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HUMAN FATALITIES FROM UNWANTED FIRES

This article is based largely on a detailed investigation of 463 fire deaths in the State of Maryland in 1972-77. It discusses toxic gases as the primary cause of death, cigarettes as a principal ignition source, and alcohol as a significant contributory factor.

INTRODUCTION

Compared to the very large number of fires that burn under human control, only a few are unwanted. Some of the latter can cause extremely costly damage and unnecessary loss of life. It is estimated that, during a one year span, about three million fires will require intervention in the United States by public fire service units[1] and that the monetary losses will be greater than 10 billion dollars. Possibly ten times as many smaller unreported fires are experienced.

A recently concluded APL-directed study[2] surveyed a particular set of unwanted fires, i.e., those that led to human fatalities. Although such fires are moderate in number (fewer than 10,000 annually in the United States) compared to the total and are relatively modest in consequences compared to the loss of life from the more common human diseases, the several thousand fire fatalities every year represent a substantial fraction of the deaths from potentially avoidable "accidental" causes. Since they are accompanied by large economic losses as well, it is generally agreed that the current level is unacceptably high and should be reduced.

To cut fire fatalities substantially, their causes as well as the links in the subsequent chain of events that finally results in death must be understood. Unfortunately, with few exceptions, the previously available statistics on fire deaths were difficult to analyze because detailed information about the physical causes of the fires and the medical consequences to humans was not generally at hand. In the absence of such data, neither the absolute rates of fire fatalities nor the statistical trends provide useful guides for developing effective countermeasures.

GENERAL STATISTICS

Annually, about 17,000 fatalities from accidental or deliberately set fires are recorded worldwide, placing them in 70th place among the 273 causes of death recognized by the World Health Organization.[3] They are documented in the death certificates from many countries that use reasonably comparable recording procedures. Fires account for about 0.5% of all deaths from disease and accidents.[3]

This international data base must be interpreted with some caution. Several large countries (the USSR, India, and China) and many smaller ones do not publish data on fire-related deaths, nor do all countries analyze their statistics with the thoroughness typical of most industrialized nations. Therefore, the statistical record is bound to err on the low side.

When fire-related death is rapid, the diagnosis of its cause and its correlation with the fire event are relatively simple. But if death is delayed by weeks or months, the relationship with the fire may become obscured by the time the death certificate is prepared. In complex circumstances, such as deaths from vehicle crashes that are accompanied by fire, assignment to a single cause is difficult or impossible without a thorough investigation, a path rarely taken in interpreting accidental fire deaths.

The worldwide data for 1974 show that fire fatality rates vary a hundredfold from a minimum of 0.1 per hundred thousand population per year in the Philippines to a maximum of 10 in Egypt (Table 1). The death rate may vary considerably within regions of individual countries, ranging in the United States, for example, from 0.9 in Hawaii to 10.7 in Alaska (Fig. 1). Marked differences can also exist within specific subdivisions. For example, Maryland has an average fatality rate of 3.3. The Baltimore urban area shows a rate of 3.95, four large suburban counties have a rate of 2.6, and 19 rural counties have a combined rate of 4.16. Within the given region, these rates are sufficiently unchanging over a period of several years to suggest that substantially constant contributory factors are at work.

Efforts to account for these wide differences in national statistics by correlations with a single social or economic indicator have proved unsuccessful. Correlations with per capita income (based on gross national product) do not account for the low fatality rates in the Netherlands and Switzerland vis-a-vis the high rates in Canada and the United States. Although the careless handling of cigarettes can be a major source of ignition (as is the case for Maryland), the very low rates of fire

Table 1

FIRE FATALITIES AND RATE PER 10^5 POPULATION (1974)[3]

