RESEARCH REPORT

Analysis of the Cost Benefits of Installing Fire Sprinklers in Houses : Phase II

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ANALYSIS OF THE COST BENEFITS OF INSTALLING FIRE SPRINKLERS IN HOUSES (PHASE II)

JUNE 1989

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THE COST OF SAVING PROPERTY AND LIVES

BY FIRE SPRINKLERING NEW HOUSES

Phase 2 of the CMHC Study: Analysis of the Costs and Benefits of Installing Fire Sprinklers in Houses

Report for the

Canada Mortgage and Housing Corporation

Attn. Jacques Rousseau

by

Scanada Consultants Limited

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Ottawa

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SUMMARY

This analysis of benefits and costs associated with sprinkler installations in new houses includes many judgemental interpretations of available data. Although Canadian data were not always obtainable, U.S. data was found to help fill in some of the important gaps. Every attempt was made to provide a reasonable assessment of both the benefits and costs, from an overall societal viewpoint rather than from an owner's or renter's particular perspective.

The major findings of this project may be summarized as follows:

- New houses are already much safer than older houses. A conservative estimate is that the fire fatality rate of the general housing stock is about 3 1/2 times greater than for houses built within the last 5 years.

- In new housing, sprinklers might save about 7.7 occupant lives per million house years, and 0.09 fireman lives.

- In general, all houses are becoming much safer (Figure 1) for a variety of reasons, the most important one being the growing use of smoke alarms. There are other reasons as well, and the trend will likely continue.

- Fire injury rates in newer houses, however, are just 10% lower than in the general stock despite the reduced incidence of fire. (Perhaps the explanation includes the fact that people survive the fire in the new house, some to become listed as injured to some degree.)

- The property loss per house for the general housing stock is about the same as for newer houses - about $45 per house per year. (New houses have less fires but their damage value is higher.)

- It is doubtful that significant reductions in municipal fire fighting services will result from the installation of sprinklers in houses. (If there were an appreciable potential for reductions, much of it could already be accorded to the widespread use of smoke alarms.)

- The installation cost of a sprinkler system for a split level house with a floor area of 140^2 m (1500 sq. ft.), according to the recent Alberta study just completed, varies from $4158 for a system using copper pipe to $2779 for a system using plastic, where the municipal water pressure is 310 kPa (45 PSI). The housebuilder's overheads are not included in these figures.

Similarly the installation cost in the same house without a municipal water supply is $6667 with copper piping and $4792 with plastic piping.

- The cost to save one life through new house sprinklering varies from **$38 million or more** for the least expensive system (plastic piping, municipal service) to about $95 million or more (private well, copper piping), assuming the same fatality risk factor applies. Table 22 comprises a summary of the main points in this analysis.

- The cost to save a life by mandating the use of sprinklers does not compare favourably with examples of other legislated safety measures, which vary from $160,000 to $2,100,000. (Figure 3.)

- The use of sprinklers only in the high hazard areas (e.g. bedrooms, living rooms and kitchen) is not more cost effective than a full system as required by NFPA 13D.

- The development of a full or partial sprinkler system using lower residual pressures and needing no special service piping should be examined as a potentially promising measure for existing high-risk housing.

- Targeting Safety measures to high-risk housing and usage may be fruitful. For example: fire fatality rates vary for different age groups; those 75 years and older have a fatality rate three times higher than the national average. Lower-income groups are also at three times the average risk for various reasons.

- The remarkably high incidence of fires associated with children playing with matches suggests that developing childproof match dispensers should be investigated, similar to the approach taken with medicines.

- Fires associated with cigarette smoking appear to be the most deadly and are the largest single cause of fatal fires. Much of this relates to ignition of fabrics. Further steps to increase the fire safety characteristics of upholstery, drapery and bedding fabrics may be cost-effective.

INTRODUCTION

The mandatory installation of sprinklers in new house construction is being advocated by some Canadian groups. Such an approach to improving fire safety has indeed become more practicable with the advent of special residential systems featuring fast response heads, sharply reduced water demand and lower costs. Even these new systems, however, entail considerable costs and further reduce the affordibility of new houses.

The added costs could be justified if the resulting saving of property and lives were also considerable. Concerns were raised that this would scarcely be the case. Today's houses, with the fire safety provisions that have already been incorporated in recent years, may very seldom be where the fires occur and property and lives are lost.

Responding to such concerns, Canada Mortgage and Housing Corporation has sponsored this study to assess the costs and benefits associated with new house sprinklering. Phase 1 of the study, to examine existing information and to recommend a technology for carrying out the analysis, was conducted by A.T. Hansen and reported to CMHC in August 1988: "Analysis of costs and benefits of installing fire sprinklers in houses - Phase 1 - Selecting an appropriate assessment procedure."

This report constitutes Phase 2 of the project, the analysis. It carries on from Phase 1 much as recommended, analyzing data from Canada and the USA to determine risks, costs, benefits and the net cost of saving a life. Since the objective is to provide public code-writing agencies with such information, the study was approached from a societal perspective as opposed to an owner's perspective. In a number of ways this simplifies the analysis and eliminates man-made complicating factors that have little to do with the overall economic merits of sprinklers.

Other cost-benefit studies of residential sprinklers have been carried out by different agencies (as reported in Phase 1) using US data. These, however, have assumed in part that all houses, regardless of age, have similar fire risks. This study does not. Rather, fire risk data are sought for new houses, which are the prime concern of building codes.

One task has been to develop cost projections for sprinkler installations that would conform to the NFPA standard 13D, "Installation of Sprinklers in One-and Two-Family Dwellings and Mobile Homes". Fortunately, Alberta Municipal Affairs, through their Innovative Housing Grants Program, undertook a similar task. The Alberta projections were made available in full for this study. Cost estimates were also provided from Quebec's Ministry of Labour.

More of the study resources could therefore be allocated to extracting, developing and analyzing risk and benefit data, improving the reliability of the study and making it more reflective of Canadian conditions.

Provincial fire marshals and fire commissioners provided much useful information. Plumbing authorities were also cooperative with regard to the interfacing of sprinkler systems with domestic potable water systems. The Ontario Housing Corporation provided data that were helpful in discussing socioeconomic factors that appear to influence fire risks, and in targeting points that might warrant additional fire protective measures.

Scanada is also indebted to the cooperation received from the USA: the National Association of House Builders and National Bureau of Standards provided useful background information that formed much of the basis for the methodology used in the Phase 2 analyses. Informetrica Limited in Ottawa assisted in reviewing these benefit-cost approaches, assessing their basic soundness in relation to Canadian circumstances.

FIRE FATALITIES

The probabilities of death, injuries and fire damage are basic components in the cost benefit analysis of sprinkler systems. By comparing rates in sprinklered and unsprinklered houses, reductions in fire losses can be estimated, and by knowing the costs associated with sprinkler installations (including of course the savings in costs) the net cost of saving a life can be determined.

It is usual in such studies to base fire risks on national statistics in which the entire housing stock is grouped together. This, however, intrinsically assumes that there is no difference in risk between old and new houses. There is mounting evidence, however, that such is not the case.

The purpose of this study is to determine whether or not it is economically justified to mandate the use of sprinklers in building codes. Since these apply essentially to new houses, it is particularly important to know if such houses have or will have the same risk as older houses. If they are significantly safer, an analysis based on general averages for the total housing stock will yield misleading conclusions, and could lead to the wrong houses being targeted for additional protection. This could result in the misapplication of considerable capital investment.

House Age vs. Fire Risk

A U.S. National Association of Home Builders study in 1987 indicated that the fatality rate in newer houses was less than for older houses by a considerable margin(1). In a sample representing 8.2% of the entire stock of single family houses, the general fatality rate was about 4.7 times that of houses built from 1981 to 1986.

Caution in the application of such data must be exercised, however, since the total number of deaths in the sample was only 191. Only 2 occurred in houses up to 4 years old, and 2 in houses 5 to 9 years old. Obviously, it would require only a small number of events to change significantly the apparent fatality rate in newer houses. The statistics represent a sample of 4.7 million houses, however, and show a strong trend towards increased safety in newer houses.

The possibility of a relationship between house age and fire risk was recognized in carrying out Phase 2 of this study. Each of the provincial fire marshalls and fire commissioners was contacted at the beginning of the study to determine if fire data could be provided that related to the age of the structure. Although several authorities responded to this request, only 2 were able to provide data that could be conveniently used in this study. Tables 1 to 4 were developed from data provided by British Columbia and Alberta. The fire fatality rates per million houses (1 and 2 family) were calculated both for newer houses and for the general housing stock.

In Tables 1 and 2 "newer houses" were assumed to include those built in the 5 year period that preceded the year of the fire record. In tables 4 and 5 the newer houses were also considered to be up to 5 years old, but including the year of the fire record. In calculating the house population in the latter case, however, only half of the houses in the data year were included. It was assumed that the houses were built at a uniform rate over the entire year so that on average only half of the houses would have been in existence over the 12 month period.

It can be observed from Tables 1 to 4 that the number of fatalities for newer houses in any given year is relatively small, and when it varies it causes the apparent fatality rate per million houses to vary by substantial amounts. To increase the size of the sample and improve its statistical relevance, data were combined for both provinces and accumulated year by year as shown in Table 5. It appears obvious in these tables that as the data extend backward in time to include houses that were built in earlier periods, the fatality rate also increases. (It is of interest to observe that the rate for the recent data years is close to that found in the NAHB study.)

Table 6 is an accumulation of similar data for the general housing stock in Alberta and British Columbia. This is provided to allow the two housing groups to be compared on an equal basis.

In comparing Table 6 to Table 5 it can be seen that the fatality rate for both groups increases as the data from earlier years is added to the total. It may also be seen that the fatality rate for newer houses is much less than for the general housing stock, and especially so for the most recently constructed houses. While the difference in fatality rates between newer houses and the general housing stock is not as great as in the NAHB study, the newer houses are safer. It should also be noted that the fatality sampling for newer houses is somewhat greater than in the NAHB study and, while still relatively small, should allow more confidence in conjunction with the latter.

The newer houses represented in Tables 1 to 5 were constructed over a period of 1978 to 1987, depending on the data years used. This period effectively straddles the time period when the National Building Code was revised to mandate the installation of wired-in smoke alarms in dwelling units (1980), and the subsequent adoption of this requirement by the various provincial authorities. The consequence of this on the fatality rates shown in Tables 1 to 6 will be reviewed later.

Quebec Fatality Statistics: Fire statistics provided by Le Directeur général de la prévention des incendies in Quebec are reproduced in Appendix A. In these statistics, fire records for the years 1978 to 1987 were combined, based on reports from municipalities with populations of 5000 people or more. These show deaths and injuries in one and two family houses related to the age of the house at that time.

Although the form of the statistics does not permit a direct comparison to be made with the statistics from British Columbia and Alberta, the Quebec statistics nevertheless show a definite trend towards increased safety in newer houses. A comparison of the fatality rates shows that the least number of deaths per 100 fires occurs in houses less than 5 years old (1.04), and increases as the age of the house increases. Houses older than 51 years, for example, have over 4 times the fatality rate (4.60) as the newer houses.

If fires occurred at a similiar rate in all houses, these values would represent the risk per house. But they do not: newer houses tend to have fewer fires per unit than older houses, as well as fewer deaths per fire.

During the period between 1978 to 1987, the average annual addition to the stock of single family houses in Quebec was about 3.3%. If it is assumed that the same percentage increase applies to two family houses, and that the category shown as "moins de 5 ans" applies to houses over a four year period, then the latter category represents about 13.2% of the total housing stock of one and two family houses. This category of houses, however, was responsible for only 3.4% of all fire deaths. To express this in other terms, it appears that the fatality rate for the entire housing stock is about 4 times greater than for the newer houses.

While these values are not precise, they do nevertheless indicate a strong trend, and, with the NAHB sample mentioned earlier, tend to confirm the results noted in the fire records for Alberta and British Columbia.

Declining Fire Fatalities

Causes of the lower fatality rate in newer houses are not known with certainty. There may be several factors contributing to this phenomenon. This trend does not only apply to newer houses but appears to be a general trend affecting most of the housing stock.

One significant reason for the decline in fatalities is the widespread use of smoke alarms. Although battery operated single station smoke alarms were introduced in 1970, it was not until the mid 1970's that their price dropped to the point where they were generally affordable to the average owner or tenant. As alarms were installed in increasing numbers, their price continued to fall, and by 1982 it was estimated that 67% of U.S. houses were equipped (2). Today, it is estimated that this is over 80% (3). According to estimates of Statistics Canada, about 83% of owner occupied Canadian households and 74% of tenant occupied households were equipped with smoke alarms in 1988 (4).

Although the National Building Code required the use of wired-in smoke alarms in 1980, their use in houses was not mandated by provincial authorities immediately. A number of provinces, including British Columbia and Alberta, use a review process prior to the enactment of new building codes. Code adoption procedures vary from province to province, and in the case of Alberta and British Columbia, it usually requires about one or two years before construction must conform to the new requirements.

In Tables 1 to 6, therefore, it may be assumed that houses constructed in 1982 or later are all equipped with wired-in smoke alarms during construction. Those constructed in 1981 would probably have a significant proportion with wired-in alarms as well, but would probably also contain some battery operated units and some with no alarms. Those constructed in 1980 or earlier would generally be equipped with battery operated alarms or no alarms.

An additional probable contribution to the decline in fatality rates is the decreasing number of occupants per housing unit, particularly in new houses. Since most fires are caused by occupant activities (5) it is only reasonable to assume that fire fatalities per dwelling decreases as the number of occupants decreases.

A major source of fires in houses involves the misuse of smoking material, with the prime materials ignited being upholstered furniture and bedding. According to NFPA studies (6), 27% of all <u>fatal</u> fires in one or two family houses in the U.S. were caused by the ignition of furniture, and 18% by the ignition of bedding. Smoking materials were the source of ignition in 36% of all fatal fires. Records compiled by the Ontario Housing Corporation for 24 fatalities indicated that

54% were the result of smokers' negligence and 21% by children playing with matches (7). It appears obvious that any improvement in the resistance of fabrics to cigarette and match type ignition sources should have a significant impact on fatality rates.

The ignition resistance of mattresses has been regulated in Canada under the Hazardous Products Act since 1982, and this has no doubt decreased fire risk from this source. Although upholstery fabrics are not yet regulated under this Act, a cooperative program between government and industry to improve fabric safety has been in effect for several years. This voluntary program has reputedly been instrumental in a general decrease in the ignitability of upholstery fabric. Replacement of existing furniture takes place slowly over a period of time, so that any improvement in overall fire statistics from this source will be gradual; but it probably affects new house performance more quickly.

A declining number of smokers is another possible contribution to the improving safety record. New home purchasers tend to be more affluent and more educated than the general average, and it is this category that has experienced the greatest reduction in the number of smokers in recent years (8). Finally, increased safety resulting from modern electrical practices and improved appliance safety standards is also a probable contributor to the declining fatality rates.

Aging Houses

Does the apparently increased safety in newer houses decline as the house ages? This must be considered if the fatality rates for newer houses are to be used as the basis for evaluating the long term benefits of sprinkler systems. If a decline in safety is a natural result of house aging, it must be allowed for in the analysis.

Evidence indicates that a significant reduction in safety as the house ages is unlikely. One indication of this is the general trend toward increased safety of the total housing

stock (Figure 1). From 1980 to 1987, fatality rates in one and two family houses have dropped steadily from about 79 persons per million houses to 45 per million. (See Appendix B for the basis of national data used in Phase 2). Since the increase in new stock during this period is only 11%, one must assume that the addition of the new houses is not the principal reason for the general increase in safety.

Figure 1 also shows a steady decline in property loss rates during the same period, from $71 per house in 1980 to $45 per house in 1987 when measured in 1989 dollars. The trend therefore is for the housing stock in general to become increasingly safer, not only new houses. Of the various factors that appear to be responsible for the reduced fatality rates, none (with the possible exception of smoke alarms themselves, which may need periodic cleaning or replacement) would appear to be adversely affected as the house ages. Barring unforseen socioeconomic changes, there is little reason to expect that the downward trend in the fatality rate will reverse itself. Indeed, as user education and technology advances - with no need for drastic or costly steps in the latter - the expectation should be towards continued improvements in life safety.

