RESEARCH REPORT

Analysis of Costs and Benefits of Installing Fire Sprinklers in Houses : Phase I

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ANALYSIS OF COSTS AND BENEFITS OF INSTALLING FIRE SPRINKLERS IN HOUSES

PHASE I

PROJECT REPORT

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ANALYSIS OF COSTS AND BENEFITS OF INSTALLING FIRE SPRINKLERS IN HOUSES

PHASE 1

SELECTING AN APPROPRIATE ASSESSMENT PROCEDURE

Prepared for Canada Mortgage and Housing Corporation

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31 August 1988.

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Canada Mortgage and Housing Corporation, the Federal Goverment's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsability to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

EXECUTIVE SUMMARY

Concern by the Canadian house building industry about the cost implications of mandating the use of sprinklers in houses, now being advocated for the National Building Code, prompted Canada Mortgage and Housing Corporation to undertake a cost-benefit study to investigate the merits of this proposal.

This report represents Phase 1 of the study. Its purpose is to outline a procedure for determining cost-benefit relationships in sprinklering one and two-family dwellings.

A library search, and interviews with IRC/NRC fire safety experts confirm that the most comprehensive cost-benefit study to date regarding the sprinklering of houses is that published by the U.S. National Bureau of Standards (NBS Technical Note 1203). Appendix D is an exerpt from the report showing the methodology used in the study. This provides a cost-benefit model from the owner's point of view.

The NBS study indicated that, from an owner's point of view, the installation of sprinklers in houses was not cost effective for typical prevailing conditions. Only by using the most favourable hypothetical assumptions could the installation of sprinklers be shown to be marginably justified on an economic basis.

The NBS model is intended to form the framework for Phase 2 of this study, with certain modifications to make it more appropriate for Canadian application, and to take advantage of additional data that have become available after completion of the NBS study. While the NBS approach is valid to allow an owner to decide on the merits of sprinklers, the provincial perspective is also important if a province is to decide if the mandating of sprinklers makes economic sense.

Canadian fire statistics should be used wherever possible in lieu of U.S. data to establish life and property risks in Phase 2. Data should be based on relatively new houses (built within the last 5 years) since fire risk apparently varies with the age of the dwelling. This was not allowed for in the NBS study but could dramatically affect its conclusions.

Provincial fire authorities should be asked to co-operate in providing appropriate fire statistics from which fire risks are be determined, as well as information on the costs associated with fire fighting services. Fire statistics should also be sought from provincial housing corporations to review possible socio-economic factors that may affect fire risk. Information on current insurance policies and practices regarding residential sprinklers should be requested from the Canadian insurance industry.

Phase 2 should study three dwelling types (mobile homes, bungalows, and two-storey houses) for both copper and plastic sprinkler systems, using several combinations of service pipe and sprinkler pipe sizes. Cost data should be determined for both public and private water systems, and include materials, overhead, labour and profit for the sprinkler system itself, plus the storage tanks and pumps required to deliver the required flow in the case of private water systems.

A sub-study of the cost-benefit relationships of progressive stages of partial sprinklering should also be undertaken in Phase 2, taking into account the risk of fatal fires in individual rooms.

The effect of service pipe and sprinkler pipe sizes on the minimum water pressure needed to deliver appropriate quantities of water to the sprinklers should also be provided in Phase 2 to permit the user to relate the available local service pressure to the probable sprinkler pipe size needed.

The results of the cost-benefit analysis should be presented in terms of the cost to prevent a fatality, rather than using an assumed monetary value per human life.(The latter approach was used in the NBS study).

The break-even costs associated with each of the primary elements in the NBS study are not considered necessary for Phase 2 and need not be determined.

Input should be sought from the building industry, the fire service, and other vested interest groups prior to finalizing the report to ensure that different viewpoints are considered. In addition, liason with the ACNBC sprinkler task group should be given priority to avoid unnecessary duplication.

The more significant changes to the NBS study considered necessary for Canadian application may be summarized as follows:

1. Fire risks should be based on experiences with newer houses, and not on the average housing stock.
2. Canadian fire data and tax requirements should be substituted for U.S. values where appropriate.
3. Sprinkler costs should be based on the current requirements in NFPA 13D.
4. Piping size should be related to available water pressure.
5. The cost-benefit model should be based on a provincial perspective as well as an owner's perspective.
6. Installation costs should include bungalows and mobile homes as well as two-storey houses.

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PHASE 1: SELECTING AN APPROPRIATE ASSESSMENT PROCEDURE

Introduction

The mandatory sprinklering of Canadian houses is being advocated by a number of agencies concerned with fire safety. Apprehension by the housing industry about the additional cost that this would impose on houses has led to the initiation of a two-part study by Canada Mortgage and Housing Corporation to examine the costs and benefits associated with the sprinklering of houses. This report is Phase 1 of the study. Its purpose is to outline a cost-benefit procedure that is appropriate for Canadian conditions. The recommendations in Phase 1 are intended to be applied to the detailed cost-benefit analysis in Phase 2.

In carrying out Phase 1, various fire safety experts at NRC's Institute for Research in Construction were interviewed.These included experts from both the Codes Section and the Fire Research Section. Their contributions to this study are gratefully acknowledged.

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A limited literature search was made to determine available published information on residential sprinkler systems. The objective of the search was to develop a perspective of the work that has been carried out or is in the planning stage. Appendix B lists the results of the search.

Certain references in Appendix B, including a number of presentations made at meetings or conferences are not available in published form but are included as a matter of record. These are identified with an asterisk.

Background

In the early 1970's, a U.S. National Commission on Fire Prevention investigated the status of fire safety in the U.S. When its report, "America Burning", was published, considerable interest was generated in improving fire safety, particularly in housing where most of the fire deaths occurred.

