} cm^6/molecule^2·s) are: 1.5, 2.3, 4.8, and 9 for M = He, Ar, N_2, and CO_2. The temperature variation of k_1 for M = He can be represented by $k_1 = 4.3 \times 10^{-25}\,T^{-2.6}$ cm^6/molecule^2·s. The rate constant k_2 was found to be 2.7×10^{-14} cm^3/molecule·s and independent of temperature.

A comparison of k_1 with results from high temperature flame and shock tube experiments on both reaction (1) and the reverse dissociation shows that low and high temperature data can be correlated in terms of a T^n dependence, with n being 2.0-2.2. Predictions of k_1 by unimolecular rate theory of the low pressure limiting rate constant are in good agreement with our result.

I. Physical Aspects of Fires

Alpert, R. L. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Pressure Modeling of Fires Controlled by Radiation," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1489 (1976) See Section M.

Corrie, J. G. (Joint Fire Research Organization, Borehamwood, Herts., England) "Measuring the Shear Stress of Fire-Fighting Foams," *Fire Research Note No. 1055,* Joint Fire Research Organization (August 1976) See Section E.

Cox, G. (Building Research Establishment, Borehamwood, Herts., England) "Some Measurements of Fire Turbulence," *Fire and Materials 1* 116-122 (1976)

Subjects: Fire turbulence measurement; Turbulence from fire

Author's Abstract

It is important to be able to predict the rate of smoke and fire spread in buildings in order to optimize the design of escape routes and the siting of detectors and sprinklers. The available mathematical procedures based on turbulence models require experimental guidance. This paper describes the measurement of some turbulence parameters in smoke and flame plumes moving under a ceiling. Time correlation techniques are applied to signals obtained from thermocouple and Langmuir probes. Space-time correlations in the hot layer show similar trends to those in decaying isotropic turbulence from wind tunnels but superimposed upon a coherent sine wave produced by vortex shedding at the fire. Data are also presented of the probability of chemical reaction at several locations in the hot layer.

George, C. W. and Johnson, C. W. (Northern Forest Fire Laboratory, Missoula, Montana) "Revised Marsh Funnel Calibrations for Measuring Fire Retardant Viscosity," *U.S.D.A. Forest Service Research Note INT-205* (1976) See Section A.

Guenther, D. A., McGarry, D. L., Shearer, R. P., and MacCleary, R. C. "Fire Analyses from Mechanical Properties," *Fire Technology 12* (3) 172 (1976)

Subjects: Fire; Fire cause analysis; Fire tests

Journal Abstract

Often after a severe fire, evidence of a flammable liquid cannot be accurately determined. It is, therefore, imperative that some additional physical measurement be made on something that is remaining. Pieces of metal are left after a fire. It has been proposed that the tensile properties of the metal woud certainly change with extremes of temperature. If certain limits could be established that would allow predictions to be made regarding the temperature to which a certain piece of metal had been subjected, the fire investigator could make a decision based upon what temperatures could be expected in a normal fire and one that was accelerated. This paper is a preliminary investigation into the feasibility of determining fire causes by analysis of tensile properties of metals.

Handa, T. and Morita, M. "Characterization of Smoke Motion in the Building Fire, II. Numerical Solutions of the Heat Flow Pattern in the Fire," *Bulletin of the Japanese Association of Fire Science and Engineering 26* (2) 29 (1976) (in Japanese) See Section J.

Jin, T., Shimada, H., and Takemoto, A. (Fire Research Institute of Japan, Tokyo, Japan) "Experiment on Smoke in Pressurized Staircase," *Report of the Fire Research Institute of Japan No. 40,* 35-42 (1975) (in Japanese) See Section A.

Maries, K. (Building Research Establishment, Borehamwood, Herts., England) "Prediction of Thermal Conductivity of GRP Laminates," *Building Research Establishment Current Paper 70/76,* Fire Research Station (1976)

Subjects: GRP laminates; Thermal conductivity of laminates

Author's Abstract

The prediction of thermal conductivity in GRP laminates from five theoretical models are compared with the experimental results for five different types of glass reinforcement. One model is shown to predict values within ± 3 percent of experimental data for all the samples except for non-planar, chopped strand, reinforcement, where the prediction was low.

Markstein, G. H. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Scaling of Radiative Characteristics of Turbulent Diffusion Flames," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1407 (1976)

Subjects: Diffusion flames; Turbulent flame; Flame radiation scaling

Author's Abstract

The following measurements were performed on single buoyancy-controlled turbulent propane diffusion flames within the range $44 \leq q \leq 412$ cm^3/s of fuel flow rate q:

1) total radiative power P, determined with a wide-view-angle radiometer,
2) total radiative power ΔP emitted by a horizontal flame slice of known height

$\triangle z$, measured with a wide-view-angle radiometer that looks at the flame through a horizontal slit, and

3) radiance emitted along a flame diameter, N_{max}, measured with a collimated beam radiometer. The latter two quantities were measured simultaneously as functions of height z above the burner nozzle over the entire length L of the flame. Total radiative power was found to scale with the first power of flow rate, $P = \chi Q = \chi \triangle h_c q$, where the fraction χ of total rate of heat release Q emitted as radiation was 0.264 and $\triangle h_c$ = 86.821 J/cm^3 is the heat of combustion per unit volume of fuel. From the local radiative properties $S = \triangle P/\triangle z$ and N_{max}, flame diameter $D = \pi^{-2} S/N_{max}$ and volumetric radiant power $p = 4\pi^3 N^2_{max}/S$ were derived. It was found further that the dependence of the data on flow rate q could be scaled by power law relationships, with the dependence on height z expressed by two dimensionless functions $s(\zeta)$, $n(\zeta)$ of the dimensionless height $\zeta = z/L$, as follows:

$$L = Cq^{\lambda} \text{ (cm) } (q \text{ in cm}^3/\text{s})$$

$$D = q^{\delta} s(\zeta)/n(\zeta) \text{ (cm)}$$

$$p = Iq^{\kappa} n^2(\zeta)/s(\zeta) \ (W/\text{cm}^3)$$

$$S = (\pi I/4)q^{1-\lambda} s(\zeta) \ (W/\text{cm})$$

$$N_{max} = (I/4\pi)q^{\delta+\kappa} n(\zeta) \ (W/\text{cm}^2\text{sr})$$

Here, the coefficients have the values $C = 9.374$, $I = 3.117$, the exponents for flame length, flame diameter and volumetric radiant power are $\lambda = 0.4516$, $\delta = 0.3547$, and $\kappa = -0.1610$, respectively, and $s(\zeta)$, $n(\zeta)$ are bell-shaped functions that have near-zero values at $\zeta = 0$ and $\zeta = 1$ and the maxima $s = 2.17$ at $\zeta = 0.45$, $n = 1.30$ at $\zeta = 0.43$. 8th degree polynomials for these functions are presented.

McQuaid, J. (Safety in Mines Research Establishment, Sheffield, England) "Air Entrainment into Bounded Axisymmetric Sprays," *Proceedings Institution Mechanical Engineers 189* (28) 197-202 (1975)

Subjects: Entrainment in sprays; Spray air entrainment

Author's Abstract

The entrainment of air into a conical spray centered on the axis of a short tube is investigated. Dimensional analysis successfully correlates the experimental results of both the present and previous investigations for the case of an unrestricted system. The case where the spray operates against a back pressure, such as might be represented by a length of ducting connected to the outlet, is also considered. Morton's analysis of entrainment into the wake of an isolated body is adapted and some agreement is obtained with experimental results for small flight distance of the drops.

Morgan, H. P. and Marshall, N. R. (Building Research Establishment, Borehamwood, Herts., England) "Smoke Hazards in Covered, Multi-level Shopping

Malls: Part I. An Experimentally Based Theory for Smoke Production," *Building Research Establishment Current Paper 48-75*, Fire Research Station (1975) See Section M.

Sellman, L. G., Ostman, B. A., and Back, E. L. (Swedish Forest Products Laboratory, Stockholm, Sweden) "Methods of Calculating the Physical Action of Flame Retardants," *Fire and Materials 1* 85-89 (1976) See Section G.

Williamson, H. V. "Halon 1301 Flow in Pipelines," *Fire Technology 11* (4) 18-32 (November 1975) See Section E.

Yuen, W. W. and Tien, C. L. (University of California, Berkeley, California) "A Simple Calculation Scheme for the Luminous Flame Emissivity," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1481 (1976) See Section G.

Yumoto, T. (Fire Research Institute of Japan, Tokyo, Japan) "The Effect of the Convective Motion in the Liquid on the Liquid Burning Rate," *Report of the Fire Research Institute of Japan No. 41* 16-32 (1976) (in Japanese)

Subjects: Convection in burning liquids; Liquid burning, convection in

Author's Abstract

An experimental study was made to explore the effect of the convective motion in the liquid on the burning rate of hexane. Hexane was burned in the cylindrical glass vessel of 26mm in diameter, and the convective motion in the liquid and the cellular convection near the liquid surface were observed by means of particle tracer technique and shadow photography, respectively. Measurements were further made on burning rate of liquid, the radiation flux from the flame to the liquid surface, and on temperatures in both the liquid and the vessel wall.

From these data the explanation of the mechanism of combustion accompanying the convective motion of the liquid in the vessel was made and following equations for predicting the burning rate of liquid fuel were obtained.

1) The first half of combustion (Up to 4 minutes after ignition)

$$\frac{R_b dC_l}{\lambda_l} = 0.755 Pe^* \left(\frac{Ma}{Ra}\right)^{\frac{1}{6}} \quad (1)$$

$$Pe^* = Re^* Pr, \; Re^* = \frac{u^*_{max}\delta_{min}}{\nu}$$

2) The second half of combustion (Over 4 minutes after ignition)

$$\frac{R_b dC_l}{\lambda_l} = 0.956 Pe^* \left(\frac{Ma}{Ra}\right)^{-\frac{1}{4}} \quad (2)$$

Equation (2) was rewritten to the same form, Eq. (3), as Spalding's equation predicting the burning rate of liquid fuel, and the Transfer number B_l was defined by the physical properties of the liquid and the scale of the convective motion of the liquid.

$$\frac{R_b d C_l}{\lambda_l} = 0.45 B_l^{\frac{3}{4}} Gr_{(l)}^{\frac{1}{4}} \tag{3}$$

$$B_l = 2.731 Pe^{*\frac{4}{3}} Ma^{-\frac{1}{3}} Pr^{\frac{1}{3}}$$

J. Meteorological Aspects of Fires

Alexander, M. E. (Canadian Forest Service, Sault Ste. Marie, Ontario) **and Hawksworth, F. G.** (Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado) "Fire and Dwarf Mistletoes in North American Coniferous Forests," *Journal of Forestry 74* (7) 446-449 (July 1976)

Subjects: Wildfire ecology; Mistletoe spread by fire

Authors' Abstract

Wildfires play a multiple role in the distribution of dwarf mistletoes. They may either inhibit or encourage these parasites, depending primarily on the size and intensity of the burn. Fire exclusion policies of the past half century have increased both infection levels and fire hazard. Prescribed burning seems applicable in some forest types and stand conditions to remove infected residuals in cutover areas or to eliminate heavily infested unmerchantable stands.

Cox, G. (Building Research Establishment, Borehamwood, Herts., England) "Some Measurements of Fire Turbulence," *Fire and Materials 1* 116-122 (1976)
See Section I.

Davis, J. R. and Dieterich, J. H. (Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado) "Predicting Rate of Fire Spread in Arizona Oak Chaparral: Field Workbook," *U.S.D.A. Forest Service Technical Report RM-24* (1976)

Subjects: Rate of fire spread; Prescribed fire; Fire spread in oak chaparral

Authors' Abstract

To facilitate field use of the rate of fire spread equation used in Arizona oak chaparral, step by step instructions are presented in workbook form. Input can be either measured or estimated from the tables and figures included; a sample computation form may be duplicated for field use. Solving the equation gives the land manager the guidelines for planning fire control efforts, or for using prescribed fire in the brush type.

Fosberg, M. A., Marlatt, W. E., and Krupnak, L. (Rocky Mountain Forest and Range Experimental Station, Fort Collins, Colorado) "Estimating Airflow Patterns Over Complex Terrain," *U.S.D.A. Forest Service Research Paper RM-162* (1976)

Subjects: Wind; Boundary layer; Air pollution; Fire weather

Authors' Abstract

A simple one-layer model of atmospheric boundary layer flow was developed for use in complex terrain. The model was derived through simplification of the fundamental Navier-Stokes flow equations.

Although the equations do not describe all flow characteristics, the resultant solution describes a diagnostic model of the vector flow field. It requires much less data than traditional approaches.

The intended primary uses for this model are in providing wind fields for fire behavior prediction and in evaluation of pollution transport patterns.

Furman, R. W. and Brink, G. E. (Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado) "The National Fire Weather Data Library: What It Is and How To Use It," *U.S.D.A. Forest Service General Technical Report RM-19* (1975)

Subject: Fire weather

Author's Abstract

The National Fire Weather Data Library is a collection of daily weather observations from fire weather stations across the Nation. Current data are accumulated on collection tapes, then merged onto library tapes annually. Example run streams are given for using the library on the UNIVAC 1108 computer at the Fort Collins Computer Center.

Handa, T., Hamada, T., Sugawa, O., Fukaya, H., and Akiyama, T. (Science University of Tokyo, Japan) "Studies on the Motion and the Thermal Behaviors of Fire Products Through the Scale Corridor: Experimental Study on the Thermal Flow through the Full Scale Corridor," *Bulletin of the Japanese Association of Fire Science and Engineering 26* (2) 1 (1976) (in Japanese)

Subjects: Fire products in corridors; Thermal flow of fire products; Corridor flow tests

The time-dependent behavior of the shallow flow of hot fire products were studied by using full scale corridors of different size (A: 13 m(L) × 1.5 m(B) × 2.5 m (H), B: 70 m(L) × 3.3 m(B) × 1.8 m(H) and by taking wood cribs as the model fire source. Cribs were placed at the end of both corridors and were ignited by a small pilot-flame at the bottom center to obtain similarity for the growth of flame. The weight and maximum burning rate of the cribs were 5 kg and 20 kg, 5 g/sec and 20 g/sec for A and B corridor respectively.

The smoke concentration (Cs) was defined by the turbidity in units of 1/m. The gas concentrations were represented by the output of the gas-sensor (Cg) in units of mV which were replaced by [CO] in the combustion gases in terms of the calibration curve. By taking CO as a labelled gas, the concentration of CO_2 was estimated from Cg on the basis of $[CO]/[CO_2]$ at the fire source, obtained by high precision I. R. measurement.

The origin for the horizontal flow corresponding to the point of the hydraulic jump was determined by the break of the logarithmic plots of T/Too vs. travelling distance, where Too was the temperature at the surface of the crib and T the temperature along the center of the fire plume or 10 cm beneath the ceiling of the corridor. As results, starting position (X = 0) was taken at 2.5 m from the center of the crib for B corridor. Then, cartesian co-ordinates (x,y) were taken with the abcissa along the corridor and the aforesaid starting position as the origin and with the ordinate in the vertical direction (y = 0 on the ceiling).

The following results were obtained:

(1) Relations in the equation (1) and (2) were obtained at and around the fire source between $\bar{T}_f$–, $\bar{T}_o$–, and $\bar{V}_o$– irrespective of time,

$$(\bar{T}_o - T_R)/(\bar{T}_f - T_R) = 0.2 \quad (1)$$

$$\bar{V}_o / \sqrt{(\bar{T}_f - T_R) - T_c} = 0.03 \quad (2)$$

where $\bar{T}_o$–, $\bar{T}_f$–, $\bar{T}$–, and T_R– are the height-average temperature of the fire plume, thickness-averaged temperature of the flow at X = 0, the critical temperature for the efflux motion and the ambient temperature, respectively. $\bar{V}_o$– was the thickness-averaged velocity at X = 0.

(2) The constancy of the flow thickness (δ_v) of ca. 0.2 m at X = 0 and of ca. 0.3 m at arbitrary X (X—35 m) was observed vs. time before the flow reached the opposite end of the closed B corridor (7 min. after the ignition).

(3) A disymmetrical triangular-shaped profile was obtained for the Y-distribution of velocity. However, a top-hat like profile tailing exponentially toward the floor was observed for the temperature.

(4) It was estimated that the flow was relatively shallow on the basis of equation (3).

$$B\delta_v/(B + 2\delta_v) \simeq 0.2 \quad (3)$$

(5) An exponential decrease of V and T at arbitrary y within δ_v and of Cg at y = 0.1 m were obtained along the corridor direction respectively.

(6) The flow behavior of quantity along the corridor was discussed in terms of the Y-averaged quantity, defined by following equation.

$$\bar{A}(X,t) = \frac{1}{\delta_v} \int_0^{\delta_v} A(X,y,t)dy \quad (4)$$

However, the stretch-out of Cs-concentration terrace vs. X was observed intermittantly before 7 min. and the obvious accumulation of smoke around X = 35 m was recognized after 7 min.

(7) Finally, in order to discuss the flow behavior in relation to the time-dependent change of the burning rate, the following transformation of the quantity A (x,t) to the parametric quantity A(x,τ) was made pursued itinerantly and successively with time along the corridor in terms of the graphical method, based on equations (5) and (6).

$$\tau \equiv t - \sum_{k=o}^{t} \frac{|X_{k+1} - X_k|}{V_{k,\,k+1}} \tag{5}$$

$$\bar{\bar{A}}\,\Big|_{tiv\,i+1}^{ziv\,i+1} = \frac{1}{2}\left\{\bar{A}(X + \Delta X,\, t + \Delta t) + \bar{A}(X,t)\right\} \tag{6}$$

where $\bar{\bar{A}}$ is the time and space mean velocity calculated by the equation (6), t was the real time after the ignition.

Handa, T. and Morita, M. "Characterization of Smoke Motion in the Building Fire, II. Numerical Solutions of the Heat Flow Pattern in the Fire," *Bulletin of the Japanese Association of Fire Science and Engineering 26* (2) 29 (1976) (in Japanese)

Subjects: Smoke motion; Building fire; Heat flow in building fires; Numerical solution heat flow

Authors' Abstract

We shall treat the problem of a two-dimensional heat-flow of a viscous incompressible fluid within a square cross section at the building fire. The governing equations are continuity, motion, and energy. Here the equation of motion is applied to Navier-Stokes' law and Boussinesp approximation. Numerical solutions of these equations are studied using a digital computer. For investigating the mathematical and computational stability of finite difference equations, and also the physical phenomena and computational technique, a finite-difference method is applied to solve these equations.

In this paper, a finite difference equation is reduced to a partial differential equation by the backward implicit scheme, and central and upstream difference schemes. Simultaneous linear algebraic equations are solved by this method using the successive overrelaxation (S.O.R.) method with overrelaxation factor $\sigma \Delta T/X^2$ (σ is nondimensional coefficient). Initial and boundary values are defined by the experiment, and the problem was solved on the IBM SYSTEM/370 Model 135-DHO for $Re = 10^4$, $Gr = 10^8$ and $Pr = 0.72$. With these parameter values, except for $\epsilon = 10$, CPU-time was about 28 min. and elapsed time about 32 min. to depict the motion of heat flow during 7 min. when PL/I (F) is used.

Harvey, A. E., Jurgensen, M. F., and Larsen, M. J. (Intermountain Forest and Range Experiment Station, Ogden, Utah) "Intensive Fiber Utilization and

Prescribed Fire: Effects on Microbial Ecology of Forests," *U.S.D.A. Forest Service General Technical Report INT-28* (1976)

Subjects: Prescribed fire; Residue management

Authors' Abstract

Reviews current knowledge of the effect of intensive wood utilziation, prescribed burning, or a combination of both treatments, on microbial ecology of forest soils. Identifies additional research that must be done to fill voids in knowledge.

Hwang, C. C., Chaiken, R. F., Singer, J. M., and Chi, D. H. N. (U.S. Bureau of Mines, Pittsburgh, Pennsylvania) "Reverse Stratified Flow in Duct Fires: A Two Dimensional Approach," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1358 (1976) See Section G.

Jin, T. (Fire Research Institute of Japan, Tokyo, Japan) "Visibility Through Fire Smoke, Part 5. Allowable Smoke Density for Escape From Fire," *Report of the Fire Research Institute of Japan No. 42* 12 (1976)

Subjects: Fire smoke; Smoke, visibility thorugh

Author's Abstract

With a view to determining the allowable smoke density for escaping from a building fire, walking speed in smoke under various conditions was studied. The allowable density values deduced from the walking speed measurements agree approximately with those given on the basis of minimum visibility of safe escaping. The allowable smoke density will be considerably affected by a) degree of familiarity with the inside of building, b) irritation caused by the smoke, c) existence of obstacles in escape route, and so on.

Jin, T. (Fire Research Institute of Japan, Tokyo, Japan) "Decrease of Smoke Density. Part 1. Decrease of Smoldering Smoke with Time," *Report of the Fire Research Institute of Japan No. 40,* 11-16 (1975) (in Japanese)

Subjects: Smoke density; Coagulation of smoke

Author's Abstract

In the present study, observations on decrease of smoke density in a smoke chamber have been made by using a smoke density meter and baffles. The growth of smoke particle size has also been measured in case of some experiments. It seems that the decrease of smoke density in the initial time range may result mainly from the coagulation of particles for smokes obtained by smoldering wood and various plastics.

Jin, T., Shimada, H., and Takemoto, A. (Fire Research Institute of Japan, Tokyo, Japan) "Experiment on Smoke in Pressurized Staircase," *Report of the Fire Research Institute of Japan No. 40,* 35-42 (1975) (in Japanese) See Section A.

Martin, R. E., Pendleton, D. W., and Burgess, W. E. "Effect of Fire Whirlwind Formation on Solid Fuel Burning Rates," *Fire Technology 12* (1) 33-40 (February 1976)

Subjects: Fire whirlwind; Vortex; Burning rate, solid fuel; Solid fuel, burning rate

Authors' Abstract

Burning rates of Douglas fir wood were measured using crosspiled sticks, ¼, ½, ¾, and 1 inch in cross-sectional dimensions. The ¼ inch crosspiles (cribs) burned up to 4.2 times as fast with whirlwind formation as without, and 1 inch cribs, as low as 1.4 times as fast with whirlwind formation as without. Differences between size classes of crib sticks were inconsistent, perhaps due to variation in wood density, high packing ratios, and crib shape.

McCammon, B. P. "Snowpack Influences on Dead Fuel Moisture," *Forest Science 22* (3) 323-328 (September 1976)

Subjects: Fire danger; Fire season; Fuel moisture

Author's Abstract

Fuel moisture at the beginning of the season was evaluated by following the seasonal trend of moisture content of large forest fuels under a snowpack. Moisture contents at three sites throughout the period of snow cover provided data for linear regression models. The fuels approached fiber saturation during the snowpack accumulation period. The short melt period provided very little liquid water for further moisture uptake. Large dead forest fuels thus emerge from a snowpack at approximately 32 percent moisture content by weight, with a range of 23 to 39 percent.

Morgan, H. P., Marshall, N. R., and Goldstone, B. M. (Building Research Establishment, Borehamwood, Herts., England) "Smoke Hazard in Covered Multi-Level Shopping Malls: Some Studies Using a Model Two Storey Mall," *Building Research Establishment Current Paper 45/76,* Fire Research Station (1976) See Section A.

Muraszew, A., Fedele, J. B. (Aerospace Corporation, El Segundo, California), **and Kuby, W. C.** (University of California, Santa Barbara) "Investigation of Fire Whirls and Firebrands," *Report No. ATR-76 (7509)-1 for the Intermountain Forest and Range Experiment Station* under Grant INT 16, U.S.D.A. Forest Service (April 1976)

Subjects: Fire whirls; Firebrands

Authors' Conclusions

The rate of firebrand burning in flight can be expressed by the rate of average density change as a function of time, wind velocity and initial firebrand size. Empirical equations were developed to define the burning in flight and on the ground.

Fuel moisture has a marked effect on the burning process. Above moisture of 4%, the ignition time is significantly increased and the burning rate decreased markedly at 9% moisture. Also, with high fuel moisture, incomplete burning of the firebrand in wind was observed. The effect of air relative humidity on burning of oven-dry firebrands was negligible.

