PREPRINT UCRL-77754

Lawrence Livermore Laboratory

TRADEOFFS BETWEEN RESIDENTIAL AND INDUSTRIAL FIRE PROTECTION FOR ULTIMATE PUBLIC SAFETY

N. J. Alvares

June 15, 1976

This paper was prepared for presentation at Proceedings of the Fifth Environmental Symposium, SRI, Menlo Park, California, May 12 & 13, 1976.

TRADEOFFS BETWEEN RESIDENTIAL AND INDUSTRIAL FIRE PROTECTION FOR ULTIMATE PUBLIC SAFETY*

Norman J. Alvares

Lawrence Livermore Laboratory, University of California

Livermore, California 94550

Abstract

In 1975, fire losses in the United States totaled about 0.25% of the GNP, or 4.4 billion dollars. Statistics on distribution of fire types show that 30% involve residential dwellings: 10% industrial, institutional, and educational buildings; 21% are due to transportation-related factors; and the remaining 38% include forest, grassland, and rubbish fires. These statistics show that industrial and public facilities account for almost 50% of the financial loss statistics, while residential and transportation losses amount to 36 and 11% of the total, respectively. More than 60% of fire fatalities are attributed to building fires, and of these, almost 90% occur in private residences.

This brief survey reveals that a relatively small number of fires are responsible for the major dollar losses, and the major loss of life in fires results from residential fires, where the number of fatalities per fire are relatively small.

Can technology be applied to reduce either the financial disaster incurred during industrial fires, or the life loss in residential fires? The

---

*This work was performed under the auspices of the U.S. Energy Research and Development Administration under contract No. W-7045-Eng-48.

evidence indicates that residential fire mortality will not be significantly reduced by technical solutions. However, there is also the potential for large life loss in industrial fires, and these could be reduced significantly by technical solutions. Therefore, increased efforts to secure the optimum amount of industrial fire protection could certainly reduce our financial losses, and possibly protect more lives.

INTRODUCTION

The title of this paper refers to tradeoffs between residential and industrial fire protection. A tradeoff is defined as to satisfy or improve the requirements of a system by emphasizing one set of needs at the expense of the rest of the needs that complete the system. If we take as our system public safety from fire, the title implies that greater hazards to life could potentially result from industrial fire causes rather than from residential fires. This reasoning is contrary to our current experience, so to investigate this thesis, I will attempt to compare mortality statistics that exist for residential fires with industrial accident statistics where mortality was not a factor but could have been.

In essence, two questions are being addressed to the funders of fire protection research: (1) To what degree should we support research efforts that focus on the problems of preventing loss of life from residential fires? (2) Is there a potential for disasters related to industrial fires that could directly or indirectly result in loss of life to a large population segment?

The first question is asked because fire mortality statistics indicate that loss of life in residential fires is a socio-economic problem which may not greatly benefit from attainable technical solutions. However, if the potential of large life loss from industrial accidents exists, indications are that we have a fire protection technology base that could significantly reduce the ultimate hazard of industrial fire disasters. Thus the proposed tradeoffs are to invest more research capital into industrial fire safety at the expense of the residential fire problem.

In discussing the tradeoff options, evidence will be presented that compelled the questions above to be formulated. This evidence will be structured in the following manner:

First, a description of some of the parameters and hazards associated with enclosure fires.

Second, some statistical evaluations pertaining to mortality and property losses in recent U.S. fire experience.

Third, a sample of some of the large financial-loss fires during the recent past that could have been prevented with proper attention to fire protection practices.

Fourth, a summary of the evidence that questions the prudence of concentrating most of our research funds on residential fire problems.

Fire Parameters and Hazards

Fires which occur in all fuel phases have similar requirements, i.e., there must be enough air and fuel available at high enough temperatures to provide the conditions for the combustion process. If the combination of these parameters is not correct, the conditions for fire may not be established.

While the proper range of air-fuel mixture and temperature level provide the necessary conditions for combustion, many other factors can contribute to the intensity and duration of burning. These factors include: (1) fuel composition, dispersion and geometry; (2) air temperature and velocity, and oxygen concentration; and (3) phase, extent, and temperature of the ignition source.

