I. Fire Casualty Studies

Each year an unnecessarily large number of people either die in fires or are severely injured by them. The development of effective countermeasures to reduce these tragic losses requires an understanding of the physical and medical causes of fire fatalities and insights into who is involved.

Introduction

To most people becoming a fire casualty (injury or fatality) appears a very simple process. Flames are hot and on exposure to them one gets burned. Smoke is generated in a fire and people are overcome by "smoke inhalation."

But this does not tell us for certain how or why people are dying and what protection should be made available to reduce these tragedies. Most people die as a result of a fire situation in which the flames have not reached them to produce burns. What are the causes of fire death? How do factors such as flame and smoke enter into the problem quantitatively? How important are alcohol, drugs, special materials, etc.? Do victims receive a warning? If victims receive a warning, why don't they or can't they escape? If time is a major factor, how much time do they need, and how can this time be provided?

To understand the mechanisms involved in becoming a fire statistic, one must recognize the complexity of the problem. An ignition source must be present which causes something to ignite. As a function of the environment and fuel load, fires will grow in many different ways. Depending upon the burning conditions, various materials will produce smoke laden with toxic gases, the most prevalent of which is carbon monoxide. Under these conditions the victim must react quickly and accurately to avoid becoming a fire casualty.

For this discussion we define three categories of fire casualties:

1. Due to burn
2. Due to "smoke inhalation"
3. Due to other causes.

The first category refers primarily to thermal burns. The second category includes those people who have primarily suffered an insult to the respiratory system by the products of combustion, including chemical burns if they can be directly attributable to a fire. The "other causes" category includes such accidents as injury by falling objects, stepping on nails, falling down stairs, heart attacks, and other such events. There can be combinations of categories as well.

The APL/JHU program has placed primary emphasis on the "smoke inhalation" casualty problem since this area historically has had the least attention from the fire community and because most fatalities are now known to result from smoke inhalation. Burns, fractures, and heart at-

TABLE 2

TOXIC PRODUCTS THAT MAY BE OBTAINED FROM COMBUSTIBLE MATERIALS (REF. 1)

Toxic Gas or Vapor	*Source Materials*
Carbon dioxide Carbon monoxide	All combustible materials containing carbon
Nitrogen oxide	Celluloid, polyurethanes
Hydrogen cyanide	Wool, silk, plastics, containing nitrogen
Formic acid Acetic acid	Cellulosic materials, cellulosic plastics, rayon
Acrolein	Wood, paper
Sulphur dioxide	Rubber, thiokols
Halogen acids	Polyvinyl chloride, fire-retardant plastics, fluorinated plastics
Ammonia	Melamine, nylon, urea formaldehyde resins
Aldehydes	Phenol formaldehyde, wood, nylon, polyester resins
Benzene	Polystyrene
Phenol	Phenol formaldehyde
Azo-bis-succino-nitrile	Foamed plastics

TABLE 3

COMBUSTION PRODUCTS OF PLASTICS AND OTHER COMMON SOLIDS (REF. 2)

	Polystyrene	*Ethyl Cellulose*	*"Saran"*	*PVC*	*Nylon*	*Rayon*	*Wool*	*Silk*	*Wood*	*Paper*
Condition No. 1—Free burning										
Carbon dioxide	2.192	2.294	1.047	0.433	1.226	1.836	1.541	1.352	1.626	1.202
Carbon monoxide	0.174	0.440	0.022	0.229	0.304	0.116	0.446	0.634	0.270	0.135
Aldehyde*	—	—	—	—	0.0064	—	—	0.0024	Trace	—
Phosgene	—	—	—	0.0001	—	—	—	—	—	—
HCN and RCN	—	—	—	—	0.0076	—	0.007	0.036	—	—
Ammonia	—	—	—	—	0.032	—	—	0.053	—	—
Chlorine-HCl	—	—	0.621	0.496	—	—	Trace	—	—	—
Acidity†	—	—	—	—	—	—	—	—	—	0.0009
Condition No. 2—Smoldering										
Carbon dioxide	1.698	0.202	0.416	0.743	0.907	1.130	0.650	1.033	0.934	1.001
Carbon monoxide	0.540	0.172	0.221	0.086	0.355	0.225	0.138	0.141	0.366	0.273
Aldehyde*	0.003	0.012	—	—	0.0065	—	‡	0.0012	Trace	Trace
Phosgene	—	—	—	0.00008	—	—	—	—	—	—
HCN and RCN	—	—	—	—	0.0098	—	0.008	0.007	§	—
Ammonia	—	—	—	—	0.210	—	0.035	0.308	—	—
Chlorine-HCl	—	—	0.774	0.473	—	—	Trace	—	Trace	—
Acidity†	—	—	—	—	—	0.042	—	—	0.009	—

* As formaldehyde.
† As acetic acid.
‡ Positive, but interference.
§ Interference.

tacks have been studied in great detail for a long period of time, and they continue to receive careful study.

"Smoke," as commonly used in fire terminology, is made up of gaseous and particulate matter. The materials in the smoke can be classified as:

1. Irritants (such as hydrochloric acid) which cause inflammation of the respiratory tract.
2. Asphyxiants, either lack of oxygen or agents which prevent oxygen from being used by (hydrogen cyanide) or carried to (carbon monoxide) the body tissues.
3. Drug-like materials which are absorbed by the blood, acting as anesthetics or otherwise affecting the central nervous system.

Toxic Atmospheres in Fires

Is there any need to be concerned about anything but the production of carbon monoxide and depletion of oxygen during a fire? An unequivocal Yes or No cannot be given. As will be shown, carbon monoxide is a contributor in most fire fatalities. Many different toxic materials can be present during a fire, and their presence and quantity depend upon many factors such as composition of the material burning, temperature, amount of oxygen available, and other parameters such that, as a result, it is difficult to define the toxic atmosphere of any one fire and its possible effect.