Country	*Number*	*Rate*
Egypt	3499	10.0
Kuwait	58	6.9
Canada	805	3.6
Scotland	161	3.1
United States	6236	2.9
Cuba	260	2.9
Mexico	1376	2.4
Finland	106	2.3
Sweden	132	1.6
Australia	197	1.5
Japan	1677	1.5
England and Wales	748	1.5
France	743	1.4
Spain	328	0.9
Israel	25	0.9
West Germany	530	0.9
Thailand	314	0.8
Switzerland	42	0.7
Italy	331	0.6
Netherlands	85	0.6
Philippines	46	0.1

fatalities in Switzerland, Italy, and the Netherlands do not reflect the substantial cigarette consumption in these countries. Similarly, the consumption of alcohol (which contributes importantly to the fire fatality rate in Maryland) is high in Italy and France, where the fire fatality rates are low compared to Canada and the United States. Yet it is widely believed that fires and fire casualties should

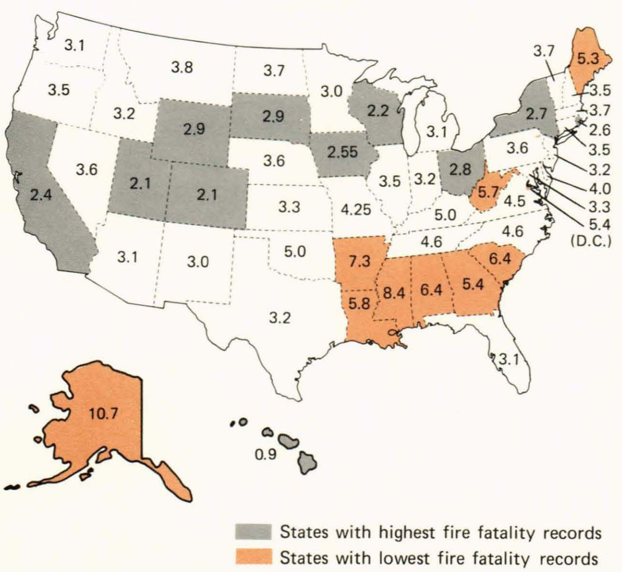

Fig. 1—Per capita (× 10^{-5}) fire fatality rates in the United States (averaged from 1954 to 1972) based on death certificates as reported in *Vital Statistics of the United States.* Low per capita fire fatality rates range from 0.9 for Hawaii to 2.9 for Wyoming. High rates range from 10.9 for Alaska to 5.3 for Maine.

correlate with properly selected and weighted social, economic, and physical indexes that measure human or system malfunctions. A successful correlation, involving six parameters, was presented in the APL study of Maryland fatalities.[2]

DETAILED STATISTICS

Few studies on fire fatalities have gone beyond the collection of vital statistics data. Four investigations, two dealing with fire fatalities in Maryland[2] and Utah[4] and two concerned with fire fatalities in Scotland[5] and Japan,[6] represent the total ongoing efforts. Their purpose is to correlate the demographic data on fire victims with the causes of fires and their medical consequences, and to draw conclusions about preventive measures and improved medical treatment of survivors.

The difficulties encountered by such studies, and the reason that only a few have been undertaken thus far, are that they require close collaboration among the fire services that furnish much of the information about the fire events, the fire investigators who reconstruct the physical causes and subsequent development of the fires, the pathologists and toxicologists who determine the medical consequences based on detailed autopsies and biomedical measurements of fire casualties, and the system analysts who assemble and interpret the information. Furthermore, without an adequate legal framework that permits detailed medical examination of the fire victims, such integrated studies cannot be performed. The APL study of fire fatalities in Maryland is based on detailed information on fire fatalities that occurred within six hours of the fire and that can be analyzed to produce conclusions about fire death causes and recommendations concerning fire prevention and the treatment of survivors. Figure 2 illustrates the operational framework of this investigation.