U.S. surveys in smoke alarm reliability indicated that the greatest single cause of failure was lack of batteries. This accounted for 61% of the failures, followed by incorrect installation practices which accounted for 36% (3). Since current Canadian building codes require detectors to be wired-in (rather than battery operated) the failure rate of detectors in new houses should be much smaller than the current overall failure rate in the U.S. of 25% (3). According to a study undertaken by the OHC on their own housing stock over a 7 year period (1977 to 1983), wired-in smoke alarms have an average annual "failure" rate (being disconnected, for the most part) of about 2.4% which is much superior to that reported for the battery type alarms. (See Appendix C). Although a decline in performance of smoke alarms may occur in time, the generally high performance rate would not appear to warrant a general downgrading of their assumed effectiveness. In any event, replacement of defective alarms is not a major undertaking and

could easily be carried out by the occupant at minimal cost. Again, user education can help ensure that such attention is given priority.

In consideration of all of the factors that may be contributing to the increased safety in newer houses, it would appear that a significant reduction in safety as houses age should not be anticipated. The risk factors that apply to newer houses appear to be justified for this study, rather than risk rates that are averaged over the entire housing stock.

Smoke Alarms and Fatality Rates

Various authorities have attempted to evaluate the effectiveness of smoke alarms in reducing fatality risks. One NRC study of 342 fatal fires estimates that smoke alarms could probably have saved about 41% of the victims (9). The 1984 NBS cost benefit study of residential sprinklers estimated that smoke alarms should reduce the fatality rate per fire from 0.00821 to 0.00390 (or about 52%) (10). Table 6 of the NBS study is reproduced in Appendix D for reference. This estimate is based on a systematic evaluation of typical fire scenarios and test data on the performance characteristics of smoke alarms under simulated fire conditions.

Other U.S. fire statistics (3) indicates that the average fatality rate per fire in the period from 1980 to 1986 was 0.0095 in houses without alarms and 0.0052 in houses with alarms. This was in spite of the fact that the alarms were inoperative in a third of the houses. The favourable statistic for houses with alarms, therefore, may in fact be partly a reflection of the more cautious or careful attitude towards fire of those occupants who elected to install alarms.

Fatality Rate in Unsprinklered New Houses

On the basis of preceding comments it is plain that selecting an appropriate fatality rate factor is not straightforward for the purpose of evaluating new houses.

The NBS study approach of assigning a common risk factor to all houses, regardless of age, is not appropriate since house age does play a significant role. It would seem to be more accurate to use the statistics for newer houses determined from Canadian records. Accordingly, therefore, it was decided to use Table 5 as the basis for the fatality rate factor in new houses. By selecting the data years so that they apply to houses constructed since 1981, it can be assumed that they represent essentially only the houses equipped with wired-in smoke alarms and otherwise built to today's standards of safety in electricals, heating and furnishings. Separate modifying factors for smoke alarms used in the NBS study are therefore not needed. This restricts the results in Table 5, however, to the data years of 1986 and 1987 for data based on Tables 1 and 2 and to the data years of 1985 to 1987 for data based on Tables 3 and 4. This expresses a fatality rate of about 12 persons per million houses. The corresponding fatality rate in Table 6 for the general housing stock in B.C. plus Alberta, combined for the years 1985 to 1987, is 41, or about 3-1/2 times as great as for the newer houses.

There may be some question whether the statistics for the two western provinces should be used directly for the data base for the entire country, or should be used as a device for modifying the national data on the general housing stock. The accumulated data for 1985 to 1987 for the national housing stock (Appendix B) shows the fatality rate to be about 48 persons per million houses (about 17% higher than the western provinces). This may reflect the fact that houses in the central and eastern provinces, which constitute the majority of the stock, have a higher proportion of older houses. It may also reflect a lower installation rate of smoke alarms, however in eastern Canada or to socioeconomic differences between various regions.

It was considered to be appropriate for this study to apply the Alberta-British Columbia findings on new houses in this manner: Reduce the national fatality rate by a factor of 3.5 to more closely represent new house risks. While this is somewhat less than the 4.7 factor suggested by U.S. statistics and the fourfold factor inferred from the Quebec statistics, it was thought that a larger risk reduction factor is not yet clearly defensible. Accordingly, the fatality rate in new, hard-wired-smoke-alarmed houses has been taken conservatively as 14 per million house years in this study.

Effect of Sprinklers on Fire Fatality Rates

Although a significant amount of data is available on the reliability and effectiveness of commercial and industrial type sprinkler systems, the number of installations of fast response residential type systems is not sufficient to provide such information. These systems were developed in response to the need for sprinklers with life protection rather than property protection as the prime objective. Such systems respond much more rapidly to heat buildup than conventional sprinklers, and are designed to operate with a considerably reduced rate of water flow.

Although statistical data are not available to assess such systems, their operating characteristics have been studied systematically under laboratory and field conditions. These studies examined the conditions that would likely occur with typical fires in sprinklered rooms. Knowing the response characteristics and the likely prevailing room conditions, various fire scenarios were studied to determine the probable effect of such systems in increasing occupant safety (paralleling a similiar assessment of the effectiveness of smoke alarms). These studies, carried out by the NBS, were used as a basis in estimating the probable reduction of fire losses in sprinklered buildings in the 1984 NBS cost benefit study of residential sprinkler systems (10).

Unfortunately, the basis for the NBS assessment model has not been published or made available. It is therefore impossible to assess the applicability of the model to Canadian conditions and data. In the absence of other information, there would appear to be no reasonable alternative to using the risk reduction factors established by the study (shown in Appendix D). Based on the credentials of those involved in the study, and the agency under whose auspices it was executed, this was considered appropriate.

The risk factors in Appendix D show that when houses are equipped with smoke alarms, those without sprinklers have an estimated risk of 0.00390 fatalities per fire while those with sprinklers have a risk of 0.00146. In these estimates, the smoke alarm reliability was assumed at 84.7% (based on field studies current at the time of the study), and sprinkler reliability of 92% (based on experiences with sprinklers in commercial and industrial application). Additional surveys subsequent to the NBS study indicate a lesser reliability rate for smoke alarms: about 75%. Considering the fact that the principal cause of failure is the absence of batteries (2) (3), the implied failure rate in the NBS study does not appear appropriate for wired-in alarms. The observations made by OHC in their study, indicating a reliability rate of 97.6%, seems to be much more appropriate. (Appendix C)

The reliability rate of 92% for residential sprinklers, on the other hand, may be somewhat high since it is based on commercial and industrial systems which would probably be inspected and tested on a more rigorous basis than systems in private houses. However, there is no appropriate data on which to base other estimates.

If smoke alarm reliability in practice is higher than that assumed in the NBS study, it is apparent that the assumed risk reduction attributable to sprinklers alone should be reduced. If, according to Appendix D, the lives saved by smoke alarms is equal to (0.00821 - 0.00390) per fire with alarms that are 84.7% reliable, then the lives saved when the alarms are 97.6% reliable should be (97.6 / 84.7) x (0.00821 -0.00390) = 0.00497. This means the fatality rate of houses with smoke alarms (in col 5) should be (0.00821 - 0.00497) = 0.00324 lives/fire. The <u>risk reduction</u> factor due to the sprinklers when used with wired-in alarms should be calculated as (0.00324 -0.00146) / 0.00324 or 55%.

The fatality rate for new houses in Canada equipped with sprinklers is therefore estimated to be 0.45 x 14 or 6.3 persons per million houses per year. That is to say, the sprinklers are estimated to save about 7.7 lives per year per million one and two family houses.

Fire Fighter Fatalities

It is well known that fire fighting is one of the more risk filled occupations, and according to Canadian fire records led to the loss of 7 lives in Canada in 1987 (5). Unfortunately, however, the statistics are not presented in such a way that these attributed to fighting fires in one and two family houses can be directly determined.

An estimate can be made, however, if a relationship is established with the number of civilian deaths. For example, in 1987, about 516 civilian lives were lost so that the ratio of fire fighters' deaths to civilian deaths is approximating 1 to 74. If it is assumed that this realtionship is constant it is possible to allow for such fatalities by multiplying the number of occupant fatalities by a factor of .013. This is about identical to the ratio used in the NBS studies (which was derived on a per-fire basis). Applying this, the lives saved by sprinklering new houses may be increased from 7.7 to 7.79 per million house years.

INJURIES

Injury Rates in Unsprinklered Houses

Although the number of occupant injuries in fires in Canadian one-and two-family houses has been relatively constant for the past 8 years, the total number of reported fires has shown a significant decline (Appendix B). The decrease in fires from 29,510 in 1980 to 20,443 in 1987 indicates that the injuries per fire have actually been increasing during that time (4.3 per hundred fires in 1980 to 6.4 in 1987). When expressed in relation to the number of housing units, however, this amounts to 229 injuries per million houses in 1980 and 211 in 1987, or relatively little change.

The relatively constant rate per million units and the increasing rate per fire incident were unexpected in view of the earlier warning provided by smoke alarms. This may in part be a matter of more incidents of injury that (without the alarm) would have been deaths: the extra margin of escape time results in many more fire victims escaping death but being injured to some degree.

(Perhaps this explains other aspects too: The alarm provides early warning to allow the occupant to extinguish a small fire even more often than otherwise; more fires thus go unreported, helping to account for the reduction in reported fire incidence where smoke alarms are installed; but those serious enough to require assistance and be reported are more apt to be injurious to the occupants who live and perhaps try to fight them.)

To determine how the injury rate was affected by the age of the house, the injury data from Alberta and British Columbia were listed for each of the years from 1983 to 1987 for newer houses built 5 years previous to the fire event (similiar to the fire fatality data previously discussed). These data are shown in Tables 7 to 12. Table 7 and 8 are based on data that exclude houses built during the year of the fire event, while Tables 9 and 10 include such data (based on 1/2 of the houses completed that year). Table 11 is based on the combined data from B.C.

and Alberta, accumulated for the various yearly periods shown. Table 12 is based on cumulative data, combined for British Columbia and Alberta for the general housing stock.

There is a slight trend in reduced injury rates for the most recently built houses, despite the fact that many more of their occupants remain alive to be candidates for injury. The advent of smoke alarms does not appear to have a very marked affect, apparently for that reason. In houses built subsequent to 1981, the injury rate appears to be from 10 to 23% less than that indicated for the total housing stock (depending on whether or not the newer houses include 1987 data). The cumulative total for newer houses for the data years from 1983 to 1987 was also 10% less than for the total housing stock over the same period.

The injury rate for all Canadian houses accumulated over the same years was 218 persons per million houses compared to 222 for Alberta-B.C. On the basis of these observations, therefore, the injury rate for unsprinklered new houses in Canada was assumed to be approximately 10% less than 218 or about 200 injuries per million houses.

Injury Rates in Sprinklered Houses

As noted in discussing fatality rates, there is insufficient experience with residential sprinkler systems to permit evaluation of their effect on fire safety in houses. The evaluation of their effect based on unpublished NBS studies mentioned earlier, however, was used in the NBS cost-benefit study to evaluate their expected performance in fires. Appendix D is a reproduction of Table 6 of this report and shows various risk factors based on the NBS study, including the effect of smoke alarms and sprinklers on the expected frequency rates.

It is of interest to note that the risk of injuries per fire when no detectors or sprinklers are present is given as 0.02676 per fire. This is assumed to decrease to 0.02546 (or about 5%) where smoke alarms are installed. (The observations made in assessing the Canadian data on newer houses showed the injury rate in newer houses to be about 10% less than for the general stock, with little discernible effect from the advent of smoke alarms).

When sprinklers are used in addition to smoke alarms, the predicted injury rate per fire is 0.01436 or a decrease of 43.6%. Since smoke alarms have little or no apparent influence on injury rates, the difference in reliability rates between battery operated and wired-in units is relatively unimportant and does not require the injury risk factors to be adjusted as was the case with the fatality risk factor. Accordingly, an injury risk rate equal to (100 - 0.436) x 200 = 113 persons per million housing units was assumed for injury rates in newer houses equipped with sprinkler systems in Canada. Sprinklers, therefore, are estimated to prevent about 87 injuries per year per million one and two family houses.

Fire Fighter Injuries

While the ratio of fire fighter fatalities to civilian fatalities is small, the ratio of fire fighter injuries to civilian injuries is much higher. According to 1987 figures (5) the total number of fire fighter injuries was 1296 compared to 3843 civilian injuries. Like the fatality records, these are not presented in a manner that permits an analysis of those injured fighting fires in one and two family houses. If it is assumed that the ratio of injured firemen to injured civilian is constant, however, one can estimate the number of injuries as being 1/3 the civilian rate.

This method of estimation may be considered somewhat symplistic but it is considered to be sufficiently accurate for the purpose of this analysis. Fire fighter injuries tend to fall into a much different pattern than civilian injuries as well, due to the nature of the work. It is also possible that there may be an "over reporting" of firefighting injuries in comparison to the civilian injuries because of the manner in which statistics are collected.

While there is an obvious need to improve this data base, it is considered appropriate for this study to assume that the firefighter injury rate to be 1/3 the civilian rate or 200/3=67 per million houses in unsprinklered houses, and 113/3=38 per million houses in sprinklered houses.

Cost of Injuries

While the number of injuries that may be prevented by sprinklers can be estimated through a systematic evaluation of various fire scenarios and the performance characteristics of residential sprinkler systems, the average costs associated with injuries are not so easily established.

The costs of injuries relate not only to the direct medical costs associated with such injuries but should include an allowance for pain and suffering as well. The NBS study took the simple approach, estimating the average overall cost per injury to be $20,000 with little discussion.

The problem is further compounded by the fact that the estimation of injuries in the U.S. study seems to be imprecise. The estimate of U.S. injuries in residential fires from more recent statistics is about 38 per 1000 fires. This appears to be about one half that reported in Canadian statistics (about 64 per 1000 fires). This may reflect on the reporting system and the types of injuries reported. Obviously, considerably more work is required to establish true current costs of fire injuries with more confidence. This, however, would require a separate study and is beyond the resources of this study.

For the purpose of this project, therefore, it was decided to use the value contained in the NBS cost-benefit study, expressed in current Canadian dollars as $30,000 per injury for both civilians and fire fighters.

PROPERTY LOSSES

Property Losses in Unsprinklered Houses

Since property losses are based on estimates rather than on actual costs, a degree of judgement is introduced into the statistics which has been absent in the other basic statistics discussed so far. In view of the fact that the statistics are based on many events and involve numerous estimates, it is generally expected that the statistics will represent a reasonably consistent measure of the total fire losses that occur.

In estimating costs, however, the estimation is bound to be influenced by experience with past events; indeed it must be in order to make good estimates. In a stable economy without inflation, the more experience an estimator relies on the more accurate the estimate will be. However, there is a question in a world of changing dollar values as to whether an estimator does in fact think in terms of current dollars, or in recollected dollars which may lag somewhat behind current dollar values.

In discussions of dollar losses in this report, it was considered to be appropriate to convert property loss statistics from previous years into 1989 dollars, based on the cost of living indices for those years relative to 1989. Whether this distorts the property loss estimates and introduces a bias is difficult to answer. In a period of a constant inflation rate this may not be important since the estimate, while possibly somewhat low, should reflect trends in total loss estimates. If the inflation rate varies as significantly as it has in the past decade, however, then judgemental inertia may not allow the estimate to reflect the more recent trends. This is brought to the reader's attention purely as a cautionary note to indicate that the adjusted loss values may have a built-in bias. Without substantiating studies to verify the suspicion, however, it is not possible to suggest an alternative.

It may be seen from Appendix B that, based on current dollar losses as reported, there has been little change in property losses from 1980 to 1987. When these are converted to 1989 dollars, however, and the losses are expressed per house, it can be seen that there is a pronounced trend of reduced losses.

In order to determine whether or not the losses in newer houses were different than those in older houses, the fire losses from Alberta and British Columbia for newer houses were listed for each of the years from 1983 to 1987, along with the fire losses for the general housing stock. Using the same procedures as described in examining fire fatalities and fire injuries discussed earlier, the data from the two provinces were combined and accumulated year by year to obtain more statistically significant results. The data for B.C. and Alberta are shown separately in Tables 13 to 16 for the two data bases used in this study. The accumulated data is shown in Table 17 for the newer houses, and in Table 18 for the general housing stock; the same procedure as used previously for analysing data for fatality and injury rates.

A comparison of the data for newer houses and the general housing stock on a year by year accumulation of data indicates that there is no discernible trend distinguishing newer houses from the general housing stock. If a comparison is made between housing with wired-in smoke alarms and the general housing stock (i.e. data from 1986-87 in Tables 13 and 14 and 1985 to 87 in Tables 15 and 16) the property loss per newer house is between $50 and $51 per house as compared to $52 for the general housing stock. In other words, there is no obvious statistical trend. For the purpose of this study it was decided to use the national data for 1987, converted to 1989 dollars. <u>That is to say, it was assumed that the average property loss for one-and two-family houses should be $44.80 per house, based on the value for the total housing stock</u>.