In numerous laboratory studies, the thermal decomposition of household materials has been examined for toxic materials. Tables 2 and 3 indicate some of the gases and organic materials that have been identified when household items burn.[1, 2]

Most of the substances shown in Tables 2 and 3 are toxic if there is exposure to a large enough concentration for sufficient time. Table 4 shows average tolerable human exposure limits for some gases.[3]

TABLE 4

MAXIMUM CONCENTRATION (PPM) OF GAS IN AIR WHICH IS TOLERABLE BY HUMANS EXPOSED FOR THE SPECIFIED TIME (REF. 3)

Gas	*Concentration*	*Time (Min.)*
Carbon monoxide	1000	60
Hydrogen chloride	50–100	60
Hydrogen cyanide	200–480	30

[1] D. J. Rasbash, "Smoke and Toxic Gas," *Fire,* Sept. 1966, 174–175.
[2] *Survey of Available Information on the Toxicity of the Combustion and Thermal Decomposition Products of Certain Building Material Under Fire Conditions,* Bulletin of Research No. 53, Underwriters' Labs., Inc., Chicago, 2nd Printing, 1970.
[3] Y. Henderson and H. W. Haggard, *Noxious Gases,* Reinhold Publishing Corp., New York, 1943.

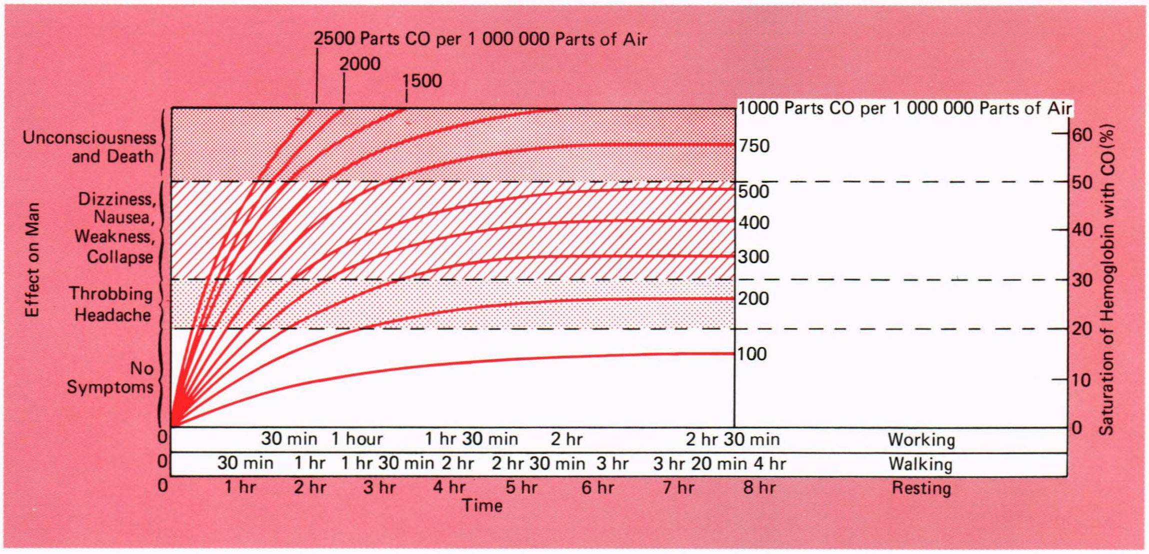

Fig. 1—Effects on man of various concentrations of carbon monoxide (Ref. 4).

Figure 1 indicates the rate of uptake of CO by a human measured as the blood carboxyhemoglobin level in percent.[4] The data are for different concentrations of CO.

Exposure Problems

There is some controversy regarding the tolerance level for carbon monoxide. For a person in good health the lethal level of blood carboxyhemoglobin (i.e., the fraction of hemoglobin occupied by carbon monoxide rather than oxygen) ranges from 50 to 65%. It is now believed that as little as 20% blood carboxyhemoglobin in conjunction with pre-existing heart disease or high levels of alcohol or drugs can also be lethal. While the 50 to 65% threshold values are reasonably well agreed to, there are as yet very little data to substantiate the second claim. The APL program is attempting to define limits in this area.

There is even more uncertainty among fire researchers, toxicologists, and physiologists on whether the consequences of the toxic gases or materials are additive or synergistic in nature and what effect the ingestion of sublethal concentrations of several toxic gases will have. Animal studies to date have not been fully conclusive, especially if the toxic substances represent the three major categories defined above. Also the problem of extrapolating animal results to humans remains. Whatever the answers, a person is exposed to a very dangerous atmosphere during a fire.

[4] T. D. Spencer, "Effects of Carbon Monoxide on Man and Canaries," *Ann. Occup. Hyg.* (London) **5**, 1962, 231–240.

"Overcome" Casualties

The "overcome" casualties of fire receive treatment at the scene or must be transported to hospitals for further treatment. They may or may not recover. Smoke inhalation can be serious or fatal in a short time. Many fatalities are at the fire scene where exposure to toxic gases may have been measured in minutes. If they survive for a short time and then die, they have usually developed respiratory difficulties, such as edema, inhibiting effective transfer of oxygen to the blood. This is in contrast to asphyxiants that interfere with the supply of oxygen to the body tissue. Burns are relatively rare as cause of death but can easily mask the asphyxiating causes in the absence of detailed investigations.

The major chemical asphyxiants which can contribute to the "overcome" problem are carbon monoxide and hydrogen cyanide. Detection of hydrogen cyanide involvement is elusive. Hydrogen cyanide has been detected as a pyrolysis product of nitrogen-containing substances (such as wool, nylon, and polyurethane) but there is no firm evidence that anyone has died or even been hospitalized because of cyanic poisoning. However, recent information indicates that dangerous levels of cyanide can be reached.

Systems Approach

When a person dies as a result of a fire it is difficult to reconstruct causes and consequences in detail. It is a complex closed-loop system with feedback. Analysis requires use of available applicable data as well as information obtained from in-depth analysis of fire fatalities. This involves gathering physical data about the fire, attempting to define the fire environment, defining the medical consequences, and reviewing and analyzing applicable research results in an attempt to understand the pertinent mechanisms (physical, clinical, pathologcial, etc.). Detailed case studies, biochemical studies, and chemical studies must be made. Figure 2 is an attempt to depict the pattern in a systems context.

The scene of the fire is investigated to determine ignition source, first items of ignition, spread factors, and materials involved. The resulting information aids in defining the fire situation and provides some insight into the toxic atmosphere present during the fire. Interpretations, extrapolations, and conclusions drawn from the data points are based on experience or reports by the fire service and research communities.