DEMOGRAPHIC RESULTS

The population in Maryland consists of 4 million persons, 25% of whom live in 19 rural counties, 25% in Baltimore, and 50% in the suburbs of Baltimore and Washington (four suburban counties). Baltimore is a typical industrial and commercial city with a densely populated inner core. The four counties contain recently built suburban communities. The 19 counties represent a mix of farming communities and small towns in the Piedmont and coastal areas and small towns in the Allegheny Mountains.

The demographic data have been divided into four categories: location, sex, race, and drug use by the victims. Prior state of health (in particular, circulatory impairment) is also significant. Many correlations are possible within the demographic data base and the separately determined physical causes and medical consequences of the fires. The objective of such correlations is to discover specific

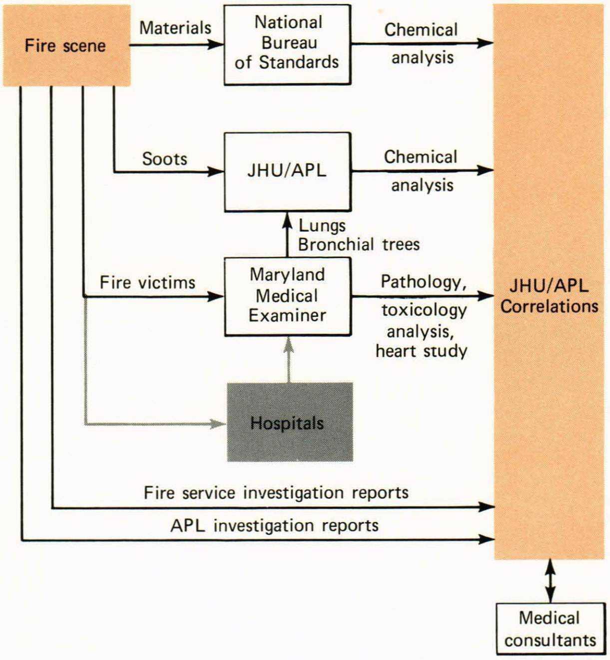

Fig. 2—The operational scheme for fire fatality investigations. Information is obtained at the fire scene, analyzed by several organizations, and correlated by APL.

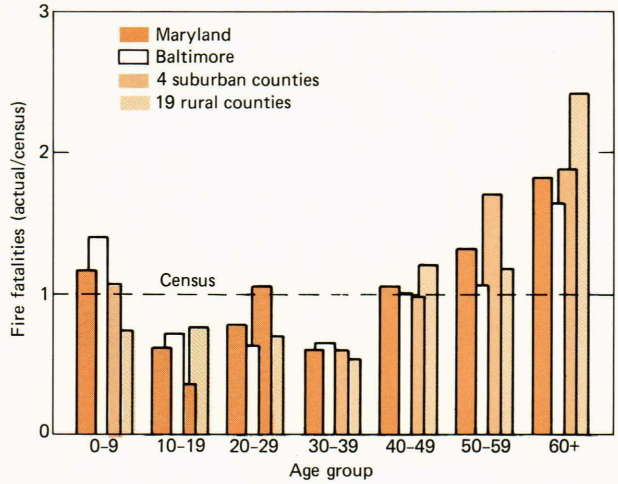

Fig. 3—Fire fatalities as a function of victim location and age. The length of each bar indicates the ratio of the observed age distribution among fire victims to the general population age distribution (1970 census). A ratio greater than 1 indicates that a particular age group suffers a larger loss of life from fires than would have been expected. (Age groups 50 to 59 and over 60 show this high incidence in all locations; for the age group 0 to 9, an especially high incidence is confined to Baltimore.)

circumstances that predispose certain segments of the population to a high risk of becoming fire casualties, and to design appropriate remedial policies.

Location

Fire fatality data for the three areas (urban, suburban, and rural) cover differing living conditions of the population. This is reflected in the fatality rates for the areas: 3.95, 2.6, and 4.16, respectively.