While this is about 10% less than that indicated in the western statistics, this may again reflect the fact that houses in central and eastern Canada have a larger proportion of older houses than in the western provinces, and these are less valuable and costly to rehabilitate than are newer houses.

Property Losses in Sprinklered Houses

The NBS procedure for evaluating the effect of sprinklers on property losses is based on an evaluation of various fire scenarios and operating characteristics of residential sprinklers as previously discussed for fire fatality and injury rates. Table 8 from the NBS study is repeated in Appendix E for reference. This table shows how direct fire losses in the NBS study were calculated theoretically for sprinklered and unsprinklered houses, with and without smoke alarms.

It may be seen from this table that the use of smoke alarms alone is theoretically assumed to decrease the total fire loss from $3360 to $2626 per fire, or a drop of about 22%. The presence of a sprinkler system in turn when used in conjunction with smoke alarms decreases the loss per fire from $2626 to $924 or a drop of about 65%. Again, the theoretical loss reductions are based on an assumed sprinkler reliability of 92% and a smoke alarm reliability of 84%.

The review of the Alberta-British Columbia data, however, has not indicated a discernible trend to reduced damages where smoke alarms are installed. While there is a general downward trend in the national fire losses as reflected in Appendix B, this seems to be due to fewer fires, not less loss per fire. In terms of current dollars the property loss <u>per reported fire</u> seems virtually unchanged since 1980, at around $13,000 per fire. (Thanks to the alarms, numerous fires may be extinguished quickly by the occupant with little or no damage, and often not reported; the loss per actual fire may be reduced even more than predicted by the National Bureau of Standards.)

In the previous discussions, adjustment factors were introduced to modify the NBS estimates regarding the sprinkler effect because the reliability factor assumed for smoke alarms was considered to be too low. On the basis of the B.C. and Alberta fire records as well as the trends in national data, the NBS-predicted damage reduction of almost 22% for the presence of smoke alarms does not appear warranted. In any case, NBS accords little difference in damages per sprinklered house regardless of the presence of smoke alarms. Because of this, a modification of the NBS calculated reduction due to sprinklers did not appear to be warranted. It was decided to use the 65% reduction factor suggested by the NBS study to estimate the effects of sprinklers on Canadian fire losses. While this tends to overstate the effect of sprinklers, such overstatement is minimal. It was therefore assumed that sprinklered houses in Canada would incur an average loss of ((100 - 0.65) x $44.8), or $15.70 per house.

While water damage from sprinklers may be considered as a property loss it is considered to be more appropriate to deal with this aspect under sprinkler costs to be discussed later.

INDIRECT COSTS

The property losses discussed in the previous section are the direct costs attributed to fires. In addition to these are the indirect costs which are not as obvious and include expenses such as the cost of temporary shelter, missed wages, demolitions, legal expenses, transportation and similiar costs as a result of the fire. Although no studies have apparently been undertaken in Canada on such costs, estimates have been made in a U.S. study made a number of years ago and used as a basis for estimates in the NBS cost-benefit study (11). A summary of the indirect cost as they appeared in the NBS study, which converted the costs to 1982 US dollars, is reproduced in Appendix F. These values, converted to 1989 Canadian dollars, are shown in Table 19.

It is assumed in the NBS cost-benefit study that the indirect costs will be reduced by sprinklers in proportion to the direct costs or property losses. The same loss reduction factors for sprinkler and alarm systems are assumed in both cases. Table 10 in Reference 10 showing these reductions is reproduced in Appendix G.

In discussing property losses, it was noted from Canadian data that there was no significant property loss reduction per reported fire when smoke alarms were installed. For consistency, the indirect losses should also show no reduction for such losses. Using the indirect cost estimate from Table 19 and the national statistics for the entire housing stock, the average total indirect costs per dwelling unit may then be expressed as approximately $2.9 per house regardless of the presence of smoke alarms, and, when sprinklered, the total indirect costs should be reduced to 0.35 x 2.9 or $1.0/house. Similiarly, the out-of-pocket indirect costs may be expressed as $1.1 per unsprinklered house and $0.4 per sprinkered house.

FIRE SERVICE COSTS

Since sprinklers have a profound effect on reducing the severity of fires, it naturally follows that as more houses are sprinklered the less need there should be for community fire services. In theory, a decreased demand for community fire protection should eventually be translated into decreased community taxes, and this should be included on the benefit side in the equation of costs and benefits of residential sprinkler systems.

In fact, however, such assessments of future benefits are extremely difficult to express in reliable quantitative terms due to a variety of complicating factors. It has been pointed out by the Ontario Fire Marshal's office (12), for example, that based on their experience, generalizations with respect to such costs and typical coverage areas are inappropriate.

The fire marshal's office notes that the strength of the fire fighting force in a community tends to reflect the ability of the community to afford such costs, and the public's demand for this service. These levels are not provincially regulated and vary substantially from community to community.

This seems to be born out in U.S. statistics. Table 30 in Reference 13 shows that the per capita cost of fire departments increases as the population increases. In 1984 it averaged $65 (U.S.) per person in communities of 1,000,000 or more and almost $30 per person in communities of less than 50,000. The statistics showed that the per capita cost varies from about $16 in Delaware to $108 in the District of Columbia. Presumably similar trends could be expected in Canada, making the selection of typical annual cost savings due to the reduction of such services very difficult to estimate as an "average". The U.S. statistics showing increasing per capita costs with increasing community size may also reflect the larger number of volunteer firemen in smaller communities, the fact that fire stations have tended to be located closer to older more congested neighbourhoods where high traffic volume and increased fire potential coexist (as noted by the Ontario Fire Marshals Office), and the fact that building heights, work load, and life and property loss potential are also factors in decisions to provide multi-company fire stations.

The Ontario Fire Marshal's Office notes that:

> "Fire stations invariably serve a mix of residential, institutional, commercial and industrial buildings and the small home would be unrepresentative of the most demanding fire scenario in its response district. Consequently any general reduction in fire service based upon a segment of dwellings furnished with sprinklers is inappropriate. However, the introduction of automatic sprinkler protection to a subdivision at the fringe of a fire station response district may serve to delay the construction of a new fire station, within reasonable limits. However, it should be considered that the fire service often provides other valuable

> services besides fire fighting where prompt response is critical, such as resuscitator calls. A citizenry that has become accustomed to such a prompt service may be unwilling to see any deterioration in that service."

The observations that modern fire departments serve a variety of functions in addition to fighting fires is reinforced by data provided by the Maryland fire department (Table 35 of reference 13). This showed that building fire incidents represented only about 13% of the total incidents while vehicle fires and other types of fires such as grass and rubbage fires represented about 12%. Emergency medical treatment on the other hand represented 27% of the incidents while rescue and response to hazardous conditions accounted for 13% of the calls. "Good intent" calls and false alarm calls accounted for 27%. Even if a station were intended to serve strictly a housing area, therefore, the number of additional functions they would be expected to perform would make it difficult to estimate the potential for cost savings through the introduction of sprinklers in new houses. While the Maryland data may or may not apply precisely to Canadian fire stations, it nevertheless indicates the variety of work undertaken by modern firefighters, and suggests that it may indeed be unrealistic to anticipate a drop in annual costs of fire departments in proportion to the number of sprinklered houses served by the fire station.

NBS Estimated Fire Protection Costs

In its cost benefit study of residential sprinklers, NBS assumed that each house should be within 1.5 miles of the fire station. The most efficient way to achieve this was to assume the fire station served a hexagonal area with the fire station at the centre. Using an average population density of 360 persons/sq.mi. and an average household of 3.28 persons, it was calculated that the station would serve 642 houses.

The annual cost of operating the future station was determined from a 1972 study of five western cities. Using an average per capita cost of $32.04 (converted to 1982 dollars), the present worth of the operating costs based on a 30 year period was calculated. The cost of an average 4000 sq. ft. masonry fire station including land was estimated as $327,500, for a total present worth (operating plus capital) of about $1,256,300 or about $1955 (before taxes) for each house.

As a scenerio in the NBS study, it was assumed that if all houses were sprinklered, the fire station costs could be eliminated if the surrounding hexagonal districts extended their services. No reasoned justification was given to show that this in fact could be done <u>without greatly reducing the level of current service in its many facets, including the saving of lives.</u>

It can be appreciated that such a rough approximation of possible savings in fire services is difficult to accept as being reasonable in the light of previously noted comments from the Ontario Fire Marshal's Office.

<u>NAHB Approach</u>

In the societal cost-benefit analyses used by the NAHB National Research Center (13), the NBS method of estimating savings in fire fighting costs was indeed considered to be unrealistic. It was assumed in the NAHB/NRC estimate that only 25% of the fire stations could be eliminated if all houses were sprinklered. It was further considered that the residential portion of the fire fighting services is only 40% of the total service cost, so that the potential savings as a result of sprinklering houses would be 25% of 40% or only 10% of the total firefighting cost.

The per capita cost of providing municipal fire fighting services in the NAHB/NRC study was assumed to be $64 per year. This is based on U.S. Census estimates and includes capital as well as operating costs. (The $64 value is representative of cities of from 300,000 to 500,000 population, and is considerably greater than the national average of $37.)

Assuming the average U.S. household to be 2.56 persons, the total cost per house was calculated as $164. Since only 10% of this can be reduced by sprinklering new houses, the estimated annual saving was calculated as only slightly more than $16. Using the 6% real interest rate assumed by NBS and a 30 year cycle, this represents a present worth of about $225 (compared to $1955 savings estimated by the NBS).

Such widely varying estimates between the two approaches does not encourage confidence in such predictions, although it would appear that the NAHB/NRC method is much more realistic.

Harmathy's Method

Harmathy's approach to estimating annual savings in fire fighting costs as a result of sprinklering is also from a societal perspective (14). Although directed at an American audience through the use of U.S. data and statistics, it was evaluated as a possible method to be considered in Phase 2 for estimating potential cost savings in Canadian municipal fire services when houses are sprinklered.

Harmathy assumes that cost reductions will be in direct proportion to the anticipated reduction in "fire fighting load". The latter is a concept proposed by Harmathy in which he assumes that the municipal services will expand in direct proportion to the "fire fighting load" which in turn is assumed to vary in direct proportion to the product of the property loss and the number of fires. While this is an intriguing hypothesis, no arguments are advanced to defend it.

The annual savings due to sprinklers is determined from the difference between the "fire fighting load" for sprinklered and unsprinklered houses. From this is estimated the proportional saving in the number of fire stations and the total national fire fighting payroll (plus 10% for operating expenses). The NBS factor for estimating reduced fire losses for sprinklered houses was used to determine the total annual fire fighting load for sprinklered houses. The capital cost for individual fire stations is estimated at $1.5 million. From these assumptions, the present worth savings in fire fighting services due to the use of sprinklers is calculated to be about $147 (1985 U.S. dollars), as compared to $225 in the NAHB/NRC study and $1955 in the NBS study.

Harmathy's method, while relatively simple and straightforward, also seems to be somewhat optimistic in predicting reductions in fire fighting costs. It intrinsically assumes that annual fire station costs are elastic and will grow or shrink in direct proportion to the demands put on it. In fact, however, this is not the case. As noted in the comments from the Ontario Fire Marshal's Office, fire stations are provided largely as a result of the taxpayer's ability to pay. Their capacity to be elastic to demands as a result of residential sprinkler growth is limited, especially in consideration of the general mix of buildings that are usually served, and the varied nature of the community services provided by fire departments.

Choosing the Appropriate Estimate of Fire Service Reduction

The foregoing assesments all appear to be overly optimistic with regard to the savings due to sprinklers. All, for example, assume that the same fire risk factor applies to every house, new or old. This, it has been shown, is not the case. New houses already have a much lower risk than existing houses and therefore a lower real need for fire protection, even unsprinklered. The sprinkler effect would be a marginal effect over any reduction that could already be justified.

In spite of the reduced life loss and the reduction in fire losses that have indeed occurred over the past several years, there has been no trend to reduce fire services to match the increased safety. In fact U.S. statistics indicate that the per capita cost of providing fire protection has increased in real terms in the face of improved fire records (13).

Each of the methods reviewed has a significant guesswork component and each lacks valid arguments to defend its assumptions. Of the three, however, the approaches by Harmathy and the NAHB/NRC study seem to be more realistic in assessing potential cost reductions, albeit still on the optimistic side. The NBS approach can be discarded as being unrealistic: the elimination of fire fighting services for sprinklered buildings, and the assumption that existing services would be extended to cover such areas, does not recognize that fire stations usually serve a variety of buildings and functions.

The NAHB/NRC approach, which uses a 40% residential component and an eventual reduction of 25% if all houses are sprinklered, seems more realistic. The per capita cost of municipal fire services of $64/year used in the study, however, appears high since it applies to municipalities in the 300,000 to 500,000 population range. The U.S. national average of $37 per person per year (1984 U.S. dollars) seems to be more justifiable. This is approximately $58/year in current Canadian dollars. Based on an average of 3.1 persons per family (1986) this would be about $180 per house per year. Of this, about 25% of the 40% residential component is estimated to be removed by sprinklering: a saving of about $18/house/year.

(This approach was favoured somewhat over Harmathy's which appears even more theoretical. In fact, however, the two methods in this case give comparable results. In terms of current Canadian dollars, Harmathy's approach suggests annual savings of about $16 per house.)

In that none of these approximations allows for the fact that the sprinklering reduction is really only marginal to the reduction that modern houses would already allow, the estimated $18 per house per year exaggerates the savings potential of sprinklers on fire service costs.

SPRINKLER COSTS

Plumbing Interface: One of the significant features of residential sprinkler systems is the relatively low water flow rate required compared to that of commercial and industrial systems. This reduces costs by permitting the potable water supply to serve as the sprinkler supply, thus eliminating the need for separate service piping for the sprinklers. Nevertheless the flow rate is still substantial in terms of most domestic potable systems. According to NFPA 13D (15) at least 68 l/min. design flow is required for any sprinkler, and 49 l/min. for each of 2 heads actuated simultaneously.

In a house with a municipal water supply, the rate of flow will depend on the pressure available at the watermain, the difference in elevation between the main and the highest sprinkler, and the frictional resistance losses in the system from the watermain to the sprinklers. The frictional losses in the piping increase as the pipe size is decreased. The losses include losses in the pipe, valves, fittings and, where installed, the water meter. The total pipe length, the number and types of fittings and valves and the velocity of flow, all have a direct effect on the magnitude of the frictional losses and hence the watermain pressure needed to deliver the flow. Although NFPA 13D specifies a minimum diameter of 3/4 inch for any copper piping serving a sprinkler, this may rarely be adequate to provide the required design flow rate. The Standard requires hydraulic calculations to be carried out to show that the required rate of flow can be achieved.

To obtain a national perspective of available water pressure and existing service pipe requirements, the various provincial plumbing authorities were contacted. The response is shown in Table 20. The reported municipal water pressure ranged from about 200 to 100 kPa (30 to 150 psi). It becomes clear that the normal 3/4 in. service piping permitted in most municipalities would not be adequate to serve residential sprinkler systems in most areas.

Water Meters: When provincial plumbing authorities were asked if it was generally required to meter the sprinkler water when water meters were installed, they were not able to generalize since this apparently varied from municipality to municipality. Regina, for example, requires such metering but Saskatoon does not. Such meters can impose a significant frictional drag and thus increase pipe size and cost.

Back Flow Prevention: Although all provinces who responded to the questionaire allowed the potable water supply to serve the sprinkler system, all required that the system be designed so that the sprinkler water could not flow back into the potable water thereby contaminating it. The type of protection required varied from a single check valve to a double check valve or to special approved backflow prevention devices.

First Costs

Since the installation of sprinklers in houses is not a common practice, accurate cost predictions are not possible on the basis of experience alone. The alternative is to estimate costs based on their components. Such estimates may tend to be influenced by commercial and industrial practices that may not translate directly to residential applications. Care must be taken therfore in such estimates to reflect actual conditions. Since such systems are relatively new to house construction there may therefore be a tendency for estimates to be somewhat conservative until sufficient experience is gained.