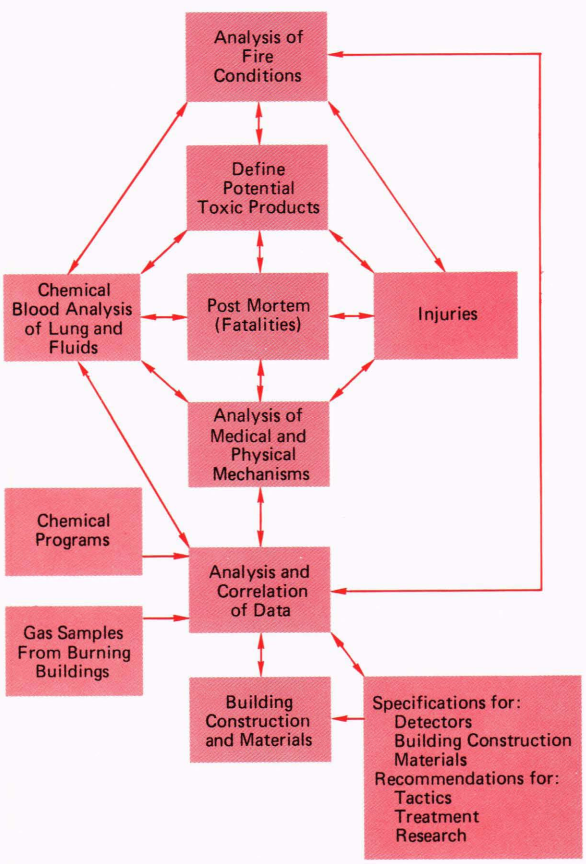

Fig. 2—Systems approach to fire casualties problem as a closed-loop system with feedback.

Extensive pathological, physiological, and toxicological post-mortem analyses are performed to fix the medical cause of death and possibly explain failure to escape.

Chemical and biochemical tests are performed to detect volatile organic gases by lung outgassing, analysis of tracheobronchial tree scrapings, materials identification, and analysis of soot scrapings obtained from the fire scene. Resultant data are used to correlate the conditions in the external atmosphere with analysis of the victim's internal organs.

Program Organization and Functions

A function diagram of the six major areas of participation of the various organizations is shown in Fig. 3. These areas are:

1. Program Coordination—APL/JHU has the primary responsibility of coordinating the study.
2. Post-Mortem Analyses—The Maryland State Medical Examiner provides detailed pathological and toxicological analyses of fire fatalities. This includes carboxyhemoglobin and blood alcohol levels as well as possible drug involvement. As a result of a special blood cyanide study, accurate and meaningful post-mortem blood cyanide levels are now being measured. Heart condition is given careful scrutiny in order to evaluate possible carbon monoxide—heart disease interactions.
3. Field Investigations—The Maryland State Fire Marshal and his staff, local county, and Baltimore City fire investigators provide routine reports on physical aspects of the fires and the demographic information about the victims. An APL fire investigator visits the scene in an attempt to obtain samples of materials that were involved in the fire, soot samples, and the data provided by the fire department investigators.
4. Biochemical and Chemical Analyses—Analyses are made by APL and the National Bureau of Standards on biological and other samples ob-

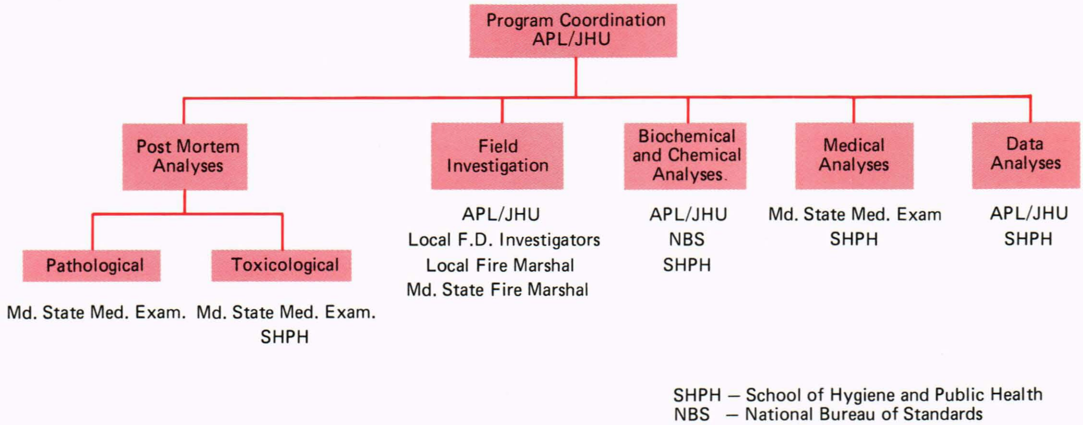

Fig. 3—Function and organization chart indicating areas of effort and organizations participating in fire casualties study.

tained during the autopsy and at the fire scene. Lung tissue for outgassing, tracheobronchial tree scrapings for metal analysis, fire-involved materials, and soot are analyzed.

5. Medical Analyses—When the post-mortem and biochemical data are available, a medical group analyzes them. A judgment is made about the cause of death and, if possible, a reason is given why escape did not take place. The Medical Examiner and School of Hygiene and Public Health provide these functions.
6. Data Analyses—All data for each case are analyzed to correlate the physical, medical, and other findings. At this time, conclusions about fire fatalities can be drawn that may aid in understanding the conditions and allow suggestions of practical solutions. The entire group is responsible in this area with most of the effort centered at APL.

Sample Population

The fatality program was designed to include primarily "overcome" cases in the State of Maryland that did not involve extended hospitalization. Maryland State Law requires an autopsy on all victims of violent death (which includes fire). However, medical examiners have the authority to waive an autopsy if, in their opinion, the cause of death is "obvious." In the early stages of the study, in particular, some of the fire fatalities were not autopsied and could not be included in the overall analysis. Persons who die in explosions or in automobile accidents with attendant fires are included in the data base if fire was the primary cause of death.

Case Data and Results

From September 1971 through December of 1974 there were 206 fire fatalities that met the time and autopsy criteria of the study, i.e., the victim must have died within six hours of the fire incident and an autopsy must have been performed. This represented approximately 50% of the fire fatalities that occurred in the State of Maryland during the study period. Approximately 45% occurred in the City of Baltimore, where all fire fatalities of interest were autopsied. Since between 25 and 30% of the fire fatalities in the State of Maryland occur in Baltimore, the overall results are somewhat biased toward Baltimore.

Approximately 140 fatalities were not submitted by the local authorities for detailed autopsies so were not included; there is no reason to believe that the omission affects the conclusions of the study. However, the seventy fatalities (20% of the total) that occurred six hours or more after rescue had quite different case histories.

The 206 fatalities occurred in 172 fires throughout the State of Maryland. There were 157 fires in residences (e.g., house, apartment, mobile home, etc.). Fifteen others occurred outdoors or in an auto or other vehicle. There were no fatalities in industrial or manufacturing fires, nor were there any airplane fire deaths.