As shown in Fig. 3, persons in the age group over 60 run a substantial risk of becoming fire casualties (approximately twice the census expectation), whereas the value for the age group 10 to 39 (approximately 0.6) falls well below the casualty rate predicted from census data. For Maryland, on the average, the fatality rate for the age group 0 to 9 agrees with the census prediction (the ratio of the observed rate to the predicted rate from the census is 1.15). However, the value for Baltimore (1.39) is different enough from that of the 19 rural counties (0.74) for a location-specific cause to be identified. As discussed below (in the section on race), the fatality incidents for blacks and whites show divergent patterns in the two locations.

Sex

For all age groups, the absolute number of male fire deaths exceeds that of female (on the average, by a factor of 1.5 to 1); it is particularly pronounced in the age group 30 to 59 (Fig. 4). As will be shown later, high consumption of alcohol by men is in large part responsible for the male/female ratio being substantially in excess of 1 at all ages beyond 20.

Race

The distribution of fire fatalities as a function of race shows a divergent pattern with age. A very substantial number of black fatalities occur in the age group 0 to 9 (1.66), which, as Fig. 5 shows, is well above the census prediction and the low value for whites in the same age group (0.65). As a consequence, the age distribution curve for the black population has two peaks (0 to 9 and over 60), while the corresponding curve for whites has only one (50 to over 60). (This pattern is particularly pronounced in urban Baltimore and the four suburban counties.) On an absolute numerical basis, fatalities in the black population always substantially exceed the census-predicted values (tinted bars in Fig. 5).

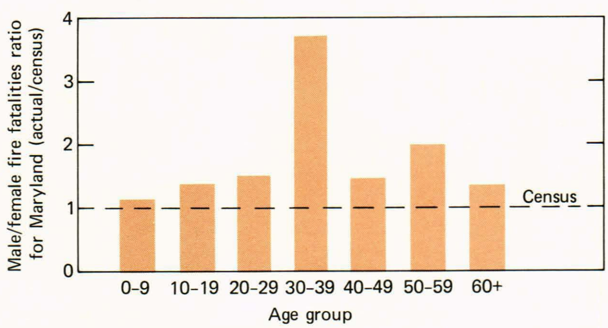

Fig. 4—Fire fatalities as a function of victim sex and age. The length of each bar indicates the ratio of male to female fire victims. Male deaths exceed female deaths, particularly in the ages from 30 to 59.

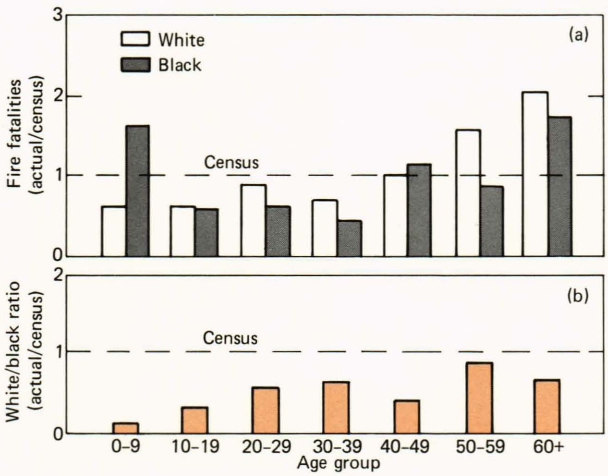

Fig. 5—Ratio of fire fatalities in Maryland (actual/census) as a function of age. The lengths of the white and black bars indicate the ratios of the observed race and age distribution of white and black fire victims to the general race and age distribution (1970 census). The black population has two peaks (0 to 9 and over 60) in which fire fatalities are substantially greater than what would have been expected from a random occurrence of death. The tinted bars indicate white/black fire fatality ratios. A value less than 1 indicates that the number of white fire victims is lower than would have been expected from random occurrence. In all age groups, the black population shows a substantially higher risk than the corresponding white age group.