Flaming time of firebrands burning in wind is relatively short and is followed by glowing combustion. Firebrands impacting at long distances from the fire front will be mostly in a glowing combustion stage, although they could burst into flame for a period of a few seconds. On the other hand, firebrands impacting near the fire front could be predominantly in a flaming stage and therefore would pose a greater fire hazard.

The experimental fire whirl generator at UCSB provided meaningful and useful whirl data. Even though the whirl strength is physically limited by rig diameter, the range of fire whirl strengths obtained was large enough to provide for acquisition of the most comprehensive set of fire whirl data for wood fuels yet obtained.

Utilizing the experimental data, a relatively simple and easily applicable integrated analytical fire whirl model has been developed for the prediction of the core fluid mechanical properties. The model depends on a minimum of inputs which characterize the swirl and the fuel, namely, Γ, z_e, $\rho_b R_o$, and d. The fire whirl model predicts reasonable results and trends. The core vertical velocity increases with increasing Γ and $\rho_b R_o$ and with decreasing d. The velocity decreases with increasing z_e for low to moderate values of $\rho_b R_o$ and is fairly insensitive to z_e for high values of $\rho_b R_o$. The core temperature increases with increasing Γ and $\rho_b R_o$ and with increasing z_e.

A firebrand trajectory model has been developed which includes the trajectory of a firebrand in a core, in an ambient swirl, and in a wind region in which the trajectory approach previously formulated is utilized. The core height z_e is the most important fire whirl parameter in determining the maximum firebrand range. The initial radial position of the firebrand is very important in determining its range, with the range increasing for initial position closer to the core centerline. Firebrands with the largest drag area to weight ratios will have the greatest range. For fire whirls with reasonably large core heights, viable bark-like firebrands can have a range of several miles in a moderate wind.

RECOMMENDATIONS

The objective of the firebrand investigation arose from the need to provide fire managers with a scientific tool for real time prediction and statistical assessment of spot fires generated by firebrands. Past investigations performed by various research workers, as well as the work performed by the authors, covered a part of the path leading to the final objective. The following must be completed to achieve the goal of minimizing spot fire hazard and damage:

1. Formulate a probability model for near range spot fires and fire front coalescence.
2. Formulate a probability model for long range spot fires which will include a probability of fire whirl occurrence.
3. Integrate the above models into the generalized fire spread model.
4. Verify the models formulated by observations of real fires and wherever possible by measurements of some of the parameters, and update the mathematical models as necessary.

Powell, D. A. and Martin, K. G. (Division of Building Research CSIRO, Melbourne, Australia) "Smoke and Fire Assessment with the Fire Propagation Test," *Fire and Materials 1* 97-102 (1976)

Subjects: Fire propagation test; smoke assessment; Fire assessment

Authors' Abstract

Assessing the total potential fire hazard of modern interior surfacings of buildings requires a method which includes determination of smoke toxicity concurrently with fire and smoke production parameters. The Fire Propagation Box Test (British Standards Institution BS 476, Part 6) is a promising contender. It has been examined in the flaming mode as a method for evaluating smoke production concurrently with fire propagation indices for a range of surfacings, rather than resorting to a separate procedure by using fans with the same apparatus, as described in the former British Standards Institution Draft for Development DD 36, now withdrawn. Based on the premise that smoke hazard must be considered in relation to rate of burning the concurrent procedure is shown to be the more valid method.

Satoh, K. (Fire Research Institute of Japan, Tokyo, Japan) "Smoke Movement in a Building Part 1. The Calculation with Approximate Calculation Method and the Experiments on the Smoke Air Stratified Flow in the Unsteady State," *Report of the Fire Research Institute of Japan No. 42* 28 (1976)

Subjects: Smoke movement in buildings; Stratified flow of smoke-air

Author's Abstract

In order to investigate the evacuation plan for the occupants of a building on fire, it is important to predict the smoke movement in the building. For this purpose, Approximate Calculation Method is generally used in Japan. However, there have been few reports concerning the experimental verification of the calculated results, especially with the smoke-air flow in the unsteady state. Accordingly, an attempt was made to compare the calculation and the experiment on the smoke-

air flow in a corridor, as a typical case. The results show that the calculation agrees on the whole with the experiment and therefore the smoke movement in a corridor may well be predicted with this calculation method.

Smoke and Other Products of Combustion, National Fire Protection Association Publication SPP-41, Boston, Massachusetts (1976)

Subjects: Smoke; Combustion products

This book is a compilation of articles published in *Fire Journal* and *Fire Technology* on smoke and the products of combustion.

Contents

"Smoke Test Methods," *American Society of Testing and Materials Standardization News 4* (8) 18 (August 1976) See Section G.

Trabaud, L. "Flammability and Combustibility of Principal Species of Garrigues in the Mediterranean Region," *AEcologia Plantarum 11* (2) 117 (1976)

Subjects: Forest fuel flammability; Flammability of forest fuels; Combustibility of forest fuels

Author's Summary

The knowledge of the forest fuel flammability is of major importance to understand the occurrence and forest fire behavior. Flammability depends upon the moisture content of the fuels. During the combustion several stages appear successively. Four of these have been studied more particularly: ignitibility, flame persistency, calcination and maximal height of the flame. The tests have been made on eight main species from the mediterranean garrigues and three kinds of litter. Each species has a different response for each of the parameters, but obeys a general law: ignitibility, flame persistency, and calcination are hyperbolic functions of the moisture content, whereas the maximal height of the flame is a logarithmic function. The influence of the fuel moisture content on flammability is compared with other parameters such as the shape of the fuel and its ether extractives or minerals. The application of the results to the fire fighting is also discussed.

K. Physiological and Psychological Problems from Fires

Arson: Some Problems and Solutions, National Fire Protection Association Publication SSP-38, Boston, Massachusetts (1976)

Subject: Arson

This book is a compilation of articles on arson published in *Fire Journal, Fire Technology* and *Fire Command.*

Contents

Fire Marshals on Duty: Responsibility for Arson Investigation
Fire Journal — September 1971

The Insurance Agent in Arson Investigation
Fire Journal — March 1976

Police and Fire Coordination in Arson Investigation
Fire Command! — July 1972

Joint Team Fights Arson in City
Fire Command! — December 1975

Courtroom Testimony: The Police Investigator as a Witness
Fire Command! — July 1972

Eight-Agency Effort Fights Arson
Fire Command! — September 1975

Psychological Characteristics of Firesetters
Fire Journal — March 1976

A-G-O: All the Goodies Are Out!
Fire Command! — January 1973

Application of Pattern Recognition in Arson Investigation
Fire Technology — February 1975

Reaching the Public: Fire Prevention for Small Communities
Fire Journal — November 1973

Assistance for Young Pyrophiliacs
Fire Command! — October 1975

Arson Research Evaluates Training Methods
Fire Command! — October 1975

The Shelton Affair: The Hidden Costs of Arson
Fire Journal — March 1976

PART TWO: SOME DEADLY LESSONS

Discotheque Fire: Twenty-four Dead
Fire Journal — November 1974

Tavern Fire: Allentown, Pennsylvania
Fire Journal — September 1974

The Upstairs Lounge Fire
Fire Journal — January 1974

Incendiary Fire Takes 37 Lives
Fire Journal — January 1973

The Third in a Series of Many? 28 Die in Pioneer Hotel, Tucson, Arizona
Fire Journal — May 1971

Four Die in New York YMCA Fire
Fire Journal — November 1972

Fatal Hotel Fire
Fire Journal — January 1972

Two Fatal Hotel Fires
Fire Journal — January 1971

Boarding Home Fire
Fire Journal — July 1973

The Lil' Haven Nursing Home Fire
Fire Journal — January 1972

The Seminole County Jail Fire
Fire Journal — January 1976

No Freedom for John
Fire Journal — May 1975

Cafeteria Set on Fire
Fire Journal — September 1973

Arson in Seattle Hotel
Fire Journal — November 1975

Large-loss School Fire
Fire Journal — November 1974

Trauma in Westwood
Fire Command! — October 1974

Incendiary Fires in Industrial Occupancies
Fire Journal — March 1976

John Hancock Center Fire
Fire Journal — March 1973

Office Building
Fire Journal — January 1974

Seattle's Spectacular Fire!
Fire Command! — September 1974

Deadly Maze Traps Two Fire Fighters
Fire Command! — December 1975

Fire in Abandoned Factory Overpowers Major Containment Efforts
Fire Command! — August 1975

Marina Fire
Fire Command! — October 1974

Balanoff, T. "Fire Fighter Mortality Report," International Association of Fire

Fighters for the National Bureau of Standards, *NBS-GCR-76-60* (March 1976) See Section L.

Barrows, C. S., Alarie, Y., and Stock, M. (University of Pittsburgh, Pennsylvania) "Sensory Irritation Evoked by the Thermal Decomposition Products of Plasticized Poly(vinyl chloride)," *Fire and Materials 1* (4) 147-153 (1976)

Subjects: Poly(vinyl chloride); Thermal decomposition, poly(vinyl chloride)

Authors' Abstract

A decrease in respiratory rate in mice during exposure to irritating airborne chemicals has been utilized as a response parameter to characterize the degree of upper respiratory tract irritation (sensory irritation) to the thermal decomposition products of plasticized poly(vinyl chloride). The plasticized poly(vinyl chloride) was placed in a low mass vertical furnace and thermally decomposed in an air atmosphere at a programmed heating rate of $20°C\ min^{-1}$. The thermogravimetric study of the plasticized poly(vinyl chloride) demonstrated that two distinct weight loss fractions occurred during the decomposition process. Groups of four male Swiss-Webster mice were exposed to the thermal decomposition products of the first weight loss fraction in the range 0.03-0.77 $mg\,l^{-1}$ and to the second weight loss fraction in the range 0.03-0.38 $mg\ l^{-1}$. Dose-response curves were plotted by utilizing the maximum percent decrease in respiratory rate during each exposure as the response parameter. Comparison of these curves to a dose-response curve for hydrogen chloride showed that both the first and second weight loss fractions of plasticized poly(vinyl chloride) were more potent than hydrogen chloride in terms of sensory irritation. From these dose-response relationships qualitative and quantitative predictions of human responses to the thermal decomposition products of pasticized poly(vinyl chloride) can be made.

Block, J. H., Block, J., and Folkman, W. S. (Pacific Southwest Forest and Range Experiment Station, Berkeley, California) "Fire and Children: Learning Survival Skills," *U.S.D.A. Forest Service Research Paper PSW-119* 14 pp (1976)

Subjects: Children-caused fires; Fire prevention; Fire safety

Authors' Abstract

A number of essentially healthy 5- and 6-year old children were studied to determine their interests in, anxieties about, attitudes toward, and reactions to fire. The relationships of particular personality characteristics of the children and the socialization techniques and teaching strategies of the mothers to the children's perceived attitudes about and observed performances with fire materials were determined. The findings suggest that fire play in very young children is common — more a function of curious, exploratory play than a function of psychologically driven, psychopathological behavior as might be true of fire-setting by older children. Similarities were found between personality characteristics of children with high accident rates and those showing a keen interest in fire. Educational programs emphasizing cautious use of fire materials need to be instituted early in a child's life as interest in fire frequently develops by the time he or she is 5 years old.

Boudreau, J. F., Kwan, Q. Y., Faragher, W. E., and Denault, G. C. (Aerospace Corporation, El Segundo, California) "Survey and Assessment of Arson and Arson Investigation," *Aerospace Report Number ATR-76(7918-05)-2* under Contract No. J-LEAA-025073 for the Law Enforcement Assistance Administration, U.S. Department of Justice (October 1976)

Subject: Arson investigation

Authors' Abstract

This report contains the results of a study of arson and of current methods and needs in arson investigation. Arson is a violent crime which killed 1,000 people and injured 10,000 others in 1975 and, at the same time, caused greater estimated property losses ($1.4 billion) than any of the major property crimes (robbery, burglary, larceny, and motor vehicle theft). Over the past decade, incendiary building fires increased 325% — more than any other type of serious crime. Currently available arson statistics and studies of the characteristics of arsonists are presented, and their limitations are noted.

A major component of the study was a questionnaire survey of a selected group of leading arson investigators to identify needs in arson investigation. The highest priorities were given to increasing the number and the training of arson investigators, to establishing an automated data system for arson investigation, to scientific research on arson investigation methods, to improving cooperation from insurance companies, and to development of equipment to aid in arson investigation. The piece of equipment most urgently needed is an improved flammable vapor detector to help the investigator locate residues of fire accelerants such as gasoline which are the most frequent fire-setting method used by arsonists.

Another component of the study was a statistical analysis of data on arson, arson arrests, and arson convictions from 108 cities over a 4-year period. It was found that cities ranking in the upper third according to arson arrest rates had 22% fewer arsons per 100,000 population than cities ranking in the bottom third, while cities in the upper third, according to conviction rate, had 26% less arson.

A review of the capabilities and needed improvements in the technical methods of arson investigation is presented. A number of recommendations for the reduction of arson and the improvement of arson investigation are included.

Chaiken, J. M., Ignall, E. J., and Walker, W. E. (The New York City Rand Institute, New York) "A Training Course in Deployment of Emergency Services: Instructor's Manual," The Rand Corporation *R1784/1-HUD* and "Student's Manual," The Rand Corporation *R-1784/2-HUD* (September 1975)

Subjects: Deployment of emergency services, training course; Training course in deployment of emergency services.

Authors' Preface

This and earlier contracts between HUD and The New York City-Rand Institute involved work with city agencies designed to improve the deployment of their emergency service units. Prior to beginning such work, a training course was often presented to agency and city officials and to local analysts. The course outline provides lesson plans and visual aids for these lectures so that they can be presented by anyone who already understands the subject. References to the appropriate source materials are also provided. Potential audiences for the course include fire service administrators and planning officers, police patrol administrators and planning officers, ambulance agency personnel, city officials, operations research analysts, and mixtures of these groups.

This instructor's manual may also be useful to individuals who wish to undertake a self-directed study of deployment analysis for emergency services. The literature in this field is quite extensive and includes methodological reports, descriptions of computer programs, and case studies of applications of deployment analysis in particular cities. Therefore, it may be difficult for the student to determine which papers are related to the subject he wishes to learn and which ones should be read ahead of others. By following this course outline, it is possible to determine a suitable sequence in which to study the various documents and to gain a general notion of the contents of each of them in advance. Instructors teaching from this manual may wish to supply copies of the lecture notes to their students, in which case they should order the following companion report from the Publications Department of The Rand Corporation:

R-1784/2-HUD, A Training Course in Deployment of Emergency Services: Student's Manual.

The student's manual provides lecture notes, visual aids, and references for such a course, to be used by students whose instructor is teaching from the companion volume:

R-1784/1-HUD, A Training Course in Deployment of Emergency Services: Instructor's Manual.

This student's manual is not designed for self-directed study. The companion instructor's manual is more suitable for this purpose.

Edginton, J. A. G. and Lynch, R. D. (Chemical Defense Establishment, Salisbury, Wiltshire, England) "The Acute Inhalation Toxicity of Carbon Monoxide from Burning Wood," *Fire Research Note No. 1040*, Joint Fire Research Organization (August 1975)

Subjects: Inhalation toxicity; CO toxicity; Wood combustion product toxicity

Authors' Summary

The acute inhalation toxicity to rats and guinea pigs of carbon monoxide as a pure gas, or as evolved during the controlled buring of two different plywoods has been measured. There were significant, though very slight, differences. The slightly greater toxicity with the plywood exposures was probably due to changes in the respiratory minute volume produced by the irritants in the wood pyrolysis products, although this is unproven.

Fire Problems Program: Quarterly Report, October - December 1976, Applied Physics Laboratory, The Johns Hopkins University, Laurel, Maryland, APL/JHU FPPQ-2-76, under grant from the National Fire Prevention and Control Administration. Program Director: A. G. Schulz; Principal Investigators: R. M. Fristrom and W. G. Berl

Subjects: Education; Information; Fire casualties; Combustion research; Systems analysis

Report Introduction

INTRODUCTION

The APL Fire Problems Program is a multidisciplinary effort with the objective of improving the nation's posture with respect to unwanted fires.

Four research areas have been chosen for study: Information and Education, Fire Casualties, Combustion Studies, and Systems Analysis and Development. The work is subdivided into sixteen tasks. This quarterly report to the National Fire Prevention and Control Administration covers the period from July 1, 1976 thorugh September 30, 1976.

Two other fire programs are conducted by the group. One is sponsored by the Center for Fire Research of the National Bureau of Standards and the other by the Mine Enforcement Safety Administration. These two programs are reported separately.

The NFPCA program objectives are summarized, followed by an Executive Summary of the quarterly highlights.

Except for very brief task reports, each task is reported on a separate page, which provides a summary of task objectives, a list of task staff members, the highlights of the quarter, and a short narrative.

Hilado, C. J. and Furst, A. "Estimating Short Term LC_{50} Values," *Fire Technology 12* (2) 109 (1976)

Subjects: Toxicity; Toxic combustion products; Pyrolysis

Journal Abstract

LC_{50} values (concentrations at which 50% of test animals die) of the most widely recognized potentially toxic products of combustion, such as carbon monoxide,

hydrogen chloride, hydrogen cyanide, and nitrogen dioxide, decrease with increased exposure time and decreased body weight. A method is given for the estimation of LC_{50} values for exposure periods of 5 to 60 minutes. For such periods, hydrogen cyanide is 29 times as toxic as carbon monoxide to 250-g rats and 2.8 times as toxic as hydrogen chloride to 30-g mice. Such correlations are of value in the design of toxicity test procedures.

Hilado, C. J. and Furst, A. (University of San Francisco, California) "Fire Safety in the Home: Relative Toxicity of the Pyrolysis Products from Some Materials Used in Home Furnishings and the Impact of California Regulations," Department of Consumer Affairs, Bureau of Home Furnishings Laboratory *Report SP-76-5,* State of California (October 1976)

Subjects: Home fire safety; Fire safety; Pyrolysis of furnishings; Toxic pyrolysis products; California regulations on home furnishings

Authors' Abstract

Seventy samples of cushioning and upholstery materials used in home furnishings were evaluated for relative toxicity of pyrolysis products, using the USF/NASA toxicity screening test method. The materials exhibited varying degrees of toxicity under pyrolysis conditions, and this relatively simple test method, exposing four mice in a 4.2 liter chamber to the pyrolysis effluents, appeared suitable for discriminating between these materials on the basis of time to incapacitation and time to death. The addition of fire retardants to these materials, in order to comply with flammability regulations, either had no significant effect on toxicity, or resulted in a reduction in relative toxicity under these test conditions. The modification of materials to comply with California upholstered furniture flammability regulations appears to have resulted in desirable limitations on toxicity. The materials in compliance exhibited longer times before incapacitation than half of the materials in this study.

Hilado, C. J. and La Bossiere, L. A. (Fire Safety Center, University of San Francisco, California), **Leon, H. A., Kourtides, D. A., and Parker, J. A.** (NASA Ames Research Center, Moffett Field, California), **and Hsu, M. S.** (San Jose State University, San Jose, California) "The Sensitivity of Relative Toxicity Rankings by the USF/NASA Test Method to Some Test Variables," *Journal of Combustion Toxicology 3* (3) 211-236 (1976)

Subjects: Toxicity rankings; USF/NASA toxicity test; Toxicity tests

Authors' Abstract

Pyrolysis temperature and the distance between the source and sensor of effluents are two important variables in tests for relative toxicity. Many materials, particularly the more thermally stable synthetic polymers, exhibit significant differences in response between temperatures of 500 and 800°C, and the distance between the sample being pyrolyzed and the test animal often represents a compromise between adequate cooling of the pyrolysis effluents and access to toxicants. Modifications of the USF/NASA toxicity screening test method to increase the upper temperature limit of pyrolysis, reduce the distance between the sample and the test animals, and increase the chamber volume available for animal occupancy did not significantly alter rankings of relative toxicity of four representative materials. The changes rendered some differences no longer significant, but did not reverse any rankings. The materials studied were cotton, wool, aromatic polyamide, and polybenzimidazole.

Hilado, C. J. and Miller, C. N. "The Effects of Changes in the USF/NASA Toxicity Screening Test Method on Data from Some Cellular Polymers," *Journal of Combustion Toxicology 3* (3) 237-258 (August 1976)

Subjects: Toxicity tests; USF/NASA toxicity test; Cellular polymers, toxicity test; Toxicity test of cellular polymers

Safety in Mines Abstracts 25 No. 1219
Safety in Mines Research Establishment

Rankings of relative toxicity can be markedly affected by changes in test variables. Revision of the USF/NASA toxicity screening test procedure to eliminate the connecting tube and supporting floor and incorporate a 1.0 g sample weight, 200°C starting temperature, and 800°C upper limit temperature for pyrolysis, reversed the rankings of flexible polyurethane and polychloroprene foams, not only in relation to each other, but also in relation to cotton and red oak. Much of the change is attributed to reduction of the distance between the sample and the test animals, and reduction of the sample weight charged. Elimination of the connecting tube increased the relative toxicity of the polyurethane foams. The materials tested were flexible polyurethane foam, without and with fire retardant; rigid polyurethane foam with fire retardant; flexible polychloroprene foam; cotton, Douglas fir, red oak, hemlock, hardboard, particle board, polystyrene, and poly (methyl methacrylate).

Hilado, C. J. and Saxon, G. L. "Relative Toxicity of Pyrolysis Products of Some Cellular Polymers," *Journal of Combustion Toxicology 3* (3) 259-269 (August 1976)

Subjects: Polymer pyrolysis products; Pyrolysis of cellular polymers; Cellular polymers, toxic pyrolysis products; Toxic products, cellular polymer pyrolysis

Safety in Mines Abstracts 25 No. 1217
Safety in Mines Research Establishment

Twelve samples of cellular polymers were evaluated in the course of developing test methods for toxic materials characterization. Six samples were flexible polyurethane foams, three were rigid polyurethane foams, two were high density rigid foams, and one was a modified polymide foam. Some effects of formulation variables are discussed.

Hilado, C. J., Slattengren, C. L., and Furst, A. (Fire Safety Center, University of San Francisco, California) **Kourtides, D. A. and Parker, J. A.** (NASA Ames Research Center, Moffett Field, California) "Relative Toxicity of Pyrolysis Products of Some Synthetic Polymers," *Journal of Combustion Toxicology 3* (3) 270-283 (1976)

Subjects: Toxic pyrolysis products; Polymer pyrolysis products; Pyrolysis products, synthetic polymers

Authors' Abstract

Nineteen samples of synthetic polymers were evaluated for relative toxicity in the course of characterizing materials intended for aircraft interior applications. The generic polymers included ABS, chlorinatd PVC, polycrabonate, poly(phenylene oxide), poly(phenylene sulfide), polysulfone, poly(aryl sulfone), poly(ether sulfone), polybismaleimide, and poly(vinyl fluoride). Test results are presented, and compared in relative rankings with similar results on cellulosic materials and other synthetic polymers. Under these test conditions, the samples of synthetic polymers were either comparable to or significantly less toxic than the samples of commercial cellulosic materials.

Jin, T. (Fire Research Institute of Japan, Tokyo, Japan) "Visibility Through Fire Smoke, Part 3. Visibility of Flashing Sign," *Report of Fire Research Institute of Japan No. 40,* 1-5 (1975) (in Japanese)

Subjects: Visibility through smoke; Smoke, visibility in light scattering; Smoke, visibility through

Author's Abstract

This paper deals with experiments on the visibility of a xenon-lamp flashing sign through fire smoke. The visibility increases linearly with the exponential increase of the capacity of condensers. In case of extremely large capacity condensers,the visibility increases only slightly, because veiling is formed by light scattered by smoke. Therefore, it is difficult to make flashing signs which have very long visibility in comparison with that of conventional signs. It is confirmed that the luminous energy (time-integration of luminance) of flashing signs is equivalent to about 1/10 of that of fixed signs required to obtain the same visibility.

Jin, T. (Fire Research Institute of Japan, Tokyo, Japan) "Visibility Through Fire Smoke, Part 4. Experiment on Light Scattering Coefficient of Various Fire Smokes," *Report of Fire Research Institute of Japan No. 40,* 6-10 (1975) (in Japanese)

Subjects: Visibility through smoke; Light scattering of smoke; Smokes, light scattering coefficients

Author's Abstract

A previous study measured light scattered from 30° to 150° by combustion smoke of various building materials.