Several approaches have been made to estimate sprinkler imstallation costs. In the NBS cost benefit study, both common rule-of-thumb estimates and component cost estimates were made. On the basis of rule-of-thumb approach, for example, it was estimated by certain fire protection consultants in 1982 that the cost range for residential sprinklers should be between $1700 to $2000 U.S. (or $2860 to $3370 current Canadian). The component cost estimate for a typical 2 storey detached house of 200 m^2 (2175 sq. ft.) floor area was $2466 for 1/2 inch in copper pipe and $3935 for 1 1/2 inch copper ($4179 and $6633 current Canadian).

When plastic piping was used the costs were reduced to $1218 for 1/2 inch piping and $2567 for 1 1/2 inch piping ($2053 and $4327 current Canadian). It may be noted that subsequent to the NBS study, NFPA 13D was revised to require a minimum pipe size of 3/4 inch.

Most fortuitously for this study, Alberta Municipal Affairs has just completed a sprinkler cost appraisal under the Innovative Housing Grants Program. The Alberta installation costs were studied for a split level detached house with a floor area of $140m^2$ (1500 sq. ft.). Four separate contractors were asked to prepare estimates on the installation costs of sprinklers designed in conformance with NFPA 13D. The contractors were asked to prepare costs (price to the builder) both for sprinklers on municipal water service and on private wells. The latter, of course, requires a storage tank and booster pump to provide the required flow rate and therefore tends to be more expensive.

In addition to estimated costs of systems installed in conformance with NFPA 13D, the contractors also prepared costs for a modified system in which only the kitchen, living room and family room were sprinklered. These are the areas where 70% of the fatal fires occur according to Alberta statistics. (It may be noted that a suggestion was made in Phase 1 that it may be more cost effective to have a partial sprinkler system because of the high risk rate in certain areas of the house).

Two of the Contractors estimated for copper pipe, one for plastic pipe and one submitted an estimate on a "Design and Install" basis and did not specify the type of material to be used.

The Alberta study concluded that the installation costs for houses on municipal water supply may be about $4158 for the copper pipe systems and $2779 for plastic piping. The fourth contractor, who did not specify the material to be used, estimated his costs at $4599.

In the case of rural systems supplied by private wells, the costs for the two copper systems averaged $6667 while the cost of the plastic system was $4792. Again, the fourth estimator was high at $7125, making the average price of the four $6313.

When a partial sprinkler system is used, the two copper systems averaged $2886 while the plastic system was $1985. The average cost for the four estimates was $2772.

The cost ratio of the partial sprinkler system compared to the NFPA 13D system averaged about 0.70 for both the plastic and copper systems. This is about the same ratio of the lives that would be protected by sprinklering the more critical areas. This would indicate therefore that the partial sprinklering is not more cost effective than full sprinklering, at least for this particular house. The relatively small cost reduction appeared to be due to the fact that the system capacity to deliver the required flow rate is the same as for the fully sprinklered system and this is the principal determinant of the pipe size and the resulting costs. Obviously, for substantial savings to be made with partial sytems, other modifications such as reduced flow-rates would also have to be considered.

Recent correspondence with the Quebec Ministry of Labor (16) indicates that, according to their estimates, sprinkler systems for bungalows can be expected to be between $2500 and $3000 (or a $2750 average). A bungalow allows a simpler system than the split level house assumed in the Alberta study, and the required delivering pressure can be reduced an additional 27 kPa (4 psi) because of the reduced height of the uppermost sprinklers. (The type of piping in the Quebec estimate was not given.)

In the calculations in this study, the cost of sprinklers was assumed to be $4158 for copper systems and $2779 for plastic systems on municipal water service. For houses on private wells, the cost of a copper system was assumed to be $6667, and the cost of a plastic system $4792. A summary of the various cost estimates is given in Table 21. (An allowance of 8% was added for the housebuilders overheads, in the final analysis.)

It will be observed in Appendix H that the sprinkler costs were determined for three sizes of service pipe (50mm, 38mm and 19mm), although the designers concluded that the 50mm size was actually required for this particular house and sprinkler head design to meet the waterflow requirements of NFPA 13 D., assuming the residual water pressure at the street to be 310 kPa (45psi).

While this size of service pipe may seem somewhat large for a house sprinkler system, it should be noted that for this particular design the sprinkler heads were the sidewall type with a K factor of 4.2. The design residual pressure at the sprinkler was required to be 225 kPa (16.4 psi) to deliver 1.07 L/S (17 US GPM) with 2 heads operating. It is possible that smaller piping may have been possible with a different design layout and head selection, or with a higher water pressure at street level, thereby reducing costs somewhat.

The relatively high residual pressures for residential sprinklers to deliver the required flow at the necessary density to the designated area is of course a limiting characteristic of such systems. New developments in sprinkler head designs will no doubt allow lower residual pressures and consequently smaller piping. This could eventually lead to much simplified systems particularly where partial sprinklering may be used to protect the most hazardous areas.

It should also be noted that the Alberta Study assumes that the water supply to the sprinklers is allowed to bypass the water meter. As was previously pointed out, this may or may not be permitted and depends on the policy of the particular municipality.

NFPA 13D specifically requires that where the service line supplies both the sprinkler system and the domestic water supply, the house must be equipped with a smoke alarm system conforming to NFPA 74, "Standard for the Installation, Maintenance and Use of Household Fire Warning Equipment". This standard is more rigorous than the requirements in the National Building Code, since the code only requires each sleeping area to be protected. This can be accomplished in many cases by a single alarm located in the hallway. Strictly speaking, the difference in cost between the two standards for smoke alarms could be justified as part of the sprinkler cost for full NFPA 13D compliance, but this has not been done in this study.

(It may also be noted that while water flow alarms are commonly installed in sprinkler systems, NFPA 13D permits them to be omitted where the house is protected by a smoke alarm (clause 3-6). Since such smoke alarms are required where the service pipe is common to the sprinkler and domestic water supply, the cost of the water flow alarm could be deducted from the additional cost for the smoke alarm.)

Annual Costs

In addition to direct costs, sprinkler systems may also require occasional servicing and should be inspected on a regular basis if they are to provide a high degree of reliability. Since there is an absence of published Canadian data on sprinkler maintenance and inspection costs, it was decided to use the assumptions developed for the NBS study. In the study it was assumed that at least one hour of inspection was required per year. This has been assumed to cost $35 per year in the analysis.

Little information seems to be available concerning water damage as a result of sprinkler discharge. While the failure rate of sprinklers is extremely low and can probably be dismissed as insignificant, there is lack of information on damage that occurs when a sprinkler is activated by a heat source. In the NBS study it was reasoned that the damage done by such discharge was considerably less than would occur with fire hoses. It was also assumed that there would be less damage from fire than if the sprinklers did not discharge. For these reasons the NBS cost-benefit study did not include an allowance for water damage.

What may not be fully appreciated, however, are the effects from the numerous fires that occur which are extinguished by the occupant and are not reported. Most of these may cause little or no damage. If, however, the fast response residential sprinklers are triggered by a significant fraction of such otherwise harmless fires, it is likely that water damage will not be negligible and should be added as an additional cost in the calculations.

According to a recent NFPA study (17) there were 115,000 cooking fires reported in the U.S. in 1985. It was estimated, however, that a further 12,000,000 went unreported. That is to say only about 1 in 100 cooking fires is reported, the rest being extinguished by the occupant without the need to call for firefighter assistance. If residential sprinklers respond as quickly to elevated temperatures as is indicated in tests, there may indeed be a potential problem, particularly in kitchens where most fires originate. Notwithstanding this likelihood, no figures are available for estimating this damage, and no allowance for water damage is included here.

Discount rate: All costs may be converted to annual costs to allow convenient evaluation of costs and benefits of measures which operate year after year. The "discount rate" used in such a conversion is simply an expression of the cost of money; whether the money is borrowed or simply allocated to one use (and therefore removed from other opportunities) is not of concern.

Where large expenditures are mandated by public regulation, the term "social discount rate" may be applied in evaluating the relative merits of diverting such funds from other uses. Informetrica Limited of Ottawa was asked to advise on this policy-related aspect of such an important benefit-cost matter as mandating sprinklering. Quoting directly from Mr. McCracken's memorandum, which is attached as Appendix H: "If resources are directed into some area, then less gets done in other areas. The [social discount] measure used is an estimate of the real rate of return to society (before taxes) of private sector activities. This is approximated by the real before-tax return to the corporate sector; in Canada this is about 10 per cent. Treasury Board has proscribed that 10% will be used for all Benefit Cost studies by the federal government...Use 10% as the real interest rate."

Using 10%, and considering a 30 year life cycle costing, the Present Worth Factor (for converting annual costs to present worth, or first costs to annual costs) becomes 9.43 for the final analysis in this study.

OTHER COST AND BENEFIT CONSIDERATIONS

Insurance

In the societal perspective taken in this study, insurance may be ignored as neither a cost nor a benefit. Costs are simply the net costs of installing and maintaining sprinklers while benefits are actual savings in property, injuries and lives. If there are reductions in insurance premiums, counting them as a benefit would involve "double counting" with the actual savings in property losses. Similarly, mortgage considerations and possible tax effects or incentives are not counted in the whole societal "model". Informetrica addresses these points in Appendix H.

(Some considerations on insurance were offered by the industry for this study. According to correspondence from the Insurers' Advisory Organization who advise Canadian insurance companies, there are few Canadian insurance companies who offer discounts for sprinklered houses(18). Those that do generally offer a 5 to 10% reduction in the typical homeowners' policy. It was also noted that IAO does not presently recommend any rate reductions for sprinklered houses. IAO also speculated that should municipalities permit fewer hydrants or fire stations as a result of the increased use of sprinklers this could likely have an adverse effect on insurance premiums. This point was also made in the two US studies previously referenced.)

Code Trade-offs

Phase 1 of this study pointed out that there are relaxations of requirements in The National Building Code where a building is sprinklered. Where such relaxations lead to cost reductions, they should of course be considered as an off setting benefit or netting of costs.

An examination of these benefits, however, indicates that they have very little application to houses. Cost savings due to sprinklers generally relate to reduced fire protection ratings, increased allowable distances to exits, greater window areas adjacent to property lines, and increased ratings for interior finishes. In the case of houses, building code requirements are already minimal, and in general there is little opportunity for further reductions. Reduced clearance to property lines is one potential area of saving, but is small and almost impossible to evaluate. In most cases zoning restrictions and not building code requirements determine the minimum side yard clearance. In addition, of course, there are design solutions, other than sprinklering, that may be more cost effective in allowing reduced side yards in a fire-safe manner. Row housing reduces side yards to zero.

There are several points that should also be kept in mind in considering the trade-off potentials with residential sprinklers. The system does not protect all parts of the buildings as would be the case with systems designed in conformance with NFPA 13, the standard used for commercial and industrial application. The water supply has a relatively short water demand requirement (10 min) and relatively low peak flow requirements. The basic assumptions underlying the development of NFPA 13D must be kept in mind in establishing such trade-offs.

At this stage, it is considered premature to make assumptions of the potentially limited trade-offs that may or may not be permitted in the future by code committees. No potential savings through building code trade-offs are assumed in this study.

COST-BENEFIT ANALYSIS

As noted previously, the cost-benefit analysis in this study is based on a societal perspective. Since this study is intended to provide information for code committees concerned with evaluating the need to mandate the use of sprinklers in houses, this was considered to be the more relevant perspective. Provincial or municipal building code agencies would be expected to be concerned with the true costs and benefits for the entire society.

The basic "model" used in these calculations was that used in the NBS study (10) but modified so that it reflected the societal perspective as in Part 2 of the NAHB/NRC study (13). The methodology of the NBS study was given in Appendix D of Phase 1 of this study and need not be repeated here, except to note some differences in the way risk factors were derived. By deriving risk factors directly from new house statistics, this study targeted the house types that would be affected by building codes. In addition, by deriving requirements based only on houses equipped with wired-in smoke alarms, it was not necessary to introduce theoretical modifying factors to account for their effect.

The findings and final analysis are listed in Tables 22 and 23. The results are given in terms of the net cost of saving a life, as was suggested in Phase 1. This is a departure from other studies of this nature which typically assign a hypothetical (and arguable) value for a life and then determine whether the total cost of the sprinklers (including annual maintenance) exceeds the benefits in terms of reduced property losses, injuries, fatalities and other benefits.

The primary finding of this study: **The net cost of saving a life by fire sprinklering new Canadian houses is $38 million or more**. While the values in Table 23 are based on sprinkler costs determined for one house and one watermain pressure, these were chosen as representative of much of the new housing stock.

With present technology, house sprinkler installations might decrease somewhat in costs were they to become established in high-volume application, but not enough to offer promise of saving property and lives in new houses with reasonable economy. In the normal course, however, new sprinkler technology will perhaps attain substantially lower costs. If lower residual pressures could be used adequately, obviating the need for special piping, then lower-cost sprinklering might well merit consideration for highest-risk existing housing.

DISCUSSION

The Cost of Saving a Life

The principal objective of building codes is to provide reasonable levels of safety and healthful conditions for building occupants. Since the proposal to mandate the use of residential sprinklers is an attempt to further these objectives, it is logical that residential buildings be targeted since these are where most lives are lost. The question that must be answered, however, is whether the cost of saving lives by sprinklering new houses represents a rational use of money or could such a capital outlay save more lives in other ways.

Few building code requirements in Canada have been subjected to the same type of cost benefit analysis employed in this study. There is relatively little direct basis, therefore, for evaluating the cost effectiveness of proposed code changes by comparison with other changes. Specifically considering the mandating of residential sprinklers, there is no comparative basis to indicate that the costs of saving a life found by this study are within an appropriate or accepted range of values implied by other code changes. It is possible to evaluate certain measures, such as requirements for installing smoke alarms (and potential refinements in product and application) and conclude that they are more cost effective than sprinklers in saving lives. Broader comparisons would be useful.

Fortunately, a U.S. appraisal was conducted on a number of federal safety and health regulations several years ago by an economist with the Office of Management and Budget (19). This study compared the relative cost effectiveness of regulations in terms of the cost to save a life. Not unexpectedly, the study showed a wide range of values for the different regulations studied, particularly between different government agencies.

Laws and regulations of course are enacted for a variety of reasons, even though they may all have the same objective. The economic component in many cases is overshadowed by public apprehension, particularly in matters affecting personal health or public safety. Health concerns in particular tend to be exaggerated in importance due to the newsworthiness of the subject and the great uncertainties involved, and may be responded to by governments to diminish public concern rather than to remove a real threat. Table 24 is a digest of the information from the U.S. study, restricted to regulations of the National Highway Traffic Administration (automotive safety), the Federal Aviation Authority (aircraft safety) and the Consumer Product Safety Commission (including fire safety). These tend to be more rationally based safety requirements in which the costs and benefits are fairly well defined.

It should be appreciated that the values in Table 24 still contain a large element of subjective judgement and should not be considered to be precise, even to two significant figures. They are shown here purely for the purpose of providing a comparison of the risks that have been regulated in the U.S. in order to give a general feeling for the costs of preventing life loss. In comparison, sprinklering new houses would entail costs higher by an order of magnitude or more, as is shown in Figure 3.

Household Occupancy Factors Affecting Fire Risk

As noted, cost-benefit studies of residential sprinkler systems have generally been based on fire risk data averaged for the entire housing stock. No attempt was made to differentiate between high and low risk groups within the stock. It was assumed that all houses were equally at risk, regardless of who occupied them or how the houses were built.

While this study has now demonstrated that newer houses are considerably safer than older houses, it has not addressed the occupants themselves and the effect that their social patterns or economic levels may have on fire risk.

The fire risk that remains in modern houses would now appear to be much less dependent on the house itself than on the behaviour of its occupants. Only in a few cases does the house now play an initiating role in fire (e.g., faulty wiring or appliances or improper installation practices). While the design of a house can play a role in affecting the occupants escape in a fire emergency, this would also appear to be of secondary importance in affecting occupant safety. Far more important is the day-to-day activity or behaviour of the occupants in initiating fires.

Building regulations by and large emphasize the role of the structure in achieving fire safety as opposed to occupant behaviour, on which regulations can exercise little control.

Although fire statistics are available from a variety of sources and on a variety of subjects, there is relatively little information to assess the socio-economic factors that influence fire risk. It is the purpose of this section, therefore, to discuss the possible effect of such influences and derive additional insight from the limited data on hand. The more clearly the contributing fire risk factors can be defined, the more effective can be the choice and deployment of remedial measures.

Knowledge and the Will to Act: Two essential elements are involved in an occupants' influence over fire safety: the occupant must first be aware of the causes of fire, and then must possess the will (and the ability) to remove these causes.

