

UNCLASSIFIED

AD

4 2 4 8 6 0

DEFENSE DOCUMENTATION CENTER

FOR

SCIENTIFIC AND TECHNICAL INFORMATION

CAMERON STATION, ALEXANDRIA, VIRGINIA



UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

CATALOGED BY DDC
AS AD No.

424 860



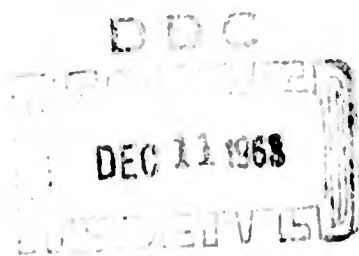
AN INVESTIGATION OF THE HAZARDS OF COMBUSTION
PRODUCTS IN BUILDING FIRES

F. W. Bieberdorf
C. H. Yuill

SwRI Project No. 3-1237-3
Final Report
USPHS Contract No. PH86-62-208

Prepared for

Division of Hospital and Medical Facilities, A
Bureau of State Services, Public Health Service
U.S. Department of Health, Education & Welfare
Washington 25, D. C.



October 14, 1963

SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO, TEXAS

SOUTHWEST RESEARCH INSTITUTE
8500 Culebra Road, San Antonio, Texas 78206

Department of Structural Research
Fire Research Section

AN INVESTIGATION OF THE HAZARDS OF COMBUSTION
PRODUCTS IN BUILDING FIRES

F. W. Bieberdorf
C. H. Yuill

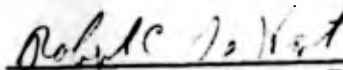
SwRI Project No. 3-1237-3
Final Report
USPHS Contract No. PH86-62-208

Prepared for

Division of Hospital and Medical Facilities
Bureau of State Services, Public Health Service
U. S. Department of Health, Education & Welfare
Washington 25, D. C.

October 14, 1963

APPROVED:


Robert C. DeHart, Director
Department of Structural
Research

FOREWORD

This report is submitted as the result of an investigation undertaken for the Division of Hospital and Medical Facilities, Bureau of State Services, Public Health Service, U. S. Department of Health, Education and Welfare under Contract No. PH86-62-208.

The study was monitored by Mr. Julian Smariga of the Division of Hospital and Medical Facilities. Valuable advice and suggestions were given the project staff by a Steering Committee composed of the following:

Dr. Gene Krackow, Taft Sanitary Engineering Center,
Cincinnati, Ohio

Dr. A. J. Lehman, Food and Drug Administration,
Washington, D. C.

Mr. C. S. Mullen, Jr., State Fire Marshal, Richmond
Virginia

Dr. Anne Phillips, Massachusetts General Hospital,
Boston, Massachusetts

Dr. Lester L. Williams, Colorado Springs, Colorado

Dr. Robert Hausman, Chief Medical Examiner for Bexar County, Texas, Dr. Herbert McKee, Assistant Director, SwRI-Houston, and Mr. Norman Turner, Manager, Building Research Section, SwRI, served as staff consultants.

The report presented herewith represents a joint effort by those mentioned above, Dr. Fred Bieberdorf, Senior Research Biologist, and Mr. Calvin Yuill, Manager of the Fire Research Section of Southwest Research Institute. The latter served as Project Leader.

Much credit is to be given to the many individuals and organizations who contributed time and information essential to the conduct of this program. Representing the fields of medicine, pathology, public health, fire protection, architecture, and law enforcement, they expressed without exception a deep interest in the work reflecting the need for resolving the problems involved. Thanks are extended also to those whose efforts in the past have been relied upon heavily in the preparation of this document.

ABSTRACT

A study has been made of the literature and previous experimental effort to define the hazard of combustion products in accidental building fires and the manner in which the selection and use of building materials may be related thereto. Particular attention has been given to the problem as it may affect the design, construction and operation of hospitals, although it is of interest to those concerned with life safety in all buildings.

It is concluded that the combustion products in accidental building fires constitute serious hazards to life safety, but that the hazard has not been defined in a manner permitting rational control. Smoke and toxic gases appear to be the primary hazards in most fires although heat, oxygen deficiency, panic, and emotional shock may become primary hazards under special conditions. Factual evidence is not available to support a selective use of building materials on the basis of their pyrolysis products. However, because of the varying conditions under which they burn or because of their chemical composition, many materials will produce quantities of smoke or toxic gases for which procedures for measurement are sorely needed.

The importance of incorporating sound fire protection engineering principles into building design and building alteration is emphasized. Fires involving heavy loss of life almost invariably are characterized by flagrant and multiple violation of such principles. Emphasis is placed on the practicability of minimizing the hazard of combustion products through the application of known principles of fire protection engineering.

Evidence to support the need for further experimental effort to define hazards and to develop controls as needed is presented, and recommendations are offered outlining the proposed nature of such work.

TABLE OF CONTENTS

	<u>Page</u>
LIST OF ILLUSTRATIONS	vi
LIST OF TABLES	vi
I. INTRODUCTION	1
II. THE PROBLEM DEFINED	3
A. Fire Casualties	3
B. Nature of the Problem	4
C. The Nature of Building Fires	6
D. New Materials - New Problems	8
E. What Has Been Done	9
III. COMBUSTION PRODUCTS - HOW THEY DEVELOP	13
A. Smoke	13
B. Flame	14
C. Heat	15
D. Combustion Gases	18
E. Decomposition of Materials in Fires	24
IV. EFFECT OF COMBUSTION PRODUCTS	27
A. Smoke	27
1. Burns	29
2. Human Tolerance to Heat	31
B. Oxygen (O ₂) Deficiency - Anoxia	33
C. Combustion Gases	33
1. Carbon Monoxide (CO)	34
2. Carbon Dioxide (CO ₂)	36
3. Hydrocyanic Acid (Prussic Acid) (HCN)	37
4. Ammonia (NH ₃)	37
5. Oxides of Nitrogen	37
6. Hydrogen Sulphide (H ₂ S)	37
7. Chlorine (Cl)	38
8. Other Gases	38

TABLE OF CONTENTS (Cont'd)

	<u>Page</u>
D. Shock	38
1. Nature of Shock	38
2. Types of Shock	39
3. Discussion	40
E. Panic	41
F. Summary	41
V. MEASURING COMBUSTION PRODUCTS	43
A. Smoke Measurement	43
B. Temperature Measurements	45
C. Methods for Gas Analysis	45
1. Standard Methods for Gas Analysis	45
2. Spectroscopy	47
3. Gas Chromatography	47
4. Animal Tests	50
5. Discussion	50
VI. MINIMIZING THE HAZARD OF COMBUSTION PRODUCTS	53
A. Fire Prevention	53
B. Fire Detection and Alarm	55
C. Fire Containment	56
D. Fire Control and Extinguishment	57
E. Evacuation and Rescue	58
VII. CONCLUSIONS	59
VIII. RECOMMENDATIONS	63
A. Analysis of Body Tissue and Blood	63
B. Study of Hazard of Combustion Gases through Gas Analysis	63
C. Study the Hazard of Combustion Gases through Animal Tests	64
D. The Hazard of Finishings versus Furnishings	65
E. New Concepts in Building Design	66
BIBLIOGRAPHY	67

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Standard Time-Temperature Curve	17
2	Plan View of Typical Chromatog	49

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Time in Minutes for Gases to Reach Danger Level	19
2	Time in Minutes for Gases to Reach Danger Level in Second Floor Room [Fire on First (Ground) Floor]	20
3	Combustion Products of Typical Materials	22

I. INTRODUCTION

It is well established that a large number of fatalities in building fires result from causes other than external burns. Even when external burns are present, evidence frequently indicates that death may have occurred some time prior to the burn injury. Materials used in building construction, particularly finish materials, are suspected of decomposing under fire conditions and emitting fatal quantities of heat, smoke, or toxic gases to the point that trapped persons may be incapacitated.

The daily press, in reporting fires, frequently refers to the number of persons or firemen "overcome by smoke" or died from smoke inhalation. " Much conflicting evidence exists as to the exact cause of death in such instances. Various investigators have shown that inhalation of heated air, oxygen deficiency, shock, and the inhalation of carbon monoxide or other poison gases can be fatal. The inability of occupants to find exits because of heavy smoke emissions may fatally prolong the exposure. Not infrequently, death occurs subsequent to the actual exposure because of the aftereffects of the exposure conditions.

Death due to conditions other than burns has been characteristic of many large-loss and widely publicized fires. In an effort to reduce life losses in accidental building fires, some authorities have attempted to regulate the use of materials that may produce large quantities of toxic gases or smoke when burning. Others would also attempt to do so if the hazard of pyrolysis products could be specifically defined and the objectionable elements effectively measured.

The application of safety measures always must be a compromise between the achievement of maximum safety and economic practicality. Thus, to assure a degree of safety in a building, some means must be at hand to determine the degree of hazard represented by a given material or combination of materials. Lacking such guidelines, it is only possible to apply arbitrary rules that frequently are general in nature, unnecessarily restrictive, and difficult to enforce. To the public official responsible for writing or enforcing building regulations and standards, this is a most serious matter. It is equally important to the building owner and to the material manufacturer, both of whom need to know the degree of safety required in each instance and that limitations on product use are justified.

To date, little progress has been made in defining the nature of the problem in measurable terms. On the other hand, no satisfactory test methods have been devised for or adapted to either quantitative or qualitative analysis of

combustion products of building materials. Whether the cost of the work involved or the failure to delineate the problem poses an obstacle that has retarded progress in this area of study is a moot point.

The provision of fire protection in institutional occupancies presents a specialized problem. In hospitals, particularly, many of the occupants are nonambulatory or elderly, and all are in strange surroundings and unfamiliar with the building plan. Furthermore, the buildings are occupied constantly day and night.

The Division of Hospital and Medical Facilities of the Bureau of State Services, Public Health Service, U.S. Department of Health, Education and Welfare is responsible for the development of standards for the construction and maintenance of hospitals receiving Federal financial assistance. It is concerned with the development of meaningful criteria for the selection and use of safe materials for use in hospital construction. The objective of this investigation, therefore, is to attempt to define the hazards of combustion products of materials in building fires and to suggest the means by which such hazards can be recognized and their effect minimized.

An extensive review and analysis of the literature and previous experimental effort pertinent to this subject has been completed. Many interested and informed persons in the United States and Canada have been consulted. Included in this group were medical examiners, pathologists, building officials, fire marshals, fire officials, public health specialists, and other having an official or personal interest in one or more of the many facets of the problem. Coroners and coroner records have been consulted to determine the usefulness of autopsies to establish the causes of fire deaths. The investigation also included a review and evaluation of methods used to make quantitative and qualitative determinations of smoke and toxic gas emissions from burning materials, and the extent to which data derived therefrom are applicable to the problem at hand.

Experimental effort was not included as a part of this exploratory program. However, previous experimental work has been evaluated, and recommendations for further work are included as a part of this report.

II. THE PROBLEM DEFINED

A. Fire Casualties

Satisfactory figures on the annual number of fire deaths and casualties resulting from fire do not exist. The National Fire Protection Association estimates the number of annual fire deaths at approximately 12,000; this estimate has not varied substantially for the last ten years (126)

A recent statement by the International Association of Fire Chiefs⁽⁹⁴⁾ presents a review of newspaper clippings on 472 fires in the United States during a nine-month period. Of the 1803 firemen reported to have been injured, 1382 or 77 percent were victims of "smoke inhalation." Of the 19 firemen who died in these fires, 11 or 58 percent died as a result of "smoke inhalation."

In 1952 the National Fire Protection Association Committee on Fire Gases introduced a classic report⁽¹²⁸⁾ on the subject with the statement, "The large number of fire casualties from the inhalation of noxious products of combustion, as distinguished from burns sustained in fires, has long been of most serious concern to the fire protection fraternity."

It is generally recognized, as any experienced fireman will attest, that many, if not a majority, of those who succumb in building fires are not seriously burned and that death or trauma must be due to other factors. The National Fire Protection Association, in an analysis of hospital fires⁽¹²⁷⁾, found

<u>Cause of Injury or Death</u>	<u>Fatalities</u>		<u>Injuries</u>	
	<u>No.</u>	<u>% of Total</u>	<u>No.</u>	<u>% of Total</u>
Bodily burns from flames	42	27	36	46
Suffocated or overcome by smoke or fire gases	98	64	39	43
Other causes	14	9	16	11

The situation with respect to fire injuries is vague in that frequently the apparent cause of death is listed, whereas the primary cause may have been

quite different. One hundred-nineteen persons died in the SS NORONIC excursion steamer fire in Toronto in 1949. (25) Bodies were burned beyond recognition - deaths were generally attributed to burns. Yet a report on that fire states that the color of the blood in the deceased indicated that death probably occurred from carbon monoxide poisoning prior to the burns.

How many of the 12,000 that annually die in fires might have escaped if they had not been incapacitated by combustion products? It is not unlikely that a more accurate determination of the causes of such fatalities would lead to the development of the means by which fire casualties could be greatly reduced.

B. Nature of the Problem

At any given time there are large numbers of people in hospitals and other institutions, in restaurants, in hotels, in apartment houses, and in places of public assembly who are dependent upon the knowledge and good intent of the owner and builder and on the enforcement of building and fire regulations in the community to assure their safety in the event of fire. A serious fire in any one of these or similar occupancies involving multiple deaths results not only in tragedy and suffering for the persons and families immediately concerned, but also in public clamor for more stringent regulations to prevent such occurrences in the future. The Coconut Grove nightclub fire in 1942, the Wincoff and La Salle Hotel fires of 1946, and the Our Lady of the Angels School fire in Chicago in 1958 are typical of fires involving large loss of life which resulted in modifications to building regulations and building standards throughout the country. In each of the cases cited, loss of life by causes other than burns was a notable characteristic.

Those concerned with the safety from fire of persons in buildings, if given the power of foresight, could take action to eliminate most problem areas. Since early times, however, building regulations have grown out of a need demonstrated by building failure through fire or collapse. Most responsible groups such as organizations of building officials and fire marshals lack the resources to assess potentially hazardous situations and to develop appropriate means of control. The result is often observed in well-intentioned but somewhat arbitrary regulations based upon generalities.

A notable exception was the work done in recent years by the City of Los Angeles Fire Department using school buildings that had outlived their usefulness. (129) One of the important findings of this empirical study was confirmation of the hazard of smoke, particularly in regard to the rapidity with which it filled corridors remote from the actual fire. Further work has been undertaken to define the smoke hazard in more specific terms, and the results, when available, will be of considerable interest. (133)

Current efforts to minimize the hazard of smoke and other combustion products have been directed primarily toward interior building finishes. This probably reflects the natural tendency to seek the path of least resistance and, where regulation is needed, to regulate first those things that are amenable to regulation. Building finishes are installed when a building is new and are subject to qualified inspection prior to the issuance of the occupancy permit. This provides a positive measure of control in the first instance as far as basic materials are concerned. Provisions in building regulations relating to maintenance, repairs, and renovations also provide for inspections except in the case of redecoration where paints and wallpapers usually are allowed.

Many point to the fact that regulation of building finishes borders on the ridiculous unless an effort is made to regulate furnishings as well. Bruce's⁽²⁶⁾ work supports this contention. This poses a serious problem in that regulation of the purchase and use of furnishings is impractical for all buildings and structures. Nevertheless, there are types of occupancies where rigid control of both furnishings and building materials is maintained in the interest of life safety. Decorative materials in night clubs, theaters, and places of public assembly are an example. The control of combustibles in hospital operating rooms is an accepted practice.

For the most part, however, there is little regulation on furnishings - rugs, drapes, upholstery, tables and chairs. Mattresses, again, are usually of combustible materials and afford one of the most prolific sources of fire and death by fire without burns. Each year, many are burned and die in fires after they have fallen asleep while smoking in an overstuffed chair or divan, or in bed.

Desirable as the regulation of building furnishings may seem to some, its impracticality, if only from the point of view of inspection and enforcement, should be obvious. It has been demonstrated, on the other hand, that building materials can be regulated on a broad scale, and sufficient experience has been had with large-loss fires to demonstrate that such action is justifiable on the grounds of public safety. When the public becomes interested in a further extension of regulatory procedures to include furnishings, such action will be forthcoming.

Some of the difficulties involved, particularly with respect to the adequacy of inspection personnel, might be obviated through control of the manufacture and sale of materials and furnishings. In any event, action in either direction should be preceded by a careful investigation, supported by realistic experimental effort, to justify need in terms of public safety.

C. The Nature of Building Fires

The character of the products of combustion that develop in accidental building fires is dependent largely upon the nature of the fire itself. The latter does not lend itself to delineation since fires differ greatly from one to the next. In general, however, it can be said that every uncontrolled fire produces smoke, heat, and a variety of combustion gases. These are produced in varying degrees, depending (1) upon the factors present which influence the combustion process and (2) upon the nature of the materials burning.

Combustion itself requires the presence of (1) combustibles, (2) oxygen, and (3) a heat source. Generally speaking, if one of these three items is removed, the fire will "go out."

For instance, the heat from a match is hardly sufficient to light a fire-place log, so secondary and more easily ignitable materials such as crumpled newsprint and kindling are lighted first. Having a much larger burning surface, the newsprint will provide sufficient heat to ignite the kindling which, in turn, will ignite the logs. The mechanism present involves heating the material to be burned to a point where it will decompose and evolve gases some of which may be highly flammable. Given sufficient heat for a long enough time and with an adequate supply of oxygen, the reaction will continue and become self-sustaining.

A source of fresh air is needed to supply the oxygen necessary to support combustion. There have been instances of rather severe fires starting in tightly closed houses that extinguished themselves. The fire may burn vigorously and gradually diminish in intensity as the oxygen in the air combines with the carbon from the burning materials to form carbon dioxide and carbon monoxide until insufficient oxygen remains to support combustion.

At the other extreme are the materials that release oxygen when heated or that include an inherent oxidizing agent. A lighted cigarette will continue to burn when left by itself because of an oxidizing agent provided. A cigar or pipe does not have such an additive and will be self-extinguishing. Nitrocellulose film is in the same category with other self-oxidizing materials which, fortunately, are few in number.

As the fire in a closed building grows in intensity, it "burns" the oxygen at a more rapid rate. As this supply diminishes, the combustion becomes incomplete, and less of the carbon is consumed. Under such conditions dense smoke and voluminous quantities of carbon monoxide and other unburned gases could be expected. It is standard procedure in fighting such fires to provide ventilation at a high point of the building, such as the roof, for the purpose of exhausting unburned gases and to help clear the air for the benefit of entering firemen.

The presence of unburned gases in this type of fire can be a severe hazard if not approached properly. To open a door or window of a burning building at a low level before venting the roof or upper story is to invite trouble. The rapid entry of a fresh supply of oxygen will mix with the unburned gases to form a highly combustible - often explosive - gaseous mixture. Firemen have been blown from a door for considerable distances by "hot air" explosions.