Since it is considered that visibility may depend on light scattered at a low scattering angle, the present paper describes the measurement of scattering from 5° to 155°, using a Ne-He laser as a light source. The light scattering by smoke from smoldering wood and plastic materials is almost equal. However, differences are found between light scattering by smoke of flaming wood and by smoke of flaming plastic. The ratio of the scattering coefficient to the extinction coefficient is determined from the light scattering. Though the ratio varies with the kinds of building materials and combustion conditions, it may be concluded the ratio is nearly equal to 1.0 for smoldering smoke and about 0.5 for flaming smoke.

Keller, J. G., Herrera, W. R., and Johnston, B. E. "An Investigation of Potential Inhalation Toxicity of Smoke from Rigid Polyurethane Foams and Polyester Fabrics Containing Antiblaze R 10 Flame Retardant Additive," *Journal of Combustion Toxicology 3* (3) 296-304 (August 1976)

Subjects: Polyurethane foam smoke toxicity; Flame retarded polyester fabric smoke toxicity; Toxic smoke from polyurethane foams

Safety in Mines Abstracts 25 No. 1243
Safety in Mines Research Establishment

Previous reports of abnormal neurological effects and increased toxicity for the non-flaming decompositon products of certain trimethylolpropane-based rigid polyurethane foams containing flame retardant additives were confirmed. In similar experiments with rigid polyurethane foams and polyester fabric samples containing a cyclic phosphonate derivative of trimethylolpropane, these effects were not observed. An explanation based on the stability of the cyclic phosphonate flame retardant additive is proposed.

Levin, B. "Psychological Characteristics of Firesetters," *Fire Journal 70* (2) 36 (1976)

Subjects: Arsonists; Firesetters

Fire Technology Abstract 76-20

Arsonists may be grouped into arson-for-profit fire setters, solitary fire setters, and group fire setters. Most arsonists can be characterized as psychopaths, and as such, often appear normal and lead reasonably normal lives, appear to lack feelings of concern for others (especially for the physical harm caused by their acts), and often do not respond to punishment. There is a tendency for arsonists to be young,

to have low intelligence, to have a stronger than average interest in fires, and to have physical deformities. The crime can be committed in secret and does not require a confrontation, so it is often the act of the physically weak and the coward.

Lynch, R. D. (Joint Fire Research Organization, Borehamwood, Herts., England) "On the Non-Existence of Synergism Between Inhaled Hydrogen Cyanide and Carbon Monoxide," *Fire Research Note 1035*, Joint Fire Research Organization (May 1975)

Subjects: Synergism, lack of, between HCN and CO; Carbon monoxide - Hydrogen cyanide synergism lack; Toxicity of HCN - CO mixtures

Author's Summary

Rats were exposed either to hydrogen cyanide, or carbon-monoxide, or various mixtures of these two gases to determine the degree of synergism, if any, with respect to the inhalation L Ct_{50}s. Within the sensitivity of the measurements, the toxicities of the two gases appear to be purely additive, i.e., no synergism exists.

Melinek, S. J. and Baldwin, R. (Building Research Establishment, Borehamwood, Herts., England) "Evacuation of Buildings — Some Effects of Changes in Performance Standards," *Building Research Establishment Current Paper 95-75*, Fire Research Station (1975)

Subjects: Building evacuation; Evacuation of buildings; High-Rise evacuation; Staircase evacuation

Authors' Abstract

An equation is derived for the total staircase width required to provide an adequate safe area for evacuation purposes in multi-storied buildings. The staircase area is calculated as a function of the time allowed for evacuation to the staircase and the number of floors initially required to be evacuated. Estimates are made of the cost of the area occupied by the staircases.

Melinek, S. J. and Booth, S. (Building Research Establishment, Borehamwood, Herts., England) "An Analysis of Evacuation Times and the Movement of Crowds in Buildings," *Building Research Establishment Current Paper 96-75*, Fire Research Station (1975)

Subjects: Evacuation times; Crowd movement; Building evacuation

Authors' Abstract

Data on the movement of crowds are reviewed. The evacuation of buildings to a protected area represented by a staircase is considered and a theory for the estimation of the total evacuation time from buildings is presented.

Michal, J. (Ore Research Institute, Praha, Czechoslovakia), **Mitera, J.** (Institute of Chemical Technology, Praha, Czechoslovakia), **and Tardon, S.** (Coal Research Institute, Ostrava-Radvanice, Czechoslovakia) "Toxicity of Thermal Degradation Products of Polyethylene and Polyprolylene," *Fire and Materials 1* (4) 160-168 (1976)

Subjects: Toxic products of polymers; Polyethylene degradation; Polypropylene degradation

Authors' Abstract

Pyrolysis, thermo-oxidation and combustion of polyethylene and polypropylene were studied and the products of these thermal degradation processes were identified by means of gas chromatography and gas chromatography-mass spectrometry. The individual products of thermal degradation were evaluated for their toxicity and a conclusion on presumed toxic effect of the combustion products of the polymers studied has been drawn.

Morikawa, T. (Fire Research Institute of Japan, Tokyo, Japan) "Evolution of Irritant Materials from Smoldering Combustion," *Report of the Fire Research Institute of Japan No. 41*, 63-75 (1976)

Subjects: Smoldering combustion; Irritants from smoldering combustion

Author's Abstract

The evolution of irritants, acrolein, formaldehyde, and volatile fatty acids were determined when various materials were heated in a current of air or nitrogen. Polyethylene, polypropylene, vinylon, and cellulosic materials produced relatively large quantities of irritants. The evolution of acrolein and formaldehyde was much more dangerous than that of volatile fatty acids in terms of toxicity. The maximum evolution of acrolein and formaldehyde in practical smoldering combustion experiments was ½ - ⅓ of that in the temperature-controlled experiments. Estimated concentrations of both acrolein and formaldehyde indicate that a considerably hazardous condition could be reached even by smoldering fires.

Paabo, M., Pitt, B., Birky, M. M., Coats, A. W., Alderson, S. E., and Brown, J. E. (National Bureau of Standards, Washington, D.C.) "Measurements and Observations of the Toxicological Hazard of Fire in a Metrorail Interior Mock-up," *Final Report NBSIR 75-966 National Bureau of Standards (February 1976)*

Subjects: Oxygen depletion; Carbon dioxide; Carbon monoxide; Cyanide; Fire toxicity tests

Authors' Abstract

Oxygen depletion, carbon monoxide, carbon dioxide, hydrogen chloride and

hydrogen cyanide were selected for measurement and identification in Metrorail fire tests.

Male rats exposed to the combustion products were examined for changes in blood chemistry, gross pathology and loss of function. Hydrogen cyanide and carbon monoxide levels in blood were elevated and functional changes were noted.

Rider, K. L. (The New York City Rand Institute) "A Parametric Model for the Allocation of Fire Companies: Executive Summary," The Rand Corporation, *R-1641/1-HUD* (August 1975)

Subjects: Fire company allocations; Model for allocation of fire companies; Parametric model for fire companies; Firefighting resource allocation; Allocation of firefighting resources

Author's Preface

This report describes in nontechnical terms a computer program called the Parametric Allocation Model. The report was written to help fire department administrators and other local governmental officials understand how the model can be used to allocate firefighting resources to various regions of the city. Among the objectives of this HUD contract are the development, field testing, and documentation of methods for improving the deployment of municipal emergency services.

For more detailed iformation about the model, readers should consult the companion volumes to this report:

R-1646/2-HUD, A Parametric Model for the Allocation of Fire Companies: User's Manual and *R-1615-NYC/HUD,* A Parametric Model for the Allocation of Fire Companies

Documentation of the Parametric Allocation Model constitute part of a series of HUD funded reports describing deployment models for police, fire, and ambulance services and applications in several cities. Further information can be obtained from the Rand Corporation.

The Program is designed to develop, field test, and provide to state and local officials new approaches and methods for responsive community management. The Program intends to provide these officials with new methods of identifying alternative policies and actions. It is also intended to provide new methods of assessing the feasibility, cost, and consequences of these alternatives. The methods are tested in representative communities under actual operating conditions, and the results are made available to users in other communities.

Seader, J. D. and Einhorn, I. N. (University of Utah, Salt Lake City, Utah) "Some Physical, Chemical, Toxicological, and Physiological Aspects of Fire Smokes," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1423 (1976)

Subjects: Smoke; Physical aspects of smokes; Chemical aspects of smokes; Toxicological aspects of smokes; Physiological aspects of smokes

Authors' Abstract

In many fires, effects of smoke are the chief cause of bodily injury or death. The effects include opacity, toxicity, lachrymatory irritation, and heat transfer. In order to understand and quantify these effects, extensive research is being conducted to study the physical, chemical, toxicological, and physiological aspects of fire smokes. The principal emphasis within the scope of this paper is directed toward the physics of smokes with only brief mention of chemical aspects. An introductory survey of the toxicological and physiological aspects of smokes is also presented.

Important physical aspects of smoke particulates include light scattering and absorption; particle-size distribution; and settling, sticking, and agglomeration rates. With respect to light obscuration, it is shown that the single most important variable is particulate mass concentration. The particulate optical density (POD) is shown to be bounded within two relatively narrow ranges; one for aerosols and one for carbonaceous soots.

Experimental apparatus and a test protocol for determining the qualitative and quantitative nature of the intoxication syndrome resulting from smoke exposure are discussed. This methodology employs both a behavioral endpoint and animal bioassay, which includes gross physiological evaluation, in-depth physiological monitoring of vital functions, blood-gas analysis, and pathological evaluation of early dysfunction and late-developing sequelae.

Stankey, G. H. (Intermountain Range and Experiment Station, Ogden, Utah) "Wilderness Fire Policy: An Investigation of Visitor Knowledge and Belief," *U.S.D.A. Forest Service Research Paper INT-180* 17pp (1976)

Subjects: Wilderness fires; Fire suppression in wilderness; Fire policy in wilderness

Author's Abstract

Discusses the attitudes and knowledge of wilderness visitors towards wilderness fire suppression policy. Although most users favored suppression, a substantial minority favored a more natural role for fire. Few found either total suppression or no suppression at all acceptable. A major finding was that as visitor knowledge about the role of fire increased, the likelihood of support for a more natural role for fire also grew. Important policy implications include educating and involving the public, making gradual changes in fire policy, and developing a communications program aimed at different audiences.

Stark, G. W. V. and Field, P. (Joint Fire Research Organization, Borehamwood, Herts., England) "Toxic Gases and Smoke from Poly(vinyl chloride) in Fires in the FRS Full-Scale Test Rig," *Fire Research Note No. 1030*, Joint Fire Research Organization (April 1975)

Subjects: Toxic gases; Smoke; Poly(vinyl chloride); PVC

Authors' Summary

Tests in which the contribution of wall linings of PVC to the fire hazards presented by traditional combustible material (wood) are reported. PVC linings in a compartment did not significantly change maximum fire gas temperatures, or smoke density, but increased the overall outputs of heat and smoke. Their main contribution was to the toxic gases by the addition of hydrogen chloride to the carbon monoxide from the combustion of wood. PVC wall paper and cloth did not contribute much to the hazard from a wood fire in a compartment. However, PVC in a corridor could lead to the discharge of larger concentrations of hydrogen chloride.

Sumi, K. and Tsuchiya, Y. (Division of Building Research, National Research Council of Canada, Ottawa) "Assessment of Relative Toxicity of Materials: Toxicity Index," *Division of Building Research Paper No. 685*, National Research Council of Canada (June 1976)

Subjects: Toxicity index; Materials toxicity; Relative toxicity of materials

Authors' Abstract

The fire toxicity concept that has been proposed as a method to assess the toxicity of decomposition products from quantitative analytical data and the known toxicities of the products is explained. The assessment gives indications of the relative importance of toxic species produced from a given material, and the relative propensity of materials in generating harmful gases and vapours. Merits and limitations of the concept and directions for further development are discussed. Some experimental data developed under a standardized method of decomposition are presented.

Sumi, K. and Tsuchiya, Y. (National Research Council of Canada, Ottawa) "Evaluating Toxicity of Decomposition Products from Analytical Data," *Division of Building Research Paper No. DBR 711*, National Research Council of Canada (1976)

Subjects: Toxicity of decomposition products; Decomposition product toxicity

Authors' Abstract

Research on fire toxicity undertaken by the Fire Research Section of the National Research Council of Canada is presented. Work to date has been directed towards quantitative analysis of decomposition products and subsequent assessment of toxicity. The fire toxicity concept proposed by the authors provides indications of

the relative importance of toxic species produced from a given material, and the propensity of materials for generating toxic decomposition products.

Toxic gases and vapors produced at fires are responsible for a large number of deaths in building fires. Statistics on fires obtained from a number of countries reveal that more people die from inhalation of decomposition products than from burns. Today it is generally accepted that this is the major cause of fire deaths. The concern over the danger of inhaling decomposition (combustion and pyrolysis) products has increased in recent years due primarily to the development and increasing use of synthetic materials, both as building materials and furnishings. Some of these new materials release decomposition products very rapidly, and some generate products that are more toxic than those produced by traditional materials such as wood and paper. The question of whether the steady increase in the use of new materials is likely to result in an increase in the life hazard for the occupants of buildings in the event of fire is of paramount importance.

The potential fire hazard of new materials has been recognized for many years. The concern over this problem is reflected in regulations applied in efforts to reduce fire losses. The hazard includes flammability, generation of dense smoke and release of toxic gases and vapors. The present regulations apply primarily to flammability; most of the regulations are intended to restrict materials that are easy to ignite or tend to contribute to rapid spread of flame. One of the ways in which industry has responded to this demand is by the develoment of fire retardants. Since materials formulated to resist ignition or rapid flame spread often produce more smoke and, in some cases, more harmful decomposition products than untreated materials, concern with the problems of smoke and fire toxicity have become even greater. Some regulations on smoke developed ratings of materials have been introduced in building regulations in Canada; regulations on fire toxicity of materials are yet to be promulgated in this country.

In recent years the toxicity of decomposition products has received a great deal of attention from fire scientists and engineers throughout the world. Laboratory studies on this subject can be classified into two main types. One involves the biological response of laboratory animals to fire gases or artificial mixtures of components found in fire gases, the other involves chemical analysis of components found in fire gases. Both approaches are needed to elucidate various aspects of the problem.

Animal experiments provide information on physiological and toxicological effects of harmful gases and vapors. They also offer a means to screen out materials with a high propensity for generating harmful decomposition products or to evaluate materials on this basis. Chemical analysis of decomposition products provides a method of identifying the species primarily responsible for toxic effects.

The purpose of this paper is to describe some of the efforts made by the Fire Research Section of the Division of Building Research towards a better understanding of fire toxicity. The work to date has been confined to analysis of decomposition products and assessment of experimental data using a fire toxicity concept (originally called toxicity index concept). Bio-assay experiments with animals have not been undertaken.

Takahashi, S. (Fire Research Institute of Japan, Tokyo, Japan) "Development of an Oxygen Generating Breathing Apparatus. I. The Reactive Characteristics of Potassium Superoxide Mainly with Exhaled Breath," *Report of the Fire Research Institute of Japan No. 41,* 33-48 (1976) (in Japanese)

Subjects: Breathing apparatus; Potassium superoxide; KO_2 breathing apparatus

Author's Abstract

Prior to the development of a new oxygen mask, some experiments were performed to determine the reactive characteristics of porous-KO_2 (P-KO_2), tableted-KO_2 (T-KO_2) and granular-KO_2 (G-KO_2, produced by pressing P-KO_2 under pressure of 120 - 150kg/cm^2 and crushing). The experiments were conducted by passing H_2O-free CO_2-Air, CO_2-free H_2O-Air and composed exhaled breath over each of the three forms of KO_2. P-KO_2 absorbs H_2O remarkably well but didn't liberate O_2 smoothly without a catalyst. In the case of CO_2-Air, the absorbance of CO_2 was not so remarkable but a large concentration of O_2 could be generated without a catalyst (Fig. 4). This was the unique properties of this KO_2 which contain about 20% of KOH. The reactivity of T-KO_2 was weak, and G-KO_2 was thought to have the most practical properties. The tests were, therefore, focussed mainly on granular KO_2 and the following new information was obtained:

1. A few minutes after passing test gas, a stagnation phenomenon of O_2 liberation was observed.
2. A principal cause of this stagnation was recognized to originate from the existence of CO_2.
3. The first period until the oxygen liberation velocity reached a maximum the reaction mechanism was thought to depend mainly on an adsorption reaction.
4. The reaction mechanism of the latter half period was thought to be a diffusion reaction. The volume of O_2 liberated in the first period was found to be expressed by the following equation:

$$v = at^n$$

where v is the volume O_2 generated until testing time t, a and n are the condition constants which depend on the physical properties of granules, atmosphere temperature, flow rate, etc. From this equation, the O_2 concentration in the mask and the volume of deficient O_2 with respect to time was calculated. This was very important for designing, especially for designing a supplementary O_2 supply device.

The equivalent weight m of KO_2-granules of diameter r, which showed the same duration time with the one representing condition of m_o and r_o, was theoretically derived as,

$$m_o r = m r_o$$

From the flow test experiment, the duration time t was found to have the following relation with the one fundamental flow test as:

$$t = t_o\ (m/m_o)\ (f_o/f)$$

where f is the flow rate.
By combining the two equations,

$$t = t_0\ (r_0/r)\ (m/m_0)\ (f_0/f)$$

was obtained. These equations can be applied especially when the canister temperature is below normal.

Watanabe, Y. (Fire Research Institute of Japan, Tokyo, Japan) "A Study of Voice Guidance for Evacuation," *Report of the Fire Research Institute of Japan No. 41*, 1-7 (1976) (in Japanese)

Subjects: Evacuation by voice; Voice guidance for evacuation

Author's Abstract

In a fire where visibility is obstructed by smoke, it is often said that it may be possible to evacuate safely using the human ears' directional sense for a source of sound. This study investigated the actual validity of a few methods of voice guidance for evacuation. Experiments were carried out in a gymnasium of 15m × 30m., and persons, blindfolded, were guided by voice to walk for about 30m from the starting point to the source of sound. Two methods were used: a human voice given through a loudspeaker and a tape-recorded voice reiterating "Exit here." The following results were obtained from the experiments.

(1) It is possible to guide a person by his aural directional sense even when his visibility is obstructed. Voice gives a person not only instructions but a definite direction of the sound.
(2) Guidance with a human voice resulted in less smoothness of walking than with the reproduced tape-record indication, but was more effective owing to assuring confidence in human mind. The walking speed was not very different in both cases.
(3) When a blind person encounters an obstruction on walking, he determines the shape of the obstruction through the sense of touch or by hands, to insure his safety, and proceeds. Then visibility is obstructed, the sense of touch as well as voice play an important role.

Wooley, W. D. and Fardell, P. J. (Joint Fire Research Organization, Borehamwood, Herts., England) "Formation of Highly Toxic Organophosphorus Product (TMPP) During the Decomposition of Certain Polyurethane Foams Under Laboratory Conditions," *Fire Research Note No. 1060*, Joint Fire Research Organization (November 1976) See Section H.

L. Operations Research, Mathematical Methods, and Statistics

Arno, S. F. (Intermountain Forest and Range Experiment Station, Ogden, Utah) "The Historical Role of Fire on the Bitterroot National Forest," *U.S.D.A. Forest Service Research Paper INT-187* (1976)

Subjects: Fire ecology; Fire frequency; Forest succession; Habitat types

Author's Abstract

Presents frequencies, intensities, and influences of fire on stand structure and composition on the Bitterroot National Forest in west-central Montana. Three study areas were established, each having a wide range of elevations and forest types. Findings are based upon study of nearly 900 individual fire scars on living trees, and on age classes of shade intolerant trees attributable to fire.

Balanoff, T. "Fire Fighter Mortality Report," International Association of Fire Fighters for the National Bureau of Standards, *NBS-GCR 76-60* (March 1976)

Subjects: Firefighter fatalities; Safety and health of firefighters

Author's Abstract

This 15-month study involved the investigation of 101 fire fighters in-the-line of duty deaths. The breakdown of cause of death was: 45 heart attacks, 13 building collapse, 12 burns, 9 smoke inhalations, 6 apparatus accidents, 5 electrocutions, and 1 equipment failure. There tended to be a higher incidence of fatalities occurring in the Mid-Atlantic, East, and New England areas. The mean age of fire fighter's fataltiy was 43.5 and the mean years of service was 15.8. Sixty percent of the fatalities occurred to men holding the rank of fire fighter. The vast majority of fire fighters who died in the line of duty worked either a split shift (10/14) or a 24-hour shift. There were 14 volunteer fire fighter fatalities.

Summaries of every case are provided in one of three sections: *Fire Fighters Killed While Fighting Fires, Fire Fighters Killed in Non-Fire Situations,* and *Fire Fighters Killed by Heart Attack.*

Fire Fighters Killed While Fighting Fires: Protective equipment, improper use, non-use and/or insufficient equipment were a contributing factor in several of the smoke inhalation and burn cases. In 9 of the 41 cases in this section there was a relationship between the fatality and the individual's fire fighting experience. There was found to be a relationship between officer leadership on the fireground in a number of the fatalities. A shortage of manpower on the ground contributed to six fatalities. Other contributing factors discussed in this section are: communications, late notification, civilian responsibilities, fire prevention, pre-fire planning, and arson.

Fire Fighters Killed in Non-Fire Fighting Situations: Equipment, type of protective clothing, and apparatus and tools were a contributing factor in the vast majority of the fifteen cases of this section. In several cases the victim fire fighters did not have the experience or proper training in which to conduct the duties required of them.

Fire Fighters Killed by Heart Attack: The mean age of the fire fighter heart attack victim was 51.3 and the mean years of service was 22. In general, the victims were slightly overweight and 60% of them smoked cigarettes regularly. There were three specific aspects of fire fighting that contributed to the development of heart disease: exposure to smoke/toxic fume inhalation, stress, and over-exertion. In over one-third of the cases, fire fighters experienced symptoms of heart trouble before the actual attack. In 7 of the 45 cases fire fighters had suffered heart attacks previous to the fatal one. There were several procedural problems after the heart attack occurred. Most serious of these were late ambulance responses, lack of proper equipment, and trained personnel (EMTs) on the fireground to perform emergency medical treatment.

Chaiken, J. M., Ignall, E. J., and Walker, W. E. (The New York City Rand Institute, New York) "Deployment Methodology for Fire Departments, How Station Locations and Dispatching Practices Can Be Analyzed and Improved," The Rand Corporation *R-1853-HUD* (September 1975)

Subjects: Deployment of fire fighting resources; Fire department deployment

Authors' Summary

This report reviews mathematical methods that have been developed to assist fire departments in analyzing and improving the deployment of their fire-fighting resources. Most of these methods are incorporated in computer programs that have been carefully tested and applied in a number of large and small cities across the country. The methods and computer programs are described and compared, but they are not discussed in detail. Instead, the reader is directed to the appropriate source documents.

The key issues of fire deployment analysis are:

- Determining the number of fire companies to have on duty city-side and in each region of the city; this may vary by time of day or by season of the year.
- Determining the specific location for each fire company.
- Developing a policy for redeploying fire companies when large numbers of companies are busy at fires.
- Developing a policy for dispatching fire companies to alarms.

The present number and arrangement of fire companies in most cities are based more on historical factors (for example, where volunteer companies were first organized) than on a careful analysis of actual needs. Several computer-based models are described that can be used to assist managers in making a more rational determination of the number of fire companies to have and where they should be

located. A method for redeploying fire companies is described. It is based on minimizing average travel times to fires, using up-to-the-minute information about the status of all fires in progress and all fire companies. The development of improved dispatching policies concentrates on determining the correct number of fire companies to send to each alarm — that is, to send more companies to potentially more serious alarms and fewer companies to alarms that are not likely to be very serious. Computer-based methods depend on collecting data adequate for estimating the likelihood that an incoming alarm signals a serious fire.

The report concludes with a discussion of the steps that should be followed in performing a deployment study. These include identifying the policy questions to be analyzed and the methods to be used, collecting and processing appropriate data, finding people with the relevant analytical skills, assembling a representative project team, acquiring and running the computer programs, and developing policy recommendations based on the analysis.