Figure 1 is a plot of the duration and severity of a typical fire. The factors listed above could all contribute to the intensity or temporal dynamics of the fire. Fires grow when the heat feedback from the flames exceeds the heat required to pyrolyze or evaporate the fuel. If the heat feed-back is not large enough, the flames will die out and smoldering combustion results, or combustion ceases altogether. Fires in well ventilated enclosures may grow at an exponentially accelerating rate so that it appears that, at some time, all combustible items in the enclosure become simultaneously involved in the fire. When this condition occurs, the enclosure is said to have experienced "flashover." If a fire with a similar fuel-air condition occurs outside of an enclosure, the burning intensity and hence the thermal output of the fire will not be as great. Depending on the type of fuel and its ventilation rate, the release of smoke will be encouraged, i.e., well ventilated cellulosic fuel fires will not produce copious smoke, while well ventilated plastics such as polystyrofoam will.

The above discussion gives us some indication as to the hazards from fire, and Figure 2 delineates these hazards in terms of property loss and hazards to life. The paths which lead from "direct property loss" and "hazards to life" to the solutions of these problems are straightforward and somewhat redundant; but the subpath indicated as "indirect property loss" implies the possibility of a broader hazard potential for fires. This path indicates the possibility that a primary fire (perhaps even a trivial fire) in a vehicle or structure could result in a wide-ranging disaster which could greatly exceed the boundary of the initiating situation.

Mortality and Property Loss Statistics

During the past decade, in our country fires have wasted approximately 12,000 lives per year, and have cost us about 0.25% of our Gross National Product per year. The latest statistics (SFPE, 1976) from 1975 show a life loss of 11,800 persons, and property damages exceeding 4.4 billion dollars. Table I gives some comparative statistics which relate selected economic data to available U.S. fire records. As brief as these statistics are, they show that the increase in the number and cost of fires per year is progressing at approximately the same rate as the G.N.P. while the annual fire deaths remain constant. This means that the annual rate of fire deaths per unit of population is decreasing by approximately 2% per year. Note also that while the rate of increase of plastics used in buildings show a significant yearly rise, the plastic materials have not obviously influenced the number or financial losses associated with fires. This could be an indication either of a wider distribution of fire protection countermeasures or a greater sophistication in fire-safe practices. Apparently we're improving with age, yet we are still among the countries with the poorest fire-related statistics.

Since our fire death rate is the highest in the world, it is instructive to investigate the structure of our mortality data. Figures 3 through 7 show respectively the location of fatal fires, the time of day when most fatal fires occur, the age distribution of fire victims, the primary cause of death in fire accidents, and the ignition sources responsible for the fires. Note that these figures were extracted from Chapter 1 of the 14th Edition of the NFPA Handbook. A brief survey of these figures shows that:

- Most fire deaths occur in the residential environment (Figure 3).
- Most fatalities occur during the sleeping hours, although the majority of residential fires occur between noon and 8:00 p.m. (Figure 4).
- The very young and very old are more frequently the victims of residential fires. The age group between 5 and 45 years is significantly less susceptible to fire fatality (Figure 5).
- Death results mostly from interruption of the respiratory function (Figure 6).

- Careless smoking habits account for more than half of the primary causes of fatal residential fires (Figure 7).
- The fact that most fire deaths are primarily the result of smoke inhalation indicates that the extent of fire at the time of incapacitation was not large; i.e., in terms of Figure 1, the fire severity could be less than 20% of the total potential severity.

In a two-year study of Maryland fire mortality statistics conducted by the Applied Physics Laboratory, John Hopkins University, almost identical trends were reported (Berl and Halpin, to be published). In their study they concluded that: "Fire disasters involving many people and fatal transportation fires were rare and do not contribute much to the total fatality record. Inhalation of carbon monoxide is responsible for incapacitation and death of 72% of the fire fatalities. A pronounced involvement of alcohol (detected in 51% of all fire victims older than twenty years), particularly with men between the ages of forty and sixty, has been observed, coupled with careless use of cigarettes. Of all male fatalities, 57% involve alcohol while only 26% of female deaths indicate alcohol abuse. The maximum rate of children's fire deaths occurs between 6 a.m. and 6 p.m., which may indicate a lack of supervision." Since this agrees with national trends, it is probable that all regional experience is similar.