As a result, the U.S. Fire Administration was established to focus attention on improving the U.S. fire record. It was largely through the initiative and funding provided by the USFA that much of the research and development was undertaken on fast response house sprinkler systems. Many reports and explanatory articles have been published describing this work. A number of these are included in the list of references in Appendix B.

Scope

The range of buildings investigated in this study is intended to be limited to one and two-family dwellings including mobile homes, bungalows and two-storey houses. By limiting the scope to one and two-family dwellings, the sprinkler installations can be designed in conformance with the more economical requirements permitted under the current sprinkler standards for houses (Reference 69).

While there may be some advantage in extending the scope to apply to all residential buildings, this would add a substantial degree of complication to the study and would probably not be feasible within the projected budget.

Whether or not an extended range should be considered as a future project, however, may depend on the results determined for one and two-family dwellings. If it can be shown that a simplified sprinkler system is uneconomical in houses, then there would be lttle to be gained in studying systems that are more expensive unless off-setting cost reductions are possible in other areas through building code trade-offs. On the other hand, if it can be shown that residential sprinklers in houses can be justified, then such studies may indeed be warranted as future projects.

The scope is intended to be limited to new construction, and should not include existing houses. Since one of the main objectives of this study is to provide cost-benefit information for committees currently reviewing the merits of mandatory sprinkler systems in building codes, this effectively limits the scope to new construction.

Sprinkler Standards

Until 1975, sprinkler systems were designed essentially for property protection. Although they also contributed to life safety, this was not their prime function. In 1975, the National Fire Protection Association, responsible for publishing U.S. national sprinkler standards, issued its first standard directed specifically at one and two-family houses and mobile homes (NFPA 13D). This was rewritten in 1980 in the light of the fast developing residential sprinkler technology and the current revised standard was issued in 1984 (Reference 69). A new edition is planned for 1988 which will allow for the effect of dropped beam and cathedral ceilings (Reference 4).

The current sprinkler standard for houses is primarily concerned with life safety rather than property protection, and achieves this largely through special sprinkler heads which are designed to react quickly and provide an efficient spray pattern using a relatively low rate of water flow. By utilizing reduced water flow requirements and allowing certain low fire risk areas to be unprotected, sprinkler system costs can be lower than for those designed to meet the more stringent general sprinkler installation standard, NFPA 13. (Reference 68)

The concessions permitted in NFPA 13D were carefully selected, keeping in mind typical domestic water use demands. The standard is not intended to be applied to buildings containing more than two dwelling units mainly for this reason (Reference 18). Where more than two dwellings are included in a building, the more rigorous requirements in NFPA 13 apply.

The NFPA Sprinkler Committee has concluded, however, that an intermediate level of sprinkler design was also needed. An additional sprinkler installation standard (NFPA 13R) has been drafted and is also scheduled for publication in 1988 (Reference 70). It is intended to apply to residential buildings beyond the scope of NFPA 13D, but will be limited to buildings up to 4 storeys in height.

Building Code Implications

The development of special residential sprinklers for increased life safety, and the availability of new sprinkler standards that permit reduced costs, created considerable interest in the use of sprinklers in residential construction, both in

the U.S. and in Canada. This has resulted in a number of representations being made by different interest groups to the model building code agencies in the U.S., and to the Associate Committee on the National Building Code in Canada, to mandate the use of sprinklers in all residential occupancies, including one and two-family dwellings.

In response to these submissions, the ACNBC agreed to establish two task groups; one to study the merits of sprinklering houses, and the other to examine other residential occupancies. At the time of this writing, only the housing task group has been appointed. Appendix C describes its terms of reference, its membership and a schedule of proposed meetings.

Both task groups will report to the Standing Committees responsible for Parts 3 and 9 of the National Building Code, who in turn will recommend appropriate code changes (if any) to the ACNBC for the 1990 edition of the Code.

To assist the code committees in their work, the Codes Section of NRC's Institute for Research in Construction has prepared a background paper (Reference 1). It outlines the requirements for sprinklers in the National Building Code as well as in provincial and federal regulations. It also lists the various submissions received recommending the mandating of sprinklers and discusses a number of options the code committees may consider.

Building Industry Response

The house building industry, concerned about the additional costs that would be incurred by mandating sprinklers and how this could affect the sale of houses, prepared a discussion paper for the January 1988 Convention of the Canadian Home Builders' Association in Calgary (Reference 50). Another paper at this meeting, prepared by IRC's Codes Section, gave a general overview of the advantages of fast response residential sprinklers, including the reduced levels of municipal fire fighting services required in sprinklered communities (Reference 44). Statements presented by the Canadian Automatic Sprinkler Association and the Canadian Wood Council at the CHBA meeting, both indicated their support for residential sprinkler systems (References 7 and 45).

U.S. house builders, like their Canadian counterparts, were also concerned about proposals to mandate sprinklers in houses in the various U.S model building codes, and raised counter arguments to these proposals (Reference 46). To date, no model building code in the U.S. has mandated the use of sprinklers in houses.

Methodology

A library search and interviews with IRC/NRC fire experts indicate that the most comprehensive study carried out on the economics of sprinklers for use in houses was that undertaken by the U.S. National Bureau of Standards (Reference 63). Appendix D is an exerpt from Section 3 of that study describing the methodology used. It is proposed as the basis for the analysis in Phase 2.

Canadian data, however, should be substituted for American data wherever possible, and use should be made of additional data that has become available subsequent to the NBS study. Differences between Canadian and U.S. income tax laws also must be taken into consideration in Phase 2. For example, unlike the U.S., mortgage interest deductions are not permitted for individual home owners in Canada. Additional changes are also suggested in Phase 1 keeping in mind that the principal audience of this study will be building code committee members.