Chandler, S. E. (Building Research Establishment, Borehamwood, Herts., England) "Fires in Residential Personal Social Services Buildings," *Buiding Research Establishment Current Paper 62/76,* Fire Research Station (1976)

Subjects: Fires, social service occupancies; Rehabilitation center fires; Child care center fires; Elderly care center fires

Author's Abstract

This report is an analysis of fires in residential personal social services buildings, e.g., old people's homes, rehabilitation centers, and children's homes. Data for the five years 1969-1973 have been analysed. The greatest risk to life was in bedrooms, where nearly a third of the night fires occurred. The most common cause of fires were matches and smokers materials (22 per cent). About half the fires resulted from careless disposal of hot substances, overheating, equipment left unattended, or spillage.

About half the fires were out on arrival of the fire brigade. Over two-thirds of the fires were tackled by staff or occupants. Furthermore, half the fires were confined to the equipment or the item in which it started. Six per cent of the fires involved casualties, rescues, escapes or evacuation — there being on average one such fire every three weeks. Seventy-eight injuries and 25 deaths were recorded, of which 62 and 22 respectively were in old people's homes. The report shows that elderly people are safer from fire in these homes than in ordinary dwellings.

Chandler, S. E. (Building Research Establishment, Borehamwood, Herts., England) "Some Trends in Furniture Fires in Domestic Premises," *Building Research Establishment Current Paper 66/76,* Fire Research Station (1976)

Subjects: Fires in domestic furniture; Domestic furniture fires; Furniture fires

Author's Abstract

Statistical data of fires in the United Kingdom resulting from the ignition of furniture in domestic premises are presented in this paper, which examines trends in these fires, with particular reference to four special survey years, 1962, 1967, 1970 and 1972. The paper shows that most of the conclusions obtained from a survey of 1970 data hold for the other years, but there have been some changes. As examples, the number of fires resulting from children or suspected arsonists and the numbers of deaths due to exposure to smoke or toxic fumes have both increased faster than furniture fires. The percentage of furniture fires resulting in death is increasing, but the proportion of house fires in which furniture was ignited has remained constant. Fires resulting from direct clothing ignition have decreased. The paper confirms that a small number of clearly defined situations accounted for most of the fires throughout the period. Monetary values are assigned to the fires according to their extent of spread and the number of injuries and deaths. The values assigned were the same in all four years. The results show that both the total cost of fires involving ignition of furniture in dwellings and the average cost per fire have risen.

Conaway, C. W. "Incendiary Fires in Industrial Occupancies," *Fire Journal 70* (2) 28 (1976)

Subjects: Incendiary fires; Industrial fires

Fire Technology Abstract 76-21

A detailed study of the incendiary fire loss experience of the Factory Insurance Association from 1968-1974 is reported. Total losses were $55 million from 684 individual fires. Attribute analysis was used to explain where incendiarism occurs, to whom it occurs, and how and when it occurs, multiplicity of losses, factors contributing to the size of losses, and factors in loss control. Recommended actions to be taken after a known or suspected incendiary fire as well as for the prevention and control of incendiary fires are given. Adequate internal and external security should be established for the entire facility or plant. Access to storage areas should be limited to authorized personnel.

Corman, H., Ignall, E. J., Rider, K. L., and Stevenson, A (New York City Rand Institute) "Fire Casualties and Their Relation to Fire Company Response Distance and Demographic Factors," *Rand Paper Series P-5409*, The Rand Corporation, Santa Monica, California (March 1975)

Subjects: Fire casualties; Casualties related to distance and demography; Demography and fire casualties

Authors' Summary

Fatalities and injuries per structural fire in New York City have been compared

by time of day, season, year, construction, region of the city, floor of origin, and occupancy. The relationship between response distance and fire casualties has also been studied. It has been found that the number of casualties per structural fire has not been increasing over time. There are, however, significant time-of-day and time-of-year effects on risk of life that should be taken into account in providing fire-protection services. Other casualty indices provided inconclusive results since certain categories, such as casualties occurring in tenements, could reflect social as well as building-construction problems.

A statistically significant, but very small, relationship was found between response distance and fire casualties. The effect of response distance on casualty risk is so overwhelmed by other factors that risk of life cannot be used as the primary criterion in developing mathematical fire-resource allocation models.

Coward, S. K. D. (Building Research Establishment, Borehamwood, Herts., England) "A Simulation Method for Estimating the Distribution of Fire Severities in Office Rooms," *Building Research Establishment Current Paper 31-75*, Fire Research Station (1975)

Subjects: Fire simulation; Room fire simulation; Office fire simulation; Fire severity simulation; Simulation of office fire severity

Author's Abstract

The text of Building Research Establishment Note N 9/74 describes how the statistical distribution of fire severity is estimated by simulation from data obtained from surveys of office rooms. For this purpose, the "severity" of a fire will be defined as the time taken for an equivalent exposure in a standard furnace test. Experiments have demonstrated that the severity of a fire involving a compartment bears a relationship to the fire load, area of walls and ceiling and window area. Values of these factors were sampled at random from their frequency distributions and combined to give an estimate of the statistical distribution of fire severity.

Jackson, R. J. "The Insurer's Role in Arson Prevention," *Fire Journal 70* (2) 45 (1976)

Subject: Arson prevention

Fire Technology Abstract 76-22

Insurance companies can help prevent fraud arson by removing the incentive and increasing the risk of apprehension. The insurance agent should know the applicant personally and be familiar with the prospective risk. The agent should have special training in giving insurance to value and not overinsuring. Underwriters should consider other insurance, building inspection reports, and available experience of other carriers. A credit check may be indicated. Underwriters should be trained to recognize potential frauds. Arson and exaggerated claims go hand in hand. Trained claim adjusters should check fire department reports and talk to the fire fighters for indications of arson, suspicious origin, or unknown cause.

Kolesar, P. (The New York City Rand Institute, New York) "A Model for Predicting Average Fire Company Travel Times," The Rand Corporation *R-1524-NYC* (June 1975)

Subjects: Time of travel for fire companies; Travel time estimation for fire companies; Fire company travel time estimation

Author's Summary

In this report we derive and test a fundamental model relating the average fire company travel time in a region, ET, to the area of the region covered, A, the number of fire companies stationed there, n, the rate at which alarms are received, λ , the expected total service time per alarm, ES, and some speed parameters. The model is one of several developed by The New York City-Rand Institute to analyze fire company deployment problems in New York City and has been applied there extensively. The model is

$$ET = \alpha + \beta \left(\frac{A}{n - \lambda ES} \right)^{\gamma}.$$

For New York City, where the model has been validated, estimates of the values of parameters are: $\alpha = 0$, $\beta = 2.2$, and $\gamma = 0.3$. The model has been used in analyzing fire company deployment problems, and recent changes in the number and location of fire companies in New York City were based partially on this analysis.

Kolesar, P. and Blum, E. H. (The New York City Rand Institute, New York) "Square Root Laws for Fire Company Travel Distances," The Rand Corporation *R-895-NYC* (June 1975)

Subjects: Fire company travel distances; Travel distance of fire companies

Author's Summary

When fire, police, or ambulance units respond to incidents where lives or property are at risk, seconds count. Once an emergency service receives a call for help, the time for personnel to reach the incident — the travel time — is one of the most important performance variables the service itself can affect.

One of the most direct influences on response time is the response or travel distance. Our analysis, which focuses on fire companies, shows that the average response distance in a region is inversely proportional to the square root of the number of locations per area from which fire companies are available to respond. The square-root law predicts that

$$ED_i = k_i \, [A/(n - \lambda ES)]^{\frac{1}{2}}$$

where ED_i is the long run expected response distance of the *ith* closest fire company,

A is the area of the region under consideration, λ is the expected number of alarms received per hour, ES is the expected total "service" time spent by all fire companies that respond to and work at an alarm per alarm, k_1 is a constant of proportionality that can be determined empirically, and n is the number of fire companies assigned to the region. Combined with empirical data relating travel times to distances, this relation provides an easy-to-use formula relating average travel times in a region to key operational and planning variables: the region's area, its alarm rate, the number of units stationed there, service times, and travel velocities. Termed the "square-root law" because of its mathematical form, the response distance relation stems directly from dimensional analysis. In addition, it can be motivated by many simple mathematical models of fire company and fire location, which show how the constants of proportionality in the law depend on location patterns.

Extensive data from Instiute simulation of New York City Fire Department operations confirm this relation in detail for application to the deployment of fire-fighting units. This evidence shows taht the law is robust — that it applies even in complex, realistic situations where none of the sufficient conditions assumed in the theoretical models used to derive it apply. For example, these simulations show that it holds well even when the number of units busy in a region varies rapidly with time.

A similar inverse square-root relation also appears to hold for maximum response distances and for the response distance probability distribution. For these cases, however, the evidence is less extensive and the relation appears less robust. Evidence is strong for the second moment of the distribution: simulation experiments confirm that the standard deviation of response distance also follows a square-root law. The simulation runs also show quantitatively where deviations from the square-root law become large enough that alternative formulations, including more detailed models, should be used instead.

The results of an experiment in which fire companies responding to alarms recorded travel times and distances yielded a simple time-distance function. When this function is combined with the square-root law for distances, a power model for average travel times results. This average travel time model addresses basic allocation questions faced by all fire departments. We illustrate how the model can be used to answer the following specific questions:

(1) Given an allocation of fire-fighting units to an area, what are the resulting average travel times?
(2) What number of fire-fighting units is required in an area in order to achieve a desired average travel time?
(3) How should a fixed number of fire-fighting units be distributed across several areas to equalize average travel times or to achieve an overall minimum average travel time?

Designed to provide a quick and inexpensive first approximation with data that are easily estimated, the model has been used extensively for operational and capital-project planning and to estimate the value of deployment improvements. When used in major policy applications and in formulating programs, it is supplemented by more detailed calculations, including the fire department computer simulation.

Munson, M. J. "Residential Fires and the Urban Poor," *Fire Journal 69* (6) 59-61 (November 1975)

Subjects: Fire; Urban area fires; Residential fires

Author's Summary

It is frequently asserted that fire incidence can be expected to be greater in high-density than in low-density population areas. High-density residential areas are often associated with poor people. To test this, population density figures were calculated for each borough in New York City and plotted against the incidence of structural fires. The pattern is remakable linear. Recognizing the limitations of statistical analysis with only five data points, one for each borough, a least squares linear regression line was fitted to the five points that showed that the slight positive slope was indeed significant. It appears that the incidence of structural fires does increase slightly as residential density increases.

Palmer, K. N. "Industrial Dust Explosions and Fires," *Archiwum Thermodynamiki i Spalania 7* (1) 22-39 (1976) See Section A.

Rider, K. L. (The New York City Rand Institute, New York) "A Parametric Model for the Allocation of Fire Companies: Executive Summary," The Rand Corporation, *R1641/1-HUD* (August 1975) See Section K.

Rider, K. L. (The New York City Rand Institute, New York) "A Parametric Model for the Allocation of Fire Companies: User's Manual," The Rand Corporation *R-1646/2-HUD* (August 1975)

Subjects: Allocation of firefighting resources; Model for allocation of fire companies

Author's Preface

The preparation of this report was supported by the Office of Policy Development and Research of the United States Department of Housing and Urban Development (HUD) under contract H-2164. Among the objectives of this HUD contract are the development, field testing, and documentation of methods to improve vehicle deployment procedures in municipal emergency service agencies throughout the United States.

This report was prepared to provide systems analysts and data processing personnel with a user's manual for a computer program that implements The New York City-Rand Institute's Parametric Allocation Model. This model can be used to generate and evaluate allocations of fire companies to regions of a city. The program, named PAM, operates in an interactive environment on a time-shared computer system. The Parametric Allocation Model was originally developed and applied to the allocation of fire companies in New York City under a contract with the New York City Fire Department to improve the deployment of their fire-fighting equipment.

A companion report provides a technical description of the Parametric Allocation Model: K. L. Rider, *A Parametric Model for the Allocation of Fire Companies,* The New York City-Rand Institute, *R-1615-NYC/HUD,* April 1975. Another report will describe the model and its uses for fire department administrators and city officials: K. L. Rider, *A Parametric Model for the Allocation of Fire Companies: Executive Summary,* The New York City-Rand Institute, *R-1646/1-HUD,* forthcoming.

These three reports are part of a series that documents several different deployment models for police, fire, and ambulance services. A second series of reports describes the application of the models in several cities. A third set of reports will present the general methodology developed for emergency service deployment analysis. It is hoped that these reports will provide local government officials with methods for systematically assessing alternative policies for providing emergency services, and will enable them to conduct deployment analyses with little or no outside technical assistance.

Rider, K. L. and Hausner, J. (The New York City Rand Institute, New York), **Shortell, R., Bligh, J., and Candiloro, T.** (Jersey City Fire Department, Jersey City, New Jersey) "An Analysis of the Deployment of Fire-Fighting Resources in Jersey City, New Jersey," The Rand Corporation *R-1566/4-HUD* (August 1975)

Subjects: Deployment of firefighting resources; Firefighting resource deployment

From Author's Summary

The analysis focused on the following questions: (1) How many fire companies should the City have? (2) Where should they be located? (3) How should they be manned? (4) What type of equipment should be used? (5) What should the initial-dispatch policy be? The objective of the analysis was to analyze each of these questions and to present Fire Department management with choices among a number of options, each having clearly defined benefits and liabilities. No attempt was made to specify definitive answers to all of these questions. Some choices involved policy judgments outside the scope of the project, and political, economic, and demographic conditions were changing too rapidly to allow long-range plans to be fixed by one study. Instead, the effort was to train members of the Fire Department to use the deployment models and methodology developed at the Institute so that the options could be continually improved and updated by the Department. The actual changes in Fire Department operations that are implemented will depend on future developments in Jersey City.

The results of each of the following major steps in the project analysis are presented in this report.

(1) Data were gathered and analyzed for use in the mathematical deployment models and in the evaluation of deployment alternatives.
(2) Projections were made of the land use and fire incidence for 1983.
(3) The current pattern of travel times of fire companies throughout the City was determined.
(4) Using the Institute's Parametric Allocation Model, a gross determination was made of what regions in the City should lose companies if companies were to be eliminated and how the remaining companies should be allocated to regions of the City.
(5) Specific locations for new firehouses were evaluated using the Institute's Firehouse Site Evaluation Model.
(6) Several deployment options, of similar cost, were developed for comparison to each other and to the current deployment of fire-fighting resources. One was based on a reduction in the number of fire companies with an increase in fire company manning. Another centered on the use of consolidated firehouses in which two engines would be stationed. A third involved the deployment of minipumpers.
(7) Several dispatching policies were evaluated.

These efforts have led to the following conclusions:

- There are currently a sufficient number of fire-fighting units deployed in Jersey City to respond to higher alarms or simultaneous alarms and to provide adequate coverage throughout the City over the next ten years.
- The personnel currently deployed on some units could be advantageously redeployed to minipumpers, or could be used to increase the manning levels of a small number of units.
- Stationing two engine companies in one consolidated firehouse is inefficient with respect to travel times to fires.
- There are a number of key sites within the City where firehouses should be strategically located regardless of future changes in population or land use. Firehouses are currently located on most of these sites.
- The current Jersey City dispatch policy is satisfactory.
- In order to ensure the continuation of deployment analysis as an integral part of Fire Department planning, the existence of a full-time planning staff consisting of Fire Department personnel should be continued. A permanent liaison should also be established with one of the state-funded universities to provide technical assistance to the planning staff in such specialized areas as operations research and data base management. Only through such an ongoing organization will the continued benefits of modern management and analytical techniques be realized.

Two benefits, important to the future operation of the Fire Department planning team, have already been derived from this project:

- The Parametric Allocation Model and the Firehouse Site Evaluation Model are now in routine use by the planning team through their own on-line computer terminal.
- Incidents are now recorded in a computer readable form as they occur. This will facilitate the updating of data bases for further analysis as the City gradually changes.

This report presents a complete description of the Jersey City project as a systems analysis case study, from problem definition through data gathering, analysis of alternative deployment policies, and final results.

Rider, K. L. and Jacobs, B. I. (The New York City Rand Institute, New York) "An Analysis of New York City Fire Department Expenditures from *1968* to *1974*," The Rand Corporation *P-5416* (March 1975)

Subjects: Fire department expenditures, New York City; Expenditures of New York City Fire Department

Authors' Summary

This paper examines New York City Fire Department expenditures for the fiscal years 1968-1969 to 1973-1974. Because the figures reported in the New York City Expense Budget indicate spending intentions rather than actual costs, this study attempts to determine actual Fire Department expense through an analysis of departmental operations as well as through the budget figures.

Fiscal years 1968-1969 to 1973-1974 indicate a general and continuous rise in Fire Department expenditures even after accounting for the increase in the cost of living. Since the wage component is over 95 percent of the budget in all six years under study, and since the number of companies deployed did not grow during these years, the substantial salary increases that were granted during the period under study were primarily responsible for the rise in costs.

Explicit unit costs such as costs per house and costs per company are obtained, facilitating the allocation of Fire Department costs to geographic regions of the City. It is found that although some companies may make runs to alarms that occur outside of the region to which they are assigned, the correction factors needed to adjust for this effect are very small.

Rodgers, F. E. (Joint Fire Research Organization, Borehamwood, Herts., England) "Investigation of a Technique for Estimating the Probability Distribution of Fire Loss Based on Extreme Value Theory," *Fire Research Note No. 1062,* Joint Fire Research Organization (December 1976)

Subjects: Fire loss, probability distribution of; Estimating fire loss

Author's Summary

The feasibility of applying a model based on the theory of extreme values to the

problems of estimating the parameters of the distribution of overall fire loss, and of estimating the annual total loss in fires is investigated. Results and comprehensive discussion of the results are given for the textile industry for the years 1966-72. The treatment of the subject is of necessity highly mathematical and somewhat complex in nature but further publications giving details of practical applications are in course of preparation.

Walker, W. E. (The New York City Rand Institute, New York) "The Deployment of Emergency Services: A Guide to Selected Methods and Models," The Rand Institute *R-1867-HUD* (September 1975)

Subjects: Emergency service deployment; Deployment of emergency services

Author's Summary

Over the past several years many new techniques for emergency service deployment analysis have been developed at The New York City-Rand Institute. These methods can be used for the comparative evaluation of fire station locations, for determining the number of patrol cars or ambulances an agency should have on duty at various times of day, for designing patrol beats for police cars, and for related issues. Much of the developmental work was sponsored by New York City, but some was sponsored by the National Science Foundation (NSF) and the U.S. Department of Housing and Urban Development (HUD).

After the developmental work was completed, HUD and two municipal governments (Trenton, New Jersey, and Yonkers, New York) sponsored field tests of the methods, so that in their final form they represent the experienced gained in many cities. Other cities that cooperated with HUD-sponsored work were Denver, Jersey City, New Haven, Tacoma, Washington, and Wilmington. In addition, over 20 cities in the U.S. and other countries have adopted one or more of the models described in this *Guide* without any direct assistance from the Institute or HUD. The HUD-sponsored work led to the publication of more than 30 reports over a period of two and one-half years. This report has been written to provide a single unified reference to all of this material in a form useful to analysts and planners who might be interested in deployment analysis.

An emergency service agency anticipating any type of deployment analysis should assign a planner having some technical skills and familiarity with the agency's data-processing capabilities to review the various approaches that can be taken, their feasibility, cost, and potential benefits. One of the two methodology reports prepared by The New York City-Rand Institute will assist the planner in this review:

- *Deployment Methodology for Fire Departments,* Jan Chaiken, Edward Ignall, and Warren Walker, The New York City-Rand Institute, *R-1853-HUD,* September 1975;
- *Allocation Methodology for Police Departments,* Jan Chaiken, The New York City-Rand Institute, *R-1852-HUD,* September 1975.

These reports describe many different computer-based models for deployment

analysis, whether developed by The New York City-Rand Institute or not. They also contain references to help the planner locate more information about the models that appear relevant to his agency's concerns.

If the planner finds any of The New York City-Rand Institute reports to be of potential interest, he can turn to this *Guide* for further details about the contents of each report. He will then know whether he wishes to order the reports and read them carefully. Some will help him in his initial feasibility review, while others will not be required until the agency has decided to proceed with its deployment analysis. For example, the executive summary of a deployment model provides information that can be helpful in deciding whether to purchase the computer program, whereas a report describing how one installs the program on a computer system is not needed until later.

Examples of the deployment analyses in some of the cities mentioned earlier have been written as case studies that give the planner a clear indication of the kinds of questions that were addressed, organizational arrangements that were made for conducting the analysis, the cost and length of time involved, and the benefits obtained. By consulting this *Guide*, the planner may find that one of the case studies describes a city similar to his own or one with a similar deployment problem. He can then obtain a copy of the appropriate report and prepare his own plans in light of successful and unsuccessful features of the analysis described in the case study.

After an agency selects a deployment problem as worthy of analysis, it will be necessary to form a suitable project team, to budget appropriate funds for the work, and to train the members of the team in the work they will do. One of the reports described in this *Guide* is a training course manual that provides complete lecture notes and examples of suitable visual aids and demonstrations of computer programs. Using guest lecturers, this course can be presented in three to five days. Or, the members of the project team could share the work of learning the material in the training course lecture notes. In this case, the information might be discussed in weekly meetings rather than being presented as formal lectures. The audience for the lectures should include high-ranking agency and municipal officials who will be called upon to implement the results of the analysis, as well as the staff that will carry out the work.

Either before or after training has been conducted, the agency will need to purchase appropriate computer programs, together with user's manuals and installation instructions. (Purchasing the programs before the training course permits them to be demonstrated as part of the training, using a data base from an example city.) This *Guide* describes each of the deployment models according to the following format:

- A brief description of the model and how it works.
- The deployment questions that the model is designed to address.
- The data that must be obtained before the model can be used.
- The results produced by the model.
- The assumptions that were made in developing the model and the restrictions that they impose on the results.

- A summary of where the model has been used and with what results.
- The effort and cost involved in preparing the model for use in a city, the size and type of computer that must be available, and special computer languages needed.
- The approximate cost of making a single run with the model.
- A list of publications that describe the model.

This information should be adequate to determine which of the documents describing models should be obtained, but each agency will have to estimate for itself the cost and time involved in preparing the data for the model, conducting the analysis, and implementing the findings.

Walker, W. E., Singleton, D. W., and Smith, B. A. (The New York City Rand Institute, New York) "An Analysis of the Deployment of Fire-Fighting Resources in Wilmington, Delaware," The Rand Corporation *R-1566/HUD* (July 1975)

Subjects: Firefighting resource deployment; Deployment of firefighting resources

Authors' Summary

Like many cities, Wilmington is faced with a stagnant or declining tax base and an increasing demand for services. The mayor is committed to providing the necessary city services in the most efficient manner. One of the first problems faced by the new administration when it took office in 1973 was what to do about implementing the recommendations of an earlier study that would have required replacing all but one of the existing firehouses. The cost of carrying out these recommendations had climbed drastically since the time of the study. In order to obtain technical assistance on this problem, the city contacted The New York City-Rand Institute, which had a contract with the U.S. Department of Housing and Urban Development to test its models in a number of cities.

Wilmington was subsequently chosen by the Institute and HUD as one of the best cities, and a project team was formed consisting of Institute staff, City administrative personnel, and Bureau of Fire personnel. Each group brought a different perspective and set of objectives to the problem: Rand was interested in demonstrating that the methodology developed and applied in New York City could help local officials in other cities make deployment decisions, and that the models could be easily used by local government personnel; the City administration was interested in determining whether a new deployment plan with fewer firehouses was feasible and how such a plan could be implemented; and the Bureau of Fire was interested in maintaining the existing high quality level of fire protection provided in Wilmington and in finding the best locations for new firehouses.

The project was performed in four stages. The results of each of the stages are presented in this report.

(1) Data were gathered and analyzed for use in the mathematical models and in the evaluation of deployment alternatives.

(2) The current pattern of fire company travel times throughout the city was determined.
(3) A gross determination was made of what regions in the city should lose companies if companies were to be eliminated and how the remaining companies should be allocated in regions of the city using the Institute's Parametric Allocation Model.
(4) Specific locations for new firehouses were evaluated using the Institute's Firehouse Site Evaluation Model.