The exact nature of the unburned gases present in a building fire is not known to the firemen and usually would be so complex that a detailed laboratory analysis would be required even for a qualitative evaluation. The presence of large quantities of carbon monoxide in most fires is confirmed by reports of high carboxyhemoglobin (carbon monoxyhemoglobin) in the blood of firemen returning from fires.⁽³⁶⁾

The nature of other gases is largely dependent upon the nature of the materials burning. The burning of hair, leather, or any organic material containing sulphur may produce the extremely toxic hydrogen sulphide. The decomposition of wool or silk may produce hydrogen cyanide. Oxides of nitrogen are formed to a minor extent in any fire by the direct combination of atmospheric oxygen and nitrogen, but this in itself is probably a minor hazard. However, oxides of nitrogen resulting from fires involving nitrocelulose film have been outstandingly hazardous, and most building codes specifically regulate the storage and use of this material. Chlorine or hydrogen chloride can be expected from the pyrolysis of certain plastics.

Certain other factors, often overlooked, should be considered in building fires. Where ample oxygen is present, the air temperatures may quickly reach and even exceed 1000° to 1500° F. These temperatures are above the ignition temperature of hydrogen sulphide (500° F), formaldehyde (806° F), hydrogen cyanide (1000° F) and carbon monoxide (1128° F). Thus a clean-burning, hot fire may be safer from the toxicity standpoint than a cooler, smouldering type fire. It should be kept in mind, however, that some gases, such as sulphur dioxide which is toxic, are inert and will not burn.

Also, the pyrolysis products of wood can be extremely hazardous. In fact, Smart, in his book on Industrial Fire and Explosion Hazards⁽¹⁵⁷⁾ saw fit to emphasize the need for precaution in approaching fires when wood is burning in confined spaces because of anticipated concentrations of carbon monoxide and other toxic gases. In spite of this, however, many building codes contain the highly fallacious requirement that interior finishes that produce smoke or toxic gases greater than those produced by wood burned under similar circumstances shall not be permitted, thus giving an impression that wood is a relatively "safe" material in a fire situation.

Finally, any consideration of the problem must not ignore the fact that thermal decomposition of most materials starts prior to any visible burning, and it may be a slow process. Again Smart refers to the evolution of decomposition products of wood at 320° F. The slow charring of wood in contact with hot pipes for long periods is not uncommon and is evidence that oxidation has taken place.

Knowledge of the importance of combustion products has become significant to the point where some fire departments insist that firemen wear self-contained breathing apparatus in any burning building that they enter. Limited experimental effort has been directed toward the burning of individual materials under controlled laboratory conditions to establish a quantitative measure of the combustion products. Very little has been done, on the other hand, to define the actual hazard involved in terms of tolerable limits for life safety of the occupants of buildings.

A distinction should be made between buildings of ordinary occupancy and buildings in which manufacturing processes are conducted (plants) or in which manufactured products are stored in large volume (warehouses). Such occupancies present specialized problems where a degree of smoke or of noxious gases can be abnormally severe, depending upon the nature of the goods involved. That type of risk is not being considered in this investigation.

D. New Materials - New Problems

When plaster, wood, paint and wallpaper were the only materials used for interior finishes, the products of combustion were no less important. However, they were less frequently recognized as a hazard, and means for regulation had not been devised. Probably the first interior finishes to receive attention were the multiple layers of paint sometimes used on shipboard which resulted in rapidly spreading fires. Multiple layers of wallpaper and paint on corridor walls also received early attention, but from the standpoint of flame spread rather than combustion products.

Serious fires in hospitals, hotels, and other occupancies in the 1935-1950 period, resulting in heavy loss of life, focused attention on the fact that many of the deceased did not die because of burns. Coupled with this was the development of new materials that, by virtue of their chemical composition, were suspected of being hazardous.

Fire-retardant treatments for wood, both pressure impregnations and coatings, involve the use of boric acid, borax, and various metallic or other salts which greatly reduce active flaming during the early stages of a fire. These may develop greater quantities of toxic gases and smoke than untreated wood.

It is interesting to note that ordinary oil- or water-mix paint has fire-retardant properties when applied to wood. Westgate⁽¹⁷³⁾ found that such paints have a self-ignition temperature in the range of 850° to 1100° F. The ignition temperature of wood and paper, generally, however, is in the range of 450° to 550° F. Also, the caloric value of paint films is of the order of 3500 to 6500 BTU per pound compared to 6500 to 8500 BTU per pound for wood and paper. Unpigmented varnish and lacquer, on the other hand, have a caloric value of 12,000 to 15,000 BTU per pound.

Plastics, by composition, may contain carbon, hydrogen, nitrogen, chlorine, fluorine, sulphur and many other elements. Under fire exposure these are released to combine with other elements and with the oxygen and nitrogen in the air to form a wide variety of gases, many of which can be toxic. Carbon monoxide, chlorine, hydrogen chloride, hydrogen cyanide, hydrogen sulphide and oxides of nitrogen are representative of gases sometimes found in quantity as plastics decompose. In addition, some plastics, like natural rubber, may produce heavy smoke while burning. For any given material, the nature of the combustion gases and smoke is largely dependent upon the amount of oxygen present.

There is support in the literature for the contention that carbon monoxide is produced at such a rate that discussion of other gases present becomes academic. There are indications also that the hazards attributed to plastics are based on fires in plastic manufacturing plants or warehouses where large volumes of materials are present.

The formulations used in the plastics industry can be varied by the use of additives to decrease their flammability. Unfortunately, such additives often have a marked tendency to increase the smoke emissions and otherwise detract from the physical properties of the end product.

E. What Has Been Done

The existence of a life hazard from combustion products in building fires has been recognized for many years. The Cleveland Clinic fire of 1929 with 125 deaths, and many others, lent emphasis to the need for some degree of control of materials that produce noxious fumes.

Of primary importance, of course, is the effect of combustion products upon the life safety of building occupants. Also of importance is the effect of combustion products on firemen. Since the latter group is more closely knit than the general public, it is not surprising that the International Association of Fire Fighters and the International Association of Fire Chiefs have been actively interested in the subject for many years. The International Association of Fire

Fighters, in fact, published a book in 1945⁽¹⁵⁵⁾ on occupational hazards of the fire services with considerable emphasis on the possible relationship between heart disease and "the effects of intoxication of carbon monoxide, the chief and most important constituent of smoke." Further studies of this potential have been undertaken in Bangor, Denver, Kansas City, Toronto and other cities.

The physiological significance of exposure of firemen to combustion products relates to relatively long exposures on a repetitive basis. While studies underway undoubtedly will add helpful and much needed information to the subject, they do not relate necessarily to the short term exposures experienced by persons caught in a burning building.

The classic study of the latter problem was undertaken by the National Fire Protection Association Committee on Fire Gases in 1947.⁽¹²⁸⁾ This study was reported in the January 1952 issue of the NFPA Quarterly. Subjects covered included the effect of exposure to heat, causes of death in fires, and specific gas and vapor hazards. No attempt was made to define the problem in terms of actual hazards or to suggest controls, and the sponsoring committee was discontinued shortly thereafter.

In 1959 work was undertaken by the Los Angeles City Fire Department in an effort to define certain elements of the problem, particularly the importance of smoke and heat in building fires. No analysis of combustion products was involved. The results of these efforts have been published by the National Fire Protection Association.^(129, 130) The dramatic results of these tests offer salutary evidence of the need for an empirical check on theoretical concepts of the cause, effect and control of fire.

The National Research Council of Canada undertook a series of tests in 1958⁽¹⁵³⁾ in which buildings to be demolished for the St. Lawrence Waterway were carefully instrumented and burned to destruction. These tests were known as the "St. Lawrence Burns."

More recently, the plastics industry has sponsored research directed toward a rationalization of the alleged hazards of smoke and other combustion products. This program is the result of a cooperative effort between the Plastics in Building Committee of the Manufacturing Chemists Association, Inc., and Underwriters' Laboratories, Inc. This study is currently under way and one report has been issued.^(133, 200)

In addition to the more formal activities such as those mentioned and the effort represented by this report, there are the many groups and committees anxiously seeking guidance and information that will aid in resolving specific problems. Organizations of building officials and firemen, committees of the

American Society for Testing and Materials and the National Fire Protection Association, official agencies including the Forest Products Laboratory and the National Bureau of Standards, the Federal Fire Council and the Fire Research Committee of the National Academy of Science-National Research Council have a continuing interest in the problem.

In related fields, a fresh look is being given to man's survival in unusual environments by the National Aeronautics and Space Agency and the Air Force School of Aerospace Medicine. In the strict military sense, studies have been made, many of a classified nature, of the effect of combustion products on man from both an offensive and defensive point of view.

All of the organizations mentioned and many more have been consulted during the course of this investigation. Where pertinent data were available and could be released, a liberal use of references to active programs and significant findings have been made. If any one general observation can be made as a result of these contacts, it is that the problem, in relation to the selection and use of building materials, has not been aggressively approached until quite recently, and the data produced to date are far from complete or conclusive.

III. COMBUSTION PRODUCTS - HOW THEY DEVELOP

Smoke and the gaseous products of combustion are discussed separately in this report. Technically the two components are dissimilar, are characterized by different hazards, and require different methods of evaluation.

A. Smoke

The old saying "where there's smoke there's fire" might also read "where there's smoke there's carbon monoxide." In the all-inclusive sense, smoke has been suspected of being hazardous for a long time. In the Second Punic War prisoners were killed by the inhalation of smoke. Seneca, in 60 A. D., committed suicide by inhaling coal vapors. Diocletian, in 300 A. D., is reported to have killed many of the Martyrs by "confining them to small spaces heated with the greenest, most smoke-producing wood possible."⁽⁴⁾

Smoke is commonly considered to be the gaseous products of burning organic materials such as wood, coal, and other carbonaceous material rendered visible by the presence of small particles of carbon which finally settle as soot. Technically, smoke represents only the unburned solids, usually carbon (and ash) suspended in air.⁽¹⁷²⁾

The first effect of smoke that may be noted on humans is that it obscures the vision, particularly if it occurs in an enclosed room or if there is a downdraft in the atmosphere. According to Kingman, et al.⁽⁹⁹⁾, a room can be considered smoke logged when the visibility level drops to four feet. As their research reports point out, the escape time for occupants of a building during the course of a fire will be determined by the rate of the deterioration of the atmosphere and the ease of escape as affected by visibility. Their experiments showed that composition of air within a room on the floor above the fire, with the door open, became unrespirable within five minutes and visibility decreased in about the same time. Closing the door delayed the effects by another five minutes. In rooms with noncombustible walls, the escape time was increased by 15 - 20 minutes.

In the Los Angeles School Fire Tests⁽¹²⁹⁾ smoke was considered to be the primary life hazard because of its effect on visibility and its irritating effect. Hallways became intolerable in the buildings in as little as two minutes after the start of the test fires. A large number of tests were conducted, and, in most, the hallways became intolerable because of smoke prior to the development of excessive heat.

Some years earlier, Bruce⁽²⁶⁾ reported on a series of room burn-out tests in which he found excessive heat developing before smoke or toxic gases. He estimated, however, that, if there had been an upstairs room over the fire, smoke and gases would probably have developed to a danger point before the heat became intolerable.

Kingman et al., (99) in building burn-out tests in England, found that limiting smoke from test fires (four tests) generally paralleled the degradation of the air. Here the fire was started in a downstairs room and measurements taken in an upstairs bedroom with the door closed in some instances and open in others.

In a similar series of tests in Canada, Shorter et al. (153), found that smoke reached the limit of tolerance considerably before heat, carbon monoxide, or oxygen levels became dangerous. The actual time for the smoke to become excessively dense in the four building burn-out tests ranged from 1.6 to 4.4 minutes. Variations in the time for smoke to develop depended upon the nature of the building materials and whether or not the room door was open or closed.

The interpretation of data such as that listed above presents a hazard in itself. The experiments are based on specific situations conditioned by the design, construction and furnishings of the buildings or rooms involved. The techniques used to measure smoke density, heat and gases do not follow standard procedures. In the case of smoke and gases at least, such standard procedures have not been established. Finally, they involve arbitrary decisions as to the exact level of tolerance to be considered acceptable in each case.

Nevertheless, each series of these tests contributes to the knowledge of the problem. Not only do they throw light on immediate problems, they point the way for improved techniques that can be used in future experimentation.

B. Flame

The combustion process starts with the decomposition of materials on exposure to heat prior to actual ignition. When ignition occurs, it is evidenced by the appearance of flame which, in itself, may be hazardous.

If we disassociate flame from heat, smoke and combustion gases, and consider it only as the visible evidence of fire, the primary hazard would appear to be the psychological one of panic. The same is true of smoke, but smoke is expected to appear before the actual fire, and many do not recognize this hazard and that of the attendant combustion gases. The appearance of flame, however, leaves no doubt in the mind that fire is close at hand and that emergency action is required immediately. This situation is conducive to panic and undoubtedly constitutes a severe but difficult-to-define fire hazard.

With one exception, flame, per se, does not lend itself to easy measurement nor is it related directly to a basic characteristic of the material as is heat, smoke, or combustion gases. The exception has to do with nonluminous flames or flames having a low luminosity that may not be visible to the human eye. Alcohol fires are notoriously hazardous because spilled alcohol burns with a low-luminosity flame not readily apparent to the observer. Use of liquid hydrogen at missile sites poses a similar problem. Preliminary experimentation in the use of sulphur as a building material raises the question as to whether or not flame may be a hazard even though, in this case, pungent odors may precede the flame. It is possible that people might be involved in a fire with no smoke and invisible flame, but such situations would be exceptional.

C. Heat

The amount of heat that develops during a building fire is a function of the caloric value, the amount of combustible material, and the rapidity with which the reaction takes place. Hydrocarbons or petroleum products have a high caloric content. Except for certain materials such as vapor barriers and sometimes electrical insulation, these products are not encountered in interior building materials. These materials, however, have been the cause of large life loss in airplane crash fires, as reported by Hasbrook⁽⁸²⁾, and in certain unusual structure fires such as the 1944 Hartford Circus (168 dead), and the 1961 Niterai, Brazil, circus tent fires (400 dead)^(98, 132) where waterproofing (not fireproofing), such as paraffin thinned with gasoline, had been used.

Wood, which is used extensively in construction both as a structural material and as a finish, also has a relatively high heat of combustion, but low in comparison to other fuels such as coal or kerosene.

In developing a method for determination of the potential heat of materials in building fires, the National Bureau of Standards⁽¹²⁴⁾ shows an average potential heat for six woods as 8012 BTU/lb, four plastics ranging from 7740 to 17,420 BTU/lb, five insulations ranging from 1050 BTU/lb for rock wool enclosed in paper to 11,110 BTU/lb for cork, and low to negative results for relatively noncombustible materials such as plaster and concrete.

In establishing the degree of fire resistance required for building elements, it is common practice to consider the weight of combustible contents typical of the space to be occupied. The "fire loading"* of typical occupancies has been listed as follows:⁽¹²⁵⁾

*"Fire loading" is expressed in terms of the weight in pounds of combustibles per square foot of floor area.

Residential 8.8 lb/ft²

Clothes Closet	19.4
Living Room	8.1
Kitchen	6.8
Bedroom	10.4
Bath	7.0

Business Office (light files)	10.9
Business Office (heavy files)	42.9

School Auditorium	5.54
School Gymnasium	7.4
School Library	11.1
Library Stack Room	35.9

Hospitals

Patient's Room	2.3
Doctor's Office	8.6
Laundry	5.0

With an approximation of the expected density of furnishings (including flooring and exposed woodwork), it is possible to utilize caloric values for various materials and calculate the possible total heat release in the event of fire.

About the turn of the century, Professor Ira Woolson, then professor of civil engineering at Columbia University, developed data by which he was able to produce a curve of time against temperature in various building fires which he felt was representative of severe fires. His methods, though crude, were nonetheless effective and consisted of visiting many buildings which had been subjected to severe fires and selecting pieces of melted glass, melted metal and other evidences of the effect of fire on materials. He then reconstructed the time sequence of the fire through consultation with firemen and others present at the time and, knowing the melting point of the various materials, was able to establish the desired relationship.

A quarter century later, in 1927, Dr. S. H. Ingberg⁽⁹³⁾ conducted building burn-out tests in Washington, D. C. on buildings that were to be demolished and which were furnished with furnishings representative of various types of occupancies. One of the objectives was to verify the time-temperature curve which was then used as a standard for all full-scale fire tests. The results differed slightly from those obtained by Professor Woolson and resulted

in a new time-temperature curve that now is a part of the fire test standard. (5) Similar experimentation in Canada, England, France, Switzerland and other countries generally verified these results.

Figure 1 is a reproduction of a standard time-temperature curve. Note that a straight-line relationship is shown in the time period from zero to five minutes. There are various reasons for this, a principal reason being that temperature relationships during the first five minutes are quite unstable and it would be extremely difficult to establish a representative curve.

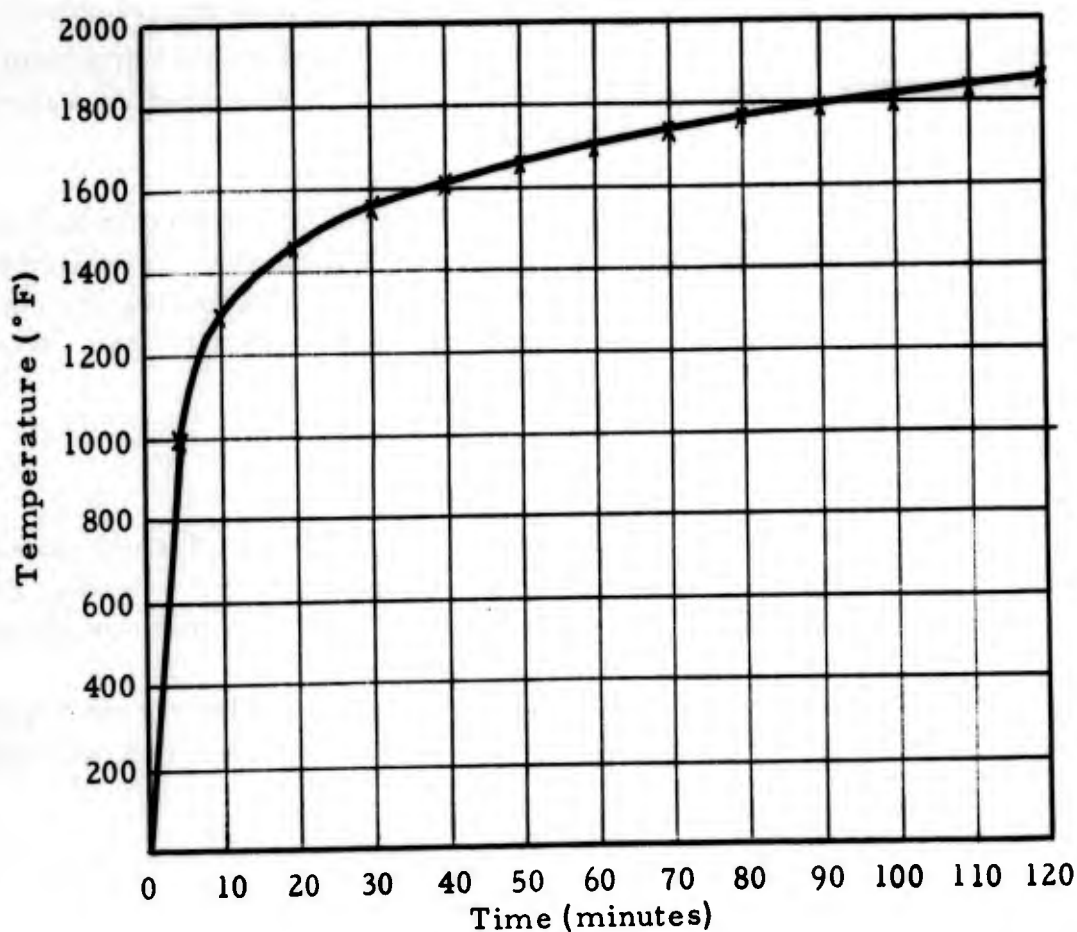


FIGURE 1. STANDARD TIME-TEMPERATURE CURVE

Insofar as escape from burning buildings is concerned, we are concerned primarily with the first few minutes of the fire when people have an opportunity to and must escape. During this period it is obvious from reference to the standard curve that the temperatures quickly reach a point above the generally accepted tolerable limit of 150° to 160°F.