The National Research Centre of the U.S. National Association of Home Builders is currently engaged in a two-part cost-benefit/societal-benefit study for the U.S. Fire Administration regarding sprinkler systems in residential occupancies (Reference 54). The cost-benefit portion of the study was completed in 1987 and is currently being analysed by the USFA. The study will be released to the public after the societal-benefit portion is complete and the entire report analysed by the USFA. The report should be reviewed in Phase 2 if it is available in time so that advantage may be taken of any additional useful data it may contain.

The NBS study to be used as the model for Phase 2 addresses the cost-benefit aspects principally from the standpoint of the owner who must decide whether or not the benefits of a sprinkler system outweigh its additional costs (although the study also looks at decision models from the municipality's viewpoint).

The provincial perspective, however, is important, if provinces are to decide whether or not mandating sprinklers is justified. A Canadian researcher, therefore, addressed the cost-benefit relationship on a more global basis (Reference 29). This approach would appear to have merit in evaluating total societal costs and benefits, and it has an additional advantage of simplifying certain aspects of the cost-benefit model used in the NBS study.

While one may question some of the assumptions used in the latter study , it is proposed that Phase 2 include this approach , along with that used in the NBS study. In using either approach, however, additional efforts should be made to provide a closer estimate on the incremental costs of establishing and operating municipal fire fighting services so that potential reductions in fire fighting costs due to the use of sprinklers may be determined more accurately.

Another Canadian study related to this project was sponsored by the Alberta Municipal Affairs Innovative Housing Grants Program (Reference 62). This study reviewed the most effective means for achieving fire safety in residential buildings, including the use of fast response residential sprinklers. While costs and benefits were not studied in depth, the report does contain useful data on service water pressures, and their effects on the design of sprinkler systems. It shows how the service water pressure required to provide the minimum sprinkler flow varies with the service water pipe size (and the size of the water meter) in sprinkler systems designed to meet the NFPA 13D standard. Phase 2 should also include this type of information so that the reader will be able to relate the sprinkler system designs used for cost-benefit comparisons in Phase 2 with the available water system pressures.

While not specifically related to this project, it may be of interest to note that IRC/NRC has sponsored a project with an Australian researcher (Dr. V.R. Beck of the Footscray Institute of Technology) to develope a risk-cost assessment model for high-rise apartment buildings. This is a complex model intended primarily for evaluating various trade-offs, including sprinklers, in terms of costs and benefits. The study is in a developmental stage, however, and does not directly affect the objectives of Phase 2.

Installation Costs

The NBS study uses several methods to estimate the installed cost of sprinklers in houses. The principal method, however, is based on component cost estimation with allowances for labour, overhead and profit. The estimates are based on a hypothetical two-storey house design having a total floor area (including unfinished basement) of 2175 sq. ft. (202 square metres), or about 1450 sq. ft. (135 square metres) of living space. Costs were computed for 1/2 in., 1 1/4 in. and 1 1/2 in. sprinkler piping for both copper and polybutylene. The systems were intended to conform to NFPA 13D. The component cost estimates were then compared to various rule-of-thumb estimates expressed in terms of sprinkler costs per unit of protected area, costs per unit of total area, unit cost per sprinkler and the sprinkler cost as a percentage of the house construction cost.

In practice, 3/4 in. or 1 in. diameter piping is more typical of that used in house sprinkler systems than the sizes used in the U.S. study. The reason given for using the 1/2 in. and 1 1/2 in. sizes was that these would bracket the size range that may be encountered in practice. The 1 1/4 in. size was included to allow a comparison with an earlier cost study (Reference 71).

It should be noted, however, that while the 1/2 in. copper piping was permitted in the 1980 edition of NFPA 13D, it is not permitted in the current standard which specifies a 3/4 in. minimum for copper and 1 in. for steel. Although NFPA 13D does not specifically mention plastic piping, it does provide for alternative materials if they have been "investigated and listed for service by a testing and inspecting agency laboratory". The size of piping and the materials permitted are naturally important considerations in cost-benefit studies since these directly affect the total cost of sprinkler systems.

There appears to be a different attitude between U.S. and Canadian certifying agencies on the use of plastic sprinkler piping, however, with ULC being more cautious than its U.S. counterpart (ULI). Currently ULC does not certify plastic sprinkler piping although ULI does. Proposed changes to the National Building Code are being distributed for public comment proposing the use of plastic sprinkler piping in buildings for light

hazard and residential occupancies provided it is protected by a ceiling membrane. If these changes are approved by the ACNBC, they presumably will have an effect on ULC policy regarding the certification of plastic sprinkler piping. Whether or not plastic piping (CPVC or polybutylene) should be included in Phase 2 of this study, therefore, is not clear-cut, particularly since it forms such a small portion of installations (about 0.3% according to Reference 29).

In view of potential cost savings, however, and the fact that it is being used in certain jurisdictions, it is suggested that the cheaper of the two plastic systems be included for cost-benefit analysis along with copper systems. The protecting ceiling membrane required in an unfinished basement, however, as proposed in the suggested Code changes would be an additional cost that would have to be included in Phase 2.

As previously noted, the available service pressure will to a large extent determine the size of piping needed to deliver the required flow at the sprinklers (Reference 62). The U.S. cost-benefit study, however, did not provide for a system designed to meet a particular service water pressure condition, but merely assumed three different pipe size systems. In order to make the study more meaningful, a relationship between the pipe size and service pressure should be included in Phase 2 as part of the study, similar to the Rockliffe study (Reference 62).

In calculating sprinkler costs, 3/4 in. sprinkler piping and water meter should be assumed in combination with 3/4 in., 1 in. and 1 1/4 in. service piping, and 1" sprinkler piping and water meter with 1 in. and 1 1/4 in. service water piping. The service water pressure needed to deliver the required water flow at the sprinklers should be computed for a typical mobile home, bungalow (with basement) and 2 storey house (also with basement) taking into account the friction losses in the system both with and without the sprinkler water flow passing through the water meter. In order to develop a material package that would be representative of average design layouts, at least three average size mobile homes, three bungalows and three 2-storey houses plans should be used to determine the quantities of sprinklers, fittings and piping required. The

quantity of materials used in Phase 2 should be averaged for each of the 3 dwelling types.