Table II is a listing of potential death risks to the U.S. population from selected hazards, including fire. Perspectively, our chances of dying from unwanted fires are relatively slim, and if we can survive the freeways and quit smoking, our chances of survival are significantly enhanced.

The statistical data indicate that we may be reaching a technical plateau in terms of our capability to further reduce the mortality experience in residential fires. The possibility of technically developing an economical solution to the problems surrounding the fire retardance of combustible materials is slight; hence we live in a flammable world that requires us to use some judgement as to how we coexist with our environment. We cannot legislate the personal habits of individuals in our society, nor can we dictate the type or number of items that individuals wish to surround themselves with for pleasure or comfort. If segments of our society continue to:

- smoke, drink, and watch late night T.V.;
- pack our old and infirm into poorly protected retirement retreats;
- leave our children, unsupervised, near or with ignition sources; and
- load our dwellings with flammable comforts;

then we will continue to have the poorest fire mortality statistics in the world.

If we recognize that these problems are not necessarily amenable to technical solutions, we may be motivated to refocus our research and technology on fire hazard problems which could be ultimately more dangerous to human life and the environment, and yet easier to solve.

Those problems of obvious concern are the potential for fire to either directly or indirectly compromise the safety controls of the transportation or industrial systems. Lack of such controls could either primarily impact a populated region or secondarily cause the release of toxic agents that could be naturally dispersed to population centers.

Examples of near misses that fall into this hazards category are: (1) large aircraft which crash and burn near urban areas; and (2) fire accidents in industrial, laboratory, or power-generating facilities where chemical, bacteriological or nuclear materials could be released to the environment.

Life Hazard Potential of Past Large-Loss Fires

Figure 8 shows the number of fires which occurred in the U.S. in 1973. Only 5% of the total fires could be classed as industrial (defense, utilities, manufacturing) and transportation (aerospace, aircraft, ships and railroads). However, these categories were responsible for over 84% of the financial loss to the country. Just the fact that these fires were so dynamic that they resulted in extensive damage suggests their potential to cause far more life loss. To illustrate this potential, I will summarize several accidents involving fires which fortunately did not claim more lives than were directly associated with the primary accident.

1. Roseville, California (SFPE, 1973)
   April 28, 1973 - Saturday, 0800 hours
   Fire and explosion in 21 boxcars loaded with 250-lb bombs. Severe destruction from shock waves and fire within 1/2-mile radius from fire site. Firebrands and shrapnel ranged over a 3/5-mile radius. Damage to property other than railroad: two schools; 20 stores and light industrial plants; one fire station.
   Direct damages exceeded $9,000,000.
   200 light casualties, but no fatalities.

2. Paris, France (Aviation Week and Space Technol., 1976)
   July 11, 1973 - Wednesday, 1402 hours
   Fire and forced landing of Varig 707 transport carrying 134 passengers and crew. Fire started in rear toilet area during approach phase of flight to Paris Orly Airport. First report of

fire problem was at 1358 hours when the aircraft commander requested an emergency descent. Rapid smoke development forced evacuation of the passenger cabin by the crew and forced the landing of the aircraft in a field 3 miles short of the runway. The aircraft fuselage remained intact and the impact force was survivable (all seat-belted members of the crew survived). At touchdown, the fire was confined to the zone of the rear toilet in the cabin, but smoke filled the cabin. Rescue attempts by surviving crew and farmers were prevented by dense smoke and heat. Firefighters (who arrived at the crash site approximately 7 minutes after touchdown) removed several more passengers from the aircraft (only 1 survived) before being driven away by the intensity of the fire. Of the deaths, 75% resulted from asphyxiation; most of the rest by inhalation toxicity.

Direct damages about $10,000,000.

11 injuries, 123 fatalities.

3. Rocky Flats, Colorado (Patterson, 1970)

May 11, 1969 - Sunday, 1427 hours

Plutonium-parts manufacturing plant fire. The fire appears to have originated in glove box storage area where plutonium scraps were kept. It is assumed that the Pu spontaneously ignited (Pu is a pyrophoric material) and the heat generated during the combustion was enough to ignite the cellulosic shielding material and the plastic glove box window. The smoke load within the glove boxes clogged the glove box filters, resulting in filter breaching, and the fire spread throughout many of the glove box production lines. Suppression by water was the only effective way of combating the fire. Internal contamination by Pu and PuO_2 was extensive. Only minor external contamination occurred in immediate vicinity of the plant (due to failure of primary ventilation filter). No contamination escaped the plant boundaries.