Actual heat measurements in experimental fires have been reported in terms of the time at which intolerable temperatures are reached. The results of the Los Angeles School Fire Tests⁽¹²⁹⁾ showed that the limiting temperatures were reached 2 - 10 minutes after the start of the fires, and in most instances after the corridor had become intolerable because of smoke and irritants.

The National Research Council of Canada⁽¹⁵³⁾ used four buildings in their tests. Fires were started on the first floor, and measurements were taken in a second floor bedroom. Intolerable temperatures were recorded from 1.8 to 2.5 minutes after the start of the fire when the bedroom door was open, and 8.7 to 11.7 minutes when the door was closed.

The problem in comparing the test results is well illustrated in these two examples. In the first instance, the maximum tolerable temperature was established at 150°F. In the second instance, 300°F was used as a limit. Thus no comparison of results can be justified.

The question of tolerable heat levels will be considered in Section IV of this report, together with the effects of short exposures to elevated temperatures on the body. Insofar as the heat developed in building fires is concerned, ample evidence exists to show that temperature levels higher than any of the accepted limits can be expected in the first few minutes.

D. Combustion Gases

There are certain gaseous products of combustion of which some are inert and some are highly toxic. Some of these gases may be readily detectable by their odor while others, such as carbon monoxide, have little or no odor.

The composition of the atmosphere in a well ventilated building should, under normal circumstances, be the same as the composition of the outdoor atmosphere as follows:

Nitrogen	78.06
Oxygen	21.0
Other	<u>.94</u>
Total	100.00

As indicated previously, oxygen in a fire combines with carbon to form carbon dioxide and carbon monoxide. Thus the oxygen-carbon monoxide-carbon dioxide balance is an obvious key to what actually happens in a fire.

In 1953, Bruce⁽²⁶⁾ demonstrated the history of the atmospheric balance, and Kingman⁽⁹⁹⁾ conducted similar experiments at about the same time. Results of the two series of tests are listed in Table 1 as a matter of interest. The

results are not comparable since the gas samples for the British tests (Kingman) were taken in a second story room, while the fire was on the first floor. Bruce took samples in the same room with the fire.

TABLE 1. TIME IN MINUTES FOR GASES TO REACH DANGER LEVEL*

<u>Test No.</u>	<u>Oxygen</u>	<u>Carbon Monoxide</u>	<u>Carbon Dioxide</u>
		<u>Bruce's Tests(26)</u>	
4	14-14.3	4.1-7.5	14-14.3
5	6-6.8	6-6.8	6-6.8
6	6-6.2	6-6.2	6-6.2
		<u>Kingman's Tests(99)</u>	
1	9-12	3-6	9-12
2	3-6	Under 3	3-6
3	27-35**	Under 3	18-24
4	24-30**	3-6	18

*Dangerous levels: Oxygen - less than 15%; carbon monoxide - over 0.1%; carbon dioxide - over 5.0%. (vol.)

**Noncombustible interior finish, combustible finish in two previous tests.

Thus in each instance but two, carbon monoxide reached a dangerous level before the oxygen level dropped below 15 percent. In two instances the carbon dioxide reached a dangerous level before the oxygen was seriously depleted.

Shorter, et al. (153), used the NFPA Fire Gas Research Report criteria of 1.28 percent carbon monoxide and 10 percent oxygen content as being the danger level. Kingman(99) presented enough data (Table 2) for a comparison.

TABLE 2. TIME IN MINUTES FOR GASES TO REACH DANGER LEVEL IN SECOND FLOOR ROOM [FIRE ON FIRST (GROUND) FLOOR]

<u>Interior Finish</u>	<u>Door</u>	<u>Carbon Monoxide</u>		<u>Oxygen</u>	
		<u>NRC*</u>	<u>BFS**</u>	<u>NRC</u>	<u>BFS</u>
Noncombustible	Open	12.1	24-30	4.2	24-30
Noncombustible	Closed	18.6	---	20.2	27-35
Combustible	Open	2.9	6-9	2.5	3-6
Combustible	Closed	5.6	9-12	12.9	9-12

*National Research Council

**British Fire Station

Correlations in most instances were poor. Nevertheless, the general conclusion of significance reached in both series of tests was that the use of noncombustible interior finish gave considerably greater escape time provided the bedroom door was closed. Bruce concluded, on the basis of measurements taken in the room with the fire, that the nature of the fire and furnishings was more significant than the wall finish.

Other significant disclosures of these investigations related to the nature of the igniting fire, the fuel, wall finishes and the position of doors (open or closed). These were important factors in the aforementioned Los Angeles School Fire Tests also. In any fire involving so many variables, the vagaries of the pattern of fire spread will be influenced by transient air currents and the unpredictable manner in which furnishings and other materials react on exposure to heat.

The rate of change of the atmosphere that occurs in a burning building will, to a large extent, be determined by the fuel that supports the combustion and the available oxygen. Burning fuels, such as the hydrocarbons used in flame throwers, will deplete the oxygen supply in a few seconds. Zapp⁽¹⁸¹⁾ in his experiments with goats, concluded that many Japanese soldiers were killed in bunkers by flame throwers because the oxygen was quickly depleted and a high carbon monoxide content filled the bunkers. His studies were made because it was observed that many of the Japanese soldiers found dead in the bunkers following attacks with flame throwers showed few signs of external burns. He concluded that, where bunkers were well ventilated, death was probably due to inhalation of hot air. Otherwise, incomplete combustion would quickly increase carbon monoxide content of the air to a fatal level.

Zapp's conclusions agree with the findings of other investigators. That is, if combustion is taking place under a depleted or low oxygen supply, the combustion will be incomplete and will result in the production of carbon monoxide along with the other combustion products. If there is an ample supply of oxygen, the carbon monoxide produced will be in a much lower ratio, and breathing of hot air is apt to be the cause of death if body burns are not present.

Fires in enclosed areas quickly change the composition of the atmosphere. Kingman, et al.⁽⁹⁹⁾, completely burned two full-scale test houses in order to measure the variations and changes that occurred during the burning process. In the early stages, combustion was complete, but, as the oxygen was used, combustion became incomplete.

During the course of a fire in a building, escape for occupants will be determined by many factors, including the rate of deterioration of the atmosphere and visibility. The danger point was reached when the oxygen content had fallen to such a low value that the occupants would have been asphyxiated. Prior to this period, the carbon monoxide level was merely considered to be unpleasant. The changes in the atmosphere brought about by a fire in general consist in (1) elevation of the temperature causing an expansion of the various gases, (2) decrease in the available oxygen resulting from the use of the oxygen in the combustion process and (3) an increase in carbon monoxide.

In a conflagration involving several buildings or city blocks, oxygen will be depleted quickly, but the heat will cause the atmosphere in the area to expand and rise. This results in a reduction of the atmospheric pressure and causes air from the surrounding areas to rush in. If the conflagration is large, it may result in a fire storm. Such fire storms resulted from the incendiary bombings of German cities during World War II. These storms, their behavior and effect upon the civilian population are graphically described by Bond⁽²¹⁾ in his report on "The Fire Attack on German Cities." Busch's vivid report⁽²⁸⁾ on the 1921 earthquake and fire in Tokyo and Yokohama referred to mass deaths in open park areas in the center of fire storms. Carbon monoxide was reported to have been the causative factor, although anoxia could be suspected.

Many experimental determinations of products of combustion other than smoke, oxygen, carbon monoxide and carbon dioxide have been made. As indicated in Section II, the pyrolysis of specific materials can be expected to release a wide range of gases ranging from irritants, to anesthetics, to nerve gases, and others of a highly toxic nature. These will be discussed individually in Section IV with particular reference to their anticipated effect.

Indicative of the complexity of combustion gases are the analyses of a few representative products presented in Table 3. For comparison with tolerable

TABLE 3. COMBUSTION PRODUCTS OF TYPICAL MATERIALS

Gas	Material					Dangerous Dosage 30-60 min
	Wood* (40)	Wool(54)	Rubber Insulation(54)	Silk(54)	Chlorinated Methacrylate(40)	
Ammonia (NH ₃)	125(40)	16,800		31,900		2,500
Carbon Dioxide (CO ₂)		62,000	135,500	126,000	26,000	33,000
Carbon Monoxide (CO)	1,000	50,000	75,500	44,000	22,000	1,500
Hydrogen Chloride (HCL)	7.5				6,000	1,000
Hydrogen Cyanide (HCN)	40.6	25,200		22,200		100
Hydrogen Sulphide (H ₂ S)	30.5	1,700	1,200			400
Oxides of Nitrogen (as N ₂ O ₄)	2,400					100
Sulphur Dioxide (SO ₂)	2.6	1,000				150
Phosgene (COCl ₂)					5	25

*Flame spread test, SwRI; all data in parts per million. Where no figure is given, data have not been obtained.

limits, the hazardous exposure for each gas is indicated. Such data have limited value and are presented only for illustrative purposes. The limitations are based upon:

- (1) lack of detailed information on test, sampling and analytical procedures, and on the exact nature and condition of the test specimen;
- (2) lack of information on the chronological history of each gaseous component which could be as important or more important than the quantity present;
- (3) the possibility of the synergistic or of the neutralizing effect of two or more of the gases present;
- (4) lack of knowledge of the effect of ambient temperature on the effect of gases present; and
- (5) necessity for setting arbitrary limits on the dangerous level of the gases in question.

In regard to item 3, the National Fire Protection Association Fire Gas Research Report referred to possible synergisms with a specific example:

"For example, a mixture of carbon monoxide and hydrogen sulphide in air, containing of each respectively 50 and 4 parts per 10,000 parts of air is fatal to animals when breathed, but neither gas in these concentrations is fatal when breathed alone."

Amdur has reported the effect of synergisms particularly in increasing airway resistance (186-189).

Again it has been suggested that in cooling gases prior to exposing animals, the potency of some component gases might be lost. Yet, if the gases were not cooled, the results might be affected by thermal injury.

In regard to appropriate levels on which to establish tolerable or dangerous limits, there is a divergence of opinion. Jacobs⁽¹⁹⁵⁾ presents a table of "Acute Physiological Response to Gases and Vapors in Air." Four levels of concentration are shown, as follows:

- (1) Kills most animals in short time.
- (2) Dangerous to life in 30-60 minutes.

- (3) Maximum concentration tolerated for 60 minutes without serious disturbance.
- (4) Slight symptoms after several hours or maximum concentration for prolonged exposure (8 hr).

The latter level is that commonly used in industry in controlling the day-after-day type of continuing exposure. In relating such data to a fire situation, a decision must be made on which level is applicable, and on this point there is no general agreement.

An exposure of 1500-2000 ppm (0.15-0.2%) carbon monoxide is listed as dangerous in a 30-60 minute exposure. Yet Claudy suggests that 0.08% concentration may cause collapse, unconsciousness and possible death in two hours.⁽³⁸⁾ Also, that a concentration of 1.28 percent (12,800 ppm) may be fatal in one to three minutes. Shorter, et al.⁽¹⁵³⁾, used the 1.28 percent figure to establish danger limits of carbon monoxide in the St. Lawrence Burns.

Because of the unknowns in the situation and lack of agreement on procedures and end points, combined with environmental factors that vary widely in character and effect, a wide variety of results can be obtained from different sources, and verification of the results of any series of tests is difficult.

In spite of shortcomings in the situation, the presence of smoke, heat and toxic gases in building fires in amounts that can cause fatalities has been established beyond reasonable doubt.

E. Decomposition of Materials in Fires

The combustion process is a highly complex series of reactions. Much is known about combustion as it occurs in furnaces and internal combustion engines. However, in the uncontrolled state there is a lack of information and much has yet to be learned. We do know that a characteristic common to many materials is degradation under exposure to elevated temperatures. Cellulosic materials commonly decompose under exposure to high temperature and in the process emit gases, many of which are combustible. If the heating process continues for a sufficient length of time, a point is reached where the material bursts into flame. This is the self-ignition temperature of the material, or the temperature at which active ignition occurs without the further application of heat or the presence of an external ignition source. Prior to that time, the gases given off by the decomposing material may be of such character and they may be mixed with the oxygen in the area in such proportions that the lighting of a match or even the striking of a spark might cause ignition.

Up to the present time we have been concerned in this report with the gases given off during the combustion process. It should be noted, however, that the gases given off during the decomposition prior to ignition may also be of a toxic nature and may or may not represent a hazard to the safety of the people in the space concerned. No evidence has been found of concerted study of this facet of the problem.

IV. EFFECT OF COMBUSTION PRODUCTS

The manner in which smoke, heat and combustion gases develop has been discussed. In this Section of the report it is the intent to discuss the physiological effect of these combustion products on the occupants of a building in which fire occurs.

Since the time of the Cocoanut Grove fire in 1942, interest in respiratory damage resulting from fires has been mounting slowly among the medical profession. Recently Phillips & Cope⁽¹³⁹⁾ have reported it is a principle killer of the burned patient yet despite the increasing number of articles appearing on the subject, the exact roles played by smoke particles, heat, lack of oxygen, and combustion gases are not yet known. In reviewing the literature it becomes apparent that the term "respiratory burn" is often used loosely to include any of the untoward respiratory changes occurring following a fire and not just for the results of exposure to heat.

A. Smoke

Smoke, as distinct from the heated gases usually accompanying it, has two potentially hazardous effects: (1) it reduces visibility and (2) it may be injurious to the mucosa (lining) of the human respiratory tract.

While the visible smoke particles may not have any immediate physiological effect upon the human being, the psychological or behavioral effects that the obscuring of vision will have upon the person trapped or caught in a building fire is unpredictable. In reading the accounts of such holocausts as occurred on the SS NORONIC⁽²⁵⁾, at the Cocoanut Grove⁽¹²¹⁾, the Iroquois Theater⁽¹⁹⁴⁾, the Hartford Circus⁽⁹⁸⁾, the Winecoff Hotel⁽¹⁹⁸⁾, and many others, one can conclude that: there will be those who will panic and, thus, by their actions, cause additional tragedy; there will be those who remain cool, retain their senses and save the lives of others; and there will be those that are overcome by emotional shock or by a heart attack and thereby add to the burdens of others. Instances where trained firemen have "panicked" in smoke-filled rooms and corridors have been reported. Fire departments often operate on a "buddy" system to prevent such occurrences or to assist each other in the event one is injured.

The visible portion of smoke, which consists mainly of carbon particles and other inert materials, until quite recently has not been considered hazardous from the point of view of internal injury. Those interested in air pollution, smoke abatement, and in the occupational hazards of firemen are finding that

such may not be the case. Rather, such smoke particles may have severe reactions upon the human body. Such expressions have been voiced by Wittich.⁽¹⁸⁰⁾ He pointed out that persons may suffer allergic respiratory effects from air pollution. Others who have expressed their concern over these inert solid particles are: Antweiler, et al.⁽⁷⁾, who studied the effects of quartz, coal dust, and other organic matter on animals; Baetjer⁽⁹⁾, who has studied the effect of chronic exposure to air pollutants on acute respiratory disease; De Saga⁽⁵⁰⁾, who investigated the action of dust in aviation medicine; and Vorwald⁽¹⁷⁰⁾, who also carried out investigations on inert dust in air pollution.

These inert particles may not always be visible. Medical researchers from Tulane University reported on October 14, 1962 that tiny particles wafted from smoldering trash-dump fires may be linked to the mysterious asthma outbreaks that annually send thousands of wheezing victims to hospitals. Charity Hospital (New Orleans) says these attacks have brought more than 64,000 victims to its emergency center in the past five years.^(171, 197) Nine asthma sufferers died in one week early in October when more than 300 patients sought treatment during that epidemic. The study indicated that such outbreaks happened in New Orleans most often when unburned material containing small bits of silica filled the air in an unusual combination of wind and weather.

While such instances involve exposures of several hours or days rather than the short-term exposure associated with building fires, they do indicate that these inert solid smoke particles should not be ignored. They could be particularly hazardous if they were to precipitate an asthmatic attack in a person who might already be in panic trying to escape from a fire.

Saland, et al.⁽¹⁴⁷⁾, in discussing the occupational hazards and injuries of New York City firemen conclude that ordinary smoke, exclusive of any specific gas, acts as an irritant to the entire respiratory tract lining causing inflammation. In mild cases there is irritation, redness of the pharynx - this latter is frequently complained of as a sore throat. In more severe exposure there occurs hypoxia of the brain causing headache and vomiting. In severe cases there is irritation and inflammation and exudation of fluid such that one may be dealing with pharyngitis, laryngitis, tracheitis, bronchitis and pneumonitis.

While there is ample evidence of smoke deposits in the lungs, little information is available regarding the deposition of smoke particles in the stomach. This possibility has been suggested. However, physicians acquainted with the problem are inclined to disagree as to the importance of the intake of toxic products through the stomach. Zapp⁽¹⁸²⁾ in his studies found that certain pyrolysis products from foamed plastics caused disturbance of the gastrointestinal tract in his test animals. The exact cause of this disturbance was not determined.

More recently, Dr. Murry H. Levin raised the question of "smoke eating" in an article⁽¹⁰⁴⁾, in which he pointed out that for years firemen, who had been fighting a particularly smoky fire, would drink a glass or two of milk in order to counteract the effect of poisons in their stomachs. Dr. Levin explains further that the products of combustion include complex acids. The lungs shut off any noxious substance, and the body automatically begins to swallow in order to avoid the poisons. When these poisonous products reach the stomach, they dissolve in the lining and are absorbed into the system. In order to counteract these materials, he suggests that they be neutralized by chewing and swallowing tablets containing calcium carbonate, and he believes that the giving of oxygen for the usual case of smoke poison is unjustified. However, when enough carbon monoxide is absorbed to produce unconsciousness, he agrees that oxygen may be necessary

Saland states that such claims as Dr. Levin's are wholly inaccurate, unproven and dangerous for anyone to accept.⁽¹³⁴⁾ He further states that seldom does a fireman swallow smoke consciously and certainly not unconsciously; if he is exposed to smoke without a mask he inhales smoke. He agrees that when an individual has had a mild smoke exposure and feels nauseated, sometimes he may be relieved by the intake of a calcium product, or by milk; but an individual who has severe vomiting should be treated for smoke inhalation.