These efforts have led to several important results:

- One of Wilmington's original nine engine companies was eliminated, producing an estimated saving of $240,000 per year with no loss of firemen's jobs and no perceptible reduction in fire protection.
- Plans were developed for the phased construction of six new firehouses to replace six existing firehouses over a four year period. This plan is reflected in the capital program adopted by the City Council for the period beginning July 1975.
- Models and associated computer programs developed by The New York City-Rand Institute for the analysis of fire company deployment problems have been transferred to analysts in the Wilmington city administration for their use in reevaluating proposed firehouse site locations as conditions change in the future.

In the process of performing the project a great deal was learned that should be of use to other communities with similar problems. The major lesson was that such a project requires the assistance of a large number of people with different interests and talents. Based on our experience we recommend that a project team be composed of one or more of the following:

- Representatives of the city's administration, to provide the project with policy direction and to ensure that the alternatives being proposed can be implemented.
- Budget analysts, to provide the necessary fiscal information and constraints. They generally have the most analytical background of all municipal personnel, which permits them to understand and learn the methodology.
- High level personnel from the agency directly affected, to provide the necessary data and insights into their specific operational problems. In this project, the Bureau of Fire was represented by the Commissioner of Public Safety, and by the Fire Chief and members of his staff.
- Union leaders, to provide employee inputs and viewpoints and to provide a potential channel for obtaining cooperation and support in the implementation process.
- Systems analysts possessing knowledge and understanding of technologies that can be applied to the problem. These people might be found in city government, but more commonly would come from an outside consulting firm or a local university. In this probject The New York City-Rand Institute provided the technical assistance.

One of the objectives of the project from the point of view of HUD and The New York City-Rand Instiute was to determine how useful and applicable the Institute's deployment models, which had been developed for use in New York City, would be in other cities. The Wilmington project showed that the models were applicable to much smaller cities, and could be used and understood by operating personnel in such cities.

But it is important to point out that the Wilmington project team learned, as other Institute-directed teams have learned in other cities, that the use of models in attacking urban problems cannot replace the decision making process or the decisionmaker. The models provide the decisionmaker with detailed information upon which he can base his decisions, but this information is only one of several inputs into the decision making process. The team also found that the information developed during the course of such a project can play an important role in providing a rationale and justification for the decisions that are finally made.

This report presents a complete description of the Wilmington project as a systems analysis case study, from problem definition through data gathering, analysis of alternative deployment policies, and final results. It shows how the Institute's deployment methodology was applied in one city, and should provide a guide to others desiring to perform a similar study, although each city is unique and the methodology will have to be modified to fit the particular case.

M. Model Studies and Scaling Laws

Alpert, R. L. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Pressure Modeling of Fires Controlled by Radiation," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1489 (1976)

Subjects: Pressure modeling of fires; Modeling of fires; Fires, radiation controlled

Author's Abstract

Pressure modeling involves the reduction of all length scales as the minus 2/3 power of ambient air pressure in order to preserve gas phase dynamics and solid phase thermal response during a fire. This concept has been critically tested until now only for convection dominated fires. The burning rate and radiant output of large-scale PMMA wall and pool fires dominated by radiative heat transfer are compared with model results in the present study. At ambient pressures from 5 to 35 atmospheres, measurements with PMMA walls from 10 to 41 cm high clearly show that modeling of fuel mass flux variations and overall burning rate of full-scale PMMA walls up to 360 cm high is highly successful. It is found that while radiative fluxes from the fire to the environment are often not modeled for such large wall fires, the net radiative feedback from flames to the fuel surface is approximately modeled. The computed magnitude of surface reradiation and the computed variation of flame radiation with pressure explain the detailed behavior of

the model burning rate relative to that at full-scale. The degree of success observed here in modeling burning rates of PMMA pool fires up to 122 cm across at 1 atm is shown to be entirely consistent with the wall fire results. While the detailed behavior of the model pool and wall fires may not precisely simulate full-scale effects, the accuracy of overall predictions based on model results is still impressive.

Butler, T. D. and O'Rourke, P. J. (Los Alamos Scientific Laboratory, University of California, Los Alamos, California) "A Numerical Method for Two Dimensional Unsteady Reacting Flows," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1503 (1976)

Subjects: Two-dimensional flows, numerical solution; Numerical solution of two-dimensional flows

Authors' Abstract

In this paper we present a method that numerically solves the full two-dimensional, time-dependent Navier-Stokes equations with species transport, mixing, and chemical reaction between species. The generality of the formulation permits the solution of flows in which deflagrations, detonations, or transitions from deflagration to detonation are found. The solution procedure is embodied in the RICE computer program. RICE is an Eulerian finite difference computer code that uses the Implicit Continuous-fluid Eulerian (ICE) technique to solve the governing equations. We first present the differential equations of motion and the solution procedure of the RICE program.

Next, a method is described for artificailly thickening the combustion zone to dimensions resolvable by the computational mesh. This is done in such a way that the physical flame speed and jump conditions across the flame front are preserved.

Finally, the results of two example calculations are presented. In the first, the artificial thickening technique is used to solve a one-dimensional laminar flame problem. In the second, the results of a full two-dimensional calculation of unsteady combustion in two connected chambers are detailed.

Davis, J. R. and Dieterich, J. H. (Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado) "Predicting Rate of Fire Spread in Arizona Oak Chaparral: Field Workbook," *U.S.D.A. Forest Service Technical Report RM-24* (1976) See Section J.

Kickert, R. N., Taylor, A. R., Firmage, D. H., and Behan, M. J. "Fire Ecology Research Needs Identified by Research Scientists and Land Managers," Proceedings of the Montana Tall Timbers Fire Ecology Conference and Fire and Land Management Symposium No. 14 217-256, Tall Timbers Research Station, Tallahassee, Florida (1976) U.S. Government Printing Office 1977-0-777-023-21

Subjects: Fire ecology; Ecology research

Authors' Introduction

In 1970, within the International Biological Program (IBP), the National Science Foundation established the Coniferous Forest Biome research organization. The overall goal of the Biome program was the analysis of the structure and function of western coniferous forest ecosystems. As a part of this endeavor, the Fire Ecology Project was established in 1973.

The general objective of the Fire Ecology Project has been to conduct an analysis of problems on the natural role of fire in the functioning of western coniferous forest ecosystems. This paper presents a part of the problem analysis. Specific objectives were to survey the opinions of environmental scientists and land managers as to specific fire ecology problems, to evaluate the literature on ecologic effects of fire, and to use these two categories of information in the design and computer implementation of system models as an approach to problem solutions.

Such models are sets of quantitative statements representing dynamic processes in landscape ecosystems. These sets of statements can be programmed on an electronic computer and can be used to imitate various ecosystem responses to changes in such quantitative fire attributes as fire periodicity, fire intensity, amount of fuel reduction, burn-area size, shape, and location.

Ku, A. C., Doria, M. L. and Lloyd, J. R. (University of Notre Dame, Indiana) "Numerical Modeling of Unsteady Buoyant Flows Generated by Fire in a Corridor," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1373 (1976)

Subjects: Fire in corridors; Corridor fire; Buoyant flows in corridor fire; Numerical modeling

Authors' Abstract

A numerical model for the prediction of unsteady, two dimensional buoyant flows is presented. The model makes use of the full elliptic balance equations for heat, mass, and momentum and allows for full coupling between density and temperature. The model is highly flexible in that it can accommodate variable transport properties and complex boundary conditions. Of particular importance, it is capable of treating surfaces such as a doorway or window across which there can be a free inflow or outflow of fluid to the computational region. The model has been used to predict the time dependent velocity and temperature fields generated by fire in an enclosure or corridor. It has proven successful in predicting the gas velocities and temperatures generated by the fire in the enclosure corridor geometries, the ventilation of the fire through windows or doorways, and the heat transfer rates to the various surfaces involved. In these cases combustion is modeled by volumetric heat sources. The results for two particular cases are presented and comparisons are made with experiment.

Markstein, G. H. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Scaling of Radiative Characteristics of Turbulent Diffusion Flames," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1407 (1976) See Section I.

Massoudi, M. S. "The Burning of Solid Polymeric Particles in a Reactive Environment, I. Wood," *Journal of Fire and Flammability* 7 (3) 347-357 (July 1976) See Section G.

Morgan, H. P., Marshall, N. R., and Goldstone, B. M. (Building Research Establishment, Borehamwood, Herts., England) "Smoke Hazard in Covered Multilevel Shopping Malls: Some Studies Using a Model Two Story Mall," *Building Research Establishment Current Paper 45/76,* Fire Research Station (1976) See Section A.

Morgan, H. P. and Marshall, N. R. (Building Research Establishment, Borehamwood, Herts., England) "Smoke Hazards in Covered, Multi-Level Shopping Malls: Part 1. An Experimentally Based Theory for Smoke Production," *Building Research Establishment Current Paper 48-75,* Fire Research Station (1975)

Subjects: Smoke hazard; Movement of smoke; Shopping malls, smoke movement

Authors' Abstract

A method is presented for calculating the amount of smoke entering the ceiling smoke reservoir of a covered multi-level shopping mall, using the smoke conditions beneath the balcony edge as initial conditions. An experiment is described which, using 1/10 scale model shops with balconies, determined these balcony edge conditions for several shop configurations and for a number of fire sizes. The plume parameters predicted from these results were confirmed by model experiments. The results indicate that very high extraction rates will be required to maintain a stable smoke-free layer beneath the smoke reservoir: e.g., for a 5 MW fire in a 14 m wide shop on the lower level, and a clear layer 3 m deep at the upper level, the predicted extraction rate required is 155 kg/s. Some methods of reducing these high extraction rates by controlling the smoke flow are suggested.

Morris, A. W. and Hopkinson, J. S. (Building Research Establishment, Borehamwood, Herts., England) "Fire Behavior of Foamed Plastics Ceilings Used in Dwellings," *Building Research Establishment Current Paper 73/76,* Fire Research Station (1976)

Subjects: Fire behavior of foamed plastics; Foamed plastics, fire behavior; Plastic ceiling material, fire behavior

Authors' Abstract

Experiments have been conducted on a range of ceiling materials incorporated in a full-scale model simulating a single-storey dwelling or the uppermost floor of

a flat or maisonette block. The possibility of fire spread from one room into the roof space and subsequent re-entry into another room adjacent to the fire compartment has been investigated. Within the experiments there was fire spread into the roof space above in all cases, with earlier penetration times with foamed plastics in comparison with traditional materials. The re-entry into the adjoining room was also dependent on the type of ceiling lining used. It is proposed to issue a further Current Paper in due course which will cover an investigation of the numbers of buildings in the United Kingdom in which these ceilings may be involved and the cost effectiveness of remedial measures.

Westbrook, C. K. (Lawrence Livermore Laboratory, University of California, Livermore, California) "Three Dimensional Numerical Modeling of Liquid Fuel Sprays," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1517 (1976)

Subjects: Liquid fuel sprays; Fuel sprays; Modeling of fuel sprays

Author's Abstract

A numerical solution technique has been developed for the spray equation and has been applied to thin sprays injected into a type of stratified charge internal combustion chamber. The difference equation method can treat general three dimensional geometries, using a statistical approach. The effects of independent variations of a large number of system parameters was studied, including initial spray dispersion, amount and type of gas swirl, gas density, injection timing, chamber geometry, initial droplet size distribution, injection velocity, drag coefficient, vaporization rate expression, injector aperture size, droplet specific gravity, and direction of injection. It was found that in the particular geometry chosen the gas swirl, the droplet size distribution produced by the injector, and the chamber gas density into which the spray is injected are the most important factors influencing the spray motion and vaporization. Although the calculations reported here applied to internal combustion engine conditions, the general method is applicable to other spray-injected combustors, including stationary combustors and rocket motors. Results from calculations indicate that the technique, used in coordination with selected laboratory measurements, could significantly enhance spray-injected combustor design efforts.

N. Instrumentation and Fire Equipment

Abbott, N. J. and Schulman, S., "Protection From Fire: Nonflammable Clothing — A Review," *Fire Technology 12* (3) 204-218 (August 1976)

Subject: Nonflammable clothing

Safety in Mines Abstracts 25 No. 1238

Safety in Mines Research Establishment

Technology has the capability of providing nonflammable protective clothing for fire fighting, industrial, and military applications. However, there are practical problems to be overcome before everyone can enjoy the protection of such garments.

Buckland, I. G., Butlin, R. N., and Annable, D. J. (Joint Fire Research Organization, Borehamwood, Herts., England) "Gas Explosions in Buildings, Part VI. Remotely Controlled Gas Sampling Probe and Closure Valves for a Gas Explosion Chamber," *Fire Research Note No. 1052,* Joint Fire Research Organization (June 1976)

Subjects: Gas explosions; Buildings, gas explosions in; Gas explosion chamber; Explosions, gas, in buildings

Authors' Summary

The Engineering Services Section have designed in collaboration with ITH Section, a new Sampling Probe System for the 28 m^3 explosion chamber at Cardington. The system is remotely operated with digital indication of the probe position. The gas mixture in the cell can be sampled at any point between the ceiling and the bottom of the extended probe. After filling the chamber the probe is retracted, thus avoiding the possibility of the probe affecting the characteristics of an ensuing explosion. All the gas inlet and exhaust valves on the rig are remotely operated using the same power source for reasons of safety and convenience.

"Continuous Flow Respirators," *Coal Age 81* (8) 145 (August 1975)

Subjects: Respirators, continuous flow

Safety in Mines Abstracts 25 No. 1237
Safety in Mines Research Establishment

Brief note on two respirators for use in contaminated atmospheres. Clean air supply is made available up to 300 ft from air source. Low pressure, externally lubricated compressors are recommended to eliminate objectionable odors that may emanate from internally lubricated compressors. Temperature alarm for CO and filter to eliminate objectionable odor is also recommended by the manufacturer.

Corrie, J. G. (Joint Fire Research Organization, Borehamwood, Herts., England) "A 200 Liter per Minute Standard Foam Branchpipe," *Fire Research Note No. 1056,* Joint Fire Research Organization (August 1976)

Subject: Foam branchpipe

Author's Summary

Constructional details of a 200 liter per minute foam branchpipe are given. The foam properties using protein foam at various concentrations and pressures, together with the properties using a range of foam liquids in common use have been determined. The throw and dispersion have been measured. Comparisons with six commercial branchpipes have been made.

Eneidi, W. L. and Taylor, R. D. "Air Purifying Powered Respiratory Pack Utilizing a Miniature Two Stage Air Mover," *American Industrial Hygiene Association Journal 37* (8) 464-468 (August 1976)

Subject: Respiratory pack, air purifying

Safety in Mines Abstracts 25 No. 1236
Safety in Mines Research Establishment

Design and construction of a moderate weight, battery powered, positive pressure respirator pack is described. Design detail of a two stage air mover is given, along with its adaptation for use as a portable air sampler.

Hayashi, T., Shibata, M., Yamaguchi, H., Sakurai, H., and Kanehara, K. "Research on Air Shutter for Fire Protection (2)," *Bulletin of the Japanese Association of Fire Science and Engineering 26* (1) 15 (1976) (in Japanese) See Section A.

Hayashi, T., Shibata, M., Yamaguchi, H., Sakurai, H., and Kanehara, K. "Researches on Air Shutter for Fire Protection (3)," *Bulletin of the Japanese Association of Fire Science and Engineering 26* (2) 17 (1976) (in Japanese) See Section A.

Mach, M. H. "Gas Chromatography-Mass Spectrometry of Simulated Arson Residue Using Gasoline as an Accelerant," *J. Forensic Sci. 22* (2) 348-57 (1977) See Section H.

Maneval, D. "Assessment of Latest Technology in Coal Refuse Pile Fire Extinguishment," 1976 Coal Show of the American Mining Congress, Detroit, 10-13 May, Washington American Mining Congress 1976. See Section E.

McCaffrey, B. J. (National Bureau of Standards, Washington, D.C.) **and Heskestad, G.** (Factory Mutual Research Corporation, Norwood, Massachusetts) "A Robust Bidirectional Low Velocity Probe for Flame and Fire Application," *Combustion and Flame 26* 125-127 (1976)

Subject: Velocity probes

Abstracted by G. Fristrom

A probe which is capable of measuring the low velocity of buoyancy driven flows associated with small to medium fires is described. The probe has angular sensitivity, which allows a more accurate assessment of velocity where flow angles are difficult to predict and responds to flow in either direction. This bidirectional property allows location of the probes without prior knowledge of the flow direction. The probe also responds correctly when the flow at a point reverses direction. The probe has a large size inlet which circumvents problems of water droplet and debris formation. Evaluation tests of the probe are described.

Moreau, P. and Boutier, A. (ONERA, Chatillon, France) "Laser Velocimeter Measurements in a Turbulent Flame" Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 1747 (1976)

Subjects: Turbulent flame; Laser velocimeter; Flame measurements

Authors' Abstract

Measurements of mean velocity, turbulence rate and velocity fluctuations were performed in a constant area combustion chamber, where a premixed air-methane flow is ignited and stabilized by a parallel flow of hot gases acting as a pilot flame. The combustion produces an acceleration of the flow and transverse velocity gradients. Turbulence increases as the combustion develops, velocity fluctuations being maximum in the reaction zone. The influence of the inlet turbulence intensity and the velocity ratio between main stream and hot jet have been investigated; generally speaking, the phenomena are similar. The r.m.s. transverse velocity fluctuation obtained during the tests does not seem to be increased by combustion, and the Reynolds stress, $u' v'$, is significant only in the neighborhood of the mixing zone. The numerical prediction of mean velocity and velocity fluctuation leads to a fairly satisfactory agreement with experimental results: the turbulence increase in the combustion zone seems to be closely related to the velocity gradient produced by the flame.

Nash, P. (Building Research Establishment, Borehamwood, Herts., England) "Portable and Installed Fire-Fighting Equipment in Buildings," *Building Research Establishment Current Paper 3/77*, Fire Research Station (1977) See Section A.

Nash, P. (Building Research Establishment, Borehamwood, Herts., England) "Sprinkler and Spray Systems for Maritime Use," *Building Research Establishment Current Paper 1/77*, Fire Research Station (1977) See Section F.

Nash, P. and Theobald, C. R. (Building Research Establishment, Borehamwood, Herts., England) "The Use of Automatic Sprinklers as Fire Sensors in Chemical Plant," *Building Research Establishment Current Paper 50/76*, Fire Research Station (1976) See Section D.

Pealat, M., Druet, S., Attal, B., and Taran, J. (ONERA, Chatillon, France) "Temperature and Concentration Measurements in Reactive Media by Coherent Anti-Stokes Raman Scattering," Sixteenth Symposium (International) on Combustion, The Combustion Institute, Pittsburgh, Pennsylvania 789 (1976)

Subjects: Temperature in reactive media; Concentrations in reactive media; Anti-Stokes Raman scattering

Authors' Abstract

We present the application of Coherent anti-Stokes Raman Scattering (CARS) to the investigation of the diffusion flame on a wetted spherical burner. The theory is reviewed briefly, together with instrumental considerations. The setup is described. Temperatures and concentrations were measured from spectral contours of N_2; CO was also detected and its concentration profile was plotted.

Pusey, J. C., Prater, D., and Corrie, J. C. (Joint Fire Research Organization, Borehamwood, Herts., England) "An Evaluation of Hand Portable Foam Type Fire Extinguishers," *Fire Research Note No. 1049,* Joint Fire Research Organization (March 1976) See Section A.

"Safer Glove Is More Comfortable," *Financial Times 27* (144) 11 (December 8, 1976)

Subject: Firefighting glove

Safety in Mines Abstracts 25 No. 1239
Safety in Mines Research Establishment

Designed to combine wearer acceptance with flexibility and close fit, the glove enables the user to retain his sense of touch. It is covered with a honeycomb web of polyvinyl to give maximum security of grip and cuts down the likelihood of dermatitis by allowing the skin to breathe. It can be machine-washed without deterioration.

Scheidweiler, A. "The Ionization Chamber as Smoke Dependent Resistance," *Fire Technology 12* (2) 113 (1976)

Subjects: Ionization chamber; Smoke detector; Fire detector

Journal Abstract

The effect of aerosols on the ionic current flowing through an ionization chamber is useful in quantitative aerosol measurement and in the development of smoke dependent detectors. The ionization chamber is regarded as a nonlinear resistance, which changes its impedance when influenced by an aerosol. Starting with the characteristic chamber equation, impedance is calculated as a function of smoke density. As a means of measurement of the sensitivity to smoke, the relative change in resistance has an advantage over the relative current changes now being used. With uniform ionization and constant field, calculated and measured values are in good agreement. This approach has been successful in practice.

Takahashi, S. (Fire Research Institute of Japan, Tokyo, Japan) "Development of an Oxygen Generating Breathing Apparatus, II. Design and Performance," Report of *The Fire Research Institute of Japan 41* 49-61 (1976)

Subjects: Oxygen generating breathing apparatus; Breathing apparatus

Author's Abstract

This paper describes the design and performance of an O_2-generating emergency self-rescuer. The desirable properties for the self-rescuer were derived by analyzing a large number of fire cases and by some considerations of the fire brigade's abilities and objectives. It was concluded that the duration time of the apparatus was of primary importance. This standard duration time is 20 minutes under an assumed breathing rate of $40l/$min or O_2 intake of $1.7l/$min. The O_2 deficiency phenomenon at the first few minutes before chemical reactions become active enough was obvious in the former report. Therefore, the supplementary O_2 supplying device was inevitable.

A small O_2 cylinder, with a capacity of $20ml$ (150 atm O_2) was used, which not only prevents a deficient O_2 supply but also prevents suffocation through the decrease of breathing gas in the bag. The necessary volume of O_2 was determined experimentally and theoretically calculated under the assumed condition of use. This apparatus is called a "return type apparatus" in comparison with the conventional "circuit type apparatus" because it inhales the regenerated and stored gas again through the O_2 canister. It is compact and may be more economical than the circuit type.

The main problems of this apparatus are that the inhaled gas is warmed again even though it is cooled in the breathing bag and becomes humid at the latter period of use, which spoils the comfortability of breathing. Under a cooler atmosphere (below 10°C), this fault would not be encountered and, if necessary, the design can be changed into a circuit type apparatus.

Tewarson, A. and Pion, R. F. (Factory Mutual Research Corporation, Norwood, Massachusetts) "Flammability of Plastics, I. Burning Intensity," *Combustion and Flame 26* 85-103 (1976) See Section B.

Theobald, C. R. (Joint Fire Research Organization, Borehamwood, Herts., England) "A Photographic Technique for the Study of Water Jets," *Fire Research Note No. 1041*, Joint Fire Research Organization (September 1975)

Subjects: Jets, photography of; Water jet photography; Photography of water jets

Author's Summary

A photographic technique has been developed for the close study of water jets moving with velocities ranging from 18 to 32 meters per second. Water jets with flow rates and ranges suitable for fire fighting use are being studied to determine the effects of both changes in nozzle design and the use of flow improving additives to the water.

Troy, J. J. "Fire Protection Provisions for Rapid-Transit Systems," *Fire Journal 70* (1) 13 (1976)

Subjects: Fire protection systems; Rapid-Transit fires

Fire Technology Abstract 76-17

In rapid-transit systems, the problems of fire protection and life safety include a high incidence of fires caused by traction and braking systems, the combustibility and toxicity of interior finish, train fires in stations, combustible loading in station areas, station evacuation, safety, and fire service operations in elevated and subway fires. Although transit fires involve mobile operations spread over a large area, adequate fire protection is based on the application of well-learned fire protection principle. Rather than the adoption of existing codes, the author recommends a code written specifically for transit operations.

Wagner, J. P., Fookson, A., and May, M (Gillette Research Institute, Rockville, Maryland) "Performance Characteristics of Semiconductor Sensors Under Pyrolytic, Flaming, and Smoldering Conditions," *Journal of Fire and Flammability 7* 72-103 (January 1976)

Subjects: Semiconductor detectors; Taguchi gas sensors; Combustion gas detectors; Detectors

Authors' Abstract

Taguchi gas sensor (TGS) 109 is shown to be a suitable fire/gas sensor for use in metal and non-metal mines. Very good response to pyrolytic and smoldering combustion products of important mine fuels, insensitivity to two important ambient contaminants — water mists and rock dust clouds — are selected performance highlights. Good carbon monoxide response and relative insensitivity to hydrocarbons when TGS 109 is operated in the CO mode, i.e., at a heater voltage, V_h, equal to 0.8 volts, and resistance to "irreversible" sensor poisoning from HCl are also noted.