An awareness of the causes of fire in most cases is largely a function of education (both formal and practical) and experience. While most people have such awareness to a degree, the very young or the mentally impaired may have little. Mental impairment, of course, may be temporary (e.g. from drugs or alcohol) or permanent, including that associated with aging or neural disease.

The will to remove known fire risks, or to avoid acting in a manner that would create such risks, is to a larger extent a type of behaviourial discipline and may be acquired through parental training or as a result of experience. Some ethnic groups tend to emphasize more rigid family discipline and parental control, with significant effect as will be seen.

Some social groups, on the other hand, appear to tolerate higher levels of risk more readily than others without taking corrective actions. Groups in lower income levels, for example, may have a higher incidence of cigarette addiction than higher income levels even though they are aware of the health risks.(8) Poverty creates its own agenda of priorities. Fire and health may assume lesser importance if a family is primarily concerned with day-to-day survival. The quest for sufficient food, clothing and other basic necessities no doubt has greater urgency than the more abstract goal of greater fire safety. The demands imposed by poverty and the consequent despair may also overshadow the need for fire discipline and supervision of children. Where both parents must work or the provider is a single parent, there may simply be insufficient time or funds available to ensure competent daily supervision.

Poverty can also have a direct effect on other activities in the home that could impinge on fire safety. With less money available for outside entertainment, the home itself tends to be used for such activities. Late evening food preparation, often using deep-fat frying or other stove-top cooking, substitutes for dining out. The consumption of alcohol in combination with such activities can increase risk levels even further.

When considering the poor as a group, it should be kept in mind that there are many causes of poverty. Mentally and physically impaired people, for example, tend to fall into this group. The elderly also form a disproportionately large portion. Certain "visible minority" groups also form a disproportionately large part of the lower income group as a result of language limitations, inadequate education, lack of appropriate job experience, discrimination and other reasons.

The fact that newer houses have much less risk of fire fatalities than older houses could reflect in part the affluence of new home purchasers as well as the inherent safety features of the house itself. When reviewing fire statistics based on social groupings, income levels, age or other group characteristics, conclusions should be arrived at with utmost care. A complex interrelationship exists within any group, and there are no doubt many qualities or characteristics that may not be recognized that also have an important bearing on fire safety.

<u>The Age Factor:</u> If the fire fatality rate in residential fires is calculated for different age groups in the general population, it can be shown that two categories seem to be at particular risk - the very young and the elderly. Figure 2 shows the fatality rates for various age groups based on information published by statistics Canada (20), for all residential households.

The 1986 Canadian fire fatality rate <u>for the general population</u> was 16.2 persons per million population. Figure 3 shows that the fatality rate in the 0 to 4 year old group was 23.2 persons per million. The fatality rate drops substantially for the 5 to 29 year olds, to 11.5 persons per million. It then becomes somewhat erratic for the years 30 to 69, peaking at 30 to 34 year age groups (19.7 persons per million), and the 55 to 59 year group (20.0 persons/million), although the average from 30 to 69 years is about the national average rate. From 70 and up however, there is a rapid escalation of fatality rates with age. Those in the group 75 and older have a fatality rate of 46 persons per million seniors, or about 3 times the national average rate. The high fatality rate of this group makes it an obvious target in any attempt to increase fire safety.

Cultural Background: While Canada does not publish fire statistics in relation to cultural groupings, the U.S. does (21). These statistics show a very marked difference between such groupings. Data based on 1983 records show that while the U.S. National average fire fatality rate for all fires was about 27 per million population (vs. 31 in Canada that year) the fire fatality rate for Chinese and Japanese Americans was only about 6 per million or less than a quarter of the general average. This would appear to reflect the traditional family discipline and supervision within this group.

The fatality rate for certain disadvantaged social groups, on the other hand, was between two and three times the U.S. average. Although the causes for these variations have not been assessed, it is presumed that large families, overcrowding, poverty and generally substandard housing are major factors. It is not known if the same comparisons would be valid for Canadian cultural groups since it is quite possible that the intervention of social housing programs in Canada could cause a significant change in the rates. (The next item seems to confirm that.) In any event the significant variations indicated by U.S. statistics would appear to warrant further studies in a Canadian context to shed light on the underlying causes of such increased fire risks.

Family vs. Senior Citizen Groups: Although national fire statistics are generally not available for specific identifiable groups in Canada (except for age group), the Ontario Housing Corporation did in fact keep fairly extensive fire records on their social housing from 1975 to 1983, which included subsidized family housing as well as housing for senior citizens(7). While the former stock may be atypical in its family structure and lower income levels, it nevertheless is instructive in showing what the fire incidence causes and fatality pattern can be in hard-wire-smoke-alarmed houses.

Table 25 shows a summary of the 889 fire events recorded by O.H.C. over the period of 1978 to 1983. Of this total, fire in seniors' units represented only 21% of the total fires (all fires are required to be reported, even though the fire department may not be involved). This low proportion was in spite of the fact the seniors' units represented from 53 to 43% of the total number of units over that period. While some of this difference can be explained on the basis of the increased number of occupants per household in the family housing group, it is suspected that unsupervised childrens' activities were also a significant factor. This is apparent when the causes of fires for the two groups are compared. Children playing with matches, for example, were responsible for 160 fires in the family units and only 2 in the seniors' units. (See below.)

(Part of the difference, however, may also be related to the type of housing provided for each group. Of the current 36,000 units provided for seniors, 20,000 are in high-rise apartment buildings and 16,000 in low-rise (6 storey or less). Of the 48,350 family units, 22,350 are in houses (detached, semi and row) while 24,500 are in high-rise and 1500 are in low-rise apartments. In other words, while about half of the family units are located in houses, all of the senior units are in apartment buildings. Unfortunately, published statistics do not permit a direct comparison of the fire risks for apartment units and houses in the general housing stock.)

Based on information provided by O.H.C., the number of seniors' units was about 33,000 in 1978, 44,000 in 1979, 36,000 in 1982 and 36,000 in 1989. Assuming that there was a uniform rate of decrease in seniors' units from 1979 to 1982, it was estimated that the average number of seniors' units over the period from 1978 to 1983 was about 38,000. Similarly, the average number of family units was estimated at 45,000 over the same period. Using O.H.C. estimates of 2.2 persons per family unit and 1.3 persons per seniors' unit, the average population of seniors was calculated to be 49,400, and for families, 104,000. Although the seniors' units were approximately 46% of the total, they accounted for only 21% of the total fires during that period. When expressed in terms of population, Table 25 shows that the senior population (32% of the total) still caused proportionately fewer fires than the family units.

It is of interest to note that fire incidents resulting from the two main causes (cooking and smoking), are in approximately the same proportions as the respective populations of the two groups. In the case of fires caused by children playing with matches, which accounted for 23% of the fires in family units, the rates of incidents between the two groups was 80 to 1 with only 2 fires reported in seniors' units over the 6 year period. Fires due to vandals or arson were 12 times more prevalent in family units; those due to apparently faulty wiring or defective appliances were over 3 times; those due to flammables such as gasoline and from open flames or sparks were over 11 times more prevalent.

<u>Cooking Fires</u>: In the OHC housing, the main cause of fire in both seniors' and family housing was cooking: 52% and over 30% respectively. Most of the fires were stove top type and many involved deep fat frying, particularly in the case of the family units. In most cases the stoves were unattended with the user in another room, in some cases asleep. Table 26 shows a rough breakdown of the cause of stove fires. There is some question as to how some of these statistics should be interpreted, however, since a number of the categories seem to overlap somewhat and the reporting may not always have been consistent within each grouping.

The fact that such a large number of fires occur at a known and fixed location would appear to invite preventative action to be taken at the stove rather than to use a general extinguishing system throughout the house. Obviously, if an inexpensive method can be developed through shielding or by the use of local automatic extinguishers, this may prove to be a much more cost effective measure than a general suppression system.

<u>Smoking</u>: The second major cause of fire, smoking, accounted for 30% of the fires in seniors' units and 17% of the fires in the OHC family units, although the total number of such fires is in roughly the same proportion as the population within the groups. Most of such fires originated in the bedroom or living room. A surprising number, however, were due to the disposal of live cigarette butts resulting in garbage fires in the kitchen, basement and balcony areas.

Table 27 shows the location of fires due to smoking for the two housing groups. The fire incidence is somewhat misleading, however, in that the seniors' housing did not contain basements. The fires that normally take place in basements including garbage fires and heating equipment fires are an additional built-in risk for those with basements (which represents roughly half of the family type units). Fires from smoking are in many instances confined to certain specific locations. In the case of fires in living rooms the majority involve the ignition of fabric covered chairs or sofas. Those in bedrooms generally involve the bedding initially, followed by ignition of mattresses. Such fabrics and textiles of course can be made less flammable as was noted before. It may be of interest that subsequent to the introduction of more stringent requirements for children' sleepwear in the U.S., the fatality rate from such fires dropped by 90% (from 1962 to 1982). (21). While results may not be achieved as quickly in household furnishings, it would appear that this approach may also be a much more economical method to reduce fire risks than a general suppression system.

<u>Children Playing With Matches</u>: While this category was the second most common cause of fire in the OHC family type units it was not a significant factor in the seniors' units. The fact that playing with matches accounted for 23% of the family housing fires, however, also invites attention for corrective action. Just as child proof medicine containers were developed to reduce the risk of accidental poisoning, consideration should be given to a similar approach for matches and lighters to prevent their use by younger children. While this problem may be somewhat more difficult to solve due to the variety of

lighters and matches available, a partial solution at least may be attainable. The trend towards reduced smoking should in any event help reduce the problem by making matches less available, but it is clear that further efforts to separate matches from children could be rewarding and perhaps extremely cost-effective.

Fatal Fires: While Table 25 provides useful general insight into the causes of fire it should be appreciated that not all fires are life threatening. Statistics from O.H.C. housing from 1978 to 1983 show that of the 24 recorded deaths, 54% were as a result of fires caused by smoking, 21% due to children playing with matches, 21% as a result of cooking fires, and 4% due to arson. Again, this is in relatively modern housing with hard-wired smoke detectors generally in service.

Of the 9 fatalities in seniors' units, eight were caused by fire from cigarette smoking and one due to cooking. Of the 15 deaths in family units, 5 were due to fires from smoking, 5 were due to playing with matches, 4 due to cooking (but all in one fire) and one from suspected arson-suicide. Of all causes of fatal fires, cigarette smoking was by far the greatest.

While the number of fatalities in this OHC sample is not large enough to be statistically reliable, it does nevertheless indicate that the greatest threat to life safety in seniors' units is cigarette smoking while in family houses the greater threats are smoking and then children playing with matches. It is of interest to note that, contrary to national statistics on fire fatalities for different age groups (Figure 2), the fatality rate for seniors in this particular sample of smoke-alarmed stock is comparable to that for family housing when the relative population of the two groups is taken into account.

Concluding Remarks: Although there are relatively few available Canadian fire statistics on which to make reliable estimates of fire risks for Canadian socioeconomic groups, the data that does exist indicates that there are substantially different risk factors between the different groupings that have been examined.

While the differences between such groups can be categorized on the basis of cultural background, economic levels, age groups and even by gender groups, the precise reasons for the apparent differences in fire risks is not known with any certainty. This section has discussed possible differences based largely on speculation since the available statistics can be interpreted in a variety of ways.

The subject area invites further study with the objective of producing a better database for legislative impact studies such as this. It would appear that if significant additional investment is being contemplated in improving fire safety in houses, additional research would be well justified to ensure that such investments are property targeted. In the case of sprinkler installations the investment per house is substantial, and when viewed on a national basis, the investment per year is in the range of half a billion dollars or so. Such a potential annual outlay of capital would justify considerably more research to ensure that the appropriate housing is targeted for protection, that costs are reduced, that other measures are given due consideration, and that the benefits in improved life safety can justify whatever measures are chosen and deployed.

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Table 1

B.C. Fatality rate per 1 million one-and-two-family houses

Data Year	Newer Houses				All Houses		
	Year of const.	Total no. of houses	Deaths	Deaths per million units	Total no. of houses	Deaths	Deaths per million units
1983	78-82	91,300	8	88	706,000	52	74
1984	79-83	88,200	2	23	715,000	40	56
1985	80-84	80,600	2	25	724,000	41	57
1986	81-85	71,100	2	28	735,000	30	41
1987	82-86	58,600	0	0	748,000	22	29

Table 2

Alberta Fatality rate per 1 million one-and-two-family houses

Data Year	Newer Houses				All Houses		
	Year of const.	Total no. of houses	Deaths	Deaths per million units	Total no. of houses	Deaths	Deaths per million units
1983	78-82	99,800	0	0	567,000	38	67
1984	79-83	92,100	5	54	573,000	22	38
1985	80-84	75,900	2	26	579,000	24	41
1986	81-85	62,100	0	0	586,000	27	46
1987	82-86	48,500	1	21	594,000	18	32

Table 3

B.C. Fatality rate per 1 million one-and-two-family houses

Data Year	Newer Houses				* All Houses		
	Year of const.	Total no. of houses	Deaths	Deaths per million units	Total No. of houses	Deaths	Deaths per million units
1983	79-83	80,900*	3	37	706,000	52	74
1984	80-84	75,000*	2	27	715,000	40	56
1985	81-85	65,800*	1	15	724,000	41	57
1986	82-86	52,000*	0	0	735,000	30	41
1987	83-87	57,300*	1	17	748,000	22	30

* includes only half of the houses constructed during the last year

Table 4

Alberta Fatality rate per 1 million one-and-two-family houses

Data Year	Newer houses				* All houses		
	Year of constr.	Total no. of houses	Deaths	Deaths per million units	Total no. of houses	Deaths	Deaths per million units
1983	79-83	86,000*	0	0	567,000	38	67
1984	80-84	71,700*	5	70	573,000	22	38
1985	81-85	58,700*	2	45	579,000	24	41
1986	82-86	44,500*	0	0	586,000	27	46
1987	83-87	39,700*	0	0	594,000	18	32

* includes only half the houses constructed during the last year.

Table 5

Fatality rates for newer one-and-two-family houses
Based on Cumulative data for B.C. and Alberta

Data Base	Data Year	Cumulative no. of deaths	Cumulative no. of houses	Fatality rate per million houses
	1987	1	107,100	9
Based on	1986-87	3	240,300	12
Tables	1985-87	7	396,800	18
1 and 2	1984-87	14	577,400	24
	1983-87	22	768,200	29
	1987	1	97,000	10
Based on	1986-87	1	193,500	5
Tables	1985-87	4	318,000	13
3 and 4	1984-87	11	464,700	24
	1983-87	14	631,600	22

Table 6

Fatality rates for all one-and-two-family houses
Based on cumulative data for B.C. and Alberta

Data Year	No. of deaths	No. of houses	Fatality rate per million houses
1987	40	1,342,000	30
1986-87	97	2,663,000	36
1985-87	162	3,966,000	41
1984-87	224	5,254,000	43
1983-87	314	6,527,000	48

Table 7

B.C. Injury rate per million one-and-two-family houses

Data Year	Newer houses				All houses		
	Year of const.	Total no. of houses	Injuries	Injuries per million units	Total no. of houses	Injuries	Injuries per million units
1983	78-82	91,300	16	175	706,000	151	214
1984	79-83	88,200	17	193	715,000	153	214
1985	80-84	80,600	30*	372	724,000	171	236
1986	81-85	71,100	10	141	735,000	144	196
1987	82-86	58,600	12	205	748,000	163	218

* possible error

Table 8

Alberta Injury rate per million one-and-two-family houses

Data Year	Newer Houses				All Houses		
	Year of const.	Total no. of houses	Injuries	Injuries per million units	Total no. of houses	Injuries	Injuries per million units
1983	78-82	99,800	14	140	567,000	142	250
1984	79-83	92,100	24	261	573,000	120	209
1985	80-84	75,900	16	211	579,000	145	250
1986	81-85	62,100	10	161	586,000	133	227
1987	82-86	48,500	7	144	594,000	125	210

Table 9

B.C. Injury rate per million one-and-two-family houses

Data	Newer Houses				All Houses		
	Yr. of const.	Total no. of houses	Injuries	Injuries per million units	Total no. of houses	Injuries	Injuries per million units
1983	79-83	80,900*	15	185	706,000	151	214
1984	80-84	75,000*	15	200	715,000	153	214
1985	81-85	65,800*	15	228	724,000	171	236
1986	82-86	52,000*	10	192	735,000	144	196
1987	83-87	57,300*	13	227	748,000	163	218

* includes only half of the houses constructed during the data year

Table 10

Alberta Injury rate per million one-and-two-family houses

Data	Newer Houses				All Houses		
	Yr. of const.	Total no. of houses	Injuries	Injuries per million units	Total no. of houses	Injuries	Injuries per million units
1983	79-83	86,000*	13	151	567,000	142	250
1984	80-84	71,700*	20	279	573,000	120	213
1985	81-85	58,700*	10	170	579,000	145	250
1986	82-86	44,500*	9	202	586,000	133	227
1987	83-87	39,700*	5	126	594,000	125	210

* includes only half of the houses constructed during the data year

Table 11

Injury Rates for newer one-and-two-family houses
Based on Cumulative data from B.C. and Alberta

Data Base	Data Year	Cumulative injuries	Cumulative no. of houses	Injury rate per million units
	1987	19	107,100	177
Based on	1986-87	39	240,300	162
Tables	1985-87	85	396,800	214
7 and 8	1984-87	126	577,400	218
	1983-87	156	768,200	203
	1987	18	97,000	186
Based on	1986-87	37	193,500	191
Tables	1985-87	62	318,000	195
9 and 10	1984-87	97	464,700	209
	1983-87	125	631,600	198

Table 12

Injury rates for all one-and-two-family houses
Based on Cumulative Data from B.C. and Alberta

Data Year	Cumulative Injuries	Cumulative no. of houses	Injury rate per million units
1987	288	1,342,000	215
1986-87	565	2,663,000	212
1985-87	881	3,966,000	222
1984-87	1154	5,254,000	220
1983-87	1447	6,527,000	222

Table 13

Average property damage rates (per house) one-and-two-family houses in B.C.