It was noted in the U.S. study that a substantial portion of the cost of materials was for a "residential sprinkler kit" from a sprinkler supplier. As well as the usual sprinkler heads and pipe valves, the kit included a water flow alarm, alarm bell, cabinet with wrench, an anti-water hammer device, and a smoke alarm. It may be noted that NFPA 13D does not require a water flow alarm if the house is equipped with a smoke alarm.. It would therefore appear that the cost of the sprinkler kit may be higher than needed to meet the minimum requirements of NFPA 13D. In addition, since the National Building Code requires a smoke alarm in every dwelling unit, this should not be considered as part of the sprinkler cost. Only the essential parts of the sprinkler system as required by NFPA 13D should be considered in Phase 2 .

Where a public water supply is not available, appropriate capacity water storage tanks and pumps have to be provided to maintain the required flow for the time duration required in NFPA 13D. The additional cost of such equipment should also be considered in Phase 2 as part of the sprinkler system in rural areas.

Sprinkler cost calculations in Phase 2 should take into consideration the variations in material costs and labour rates across the country. The range of typical unit prices and wage rates should be tabulated as part of the study, but specific cost-benefit calculations should be based on average or representative values to reduce the number of required calculations.

The labour rates for installing sprinkler systems should be representative of the trades normally responsible for sprinkler installations (plumbers, pipe fitters and other specialty trades). Whether union or non-union rates are used will depend on prevailing practices in the house building industry.

The total average costs for sprinkler systems determined by component costs should also be expressed as the cost per unit of protected floor area, cost per unit of total <u>living area</u>, cost per sprinkler and as a percentage of the total building construction cost, so that the values may

be readily compared to common Canadian rule-of-thumb estimates.

Maintenance, Repair and Replacement Costs.

The NBS study assumed maintenance and associated annual repair costs to be based on one inspection per year performed by a sprinkler or plumbing contractor. This includes conducting flow tests, alarm system tests, pump and tank checks (if used), valve inspection, parts replacement (when required) and a general check of the entire system.

Whether home owners would regularly carry out such maintenance procedures voluntarily remains to be seen. It does seem unlikely, however, that such regular annual maintenance would be carried out unless required by law. It would seem more probable that there would be little if any maintenance except to correct an immediate problem such as a leak, and even this may be corrected by the owner himself. In Phase 2, therefore, it may be more reasonable to ignore maintenance costs but reduce the sprinkler reliability factor. This will be discussed later.

Benefits

The obvious benefits of installing sprinkler systems in houses are the potential decreases in life loss, injuries and property damage. Secondary benefits may take the form of decreased insurance costs and a reduction in the required level of fire fighting services, presumably resulting in reduced property taxes.

In the NBS cost-benefit study the value of a human life is estimated at $500,000 and the value per averted injury, $20,000. Whether it is ethically or morally acceptable or even practical to establish a commercial value for human life is questionable. On the other hand, in order to make reasonable judgements on whether or not the most appropriate safety measures are being selected, the legislating authority should be aware of the relative costs to save a life or prevent an injury. This permits the legislator to compare the cost of one safety option with another, and in this way enable him to make the most effective use of available resources. This is particularly important from a provincial perspective where the costs for life safety cover many areas in addition to buildings. Phase 2, therefore, should not

attempt to place a value on a life but should express the results of the analysis in terms of the cost to prevent a fatality. It is also appropriate as part of the study to compare the life saving costs of other safety measures such as the use of smoke alarms where sufficient data is available in order to provide a balanced perspective.

The benefits derived from provincial medical programs for those injured in fires need not be included as costs from a home-owner's viewpoint. Only out-of-pocket expenses due to injuries are relevant. From the point of view of the province, however, all medical expenses must be considered as costs.

Similarly, while deaths and injuries to fire fighters may not directly affect the cost to home owners, they must be included from the point of view of the province. As previously noted, cost-benefit models should be developed in Phase 2 for both points of view.

In considering fire costs, although direct costs are relatively easy to obtain through fire records, indirect costs may be somewhat more difficult to establish. The NBS cost-benefit study uses estimates based on a previous U.S. study (Reference 48) to determine indirect costs. This approach should be used in Phase 2 as well since there appears to be no equivalent Canadian study. The values of course have to be adjusted to current Canadian conditions.

Role of Statistical Data

As previously noted, determination of the effect of sprinklers on life safety and property damage should rely as much as possible on known Canadian fire statistics. These data are used to determine the probability of fire deaths, injuries and property damage. By comparing the records of sprinklered and unsprinklered dwellings, the probable benefits of sprinklering can be estimated.

At present there are relatively few sprinklered dwellings, however, so that the existing fire records can be assumed to represent only unsprinklered cases. Since there is an inadequate number of sprinklered dwellings on which to develop reliable fire data, some other means must be used to estimate the effect of sprinklers on

life safety and property losses. The NBS cost-benefit study makes reference to an unpublished 1982 study (Reference 24) as the basis for estimating the effectiveness of residential sprinklers. The study, however, is based on hypothetical considerations and not on statistics. It assesses the effect of such systems on life safety and property damage with and without the inclusion of smoke alarms. While the absence of statistics is an obvious shortcoming, there appears to be no practical alternative to the use of this approach in Phase 2.

In using this approach, however, the reduced risk due to sprinklers should be based on the assumption that all new dwelling units are already required by Canadian building codes to be equipped with smoke alarms. Only the incremental increase in protection due to the addition of sprinklers should be considered as a benefit. In other words, sprinklers should not claim any of the risk reductions resulting from the use of smoke alarms alone.