Lack of response to TGS 109 to flaming combustion from liquid and solid hydrocarbons in a test enclosure employing low fuel loadings (i.e., ratio of fuel weight to floor area of enclosure) is one drawback noted. False alarming problems for TGS 109 are also discussed.

Comparative performance data of TGS 109 versus conventional heat and smoke detectors for flaming and smoldering combustion sources are presented. The application of the TGS device to the residential detection problem is considered. The need for realistic test methods for evaluation detector performance and further research study in the area are also pointed out.

Wagner, J. P., May, M., and Fookson, A. (Gillette Research Institute, Rockville, Maryland) "Comparative Performance of Ionization Versus Photoelectric Fire Detectors — Pyrolytic Degradation Products," *Journal Fire and Flammability 6* 511-533 (October 1975)

Subjects: Fire detector; Photoelectric fire detectors; Ionization fire detectors

Authors' Abstract

Performance data for commercial ionization and photoelectric type fire detectors for response to degradation products of important metal and non-metal mine fuels are presented. Poor response to plastic degradation products was exhibited by all the ionization detectors tested. At alarm, smoke levels ranged from 10 to 40 percent obscuration per foot. Exceptionally good performance was exhibited for Pyrotector SK 700 — a near IR LED photoelectric detector; however, because of known response to visible products of combustion from diesels and blasting or shot firing operations, its recommended use is in an integrated or hybrid system. Gas sensing techniques are an obvious choice.

Woolley, W. D. and Rodgers, S. P. (Joint Fire Research Organization, Borehamwood, Herts., England) "Performance of Asbestos Fire Blankets," *Fire Research Note No. 1057,* Joint Fire Research Organization (November 1976) See Section E.

O. Miscellaneous

"Attacking the Fire Problem: A Plan for Action 1976 Edition," Editors **F. B. Clarke** and **D. W. Raisher,** National Bureau of Standards, *Center for Fire Research Special Publication 416,* 41 pp. (January 1976)

Subjects: Building design; Consumer protection; Fire control; Fire detection; Fire research; Fire spread; Flammability

Editors' Abstract

The mission of the Center for Fire Research is to insure the development of the technical base for the standards and specifications needed in support of the National goal to reduce fire losses by 50% over the next generation. A systems approach to accomplish this mission is described. The Center consists of four basic programs in the area of Fire Science and five applied research programs in the area of Fire

Safety Engineering. Each applied program addresses an aspect of the Fire Problem, using fundamental information supplied by the basic research function. Active participation by staff members in voluntary standards organizations is the principal means of making this technology available for codes and standards needed to reduce the Nation's fire loss.

Building Research Establishment Annual Report 1975, Building Research Establishment, Department of the Environment, Borehamwood, Herts., England, ISBN-0-11-670545-0 (1976)

Subject: Fire research

Fire Research Topics

Statistics

Economics of Fire Protection
Statistical Studies of Fires Starting in Furniture

Escape from Fire

Field Investigations

Detection and Extinction

False Alarms
Prediction of Smoke Detector Response
Extinguishing Materials and Equipment

Smoke and Toxic Gases in Fires

Explosions

Foamed Plastics Ceiling Boards

Plastics Emergency Housing

Composite Structures Furnace

Enclosed Shopping Complexes

High Alumina Cement Content

Fire Instrumentation

Building Research Establishment Information Directory 1976: Current Publications Films and Services, Building Research Establishment, Department of the Environment, Borehamwood, Herts., England (1976)

A classified list of current publications and films available from the Applications Services Division, Building Research Establishment. Fire topics are fire spread, smoke and toxic gases, fire resistance of materials, venting, fires in buildings, detection, fire-fighting, sprinkler systems, hazards, statistics, economics, surveys and reports, and road vehicle fires.

Boudreau, J. F., Kwan, Q. Y., Faragher, W. E., and Denault, G. C. (Aerospace Corporation, El Segundo, California) "Survey and Assessment of Arson and Arson Investigation," *Aerospace Report No. ATR-76 (7918-05)-2* under Contract No. J-LEAA-025-73, Law Enforcement Assistance Administration (October 1976)

Subjects: Arson study; Arson investigation; Methods of arson investigation

Authors' Abstract

This report contains the results of a study of arson and of current methods and needs in arson investigaiton. Arson is a violent crime which killed 1000 people and injured 10,000 others in 1975 and which at the same time caused greater estimated property losses ($1.4 billion) than any of the major property crimes (robbery, burglary, larceny, and motor vehicle theft). Over the past decade, incendiary building fires increased 325% — more than any other type of serious crime. Currently available arson statistics and studies of the characteristics of arsonists are presented, and their limitations are noted.

A major component of the study was a questionnaire survey of a selected group of leading arson investigators to identify needs in arson investigation. The highest priorities were given to increasing the number and the training of arson investigators, to establishing an automated data system for arson investigation, to scientific research on arson investigation methods, to improving cooperation from insurance companies, and to development of equipment to aid in arson investigation. The piece of equipment most urgently needed is an improved flammable vapor detector to help the investigator locate residues of fire accelerants such as gasoline which are the most frequent fire-setting method used by arsonists.

Another component of the study was a statistical analysis of data on arson, arson arrests, and arson convictions from 108 cities over a 4-year period. It was found that cities ranking in the upper third according to arson arrest rates had 22% fewer arsons per 100,000 population than cities ranking in the bottom third, while cities in the upper third according to conviction rate had 26% less arson.

A review of the capabilities and needed improvements in the technical methods of arson investigation is presented. A number of recommendations for the reduction of arson and the improvement of arson investigation are included.

Fire Management, U.S.D.A. Forest Service quarterly publication devoted to forest fire management

Volume 37 Number 1, Winter 1976

New Map Working Tool Designed - L. Seger and C. Frobig
Fire Management in Everglades National Park - L. Bancroft

Volume 37 Number 2, Spring 1976

Fire Prevention — Its Future - T. Price and E. McNamara
Evaluation of Fire Cause Statistics: A First Step in Preventing Fires - L. Donoghue
Jet Stream Influence on the Willow Fire - J. Dieterich
Strategies for Reducing Incendiary Fire Occurrence in the South
Fire Weather Observer's Handbook Reissued
The Computation of Fuel and Fire Danger Parameters Using a Pocket Calculator - C. Roberts
FOCUS: How Can It Be Used by Fire Managers? - W. Phoenix
Working with Neighbors - M. Newell
Forestry and Forest Fire in Turkey - A. Ozyigit and C. Wilson

Volume 37 Number 3, Summer 1976

Physical Fitness — What Can Be Done About It? - J. Dukes
Wildfire Hazard Classification Mapping for Suburban Land Use Planning - J. Getter
Predicting Weights of Douglas Fir Slash for Material Up To 3 Inches in Diameter - P. Woodward, S. Pickford, and R. Martin
Equipment Development Reporting - A. Jukkala
National Advanced Fire Prevention Training - R. Newcomb
Tank Filler Hose
Precipitation Duration Meter - S. Withrow
A Fire Potential Assessment Model for Brush and Grass Fuels - R. Van Gelder

Volume 37 Number 4, Fall 1976

Computerized Fire Studies - D. Rondeau
Man Caused Versus Lightning Caused Fires: A Geographic and Reporting Problem - W. Main and D. Haines
Drought and Fire in the Lake States - V. Johnson
Ax and Pulaski Head Remover and Installer
Do You Have a Fire Bug in Your Home?
Fire Control Makes Use of Lightning Detection - M. Gillean
Heated Cover Keeps Slip-on Pumpers Warm - W. Craig
Preplanned Electronic Dispatching an Efficient Approach in Large and Multiple Fire Situations - J. Schramel and T. Videtto

Fire Problems Program: Quarterly Report, October - December 1976, Applied Physics Laboratory, The Johns Hopkins University, Laurel, Maryland, APL/JHU FPPQ-2-76, under grant from the National Fire Prevention and Control Administration. Program Director: A. G. Schulz; Principal Investigators: R. M. Fristrom and W. G. Berl. See Section K.

Fire Sciences Dictionary, B. W. Kuvshinoff, R. M. Fristrom, G. L. Ordway, and R. L. Tuve, Editors (Applied Physics Laboratory, The Johns Hopkins University) Wiley Interscience Publication, John Wiley and Sons, Inc., New York (1977)

Subjects: Fire science dictionary; Dictionary, fire science

The Fire Sciences Dictionary contains definitions of approximately 8,000 terms from all principal fire related areas.

Guenther, D. A., McGarry, D. L., Shearer, R. P., and MacCleary, R. C. "Fire Analysis from Mechanical Properties," *Fire Technology 12* (3) 173-185 (August 1976)

Subjects: Fire analysis of metals; Metal fire analysis

Safety in Mines Abstracts 25 No. 1222
Safety in Mines Research Establishment

This paper reports on a preliminary investigation into the feasibility of determining fire causes by analysis of the tensile properties of metals.

Habeck, J. R. (University of Montana, Missoula, Montana) "Forests, Fuels, and Fire in the Selway Bitterroot Wilderness, Idaho," Proceedings Montana Tall Timbers Fire Ecology Conference and Fire and Land Management Symposium No. 14, 305-352, Tall Timbers Research Station, Tallahassee, Florida (1976) U.S. Government Printing Office 1977-0-777-023-23

Subjects: Forest fuels; Fire in Selway Bitterroot wilderness; Forest fire

Author's Summary

The vegetation within the SBW represents a generally typical array of forest communities of the sort found in much of northern Idaho and western Montana. For tens of thousands of years the flora in this region has evolved in the presence of periodic fire, and many exhibit structural and reproductive features that appear to be related to their survival and perpetuation within a fire environment. In addition the flora and the forest communities it forms are spatially arranged in response to the well-developed environmental gradients (moisture, temperature, etc.) that any rugged, mountainous terrain exhibits. Fire and topography combined to form a highly diverse biotic system. The influence of topography remains, but the impact of fire has been very effectively altered during the past five decades. Forest communities at lower elevations, those that experienced frequent fire, appear to show the greatest compositional response to the reduction in fire. The coniferous forests at this latitude have rates of organic matter production that are higher than the rates of microbial decomposition. In the absence of fire as a decomposing process, fuel loadings gradually build up, and forest compositions change as stand maturity is achieved. The percentage of intermediate and old-aged communities occupying SBW landscape is gradually increasing, and the diversity of community life forms is becoming reduced. Loucks (1970) has pointed out that perturbations such as fire tend to recycle the system, and are important in maintaining a periodic wave of peak biotic diversity.

Hope is held that the detailed, quantitative analysis of the Selway-Bitterroot Wilderness forests and fuels will provide further evidence that fire cannot be further ignored as an important ecosystem process in this region. Successful landscape management must give attention to all ecosystem components and processes, including fire. How fire is successfully returned to landscape management planning cannot be discussed at length here. However, it is suggested that for wilderness areas any fire management planning should allow for a conspicuous degree of randomness in future fire influence. Man is probably capable of developing and implementing plans that dictate the design of future landscape patterns, and such plans might even maximize biotic diversity. Although such a result might not be entirely unavoidable under any management plan, it is hoped that the highest degree of pristine wilderness qualities can be sustained.

Hahl, R. G. (Defense Civil Preparedness Agency, Washington, D.C.) "Defense Civil Preparedness Agency Fire Research Bibliography," *Final Report 1962 - 1975, DCPA-RE-24,* Defense Civil Preparedness Agency (January 1976)

Subjects: Thermal radiation; Thermal hardening; Fire; Casualties; Property damage; Thermal countermeasures; Rescue systems; Damage control; Life hazards; Mass fire behavior

Author's Abstract

A short introduction to management of Office of Civil Defense fire research is provided. All documents produced by this program from 1962 to 30 June 1975 are listed and their scopes summarized.

Harvey, A. E., Jurgensen, M. F., and Larsen, M. J. (Intermountain Forest and Range Experiment Station, Ogden, Utah) "Intensive Fiber Utilization and Prescribed Fire: Effects on Microbial Ecology of Forests," *U.S.D.A. Forest Service General Technical Report INT-28* (1976) See Section J.

Jin, T. (Fire Research Institute of Japan, Tokyo, Japan) "Visibility Through Fire Smoke, Part 5. Allowable Smoke for Escape From Fire," *Report of the Fire Research Institute of Japan No. 42* 12 (1976) See Section J.

Lathrop, J. K. "Two Die in High-Rise Senior Citizens Home, Albany, New York," *Fire Journal 69* (5) 60-62 (September 1975) See Section A.

References to Scientific Literature on Fire, Department of the Environment and Fire Offices' Committee, Joint Fire Research Organization, Borehamwood, Herts., England, compiled by **P. Mealing**, Part 26B, July - December 1975, 98 pp (published April 1976)

Topics

OCCURRENCE OF FIRE
FIRE HAZARDS AND FIRE PRECAUTIONS
INITIATION AND DEVELOPMENT OF COMBUSTION
FIRE RESISTANCE
FIRE DETECTION AND EXTINCTION
NUCLEAR ENERGY
GENERAL

"Rocky Mountain Forest and Range Experiment Station: A List of Published Research, April 1, 1972 through March 31, 1976," *U.S.D.A. Forest Service General Technical Report RM-31* (1976)

Subject: Forest Service research

Abstracted by G. Fristrom

This document contains an annotated list of Station publications. Subject categories are: forest management, range and wildlife habitat management, watershed management, fire and atmospheric sciences, forest insects and diseases, recreation, resource assessment and economics, forest products, and other.

BOOKS

Kanury A. M. (Fire Research Group, Stanford Research Institute, Menlo Park, California) *Introduction to Combustion Phenomena*, Gordon and Breach Science Publishers, New York (1975)

Subjects: Combustion chemistry; Combustion physics; Diffusion flames; Premixed flames

Chapter 1 Introduction
Chapter 2 Chemistry of Combustion
Chapter 3 Physics of Combustion
Chapter 4 Kinetically Controlled Combustion Phenomena
Chapter 5 Diffusion Flames in Liquid Fuel Combustion
Chapter 6 Combustion of Solids
Chapter 7 Combustion of Gaseous Fuel Jets
Chapter 8 Flames in Premixed Gases
Postscript
Appendix A Review of Thermodynamics of Gases
Appendix B Thermochemistry (First Law of Thermodynamics Applied to Chemically Reacting Systems)

Today's Fire Service: Anniversary Publication, 100 Years of the Swiss Fire Service Association, 1870-1970, Stamfil and Co., AG, Bern, Switzerland (1976)

Subject: Swiss Fire Service

Contents

Murgai, M. P. *Similarity Analysis in Fire Research, With Special Reference to Fire Convection Inside Enclosures,* Oxford & IBH Publishing Co., New Delhi, Bombay, and Calcutta, India (1976)

Publisher's Description

In an earlier attempt all the material contained in the present volume was included in a single volume entitled *Natural Convection from Combustion Sources.* On reconsideration it was realized that the whole subject matter contained in the first version could indeed be divided into two separate coherent themes and presented under two different titles. The present work is the outcome of such an effort.

As the name implies, this book deals with the application of the principles of similarity analysis to different areas in fire research. The first chapter is an introduction to the philosophy of modelling and the scope of the various methods used for this purpose and discussed in detail in subsequent chapters. The second chapter pertains to the method of dimensional analysis and its applications to various examples both in the field of free-burning fires and those inside enclosures. The latter subject is discussed in somewhat greater detail in this chapter. Chapters 3 and 4 are devoted to the methods of similitude and differential equations and their use to extract modelling laws for free-burning fires, fire storms, etc.

Contents

Murgai, M. P. *Natural Convection From Combustion Sources,* Oxford & IBH Publishing Co., New Delhi, Bombay, and Calcutta, India (1976)

Publisher's Description

This work is an attempt to put the existing accumulated knowledge on natural convection above fires into a book form. Interest has grown in the last few years in the various problems connected with both indoor and outdoor fires. The role of natural convection in the detection, sustenance, and spread of fire is well recognized. It is only through a thorough understanding of fire that adequate means of its prevention and extinguishment can be devised. It is hoped that this book will contribute towards highlighting the importance of natural convection in the understanding of fire.

Beginning with a brief survey of the fire problem in general — from ignition to extinguishment — the book brings out the role of natural convection in large-scale fires, and then passes on to the fundamental equations constituting the basis of discussion in the book. The core of the subject, namely, the natural convection above free-burning fires is discussed both for the combustion-free zone as well as the combustion zone. The subject matter is concluded with the most difficult problem in this area, namely, the fire storms, the fire whirl and related topics.

Contents

MEETINGS

International Symposium on Physiological and Toxicological Aspects of Combustion Products, March 18-20, 1974, University of Utah, Salt Lake City, Utah

This Symposium was held under the joint auspices of the Committee on Fire Research of the National Research Council and the Flammability Research Center of the University of Utah. A wide variety of topics were discussed and the Symposium Proceedings, which are available from the Printing and Publishing Office of the National Academy of Sciences, Washington, D.C., represent a good summary of the state of the art at the time. The scope can be judged from the Table of Contents shown below. Summaries of the presentations of this and a second Symposium held in 1976 are included following the entry of the second Symposium in this section.

CONTENTS:

SESSION III - PHYSIOLOGICAL AND TOXICOLOGICAL ASPECTS OF FIRE EXPOSURE
Moderator: Irving N. Einhorn
University of Utah

Fires, Toxicity and Plastics
John A. Zapp, Jr.
E. I. du Pont de Nemours and Company

Effects of Exposure to Carbon Monoxide and Hydrogen Cyanide
Paul W. Smith, Charles R. Crane, Donald C. Sanders, John K. Abbott, and Boyd Endecott
Federal Aviation Administration

Synergistic Effects of Combustion Products
George W. Armstrong
Southwest Research Institute

Toxicity Associated with Flame-Retarded Plastics
V. L. Carter, Jr., D. A. Bafus, H. P. Warrington and E. S. Harris
NASA Johnson Space Center

Survival Response During Fire Exposure
Jack H. Petajan
University of Utah

Long-Term Nervous System Effects Resulting from Carbon Monoxide Exposure
Margaret L. Grunnet
University of Utah

Methodology for Toxicological Analyses of Combustion Products
Georg Kimmerle
Bayer, A. G., Institut für Toxikologie (Wuppertal, Germany)

Use of Animals in Experiments to Predict Human Response
F. Coulston and T. B. Griffin
Albany Medical College

SESSION IV - SMOKE: ITS DEVELOPMENT AND CHARACTERIZATION
Moderator: Robert M. Fristrom
Applied Physics Laboratory

Factors Affecting Smoke Development and Measurement
J. D. Seader and W. P. Chien
University of Utah

Computerized Analytical System for the Analysis of Thermal Decomposition Products
I. N. Einhorn, M. M. Birky, F. D. Hileman, M. S. Ramakrishnan, P. W. Ryan, K. J. Voorhees and L. H. Wojcik
University of Utah

APPENDIX

Biomedical Research of the Defense Civil Preparedness Agency (A Literature Overview)

James W. Kerr
Defense Civil Preparedness Agency

Pyrolysis of a Flexible-Urethane Foam
F. D. Hileman, K. J. Voorhees and I. N. Einhorn
University of Utah

Second International Symposium on Chemical Reaction Dynamics on the Topic "Flames as Chemical Reactions in Flow," Padua, Italy, (December 1975)

R. M. Fristrom, Applied Physics Laboratory, The Johns Hopkins University

From December 15 through 17, 1975, the University of Padua hosted the Second International Symposium on Chemical Reaction Dynamics on the topic "Flames as Chemical Reactions in Flow." The meeting was attended by over a hundred interested scientists. It was sponsored by

Consiglio Nazionale delle Ricerche, Roma
Societe de Chimie Industrielle, Paris
The Chemical Society, London
Institute of Combustion, Sezione Italiana, Milano
Societa Chimica Italiana, Roma
Europäische Föderation für Chemie-Ingenieur-Wesen, Frankfurt

and hosted by Professor I. Sorgato of the Center for the Study of High Temperature Reactions of the University.

The program provided a broad survey of the present state of flame studies. The theme of the symposium was chemical reactions in flames. The phenomena covered was broad and included chemical kinetics, nonequilibrium distributions, energy transfer and relaxation and engineering problems in combustion. The symposium was divided into three sessions: (1) New aspects of basic studies on flames, (2) Transport processes interactions with chemical kinetics in flames, and (3) High intensity flames. There were nine plenary lectures providing surveys of many aspects of flame studies and twenty-eight contributed papers. The sessions allowed sufficient time for a spirited discussion and the interchange of information both in the sessions and after the sessions made the meeting especially interesting. The visit to this historic University and the justly famous Italian hospitality made this meeting a rewarding experience for the participants both scientifically and culturally.

This Symposium produced an unusually high fraction of papers useful to the research worker in combustion. The papers were available to the participants as preprints. This greatly facilitated the discussion. It is a pity that more symposia are not organized as well as this one. The papers have been published in the Symposium Proceedings edited by the "Consiglio Nazionale delle Ricerche," Rome, Italy.

Program

I Session — New Aspects of Flame Study

Chairman Prof. A. R. Ubbelohde

F. Weinberg, Imperial College, Londra - Combustion strategy and reaction rate laws in flames.

V. N. Kondratiev - Academia delle Scienze URSS, Mosca - New Problems of flames chemical kinetics.

Chairman Prof. V. N. Kondratiev

A. R. Ubbelohde - Imperial College, Londra - Energy release in flames from fuel molecules yielding solid products.

G. De Maria - Centro di studio di Termodinamica chimica alle A. T., CNR, Roma - The role of high temperature molecules in transition phenomena.

J. M. Beer - The University of Sheffield, Sheffield - Some aspects of combustion aerodynamics.

M. Sing, R. Borghi, R. Moreau - O.N.E.R.A., Parigi - Reactions chimiques en flames turbulentes.

V. Caprio, A. Insola, P. G. Lignola - Laboratorio Ricerche sulla Combustione CNR, Napoli - Thermokinetic oscillations in cool flame processes.

II Session - The Chemical Kinetics of Flames
Chairman Prof. J. M. Beer

H. Gg. Wagner - Institut für Physikalische Chemie, Göttingen - Flamen: ein Mittel zur Untersuchung chemischer Reaktionen.

B. Brunetti, G. Liuti - Istituto Chimico dell'Universita, Perugia - Photometric investigations in active nitrogen-oxygen atom-ketene flames.

W. Seweryniak - Instytut Technologii Nieroganiczenej, Wroclaw - Modificators of the methane-oxygen reaction kinetics.

R. Fristrom - A.P.L., The Johns Hopkins University, Silver Spring, Md. - Flames as chemical reactors.

M. Spoliti - Centro di studio di Termodinamica chimica alle A. T., CNR, Roma - Electronic transitions of active molecules in flames.

S. Crescitelli, F. Napolitano, G. Russo, L. Tranchino, V. Tufano - Laboratorio di ricerche sulla Combustione, CNR, Napoli - Flame propagation in channels of near limits mixtures.

Chairman Prof. H. Gg. Wagner

G. Dixon-Lewis - The University of Leeds, Leeds - Transport phenomena, chemical mechanism and laminar flame properties.

M. Taniewskai - Instytut Technologii organicznej, Gliwice - Thermal and induced by chlorohydrocarbons decomposition of some hydrocarbons.

S. A. Rienzi - Centro di studio sulle reazioni alle A. T. e A. P., CNR, Padova - Cinetica nella fiamma piatta H_2+O_2 a pressione moderata.

S. A. Tsyganov - Instituto di Chimica Fisica, Mosca - (titolo non pervenuto).

I. Glassman - Princeton University, Princeton, N. J. - Studies of hydrocarbon oxidation in flow reactors.

E. Beretta, A. D'Alessio, A. Di Lorenzo - Laboratorio de ricerche sulla Combustione, CNR, Napoli - Kinetics of formation of polycyclic aromatic hydrocarbons and of soot in premixed flames.

G. Dumas - Laboratoire de Chimie Generale, Parigi - Oscillations de relaxation au cours de l'autoinflammation du n-eptan.

Chairman Prof. G. Dixon-Lewis

K. H. Hoyermann, H. Jander - Institute für Physikalische Chemie, Göttingen - Experimentelle Untersunchung zur NO-Bildung in H_2/Kohlenwasserstoff/CO - Luft Flammen.