Data Year	Year of const.	Total no. of houses	Total fire loss*	Fire loss per house*	Total no. of houses	Total fire loss*	Fire loss per house*
1983	78-82	91,300	$8.07M	$88.4	706,000	$42.0M	$59.5
1984	79-83	88,200	$6.45M	$73.1	715,000	$41.6M	$58.2
1985	80-84	80,600	$7.91M	$98.1	724,000	$49.7M	$68.6
1986	81-85	71,100	$4.45M	$62.6	735,000	$39.7M	$54.0
1987	82-86	58,600	$2.25M	$38.4	748,000	$36.9M	$49.3

* 1989 dollars

Table 14

Average property damage rate (per house) One-and two-family houses in Alberta

Data Year	Year of const.	Total no of houses	Total fire loss*	Fire loss per house*	Total no. of houses	Total fire loss*	Fire loss per house*
1983	78-82	99,800	$5.42M	$54.3	706,000	$29.3M	$41.5
1984	79-83	92,100	$5.03M	$54.6	715,000	$25.2M	$35.2
1985	80-84	75,900	$6.31M	$83.1	724,000	$28.2M	$39.0
1986	81-85	62,100	$3.82M	$61.5	735,000	$27.0M	$36.7
1987	82-86	48,500	$1.80M	$37.1	748,000	$23.1M	$30.9

* 1989 dollars

Table 15

Average property damage rate (per house)

One-and-two-family houses in B.C.

Data Year	Newer houses				All houses		
	Year of const.	Total no of houses	Total fire loss*	Fire loss per house*	Total no. of houses	Total fire loss*	Fire loss per house*
1983	79-83	80,900**	$6.86M	$84.8	706,000	$42.0M	$59.5
1984	80-84	75,000**	$5.33M	$71.1	715,000	$41.6M	$58.2
1985	81-85	65,800**	$4.75M	$72.2	724,000	$49.7M	$68.6
1986	82-86	52,000**	$1.91M	$36.7	735,000	$39.7M	$54.0
1987	83-87	57,300**	$2.05M	$35.8	748,000	$36.9M	$49.3

* 1989 dollars

** includes only half the houses constructed during the data year

Table 16

Average property damage rate (per house)

One-and-two-family houses in Alberta

Data Year	Newer Houses				All Houses		
	Year of const.	Total no of houses	Total fire loss*	Fire loss per house*	Total no. of houses	Total fire loss*	Fire loss per house*
1983	79-83	86,000**	$4.20M	$48.8	706,000	$29.3M	$41.5
1984	80-84	71,700**	$4.63M	$64.6	715,000	$25.2M	$35.2
1985	81-85	58,700**	$3.33M	$56.7	724,000	$28.2M	$39.0
1986	82-86	44,500**	$2.50M	$56.2	735,000	$27.0M	$36.7
1987	83-87	39,700**	$1.35M	$34.0	748,000	$23.1M	$30.9

* 1989 dollars

** includes only half the houses constructed during the data year

Table 17

Property loss rates for newer one-and-two-family houses
Based on cumulative data from B.C. and Alberta

Data Base	Data Year	Cumulative fire losses*	Cumulative no. of houses	Property loss per house*
	1987	$ 4.05M	107,100	$37.8
Based on	1986-87	$12.32M	240,300	$51.3
Tables	1985-87	$26.54M	396,800	$66.9
13 an 14	1984-87	$38.02M	577,400	$49.5
	1983-87	$51.51M	768,200	$67.0
	1987	$ 3.40M	97,000	$35.1
Based on	1986-87	$ 7.81M	193,500	$40.4
Tables	1985-87	$15.89M	318,000	$50.0
15 and 16	1984-87	$25.85M	464,700	$55.6
	1983-87	$36.91M	631,600	$58.4

* 1989 dollars

Table 18

Property losses for all one-and-two-family houses
Based on cumulative data from B.C. and Alberta

Data Year	Cumulative fire losses*	Cumulative no. of houses	Property Loss per house*
1987	$ 60.0M	1,342,000	$44.7
1986-87	$126.7M	2,663,000	$47.6
1985-87	$204.6M	3,966,000	$51.6
1984-87	$271.4M	5,254,000	$51.7
1983-87	$342.7M	6,527,000	$52.5

* 1989 dollars

Table 19

Estimated Indirect Costs of Residential Fires*

Type of indirect fire costs **	Percentage of fires involving the various types of indirect costs	Avg. total indirect cost per residential fire given existing use of fire protection devices ***	Average "out-of-pocket" cost per fire given existing use of fire protection devices ***
Temporary shelter	24.1	$542	$123
Missed work	13.1	$143	$ 97
Extra food costs	11.4	$ 54	$ 36
Demolition	0.9	$ 21	$ 13
Legal expenses	1.3	$ 16	$ 12
Transportation	3.6	$ 10	$ 8
Emotional counseling	11.2	$ 25	$ 5
Child care	1.7	$ 3	$ 3
Other	4.4	$ 54	$ 48
All types ****	29.4	$868	$345

* The original estimates stated in earlier 1977 dollars, were developed by Princeton University and Mathematica Policy Research, Inc. for the Federal Emergency Management Agency, as reported by Michael J. Munson and James C. Ohls in Indirect Costs of Residentail Fires, Federal Emergency Management Agency, FA-6, April 1980 (U.S. Government Printing Office: 1980, pp. 24-26.

These were converted to 1977 Canadian dollars ($1.06 Can. = $1.00 U.S.) and then converted into 1989 Canadian dollars ($1.00 in 1977 = $2.29 in 1989)

** Expenses for medical care have been omitted and are assumed to be accounted for in the amounts for the respective values of injuries averted.

*** Weighted average over all fires, including those not involving indirect losses.

**** 29.4 percent of all residential fires had at least one of these components.

Table 20
Watermain Pressures and Service Pipe Sizes

Province	Minimum Service Size (in.)	Water Pressure Range		Remarks
		PSI	kPa	
B.C.	3/4	40-75	275-520	Greater Vancouver
		40-60	275-410	B.C. generally
Alta. *	3/4	30-120 *	210-830	
Sask.	3/4	40-70	275-480	Generally
Man.	3/4	20-80	140-550	Rural
		50-75	345-520	Urban
Ont.	3/4	40-50	275-345	Generally
Que.	3/4	50-150	345-1030	Generally
N.B.	3/4	32-100	220-690	Generally
Nfld.	3/4	30-70	210-480	Generally

* Based on Appendix H

Table 21

<u>Comparative Costs of Sprinkler Installations</u>

(Current Canadian dollars. Builders o'head <u>not</u> included)

Type of House	Source of information	Municipal Water		Private Well	
		Copper	Plastic	Copper	Plastic
General estimate	NBS (Reference 10)	\$2860 to* \$3370	--- ---	--- ---	--- ---
2 storey house 200 m^2 1 1/2 inch pipe service	NBS (Reference 10) Component costs	\$6633	\$4327	---	---
Split Level house 140 m^2 (1500 sq. ft.) 2 in. pipe service	Alberta Municipal Affairs (Appendix H)	\$4158	\$2779	\$6667	\$4792
General estimate, Bungalow	Quebec,Ministry of Labour (Reference 15)	\$2750*	---	---	---

* Piping material not stated, copper assumed.

TABLE 22: SUMMARY OF FINDINGS

A. Sprinkler Benefits - New houses - Annual:

		Unsprinkl'd	Sprinkl'd	Benefit
A1	Fatalities/million houses (including firefighters)	14 (14.16)	6.3 (6.37)	7.7 (7.79)
A2	Occupant injuries/million Cost (@ $30,000/injury)	200 $6.00	113 $3.39	87 $2.61
A3	Firefighter injuries/million Cost (@ $30,000/injury)	68 $2.04	38 $1.14	30 $0.90
A4	Property loss/house	$44.80	$15.70	$29.10
A5	Indirect costs/house	$2.90	$1.00	$1.90
A6	Fire service costs/house *(benefit overstated; see text)	$72	$54	$22*
A7	**Total savings: per house per year, less than -**			**$56**

B. Sprinkler costs - annual

B1 Installation (urban, plastic pipe example),
- at least $3000; Annualized" cost = 3,000/9.43, at least $318

(Discount rate 10%; term 30 years;
Present Worth Factor 9.43)

B2 Inspection, certification, at least $35

B3 Maintenance, water damage repair: appreciable? no info.

B4 Total costs: per house per year, greater than - $353

C. Cost of saving one life at least $38 million

(Net cost (353-56) = $297 per house per year; saving 7.79 lives per million house years: $(297/7.79)x10^6$)

Table 23

Net Cost of Saving a Life by Sprinklering New Houses

1.	Urban*, with municipal water supply	at least
	a) Plastic pipe ($3,000 ** installation)	$38 million
	b) Copper pipe ($4,490 ** installation)	$58 million
2.	Rural*, with no municipal water supply	
	a) Plastic pipe ($5,175 ** installation)	$68 million
	b) Copper pipe ($7,200 ** installation)	$95 million

* Assumes there is no difference in fatality rates between rural and urban new housing, all with smoke detectors.

** In brackets: sprinkler costs from the Alberta study, increased by 8% to allow for housebuilder overheads.

Table 24

A Comparison of the Cost of Saving Lives in Selected U.S. Regulations

Subject	Year	Lives/saved yr.	Cost/Life saved*
Steering Column protection (collapsible Column)	1967	1300	$ 160,000
Passive restraints/belts (air bags or automatic * seat belts)	1984	1850	$ 480,000
Auto fuel System integrity	1975	400	$ 480,000
Automobile side doors (impact resistance)	1970	480	$2,100,000
Cabin fire protection (aircraft)	1985	15	$ 480,000
Seat cushion flammability (aircraft)		37	$ 960,000
Floor emergency lighting (aircraft)	1984	5	$1,100,000
Unvented space heaters (consumer protection)	1980	63	$ 160,000
Childrens Sleepwear flammability	1973	106	$2,100,000
		Average	$ 890,000

* Based on $1.00 U.S. in 1984 = $1.58 Canadian in 1989
(Rounded to 2 significant figures)

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Table 25

Summary of causes of all fire events - O.H.C. - 1978-1983

Cause of Fire	Senior Citizen Units								Family Units							
	1978	1979	1980	1981	1982	1983	Total	%	1978	1979	1980	1981	1982	1983	Total	%
Stove (cooking)	8	16	13	14	22	24	97	52	20	41	40	31	42	42	214	30.5
Smoking	12	11	11	7	7	9	57	30	13	25	13	22	27	21	121	19
Children with matches	--	--	--	--	1	1	2	1	15	34	28	23	32	28	160	23
Vandals, Arson	--	--	2	--	1	1	4	2	6	8	9	6	13	6	48	7
Wiring,appliances	2	3	1	4	9	3	22	12	5	9	11	17	15	17	74	10.5
Flammables, gasoline.	--	--	--	1	--	--	1	.5	4	12	3	2	1	4	26	4
Openflame, spark	--	--	1	1	2	--	4	2	1	--	10	5	4	10	30	4
Others, and unknown	--	--	--	1	--	--	1	.5	11	--	--	5	3	10	28	4
Totals	22	30	28	18	42	38	188	100	75	129	114	111	137	138	701	100

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Table 26

Cooking Fire Causes

Cause	Seniors (97 fires)	Family (214 fires)
Cooking with oil or grease on top of stove	31%	62%
Overheated pots or pans on top of stove(e.g pot or pan boiled dry)	38%	19%
Non-food combustibles left in oven or on top of stove elements	12%	4%
Burner accidentally left on	--	5%
Clothing ignited	6%	<1%
Miscellaneous	12%	6%

Table 27

Location of Fires Resulting From Smoking

Location	Seniors' Units (57 incidents)	Family Units (121 incidents)
Living room	60%	43%
Bedroom	19%	35%
Kitchen	9%	7%
Basement	___	7%
Bathroom	2%	<1%
Outside	___	<1%
Not given	___	<1%