Sixty-two people died in 29 of the fires; i.e., 30% of the victims died in 17% of the fires. Not all of these victims are included in the study since autopsies were not performed on all of them. In the reported data there were no more than four fatalities in any single incident. (However, it should be noted that in several more recent fires, seven or eight persons have died in the same fire.)

The suspected causes of the fatal fires in this study are given in Table 5. "Smoking" covers misplaced cigarettes, cigarettes discarded in waste-baskets, etc. This is by far the greatest contributor to fatal fires in Maryland. Fifty-two percent of the fires are traceable to "smoking," the remainder being due to a large variety of causes.

Human error is a key problem as may be seen by Table 5. Smoking and careless use of matches and candles together account for 61% of the fatal fires. Many of the flammable liquid fires can be attributed to mishandling and storage, and some of the fires classified as "other" are caused by lack of proper precaution.

The causes of fires in Table 5 differ significantly from fires which result primarily in damage to property. Malfunction of heating and electrical equipment and kitchen-originated fires are found to be the predominant cause of property damage.

Fires caused by "smoking" also require attention to the involvement of alcohol, a factor in 70% of the "smoking" fires. More than one-third of the fires are due to the combination of alcohol use and smoking.

Alcohol must be considered a serious problem in the ignition, detection, and escape phases. The data indicate that men in the "40 and over" age bracket are heavy contributors to fires in which smoking and alcohol are both involved.

Figure 4 shows the age distribution and alcohol involvement of fire victims. These data are absolute values and are not normalized to population data. Note that young children and adults over 60 are more frequent fire fatalities than people in other age brackets. Several reasons are suggested. The very young have not physiologically matured to withstand the toxic fire atmosphere, and older people succumb to the toxic stresses. The young are unable to escape on their own and are frequently lost in fires.

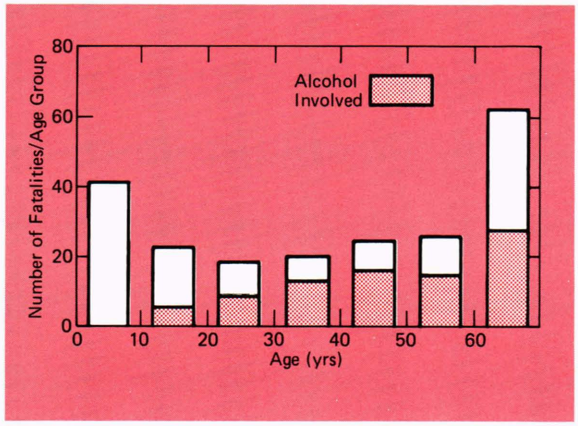

Fig. 4—Age distribution and alcohol involvement in the fire fatalities included in the APL/JHU study for the period Sept. 1971–Dec. 1974.

Since smoking-related fires are most frequent, it is not surprising that most fatal fires originate in the bedroom and living room. Fires originated in the bedroom in 49% and in the living room in 22% of the incidents (see Table 6). The listing of room origin as shown in this table differs significantly from estimates of the most frequent point of origin of all fires, which is the kitchen. This difference must be considered in the design

TABLE 5

CAUSE OF FATAL FIRES AS INDICATED BY FIRE INVESTIGATORS FOR THE TIME PERIOD SEPTEMBER 1971–DECEMBER 1974 (172 FIRES)

"Smoking"	52 %
Careless use of matches	7
Flammable liquids	8
Heating equipment	6
Electrical malfunctions	4
Careless use of candles	2
Other	11
Unknown	10
	100 %

TABLE 6

ROOM OF ORIGIN APL/JHU FIRE FATALITY STUDY SEPT 1971–DEC 1974 (172 FIRES)

Bedroom	49 %
Living room	22
Kitchen	7
Basement	6
Dining room	1
Other	12
Unknown	3
	100 %

of countermeasures for reducing fatal fire losses.

The location of the victim is shown in Table 7. 40% of the victims were found in the room of origin of the fire.

TABLE 7

VICTIM LOCATION
APL/JHU FIRE FATALITY STUDY
SEPT 1971–DEC 1974
(206 FATALITIES)

Bedroom	49 %
Living room	17
Hallway or stairs	14
Kitchen	2
Bathroom	2
Closet	3
Other	10
Unknown	3
	100 %

A large number of the fires occur while the victims are in bed. Another problem exists with children playing with matches—hiding in the bedroom offers them privacy. Often when a fire starts they hide under the bed or in the closets of the rooms and are not found in frantic searches when the fire is detected. Other people fall victims in the bedroom because they have entered that area attempting to rescue others or to save valuables. Others appear to be using the bedroom as an escape route. Thus the very privacy of the bedroom area appears to contribute to the danger.

Victim location shows that about 80% of all victims physically able to escape were alerted and attempted to escape. In some cases they had sufficient time to give an alarm to others or to notify the fire department, but delayed escape. It is clear that there is an insufficient understanding of the several dangers presented by fire. Erroneous decisions are frequently made. People use precious time attempting to extinguish the fire and in some cases do not alert others.

The question of time requires discussion. Very little reliable information is available concerning the lapse of time between ignition and alert for need to escape from the hostile environment. Some attempted escapes fail because of panic or improper moves, but most victims appear to have enough warning to escape. In some cases (smoldering types of fires), hours are available to detect the problem, sound an appropriate alarm, and escape. When information about the "smoking" type fire is sought, people often remember having handled or having seen cigarettes handled approximately two to three hours prior to the detection of the fire. In other fires (flash fires) the time factor is in the order of minutes. The real time safety factors are not known.

Another point of interest is the time of day that the fatal fires occur. Many fire department personnel believe that *all* fatal fires occur between midnight and 4 a.m. There are peaks during this time period, but it only accounts for 31% of the fires. The time of day distribution in a study of the fire fatalities in Maryland during 1967–1968[5] showed similar results.

Fire fatalities increase during the colder months. This fact cannot be attributed completely to the use of heating equipment during that portion of the year. Table 5 showed that only a small fraction of fires resulted from faulty heating equipment. Closed buildings are poorly ventilated resulting in high concentrations of toxic products within.