L. J. Jesch - Department of Mechanical Engineering, University, Birmingham - Velocity measurements in reacting flow.

A. Feugier - Institut Francais du Petrole, Rueil Malmaison - Role des ions d'additifs metalliques dans la nucleation et agglomeration dans les flames.

M. Capitelli - Centro di studio per la Chimica dei plasmi, CNR, Bari - Diffusion coefficients of electronically excited atoms and ions.

R. Thomas, R. R. Burke - Centre de Recherches en Physique de l'Environnement, Orleans-La Source - Cinetique de la chaine de reacitons O_2^+—H^+ $(H_2O)_n$ entre 80° et 120° K.

III Session - High Intensity Flames
Chairman Prof. R. Fristrom

A. PLASMA FLAMES

F. Fetting - Institut für Chemische Technologie, Darmstadt - Mischung und chemische Reaktionen im thermischen Plasma (Herstellung von Hydrazin und Stickoxid als Beispiel).

L. Angelin, G. Cevales - Centro di studio sulle Reazioni alle A. T. e A. P., CNR Padova - Erzeugung von Karbonitriden im RF-Plasma-Durchfluss.

P. Capezzuto, F. Cramarossa, R. D'Agostino, E. Molinari - Centro di studio per la Chimica dei plasmi, CNR, Bari - Hydrocarbon decomposition in a radiofrequency discharge at moderate pressure.

S. Vebrek - Anorganisch-chemisches Institut der Universität, Zürich - Wechselwirkung von Niederdruckplasmen mit Festkörper-Oberflächen.

B. FLAMES OF CHEMICAL PROPELLANTS

Chairman - Prof. I. Glassman

H. Ziebland - E.R.D.E., Waltham Abbey, U.K. - Flame and gas radiation at elevated temperature and pressure in H_2 and O_2 combustion chamber.

L. De Luca - Centro di Studio per le ricerche sulla Propulsione e sull'Energetica, CNR, Milano - Nonlinear stability analysis of solid propellant combustion.

A. Barrows - U.S. Army Ballistic Laboratories, Aberdeen, Md., - Solid propellant unsteady combustion

A. S. Wilson, D. E. Jensen - Rocket Propulsion Establishment, Westcott, U. K., The computation of recirculation turbulent reacting flow.

W. W. Balwanz, S. L. Lee - U.S. Naval Res. Lab., Washington, D.C.; State University of New York, N. Y., - Ionization of turbulent diffusion flame of a combustible jet.

Chairman - Prof. C. Casci

J. R. Osborn - Purdue University, LaFayette, Indiana - Burning and flames of composite propellants.

L. G. Napolitano, R. Monti - Istituto di Aerodinamica dell'Universita, Napoli - Fluidodynamic aspects of turbulent flames.

C. Buongiorno, R. Piva - Scuola di Ingegneria Aerospaziale, Roma - Problemi di fiamme supersoniche in endoreattori.

G. B. Guarise - Centro di studio sulle reazioni alle A. T. e A. P., CNR, Padova - *Fiamme di propellenti* H_2+O_2 *in reatore modulare.*

Y. M. Timnat - Technion, Israel Institute of Technology, Haifa - Effects of turbulence and two-phase flow in propellant flames.

FINAL COMMENT

I. Sorgato - Centro di studio sulle reazioni alle A. T. e A. P., CNR, Padova - La fiamme quale sistema di reazioni e di flusso.

International Symposium on Toxicity and Physiology of Combustion Products, March 22-26, 1976, University of Utah, Salt Lake City, Utah

This Symposium was held under the joint auspices of the Committee on Fire Research of the National Research Council and the Flammability Research Center of the University of Utah. No Proceedings were published but a number of the papers presented have been published in various fire technology journals. A summary of this and the preceding Symposium, (1974), written by three members of the Committee on Fire Research, appears at the end of the list of papers presented.

Program

Symposium Chairman, I. N. Einhorn, University of Utah

Keynote Address: "What Is Toxicity?" - M. F. Cramer (National Center for Toxicological Research, Jefferson, Arkansas)

Session I: Chairman, C. W. Walters (Committee on Fire Research, National Academy of Sciences)

"Clinical Smoke Poisoning," B. A. Zikria, Columbia University Medical Center, New York City, New York

"Fire Injury Studies," B. M. Halpin, Applied Physics Laboratory, The Johns Hopkins University, Laurel, Maryland

"Aircraft Fire Injuries," W. F. Lovell, Northwest Hospital, Seattle, Washington

"The Medical Legal Investigation of Fire Victims in Los Angeles," T. T. Noguchi, Chief Medical Examiner, Los Angeles City, California

"Hazards of Materials in Urban Fires," J. T. O'Hagan, Commissioner, New York City Fire Department, New York

"Fire Injuries - Poly(vinyl Chloride) Fires," V. H. Esch, District of Columbia Fire Department, Washington, D.C.

Session II: Chairman, J. F. Cramer (National Center for Toxicological Research, Jefferson, Arkansas)

"A Proposed Method for the Assessment of Relative Toxicity of Materials" - D. P. Dressler, Department of Surgery, Harvard Medical School, Cambridge, Massachusetts

"Inhalation Toxicology of Combustion Products," Y. C. Alarie, University of Pittsburgh, Graduate School of Public Health, Pittsburgh, Pennsylvania

"Assessment of Relative Toxicity of Materials - A Toxicity Index," K. Sumi, National Research Council of Canada, Ottawa, Canada

"Comparative Toxicology of Plastics During Thermal Decomposition," H. H. Cornish, School of Public Health, University of Michigan, Ann Arbor, Michigan

"Survival - Intoxication Syndrome," J. H. Petajan, Flammability Research Center, University of Utah

"Behavioral Assessment," S. C. Packham, Flammability Research Center, University of Utah

"The Physiogram as a Method for the Evaluation of Toxicity of Combustion Products in Controlled Ventilation Experiments," J. M. Jouany, University of South Paris, Chatenay-Malabray, France

"Material's Toxicology Evaluation by Direct Animal Exposure," P. W. Smith, Aviation Toxicology Laboratory, Federal Aviation Administration, Oklahoma City, Oklahoma

"Safety Response Envelope," R. C. Baldwin, Flammability Research Center, University of Utah

"A Simplistic Acute Comparative Inhalation Methodology," E. Rider, Biological Services Division and Environmental Sciences Division, U.S. Testing Company, Inc., Hoboken, New Jersey

"Chronic Versus Acute Exposure Studies," W. J. Rippenstein, Health Sciences Division, NASA, Houston, Texas

"Toxicology of Combustion Products - Small Animal Studies," H. TH. Hofman, BASF Aktiengesellschaft, Ludwigshafen AM Rhein, West Germany

"Pathological and Neuropathological Aspects of Combustion," M. L. Grunnet, Flammability Research Center, University of Utah

"Methods for Evaluation of the Cardiovascular Respiratory Response in Large Scale Burn Tests," J. G. Gaume, McDonnell Douglas Corporation, Long Beach, California

"Large Scale Test Burns as a Means of Evaluating Fire Performance and Toxicity Factors," G. W. Armstrong, Southwest Research Institute, San Antonio, Texas

"Large Scale Fire Tests with Animals," M. M. Birky, National Bureau of Standards, Washington, D.C.

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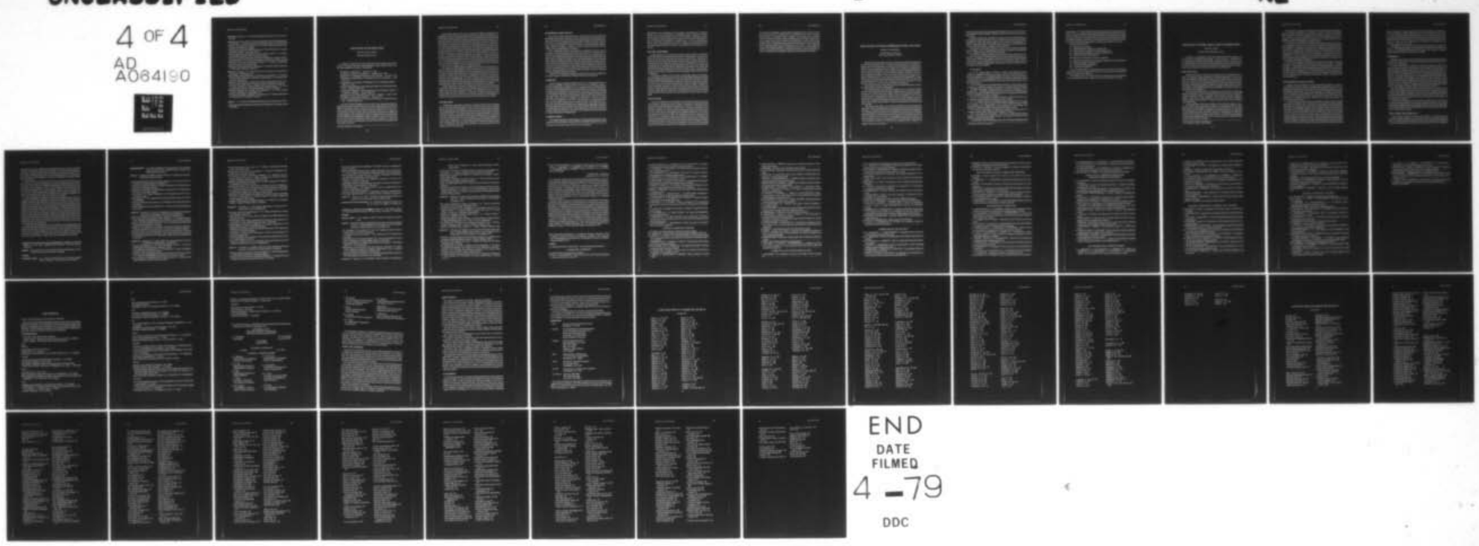

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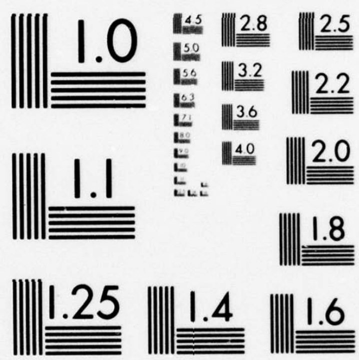

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Session III: Chairman, J. H. Futrell (Flammability Research Center, University of Utah)

"Methodology for the Analysis of Products Resulting from Thermal Degradation of Materials," I. N. Einhorn, Flammability Research Center, University of Utah
"Prediction of Combustion Products," W. D. Woolley, Building Research Establishment, Borehamwood, England
"Combustion of Poly(vinyl Chloride) Polymers," M. M. O'Mara, B. F. Goodrich Chemical Company, Avon Lake, Ohio
"Thermal Degradation of Rigid and Flexible Urethane Foams," K. J. Voorhees, Flammability Research Center, University of Utah
"Analysis of Smoke Produced During Thermal Degradation of Natural and Synthetic Materials," B. T. Zinn, Georgia Institute of Technology, Atlanta, Georgia
"Prediction of the Smoke Tendency of Materials," J. D. Seader, Flammability Research Center, University of Utah
"Prediction of Smoke Movement in Buildings," E. E. Zukoski, California Institute of Technology, Pasadena, California

Session IV: Chairman, J. W. Lyons (Center for Fire Research, National Bureau of Standards, Washington, D.C.)
"Public Safety Aspects Pertaining to Combustion of Materials," L. J. Sharman, Office of Safety Standards Coordination and Appraisal, U.S. Consumer Product Safety Commission
"Aspects of Enforcement of Upholstered Furniture Flammability Laws," H. C. Winslow, State Department of Consumer Affairs, Sacramento, California
"A Toxicity Standard for Cellular Plastics Used in Construction," J. H. Nosse, International Conference of Building Officials, Whittier, California
"Proposed Standards for Aircraft Interior Materials," J. E. Purcell, Federal Aviation Administration, Washington, D.C.
"Fire Toxicity Standards - Materials of Construction," C. Y. Brisson, Directorate of Public Safety, The Republic of France

Session V: I. N. Einhorn (Flammability Research Center, University of Utah)

A Proposed National Program for Evaluation of Combustion Toxicology - Panel Discussion

LIFE SAFETY IN THE FIRE SCENE

CARL W. WALTER, M.D.*
Harvard Medical School

A number of symposia have been sponsored by the Committee on Fire Research over the past seven years, each addressing a timely subject related to fire. The titles indicate the diversity of the problem.

Workshop on Mass Burns — March 13-14, 1968
Symposium on Needs of Fire Services — October 30-31, 1968
Symposium on Training and Education in Fire Services — April 8-9, 1970
Symposium on Employment of Air Operations in the Fire Services — June 9-10, 1971
Symposium on an Appraisal of Halogenated Fire Extinguishing Agents — April 11-12, 1972
International Symposium on Air Quality and Smoke from Urban and Forest Fires — October 24-26, 1973
International Symposium on Physiological and Toxicological Aspects of Combustion Products — March 18-20, 1974
Symposium on Fire Detection for Life Safety — March 31 - April 1, 1975
Workshop on Arson and Incendiarism — July 29, 1975
International Symposium on Toxicity and Physiology of Combustion Products — March 22-26, 1976

This series provides perspective for the recent three symposiums which described man's concerns and interactions with smoke. Ingrained patterns of human behavior, hazards of exposure to smoke, poisonous components of smoke, materials with particularly noxious products of decomposition by heat or flame, the complex trauma of the fire scene, and resuscitation of casualties were emphasized in varying degrees. Safety regulations needed to mitigate the impact of each subject area were discussed and enthusiastic support for specific controls developed. Yet, in the context of these symposiums, human behavior emerges as an overriding factor for survival in a fire and human occupancy determines the probability and the intensity of the fire.

*Chairman, Committee on Fire Research

Epidemiologic studies (*Fire Injury Studies*, B. M. Halpin) establish fires in dwellings as the major cause of casualties and death. Smoking is the chief cause of ignition (52 percent). The bedroom is the room of origin in 49 percent and the living room in 22 percent of the cases. Victims are found in the bedroom in 49 percent, in the living room in 17 percent, and in the hall or on stairs in 14 percent of the cases. The majority of victims are less than 10 years old (20 percent), or over 60 (31 percent); and incapacitation due to alcohol is a factor in 38 percent of the deaths. Thus, it is obvious that education, early detection, and automatic extinguishment are the important factors in saving life and preventing injury in dwellings. Special fire situations either due to type of occupancy (e.g., nursing homes or aircraft) or presence of unusually combustible materials (e.g., plastics or spattered fuel) may prompt headlines, but the major problem epidemiologically remains the dwelling fire. The occupational hazard of the fire service permeates the entire gamut of fire scenes and justifies education of the fire services and continued research into the toxicity of smoke. Regulation of some material characteristics related to definable hazards can have an impact on the occupational hazard.

The situation could be improved significantly by an active four-point program: (1) education that emphasizes the role of human error in fire, the patterns of burning, and the spread and hazards of smoke; (2) aggressive fire protection practices that include periodic inspection of occupancies; (3) early detection and containment of smoke; and (4) automatic extinguishment of flame. Current understanding of the pathophysiology of exposure to gases and aerosols emitted from heated materials establishes the relevance of animal models and the practicality of perfecting a system for predicting the potential for human injury. It also provides knowledge upon which to base the diagnosis and treatment of casualties.

Smoke obscuration and heat are common to most fires, and safe refuge and escape both depend upon control of these characteristic hazards of fire. Yet, these subjects have not been considered in detail. The emphasis was on the noxious (toxic) properties of the products of combustion of specific materials, and on defining their relevance to human injury. Several categories of methodology for toxicity evaluations stand out in the contents of the symposiums on smoke.

EXPLORATORY

Collaborative investigation with the fire services at the fire scene, as exemplified by the Flammability Research Center, University of Utah, and the Applied Physics Laboratory, Johns Hopkins University, can be characterized as exploratory methodology that determines the relevance to the real life situation of bioassay using animal models. The epidemiologic base, the nature and degree of exposure of victims, and the occupational hazard of firemen establish priorities and identify the need for education, prevention, and regulation. Such studies lend perspective to the role of "supertoxins," or to the impact of special fire situations (PVC, aircraft, explosion, flash fire) on societal expressions of cultural and legal compulsions or convictions. They also direct attention to hazard assessment and the human trauma of the fire scene.

SYNDROME OF FIRE TRAUMA

In contrast with the extensive literature on burns, there is little systematized knowledge on the injury produced by gases and aerosols that result from fires. Data on the effects of fire on humans is now accumulating at an accelerating rate. The source of new knowledge stems from perceptive study of casualties, occupational exposures and deaths. Disciplines that have contributed include epidemiology, clinical investigation, bioassay of smoke, analytical chemistry, forensic medicine, and neuropathology of casualties.

More sophisticated clinical investigation of casualties at the fire scene is imperative to develop therapeutically useful descriptions of the trauma and the transient and chronic pathophysiology that must be corrected. A triage and resuscitation service specifically equipped to study and manage fire casualties offers the opportunity for progress in saving life and decreasing morbidity in this neglected field. Competent technical assistance, elaborate methodology, and physicians with special interest in the problem must be organized and mobilized as the community response to fire in the population centers where research collaboration with the fire services has already evolved. The sophisticated technology used in animal model bioassay must be applied to the study of human casualties. Criteria for diagnosis must be established and therapy devised.

Petajan, Zikria, Halpin, and Noguchi* described vistas of new knowledge and the improvement in resuscitation of humans that can be anticipated.

SCREENING

Various bioassay methods described testify to the continuing pursuit of a universally acceptable screening method for toxicity of combustion products. A novel method under investigation at the Graduate School of Public Health, University of Pittsburgh (Barrow, Alarie, and Stock) merits further evaluation as a comprehensive and relevant simple method for screening of materials according to irritating and potentially noxious gases and aerosols produced during pyrolysis and combustion. The thermal decomposition simulates fires that cause human morbidity, with pyrolysis or combustion occurring under a steadily increasing (20° C/minute) temperature up to 700° C. The end point is a mammalian physiologic reaction inately programmed for self-preservation. The mouse brain integrates the variety of noxious stimulants and responds with a single signal-respiratory inhibition. Quantitative dose response data are derived that relate the loss of weight of combustible and respiration rate. The concentration of irritants required to decrease respiration 50 percent is termed RD/50, which has previously been related to human symptoms and incapacitation.

UNDERSTANDING

The elegant and complex methodology of the Flammability Research Center, University of Utah (Einhorn, Petajan, Baldwin, Packham) yields data that permit

*References to authors relate to papers presented at the 1976 symposium.

identification of the components of the products of decomposition of materials subject to various levels of heat flux. The biologic results of exposure to the gases and aerosols are demonstrable by behavioral, physiologic or pathologic parameters. In addition to determining levels of respiratory tract irritation, incapacitation and its toxicology are elucidated as transient, acute, or chronic manifestations. Hence, a base of knowledge for prevention or treatment is accumulated. The data have medicolegal relevance and import, and establish criteria for regulatory procedures.

HAZARD ASSESSMENT

Large scale fire tests of materials assembled as interior finishes or furnishings clearly demonstrate the human hazard in terms of flammability, visibility, heat, irritation, and toxicity. These tests yield impressive data but their relationship to reality has not been fully demonstrated, except perhaps for highly flammable or smoldering materials. Apparently absolute values for identification of a safe range of materials are not known; and the degradation that occurs due to soiling, use, and deterioration of some materials compounds the uncertainty. The customs and mores of the occupants determine the sources of ignition, degree of flammability, and heat release of the combustible load that accumulates in otherwise fire resistive occupancies.

The hazard to humans of fire in terms of predictable exposure is ill defined. Data are meager other than from burns that result from highly flammable clothing, drenching with flammable liquids, or exposure to flash fires. What is the tolerance for heat at 60° C? How and where does obscuration prevent escape? What incapacitates the normal person? What complementary exposure is needed to incapacitate a person partially obtunded by drugs, alcohol, or disease? What invisible toxic products of decomposition by heat can be identified? Flammability tests typified by those of Birky, Winslow, Williamson, and Emmons must be correlated with the animal model bioassay technics to provide perspective and relevance to human safety.

REGULATIONS

The role of regulations in ensuring safety in fire resistant structures by concern for the control of smoke, safe areas of refuge, or rapid egress is widely appreciated. The prohibition of highly flammable materials or smoke-producing polymers that smolder is accepted. The power of regulations as a dynamic educational process and motivating force for understanding that integrates discordant groups is apparent only to those who have struggled with promulgating regulations. A base of data and assessment of hazards are but partial ingredients for success. Because human behavior is the overriding problem, the philosophies of both the individual and society become determinants. Dependable safety for children, those handicapped, incapacitated, addicted, or aged, can be achieved only by the combination of education, early detection, and automatic extinguishment in the context of fire resistant structures. Is it politic to require such a commitment in terms of continuous effort and expense? Technology to permit general application exists. Current costs of protection systems are an expression of low manufacturing volume, restrictive labor practices, and obsolete codes. Programs for education must encompass control of sources of ignition, (chiefly smoking), patterns of flame spread, movement of smoke, self-protective measures, and techniques of escape. Fire protection programs must be organized and activated to describe and control the combustible load in dwellings and detect the other common causes of fire — electric appliance failure, faulty heating equipment, cooking fires, and do-it-yourself accidents. The problems of incendiarism and arson that elude description and understanding constitute a challenge for psychologists, educators, and regulatory authorities.

FIRE INJURIES AND HUMAN PROBLEMS IN FIRE CASUALTIES

ROBERT M. FRISTROM*

Applied Physics Laboratory
The Johns Hopkins University

The gathering of information on fire casualties has not yet been systematically attacked on a nationwide scale. A number of excellent statewide or citywide programs have been initiated and are continuing, but some of them are woefully underfunded. The understanding of the true origins of fire casualties and determination of their numbers and distribution are an important aspect of unwanted fires because, until we know the problem, we will not be able to remedy it effectively. There are three fundamental problems: (1) how many and which groups of people are exposed to unwanted fires, (2) how many and which groups of people fail to escape fires, and (3) how many and which groups of people are injured in fires and what are the distributions of injury. We would like to associate the answers to these questions with one or more causes and specific fire parameters.

Some of these areas are under intensive study; others have hardly been touched, and many efforts are grossly underfunded.

The determination of the population exposed to fires is a complex problem and must often be inferred from secondary evidence since at the scene of a disaster the focus is on victims rather than escapees. This can be an important problem to the fireman since unaccounted-for persons must be searched for, and a victim whose presence is unsuspected may be left to die. From the standpoint of the fire analyst, this is important data because it determines the base exposed population. Thus, better numbers and methods in this area would help both the fireman and the researcher.

The major present effort is in the area of fatalities where several good programs have been accumulating state or citywide data for several years. The problem is twofold — those victims who die on the fire scene and those who die subsequently. The immediate deaths provide the more straightforward problem. The subsequent deaths are difficult to document because after a few days of hospitalization the fire may be forgotten. In some cases, a value judgment must be made whether the death was due to the fire or a secondary infection. The distribution of death causes is quite different between the immediate and subsequent death categories, the

*Member, Committee on Fire Research

former being dominantly CO poisoning with relatively few burn victims. The latter is dominated by smoke inhalation, respiratory problems, and burns with almost no CO victims.

Sublethal casualties have received less attention because of the difficulties of obtaining and evaluating the data. This is an important area because it has been thought that a major part of the overall fire costs has been in hospitalization of victims. Preliminary studies at APL-JHU have not borne out this assumption, and more extensive information is needed to clarify this point.

The questions of the causes of failure to escape a fire are important and difficult to establish. This is an important area since if one is trapped in a burning building for a sufficient length of time, death is probable.

The problem of long-term effects of fires are important particularly for firemen who are regularly exposed and who may not always take proper precautions. It may also be important for escapees to allow early treatment for smoke inhalation whose effects may be delayed many hours. The very long-term effects, such as carcinogens, mutagens and teratogens, would appear to be an environmental problem rather than a fire problem.

In the papers:*

Dr. M. F. Cranmer spoke on "What Is Toxicity." He emphasized that in addition to immediate toxicity there are many long-term effects which could conceivably be problems, i.e., carcinogens (producers of cancer), mutagens (producers of genetic defects), and teratogens (producers of birth defects). These latter should be considered in occupational safety for firemen and environmental safety for the general population.