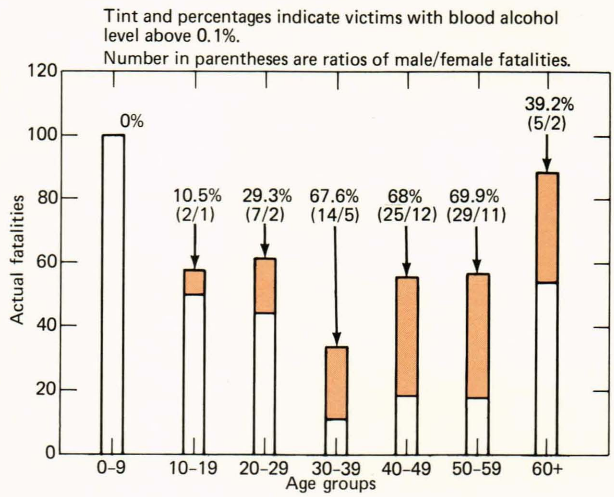

Fig. 6—Alcohol in fire fatalities. Each bar represents the absolute number of fire victims in each age group; the tinted portion represents victims with blood alcohol levels above 0.1% (the legal definition of drunkenness). In ages 30 to 59, more than two thirds of the fire victims were intoxicated. Intoxicated males substantially outnumber intoxicated females.

Drug Use, Principally Alcohol

Fifty percent of all fire fatalities over the age of 20 show a blood alcohol level above 0.1%, the legal level for drunkenness in Maryland (Fig. 6). The fraction of casualties with levels greater than 0.1% rises rapidly from about 30% in the 20 to 29 age group to approximately 70% of all fatalities in the 30 to 59 age group, with a decline to 35% in the group over 60. The common and often very heavy ingestion of alcohol by fire fatalities occurs primarily with men, who account for about two-thirds of the heavily intoxicated cases. This parallels the high alcoholism rates of men in these age groups.

Mind-affecting drugs other than alcohol are rarely found in fire victims and make a negligible contribution to fire losses.

PHYSICAL CAUSES AND HUMAN RESPONSES

Of the fatal fires investigated in Maryland, 85% were caused by human misjudgment or deliberate action, while only 15% were attributable to electrical or mechanical (mostly heating) design faults (Table 2). By far the largest single cause of fires is the careless handling of cigarettes (44.4%). In contrast, automobile collisions in which fire is considered the principal cause of death are relatively rare (3.45%).

Fatal fire incidents are concentrated in the 12 PM to 6 AM period (50.6%), with approximately equal distribution during the remaining hours. Two-thirds of the fatalities occur in the colder months (November-April), with multiple fatalities particularly frequent during this period.

Of the 82% of deaths that occur in residences, four-fifths take place in either the living room or the bedroom. Reconstruction of the escape efforts of the victims is complicated by the fact that their movements cannot be fully retraced. However, with rare exceptions (very young children and invalids),

Table 2

MARYLAND FIRE FATALITIES (1972-1977)
BY CAUSE OF IGNITION[2]

Causes	*Fires*	*Fatalities* *Number*	*Fatalities* *Percentage*
Smoking	135	184	44.4
Heating equipment malfunction	19	33	8.0
Arson/suspicious origin	16	31	7.4
Electrical malfunction	20	29	7.0
Matches	18	27	6.5
Unknown	12	16	3.9
Cooking	10	16	3.9
Suicide	14	14	3.4
Stove	11	14	3.4
Automobile	11	14	3.4
Explosion	8	13	3.1
Flammable substance	9	9	2.2
Set fire	5	5	1.2
Candle	4	5	1.2
Other	3	4	1.0
Total	295	414	100.0

fire victims have been alerted to the presence of the fires and have made unsuccessful efforts to escape. Most of the victims are found in bedrooms (59%). Only 29.5% of the fatalities occur in the room where the fire originated. The majority are overcome while trying to escape from that room or are incapacitated by toxic combustion products that have moved to other inhabited parts of the building.