The medical causes for fire fatalities are primarily based on measurement of the carboxyhemoglobin content (i.e., the amount of carbon monoxide attached to red blood cells). The

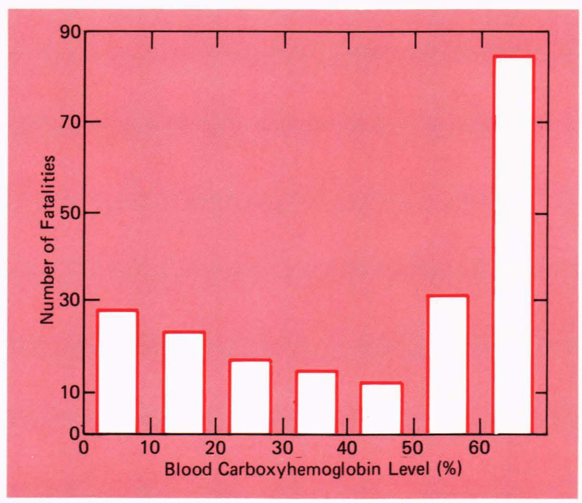

Fig. 5—Distribution of blood carboxyhemoglobin levels included in the APL/JHU study for the period Sept. 1971–Dec. 1974.

[5] B. Halpin, *Sample Survey of Maryland Fire Fatality Data*, APL/JHU Report FPP TR 10, Nov. 1971.

distribution of blood carboxyhemoglobin (COHb) levels is shown in Fig. 5. It is assumed that a 50% level is sufficient to be assigned as the cause of death. Thus, approximately 50% of the fatalities studied are classified as due to carbon monoxide poisoning. In 30% of the fatalities a combination of blood carboxyhemoglobin (between 20% and 49%) and other factors such as pre-existing heart disease, high levels of blood alcohol, or burns was blamed. These combinatory effects are being more carefully analyzed to determine the appropriateness of the conclusion.

The two groups, both involving carbon monoxide, account for 80% of the fatalities. In half of the remaining cases, which include self-immolation, victims have very low blood carboxyhemoglobin levels and usually insufficient skin surface burns to cause death. It has been concluded that laryngeal spasms occur which do not release until the victim is asphyxiated.

In the remaining 10% of the cases sufficient toxicological or pathological reasons for death cannot be found. The types of fire in these cases may indicate that some other as yet unknown toxic agents are responsible. These incidents are under special study.

Importantly in victims having a COHb level of 15% or more, significant soot deposition can be found in the lower respiratory system. The significance of this may be that soot is a vehicle for transporting toxic agents, such as HCl[6] and HCN and other substances such as metal oxides, that may cause toxic poisoning and/or edema leading to severe respiratory complications. One flash fire gave rise to rapid lung edema with heavy soot deposits but a low COHb level.

While synthetic polymeric materials are frequently involved in fires and produce irritating or toxic gases such as HCl and HCN, they have been the primary articles burning in only 5% of the fires reported in this study. Thus, at this point we cannot state that smoke from burning synthetic materials is a significant factor in the fire deaths in Maryland.

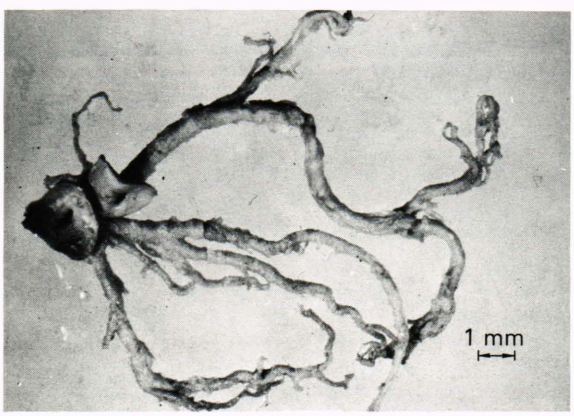

Fig. 6—Arterial tree isolated from the heart.

Heart Study*

During pollution alerts, people with respiratory and heart problems are advised to avoid extended exposure to the outdoors. Atmospheres at a fire scene are highly polluted. It is not surprising, therefore, that persons with pre-existing heart and respiratory disease can be assumed to be in great jeopardy in a fire. As a result it is likely that the deaths of some people can be ascribed to a combination of a sublethal level of carboxyhemoglobin and some degree of atherosclerosis and lung disease.

A special study of the coronary trees of fire victims was undertaken in an attempt to define the interactions between heart disease, carbon monoxide and its fatal consequences. No corresponding study of lung disease and carbon monoxide exists. The approach is to isolate the arterial tree from the heart of the victim (Fig. 6), each branch to be sectioned and examined millimeter by millimeter. Figure 7 gives a view of the sections of a branch which indicates varying degrees of closure of the lumen.

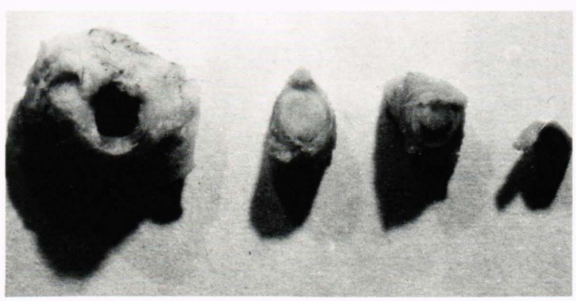

Fig. 7—Sections of a branch of the arterial tree showing various degrees of closure.

[6] J. P. Stone, R. N. Hazlett, J. E. Johnson, and H. W. Carhart, "The Transport of Hydrogen Chloride by Soot from Burning Polyvinvl Chloride," *J. Fire & Flammability* **4**, Jan. 1973, 42–51.

* This study is under the direction of Dr. R. A. Fisher (State of Maryland Medical Examiner).

It is currently believed that there is a relationship between the degree of closure, the distance of the blockage from the heart, the arterial branch in which the blockage is located and the CO level. This hypothesis has a scoring system for the severity of the coronary stenosis.

Since the results are probably influenced by parameters such as age, sex, race, heart condition, blood carboxyhemoglobin levels, medication, and other gases, it is quite difficult to isolate the appropriate parameters.

To establish to what extent age was a factor, Table 8 was obtained for 72 people who were victims of residential fires. It is interesting to note the incidence and degree of pre-existing heart disease in the 20–39 year age span, since this does not fit the pattern of heart disease in the normal population. It is plausible to conclude that in the Fatality Study there is a strong tie between heart disease and the fire deaths.

Figures 8 and 9 attempt to show the distribution of blood carboxyhemoglobin versus the coronary stenosis score (percent of narrowing) for men and women. A coronary stenosis score of 30 has been selected as a critical point.