Dr. B. A. Zikria spoke on "Clinical Smoke Poisoning," illustrating his studies particularly of respiratory damage in fire victims at Columbia General Hospital.

Mr. Halpin discussed "Fire Injury Studies in the State of Maryland." These are threefold — immediate casualties on the fire scene based on investigations and autopsies, subsequent casualties in the hospital based on investigations and hospital records, and long-term studies of firemen.

Dr. W. F. Lovell discussed "Aircraft Fire Injuries." Of particular interest was the relation between locations of victims and cause of death.

Dr. T. T. Noguchi talked on "The Medical Legal Investigation of Fire Victims in Los Angeles." The scope of efforts in this well-run Medical Examiner's Office was impressive, and it is hoped that a more systematic use can be made of the information which is available from this and other similar sources.

Fire Chief S. Ifshin spoke on "Hazards of Material in Urban Fires." He emphasized critical times in fires and the problems of firemen.

Dr. V. Esch spoke on "Fire Injuries — PVC Fires," emphasizing the hazards presented by new materials and the problems of proper early treatment where unknown materials may be present.

A human aspect of the fire problem which was only obliquely addressed in this

*Presented at the March 1976 symposium.

Symposium is: Given a knowledge of the fire casualty problem, what can be done about it? This is a complex area of regulation and education. Regulation of materials was discussed in some detail, but the problems of regulating and motivating people to improve their fire safety habits were not discussed, partly because these are political problems. Another less controversial area is the question of appropriate rescue and first-aid procedures to maximize the number of survivors.

Education should aim at:

(1) Reducing fire incidence,
(2) Reducing human exposure to unwanted fires,
(3) Improving the acceptance of early warning devices,
(4) Improving escape behavior of those involved in fires,
(5) Reducing anti-social fire behavior.

Mechanisms for attaining these objectives might be:

(1) Education in the home, school, churches and public service organizations,
(2) Media campaigns, particularly TV,
(3) Consumer advocate programs,
(4) Government regulations.

In any education effort, it is important to have some measure of the progress and success so that the feedback of information on the success or failure can improve the program and reinforce it.

The present status is that many of thse fire problems have been recognized and are being addressed, but a major part of the work remains to be done.

TOXICOLOGY AND FIRE: REGULATORY CONSIDERATIONS

JAMES W. KERR*

Defense Civil Preparedness Agency

Inevitably, as investigations of fire deaths and property losses progress, the first reaction is to point the finger of blame — justly or unjustly — and the second is to demand that "somebody do something." Regulating of those matters that can be regulated seems an obvious solution, but the approaches thereto and the benefits of various options are more obscure. We analyze here some of the major considerations relevant, and some of the points raised in our deliberations.

WHY REGULATE

Noteworthy scientific, economic, social public welfare, and political motivations favor institution and continuation of regulating generally in the fire area (some connotations of "Big Brother" aside). On the scientific side, one notes that there is no "safe" item, but that a technological approach is needed to define the continuum of hazard, and to address the question of what can and cannot be done. The matter of toxicology appears amenable to enough scientific analysis to permit promulgation of reasonable standards, and possibilities for casualty reduction are better than merely speculative.

On the socio-economic side, one finds pressure from all sectors, demanding regulatory measures; we note here and elsewhere that these must be coupled with suitable educational efforts. Consumers need protection and lack expertise; industry needs data to keep competitive and for protection against litigation; actuarial matters need definition; voluntary standards suffer from potentially fatal compromises.

Political aspects are less easy to describe, but the climate appears to favor strong, credible, enforceable measures taken for the public good. Pressure from the private sector (the public) is always felt first on political levels; it is now being felt, and must be met. There are nonetheless conflicts at political levels, typified by the well-publicized tobacco dichotomy, wherein the Department of Agriculture subsidizes that which the Surgeon General decries. If indeed burning cigarettes are the greatest single menace in the fire toxicology universe, the political considerations could become overriding.

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*Liaison Member, Committee on Fire Research;
Fire Commissioner, Fairfax County, Virginia.

While industry, transport, warehousing, and related activities seem relatively easy to describe and regulate, the consumer is very hard to protect. One hundred percent protection of the public against their own follies or vagaries is never feasible; it remains to be seen to what degree they can be protected against toxic fire products. A distressingly simple level of education (e.g., "Always look for the UL label") might also be the highest attainable overall.

In any case, the government at all levels cannot blink the question of regulation. Regulations now exist, more and better are needed, and enforcement is too often neglected or half-hearted. In some cases, inadequacies of enforcement can be attributed to unsuitability of the regulation. It seems reasonable that we should move now to upgrade those regulations (statutory or other) that our state of knowledge permit, and study the rest. Crash programs are needed in some areas, particularly in toxicity screening. On the other hand, application must be measured; precipitate rule-making has led to disastrous results in some cases, such as those recently addressing food additives.

Pressures for regulatory help come from all sides. Federal agency roles and missions prescribe carrying out such functions; industry of all types — including insurance — accommodate them; quasi-official rule-making groups are in motion; consumer movements and union management demand attention. But this is all for the good, because regulations are an integrating force; by their existence they provide a motive for understanding; the very act of promulgation forces participation by all who should be concerned, and provides a forum for education even if almost subliminal.

DEVELOPMENT OF REGULATIONS

Progress toward production of useful, meaningful regulations or rules or standards (the terms are used here interchangeably, though such practice is not in keeping with bureaucratic habit) represents a considered movement or at worst a groping toward the ability to set forth a quantitative formulation of factors that we now can appreciate only qualitatively. It represents a movement from instinctively or intuitively grasped factors to their expression in scientific fashion, from speculation to synthesis, from expert opinion to proven data, from concensus to fully documented statement.

At the moment some standards are promulgated by default; if the responsible agency fails to produce, those in need turn to any recognized authority audible. Even when this vacuum does not exist, there is a tendency for users to accept at face value data from prestigious federal sources, brushing aside caveats where they exist. By this route Federal agencies with no regulatory role become the *de facto* rule makers. This situation needs attention. In other cases, when a rule is needed, a rule is made; that situation requires urgent, vigorously-pursued research to verify the regulation after the fact. Such verificatory feedback is always technologically required if not legally mandatory, even following the orderly development of a good regulation. Relevance of supporting research must be assured if objectives are to be met; present funding levels make infeasible the dispensing of federal largesse in support of what are merely good ideas. Broad studies must lend themselves to focusing on specific applicatory cases. A further pitfall can be the pursuit of a topic beyond the point of diminishing returns, in the blind hope that a life might be saved through reading one more decimal place. Appreciation for the lead time needed to firm up the basis for a rule can often be gleaned from parallel expert experience. Some cases are intractable, but as stated above we believe the fire toxicology question to be solvable.

The speakers at the March '76 Utah symposium all spoke of "feeling their way," or "promulgating tentative pronouncements, pulling them back and trying once more." Some rules seemed based on intuition, some on logic; all speakers sought scientific feedback to improve their products.

DESIDERATA

Regulations must be at once soundly based in scientific knowledge and pragmatically cast. These are not necessarily incompatible considerations but they do require some examination.

Tests and other bases for reaching the conclusions needed to formulate and apply rules must be properly conceived, executed, analyzed and reported; sound ethical scientific conduct is the key element. Series of tests, not single situation or one-shot affairs are called for. But the rules themselves merely reflect the test conclusions; they do not develop the tests. Thus a regulation would require performance vs. a standard, the description of the standard if normally in a different rule, and can be upgraded as knowledge increases. Whether based on bioassay or other measurement, the rule must demand system behavior, not prescribe (for example) a specific material. Ranges of figures are usually appropriate, rather than a fixed number; in any case, caveats as to applicability and use are indispensable. Scales of relative merit might be optimal in some cases and useless in others.

The rules themselves must place their subject matter (here toxicology) in the continuum of the larger topic (fire). They must be no more complex than required to achieve their objective (regardless of the fact that their backup data might be deep and detailed). They must be internally consistent, reflect pertinent basics in the topic area, realistic, attainable by the user, believable by all concerned, and enforceable by the monitor.

Historically, new programs and new rules have followed crises, not successes. One must be on guard against over-reacting to unpleasant stimuli, for every public utterance has its legacy value. Maximizing good legacy must be a continuing objective. Picking up research output and applying it to rules must be provided for somewhere in the regulatory system.

APPLICATION AND INTERFACES

Just as toxicity is a part of the overall fire problem, so are regulations only a part of the solution. Relevance to each situation, each echelon of government, each facet of our culture must be evaluated not only in the preparation and codification but also in the application, execution, and enforcement. Too narrow a designation of jurisdiction can lead to debilitating compartmentalization, but broad vagueness can lead to difficulties in application, sometimes to court decisions that negate all good interest. Major potential for such mishaps is found in deciding about need for retrofit of existing systems, and in circumscribing of liability. The latter problem can apply to both promulgators and executors of regulations, though probably not to the drafters.

Caution must be exercised by rule makers to say exactly what they mean, for many of those charged with complying or assuring compliance pay more respect to the letter than to the intent. Therefore, educational or orientation efforts aimed at members of the regulatory structure must coincide with and supplement rule making and promulgation. We cannot legislate common sense, but we can make every effort to draft comprehensible standards, based on valid reproducible test results. (As previously noted, the tests themselves do not appear in standards, but their results determine the quantitative aspects of standards.)

Constant updating of standards is needed during preparation and after promulgation. They must be supported by confirmatory research and by a foolproof feedback mechanism that brings the reactions and comments of enforcers to the attention of the rule makers. If those in the field regard research successes as threats to their cozy operating systems, something must be changed, preferably both that attitude and the system that generates and tolerates it. Sometimes, however, the research is suppressed or skewed to avoid confrontations, though good products tend to surface eventually. Once again, education is the only way to get enforcers involved in the systems constructively. This need is brought home dramatically in the field of criminal justice; if standards are to be enforceable, they must survive the ultimate court test, which is a criminal, not merely a civil action. For this reason, the interface with prosecutors and that whole facet of the system must be well thought through and maintained.

Finally, lest the overall impression be created that we are dealing merely with objects and materials and homes, let us note one out-of-doors problem. While most technical people agree that prescribed burning of grass, underbrush and other forest trash is not only desirable but also in some cases (specific conifer forests) necessary for propagation, environmental laws tend to prohibit such measures. If research cannot say which is "right," can rules accommodate all the needs?

National Fire Prevention and Control Administration Conference on Fire Re-Search, July 14-16, 1976, Applied Physics Laboratory, The Johns Hopkins University

Subjects: Flame spread; Fire systems studies; Physico-chemical aspects of fires; Combustion products; Fire safety in buildings

Program

Welcoming Address: A. G. Schulz, Assistant Director for Planning, Applied Physics Laboratory, The Johns Hopkins University

Opening Remarks: J. E. Clark, National Fire Prevention and Control Administration, R. M. Fristorm, Applied Physics Laboratory, The Johns Hopkins University

Session I: Chairman R. Bland, Associate Professor of Engineering Research, Pennsylvania State University

"Long Range Planning - The Fire Scenario Approach," J. W. Lyons, Center for Fire Research, National Bureau of Standards

"Chemistry of Combustion in Fires," R. Sawyer, Department of Thermal Systems, University of California, Berkeley

"Making Test Data Useful," R. B. Williamson, Department of Civil Engineering, University of California, Berkeley

"Fire Growth," P. J. Pagni, Department of Civil Engineering, University of California, Berkeley

"Fire Radiation," C. Tien, Department of Civil Engineering, University of California, Berkeley

"The Study of Radiation from Flames," G. H. Markstein, Factory Mutual Research Corporation

"Pressure Modeling of Fire in Enclosures," R. L. Alpert, Factory Mutual Research Corporation

Session II: Chairman C. C. Theil, Jr., Acting Director, Advanced Environmental Research and Technology, National Science Foundation

"Where is the Horizon?" Rexford Wilson, President, FIREPRO, Inc.

"Flame Extinctions in Relationship to Fire Suppression," F. A. Williams, Department of Mechanical Engineering Sciences, University of California, San Diego

"Behavior of Water Droplets in Fire Plume," M. Yuen, Department of Mechanical Engineering, Northwestern University

"Report on Fire Research at the College of Environmental Design, Berkeley," R. Bender, Department of Architecture, University of California, Berkeley

"Research Needs," P. Armstrong, Rand Corporation, Santa Monica, California

"Fire Research Programs," R. Friedman, Factory Mutual Research Corporation

"Full Scale Bedroom Fire Test," R. Alpert and J. deRis, Factory Mutual Research Corporation

Session III: Chairman R. S. Levine, Chief, Fire Services Division, Center for Fire Research, National Bureau of Standards

"Overview and Objectives of the Utah Flammability Center," I. N. Einhorn, Flammability Research Center, University of Utah

"Toxicological Screening Protocol," G. E. Hartzell and S. C. Israel, Flammability Research Center, University of Utah

"Analysis of Thermal Degradation Processes and Products for Wood and PVC," F. D. Hileman, Flammability Research Center, University of Utah

"New Techniques for Identification of Urethane Polymers," I. N. Einhorn, Flammability Research Center, University of Utah

"The Bicyclophosphate Ester Story," R. C. Baldwin, Flammability Research Center, University of Utah

"Human Injury Study and Future Programs," I. N. Einhorn, Flammability Research Center, University of Utah

"The Architect and the Fire Problem in Buildings," R. A. Hechtman, Environmental Systems Laboratories, College of Architecture and Urban Studies, Virginia Polytechnic Institute and State University

"Mathematical Modeling of Enclosure Fires," H. Mitler, Department of Mechanical Engineering, Harvard University

"Experimental Studies of Convective Flows Associated with Fires in Buildings," E. E. Zukowski, Department of Engineering, California Institute of Technology

"Fire and Smoke Spread in Corridors," J. R. Lloyd, Department of Aerospace and Mechanical Engineering, University of Notre Dame

"Investigation of the Properties of Combustion Products Generated in Building Fires," B. T. Zinn and S. N. Tsoukalas, School of Aerospace Engineering, Georgia Institute of Technology

"Consumer Product Safety Commission Interest," L. J. Sharman, Fire Programs Officers, Consumer Product Safety Commission

Session IV: Chairman D. A. Lucht, Deputy Administrator, National Fire Prevention and Control Administration

"The Status of Fire Toxicology Research," C. W. Walter, Medical School Alumni Fund, Harvard University

"Project Smoke," M. S. Levine, School of Hygiene and Public Health, Johns Hopkins University

"Fire Fatalities," B. M. Halpin, Applied Physics Laboratory, Johns Hopkins University and R. Fisher, Medical Examiner, State of Maryland

"Human Behavior Under Fire Conditions," E. Crossman, Department of Civil Engineering, University of California, Berkeley

"The Reaction of Structures to Fires," B. Bresler, Department of Civil Engineering, University of California, Berkeley

"Fire Research - A View from the Fire Service," J. Shern, Chief, Pasadena, California Fire Department

"Fire Documentation and Information," B. Kuvshinoff, Applied Physics Laboratory, Johns Hopkins University

"National Fire Data Center," P. S. Schaenman, National Fire Data Center, National Fire Prevention and Control Adminstration

Session V: Chairman I. A. Benjamin, Chief, Fire Safety Engineering Division, Center for Fire Research, National Bureau of Standards

"Building Codes as They Relate to the Fire Problem," J. E. Bihr, Managing Director, International Conference of Building Officials

"Prediction of Fire Hazard from Fabrics and Materials," P. Durbetaki, School of Mechanical Engineering, Georgia Institute of Technology

"Analysis of Upward Flame Spreading," M. Sibulkin, Division of Engineering, Brown University

"Recent Experimental Measurements of Flame Spreading Across Liquid Fuel," F. L. Dryer, Department of Aerospace Mechanical Science, Princeton University

"Flame Spread Over Liquid Fuels," K. E. Torrance, Department of Mechanical and Aerospace Engineering, Cornell University

"Chemistry of Cellulosic Fires," F. Shafizadeh, Department of Forestry and Chemistry, University of Montana

"Flammability Studies of Cellular Plastics," R. Magee, Department of Mechanical Engineering, Stevens Institute of Technology

"Combustion Studies," L. W. Hunter and R. M. Fristrom, Applied Physics Laboratory, Johns Hopkins University

"Fire Service Research Utilization," L. MacGillivray, Research Triangle Institute

"Technology Agents Program," R. J. Phillips, Public Technology Incorporated

Session VI: Chairman J. E. Clark, National Fire Safety Research Office, National Fire Prevention and Control Administration

Summary and General Discussions: W. J. Christian, Underwriters Laboratories
W. M. Neville, Los Angeles Fire Department

Conference on Protection for Firefighters, March 9-11, 1976, Illinois Institute of Technology Research Institute, Chicago, Illinois; Chairman T. E. Waterman

Program

Keynote Address: C. W. Volkamer, Chief Fire Marshal, Chicago Fire Department

Session I: Chairmen, B. Halpin, Applied Physics Laboratory, The Johns Hopkins University, Laurel, Maryland, and S. Schulman, Air Force Materials Laboratory, Wright Patterson Air Force Base, Ohio

"The Firefighters' Environment," M. Tyler, Fire Suppression Special Projects, Wright Patterson Air Force Base, Ohio

"A Firefighter in His Environment," T. Herz, Baltimore City Fire Department, Maryland

"Health Hazards of the Fire Environment," M. Levine, Johns Hopkins University School of Hygiene and Public Health, Baltimore, Maryland

"Physiological Hazards in Firefighting as Seen by a Fire Surgeon," V. Esch, Washington, D.C. Fire Department

"Deficiencies of Fire Proximity Suits and Evaluation Techniques," N. Abbott, Fabric Research Laboratories, Dedham, Massachusetts, and S. Schulman, Air Force Materials Laboratory, WPAFB, Ohio

"Summary and Overview of Session I," B. M. Halpin, Applied Physics Laboratory, The Johns Hopkins University, Laurel, Maryland

Session II: Chairmen, R. S. Rockenbach, Chief Grayslake Fire Department, Illinois, and E. Waldron, U.S. Army Natick Laboratories, Natick, Massachusetts

"Performance of Protective Clothing During an Actual Fire and Suggested Improvements," J. L. Peterson, Sugar Grove Fire Department, Illinois

"Manufacturer's Viewpoint on Footware," W. Hanley, Servus Rubber Company, Rock Island, Illinois

"Manufacturer's Viewpoint on Turnout Coats," H. J. White, Midwestern Safty Manufacturing Company, Mackinaw, Illinois

"Kelvar - Nonflammable Fibers," R. I. Lacey, du Pont de Nemours, Wilmington, Delaware

"Objective Determination of Comfort, Fit, and Acceptability of Protective Clothing and Equipment," E. R. Barron, U.S. Army Development Center, Natick, Massachusetts, and H. G. Wakekey, Illinois Institute of Technology Research Institute, Chicago, Illinois

Session III: Chairmen, J. I. Kamin, Safety Research, NIOSH, Cincinnati, Ohio, and M. J. Smith, International Association of Fire Fighters, Washington, D.C.

"The Practical Problems of Today's Fire Fighters," M. J. Smith, International Association of Fire Fighters, Washington, D.C.

"A Research Program for the Development of Performance Criteria for Firefighters' Gloves," J. I. Kamin, NIOSH, Cincinnati, Ohio, and G. C. Coletta, Arthur D. Little, Inc., Cambridge, Massachusetts

"Analysis of Firefighters' Protective Head Devices," A. A. Scalone, Dayton T. Brown, Inc., Bohemia, New York

"Research, Regulation, Waste, and Chaos: The Recent History of Federal Efforts to Make Firefighting Safer," H. P. Utrech, The Fire Independent

"The Respiratory Protection/Face Protection Interaction," M. L. Barnhart, Bendix Corporation, and J. I. Kamin, NIOSH, Cincinnati, Ohio

"Overview of NIOSH Safety Activities," J. I. Kamin, NIOSH, Cincinnati, Ohio

Session IV: Chairmen, M. McHenry, Fire Equipment Manufacturing Association, Arlington Heights, Illinois, and A. Sears, National Fire Prevention and Control Administration, Washington, D.C.

"Overview: National Programs and Institutional Problems," M. McHenry, Fire Equipment Manufacturing Association, Arlington Heights, Illinois

"The Life We Save May Be Our Own," L. Borgelt, Fire Protection and Safety, Oklahoma State University

"Fire Department Involvement in Research and Development," J. M. Turner, Equipment Development, Los Angeles County Fire Department, California

"Activities of the National Fire Protection Association," M. Grimes, Public Protection Division, NFPA, Boston, Massachusetts

"Recommended Performance Standards for Protective Clothing for Firefighters," A Sears, National Fire Prevention and Control Administration, Washington, D. C.

Fourth All-Union Symposium on Combustion and Explosion, Results summarized by **V. V. Baraykin, V. A. Veretennikov, Yu. M. Grigor'ev, T. A. Zholudev, A. S. Rozrnberg, and E. N. Rumanov**, *Fizika Goreniya Vzryva 11* (1) 154-58 (1975) (in Russian)

Translated by L. Holtschlag
Abstracted by R. M. Fristrom

Seven hundred representatives from 210 organizations participated in the work of the symposium, which took place at the Noginsk Scientific Center of the Academy of Sciences of the USSR on September 24-27, 1974. F. N. Dubovitskiy opened the symposium. He introduced the organizing commitees and outlined the past three years development of combustion and explosion physics. He covered recent research on chemico-technological problems, metallurgical problems, problems of physico-chemical transformations in shock waves, the design of chemical lasers, aspects of pollution, problems of large fires and of fire explosion safety of chemical products, and the development of new experimental methods of investigating combustion products.

The three major sections of the Symposium were on combustion, detonation, and kinetics. In the combustion section, 40 papers covering a wide range of topics were given. The 20 papers of the detonation section covered gaseous detonations, detonations of condensed explosives, and shock propagation in condensed media. The 20 papers of the kinetics section were devoted to chemical transformations of energetic systems in the gaseous, liquid, and solid states. In addition to the major sections, inter-sectional sessions were held on elementary processes, laser methods, gasdynamic lasers, shock wave heterogeneous combustion, and combustion theory.

There were few papers on fire problems. One exception was a paper by Yu. A. Gostintev, S. S. Novikov, and L. A. Sukhanov, "On the Hydrodynamic Stability of Structure of Rapidly Spreading Fire," This theoretical analysis was applied to suggest methods of extinguishing steppe fires. The Symposium papers will be published by *Science Press* in a special collection some time in 1975.

Fifth International Symposium on Combustion Processes Abstracts, Polish Academy of Sciences, Division of Combustion Problems of the Committee for Thermodynamics and Combustion, Technological University of Krakow, Poland (September 1977)

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COMBUSTION AND GASIFICATION OF COAL

COMBUSTION OF LIQUID FUELS

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HETEROGENEOUS COMBUSTION

MODELLING OF COMBUSTION PROCESSES AND MEASUREMENT TECHNIQUES

THE PROPERTIES OF GASEOUS FLAMES

BURNERS, COMBUSTION CHAMBERS, AND FURNACES

IGNITION, EXPLOSIONS, AND FIRES

NEW JOURNALS

Fireline, Infotech Publications, San Francisco, California

This new entry in the fire problem field is a successor to the *Fire Line Newsletter* which terminated June 1975. The new effort shows promise of performing a useful function in providing current information to the fire protection engineer, fire practitioner, and fire research community. The coverage can be seen from the first years index. We wish the editors well in their new endeavor.

Contributing Editors:

Tom Anyos - SRI, Menlo Park, California
Norman Alvares - Lawrence Livermore Laboratory, Livermore, California
Loyd E. Almgren - FPE Group, San Francisco, California

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LNG Friend or Foe? - W. E. Gale, Jr.
Cascade Fires - S. J. Wiersma
Tailoring City Fire Protection to Local Needs and Resources - L. E. Almgren

February

The SRI Large Scale Heat Release Rate Calorimeter - S. B. Martin
Fire Detector Reliability - E. K. Vining
Flammability Guidelines Offered by the Department of Transportation
A Brief Study of Water Consumed in Firefighting in Five Areas - L. Witzeman

March

In Pursuit of Fire - D. P. Lund
Public Attitudes in California Toward Fire in the Wildlands - H. E. Moore
Risk Management Technique for Design and Operation of LNG Facilities and Equipment - O. H. Fedor and J. D. Coutinho

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