CANADIAN FIRE LOSSES

ONE AND TWO FAMILY HOUSES

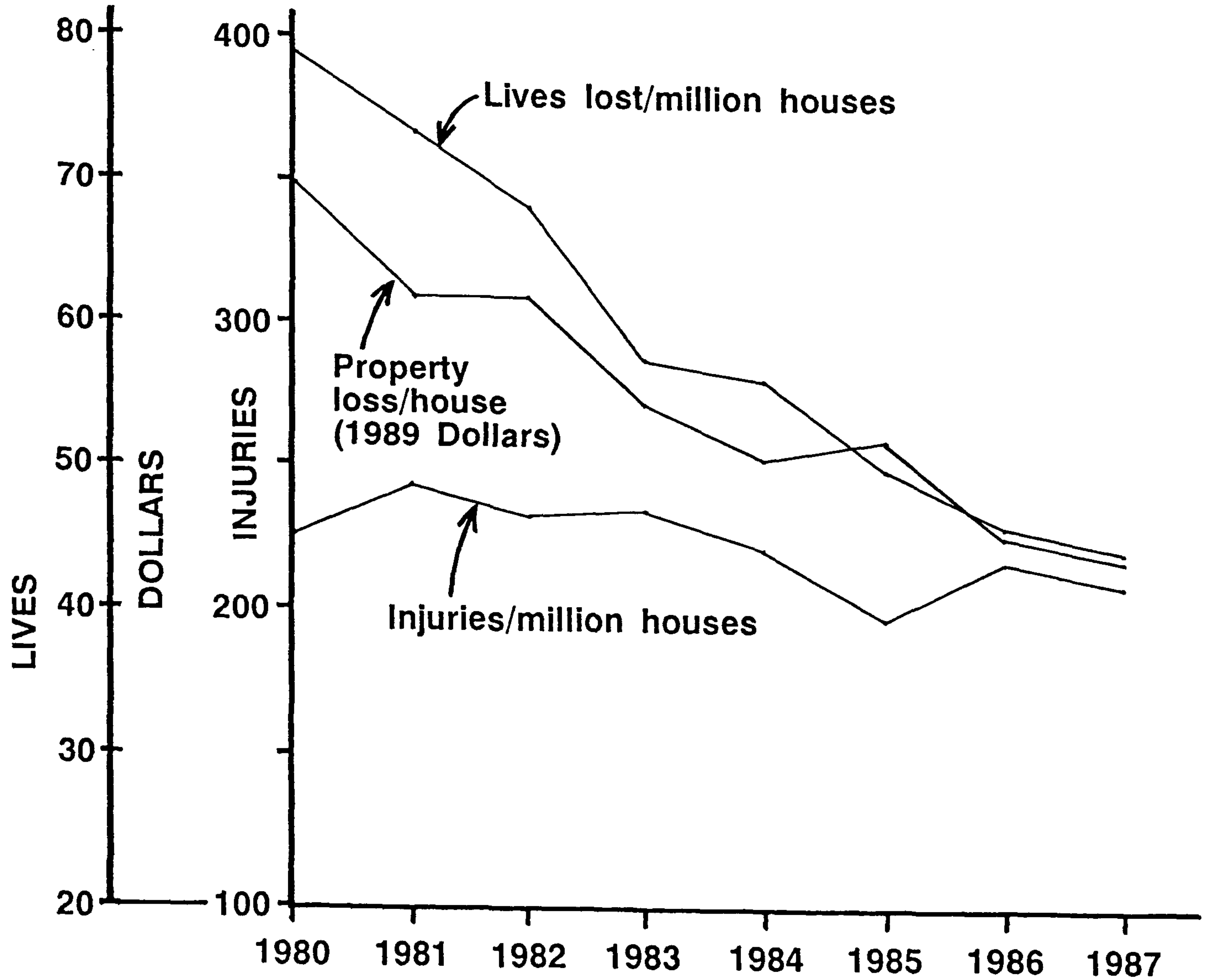

FIGURE 1

FATALITIES PER MILLION AT VARIOUS AGE GROUPINGS

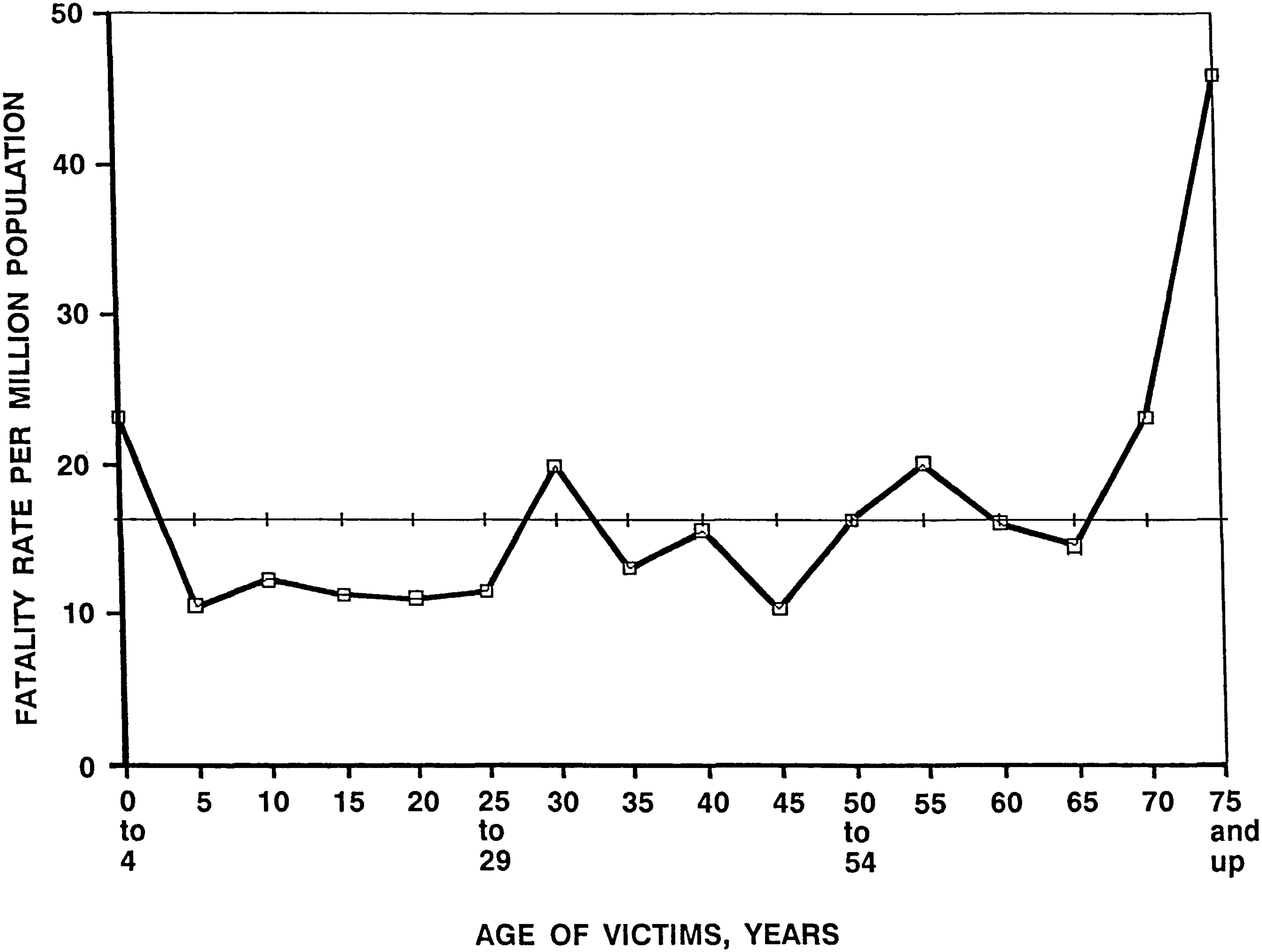

FIGURE 2

COST PER LIFE SAVED

AUTOMOBILE SAFETY

1. STEERING COLUMN PROTECTION
2. PASSIVE RESTRAINTS / BELTS
3. FUEL SYSTEM INTEGRITY

AIRCRAFT SAFETY

4. CABIN FIRE PROTECTION
5. SEAT CUSHION FLAMMABILITY

HOUSE / FIRE SAFETY

6. UNVENTED SPACE HEATERS
7. CHILDREN'S SLEEPWEAR FLAMMABILITY
8. SMOKE DETECTORS
9. MATCHES SAFETY BOXES
10. SPRINKLERS

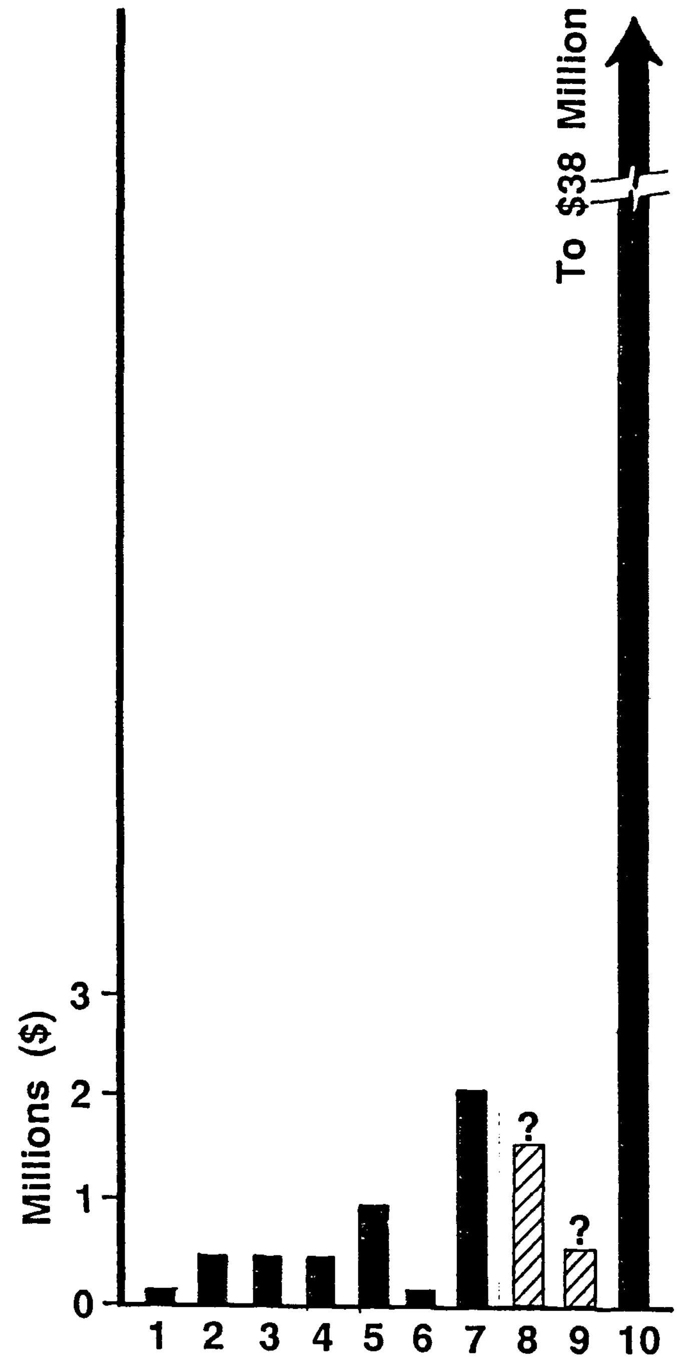

FIGURE 3

APPENDIX A

Excerpts from data provided by Quebec's

Le Directeur général de la prévention des incendies

Tableau 3

Incendies, décès et blessés dans les 1 et 2 logements
selon l'âge des bâtiments
Ensemble du Québec, 1078-1987

ÂGE	Incendie		Décès		Décès/ 100 incendies	Blessés		Blessés/ 100 incendies
	Nombre	%	Nombre	%		Nobre	%	
Moins de 5 ans	1 055	7	11	3,4	1,04	71	4,8	6,73
5 à 10 ans	2 345	15	26	8,1	1,11	143	9,7	6,09
11 à 20 ans	4 103	27	63	19,6	1,54	313	21,2	7,63
21 à 30 ans	2 722	18	48	14,9	1,76	242	16,4	8,90
31 à 50 ans	2 575	17	78	24,3	3,03	296	20,1	11,50
Plus de 51 ans	1 889	12	87	27,1	4,60	360	24,4	19,01
Indéterminé	521	4	8	2,5	1,54	50	3,4	9,60
	15,210	100	321	100	2,10	1 475	100	9,70

Source: système d'information sur les sinistres, D.G.P.I., novembre 1988

Note: Les données proviennent des rapports d'intervention soumis par les municipalités plus de 5 000 de population.

Tableau 8 (App. A)

Pertes matérielles par 100$ de valeur avant incendie
selon lâge des bâtiments
Ensemble du Québec, 1978-1987

	Incendies Nombre	%	Pertes materielles M$	%	Valeur avant incendie M$	%	Pertes matériell 100$ de valeur a incendie
Moins de 5 ans	1 982	7	69,5	6	3 074	11	2,2
5 à 10 ans	4 564	16	131,9	11	5 266,1	18	2,5
11 à 20 ans	7 769	27	361,1	32	9 288,0	32	3,9
21 à 30 ans	5 029	18	178,7	16	4 408,1	15	4,0
31 à 50 ans	4 495	16	178,9	16	3 255,5	11	5,5
Plus 51 ans	3 487	12	188,2	16	2 676,8	9	7.0
Indéterminé	1 182	4	36,6	3	887,9	3	4,1
	28 508	100	1 144,9	100	28 856	100	4,0

Source: système d'information sur les sinistres, D.G.P.I., 1988-11-14

Note: (1) Les données sont exprimees en dollars constants de 1987 et ne proviennent que des rapports d'intervention

(2) Seuls les incendies où la valeur avant incendie du bâtiment étail connue ont étè retenus.

APPENDIX B

Summary of national statistics used in calculations in Phase 2

Summary of National Statistics Used in Calculations in Phase 2

Year	Total Stock of one and two family houses *	deaths **	Injuries **	Total property losses (Millions of dollars) Unadjusted	1989 dollars ***	No. of fires **
1980	5,575,000	442	1275	$233	$394	29,510
1981	5,568,000	413	1376	$232	$348	26,914
1982	5,706,000	394	1345	$266	$360	25,316
1983	5,786,000	336	1376	$247	$316	24,449
1984	5,867,000	333	1320	$244	$299	22,815
1985	5,946,000	304	1187	$264	$311	22,365
1986	6,055,000	283	1327	$247	$280	21,415
1987	6,188,000	277	1307	$255	$277	20,443

* Based on data provided by CMHC

** Based on the annual reports of "Fire Losses in Canada", prepared under the auspices of the Fire Commissioner of Canada

*** Assumed Index Values:

1980 - 59.2	1984 - 81.5	1988 - 96.1
1981 - 66.6	1985 - 84.8	1989 - 100
1982 - 73.8	1986 - 88.3	
1983 - 78.1	1987 - 92.1	

APPENDIX C

Residential smoke detectors - in-use reliability

Ontario Housing Corporation

RESIDENTIAL SMOKE DETECTORS - 'IN-USE' RELIABILITY

ONTARIO HOUSING CORPORATION

(App. C)

SUMMARY OF MAINTENANCE

Year		Number of detectors serviced	Number found defective	% defective
Spring	1977	10,011	145	1.4%
Fall	1977	5,269	69	1.3
Spring	1978	50,806	1,203	2.4
Fall	1978	35,703	776	2.2
Spring	1979	48,065	1,051	2.2
Fall	1979	27,629	514	1.9
Spring	1980	52,116	1,142	2.2
Fall	1980	34,688	767	2.2
Spring	1981	53,064	1,238	2.3
Fall	1981	26,814	841	3.1
Spring	1982	58,443	1,548	2.5
Fall	1982	35,579	934	2.6
Spring	1983	53,718	1,553	2.9
	TOTALS	491,905	11,781	2.4%

SUMMARY BY TYPE AND MAKE

Model/Manufacturer		Number of Service Checks	Annual Failure Rate
Photo-electric			
Edwards S-127	Electro Signal	34,083	3.1%
Ion chamber			
Guardion FRU-1, FRU-2	Pyrotronics	235,349	1.9%
Fire Alert RSD-117	Kidde	37,573	2.3%
Centurion PSD-115	Tellus	72,093	3.4%
Smoke Signal POC-76	Westclox	74,720	2.4%
Smokegard 900	Statitrol	23,235	2.7%
TC-49A	Honeywell	14,852	2.6%
		491,905	

APPENDIX D

Estimated impact of sprinklers on direct fire loss

in one and two family houses

(US NBS, ref. 10)

Table 6. Estimated Impact of Sprinklers on Fire Deaths and Injuries in One- and Two-Family Houses

Type of Event	Reported fires and losses in 1 & 2 family houses in the U.S. in 1981[a] (1)	Average Deaths & Injuries per fire given existing use of fire protection devices[c] (2)	Predicted Deaths & Injuries per fire assuming neither smoke detectors nor sprinklers[d] (3)	Predicted Deaths and Injuries per fire assuming sprinklers but not detectors [d,e] (4)	Predicted Deaths & Injuries per fire assuming smoke detectors but not sprinklers[d,g] (5)	Predicted Deaths & Injuries per fire assuming smoke detectors and sprinklers[d,e,f] (6)
Fires in 1- and 2-family houses	522,175					
Civilian deaths	3,895[b]	.00746	.00821	.00253	.00390	.00146
Civilian injuries	13,851	.02653	.02676	.01446	.02546	.01436

[a]Fire in the United States, Fourth Edition, Federal Emergency Management Agency, September 1982, Washington, D. C. 20472

[b]Reduced by 6 percent to account for unreported deaths included in the national estimate.

[c]The rate of deaths & injuries per fire in the reported fire data reflects an existing use of smoke detectors by approximately 2 in 3 households on the average; the rate is found by dividing the number of deaths or injuries by the number of fires in col. 1.

[d]Based on simulated test data from the NBS/SRI Fire Loss Model. See A. Gomberg, et al., A Decision Model for Evaluating Residential Fire-Risk Reduction Alternatives, NBSIR, in preparation 1984.

[e]The data reflect the assumption of a .08 probability that the sprinkler system will not operate effectively due to improper installation or maintenance. installation or maintenance.

[f]The data reflect the assumption of a .153 probability that the smoke detector will be non-functional at a given time, based on the results of field survey.[1]

[1]Gomberg et al., A Decision Model for Evaluating Residential Fire-Risk Reduction Alternatives.

APPENDIX E

Estimated impact of sprinklers on direct fire loss in one- and two-family houses

(US NBS, ref. 10)

Table 8. Estimated Impact of Sprinklers on Direct Fire Loss in One- and Two-Family Houses

	Direct Loss Per Fire	
	Total Loss 1982 ($)	Uninsured Loss[a] 1982 ($)
(1) Total amount reported in 1981,[b] adjusted to 1982 dollars	1,684,000,000	
(2) Amount per fire given existing use of fire protection devices[c]	3,225	645
(3) Amount per fire assuming no use of smoke detectors nor sprinklers[d]	3,360	672
(4) Amount per fire assuming use of sprinklers but no detectors[d]	994	199
(5) Amount per fire assuming use of smoke detectors but no sprinklers[d,e]	2,626	525
(6) Amount per fire assuming use of both smoke detectors and sprinklers[d,e]	924	185
	Percentage Decrease in Direct Loss (%)	
(7) Condition 1: No Detector/Sprinkler System[f]	70	
(8) Condition 2: Detector/Sprinkler System[g]	65	

[a]Insurance of property by the homeowner is assumed to cover 80 percent of any property loss.