Dr. Phillips suggests that the truth lies between the two although she considers the respiratory hazard far more serious and the need for oxygen urgent. She adds the further possibility that not only may inhaled gases damage both lung and stomach, but gastric juices, regurgitated by the distressed stomach, may be choked into the airway. This would add further to the distress caused by the injury already present.⁽¹⁹⁹⁾

In summary, the preponderance of informed opinion appears to be that the initial hazard of smoke is related to visibility and, to a lesser extent, to panic. Late effects of severe exposure are internal trauma and possibly toxemia.

1. Burns

Available evidence suggests that heat itself is not the major factor in the respiratory tract damage seen clinically. Autopsies on burned victims generally show irritation and ulceration of the respiratory lining cells (epithelium) extending into the smaller (secondary and tertiary) branch; whereas, experimentally, dry heat extends only to the upper portion of the airway.

The application of mild heat to animal tissues brings about a reversible dilation of the blood capillaries. For a time the tissues appear reddened, as in a sunburn, and then recovery ensues.

More intense heat or similar heat over a longer period damages the capillary walls. Fluid, containing dissolved salts and protein, leaks through the injured walls. This so-called "serous fluid" or "edema fluid" distends the tissue spaces, causing the tissue to swell (edema) and, if near the skin surface, it produces blisters.

If the heat is still more intense or the exposure even longer, irreversible coagulation of certain protein constituents occurs. The burned skin becomes charred. The superficial capillaries cease to leak because the blood within them is coagulated. Leakage continues in the deeper capillaries, however, further distending the tissues.

In the respiratory tract, exposed to intense heat, the lining or epithelial cells, already heat damaged and now further deprived of their blood supply, are displaced by the edema fluid which pushes up beneath them. They then come to lie as free debris in the airway leaving a raw, bleeding and ulcerated surface behind them.

Dr. Aub, et al. (190), in his report on the Cocoanut Grove burn victims stated "Many burned patients have pulmonary lesions due to thermal or chemical burns of the lungs." This was well emphasized in the Cocoanut Grove cases treated at the Massachusetts General Hospital. All seven of the deaths in the hospital were due to pulmonary complications. In fact, only three of the 39 patients who were hospitalized for an extended period were wholly free from respiratory symptoms, and they had covered their mouths with wet cloths. There was little correlation between the severity of surface burns and the extent of pulmonary damage.

The first clue to the high incidence of pulmonary burns was afforded by the number who died within ten minutes after walking into the hospital. The surviving patients on arrival showed varying degrees of restlessness or excitement but soon became quiet following medication. About three hours after the fire, dyspnea (difficulty in breathing) appeared, associated with cyanosis, restlessness, and increased rales (noises in the chest). Autopsies showed a rapid accumulation of fluid, ulceration of the lining of the respiratory tract, plugging of the smaller bronchi, and collapse of air cells below the plugs. The more critical periods were the first 48 hours and from the 5th to the 15th days after the fire.

Swelling of the walls of the smaller bronchi narrows the air passages dangerously, and the escaping edema fluid and debris further obstruct

the airway. In some cases of respiratory tract damage autopsied at the Massachusetts General Hospital, all of the smaller bronchi examined were occluded. This prevents the exchange of gases - uptake of oxygen and giving up of carbon dioxide - which is the normal lung function.

In experimental hot air burns it is the trachea that is injured first, most of the heat being absorbed and cooled by the tracheal tissue before reaching the lower respiratory system. Moritz, et al.(118), in their studies of the inhalation of hot air, state, "Only when the temperature of the air was high enough to produce instantaneous burning of the skin and mucosa, was there sufficient residual heat in the air to cause pulmonary injury." The burning resulting from moist air was much more severe because of the residual heat (heat units) carried in the moisture and absorbed by the respiratory system. They used pigs as their test animals, forcing them to inhale hot air. Temperatures ranging between 350° to 500°C (662° to 932° F) were required to bring about sudden injury. At 350°C (662° F) the animals developed only mild reactions, and 500°C (932° F) caused acute tracheitis 8 to 12 cm below the larynx. The inhalation of very hot, dry air produces severe burns of the upper respiratory tract and causes laryngeal edema because all of the available heat is lost on the upper part of the respiratory tract. The inhalation of steam produces thermal injury to the entire respiratory tract, including the terminal air sacs, because steam has more heat to give up to its surroundings than does dry air.

Zapp's(181) investigations with goats were carried out in closed bunker-type structures and also in the open. His results indicate that, under fire exposure, if ventilation is good, heat is the dominant lethal factor, and rapid death results from a general or local elevation of the body temperature. If ventilation is poor, inhalation of a toxic atmosphere is the dominant lethal factor, and death is the result of anoxia which stems from a primary oxygen deficiency aggravated by the presence of carbon monoxide.

2. Human Tolerance to Heat

The literature dealing with the subject of heat tolerance of man is rather extensive and somewhat confused and misleading. While heat tolerance has been investigated extensively by Blockley(17, 18) and by Buttner(30, 31), whose investigations are considered reliable, even their reports are not always clear, especially in regard to protective measures that were taken when exposures to extreme heat were made.

The nonscientific literature is really misleading. A popular weekly journal describes the heat tolerance endured in a Finnish sauna bath as follows: "The sauna was brought to the U.S. by Finnish immigrants and is still widely used in its traditional, homemade form, especially in the Minnesota and Dakota farm country, where Finnish-Americans keep the temperature of

their baths at 250°F or more. However, the newer sauna bathers, a less hardy breed, claim that only 200° is necessary and may actually set the temperature at a mere 170°." They, indeed, would have to be a hardy breed to withstand 170°, even for a minute without the protection of clothing.

An investigation by the authors disclosed actual air temperatures of a sauna bath to be on the order of 115°F at chair height with temperature controls set at 220°F.

Blockley and Taylor⁽¹⁸⁾, in their report on human tolerance limits, state that tolerance for extreme temperature is a practical problem of industrial physiology and hygiene. Under special, though usually emergency, conditions workmen may be exposed to severe dry or humid heat. A number of verbal reports and communications have been received from individuals in which kiln technicians report many exposures for two or three minutes to 250°F and, on several occasions, to 500°F. A plastics engineer regularly spends 10 minutes out of each 30 in an oven at 200°F. A mining engineer tells of rescue parties exploring "pockets" in a burning mine where temperatures ranging up to 240°F were encountered. A marine engineer refers to cleaning boilers at 200°F temperatures. How much protective clothing was worn by those who took part in the described incidents is not indicated.

Moritz, et al., in their studies of thermal injury, emphasize the time and temperature relationship. They found that 195°F could be tolerated for 45 minutes; at 212°F burning of the skin occurred in 12 minutes; and at 356°F, 30 seconds was the longest exposure tolerated without irreversible injury. Buttner, in his conflagration heat studies⁽²⁹⁾, sets the pain threshold at 122°F. This is considerably lower than other reported tolerated temperatures. The experience and studies made by these investigators indicate that 156°-160°F for a few minutes is the upper tolerance limit without causing irreversible injury.

Claudy, as a result of his work with the District of Columbia Fire Department, suggests 120°-130°F as the limit beyond which trained firemen should not be exposed without protective breathing equipment. Even self-contained masks and full clothing could not protect the men for more than 10 minutes in dry air at 180°-190°F (160°-165°F for 5 minutes in steamy atmospheres).⁽³⁸⁾

Claudy's data were admittedly affected by stratification of air in the test room with dry air. His data, however, lend credence to the 150°F taken by some experimenters to be the safe upper limit for ambient temperature. Even so, if the varying ages and physical conditions of people caught in fires are considered, it would appear that 130°F would be the safer limit.

B. Oxygen (O₂) Deficiency - Anoxia

The normal oxygen content of air at sea level is 21 percent by volume. As indicated previously, in the absence of a fresh air supply and in the presence of combustion, the oxygen supply will be depleted rapidly. The NFPA Report on Fire Gases⁽¹²⁸⁾ cites the effect of a diminishing supply of oxygen as:

21%	-	normal
12-15%	-	disturbance of muscular coordination
10-14%	-	faulty judgment and rapid fatigue
6-10%	-	collapse with possibility of death
6%	-	death in 6-8 minutes

Thus, the 10 percent oxygen content considered by various investigators as the tolerable lower limit appears valid. Also, it has been established⁽¹⁹³⁾ that with most combustibles an atmosphere with less than 15 percent oxygen will not support combustion. Therefore, it may be possible that man can survive where fire will not. Furthermore, as the oxygen supply diminishes in a fire situation, the production of carbon dioxide - a gas that stimulates respiration - and of toxic carbon monoxide increases rapidly. As the physiological effect of the decreasing oxygen supply increases, so also will the deleterious effect of the increasing amounts of other gases. The additive effect of the two situations has not been defined and possibly cannot be defined. Such considerations, however, do emphasize the possibility of being too definitive in approaching the problem.

To further complicate the matter, the presence of heat, smoke, noise and emotional stress cannot be neglected if the actual physiological response of individuals is to be analyzed. The age, physical condition, and degree of exertion of the exposed persons also must be considered.

In summary, and in spite of some evidence to the contrary⁽⁹⁹⁾, oxygen deficiency by itself does not appear to be a serious factor in fires within buildings. However, in connection with other gases present, oxygen deficiency may produce serious and possibly irreversible effects.

C. Combustion Gases

The Coconut Grove holocaust, more than any other human disaster, has publicized the importance of pulmonary injuries occurring during fires. Benzaquin⁽¹¹⁾, in his story of this tragic fire, describes it aptly when he

states, "Very early in the emergency the frightful effects of the gases the victims had inhaled in the Grove began to appear." Patients who seemed hardly burned at all would begin to cough and gasp. Some of them had to have tubes inserted down their throats to keep them from choking. The lungs of others filled up so fast that even tracheotomy could not save them. The inhaled poisons caused the lungs to fill with fluids - a condition called pulmonary edema. Just as the burned areas exuded serum on the outside, so did the inner surfaces of the lungs.

Combustion gases may be injurious in two ways, first by causing local irritation and second by poisoning the patient systemically after they are absorbed.

Experience has shown the importance of combustion gases in fires involving large quantities of chlorinated, sulphated, and fluorinated compounds, and in cellulosic materials that may produce hydrogen cyanide, oxides of nitrogen, and other gases. The use of such materials in building construction, particularly for finish and decorative uses, has led to a direct interest in combustion gases.

Consideration has been given to the conditions under which these gases may develop. It is intended here to describe the more important components of fire gases and their possible effect on people attempting to escape from a burning building.

1. Carbon Monoxide (CO)

This gas, insidious because it lacks color and odor, is a product of the combustion of carbonaceous materials in an oxygen-lean atmosphere. Almost any combustible material encountered in building construction will produce copious quantities of carbon monoxide with incomplete combustion.

The importance of carbon monoxide is indicated by the vast number of investigations that have been made. A total of nineteen papers dealing with various phases of carbon monoxide poisoning were reviewed. In addition, its importance was emphasized in twenty papers dealing with combustion gases. Two complete books of over 100 pages each are devoted to the toxicology of carbon monoxide. (53, 56)

Gonzales et al., in their book on legal medicine and toxicology, state that carbon monoxide is the most common gaseous poison. It is always present when incomplete combustion occurs. According to Claudy^(36, 37), Irwin⁽⁹⁵⁾, and Williams⁽¹⁷⁷⁾, it is considered to be one of the foremost occupational hazards of firemen.

In low concentrations, carbon monoxide is not toxic unless inhaled over a long period of time. The threshold limit for carbon monoxide is 100 ppm, based upon prolonged exposures averaging eight hours per day. It is dangerous in a 30-60 minute exposure at a concentration of 1500 parts per million and two or three minutes at a concentration of 12,800 parts per million are considered fatal, according to widely accepted limits.

Carbon monoxide is poisonous because the hemoglobin in the blood combines with it in preference to oxygen. Normally, hemoglobin, travelling about the body in the red blood cells, picks up oxygen in the lung where oxygen tension is high and loses it in the tissues where oxygen tension is low. If carbon monoxide is present, carbon monoxyhemoglobin is formed, and the victim may die for lack of sufficient free hemoglobin to carry oxygen to the brain, heart and other vital organs. There is a suspicion that carbon monoxide may have a direct, deleterious effect on the heart. No conclusive evidence of this has been found in the literature.

Several factors govern the toxicity of carbon monoxide. The most important factors are (1) the concentration of the gas in the inspired air, (2) the duration of the exposure, (3) the respiratory time/volume, (4) the cardiac output, (5) the oxygen demand of the tissues and (6) the hemoglobin concentration of the blood. Therefore, anemic persons are more susceptible to carbon monoxide poisoning than the individual with normal amounts of hemoglobin. An increased metabolic rate enhances the severity of symptoms in carbon monoxide poisoning. This accounts for the fact that children succumb earlier than adults when exposed to a given concentration of the gas. (65) The same principle holds true in the use of small animals with high metabolic rates for the detection of toxic gases, i. e., the use of canaries in mines for the detection of "mine damp". The test animal dies before toxic symptoms are noted in man. The heart rate could probably be an indication as to the susceptibility of animals to carbon monoxide. These range from a rate of 100-130 pulses per minute with dogs, 88-128 in children 6-8 years, 60-90 in man, to a rate of 600 pulses per minute with mice, and up to 1000 with canaries.

Often carbon monoxide is used as a catch-all when no other proof or evidence of death is available. It is a poisonous gas - a killer. There has been a fire - smoke and fire gases. What better explanation as to the cause of death than carbon monoxide? Everyone accepts it and no one can readily dispute the conclusion. What need for further investigation?

How much carbon monoxide can the human or other animal withstand or survive? Again there is much variation as to tolerance limits in the literature. The blood has an affinity for carbon monoxide which combines with the hemoglobin to form carboxyhemoglobin.

Indicative of the lethal qualities of carbon monoxide is the danger level shown below as a function of the time of exposure. (38)

<u>Time (minutes)</u>	<u>% by Volume in Air</u>	<u>Parts per Million</u>
1-3	1.28	12,800
10-15	0.64	6,400
30-60	0.32	3,200
120	0.16	1,600

The numerical relationship of the concentrations listed almost appears to be by design rather than by laboratory test and analysis.

Haggard and Henderson⁽⁷²⁾ formulated a simple rule for the calculation of the toxic potentialities of a given amount of carbon monoxide in air. This rule states that when the product of the hours of exposure times the parts of carbon monoxide per 10,000 of air is a number under 6, there is no perceptible clinical effect. When it reaches 9, symptoms begin and at 15 there is danger to life. For example, if air contains 0.1 percent (10 parts per 10,000) of carbon monoxide, a stay in such an environment for 90 minutes would be dangerous ($10 \times 1.5 = 15$).

Many claims have been made that some analytical methods commonly used for the determination of carbon monoxide in air or blood are sometimes crude and inaccurate. Many professional people consulted expressed doubts about the procedures used.

2. Carbon Dioxide (CO₂)

Carbon dioxide is ordinarily not considered to be a toxic gas. It is inert, colorless and odorless, and toxic only in relatively heavy concentrations. It is the most important stimulus to respiration in the normal individual. Inhalation of carbon dioxide rapidly leads to abnormal breathing. As little as two percent of carbon dioxide in the inspired air effectively stimulates respiration and three percent doubles the lung ventilation. In contrast to the cherry red coloring typical of carbon monoxide poisoning, the carbon dioxide victim will show a gray or blue color - an effect called cyanosis. Inhalation of 7 to 10 percent carbon dioxide may be fatal in a short period.

In the patient with respiratory tract damage caused by inhalation of other injurious products of combustion, carbon dioxide may also be a problem. If the airway is obstructed, not only is oxygen uptake reduced but also elimination of carbon dioxide.

3. Hydrocyanic Acid (Prussic Acid) (HCN)

Hydrocyanic acid is one of the most rapidly acting poisons. Inhalation of its vapors in as small a concentration as 0.01 percent (100 ppm) can be fatal in a 30-60 minute exposure. It has a sweet odor resembling bitter almonds and, fortunately, is slightly lighter than air so that air currents may sweep it away from the fire area. Easily absorbed through the skin, this gas stimulates respiration in low concentrations.

The cyanides have no therapeutic value and no tolerance limits can be set. HCN is a combustion product of wool, silk, some plastics, and other chlorinated compounds.

4. Ammonia (NH₃)

Ammonia gas is a colorless gas with a soapy taste and a pungent odor which aids in its detection. Ordinarily, it is not considered a hazard except under special circumstances such as in a fire involving refrigerants, wool, silk or other nitrogen-containing compounds.

5. Oxides of Nitrogen

Nitrogen tetroxide, nitrogen dioxide, and nitric oxide are fumes or gases resulting from nitric acid, and termed oxides of nitrogen. These fumes or gases are all very toxic when inhaled. They may be a product of combustion in fires involving plants that utilize nitric acid (HNO₃) in the manufacturing process. They also occur in the pyrolysis of sawdust, nitrocellulose, pyroxilin, certain paints, and lacquers. An exposure to 0.01 percent or 100 ppm for 30 minutes can be fatal.

6. Hydrogen Sulphide (H₂S)

Hydrogen sulphide is a colorless, flammable gas easily recognized by its characteristic "rotten egg" odor. It is highly toxic, a concentration of 0.04-0.07 percent (400-700 ppm) being sufficient to be dangerous in a 30-60 minute exposure. Higher concentrations (0.1%) are rapidly fatal.

The gas may be encountered during the thermal decomposition of sulphur-containing compounds. Leather, wool, hair, silk, rubber, and other organic materials may produce hydrogen sulphide when burning in an oxygen-lean atmosphere.

This gas is deceptive in that, in spite of a strong odor in low concentrations, strong concentrations paralyze the sense of smell to the extent that it will not be detected.

7. Chlorine (Cl)

Chlorine is a greenish yellow, nonflammable gas easily recognized by its pungent odor. It may be expected where chlorinated materials such as polyvinyl chloride are burned in quantity. Inhalation will affect moist tissues and respiratory organs. Mild exposures respond to treatment, but heavy dosages may have serious effect as demonstrated by its use as a poison gas in World War I. Concentrations of 0.0035% to 0.0060% (35-60 ppm) are dangerous in 30-60 minute exposures.

8. Other Gases

Many other gases may be encountered in building fires in varying amounts. Sulphur dioxide, hydrogen chloride, phosgene, and others may be present in dangerous amounts under special circumstances, i. e., burning conditions and volume of material involved. It is probable that individually they do not comprise a serious hazard except under special circumstances. What synergisms may exist is not known.

There exist a number of gases that can best be described as irritants or lachrymators. Acrolein, a pyrolysis product of some paints (and some of the aldehydes formed as wood burns) is typical of this group of gases that cause an excessive flow of tears and a burning sensation in both eyes and respiratory passages. A mild dosage of some of the more toxic gases mentioned may produce similar effects. Under severe conditions these reactions can effectively interfere with reasoned judgment and normal vision, increase respiratory resistance, and may induce panic.

D. Shock

1. Nature of Shock

Shock can be described as a state of collapse caused by acute peripheral circulatory failure which may occur in such conditions as severe trauma, major surgery, massive hemorrhage, dehydration, overwhelming infections and drug toxicity. The term shock is also used loosely in describing emotional shock, insulin shock, therapeutic electric shock, allergic shock and the "stroke" or shock associated with the elderly and caused by obstruction or hemorrhage. Shock pertinent to fire is discussed in this section.