Direct damage exceeded $45,000,000.

No lost time injuries, no fatalities.

4. Browns Ferry, Alabama (NRC, 1975)

March 22, 1975 - Saturday, 1200 hours

Fire in the cable spreading room. The fire started when the flame of a candle used to locate leaks in the cable penetration of a containment barrier ignited the material used to seal the penetration. Several attempts to manually extinguish the fire with gaseous agents failed. The fire continued for 7-1/2 hours until municipal fire fighters extinguished the fire with water. During the time of the fire, the automatic control and power circuits which control the reactor emergency systems were rendered useless. The operating staff at the reactor were able to maintain critical cooling to the reactor core by manual control of crucial valves and pumps. Without this manual capability, core meltdown and ultimate release of radioactive fission products was a definite but remote possibility.

Direct damages about $70,000,000.

No significant casualties, no fatalities.

In the accident scenarios described above, it is apparent that a slight change in location, time frame, fire dynamics or climatic conditions could have resulted in a far different number of fire fatalities. It is also apparent that proper application of both passive and active fire protection countermeasures could have significantly reduced the material losses, and the potential for life hazard. e.g.: There is no reason why boxcars or tank cars carrying flammable or explosion-sensitive materials should not be required to have portable, automatically initiated suppression and alarm systems along with the cargo; there is no reason why commercial aircraft cannot be equipped with detection, alarm, and automatic suppression systems. (The FAA is considering this possibility now.) While the Rocky Flats plutonium parts plant has probably one of the most sophisticated fire protection systems now installed anywhere in the U.S. (it is probably unique in this respect), there are hundreds of facilities which routinely deal with extremely dangerous materials. Fire is the one hazard that is universal to them all. Consequently, they should all have more than adequate fire protection. This requirement should be applied to all energy-producing facilities, not only as a life safety measure, but also as a method of maintaining the economy of our industrial system.

SUMMARY

The evidence on residential fire mortality in the U.S. indicates that the problem will not be significantly reduced by technical solutions. It is possible that properly maintained early warning systems could affect some reduction in the death rate. This assumes that the initial device is reliable and sensitive. However, experience in public housing suggests that vandalism would probably comprise any public system, and procrastination would probably reduce the effect of private systems. If it were possible to make fire occurrence a disgrace and a legally punishable offense, there might be a greater chance to increase residential fire safety. Since there appears to be no legislative movement in this direction, a more pragmatic emphasis of fire safety for the ultimate public good could be to increase efforts to secure the optimum amount of industrial fire protection. This goal is amenable to both technical innovation and legislative control, and may in the long run protect more lives.

REFERENCES

Aviation Week and Space Technology: April 12, 1976, "Fire Cited in Varig 707 Crash Near Orly," p. 20.

Berl, Walter G. and Halpin, Byron M.: to be published, "Fire-Related Fatalities: An Analysis of Their Demography, Physical Origins and Medical Causes," presented at Symposium on Fire Standards and Safety, NBS, Washington, D.C., April 5 and 6, 1976.

NRC; August 4, 1975, "NRC Report on Browns Ferry Fire," Atomic Energy Clearing House, Congressional Information Bureau, Inc., Washington, D.C., 20005, Vol. 21, No. 31.

Patterson, David E.: January 1970, "The Rocky Flats Fire," Fire Journal.

Soc. Fire Protection Engrs." November 1973, "Bimonthly Fire Record," Fire Journal, p. 59.

SFPE: 1976, "1975 Fire Statistics," Society of Fire Protection Engineers, 60 Batterymarch St., Boston, Mass. 02110, Bulletin 76-2, p. 4.

Table I. Relation of selected economic data to U.S. fire records.