[b]Fire in the United States, Fourth Edition, Federal Emergency Management Agency, September 1982, Washington, D. C. The 1981 estimate was adjusted to 1982 dollars by applying the Consumer Price Indices for October 1981 of 279.9 and for October 1982 of 294.1.

[c]The rate of deaths and injuries per fire in the reported fire data reflects an existing use of smoke detectors by approximately 2 in 3 households on the average.

[d]Based on simulated test data from the NBS/SRI Fire Loss Model in Alan Gomberg et al., A Decision Model for Evaluating Residential Fire-Risk Reduction Alternatives, NBSIR, in preparation 1984.

[e]The data reflect the assumption of a 16 percent probability that the smoke detector will be nonfunctional at a given time, based on the results of field survey.

[f]Row 7 is derived as $\frac{\text{Row 3} - \text{Row 4}}{\text{Row 3}}$.

[g]Row 8 is derived as $\frac{\text{Row 5} - \text{Row 6}}{\text{Row 5}}$.

Appendix F

Estimated indirect costs of residential fires

(US NBS, ref. 10)

Table 9. Estimated Indirect Costs of Residential Fires[a]

Type of Indirect Fire Costs[b]	Percentage of Fires Involving the Various Types of Indirect Costs (%)	Average Total Indirect Cost per Residential Fire Given Existing Use of Fire Protection Devices[c] (1982 $)	Average "Out-of-Pocket" Cost per Fire Given Existing Use of Fire Protection Devices[c] (1982 $)
Temporary Shelter	24.1	330	75
Missed Work	13.1	87	59
Extra Food Costs	11.4	33	22
Demolition	0.9	13	8
Legal Expenses	1.3	10	7
Transportation	3.6	6	5
Emotional Counseling	11.2	15	3
Child Care	1.7	2	2
Other	4.4	33	29
All Types[d]	29.4	529	210

[a]The original estimates stated in early 1977 dollars, were developed by Princeton University and Mathematica Policy Research, Inc. for the Federal Emergency Management Agency, as reported by Michael J. Munson and James C. Ohls in Indirect Costs of Residential Fires, Federal Emergency Management Agency, FA-6, April 1980 (U.S. Government Printing Office: 1980), pp. 24-26. The estimates were adjusted to 1982 dollars by application of the Consumer Price Indices for January 1977 of 175.3 and for October 1982 of 294.1 (U.S. Department of Labor CPI Information Service, November 1982).

[b]Expenses for medical care and funerals have been omitted here. They are assumed to be accounted for in the amounts quoted in section 3.2.1 for the respective values of deaths and injuries averted.

[c]Weighted average over all fires, including those not involving indirect losses.

[d]29.4 percent of all residential fires had at least one of these components.

APPENDIX G

Estimated impact of sprinklers on indirect costs...

(US NBS, ref. 10)

Table 10. Estimated Impact of Sprinklers on Indirect Fire Costs in One- and Two-Family Houses

	Average Indirect Costs Per Fire	
	Total Cost (1982 $)	Out-of-Pocket (1982 $)
(1) Amount Estimated Under Existing Use of Fire Protection Devices[a]	529	210
(2) Amount Assuming No Use of Smoke Detectors nor Sprinklers[b]	551	218
(3) Amount Assuming Use of Sprinklers but No Detectors[b]	163	65
(4) Amount Assuming Use of Smoke Detectors but No Sprinklers[b]	431	171
(5) Amount Assuming Use of Smoke Detectors and Sprinklers[b]	151	60
	Percentage Decrease in Indirect Costs (%)	
(6) Condition 1: No Detector/Sprinkler System	70	
(7) Condition 2: Detector/Sprinkler System	65	

[a]Taken from table 9.

[b]Estimated from tables 8 and 9.

APPENDIX H

Review of articles on benefit-cost of sprinklers

(Informetrica)

Informetrica
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(App. H)

9 March 1989

MEMORANDUM

TO: Robert Platts, Scanada Consultants Limited

FROM: M.C. McCracken, Informetrica Limited

RE: Review of Articles on Benefit-Cost of Residential Sprinklers

1. As we discussed, I have reviewed several documents that contain benefit-cost studies of the mandatory installation of residential sprinkler systems in new single or low-rise housing. As well, I have reviewed your printout of the model to calculate the social benefit-costs using the NAHB study (1988). The studies reviewed include:

   o David J. Dacquisto, **Cost-Benefit Analysis of Residential Fire Sprinklers**, U.S. Fire Administration (NAHB/NRC#4002), June 1988, 159pp.

   o T.Z. Harmathy, **On the Economics of Mandatory Sprinklering of Dwellings**, National Research Council of Canada, May 1988, 28pp.

   o A.T. Hansen, "Analysis of Costs and Benefits of Installing Fire Sprinklers in Houses", Project Report - Phase I, CMHC, 31 August 1989, 22pp.

   o Rosalie T. Ruegg and Sieglinde K. Fuller, **A Benefit-Cost Model of Residential Fire Sprinkler Systems**, NBS Technical Note 1203, November 1984, 117pp. (Only scanned; looks like a useful reference piece, and referred to in other studies extensively.)

2. **Comments on the NAHB/NRC(1988) Study** - This study is the most complete to date, representing a good starting point for further work. Information is selected from the earlier NBS study as needed. Most of the major issues have been addressed.

   Mortgage Financing - The study assumes that mortgage financing is used for the sprinkler installation. In Canada the tax deductibility of mortgage interest is not possible. As well, some of the cost is "polluted" with differences in the discount rate used for consumers and their mortgage rate. I would suggest that in the Canadian studies, no attempt be made to introduce mortgage financing into the study - this could be a separate issue.

Water Damage - Mention is made (p.35) of false activations, but no numbers are provided or estimates of the damage. Is this a problem area?

Indirect Costs - When dealing with the consumer perspective, only costs borne by him are included (p.42-43). In the social perspective, all of these costs should be included. (The numbers in this section are not consistent with the computer runs, see Table 18 which reduces losses from smoke detectors.)

Lower fire probability with Smoke Detectors - (p.46-49) I view this analysis as suspicious. It is not clear to me that installation of a SD should lessen the probability of a fire. One missing link may be that homes with SD have the same probability of a fire, but because of early detection they are extinguished by the occupant and no reported fire occurs. A second explanation could be that SD installation is a proxy for the age of the house, income level, type of tenure, etc. Do we have any Canadian data on housing profiles of the installed base and no SD group? Is there information on SD/not functional that could be compared to the SD working group?

Adjustment to 100% SD installed - (p.52) The study adjusts losses and probabilities to full SD installation, instead of 75% coverage. This implicitly assumes that there would be a mandatory move on SD, before installation of sprinklers. This reduces the "gain" for sprinklers, but seems reasonable to do given the evaluation of a mandated move.

Valuation of Life - (p.55ff) The study uses $500,000 per life and $20,000 per injury, updated from 1982 to 1984 by the CPI. These values are at the low end of the range of estimates prevailing. There are no standard values proscribed in Canada at this time.

Survey of Willingness to Pay - The survey results raise more questions than are answered. Although people were asked about their willingness to pay for reduction in life or injury by 50% and 100% there must be some likelihood that they also assumed reduced property damage. The number of people in the household was asked for, but no mention is made if this factor influenced the response. Did people think of it on a per person basis, or for the family unit of 2, 3, 4, etc.? People were asked if they had smoke alarms, sprinklers, etc. but there is no sense if this was relevant to the responses. Did people have a knowledge of the probabilities of death or injury from fire? Question was asked, but was any adjustment made for their misperceptions? (I suggest that you do not use these results; if a study is done in Canada, some of the weaknesses in this survey should be corrected.) It appears that the median response is roughly in line with the $500,000 estimate used, whereas the mean response is about two times larger.

Expected Duration of Occupancy - (p.63) If a person does not expect to remain in house for 30 years, then there will be a lower value placed on the installed sprinkler system, unless the residual value at that time is captured when the house is sold. Is there any experience on SD? Do buyers pay more for a house with installed SD?

Insurance - (p.70-71) For the societal perspective, the report suggests that insurance can be ignored, viewing it simply as a pooler of risks. The effect is to place increased weight on the accuracy of the property loss and indirect costs. For your study, insurance should be ignored. (See discussion of Underwriting Costs below.)

Social Discount Rate - (p.92) The use of a 5 per cent discount rate is inappropriate. The issue is not what government can borrow at, but rather what does one activity crowd out if it proceeds. There is an implicit assumption in most Benefit-cost work, that the resources in the economy are fully-employed. If resources are directed into some area, then less gets done in other areas. The measure used is an estimate of the real rate of return to society (before taxes) of private sector activities. This is approximated by the real before-tax return to the corporate sector; in Canada this is about 10 per cent. Treasury Board has proscribed that 10% will be used for all Benefit cost studies by the federal government; regulatory impact studies are required to use 10%, with 5% and 15% variants to test the sensitivity. **Use 10% as the real interest rate.**

Discounting of Life Benefits - The comment is made (p.97) that future life benefits, in some people's view, should not be discounted at all. In their calculations they use the $500,000 value to calculate the expected loss in each year, but in one case do not discount it to obtain a present value. My problem starts with the the interpretation of what the $500,000 represents. Surely, it too is a present value representing some future stream of enjoyment discounted at an unknown rate.

Effect on Fire-fighting Expenditures - How might costs be affected? One major cost of fire-fighting are the people costs - wages, et al. If part of the wage reflects the danger and risk of death and injury, then by reducing this component wages of all fire-fighters should be reduced. In addition, there may be a need for fewer fire-fighters. If wages are not adjusted in the analysis, then it may be appropriate to include the value of the reduced risk to fire-fighters as a benefit. I am somewhat surprised that the local benefits and fire-fighter safety are so large; almost the same size as that of the household private benefit. Does this suggest that we have over-invested in fire-fighting capacity?

Other Infrastructure Savings - (p.122ff) With reduced probability of loss of life and property damage, it is suggested that design changes can be made in new residential communities for such things as distance to hydrants, width of streets, smaller water mains, etc. resulting in savings during construction.

My concern here is that there may be two types of infrastructure savings that need to be distinguished. The first type is a "true savings", such that with mandatory sprinklers the previous design includes capacities that are no longer needed. If the design is not changed there is a waste.

The second type of change would flow from a decision to maintain the previous performance or expected values for damage, loss of life, etc. by reducing the standards to the point where the situation prior to the mandatory sprinkler (MS) is obtained. In this situation it is a "re-distribution" of the benefits from MS to the builder or local government, but it is not a net social benefit overall.

Estimation of Savings on Fire-fighting and Infrastructure - With the growing penetration of smoke detectors (SD), is there any evidence of reductions in these public expenditures? If so, how much? If not, why should sprinklers result in savings, with their more modest reductions in losses relative to SD?

3. **Comments on NRC of Canada (1988)** - The Harmathy study attempts to "boil down" the analysis to the elements essential to the social benefit-cost evaluation of mandatory sprinklers (MS). The reader should be warned that the scaling of the numbers is based on U.S. housing starts and all numbers are presumably in U.S. dollars.

Discount Rate - A real discount rate of 6% is used, instead of the 5% from a social viewpoint used in the NAHB or the 10% recommended in Canada.

Reduction of Risk - It appears that the study implicitly uses the "unadjusted for smoke detector" probabilities of fire and death. As well, the probability from the entire stock is applied to the new starts without any adjustment.

Fire-fighting Load - (p.18) The study uses the product of the number of fires and the total property damage as a proxy for the load on fire-fighters. It seems to me that either the property loss alone or the product of the number of fires and the loss per fire would be an adequate measure.

Underwriting Costs - One social benefit is the savings in the resources used for underwriting homeowners insurance. The study takes that portion of the total claims related to fire (45%) and reduces the cost of that component by the reduction in property losses due to MS. Underwriting costs are likely to be a complex function of the number of policies, the number of claims, and, perhaps, the value of the claims. I suspect that the savings here are over-estimated.

This study is equivalent to a benefit-cost study; the difference between the two scenarios is nothing more (or less) than that.

If this study was updated on the basis of the NAHB work, then it would be a similar framework. The scaling of the results by the size of housing starts is unnecessary; it could equally apply to a typical house, or a community.

4. **The Hansen Study (CMHC)** - This study is a preview of the issues based on a review of the literature. (A number of small points have been annotated in the document.)

Annual Maintenance - It should be noted that there is an incentive to the homeowner to maintain the system to avoid water damage, although the risk is there now with other water pipes. Juggling of costs and reduced reliability should be done with some care so as not to bias results.

Medical Costs - (p.14) While treatment costs may be covered by insurance, the pain, suffering, and loss of income are not. Avoiding injury is still worth something! (In the U.S. studies it appears that the loss due to injury is this psychic cost, not the medical expense.) After all, on this rationale dying would be worth nothing, except perhaps avoiding the cost of a funeral! Thus there is a net benefit from avoiding injury.

Probabilities in a Dual System - (p.15) The probability of detection with a SD is 0.85 to 0.92; the reliability of a sprinkler is stated to be 0.92. If the issue is "detection" then a **combined** system would have a high reliability of 0.988 to .994. (Both systems would have to fail to miss detection.)

Failure of Sprinkler Head - (p.16) Do reliability measures reflect the failure of a single head or the whole system? (Same question can be asked with regard to SD systems with multiple detectors.) If fire does not start under bad head, then it is a non sequitur. Even if one head fails do other heads (or SDs) kick in and still help?

Fire Experience of New Homes - (p.17) The point is made that new house fire probabilities may be lower than for the average stock. A number of possibilities arise. Are these lower probabilities characteristics of the house that will stick with it forever? Or do they converge with age to higher levels? Or do they rise but remain below that of houses of older vintage? Other variables might include size, cost of house, ownership status, fuel type, etc. A study of the fire probabilities as a function of a number of variables is warranted.

U.S. Data for Canada - (p.18) Blind application of U.S. data to the Canadian situation should be avoided if at all possible.

Fire Insurance - If there is insurance, both the contents and the structure are covered. The premium paid by a household is a function of:

- o probability of a fire
- o expected value of damage given a fire
- o costs associated with processing a claim
- o selling costs
- o administrative costs
- o profit for insurer

One could do worse than to take the **premium** for full replacement value fire insurance with no deductible as an "upper limit" on the expected value of property damage for a household, since the "premium" represents a way of avoiding the cost with or without a sprinkler system. The "lifetime" present value of this premium would be the starting point for applying the reduction percentage due to installation of sprinklers. The reduction in property loss would be a social benefit. If the householder remains fully insured then he receives no direct benefit. If there is competition in fire insurance, either the specific premiums for homes with sprinkler systems will decline, or all premiums will decline, spreading the benefit among all households. This is an issue of the distribution of the benefits, not the total size of benefit.

Until some time passes, there is not likely to be a reduction in premiums. When they do, it could be viewed as a benefit unless the benefit has already been included through the "estimated" savings on property. Note that if people don't insure, then the "value" is less than the premium in their minds.

This document is a useful summary of the many issues surrounding the evaluation of the benefit-cost of MS.

5. **Items not Addressed** - This section contains side-comments on issues that occurred to me while reading the various studies, that were not addressed therein. No doubt many of these may have occurred to the researchers as well, but either been judged to be of small importance or not amenable to quantification.

   - With risk of death reduced, is there any effect on life insurance rates?

   - Is any allowance made for damage to other structures? Damage to adjacent houses or apartments that is avoided would seem to be a benefit. Water damage to other units a potential additional cost?

   - In the data, it is not clear if there is any analysis of multiple deaths per fire. Does a sprinkler system change the distribution of the number of deaths per fire in any non-proportional manner?

   - If MS were to become a policy, then the costs of such systems could decline with mass production, increased experience in installation, enhanced competition, etc. By how much would the cost have to decline for MS to produce net benefits?

   - A house is a "container" with a number of people inside. The protection from MS applies to all of them (and pets). If this dimension is considered, then the "value of life safety" should be for the group. If a fire occurs in a house, each person is subject to the probability of death or injury. It is not clear to me that the methodology fully accounts for this. I suspect that a house with five occupants might "value" a sprinkler system differently than a house with one occupant.

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