Many types of injury or disease may result in shock or shock-like states, mild or severe, as a result of peripheral circulatory failure. Many conditions such as syncope (fainting), hemorrhage and wound shock, thermal burns, dehydration shock, toxic or septic vasomotor collapse, may occur each having a special pattern of disordered physiology.

It appears that the term shock has become a catch-all to describe one or more disorders or reactions of an individual brought about by a sudden external action, trauma or environment.

Shock is not a single condition, but rather a combination of several sudden changes that have occurred within an organism or individual. Shock produced in animals in the laboratory usually involves a clearly identified set of initiating circumstances which range from hemorrhage, bowel ischemia (a local deficiency of blood chiefly due to the contraction of a blood vessel), muscle trauma or overt infection. Once shock is established, numerous contributory factors become involved with time and progressively undermine the capacity to respond to any restorative measures. It is this aspect of the problem which has received much attention and continues to be controversial. One of the specific points in question is whether there are any specific metabolic disturbances that determine irreversibility and which will lead inexorably to death from shock despite any treatments.

There is no doubt that a series of biochemical changes follows shock, but it is not known if any of these changes cause "irreversibility." No biochemical change has yet been described which is accepted by all investigators as the cause of irreversibility.

There is a general pattern of metabolic changes which seems to be characteristic of the shock syndrome but not necessarily specific to it. This involves proteins, carbohydrates, fats, water, electrolytes, vitamins and endocrines.

The blood sugar concentration is generally elevated during shock and persists until the late stages, when the blood sugar falls, sometimes to subnormal levels, especially when the environmental temperature is high. There is generally some increase in blood lactate and pyruvate, particularly as shock progresses. The hypoglycemia (low blood sugars) that develops later in shock is generally considered a result of a depletion of liver and muscle glycogen. In the laboratory, untreated animals dying of prolonged shock almost invariably do so because of the hypoglycemia.

2. Types of Shock

a. Syncope or Fainting

This is perhaps the simplest form of shock and is a temporary loss of consciousness due to cerebral anoxia. Predisposing factors include fatigue, prolonged standing, i. e., pooling of blood in the lower extremities, getting up after prolonged bed rest, nausea, pain, emotional disturbance,

anemia, dehydration, infection, heart disease and hypertension. Fainting may occur suddenly, and, except for cases where the person is subjected to a physical blow or abrupt trauma, there are premonitory symptoms.

b. Thermal Burn Shock

Shock in thermal burns involves a mechanism clearly described by Phillips.⁽¹⁹⁹⁾

"In the terminology of the surgeon caring for burn patients, however, shock is a clear-cut and important entity. In patients with burns of more than 25 percent of the body surface (15% in children) the loss of fluid from the circulation into the burned area results in a reduction in the circulating plasma volume. When plasma is lost into the burn, small blood vessels in portions of the body unimportant to survival constrict to permit as much blood as possible to circulate through the heart, brain, lungs, liver and kidneys. If plasma loss continues so that the amount of fluid circulating is insufficient for function of the vital centers, shock becomes manifest. The kidneys cease to function; blood supply to the intestinal tract diminishes, and nausea and vomiting may occur. When circulation to the brain is inadequate, consciousness is lost. Finally, when the circulating volume is drastically reduced the heart ceases to beat."

c. Toxic Shock

Whether there is a "toxic" shock, in the sense of shock due to inhalation of some toxic material which causes a generalized blood vessel dilatation with resultant inadequacy of the circulation, is not clear. Its existence is entirely possible, however, provided appropriate materials were inhaled.

3. Discussion

Shock, as an entity, encompasses a rather complex array of reactions, no one of which can be said to represent the key factor leading to circulatory collapse. Keeping this fact in mind, it can also be concluded that there are many factors which may set off one or more of these complex reactions. Certainly, a person being trapped in an unusual circumstance, surrounded by heat, smoke, and toxic gases, may very well react by going into shock, either from fear or by inhaling heated toxic gases. How rapidly a

person can go into shock or faint is mere speculation, but it could be a matter of only seconds. Thus, shock may very well be one of the important causes of death in accidental fires.

Cope and Rhineland⁽⁴⁵⁾ conclude that the treatment of shock in the casualties demands priority in a disaster, and immediate shock therapy may prevent early death among burn casualties. The prevention of shock is more effective than its treatment. This is particularly true of burn casualties where the shock, except for the primary phase due to pain and exposure, has a longer latent period than shock from hemorrhage. Blood loss can occur more rapidly than plasma loss due to leakage which begins at once.

E. Panic

Panic, as used ordinarily, refers to extreme and groundless fear caused by a sudden overpowering fright when one is suddenly confronted by a hazardous circumstance. Panic follows fright; the reactions which have been discussed in the nature of shock are probably closely related to the actions or reactions which take place under this extreme stress. The results are, of course, unpredictable. It is probably difficult to separate shock and panic completely.

F. Summary

Combustion gases present a multiple hazard to life safety in building fires. As irritants they may cause extreme discomfort and panic. As poisons they may cause immediate reactions or may initiate reactions that become apparent (and in some instances fatal) at a later time. Some gases accelerate respiration and thereby increase the intake of poisonous gases. In combination, some gases may be more hazardous than either component.

Finally it should be noted and emphasized the reaction of any individual to various concentrations of poisonous gases will depend on age, physical condition and many other factors related to the person and to the circumstances of the exposure. Such considerations are particularly important with a hospital population where some patients already are in an impaired physiologic state.

V. MEASURING COMBUSTION PRODUCTS

The discussion thus far provides a clear indication that efforts to define the hazard of combustion products as a means toward the development of such controls as may be needed has been characterized by:

- (1) sporadic and unrelated, but nonetheless valuable, experimental efforts;
- (2) a lack of definitive data on which an objective appraisal of the hazards involved can be based; and
- (3) failure to develop applicable procedures for evaluation of hazards - which logically should await definition of the hazards.

Thus it seems apparent that further research is needed with respect to smoke, heat and combustion gases. A review of the means available for determining essential information is in order, therefore, and may indicate the most favorable lines of investigation to pursue.

A. Smoke Measurement

The techniques used in smoke measurement have been well established and vary according to the purpose to be served. In municipal smoke control programs, inspectors visually match the color of smoke from industrial chimneys with the shades on the Ringelmann chart.⁽¹⁹⁶⁾ This is the simplest form of measurement and serves its purpose. It is not well adapted, however, to the more exacting requirements of the measurement of smoke density in closed areas where visibility is the primary problem.

In air pollution programs, special consideration has been given to the development of satisfactory methods for measuring diesel exhaust smokes. In a paper presented before the 1962 Automotive Engineering Congress, Savage⁽¹⁴⁸⁾ listed five types of instruments for the precise measurement of smoke:

- (1) filter paper disc;
- (2) the moving filter paper strip;
- (3) light absorption meter;
- (4) photographic methods; and
- (5) smoke impingement.

While the advantages and disadvantages of each are discussed, Savage concludes that smoke measurement is not difficult and can be evaluated by any smokemeter. Interestingly enough, he concludes that:

"Because there is no acceptable means of relating the instruments' readings to an agreed subjective assessment of the 'objectionable' density, the framing of effective legislation to control the emission of diesel engine exhaust smoke is difficult."

This statement is equally applicable to the hazard of smoke in building fires.

Another approach to evaluating the hazard of smoke from the standpoint of visibility was described by Rasbash.⁽¹⁴²⁾ In evaluating the efficiency of hand lamps in smoke, the Fire Research Organization in England developed a smoke chamber 6' X 26' and 9' high. A black letter "C" (5-1/2" OD - 3-1/3" ID) was placed on a white screen and the whole fastened to a trolley. This "target" was drawn away from the fixed position of the lamp being evaluated and the observer. A relationship between visibility and beam intensity could then be plotted for each lamp.

A noteworthy observation was that with a given lamp and a given smoke, visibility with the same observer varied by as much as 15 percent from day to day. To eliminate this error it was necessary to use one of the lamps as a standard and by so doing the error was reduced to the order of 2 percent.

A modification of this method has been used by the Los Angeles Fire Department in their Operation School Burning. Here the results were correlated with a light absorption system using a light beam directed across the corridor into a mirror and back to a photoelectric cell. The output of the photoelectric cell was proportional to the density of smoke in the corridor at a 5-foot level.

The latter type measurement is used in the 25-foot tunnel furnace⁽⁶⁾ which is used to officially rate the surface burning characteristics of finish materials. It is believed that stratification or turbulence of air passing through the furnace during the test may affect the uniformity of results obtained. Although good reproducibility of results is obtained on the respective furnaces, the degree of correlation between furnaces is less than desired. Current work with existing facilities should improve this situation.

In the radiant panel flame-spread test used for development work, smoke is drawn out of the exhaust flow and passed through a filter. The pretest and posttest difference in filter weight provides a relative measure of the amount of smoke generated during the test.

Underwriters' Laboratories in Northbrook, Illinois are attempting to correlate smoke density ratings achieved in the 25-foot flame-spread tunnel test with visibility in a room into which combustion products are exhausted. Southwest Research Institute has attempted to relate visibility in the tunnel furnace with smoke emissions from the red oak flooring control specimens, using an exit sign at the exhaust end of the furnace and smoke bombs at the intake end. No conclusive results have yet been obtained in either case.

Efforts to establish a definitive hazard of smoke in building fires are directed toward establishing limits of visibility. No attempts have been made as yet to determine the relative hazard of dry versus oily smoke or light and dark smokes.

B. Temperature Measurements

The measurement of temperatures in actual or test fires presents no problem. The instrumentation is relatively simple in operation and in the selection available. While direct reading mercury and other type thermometers can be used, the use of multiple thermocouples connected to a multichannel recording potentiometer offers a simple and satisfactory approach.

The problem here lies more in the area of general application of specific data without recognizing that each fire has its own time-temperature history. Thus, for experimental purposes, it is necessary to select, on some substantial basis, a situation fairly representative of what may be expected in fires. As discussed in Section II B, this has been done as a basis for hourly fire-resistance ratings. However, more specific data are needed to establish the sequence of events in the first five minutes of a fire and the extent to which these events are influenced by the heat release and other characteristics of building materials.

C. Methods for Gas Analysis

The analysis of combustion gases is difficult because (1) of the complexity of the gaseous mixture, (2) the varying nature of the materials burning, and (3) the infinite variety of conditions existing in fires. There are, however, a variety of methods by which a qualitative and quantitative determination of the components of fire gases can be made. The more significant of these are discussed in this section.

1. Standard Methods for Gas Analysis

For the purpose of establishing the hazard of combustion gases, greater emphasis must be placed upon the type of fire or combustion used as

the basis of the experiment and the techniques of sampling employed. Abuse in either direction will unnecessarily limit the success of any analytical program.

Standard and long accepted methods of gas analysis are absorption and subsequent titration, gravimetric determinations, fractional distillation, thermal conductivity and colorimetric methods.

The most common technique involves oxidation or selective absorption of the various components in specific liquid reagents, as in the familiar Orsat method. The procedure is to systematically measure changes in gas volume made by successively removing certain components from the mixture. Known liquids are specific for the chemical absorption of some gases - cuprous chloride for carbon monoxide, potassium hydroxide for carbon dioxide, etc. A measured volume of the gas mixture is passed through absorption pipettes arranged in a series. The difference in volume due to absorption represents the amount of the particular component expressed as a percentage of the total volume. Both portable and bench type apparatus is available for this type of analysis.

While reasonably precise and reproducible when used by competent personnel, these methods do not pick up trace amounts of components (the presence of which may be unimportant), they involve the use of cooled gases (some components may be lost through condensation), they do not evaluate synergistic effects, and they do not lend themselves to a continuous flow type of analysis.

For carbon monoxide, carbon dioxide, oxygen, hydrogen sulphide and several other gases, there are hand-portable, compact units that can be used for spot sampling. Some are dial reading instruments and others give a colorimetric indication. A rubber bulb that fits the palm of the hand is used to pump air through the instrument.

For spot determinations of one or two gases in a room (or for the presence of a combustible or explosive mixture of gases), these indicators are accurate, reliable and satisfactory. They would be rather impractical, however, for analyses of multiple components.

Where permanent "on-stream" equipment is needed for continuous combustible gas analysis, more elaborate equipment is available with the indicators attached to recorders. They are available for use with any gas or vapor where the molecular weight and explosive range are known. They are most commonly used in processing plants for oxygen, carbon dioxide and carbon monoxide control. They are available for such gases as hydrogen sulphide and hydrogen cyanide.

For permanent process control this equipment is of particular value. Because of bulk and cost, however, it is not well suited to the analysis of combustion products in building fires as might be undertaken in research programs.

2. Spectroscopy

Newton's discovery in 1666 of the production of a spectrum by the action of a prism on sunlight paved the way for the development of this analytical method. While many specialized variations of spectroscopic methods exist, the general principle is the same for all.

The spectrum for a particular gas mixture is determined by changing the state of the gas to an incandescent vapor which then emits light with a characteristic wavelength for each component. Accurate measurement of the various elements and comparison with the spectra of known elements serve to identify the lines and the composition of the material. Both qualitative and quantitative measurements of minute amounts of component gases can be determined. This method is described as emission spectroscopy.

Absorption spectroscopy involves passing light from a source giving a continuous spectrum through the material in question and determination of the wavelengths absorbed and transmitted.

The various common gases have been characterized and catalogued⁽¹⁴⁰⁾ since each one has a particular absorption line. For example, carbon monoxide is absorbed at 4.6 microns while carbon dioxide is absorbed at 4.3 microns. It will be noted that these are relatively close on the spectrum. The more complicated the gas mixtures the more difficult it is to separate them, especially if the spectra are close together. Quantitative determinations can be made by calibrating each individual instrument before it is used in making an analysis.

3. Gas Chromatography

One of the newest and most versatile analytical techniques is gas-liquid chromatography, usually referred to as gas chromatography. The name comes from the original method of liquid-solid chromatography described by Michael Tswett, a Russian botanist, in 1906. He found that when a solution of chlorophyll was allowed to filter through a column of firmly packed, pulverized calcium carbonate, the different fractions of the chlorophyll mixture separated into distinctly colored bands. This he called a chromatogram.

In gas chromatography the compounds in a mixture migrate at differing rates when carried along by an inert gas through a tube that has been packed or treated in a special way. This is known as the fractionating column.

The fractionating column consists of a tube about 1/4 inch in diameter and of variable length, frequently from one to two meters long. The tube is packed with an inert material such as firebrick or diatomaceous earth that has been pulverized and coated with a nonvolatile liquid called a partitioner. Following the packing of the tube, it is usually bent into a series of U turns or wound into a helix so that it can be fitted easily into an insulated box, the temperature of which is thermostatically controlled. A sample of gas to be analyzed is injected into the tube through a special stopper with the aid of a syringe. A carrier gas (helium, argon or other inert gases) moving through the column will sweep the sample through the specially treated column. The various components of the sample migrate at different speeds. A detector measures the electrical conductivity of the gas leaving the column as well as that of the carrier gas entering the column. The difference, as determined by a Wheatstone bridge, is recorded on a chart. Before injecting the sample, the instrument is calibrated by analyzing samples of known composition. By comparing the recordings of the unknown with the known, values of the unknown are determined.

The state-of-the-art of chromatography is advancing rapidly, and improvements are being made in instrument design. Analysis of a continuous stream of heated gas is now within the capability of the equipment.

The gas chromatography instrument is described simply as an analytical tool which sharply separates components of a complex mixture. It can be used to characterize perfumes and flavors, and its sensitivity rivals that of the human nose. Separation takes place when a sample mixture is driven by an inert gas through a capillary tube containing a partitioner. The role of the partitioner is to dissolve (and adsorb) various components of the sample in differential fashion. After fractionation, the separate components pass through a detector whose output is recorded on a chart. A diagram showing the arrangement of a typical instrument is shown in Figure 2.

Chromatography offers the possibility of analyzing solids and liquids as well as gases by heating specimens to the point where they will emit gases that can be analyzed. (192)

Gas chromatography will not, of course, determine the difference between nonpoisonous and poisonous gases. The poisonous gases can only be detected with use of animals. However, gas chromatography may be used in combination with animals and thereby obtain a closer estimate of the lethal dosage of a single gas or combination of poisonous gases.

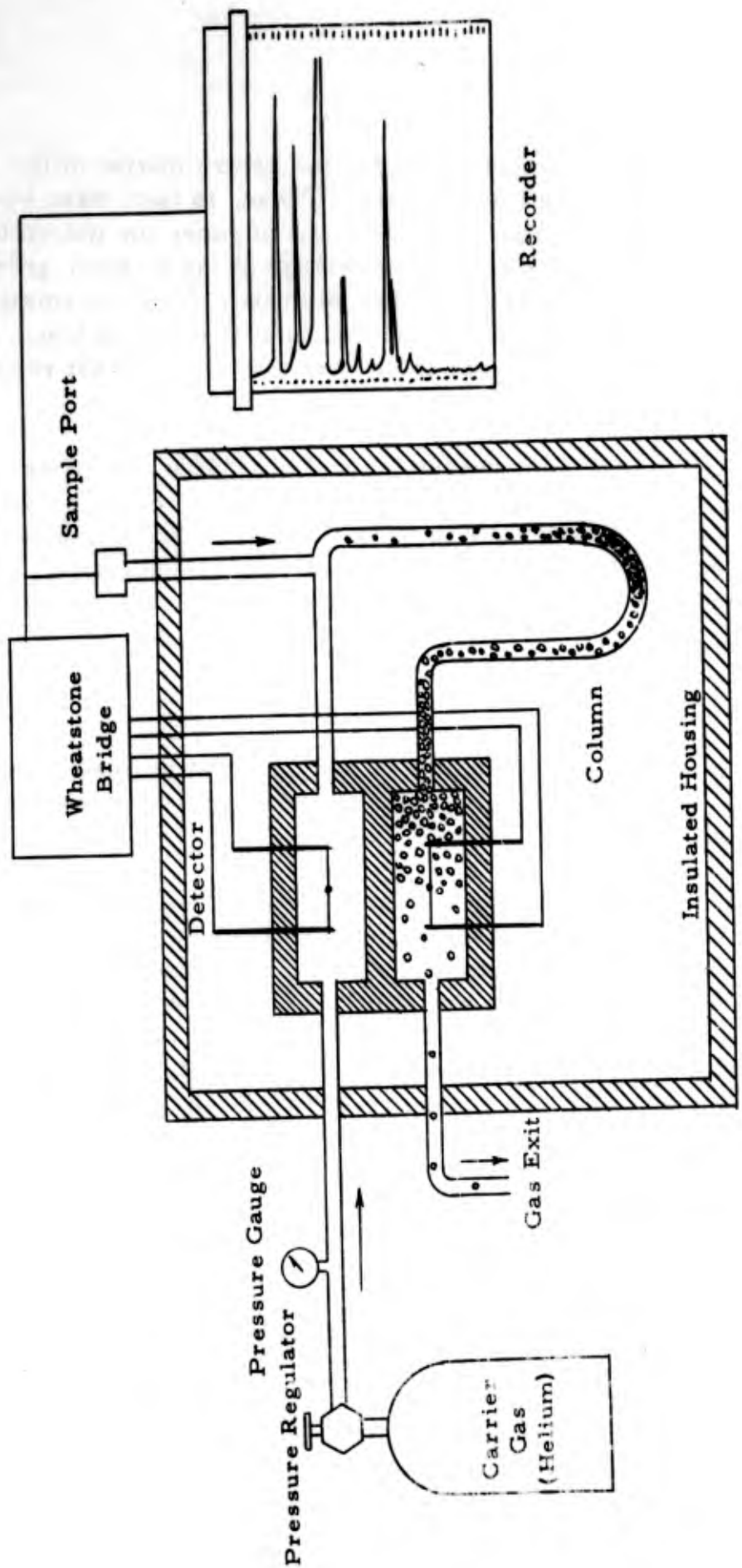


FIGURE 2. PLAN VIEW OF TYPICAL CHROMATOGRAPH

4. Animal Tests

The techniques for using animals for the determination of the physiological effect of gases are well established. These, in fact, have been the basis for determining the allowable concentrations of gases for industrial workers. The method requires considerable knowledge of the history, growth, physical conditions, and susceptibility of the animals used. The test animals must be carefully maintained to assure a healthy state at the time of test. A sufficient number of animals must be used to prevent distortion of test results by an unusual reaction in one animal.