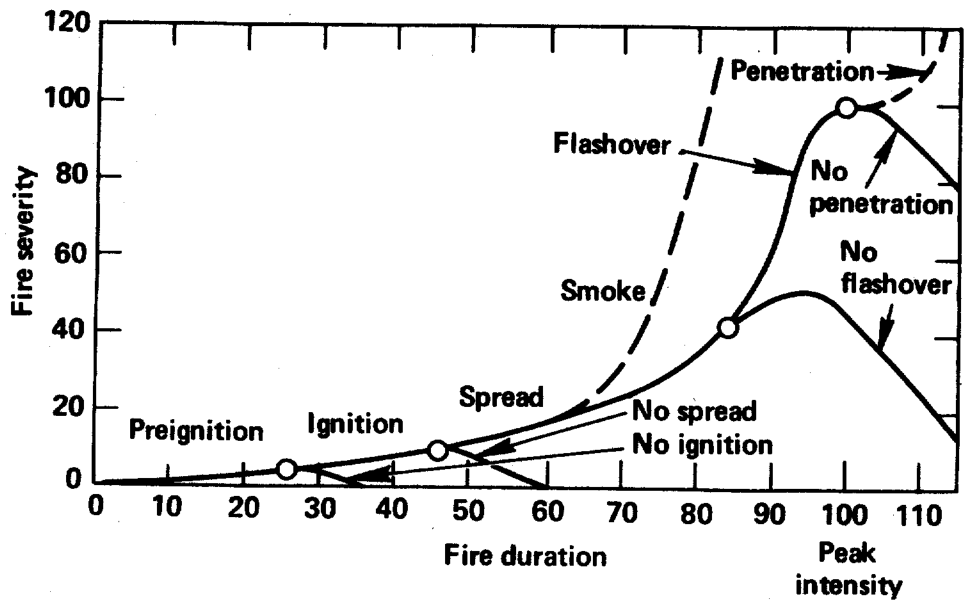
Annual rate of population increase	≈ 2%
Annual rate of Gross National Product increase	≈ 6%
Annual growth rate of plastics as building materials (since about 1961)	≈ 12 to 16%
Annual increase rate in number of fires	≈ 5%
Annual direct fire loss increase rate (since about 1966)	≈ 6%
Annual fire deaths (since about 1961)	≈ 12,000
Annual fire injuries	≈ 120,000

Table II. Death risk to U.S. populations from selected hazards.

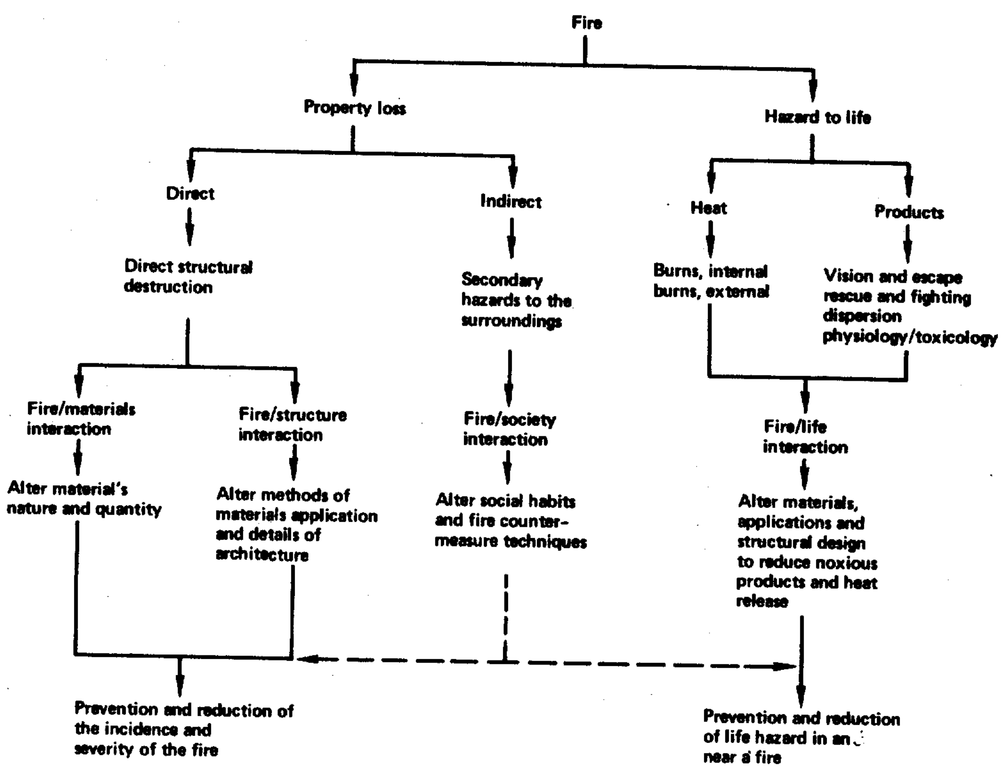
Hazard	Annual chance of death, one person out of:	Probability of death per person year
Cancer (all types)	625	1.6×10^{-3}
Auto accident	3,600	2.8×10^{-4}
Fire (including smokers)	17,000	$6,0 \times 10^{-5}$
Drowning	27,000	3.7×10^{-5}
Fire (non-smokers)	38,000	2.6×10^{-5}
Choking on food	∿100,000	$\sim 10^{-5}$
Cancer from medical x rays	>100,000	$<1 \times 10^{-5}$
Lightening	1,000,000	0.8×10^{-6}