The major sources of the "first-ignited" material are bedroom and living room furnishings, reflecting the fact that fires start principally in these rooms.

MEDICAL CONSEQUENCES

A detailed autopsy record is available for all fire victims in the Maryland study, together with analyses of carbon monoxide and hydrogen cyanide, and of alcohol and other drug levels in the blood. The nature and distribution of ingested soots are recorded qualitatively.

Sixty percent of the fire victims showed a carboxyhemoglobin (COHb) level greater than 50%, a level considered borderline for survival. Measurements of hydrogen cyanide (HCN) have shown that many fire victims with high carbon monoxide (CO) intakes have also been exposed to substantial amounts of hydrogen cyanide. Hydrogen cyanide generation from nitrogen-containing natural and synthetic polymers (wool, nylon, polyurethane) can occur at relatively low temperatures and, in some instances, may precede the generation of high concentrations of carbon monoxide.

A number of the fire victims with COHb levels below 50%, who therefore are not likely to have died from carbon monoxide ingestion alone, are found to have inhaled substantial but also subfatal doses of hydrogen cyanide. Although the toxicological literature on the combined effect of these two toxicants is not extensive, animal experiments show that the two gases act in an additive fashion so that exposure to a combination of individually sublethal concentrations may prove fatal.

A second cause of death from sublethal carbon monoxide intake can be tied to an observation that the condition of the cardiovascular systems of fire victims, expressed in terms of blood flow obstruction in the main heart blood vessels, is substantially inferior to that of a comparable random population. Persons with such impaired circulatory systems tend to succumb at carbon monoxide levels below 50%. These findings were obscured for some time by the fact that, in the presence of high alcohol intake, the circulatory system is sufficiently relaxed to compensate for this physical inadequacy. As a consequence, intoxicated persons with poor coronary circulation would succumb only if the carboxyhemoglobin level were in excess of 50%.

High concentrations of inorganic metals (lead, antimony, and others) and of adsorbed pulmonary irritants (aldehydes and hydrochloric acid) have frequently been observed in the soots deposited throughout the trachea and lung tissues. Acetaldehyde has also been recovered from lung specimens of fire victims. These contaminants probably are a minor factor in the "rapid" fatality cases but may play an important role in the "delayed" fatalities where the soot deposits may cause serious pulmonary disturbances hours or even days after exposure to the fire gases.

The medical causes of death are summarized in Fig. 7. The quantitative information concerning the number and nature of fire deaths that occur more than six hours after fire exposure ("delayed" fatalities) is only approximate and was obtained in a separate study (unpublished) of hospital records in Baltimore. However, the fact that toxic gases are the primary cause of all fire deaths (76% of all fatalities are caused by toxic gas ingestion) is unlikely to change as more detailed data on delayed fatalities become available.

DISCUSSION

A number of generalizations on the causes and suggestions for preventive measures can be derived from the foregoing observations. Compared to the general population, the likelihood of being a fire fatality is somewhat higher in the age group 0 to 9, elevated in the group 40 to 59, and highest in the age group over 60. The inability to escape from the fire scene partly accounts for the rise in fatalities at both ends of the age spectrum. Tolerance to toxic combustion products is also probably lowest in these age groups. In the older population, increasing impairment of the cardiopulmonary system contributes to lower tolerance levels for toxic exposures and thus increases the probability of death.