Obviously this is a time-consuming and expensive procedure. Fortunately most of the work needed for quantitative definition of toxic gases has been done. What is needed is definitive work with synergisms, identification of the relative effect of heated versus cool gases, determination of reaction under calm and excited states, and the physiological effect of smoke particles

5. Discussion

Critical elements in the qualitative and quantitative analysis of combustion gases are the fire situation from which the samples are taken and the method of sampling.

Fire conditions vary widely and there is no widely accepted norm that will permit sufficient uniformity in experimental work to assure correlation of test results. The sampling of gases in actual fires would be generally helpful and could be done in cooperation with a municipal fire department. The limiting factor here is that usually fires are well advanced by the time the fire department arrives and completes the rescue work that must take precedence over all else. Thus, the nature of the gases present at the time of sampling probably would differ from those present in the earlier stages of the fire - the period most important to those in the building.

An alternative approach would be to conduct controlled room burnout tests similar to those mentioned but with emphasis on gas analysis and animal tests. Using the results of these tests, it should be possible to establish the feasibility of developing a small-scale test to accomplish the same result.

Building code and other approval authorities concerned with building materials currently accept gas analysis based on gas samples taken from the flame-spread tunnel furnace. Results on any given material are compared to the results obtained on a wood specimen subject to the identical

test. Assuming reliable procedures for gas sampling and gas analysis, the "given material" results indicate the kind and amount of the several gases present. From the burning of the wood specimen, other gases can be expected. In each case, dangerous quantities of the gases can be found. Therefore, it is sometimes impossible to state that the gases from the material in question are no more hazardous than the wood used as a basis for comparison.

In the case with smoke measurements, also, the nature of the fire from which samples are taken can lead to a variety of results. It is suggested that by varying air supply, fuel supply, moisture content of test specimens, and other factors, a wide variety of results may be obtained from one material. The smaller the test method, the greater effect minor variations in test conditions could make. Large differences in the results could be obtained. Hence, the need for developing a standard test that would be reasonably representative of conditions in the earlier stages of a building fire.

The use of chromatography in connection with the tunnel test and room burnout tests apparently offers the greatest potential in defining the hazard of combustion gases and the quality and quantity of the gases present. Animal tests could be used to establish the hazard involved.

VI. MINIMIZING THE HAZARD OF COMBUSTION PRODUCTS

The achievement of fire safety in hospitals and other buildings need not necessarily await a solution to the problems posed by combustion products. We already have the knowledge to attain a high degree of fire safety in buildings including hospitals. In addition, there are numerous methods that can be adopted to minimize the hazards of heat, smoke and combustion gases. The means of assuring fire safety in buildings have been developed largely as a result of the study of actual building fires, including the manner in which the fires start and spread and evaluation of the success of corrective measures.

The methods for achieving this objective can be classified as:

- (1) fire prevention;
- (2) fire detection and alarm;
- (3) fire containment;
- (4) fire control and extinguishment; and
- (5) provision for evacuation and rescue.

Each of these measures will be considered with reference to the original design of the structure and to building operation and maintenance.

A. Fire Prevention

The hazard of combustion products could be eliminated if the materials of which buildings are constructed, finished and equipped were not susceptible to thermal decomposition on exposure to elevated temperatures. Such an approach is hardly practicable, however.

In the first instance, economic factors make it necessary to select materials on the basis of satisfactory performance at minimum cost. Second, there may be functions to be performed for which completely inert materials do not exist. Third, a reasonable degree of comfort is a prime requisite in most buildings, particularly those occupied day and night, and satisfactory noncombustible substitutes for such objects as furniture, bedding, and mattresses have not yet been found. Finally, our esthetic sense calls for decorative treatment that frequently involves hazards that could be eliminated if walls, floors, ceilings and fenestration could be left completely bare.

On the other hand, there are many organic materials that perform satisfactorily as a building or decorative material and, properly used, present no undue fire hazard. The problem here is in defining the exact limits between that which is safe and that which is not safe.

Most building regulations require that buildings of a high human occupancy load, particularly those located in congested areas, shall be of fire-resistive construction and that only noncombustible materials can be used therein. Certain exceptions are made for window and door trim, temporary partitions, wainscoting, lighting fixtures, and certain other items.

Again, it should be noted that a degree of combustibility can be tolerated in many instances if the combustibility is recognized and compensatory measures, such as automatic sprinkler systems or fire stopping are utilized.

It should be noted also that official state, county and municipal building regulations, including both building codes and fire prevention codes, by their very nature only establish minimum standards for fire safety. The designer must be continually alert to utilize materials and design features that incorporate an additional degree of safety at little or no added expense. In hospitals, particularly, with the sick and infirm of all ages, frequently under emotional stress, maximum safety should be the goal.

In designing to prevent fire, consideration must be given to fire causes as determined by experience. In a recent report on hospital fires⁽¹²⁷⁾ by the National Fire Protection Association, some 300 fires were reviewed and, among other data, tables were presented showing the causes of fires and their place of origin. Prominent among the causes of hospital fires were fixed electrical services and wiring, power-consuming appliances, and heating system defects. Prominent among the locations in which fire started were power and heat service areas, store rooms, elevator and dumb waiter shafts, laundry and waste chutes, incinerator rooms, patient and operating rooms, and oxygen tents. Both categories obviously indicate areas and services in need of particular attention for fire safe design and construction.

While inert or noncombustible construction materials may not be practicable for the entire building, it might be feasible to use such materials in the more critical areas as exitways, refuge areas, vertical shafts and service areas. Equipment such as motors, refrigerators and other special equipment can be selected on the basis of approved, safe construction and they should be installed and operated under strict supervision. Good housekeeping, in hospitals as elsewhere, is a prime requisite for the prevention of fire. This can only be assured through frequent and competent inspection and training of key personnel in the principles of fire safety.

A more sophisticated approach to fire prevention or to preventing the development of hazardous situations lies in the design of buildings. Some exploratory work, as yet unpublished, has been done for instance in the pressurization of corridors or exit ways in the event of fire. The theory being, of course, that higher ambient pressure (of a very low order actually) would prevent the spread of smoke or toxic gases into the protected area.

Similarly, work has been done on the development of ventilating techniques to reduce the smoke hazard in fires. A theory is developing that positive results can be obtained by providing ventilation above rather than below the neutral axis of corridors (above rather than below mid-height of the corridor).

Interesting tests have been conducted involving the spread of heat, smoke and gases from the first floor to the top of a 20-story apartment house in France. This is resulting in a re-evaluation of mechanical ventilating systems, fire-escapes (smoke towers), corridor ventilation and other factors. Final conclusions are yet to be reported. (191)

B. Fire Detection and Alarm

Early detection and alarm are prerequisites to the initiation of defensive measures against fire. Visual detection of incipient fires frequently results in immediate extinguishment. On the other hand, the history of fire is replete with instances of delayed alarms - of heavy life and property losses when individuals attempted to control the fire before sounding an alarm or were unfamiliar with the procedures for doing so.

Manually operated alarm systems are useful but subject to the frailties of those in the vicinity. One person may assume that another has given the alarm or excitement and activity of the moment may cause confusion and dangerous delays. The primary value of manual alarms in occupancies such as hospitals is in their use as a supplement to automatic action.

Various fire detection and alarm systems are available that will operate automatically in the event of fire. Their success depends largely upon the care with which the installation is designed, and regular maintenance. Most of these are heat actuated systems.

As a result of the Los Angeles School Fire Tests⁽¹²⁹⁾, the concept of heat-actuated devices is undergoing careful scrutiny. If, as indicated by those tests, exit ways from buildings are made untenable by smoke and combustion gases before heat develops to the level necessary to activate protective devices, heat-actuated devices will be of limited value to say the least. Recent tests in a 20-story building in France further emphasize the rapidity with which smoke and

combustion gases spread throughout a structure. (191) The use of smoke or combustion gas detectors or "sniffers" should be considered in planning the installation.

Whenever possible, the alarm system in a hospital or institutional occupancy should be connected with the municipal fire-alarm headquarters. This is essential to prevent loss of time in fire department response - a critical factor in almost any fire.

C. Fire Containment

Containment is a basic precept of safe structural design whether the structure be a ship, aircraft, hospital, or other building. Exercise of this principle could do much in a practical sense to minimize fire losses. In essence, it is simply the design of a space so that if a fire should start, it would not spread to other spaces. The same principles can be applied to the spread of smoke and other combustion products.

There are many proven approaches to the containment principal which involve the use of fire-resistive construction, fire-stopping or the elimination of concealed spaces, the installation and use of fire doors and smoke barriers, limitations on the size of open areas, cut-offs on corridors and many other well-known measures. The use of wire glass in corridor windows provides a relatively inexpensive means of achieving a greater degree of fire safety in hospitals by preserving the integrity of protected areas. The use of solid doors or fire-doors to patient rooms with self-closing hardware increases the safety both of the patient and of those using corridors as exit ways.

Fire-resistive enclosure of vertical shafts (stairways, laundry chutes, dumb waiters, elevators, etc.) will retard the spread of fire from one floor to another. Openings in shafts should, of course, be protected by automatically closing doors. In a similar vein, floor openings around ducts or pipe chases should be tightly closed.

Horizontal spaces such as the plenum area above suspended ceilings should be fire-stopped to prevent spread of fire in hidden areas where detection is difficult. Air conditioning and heating ducts must be continuous for effective operation but can be provided with automatic cut-offs actuated by heat and smoke detectors. This is particularly important since ingestion of smoke, heat or gases into return air ducts may distribute a hazardous condition throughout the building.

Corridor separations can be provided so that the building can be divided into two or three areas or "compartments." This not only retards the spread of fire and its attendant hazards but also provides relatively safe areas for the

building occupants. In hospitals, where there may be difficulty in moving patients from floor to floor, compartmentation can be particularly useful.

One further obvious application of the principle of compartmentation is the isolation of rooms or spaces where combustibles are stored in quantity or where hazardous equipment or processes are in use. These include boiler rooms, storage valuts, linen closets, pharmacies, laboratories and similar areas. Reference to locations where fires start as shown by fire records provides a good indication of the need for compartmentation.

D. Fire Control and Extinguishment

A system that includes elements of detection, alarm and control and is automatic in operation would be ideal. Such a system does exist, in fact, in the form of automatic sprinkler installations. Sprinkler heads are designed to be released at specified temperatures so that the system is automatic. The system can include activation of alarms within the building and at the municipal fire station. By covering the area in which the fire starts, extinguishment is obtained. Furthermore, the cost of installing this type of system frequently can be met by savings in fire insurance premiums.

The National Fire Protection Association's report "Occupancy Fire Record - Hospitals," reviews the effect of sprinklers in 133 hospital fires between 1925 and 1959. The results were tabulated as follows:

	<u>Fires</u>	<u>%</u>
Extinguished fire	98	73.7
Held in check	31	23.3
Unsatisfactory*	<u>4</u>	<u>3.0</u>
	133	100.0

There are other approaches to securing fire control and extinguishment. These may include the installation of basement to roof standpipes or water mains completely separate from the domestic water supply and with fire hose connections on each floor. Most fires are very small at their inception and, if discovered early enough, can be extinguished with little effort. For such purposes there are first aid, hand fire extinguishers which, if properly maintained and used, can be effective in stopping fire in its initial stages. While such protection is important, a regularly scheduled maintenance service and training of personnel in the use of the extinguishers is required.

*In two cases the water had been shut off.

E. Evacuation and Rescue

Again, based on the knowledge that in spite of precautions fires may start, the design of buildings must incorporate ample provision for emergency egress. Aisles, corridors, and stairs forming part of the exit path should be "compartmentized" to the maximum extent possible to permit effective evacuation. But corridors and stairs take up expensive space which reflects directly in building costs so that, again, practical limitations are involved. However, on the basis of sound fire protection engineering supported by many years of experience, there have been developed nationally accepted standards for safe egress from buildings.⁽¹³¹⁾ These incorporate many safeguards against the development of excessive smoke and toxic gases in exit ways and passages.

The width of exit ways, both horizontal and vertical must be satisfactory for the occupancy involved. Each building "compartment" should have its own stair so that passage through an involved area would not be necessary. Building maintenance should provide strict rules against storage or any use of exit space that might obstruct egress in an emergency. Where a permanent staff is at hand as in institutional uses, a rigorous training program is essential to avoid unnecessary confusion and to prevent panic in emergency situations.

Finally, and a point frequently overlooked, is the need for access for firemen. This would normally be through interior stairs, corridors and elevators. With modern aerial equipment, however, access through exterior openings may provide a quicker way of reaching the heart of the fire and of effecting rescue. From this point of view, openable windows provide a means for escape and access as well as serving a ventilation function. Windowless exterior walls should have clearly identified access or "knock-out" panels.

It has not been possible in this brief treatment of the subject to do more than highlight the means of minimizing the hazards of combustion products in building fires. To do so would involve a lengthy discussion that would not be germane to the basic purpose of this study. Moreover, this area of interest is adequately covered by the several up-to-date standards developed by the National Fire Protection Association and the National Board of Fire Underwriters. Developed through committee action, many of these standards reflect characteristic compromises and therefore are somewhat conservative. However, they have been widely adopted, usually by reference, in local building regulations.

A further resource is to be found in the person of the local fire marshal, fire chief or building official who is always willing to discuss fire-safe construction and who invariably has a wealth of experience as well as the standards mentioned to guide him. Fire insurance rating bureaus, likewise, are in a position to offer sound advice. In both instances, maximum benefits can be achieved if fire safety is considered in the early stages of building design when minor changes often can provide significant improvements at much less expense than modifications made after the structure is complete.

VII. CONCLUSIONS

This review of the state-of-the-art of efforts to define the hazard of combustion products and to develop reasonable controls leads to the conclusions presented below:

General

- (1) Large fires are characterized by failure to apply known principles of fire protection engineering and by the existence of not one but several causative or contributory factors that lead to the losses involved.
- (2) Interest in developing methods for minimizing the hazards of smoke, heat and combustion gases should not overshadow the primary need for safe building design and the installation of appropriate fire detection, warning and control equipment.
- (3) The nature of smoke, heat and of combustion gases, their effect on building occupants, and the analytical techniques involved with each are quite different. Therefore, it is concluded that more progress can be made by considering each element separately and by discontinuing the common practice of considering all combustion products as "smoke."
- (4) Current efforts to regulate materials on the basis of smoke emission and the development of toxic gases may be questionable, but represent a sincere effort to control a recognized but undefined hazard. Every encouragement should be given to the continuance of objective experimental work, based upon sound principles of scientific investigation, to the end that the problem may be resolved.
- (5) It is obvious that most materials produce smoke, heat and toxic gases in varying degrees and under the variable conditions of building fires. The problem of control could best be attacked through definition of safe locations and amounts of the more hazardous materials rather than by outright prohibition.

Effect of Combustion Products

- (6) Ample evidence has been found to support the contention that the development of smoke, heat and combustion gases in building fires has a direct bearing on the safety of the building occupants.

- (7) It is concluded that the heat developed in building fires is usually of secondary importance to the development of smoke and combustion gases because of the more rapid spread of the latter elements. The possible effect of elevated temperatures on the potency of combustion gases has not been established.
- (8) While exceptions no doubt can be found, it is believed that generally humans can tolerate a greater oxygen deficiency than fire and therefore the development of smoke and combustion gases are of greater significance. The more important effect of an oxygen deficient atmosphere is in inducing incomplete combustion and thereby accelerating the production of dangerous gases.
- (9) The preponderant evidence is that the significant hazard of smoke is in obscuring vision. Secondary smoke hazards are inducing panic and the as yet poorly defined physiological effect of smoke particles that may be inhaled or swallowed.
- (10) Carbon monoxide poisoning is most commonly listed as the cause of death in building fires where severe external burns are not present. A lack of confidence in the analytical methods used in autopsies has been expressed frequently. Also where there are indications of carbon monoxide poisoning, determination of the possible presence of other toxic gases usually has not been made. Thus there is need for more positive support for the general belief that carbon monoxide is the primary hazard.
- (11) Interrelationships between the development of carbon monoxide, carbon dioxide, oxygen deficiency and other gases plus the possible existence of undetermined synergisms point to the difficulty, on the basis of present knowledge, of isolating any one gas as a primary hazard in a given situation.
- (12) Both panic and shock are important factors in any fire situation. Evidence has not been found that would substantiate a relationship between panic and shock and the use of specific building materials.

Need for Further Research

- (13) No factual evidence has been found in this study to justify the prohibition of any material on the basis of its pyrolysis products. Ample evidence does exist to support the need for a determination of the conditions under which the development of known quantities of smoke and toxic gases constitute a hazard to life safety in building fires. If this is accomplished, the characterization of building materials should be relatively simple.

- (14) There is a substantial quantity of experimental data available that is pertinent to this subject. Most of these data are of limited value because of variations in test methods and test procedures. Criteria are needed that would serve as a guide to the conduct of future experimental effort.

- (15) Recent developments in the nature and versatility of techniques and equipment for the analyses of gaseous mixtures, particularly in the areas of chromatography and spectroscopy, provide the means for further research on this subject. No comprehensive efforts to apply such facilities to the problem at hand have been found.

VIII. RECOMMENDATIONS

Further study is required to establish the hazard of thermal decomposition products of building materials. Four recommendations are presented to accomplish this objective. These are:

- (1) Analysis of body tissue and blood to determine cause of death in accidental fire deaths.
- (2) Use of currently available analytical techniques to determine the hazard of combustion gases developed as building materials burn.
- (3) Use of animal tests in combination with fire tests of building materials to determine the hazard of combustion gases.
- (4) The use of the tunnel test and room burn-out tests to determine the relative importance of building finishes and building furnishings.

A more detailed discussion of each of the above items follows.

A. Analysis of Body Tissue and Blood

An analytical program is recommended whereby cooperative arrangements would be made with at least three medical examiners in large cities. Blood and lung tissue samples would be obtained from fatalities in building fires where the cause of death was other than external burns. The objective would be to determine the accuracy of superficial tests as a means of establishing the cause of death and to establish the presence and amount of toxic components. Chromatographic or spectroscopic analytical techniques would be used for this purpose.