If the hypothesis were true that people with pre-existing heart disease cannot tolerate as much carbon monoxide as those with unimpaired hearts (because of inability to compensate for the diminished oxygen delivery), then one would expect to see in Figs. 8 and 9 a significant number of cases with a stenosis score of 30 or more with blood carboxyhemoglobin levels below 50%. The data

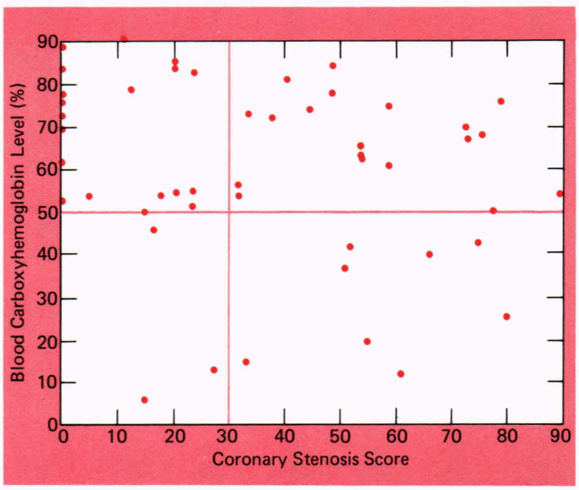

Fig. 8—Carboxyhemoglobin level versus coronary stenosis (51 men).

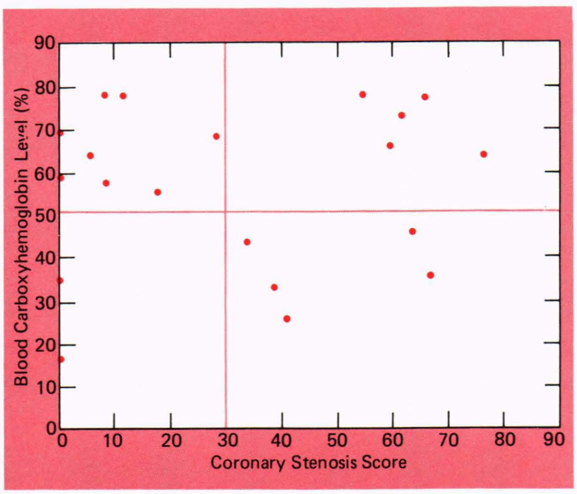

Fig. 9—Carboxyhemoglobin level versus coronary stenosis (21 women).

TABLE 8

PERCENT CORONARY ARTERIAL NARROWING IN FIRE VICTIMS AS A FUNCTION OF THE VICTIM

	Percent Narrowing					
Age (Yrs)	*0 to 24*	*25 to 49*	*50 to 74*	*75 to 89*	*90 to 100*	*Total*
20 to 39	9	1	3	4	6	23
40 to 49	1	0	2	0	9	12
50 to 59	1	2	2	1	6	12
60 to 69	2	0	2	2	9	15
70 +	1	0	3	0	6	10
Total	14	3	12	7	36	72

in Figs. 8 and 9 partially bear this out but do not fully explain the sizable number of fatalities of people with severe heart disease (i.e., high stenosis score) who survived long enough to build up a carboxyhemoglobin level of about 50%.

Cyanide Study*

Hydrogen cyanide (HCN) gas is a chemical asphyxiant which inhibits enzyme catalysts in the cell thereby impairing the use of oxygen by body tissues. Thus, cyanide poisoning is a form of asphyxia.

Cyanide is unstable in post-mortem blood since it is metabolized to thiocyanate by rhodinase, an enzyme which is found in normal blood serum. Therefore, the determination of accurate quantitative levels of blood cyanide has been a considerable problem for toxicologists, particularly when the cyanide enters the respiratory system as a gas.

Since HCN is a product of the combustion of such substances as wool and polyurethane foams, some HCN will be present in the fire gases when these materials are burned. Soot samples taken at fire scenes have shown cyanide adsorbed on the soot particles. It was of interest, therefore, to determine if cyanide could be found in the fire victims.

A special study was initiated to evaluate techniques for cyanide measurement. It was found that a blood sample has to be obtained within 24 hours of death because of the stability problem. Once separated from blood, the cyanide can then be stored as a solution and refrigerated. With proper handling procedures, reproducible, accurate blood cyanide levels can be obtained.

Determinations have been made on fire victims since January of 1975. A total of 77 cases have been analyzed with the blood cyanide ranging from below the limits of detectability (0.01 μg/ml) to 4.36 μg/ml. The latter is considered by most toxicologists to be above lethal level and could, therefore, be considered as a primary cause of the fatal outcome.

With the growing capability of measuring levels of a variety of toxicants in addition to carbon monoxide, it becomes increasingly important to identify the materials burned in the fatal fires as well as other pertinent fire scene data such as body location. The presence of a significant blood cyanide level, together with a high cyanide level in the soot samples, as well as of materials which can produce cyanide during a fire would tend to substantiate claims that cyanide is present and responsible for incapacitating some of the fire victims. If found in a significant number of cases it would shed more light on the possible effect of a sublethal level in influencing behavior in ways which make escape from fires difficult or impossible.

Analysis of Soots and Organic Vapors*

Controlled combustion in furnaces and engines, where excess air is available, rarely produces toxic or objectionable combustion products. However, in most fires, where there is not only generally a substantial deficiency of air and poor mixing of fuel and air but also frequently a substantial thermal breakdown of materials into substances that are not involved in the combustion reactions, the amount and variety of objectionable products can be very large indeed. Thus, the smoke and gases from fires play an important role, and in the case of fire fatalities a dominant role. Their consequences are not confined to persons caught unawares in fire situations, but extend to the fire fighters who are required to do their suppression work inside gas-filled buildings.

The chemical complexity of the reaction products is enormous. It depends so much on the nature of the involved materials, their spatial arrangement, the level of radiation that leads to thermal breakdowns, oxygen concentration, and other variables that it is virtually impossible to make predictions about composition and quantity. However, from many model experiments and laboratory tests, a substantial body of empirical information has been accumulated that gives some guidance as to what can be expected. Thus, the almost universal presence of carbon monoxide, frequently in very high and toxic concentrations, is well established. If the fuel contains nitrogen (as is the case for wool, nylon or polyurethane plastics) hydrogen cyanide is formed in substantial amounts. Polyvinyl chloride (PVC) is a copious source of hydrochloric acid on burning.

* This study is being directed by Dr. Y. H. Caplan (Chief Toxicologist, State of Maryland Medical Examiner's Office).