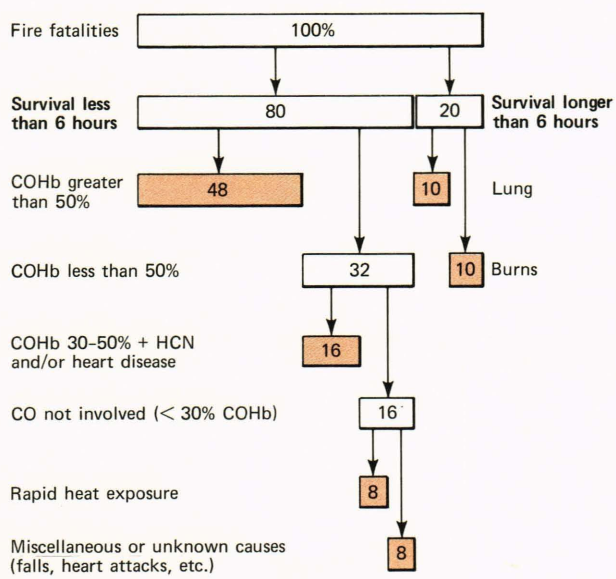

Fig. 7—Overall assessment of principal medical causes of fire-caused deaths. Numbers inside the boxes indicate the percentage of fatal outcomes in each category.

The mishandling of ignition sources (e.g., cigarettes, matches, home heating and cooking devices) is likely to increase with age. Ingestion of alcohol contributes to this increase and also impairs the victim's effort to escape a fire.

The large number of child deaths (ages 0 to 9) in the black community, particularly in urban and suburban settings, is probably related to the absence of adults during working hours to assist with rescue and to a higher number of occupants per house.

CONCLUSIONS

An important goal of detailed studies on fire fatalities is to understand the causes of death and thereby develop practical methods to reduce fatalities in the future. It is evident that those causes that contribute the largest share to fatal fire incidents should be addressed (e.g., cigarettes in the Maryland study). Bedrooms and living rooms in residences are the most common areas of fire origin, most incidents occur at night, and most victims are found in bedrooms. The strong involvement of alcohol should be noted. The excess of fire deaths among black urban children and in the older population in general identifies specific groups as higher than normal risks.

In line with the above findings, the potential value of smoke detectors was assessed. Taking account of the probable fire scenarios and behavior patterns of the victims, the analysis indicated that very substantial savings in life could be realized by the installation of smoke detectors (Fig. 8). The relatively long smoldering time of cigarettes allows for the early detection of a potentially hazardous situation by fire detectors. The predominance of fires originating in bedrooms and living rooms indicates where and how many detectors should be installed in the home for good results. Now that the use of fire detectors is mandated by county law in Maryland, it will be interesting to learn whether they will have the expected beneficial results.

Upgrading or modifying materials to withstand cigarette ignition has obvious merits, as would changes in the igniting power of cigarettes themselves. Inexpensive domestic sprinklers, together with detectors, may be the best solution to reducing both human and economic losses. The value of public education in pointing out the risks of careless smoking, particularly when accompanied by excessive drinking, can hardly be overestimated.

The detailed investigations carried out thus far have concerned themselves exclusively with fatal outcomes; however, a similar study on serious injuries would be of great value. The treatment of such injuries must be based on the causative agents generated in specific fire situations by the large number of new synthetic materials, furnishings made from a wide variety of polymeric materials, and by fire inhibitors that produce unusual toxic products if they are involved in fires. While carbon monoxide is likely to remain the predominant toxicant in fire injuries and deaths, methods should be developed to detect and measure rapidly other toxic substances (such as halogen acids and hydrogen cyanide) and to institute the most effective treatment as quickly as possible.

Fire outcome			Predicted results with installed fire protection system			
		Actual		Detector system	Suppression system	Remote alarm system
Casualties	Deaths	114	Saved	81	99	89
			Probably saved	20	6	14
			No	13	9	11
	Injuries	119	Saved	101	114	105
			Probably saved	9	1	5
			No	9	4	9

Fig. 8—Estimated impact of different fire protection systems on fire fatalities and injuries, on the assumption that the systems are properly installed and that correct use is made of warning signals. ("Detector system" refers to smoke detectors; "suppression system" refers to sprinkler installations; a "remote alarm system" combines smoke detectors with direct interconnection to fire department dispatch.) The figure shows that 90% or more of the deaths and injuries could have been prevented by the installation of appropriate fire protection systems.

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