B. Study of Hazard of Combustion Gases through Gas Analysis

Experimental work should be undertaken with the following objectives:

- (1) Determine whether or not carbon monoxide is the primary agent responsible for toxic effects.
- (2) If not, identify other components which are responsible, and the conditions under which they may be hazardous.

- (3) Study of patterns of synergistic action which occur in a complex mixture.
- (4) Determine what building materials and combustion conditions especially favor the formation of toxic combustion products.

C. Study the Hazard of Combustion Gases through Animal Tests

Because of the complex nature of the combustion gases and the lack of sufficient toxicity data on such mixtures, chemical analysis of combustion gases to identify the various components will not provide information on the overall toxicity. Therefore, animal experiments are recommended as a primary means of studying toxic effects. This could be done on a rather small scale using the flame spread tunnel or other flame spread test facilities which are available and are used frequently for routine test work. Combustion conditions are reasonably reproducible from one run to another, which gives a convenient method of making duplicate runs.

Gas samples could be taken at the point where combustion products are exhausted. These samples can then be passed through various treatment processes before being introduced into an air tight cage containing mice or other suitable animals. The following sequence of tests, or some variation thereof, might be appropriate:

- (1) Cool the gases to room temperature.
- (2) Cool the gases to perhaps 150°F, or the highest temperature that will not endanger the animals due to heat effects.
- (3) Cool the gases to room temperature and dilute different amounts, varying the degree of dilution to find a threshold dilution value below which no toxic effects occur.
- (4) Depending on the results obtained to this point, selectively remove various components suspected of being toxic and thus determine the toxicity of the remaining constituents by their effect on the animals used.

To complete the last step (4), extensive analytical data will be required. This can be done most conveniently by gas chromatography. While identification of all of the constituents of such a complex mixture will probably not be possible, the analytical work is needed to identify as many constituents as possible, to determine the toxicity of the components identified and, as a preliminary effort, to determine the extent of synergistic action.

All experiments should be conducted with a large enough number of animals to permit statistical evaluation of the results. Control animals should be used in all cases, comparing exposed animals with those which received no exposure, and also with those which received exposure to heated air at the same temperature (perhaps 150°F) but in the absence of combustion gases.

The question of the water vapor content of the test gas mixtures also deserves consideration. Probably this should be studied experimentally, first by studying combustion gases as they are removed from the furnace or as they are diluted with room air and, second, by dilution with room air saturated with water vapor at the test temperature. This can be done readily by passing the diluent air through a water trap to pick up the necessary amount of water vapor before combustion gases are diluted prior to passing them into the exposure chamber.

Some interesting results might be obtained by analyzing blood samples from animals who perish during exposure tests to see which components of combustion gases can be identified.

In connection with carbon monoxide effects, exposure tests using pure carbon monoxide at the concentrations measured in combustion gases would probably be helpful in determining whether or not carbon monoxide is the primary agent. Carbon monoxide can be passed through a water saturator and heated to the proper temperature so that all conditions of the exposure will be duplicated except for the absence of other combustion gases.

D. The Hazard of Finishings versus Furnishings

A fourth study is proposed in two related parts, each of which would provide essential information. The first part would be aimed at resolving the relative importance of building finishes and furnishings. Using existing flame spread test facilities, it is proposed that a combustible material such as Douglas fir or red oak flooring (the latter being the normal control specimen in the tunnel test) and a noncombustible material such as asbestos-cement board be subjected to the test flame and the combustion gases analyzed. It is then proposed to rerun the same materials in a series of tests in which various articles representative of upholstery, bedding, and decorative materials are introduced and burned. The analysis of the gases produced and sampled would represent the added effect of any of the furnishings. An effort would be made to maintain the same mass relationship of materials in the tests as might be found in actual occupied spaces.

Depending on the results obtained in this series of tests, a second series might be undertaken using a full-scale room and actual furnishings and finishes.

This program would consist of room burn-out tests using the facility prepared for the latter half of the second recommendation. The objective would be to correlate the combustion gases found with representative interior finish and furnishing materials in the widely accepted 25-foot tunnel test with combustion gases obtained in a full-scale room finished with similar materials.

It is assumed that any or all action taken along the lines suggested would incorporate close cooperation with interested and informed doctors and toxicologists. It is believed that such cooperation would be essential to the achievement of optimum results.

Also it is suggested that consideration be given to the possibility of a cooperative agreement with a municipal fire department through which gas samples can be taken at actual fires. The problems of on-the-spot analysis of the gas samples and of changes that might occur if the analysis is delayed are recognized.

E. New Concepts in Building Design

A further approach to the problem lies in the development of new concepts in the design of buildings. The objective would be to minimize the effect of combustion products in the event of fire in buildings. Design analysis accompanied by experimental effort would be required to accomplish this result. Efforts so expended, however, could very well lead to measures that would lessen the importance of otherwise hazardous situations.

BIBLIOGRAPHY

1. Adams, E. M., Spencer, H. C., Rowe, V. K., and Irish, D. D., "Vapor Toxicity of 1, 1, 1-Trichlorethane (Methyl-Chloroform) Determined by Experiments on Laboratory Animals," AMA Arch. of Ind. Health, Vol. 1, pp 225-236, Feb. 1950.
2. Air Materiel Command, Toxic Hazards in Military Flying and in the Aviation Industry, Aviation Medicine Symposium, Nov. 1957.
3. American Conference of Government Industrial Hygienists, Threshold Limit Values for 1961, 12 pp, 1961.
4. American Society of Clinical Pathologists, Proceedings, 27th Seminar, Oct. 6, 1961.
5. ASTM, Standard Methods of Fire Tests of Building Construction and Materials, E119, 1961.
6. ASTM, Standard Method of Test for Surface Burning Characteristics of Building Materials, E84-61, 1961.
7. Antweiler, A., Baumen, H., and Schiller, E., "Tests with Subcutaneous Injections of Quartz, Rutile and Coal Dusts and Organic Materials," Beitr Silikose Forsche No. 75, pp 59-87, 1962.
8. Aviado, D. M., and Schmidt, C. F., "Respiratory Burns with Special Reference to Pulmonary Edema and Congestion," Circulation, Vol. 6, pp. 666-80, 1952.
9. Baetjer, A. M., "Effect of Chronic Exposure of Air Pollutants on Acute Infectious Respiratory Disease," Air Pollution Conference Proceedings, McGraw-Hill Co., pp 512-519, 1952.
10. Battle, B. P., Arson, A Handbook of Detection Investigations, Greenburg Publisher, New York, 1954.
11. Benzaquin, Paul, The Coconut Grove Disaster, Henry Holt and Co., 238 pp, New York, 1959.
12. Berger, L. B., and Schrenk, H. H., "Danger from Carbon Monoxide in the Home," Bur. of Mines Cir. 7676, 6 pp, February 1954.

13. Berger, L. B., Schrenk, H. H., Gale, J. A., Stewart, K. W., and Sieffert, L. E., "Toxicity and Flame Resistance of Thermosetting Plastics," U. S. Bur. of Mines R. I. 4134, 11 pp, October 1947.
14. Berl, E., "Smoke Prevention Through the Eyes of a Chemist," Am. Proc. of Smoke, 37:46-55, 1943.
15. Berninger, H., and Smith, R., "Carbon Monoxide - Determination Modification of Spechometric CO Determination in Blood," Clinical Chem., 5:127-34, 1959.
16. Beryushev, K. G., Romyantserv, M. V., and Koragodina, I. L., "Noises and Exhaust Gases on Hygenic Conditions of Hospital," USSR Lit. Survey on Air Pollution, Vol. 1, Trans. B. S. Levine, 1961.
17. Blockley, W. V., and Lyman, J., "Heat Tolerance," WADC Technical Report No. 6022 (University of California), 30 pp, October 1950.
18. Blockley, W. V., and Taylor, C. L., "Human Tolerance Limits for Extreme Heat," Heating, Piping and Air Conditioning, pp 111-116, May 1949.
19. Blockley, W. V., and Lyman, J., "Studies in Heat Tolerance," WADC Report No. 6521 (University of California), 1951.
20. Bond, H., Fire and the Air War, NFPA, Boston, 256 pp, 1946.
21. Bond, H., "The Fire Attack on German Cities," NFPA Quarterly 38:246-264, January 1946.
22. Bond, H., and Reissman, K. R., The Problem of Medical Care and Hospitalization under Air Attack, USAF-SAM Unnumbered Project, Incidence of Air Casualties in Berlin, 41 pp, 1948.
23. Broadhurst, V. A., "Hazards in Paint Factories," Paint Mfg., 29:121-4, 1959.
24. Brooks, V. J., and Alyea, H., Poisons: Their Properties, Chemical Identification, Symptoms and Emergency Treatment, D. Van Nostrand Co., Inc., New York, 1946.
25. Brown, T. C., Delaney, R. J., and Robinson, W. L., "Medical Identification in the NORONIC Disaster," Jour. American Medical Ass'n., Vol. 148, pp 621-627, February 23, 1952.

26. Bruce, H. D., "Experimental Dwelling-Room Fires," Forest Products Laboratory Report No. D1941, 23 pp, June 1953.
27. Brystrova, T. A., "Effects of SO₂ with Aid of Labeled Atoms," Air Pollution Literature and Related Diseases, Vol. 7, A Survey 60-21049 USDC, Trans, by Levine, B. S., 1960.
28. Busch, N. F., Two Minutes to Noon, Simon and Schuster, 191 pp, 1962.
29. Buttner, * K., "Effects of Conflagration Heat," German Aviation Medicine, Ch XIII-A, 1167-68, 1950.
30. Buttner, K., "Effects of Extreme Heat on Man," AMA Journal, 144:732-40, 1950.
31. Buttner, K., "Physical Heat Balance on Man," German Aviation Medicine, Vol. III, C-766-791, 1950.
32. Buttner, K., "Protective Clothing for Heat and Cold," German Aviation Medicine, Vol. III-1-1 876-886, 1950.
33. Buttner, K., "Effects of Extreme Heat and Cold on Human Skin, II, Surface Temperature Pain and Heat Conductivity in Experiments with Radiant Heat," Journal of Applied Physiology, 3:703-13, 1951.
34. Buttner, K., "Effects of Extreme Heat and Cold on Human Skin, I, Analysis of Temperature Changes Caused by Different Kinds of Heat Application," Journal Applied Physiology, 3:691-702, 1951.
35. Churchill, E. D., Fine, J., and Stead, E. A., Jr., "Shock," Symposium, Divn. Medical Science and Nat. Research Council, Army Medical Service Graduate School, Army Medical Center, May 1951.
36. Claudy, William D., "Carbon Monoxide in Fire Fighting," Firemen, 21:12-13-22, June 1954, Part I.
37. Claudy, William D., "Carbon Monoxide in Fire Fighting," Firemen, 21:8-9, July 1954, Part II.
38. Claudy, William D., Respiratory Hazards of the Fire Service, 134 pp, NFPA, 1958.

* Also spelled Buettner.

39. Coleman, E. H., "Gaseous Combustion Products from Plastics," Plastics, October 1959.
40. Coleman, E. H., and Thomas, C. H., "The Products of Combustion of Chlorinated Plastics," Jour. of Applied Chem., Vol. 4, pp 379-383, July 1954.
41. Coleman, E. H., "When Plastics Burn - What are the Hazards from Toxic Fumes," Product Engineering, pp 40-41, Mid-Sept. 1960.
42. Comstock, C. J., Kerchner, J., and Oberst, F., Toxicology of Inhaled Trifluoromonobromomethane and Difluorodibromomethane from Subacute and Chronic Exposure of Rats and Dogs, Army Chemical Center, Maryland, April 1953.
43. "Combustible Linings in Dwellings - Houses," Fire Offices' Committee, Fire Protection Association Booklet No. 16, London, 1953.
44. "Controlled Burning of Combustible Materials," National Bureau of Standards Tech. News. Bull., Vol. 40, N 11, pp 156-157, November 1956.
45. Cope, Oliver, and Rhinelander, F. W., "The Problem of Burn Shock Complicated by Pulmonary Damage," Ann. Surg. 117:915-928, 1943.
46. Cowling, A. H., and Evis, F. A., Pollution and Smoke Control, Final Report of the Legislative Assembly of Ontario, Canada, 500 pp, February 1957.
47. Critical Thermal Energies of Construction Materials, Air Materiel Command, Proj: 50-40-3, Part 1, December 1954.
48. Daub, H. P., "Pulmonary Changes from Inhalation of Noxious Gases (Nitric Oxide Fumes)," Radiology, 21:105-113, August 1933.
49. Day, H. W., "Heart Disease and Its Relationship to the Fire Service," International Fire Fighter, 8 pp, February 1950.
50. DeSaga, H., Expt. Investigation of the Action of WW II Dust in Aviation Medicine, Gov't. Printing Office, 1950.
51. Dominguez, A. M., Christensen, H. E., Goldbaum, L. R., and Stembridge, V. A., "Carbon Monoxide in Blood or Tissue, Gas Chromatographic Method," Toxicol. & App. Pharmacol., 1:135-40, 1959.

52. Doremus, C. A., and McNally, W. D., "Gaseous Poisons," Legal Medicine, Vol. 2, pp 431-433, 1923.
53. Drinker, C. K., Carbon Monoxide Asphyxia, Oxford University Press, 1938.
54. Easton, W. H., "Smoke and Fire Gases," Industrial Med., 11:466-467, October 1942.
55. Eaton, R. M., "Pulmonary Edema, Expt. Observation on Dogs Following Acute Blood Loss," J. Thoracic Surgery, 16:668-694, 1947.
56. Elkins, H. B., The Chemistry of Industrial Toxicology, Physiological Effects of CO, John Wiley & Son, New York, 1950.
57. Fineberg, C., Miller, B. J., and Albritten, F. F., "Thermal Burns of the Respiratory Tract," Surg. Gynecology and Obst., 98:318-323, 1954.
58. Finland, M., Davidson, G. S., and Levenson, S. M., "Clinical and Therapeutic Aspects of Conflagration Injuries to Respiratory Tracts Sustained by Victims of Coconut Grove Disaster," Medicine, 25:215-30, 1946.
59. Forty-One Fatal Burn Injuries, 1950-53, Brook Army Medical Center, Ad hoc Panel of the Committee on Pathology, Division of Medical Sciences, National Academy of Sciences, National Research Council, Washington 25, D. C.
60. Friess, Herbert, and Mueller, H. O., "Dust and Smokes in the Electron Microscope," Gas Mask, 11:1-9, 1939.
61. Fusco, M., Fusco, L., and Silvestroni, A., "Hemodynamics in Acute Experimental Poisoning with Carbon Monoxide," Folca Med. 42:1508-23, Naples, Univ. of Naples, 1959.
62. Gerlach, Heinz A., "Results of Blood Gas Analysis During Bronchial Examination in General Anesthesia with Muscle Relaxant," Rhein Landeskrankenhaus Mannaesheede, Biz., Cologne, Germany.
63. Gettler, A. O., "The Toxicologist as a Crime Detector, Examination of Cadavers for CO and Other Hydrocarbons," Penna. Med. J., 51:159-64, 1947.

64. Goldbaum, L. R., Glantz, W. M., Stenbridge, V. A., Dominguez, A. M., Christensen, H. E., Lovell, F. W., Gleason, T. L., and Townsend, F. M., "Carbon Monoxide in Fatal Aircraft Victims," Aerospace Med., 30:711-715, October 1959.
65. Goodman, L. S., and Gilman, A., "Noxious Gases and Vapors, CO, HCN, etc.," The Pharmacological Basis of Therapeutics, Ch. 40, pp 926-947, MacMillan Co., New York, 1960.
66. Gonzales, T. A., Morgan, V., Halpern, M., and Umberger, C. J., "Gaseous Poisons," Legal Medicine, Pathology, and Toxicology, Ch. 42, 955-968, Appleton Century Crafts, New York, 1954.
67. Grassens, J. F., and LaFontaine, A., "Air Pollution in Modern Cities by Chemicals and the Problem of Exhaust Gases (CO and SO₂)," Arch. Belges, Med. Sociale Hyg., 16:217-37, 1958.
68. Graziani, G., and Guareno, Q., "Acute Poisoning with Carbon Dioxide Effect on Nervous System," Folca Med. (Italy) 39:457-70, 1956.
69. Green, H. D., Shock and Circulatory Homeostasis, Josiah Macy, Jr. Foundation, New York, 1952, 1953.
70. Grimaldi, J. V., "The Hazard of Synthetic Plastics," Mechanical Engineering, pp 987-989, December 1950.
71. Haessler, Walter M., The Extinguishment of Fire, The FyrFyter Company, Dayton, Ohio, 1962.
72. Haggard, H. W., and Henderson, Y., Noxious Gases and the Principles of Respiration Influencing Their Actions, Reinhold Publishing Corporation, 1943.
73. Hall, J. N., and Cooper, C. E., "The Effects of the Inhalation of The Fumes of Nitric Acid," Jour. AMA, 45:396-398, August 1905.
74. Ham, T. H., "Studies on Destruction of Red Blood Cells," Arch. Int. Med., 64:1271, 1939.
75. Hamilton, A., and Johnstone, R. T., Carbon Monoxide in Industrial Toxicology, Oxford Univ. Press, 1945.
76. Hanifin, F., "Under Fire Conditions Will Plastics Emit Toxic Fumes," Fire Engineering, Vol. 112, No. 5, pp 380-382, May 1959.

77. Harrison, W., and Liebow, A. A., "The Effects of Massive Intravenous Infusions with Special Reference to Pulmonary Congestion and Edema," Yale J. Biol. & Med., 26:372-384, 1954.
78. Health Hazards and Toxicity of Plastics, A Cross-Indexed Bibliography, Plastic Technical Evaluation Center, Department of Defense, Picatinny Arsenal, 1962.
79. Hardy, J. D., and Oppel, T. W., "Studies in Temperature Sensation, Sensitivity of Body to Heat and Summation of Organ Response," J. Clinic Invest., 16:544, 1937.
80. Hardy, J. D., and Oppel, T. W., "Studies in Temperature Sensation," J. Clinic Invest., 17:771-78, 1938.
81. Hardy, J. D., "The Radiating Power of Human Skin in the Infrared," Am. J. Physiology, 127:454-462, 1939.
82. Hasbrook, H. A., Garner, J. D., and Snow, C. C., Evacuation Problems of Denver Jet Crash, NFPA 56:101-109, October 1962.
83. Halpern, C., and Ruegg, F. W., "A Study of Sampling of Flame Gases," Jour. of Res., NBS, Vol. 60, No. 1, pp 29-37, January 1958.
84. Harrison, W. and Liebow, A. A., "The Effects of Massive Intravenous Infusion with Special Reference to Pulmonary Edema," Yale J. Biol. & Med., 26:372-384, 1954.
85. Hastings, B. K., Schaefer, K. E., Nicholas, G., and Carey, C. R., Effects of Prolonged Exposure to Elevated Concentration of Carbon Dioxide on Respiration, Alveolar Carbon Dioxide Tension and Lung Volume, Naval Res. Lab. Report No. 250, 10 pp, June 14, 1954.
86. Henriques, F. C., Jr., "Studies of Thermal Injury VIII Automatic Recording Caloric Applicators and Skin Tissue, and Skin Surface Thermocouples," Rev. Sci. Inst., 18:673-681, 1947.
87. Henriques, F. C., Jr., "The Predictability and the Significance of Thermally Induced Rate Processes Leading to Irreversible Epidermal Injury," Arch. Path., 43:489-502, 1947.
88. Henriques, F. C., Jr., and Mortiz, A. R., "The Conduction of Heat to and through Skin and the Temperature Obtained Therein," a Theoretical and Experimental Investigation, Am. J. Path, 23:531-49, 1947.