According to estimates derived from Reference 24, the use of smoke alarms alone will reduce deaths by 69%, and injuries by 46%. If sprinklers are added, a further 63% reduction in deaths and 44% reduction in injuries is calculated. In other words, if 100 lives can be expected to be lost where no sprinklers or smoke alarms are used, then only 31 lives will be lost if the houses are equipped with alarms only, and 11 lives if equipped with both alarms and sprinklers.

The use of smoke alarms alone is assumed to reduce fire losses by 30% while the use of sprinklers in addition to the alarms will reduce losses a further 65%. A $100 loss for unprotected buildings, therefore, is assumed to be reduced to $70 where only smoke detectors are installed and to $24.50 where both detectors and sprinklers are used.

In deriving these estimates in the NBS study, a sprinkler functional reliability was assumed to be 92% and smoke alarms, 85%. These are important factors in evaluating the effectiveness of sprinklers and smoke alarms in reducing life and property losses since, if they are too high or too low, they will produce results which will be too optimistic or too pessimistic.

While there are considerable data available to evaluate the effectiveness of commercial sprinkler systems, there would appear to be insufficient experience with installations conforming to NFPA 13D to evaluate their performance with similar confidence. In view of the fact that such systems offer only partial protection, and that they are under the control of independent home owners who in all probability will do their own maintenance, it would seem to be prudent to reduce the reliability factor somewhat, say to 90%.

According to a study undertaken by the Ontario Housing Corporation in 1983, it was found that about 8% of the smoke alarms in houses involved in fires had been either disconnected or were non-functional, indicating a 92% functional reliability (Reference 14). All of these systems were wired-in and inspected once a year. This would seem to suggest that the 85% functional reliability assumed in the NBS study may be somewhat low for houses with wired-in systems. Although the 85% compares closely with Alberta experience (Reference 62), both included a substantial population of battery operated smoke alarms which are more apt to be inoperable as a result of defective batteries (Reference 28). In Phase 2, a 90% reliability factor may be more appropriate since all smoke alarms used in new Canadian houses are required to be wired-in. The estimates of effectiveness of detectors and sprinklers assumed in the NBS study should therefore be adjusted accordingly in Phase 2.

Canadian Fire Statistics

Although Canadian fire loss statistics are reported Nationally (Reference 16), they are collected through provincial agencies who also publish their own data. Although ostensibly using similar collecting and reporting systems, there appears to be significant differences between provinces in the amount of detail recorded.

Not all collected data are published, of course, but this information can be retrieved from data banks through provincial cooperation. A list of provincial and territorial fire marshals and fire commissioners is provided in Appendix A as recommended contacts for obtaining provincial fire data.

A general review of Canadian statistics shows that fire deaths in one and two-family houses has been

declining from 1980 (442 deaths) to 1986 (283 deaths), the last year for which national fire statistics are available. This 36% decrease is in spite of the estimated 11% increase in the number of housing units during that period. The cause of the decline is not known, although there are probably several factors at work. The increasing number of childless households, the declining number of occupants per household, the declining number of smokers, the growing use of smoke alarms, and the continuing improvement in safety standards for household heating and electrical equipment would all appear to be contributing factors.

Accuracy of Statistics

Since the conclusions to be reached in Phase 2 will be directly affected by the statistics used in determining fire risks and losses, it is important that they represent as accurately as possible the conditions being assessed. The life and property loss risks used in the NBS cost-benefit study are calculated on the basis of events averaged for the entire number of fire incidents recorded without regard for the ages of the houses. The same approach was used in the Canadian study previously mentioned (Reference 29). This is understandable since this is how fire statistics are normally published both in Canada and the U.S.. This would be appropriate provided the probability of deaths, injuries and property damage is the same for new houses as for old. Evidence indicates, however, that this may not be the case.

The U.S. National Association of Home Builders suspected that newer houses constituted much less of a fire risk than older houses. The Association undertook a study in 1987 to compare the fire records of houses in different age groups (Reference 49). The study indicated that in 1986, deaths per million housing units was 9.57 for those built in the period 1981 to 1986, while the average for all houses was 44.55 per million units. In other words, the apparent risk of fire deaths in newer houses was about 1/5 that of the overall average. This naturally has a profound effect on a cost-benefit analysis targeted at new houses. The sample size in the NAHB study, it may be noted, was fairly large (7.6% of the U.S. housing stock) so that the results should approximate the national average. Unfortunately,

the results of this study were not available in time for the NBS study.

Although published Canadian statistics on house fires are not broken down by age groups, it may be possible to obtain such data from some of the provincial data banks since it is known that the age of a structure involved in each fire incident is recorded in some provinicial jurisdictions. It is considered important in light of the NAHB study to determine life risk and property damage data based on the records of relatively new houses (i.e. 1983 to 1987) to establish more accurate risk factors for Phase 2 of this study. If Canadian data for newer houses cannot be obtained, the risk factors for new housing should be adjusted to reflect the data in the NAHB study.

The risk of death and property loss may be affected by socio-economic factors as well, but these may be much more difficult to assess. The Ontario Housing Corporation, however, collected fire data on their housing stock (about 85,000 units) from 1975 to 1983. Of these, about 49,000 were assisted family type units and the remaining 36,000 were senior citizen units. During the period for which records were kept, there were 29 fatalities in 956 fires. All units were equipped with wired-in smoke alarms, maintained on an annual basis by the Corporation. These statistics showed a much higher fatality record for family type units compared to senior citizen housing. In Phase 2, these statistics should be reviewed as well as similar statistics from other provincial housing corporations (if these are obtainable), to see if conclusions can be made regarding the risks in assisted housing compared to non-assisted housing.