* Dr. Geraldine A. Fristrom and D. O. Shapiro conducted the experiments and data analysis for this section.

Aldehydes, well known as irritants of eyes and mucous membranes, are common constituents of fire gases. In addition, complex liquid tarry materials, ill-defined solid soots or mixtures of the two are readily formed, particularly from synthetic polymers such as polystyrene or polyurethane.

In addition, in real-life situations where the fires are not confined to one substance alone, a number of additional combustion products may appear. When involved in fires that generate reducing atmospheres at high temperatures, metals, such as copper or cadmium from electrical appliances, inorganic substances, such as lead or titanium from paint pigments, or intended flame inhibitors containing bromine or antimony, can turn into gaseous products or become aerosols of small particle size which are carried with the other gaseous reaction products throughout the structure and into the lungs of occupants.

A program is underway to clarify the nature of the substances that are actually ingested by persons who have become fire casualties, apart from such gases as CO or HCN that are measured as part of the general autopsy. This is done by a detailed chemical and instrumental analysis of the "internal" soots that can be isolated from the tracheobronchial trees of fire victims and of "external" soot deposits that are collected at the fire scene from walls, mirrors, or windows. The former will not give evidence for compounds that are readily dissolved by body fluids (such as hydrochloric acid). The latter, on the other hand, presents a total cross-section of all the particles that are deposited during the course of the fire, extending well beyond what may have been ingested by the fire victim. Nevertheless, a rough correspondence should exist between the two.

The results of this program indicate that sooty deposits are found in the trachea and bronchia of nearly all the fire casualties. Furthermore, the "external" and "internal" soots contain a surprisingly large number of inorganic metals, frequently in large amounts (Tables 9 and 10). The chemical nature of the metallic compounds in terms of composition or particle size is not yet known. Nor are the mechanisms clear by which they were transported from the source into the victims' lungs. It raises as yet unresolved questions concerning their clinical significance, particularly in those instances where fire exposure had led to serious injury rather than death. However, it has been noted that "internal" soots may contain very large amounts of adsorbed hydrochloric acid (10% by weight has occasionally been observed), presumably from chlorinated polymers, which can produce severe chemical burns in the lung tissue. Clearly, proper antidotes should be provided quickly if such large amounts of a corrosive acid have been ingested.

Detection of volatile organic substances has proved somewhat difficult. A number of sub-

TABLE 9

FIRE CASUALTIES
TRACHEOBRONCHIAL TREE ANALYSES
(ATOMIC ABSORPTION)

	Metals (μg/g *Sample*)				
Sample	*Cd*	*Cu*	*Mn*	*Pb*	*Sb*
1	—	344	—	—	—
2	28	33	—	708	—
3	4	227	15	30	—
4	—	376	28	—	—
5	28	13	—	38	638
6	14	—	—	767	—
7	5	—	—	—	643
8	29	9	—	580	182
9	26	16	—	363	—
10	24	8	—	608	58
11	19	—	—	453	—

— indicates concentration was below the detection limit.

TABLE 10

FIRE CASUALTIES
EXTERNAL–INTERNAL CORRELATIONS
(μg/g OF SAMPLE)

	Cd	*Cu*	*Mn*	*Pb*	*Sb*	*Cl⁻*
Case 1						
Ext.	41	30	28	174	6847	101090
Int.	5	—	—	—	643	
Case 2						
Ext.	69	48	41	394	—	42450
Int.	87	45	—	150	—	
Case 3						
Ext.	707	64	40	7045	1102	21420
Int. 1	29	9	—	580	182	
2	26	16	—	363	—	
3	24	8	—	608	58	
4	19	—	—	453	—	
Case 4						
Ext.	55	20	—	1855	—	
Int. 1	2	11	1	11	—	
2	17	16	—	40	—	
3	20	14	—	44	—	
4	23	9	—	37	—	

— indicates concentration was below the detection limit.

stances like ethyl alcohol or acetone are frequently present but cannot specifically be attributed to the fire gas atmospheres. However, a careful determination of gases released from outgassed lungs of fire victims made it possible to isolate acetaldehyde as a specific substance that must have had its origin in the fire combustion products.

The conclusion that has been reached thus far is that the "minor" toxic constituents that are found in or suspected to have entered the lungs of fire victims can rarely be held responsible for fire fatalities that occur quickly. However, in delayed cases, where the effects of carbon monoxide (or, possibly, of hydrogen cyanide) were not fatal by themselves, the subsequent medical consequences may be strongly affected by the nature of the "minor" products. Aldehyde irritations, acid burns, and metal toxicity are all potential contributing factors in varying degrees. Their nature and severity could be ascertained, and proper countermeasures taken, if "external" soot analyses were carried out routinely or if "internal" soot samples were obtainable for analysis.

Exposure of People to Fire Gases (Project Smoke)*

"Project Smoke" refers to a series of investigations into the acute and chronic consequences of exposure of civilians and fire fighters to the fire atmosphere. The acute effects of exposure to the fire atmosphere may be determined either by measuring levels of exposure to toxic gases or by analyzing the medical consequences of such exposures and correlating the findings of each approach. The chronic effects of single or repeated exposure can be obtained by a long-term study of heart and lung disease in fire fighters.

Levels of Exposure—The levels of acute exposure to fire atmospheres were measured in 520 fire fighters in the City of Baltimore during a six-month period. Carbon monoxide was selected for measurement as it is ubiquitous in fire atmospheres and is readily taken up by the blood to form carboxyhemoglobin. In order to determine the upper levels of this exposure under actual working conditions on the fireground, blood samples were drawn at the scene of most major fires in Baltimore from fire fighters who had previously volunteered for this study. No alteration in normal fire fighting procedures was involved. The blood samples were then analyzed for carboxyhemoglobin levels.

Our findings indicate that fire fighters are indeed exposed to elevated levels of carbon monoxide and that this occurs whether or not the fire fighters are cigarette smokers (Figs. 10 and 11). Neither the amount of smoke present at the fire nor the length of time spent fighting the fire correlated well with levels of carboxyhemoglobin. Since carbon monoxide is colorless and odorless, fire fighters and others may not be fully aware of the potential hazards of exposure to fire-generated gases.