FIGURE CAPTIONS

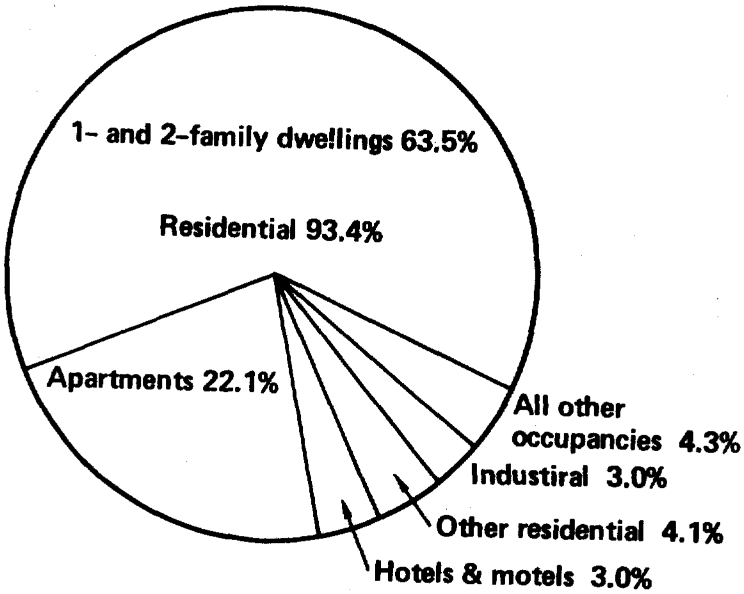
VRS/sc



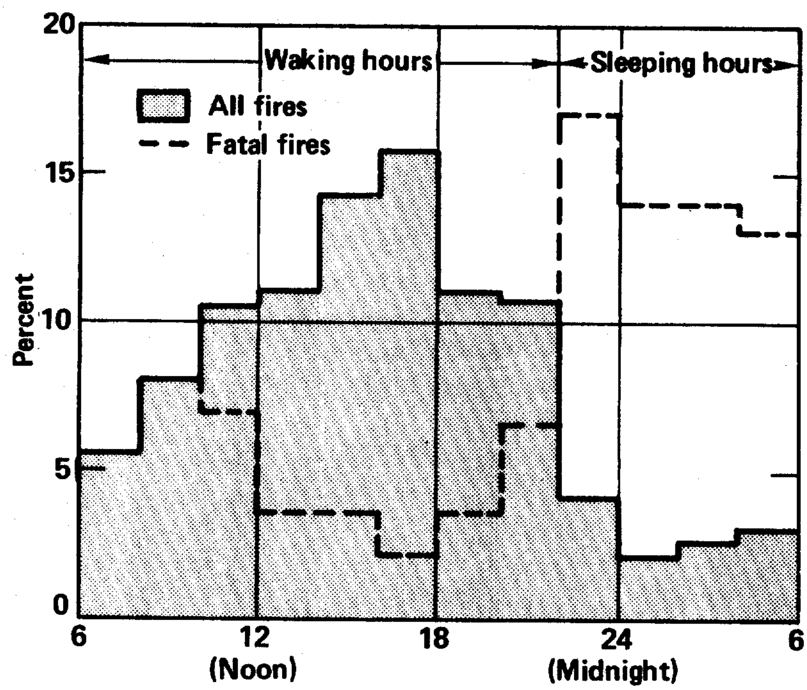
Alvares - Fig. 1