Insurance

In computing the damage cost per fire, the NBS cost-benefit study assumed that at least 80% of the direct costs are recoverable through insurance. Insurance premiums were therefore recognized as an annual cost. If the installation of sprinklers significantly reduces property losses, this should be reflected in the home owners' insurance rates, at least for that portion applying to fire insurance. There may be insufficient experience with residential sprinkler systems in Canada to determine this, however, so that at present, the home owner may or may not benefit from reduced premiums. In Phase 2, the

Insurers' Advisory Organization and the larger insurance companies should therefore be contacted to determine current policy of premium reductions for sprinklered buildings.

Reduced Fire Fighting Services

It has been suggested in the NBS cost-benefit study, that where communities are sprinklered, significant reductions in the level of fire fighting services will be possible and this should result in decreased taxes. Whether it is reasonable to expect decreased insurance rates while at the same time decreasing the level of fire fighting may be somewhat optimistic and should also be investigated in Phase 2.

An approximation of the potential cost saving per house in eliminating fire fighting services in a residential community was made as part of the NBS cost-benefit study. The potential benefits in reduced costs from this estimate appear to far outweigh the benefits from reduced life, injury and property losses as a result of sprinkler installations. It is obvious of course that elimination of community fire fighting services is not realistic although some reduction in the level of services would eventually occur. The degree to which fire fighting services can be reduced naturally varies with the nature of the neighbourhood and the existing level of service.

The Canadian study (Reference 29) used a somewhat different approach than the NBS study in calculating savings from reduced fire fighting services. This should also be considered in Phase 2 in developing a rationale for estimating potential benefits that can be achieved. Consultations with the various provincial fire services should also be undertaken to determine appropriate cost reduction benefits. Several communities in the U.S. that have mandated sprinklering of houses should also be contacted so that their experiences in the degree to which fire fighting services can be reduced may be evaluated.

Other Options

According to U.S. fire records prepared by the National Fire Protection Association (Appendix A in Reference 69), 41% of fire fatalities are from fires originating in living rooms, 27% in bedrooms and 15% in kitchens. That is, about 83% of fire fatalities originate in these three areas.

(Unfortunately, equivalent Canadian data do not appear to have been published, but may be available from provincial authorities).These values would seem to indicate that it may be more cost effective to sprinkler some parts of houses than others. While NFPA 13D to some extent recognizes this principle by permitting certain low risk areas to be unprotected, it may be that the principle can be extended further.

Phase 2, therefore, should include a cost-benefit analysis to investigate the merits of various stages of partial sprinklering. This sub-study should include sprinklers in (a) living room only, (b) living room plus bedrooms and (c) living room, bedrooms and kitchen. In this way, the cost of saving lives by progressive stages of sprinklering can be evaluated against the cost of systems conforming to NFPA 13D. While it is appreciated that partial sprinklering is not viewed favourably by many fire protection experts, it is considered to be appropriate for investigation from its cost saving potential.

Sprinkler Trade-Offs

Throughout the National Building Code there are many examples of "trade-offs" permitted when sprinkler systems are installed. The additional protection resulting from the use of sprinklers has permitted relaxations in other requirements such as reduced fire resistance for building assemblies, increased travel distances to exits, greater window areas close to property lines, and increased flame spread ratings for interior finishes.

In the case of houses, however, building code requirements are already minimal. There are relatively few opportunities for further reductions, except perhaps for spatial separations. Even for apartment buildings, there are relatively few areas where the use of sprinklers would justify significant trade-offs (except in high buildings as a substitute for smoke control measures).

In considering code trade-offs for systems designed in conformance with NFPA 13D, however, there are several points that should be kept in mind. The system does not protect all parts of the building (as previously noted), it has a relatively short water demand requirement (10 min.) and relatively low peak flow requirements.

The differences between NFPA 13 and NFPA 13D are discussed in Reference 33. The basic assumptions underlying the development of NFPA 13D must therefore be kept in mind by code committees in permitting such trade-offs.

At this stage, it is considered premature to make specific assumptions about the trade-offs that may or may not be permitted in the future by code committees. Since there would appear to be insufficient practical experience with the performance of such residential systems to permit their realistic evaluation as trade offs, these need not be included in the Phase 2 analyses.

Presentation of Results

In illustrating how the cost-benefit model can be used in practical applications, the NBS study presents a total of 9 case studies. The first assumes the least expensive sprinkler system is used (1/2 in. plastic), in which no allowance is made for reduced taxation or for special income tax incentives, and no water demand fees are assumed for sprinkler installations. It also assumes that the house is equipped with a smoke alarm before the sprinklers are added. This is referred to as the "base case".

Using this as a bench mark, various other design combinations are assumed, some of which make allowances for reduced property taxes, hypothetical income tax incentives, the use of 1.25 in. copper pipe, special water demand charges, waiver of property tax charges on sprinklers, elimination of insurance and other similar assumptions. Additional calculations are presented in which each of the principal variables in the base case model are altered to give a break-even value for that variable, leaving the other variables unaltered.

The results in Phase 2 are intended to be presented somewhat differently. Although a variety of scenarios need to be analysed to examine the design assumptions referred to in the previous sections, break-even point calculations are considered unnecessary since, as noted, all results will be expressed in terms of the cost to save a life.

The calculations in Phase 2 should deal with real rather than hypothetical values wherever possible. For example, if municipalities are not offering

tax reductions for sprinklered buildings, then cost reductions should not be assumed, at least from the individual owner's point of view. From a provincial perspective, however, the cost reduction resulting from reduced fire fighting services is real and should be included.

Fire insurance premium reductions are somewhat similar. If there is an accepted policy to reduce premiums for sprinklered houses,it should be assumed as a benefit. If not, then the owner has no real benefit. From the provincial perspective, however, the inclusion of fire insurance is less relevant. However,fire damage represents a real loss, and any calculated reduction in total fire loss is a bona fide benefit. Theoretical insurance premium reductions should be discussed in Phase 2, however.