89. Henriques, F. C., Jr., and Moritz, A. R., "The Relative Importance of Time and Surface Temperatures in Causation of Cutaneous Burns," Am. J. Path., 23:695-720, 1947.
90. Hibben, H. A., History of the Significance of CO as a Hazard to Military Aviation in the U. S., Thesis in Aerospace Med. Library, 30 pp, December 1956.
91. Hibben, H. A., Study of Relationship of CO Blood Levels to Aircraft Accidents, Thesis in Aerospace Med. Library, 41 pp, June 1957.
92. Humery, R., "The Injurious Effects of Smoke, Dust, and Toxic Gases," Mem. Soc. Ing. Civils, France, 92:364-71, 1939.
93. Ingberg, S. H., "Tests of the Severity of Building Fires," NFPA Quarterly, Vol. 22, No. 1, pp 43-61, July 1928.
94. International Association of Fire Chiefs, Smoke Inhalation Injuries, Hospitalizes, Kills, 4 pp, 1962.
95. Irwin, C. W., "Occupational Hazards of the Fire Service," Firemen, 20:14-16, June 1953.
96. Juillerat, E., Jr., "The Hartford Hospital Fire," NFPA Quarterly, Vol. 55, No. 3, pp 3-10, January 1962.
97. Killer Gas, Texas Health Bulletin, p 11, January 1963.
98. Kimball, W. Y., "Hartford Circus Holocaust," NFPA Quarterly, Vol. 38, No. 1, pp 9-20, July 1944.
99. Kingman, E. F. T., Coleman, E. H., and Rasbash, D. J., "The Products of Combustion in Burning Buildings," J. of Applied Chem., 3:463-8, 1953.
100. Kitzes, G., Research on the Role of CO in Aviation, WADC Tech. Rept. No. 57-291, USAF, 12 pp, 1958.
101. Kleinfield, M., Messite, J., and Giel, C., "Pulmonary Edema of Non-Cardiac Origin," Am. Jour. Med. 235:660, 1958.
102. Lawson, D. I., and Kingman, F. E. T., "Fire Hazards of Plastics," Rubber and Plastics Age, Vol. 36, No. 11, 2 pp, November 1955.

103. Levenson, S. M., Einheber, A., and Malm, O. J., "Metabolic Aspect of Shock," JAMA, 181:168-177, September 8, 1962.
104. Levin, M., "Observations on the Treatment of Smoke Poisoning," Fire Engineering, Vol. 116, No. 1, p 45, January 1963.
105. Levine, B. S., Trans USDC, "The Effect of High Temperature on the Toxicity of Carbon Monoxide," USSR Lit. Survey on Air Pollution and Related Diseases, 1960.
106. Mallory, T. B., and Brickley, W. S., "Management of Coconut Grove Burns at the Massachusetts General Hospital: Pathology," Ann. Surg., 117:865-884, 1943.
107. Malmo, R. B., Baum, W. S., Sievers, R. F., "A Comparative Study of the Effects of Exercise and Anoxia upon the Human Electrocardiogram," Jour. of Aviation Medicine, Vol. 16, No. 6, pp 422-429, December 1945.
108. Mastromatteo, E., "Mortality in City Firemen, Part I," AMA Archives of Industrial Health, pp 1-7, Vol. 20, July 1959.
109. Mastromatteo, E., "Mortality in City Firemen, Part II," AMA Arch. of Industrial Health, Vol. 20, pp 227-233, September 1959.
110. Mastromatteo, E., Fisher, A. M., Christie, H., and Danziger, H., "Acute Inhalation Toxicity of Vinyl Chloride to Laboratory Animals," Amer. Ind. Hygiene Assoc. Jour., Vol. 21, No. 5, pp 394-398, October 1960.
111. McCord, Carey P., "Properties, Physiology, and Psychology of Odors," Air Pollution Conference Louis McCabe, McGraw-Hill, New York, 1952.
112. McCormick, W. E., and Wilson, R. H., "The Toxicology of Synthetic Resins," AMA Archives, Ind. Health, 21:536-48, June 1960.
113. Medical Manual of Chemical Warfare, Symposium on Irritant and Nonirritant Gases, Chemical Publishing Co., New York, 1960.
114. Moritz, A. R., "The Pathology and Pathogenesis of Cutaneous Burns," An Experimental Study, Am. J. Path. 23:915-42, 1947.

115. Moritz, A. R., Henriques, F. C., Jr., Dutra, F. R., and Weisiger, J. R., "An Exploration of the Casualty Producing Attributes of Confoagurations Local and Systemic Effects of General Cutaneous Exposure to Excessive Heat of Varying Duration and Intensity," Arch. Path. 43:466-502, 1947.
116. Moritz, A. R., Symposium on Burns, National Academy of Science National Research Council, Washington, D.C., 1951.
117. Moritz, A. R., McLean, R., and Roos, A., "Hyperpotassemia Caused by Cutaneous Exposure to Excessive Heat," J. Clinic Invest., 26:497-504, 1947.
118. Moritz, A. R., Henriques, F. C., and McLean, R., "Effect of Inhaled Heat on Air Passages and Lungs," Am. J. Pathology, 21:311-331, March 1945.
119. Morrow, A. E., "Loss of Life Among Wearers of Oxygen Breathing Apparatus," Bur. of Mines Cir. 7943, 29 pp, 1959.
120. Moss, R. H., et al., "Toxicity of CO and HCN Gas Mixture," A Preliminary Report, Arch. Ind. Hyg. & Occup. Med., 4:53, 1951.
121. Moulton, R. S., The Coconut Grove Night Club Fire, NFPA Special Report, 19 pp, January 1943.
122. Moyer, C. A., "The Sociologic Aspect of Trauma," Am. Jour. of Surgery, 87:421-30, 1954.
123. Musselman, N. P., Graff, W. A., Yevich, P. O., Wilinski, F. T., Weeks, M. H., and Oberst, F. W., Continuous Exposure of Laboratory Animals to Low Concentration of Carbon Monoxide, CwLR 2337, U.S. Army Chemical Warfare Lab., Army Chemical Center, Md., 30 pp, January 1960.
124. National Bureau of Standards, NBS Technical News Bulletin, Vol. 44, No. 11, "Potential Heat of Materials in Building Fires."
125. National Bureau of Standards, "Fire Resistance Classifications of Building Constructions, BMS 92, 1942.
126. National Fire Protection Association, Fire Protection Handbook, Twelfth Edition, 2198 pp, 1962.

127. National Fire Protection Association, "Occupancy Fire Record - Hospitals," FRB 61-1, 24 pp, 1961.
128. NFPA Committee on Fire Gas Research, Fire Gas Research Report, National Fire Protection Association Quarterly, Vol. 45, No. 3, pp 280-306, January 1952.
129. National Fire Protection Association, Operation School Burning, No. 1, 269 pp, 1959.
130. National Fire Protection Association, Operation School Burning, No. 2, 352 pp, 1961.
131. National Fire Protection Association, Building Exits Code, No. 101, 1961.
132. National Fire Protection Association, Fire News No. 515, February 1962.
133. National Fire Protection Association, Fire News No. 514, pp 5-6, January 1962.
134. National Fire Protection Association, Editorial, Firemen, Vol. 30, No. 4, p 7, April 1963.
135. Olsen, J. C., Brunjes, A. C., and Sabetta, V. J., "Gases Produced by Decomposition of Nitrocellulose Photographic Films," Ind. and Eng. Chem., 22-860-63, 1930.
136. Olsen, J. C., Ferguson, G. E., and Scheflon, L., "Gases from Thermal Decomposition of Common Combustible Materials," Ind. & Eng. Chem., 22-860-63, 1933.
137. Petry, H., "The Present State of Our Knowledge of Chronic CO Poisoning," Arch. Gerverpath, Gewerbehyg, 18:22-36, 1960.
138. Phillips, A. W., and Cope, O., "Burn Therapy; Concealed Progress Due to a Shifting Battlefront," Ann. Surgery, 152:767-76, 1960.
139. Phillips, A. W., Cope, Oliver, "Burn Therapy II. The Revelation of Respiratory Tract Damage as a Principle Killer of Burn Patients," Ann. Surg. 155:1-10, 1962.

140. Pierson, R. H., Fletcher, A. N., St. Clair Gants, E., "Catalog of Infrared Spectra for Qualitative Analysis of Gases," Analytical Chemistry, Vol. 28, pp 1218-1239, August 1958.
141. Quartermaster Report, Research and Development Division, Heat Exchange in Hot Environment, Navy Report No. 183, January 1952.
142. Rasbash, D. R., "The Efficiency of Hand Lamps in Smoke," Institution of Fire Engineers Quarterly, undated reprint, 16 pp, Chantry Publications, Ltd., London.
143. Reutsch, G., "Symptoms of Toxicology of Hydrazoic Acid Compounds in Humans," Org. Chem., 68:439-40, 1956.
144. "Review of Physiological Limitations to Heat," Navy Report TED No. NAM AE 50916, Naval Air Materiel Center, December 1949.
145. Roberts, B., Fitts, W. J. and Randin, I. S., "Treatment of Thermal Burns: Ten Year Progress," Am. Jour. Surg., 87:364-367, 1954.
146. Roos, A., Weisiger, J. R., and Moritz, A. R., "Thermal Burns, Physiological Mechanism Responsible for Death During Cutaneous Exposure to Excessive Heat," J. Clinic. Invest., 26:505-19, 1947.
147. Saland, G., Kramer, M. L., Schein, A. J., and Seley, G. P., Occupational Hazards and Injuries of New York Firemen, Med. Division of Fire Dept., 20 pp, City of New York, 1962.
148. Savage, J. D., The Measurement and Control of Diesel Exhaust Smoke Emission, Society of Automotive Engineers preprint No. 440B, 8 pp, 1962.
149. Schaefer, K. E., "A Concept of Triple Tolerance Limits Based on Chronic Carbon Dioxide Toxicity Studies," Aerospace Med., 37:197-204, 1961.
150. Schaefer, K. E., Cornich, E. R., and Lukas, C. A., Jr, "Respiration and Circulation During and After Inhalation of Various Concentrations of CO," Medical Research Lab. Report No. 189, Bureau Med. & Surg., Navy Dept., Vol. XI, ASTIA 155-032, March 1952.
151. Schriesheim, A., "Method for the Controlled Burning of Combustible Materials and the Analysis of the Combustion Gases," Nat. Bur. of Stds., Jour. of Research, Vol. 57, No. 4, (RP 2715) pp 245-249, October 1956.

152. Sendray, Julius, Jr., et al., "Comparison and Effect of Vapors Emanating from Insulated Electrical Equipment under Conditions of Simulated Submarine Operations," Proj. NR 004 005, 02.01, Naval Medical Res. Inst., Bethesda, Md., August 1950.
153. Shorter, G. W., McGuire, J. H., Hutcheon, N. B., and Legget, R. F., "The St. Lawrence Burns," NFPA Quarterly, Vol. 53, No. 4, pp 300-316, April 1960.
154. Simms, D. L. and Hinkley, P. L., Protective Clothing Against Flame and Heat, Fire Research Special Report No. 3, Dept. of Scientific and Ind. Research and Fire Office Committee, Joint Fire Research Organization, London, 1960.
155. Skolnick, M. H., and Richardson, G. J., Fire Fighters Occupational Diseases, International Association of Fire Fighters, 106 pp, 1945.
156. Smariga, J. E., "Fire Safety in Existing Structures," The Modern Hospital, 2 pp, March 1950.
157. Smart, R. C., The Technology of Industrial Fire and Explosion Hazards, Vol. II, Chapman and Hall, Ltd., 201 pp, London, 1947.
158. Snell, F. D., What Are the Hazards of New Materials?, 23 pp, Foster D. Snell, Inc., 1946.
159. Starrock, P. E., An Estimation of Exposure to Carbon Monoxide by Breath Analysis, 11 pp, WADC TR 57-291, March 1958.
160. Stephen, Walter W., "Fighting Fires Involving Toxic and Irritant Gases," Fire Engineering, 92:98-100, 1939.
161. Stokinger, H. E., Wagner, W. D. and Dobrogarski, O. J., "Ozone Toxicity Studies III, Chronic Injury to Lungs of Animals Following Exposure at a Low Level," AMA Arch. Ind. Health, 16:514-522, 1957.
162. Stokinger, H. E., "Teflon, A Plastic with Inhalation Hazard," Occupational Health, 13:88, 1953.
163. Tamas, A., and McElroy, J., Postmortem Carbon Monoxide Analysis: Significance of Tissue Blood Content, WADC TR 57-686, 15 pp, 1957.
164. Thomas, Q. M., "Hypoxia and Carbon Monoxide," Flying, 2 pp, July 1962.

165. "The World's Worst Forest Fire," Ansul Chemical Company News Notes, pp 3-8, Fall, 1958.
166. U. S. Strategic Bombing Survey, "The Effects of Atomic Bombings on Hiroshima and Nagasaki," Chairman's Office, June 30, 1945.
167. U. S. Strategic Bombing Survey, "The Effects of Bombing on Health and Medical Care in Germany," Medical Branch Report, War Dept., Washington, D. C., 388 pp, October 1945.
168. U. S. Strategic Bombing Survey, "Part II, The Effects of the Atomic Bombings," Hiroshima and Nagasaki, 46 pp, U. S. Gov't. Printing Office, June 1946.
169. Vance, M., Gonzales, T. A., Halpern, M., and Umberger, C. J., "Asphyxiating Gases," Legal Med. and Toxicology, pp 484-521, Appleton Century, New York, 1952.
170. Vorwald, A. J., "Effects of 'Inert' Dust in Air Pollution," Trudeau Foundation, Saranac Lake, N. Y., Air Pollution Proceedings, U. S. Tech. Conference Report, McGraw-Hill Co., 485-88, 1952.
171. Washington Post, AP News Release, October 15, 1962.
172. Websters Third New International Dictionary, G & C Merriam Co., 1961.
173. Westgate, M. W., Fire and Toxic Gas Hazard of Paint Films, National Paint, Varnish and Lacquer Association, Inc., Cir. 724, March 1948.
174. Westgate, M. W., Paint Films Reduce Carbon Monoxide Hazard in Smoldering Ruins, National Paint, Varnish & Lacquer Assoc, Cir. 734, September 1949.
175. Wetmiller, R. S. and Endsly, L. E., "Effect of Diesel Fuel in Exhaust Smoke and Odor," SAE Jour. 50:509-20, 1942.
176. Wilkens, E. T., "Air Pollution - Some Chemical and Physical Aspects of Its Effects on Living Materials," Report of Survey 1951-54, Inst. Biology, No. 8:33-59, Fuel Research Sta., Greenwich, London, 1959.
177. Williams, L. L., "Toxicity of Fire," Fire Engineering, 112:373, 75, May 1959.

178. Williams, L. L., Cripple Creek Conflagrations, reprint from Denver Westerner's Brand Book, Vol. 17, pp 467-503, 1961.
179. Wilson, R. H., and McCormick, W. E., "Toxicology of Plastics and Rubber - Plastomers and Monomers," Ind. Med. & Surgery, 23:11, November 1954.
180. Wittich, F. W., "Respiratory Tract Allergic Effects from Chemicals and Air Pollution," Air Pollution Proceedings of U. S. Tech. Conf. on Air Pollution, McGraw-Hill Company, 1952.
181. Zapp, J. A., Toxicology of Fire, Medical Div. Special Report, Chemical Corps, Army Chemical Center, Md., 106 pp, April 1951.
182. Zapp, J. A., "Hazards of Isocyanates in Polyurethane Foam Plastics Production," AMA Arch. of Ind. Health, Vol. 15, April 1957.
183. Zapp, J. A., et al., Toxicity of Pyrolysis Products of Teflon, Tetra-Fluoroethylene Resin, presented at 1955 meeting of Am. Hygiene Association, April 1955.
184. Zweifach, B. W., "Tissue Mediators in the Genesis of Experimental Shock," JAMA, 181:160-165, September 1962.
185. Zapp, J. A., The Anatomy of a Rumor, E. I. du Pont de Nemours & Co., 14 pp, 1962.

Addenda

186. Amdur, M. O., "Interpretation of the Data, Regarding the Respiratory Reaction of Guinea Pigs Toward HCHO, in the Presence and Absence of NaCl Aerosols," In Study of the Properties of Aerosols, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, 1958.
187. Amdur, M. O., "The Influence of Aerosols Upon the Respiratory Response of Guinea Pigs to Sulfur Dioxide," Am. Ind. Hyg. Assoc. Quart. 18, 149-55 (June 1957).
188. Amdur, M. O., "The Physiological Response of Guinea Pigs to Atmospheric Pollutants," Intern. J. Air Poll. (London) 1, 170-83 (January 1959).
189. Amdur, M. O., "The Response of Guinea Pigs to Inhalation of Formaldehyde and Formic Acid Alone and with a Sodium Chloride Aerosol," Inter. J. Air Poll (London) 3, 201-20 (October 1960)

190. Aub, J. C., Pittman, H., and Brues, A. M., "Management of Cocoon Grove Burns at the Massachusetts General Hospital - Pulmonary Complications," Ann. Surg. 117:834-840, 1943.
191. Beltramelli, Clement and Fackler, "Problems Raised by Smoke in Fires in Tall Blocks of Flats," Fire International, Vol. 1, pp 18-33, July 1963.
192. Burchfield, H. P., and Storrs, E. E., Biochemical Applications of Gas Chromatography, 680 pp, Academic Press, 1962.
193. Bureau of Mines, "Fires, Gases, and Ventilation in Metal and Non-metallic Mines," Miners' Circular 55, U. S. Gov't Printing Office, 1957.
194. Everett, M., The Great Chicago Theater Disaster, 368 pp, Publishers Union of America, 1904.
195. Jacobs, M. B., Analytical Chemistry of Industrial Poisons, Hazards and Solvents, Interscience Publishers, 788 pp, 1949.
196. Kudlich, R. (revised by Burdick, L. R.), Ringelmann Smoke Chart, Bur. of Mines Circular 7718, 3 pp & Chart, August 1955.
197. Lewis, Robert, et al., "Air Pollution and New Orleans Asthma," Public Health Reports, No. 11, 947-54, November 1962.
198. McElroy, James K., "The Hotel Winecoff Disaster," NFPA Quarterly, Vol. 40, No. 3, pp 140-159, January 1947.
199. Private Communication with Dr. Anne Phillips, 1963.
200. Underwriter's Laboratories, Inc., Survey of Available Information on the Toxicity of the Combustion and Thermal Decomposition Products of Certain Building Materials under Fire Conditions, Bulletin of Research No. 53, July 1963.

UNCLASSIFIED

UNCLASSIFIED