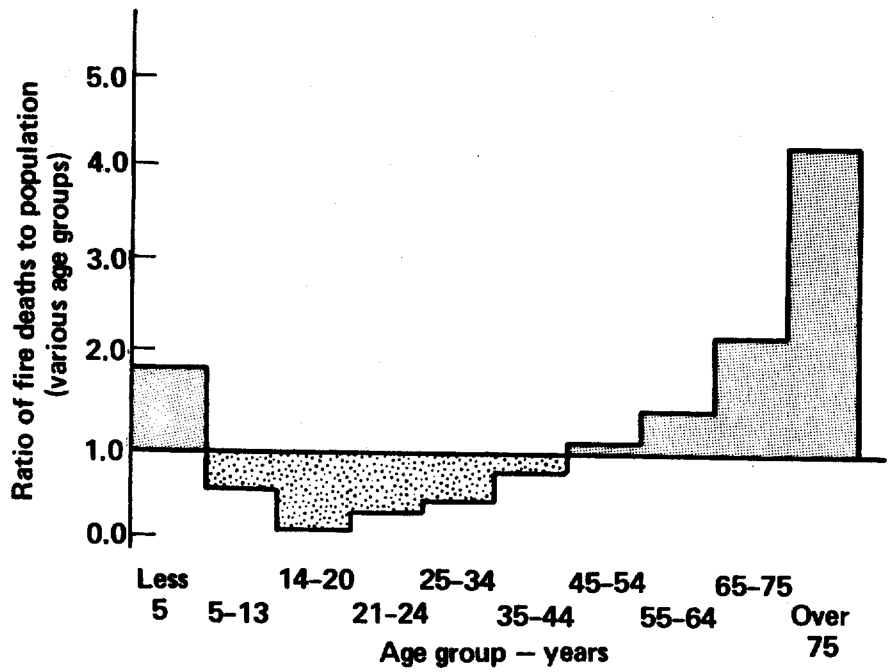
Alvares - Fig. 2



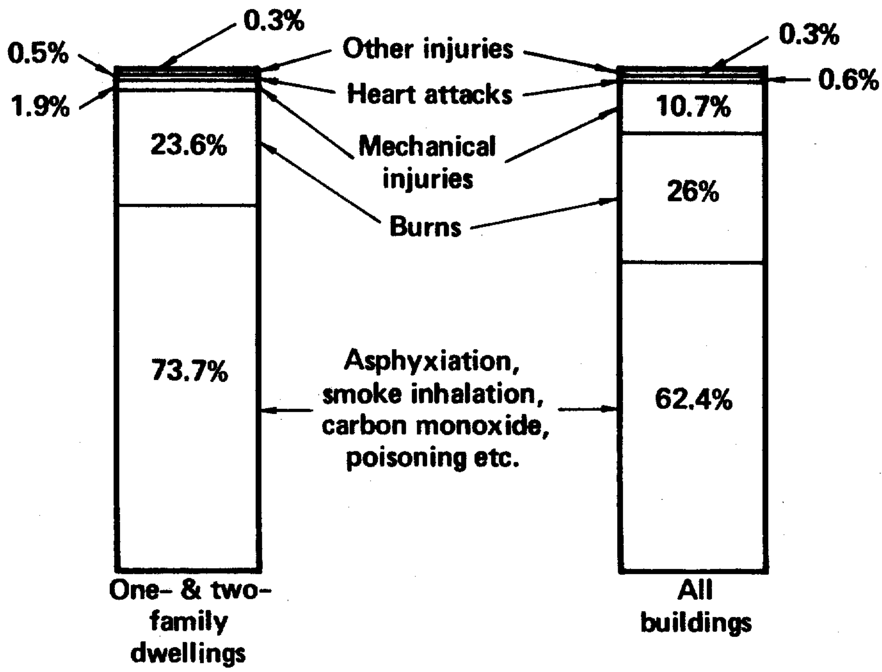
Alvares - Fig. 3



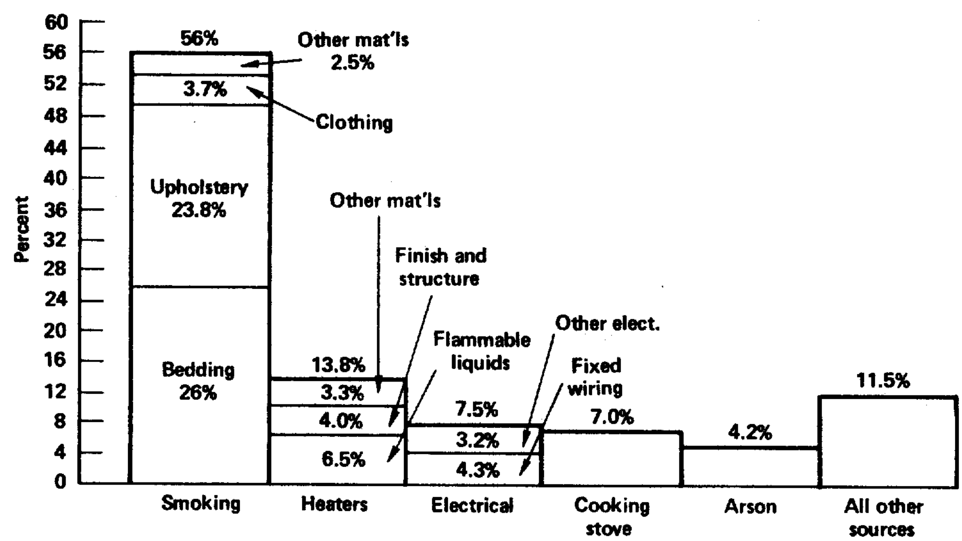