Critical Review

Cost-benefit studies to assess the installation of sprinkler systems are by their nature, only approximations, since they involve many assumptions for which there may be no precise data. Such studies also involve the use of statistics that provide the basis for many of the assumptions used in the analysis. These are also subject to interpretation and personal judgement. The subject of life safety is an emotional issue and cannot always be discussed strictly in terms of monetary values. For all of these reasons, therefore, before the conclusions of Phase 2 are finalized, input should be solicited from the principal antagonists regarding the use of sprinklers, including both the house building industry and the fire services. This will permit valid criticisms of the assumptions used in Phase 2 to be considered before final recommendations are incorporated.

It will be noted from Appendix C, that the terms of reference of the ACNBC task group on sprinklered houses are in some ways similar to those of this study. To avoid unnecessary duplication of effort, and avoid misunderstandings regarding the nature of this project, liason should be established at an early stage with the secretariate of the task group on house sprinklers through the Codes Section of NRC's Institute for Research in Construction.

APPENDIX A

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Government of the Northwest Territories
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APPENDIX B

List of References

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APPENDIX C

ACNBC Task Group on the Sprinklering of Houses

NBC/NFC News, June, 1988

Joint Task Group on Mandatory Automatic Sprinkler Installation in Houses

The Standing Committees on Fire Protection, Occupancy, and Housing and Small Buildings have formed a Joint Task Group to study the implications of the mandatory installation of automatic sprinkler systems in houses (defined to include single family dwellings, semi-detached dwellings, row houses, duplexes and triplexes).

The Task Group intends to undertake the following activities:

- examine the use of NFPA 13 and NFPA 13D as potential reference standards;
- examine feedback from communities where automatic sprinklers are already mandatory;
- analyze the potential impact on life safety of the mandatory installation of sprinklers;
- analyze available statistics on where fire deaths are occurring;
- study the issues relating to inspection and maintenance;
- examine the costs and benefits of sprinklers and alternative life safety systems;
- review tradeoff potentials;
- review the information and recommendations prepared by others.

Three meetings will be held in different cities across Canada to receive briefs and presentations from interested groups and individuals. As with all meetings, they will be open to the public.

Any person or group wishing to attend should contact: H.W. Nichol, Technical Secretary to the Task Group, Codes Section, Institute for Research in Construction, National Research Council, Ottawa K1A 0R6 (613) 993-0042. This contact should be made as soon as possible so that suitable meeting places can be selected. The locations and dates will be announced in a future edition of the NBC/NFC News. At that point, requests to attend a specific meeting can be made in accordance with ACNBC policies and procedures.

SCHEDULE OF MEETINGS

Joint Task Group on Mandatory Automatic Sprinkler Systems in Houses

Meeting 1	Date:	7 June 1988
	Time:	09:00 h
	Place:	Ottawa
Meeting 2	Date:	21 & 22 November 1988
	Time:	09:00 h
	Place:	Montreal
Meeting 3	Date:	21 & 22 March 1989
	Time:	09:00 h
	Place:	Vancouver
Meeting 4	Date:	April 1989
	Time:	09:00 h
	Place:	As yet unspecified
Meeting 5	Date:	June 1989
	Time:	09:00 h
	Place:	Ottawa
Meeting 6	Date:	October 1989
	Time:	09:00 h
	Place:	Ottawa

The purpose of Meetings 2, 3, and 4 is to permit direct public input and to review technical data. The purpose of Meetings 5 and 6 is to complete the review of technical data and prepare recommendations for review by the Standing Committees.

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APPENDIX D

Methodology

(Exerpt from NBS Technical Note No. 1203)

2. METHODOLOGY

2.1 The Decision Process

The decision to include fire sprinkler systems in houses may be made by individual homeowners, by builders/developers who, responding to market demand, may offer them as a standard feature in speculative housing, or by municipal governments who may mandate their use through the code process. The investment decisions of individual homeowners and builders/developers may be influenced by costs and benefits, as well as related tax, code, and zoning provisions of local, State, and national governments. Some municipal governments may offer builders/developers and homeowners financial inducements to install sprinkler systems, predicated on a substitutability of self-protection strategies, such as sprinklers, for collectively provided fire protection strategies, such as fire stations. For instance, builders/developers who agree to install sprinklers in speculative housing may be offered cost-reducing concessions by the local government in the form of zoning approvals for higher density housing, reduced code requirements for fire resistant construction, and lessened land set-aside requirements for fire lanes and stations. These cost reductions may increase the builder's profit, and/or lower housing costs to consumers. Hence, while public officials do not directly purchase and install residential sprinkler systems, their decisions can critically affect the investment decisions of those who do.

The ability of a community to reduce collectively provided protection services in exchange for self protection is dependent on the proportion of residents who invest in sprinklers. For example, the decision of only a few homeowners to install sprinklers affords little opportunity for changing housing densities or scaling down the size of fire stations.

2.2 Model of the Homeowner's Investment Decision

For the purpose of this study, the homeowner's decision criterion for investing in fire protection will be defined as maximizing the expected value of net benefits from the available budget. Thus, the evaluation model captures both the expected value of benefits to be derived from a residential sprinkler system and the total life-cycle costs of owning, operating, maintaining, and repairing a system. Total present value benefits $\sum_{j=1}^{N}\left(\frac{EVB_j}{(1+d)^j}\right)$ consist of expected reductions in risk of death and injury, reductions in expected direct and indirect losses, and reductions in certain homeownership costs. Total present value costs $\sum_{j=1}^{N}\left(\frac{EVC_j}{(1+d)^j}\right)$ are the sum of purchase and installation costs, operating, repair and maintenance costs, and other increased costs of homeownership attributable to the sprinkler system. Net present value benefits are the excess of benefits over costs, and net present value losses are the excess of costs over benefits.