The use of a self-contained, well fitted compressed-air breathing apparatus offers protection from gas exposures. However, masks tend to be worn intermittently due to the circumstances of the fire. Our findings show that intermittent use of the mask is associated with elevated carboxy-

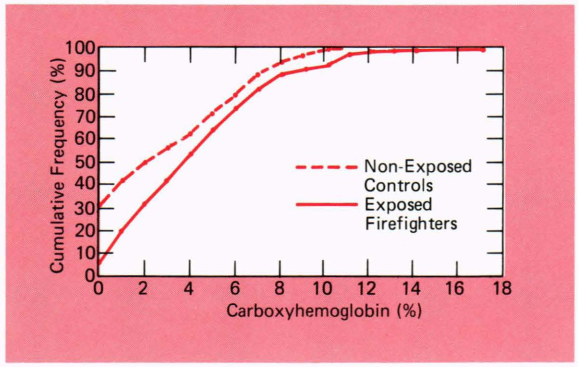

Fig. 10—Cumulative frequency distribution of COHb levels in fire fighters and controls (cigarette smokers).

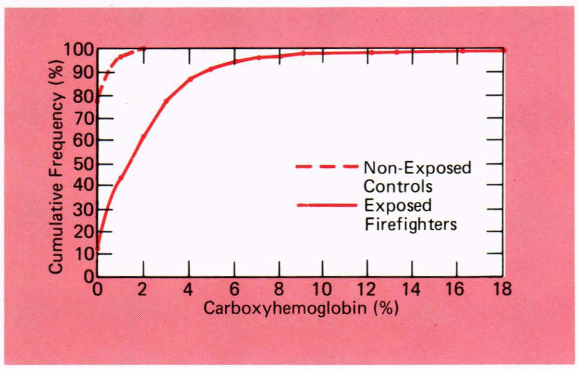

Fig. 11—Cumulative frequency distribution of COHb levels in fire fighters and controls (non-smokers).

* This study is under the direction of Drs. M. Levine and E. P. Radford, Jr. (The Johns Hopkins University, School of Hygiene and Public Health).

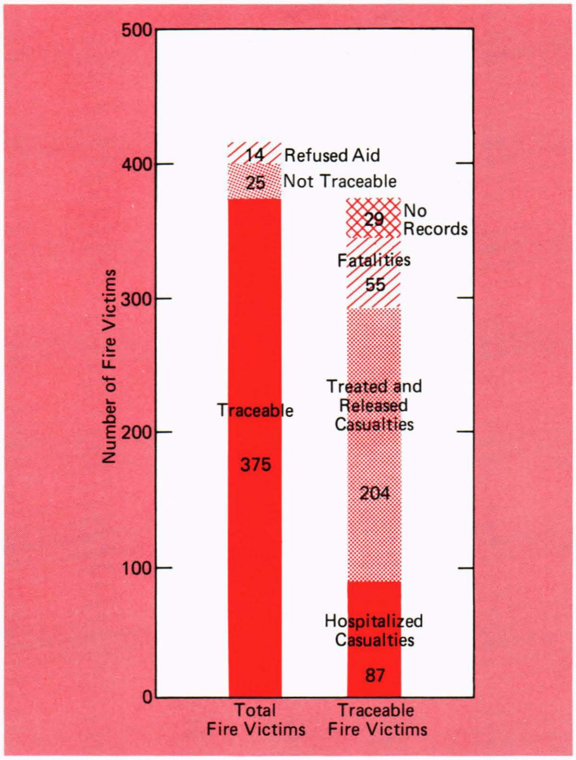

Fig. 12—Analysis of hospital records on fire victims in Baltimore City, Jan. 1973–Mar. 1974.

hemoglobin levels and tends to reverse the protective effect of mask wearing.

Men with the highest carbon monoxide intake differ from the rest of the study group in their more frequent heavy smoking histories and/or less frequent use of protective masks.

These findings indicate that the design of breathing apparatus must be improved so that it may be used more easily and for longer periods of time. In addition, attention should be paid to proper procedures for mask use.

Consequences of Exposure—Outcomes of acute exposures were determined from hospital records of fire victims in Baltimore City. Four hundred and fourteen persons were on record with the Fire Department as having been involved in a fire during the 14-month period from January 1973 to March 1974. Fourteen refused any aid or treatment and 25 could not be traced (Fig. 12). Of the remaining 375 victims who were taken to the hospitals, no record was available of the exact treatment of 29 patients. Thus, the course of 346 victims was followed in detail.

Approximately 15% of the casualties from fires (55) did not survive. Of the 55 persons who died, 80% survived for less than one day, and the remaining 20% received more extended hospital treatment prior to their demise. Approximately 25% were hospitalized for treatment (87), and the remaining 60% were treated and released. The ratio of hospitalized casualty cases compared to fatalities (87/55) is substantially lower than is generally quoted in published estimates of fire injuries. In the majority of fatal cases, the primary cause of death as determined by autopsy was inhalation of the toxic products of combustion. However, survivors suffered most frequently from burn injuries (Fig. 13).

Chronic Effects—The results of chronic exposure to the toxic products of fire atmosphere is of great interest to fire fighters. To estimate the long-term effects of such exposures, we have initiated cross-sectional epidemiologic studies of the occurrence of chronic heart and lung disease in fire fighters. These investigations are now in progress and involve measurements of pulmonary function, blood pressures, and electrocardigrams, as well as a detailed health questionnaire. These findings will be correlated with the degree of exposure to fire atmospheres. Mortality studies are also in progress to determine if any specific cause of death can be related to the fire fighting occupation as, for example, quantity of exposure.

The data from this broad series of investigations will provide a comprehensive view of the acute and chronic consequences resulting from inadvertent or occupational exposure to the fire environment and may suggest means for their prevention and control.

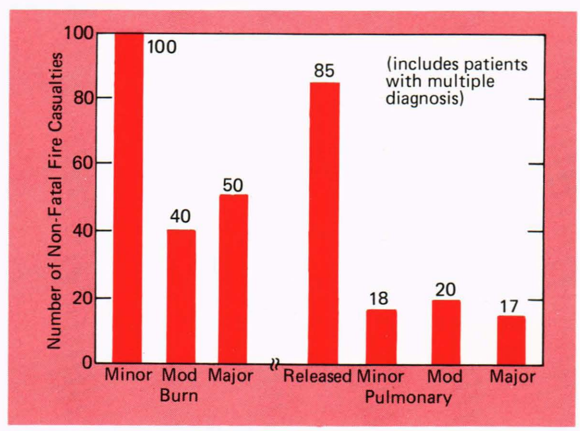

Fig. 13—Diagnosis of fire injuries in Baltimore City, Jan. 1973–Mar. 1974.