Alvares - Fig. 4



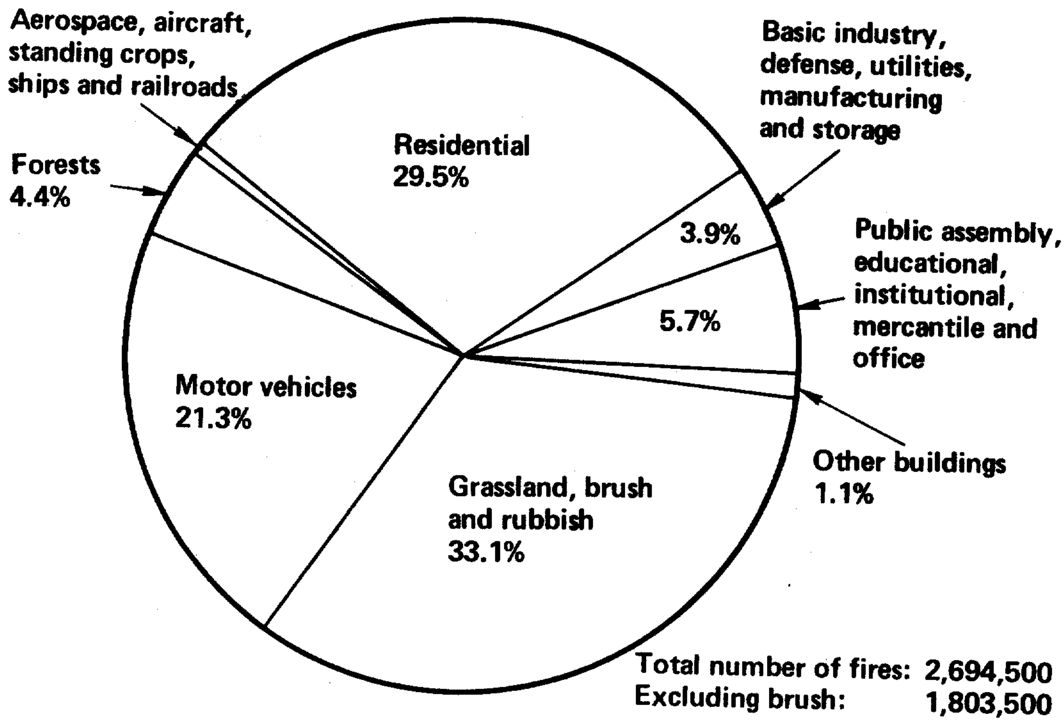
Alvares - Fig. 5



Alvares - Fig. 6



Alvares - Fig. 7



Alvares - Fig. 8