The model can be represented as follows:

$$ENB = \sum_{j=1}^{N}\left(\frac{EVB_j - EVC_j}{(1+d)^j}\right), \qquad (1)$$

where,

ENB = expected present value dollars of net benefits (or loss) to a homeowner from owning a fire sprinkler system,

EVB_j = expected value of homeowner's benefits in year j,

EVC_j = expected value of homeowner's costs in year j,

N = the number of years over which benefits and costs of the system are evaluated, beginning with j = 1, and

d = the homeowner's discount rate.

Dividing total benefits and total costs of the sprinkler system into major components, the model may be restated as follows:

$$\sum_{j=1}^{N}\left(\frac{EVB_j}{(1+d)^j}\right) = \overline{DI} + \overline{PL} + \overline{C} + \overline{IN} + \overline{MTS} + \overline{OB} \qquad (2)$$

$$\sum_{j=1}^{N}\left(\frac{EVC_j}{(1+d)^j}\right) = \overline{PI} - \overline{S} + \overline{OP} + \overline{M} + \overline{P} + \overline{OC} \qquad (3)$$

and $ENB = [\overline{DI} + \overline{PL} + \overline{C} + \overline{IN} + \overline{MTS} + \overline{OB}] - [\overline{PI} - \overline{S} + \overline{OP} + \overline{M} + \overline{P} + \overline{OC}]$ (4)

where,

The "bar" denotes present value, and

$\overline{DI}$ = present value of reduced risk of death and injury,

$\overline{PL}$ = present value of reduced risk of uninsured and non-reimbursable direct losses,

$\overline{C}$ = present value of reduced risk of out-of-pocket indirect costs,

$\overline{IN}$ = present value of insurance premium discounts (Note that total insurance costs need not be taken into account if it is assumed that insurance will be purchased whether or not the homeowner buys sprinklers, i.e. only the differential cost attributable to sprinklers need be included.),

$\overline{MTS}$ = present value of local tax savings due to municipal cost reductions,

$\overline{OB}$ = present value of other sprinkler benefits, such as lower construction costs due to lower requirements for fire resistant construction,

$\overline{PI}$ = present value of purchase and installation costs taking into account financing, deductions of interest costs from taxable income, and other applicable tax effects,

$\overline{S}$ = present value of resale proceeds of the sprinkler system if the house is sold prior to the end of its useful life,

$\overline{OP}$ = expected present value of total life-cycle operating costs,

$\overline{M}$ = present value of maintenance, repair, and replacement costs,

$\overline{P}$ = present value of property tax,

$\overline{OC}$ = present value of other costs resulting from sprinkler use.

The formulas for calculating each of the above present value benefit and cost items are described below. The present value benefits of reduced risk of death and injury to the homeowner ($\overline{DI}$) are modeled as follows:

$$\overline{DI} = [(p(s,f) \cdot P(F\&D)_{pc} \cdot DV) + (i(s,f) \cdot P(F\&I)_{pc} \cdot IV)] \cdot (UPW^{*}_{d,n,e}) , \quad (5)$$

where,

$p(s,f)$ = predicted fractional reduction in the probability of death given a fire, attributable to a sprinkler system, i.e.,

$$p(s,f) = \frac{P(D|F)_{pc} - P(D|F)_{s}}{P(D|F)_{pc}}$$

where $P(D|F)$ denotes the probability of death given a fire and subscripts pc and s denote risk conditions prior to and after sprinkler installation, respectively,

$P(F\&D)_{pc}$ = joint probability of fire (F) and death (D) given a condition of prior protection, pc, i.e., $P(F\&D)_{pc} = P(F)\ P(D|F)_{pc}$,

DV = estimated dollar value of a death averted,

$i(s,f)$ = predicted fractional reduction in the probability of an injury given a fire, $P(I|F)$, attributable to a sprinkler system, where $i(s,f)$ is analogous to $p(s,f)$ above.

$P(F\&I)_{pc}$ = joint probability of fire (F) and injury (I) given a condition of prior protection, pc, i.e., $P(F\&I)_{pc} = P(F)\ P(I|F)_{pc}$,

IV = estimated dollar value of an injury averted.

$UPW^*_{d,n,e}$ = a modified uniform present worth discount formula for finding the present value to the homeowner of a series of amounts escalating at a compound rate of e over n periods, where

$$UPW^*_{d,n,e} = \frac{(1+e)}{(d-e)} \cdot \left[1 - \left(\frac{1+e}{1+d}\right)^n\right], \text{ if } e \neq d, \text{ and}$$

$$UPW^*_{d,n,e} = n, \text{ if } e = d.$$

This expression of the formula does not include the number of occupants of the house because it is developed for intended use with fire, death, and injury frequency data which implicitly reflect some average occupancy rate. To apply the model to cases with specific occupancy levels, it would be necessary to add an adjustment factor to account for occupancy levels smaller or larger than implied in national data averages.

The present value benefits of reduced risk of uninsured and non-reimbursable direct losses to the homeowner ($\overline{PL}$) can be modeled as follows:

$$\overline{PL} = \ell(s,f) \cdot P(F) \cdot LD_{pc} \cdot UPW^*_{d,n,e} \qquad (6)$$

where,

$\ell(s,f)$ = predicted fractional reduction in direct uninsured and non-reimbursable fire loss attributable to a sprinkler system,

$P(F)$ = probability of fire occurring,

LD_{pc} = estimated dollar value of direct uninsured and non-reimbursable loss per fire under prior protection state, pc, and

$UPW^*_{d,n,e}$ as defined previously for equation 5.

The present value benefits of reduced risk of out-of-pocket indirect costs ($\overline{C}$), such as legal expenses, temporary shelter, and transportation, can be modeled as follows:

$$\overline{C} = c(s,f) \cdot P(F) \cdot CV_{pc} \cdot UPW^*_{d,n,e} \quad , \tag{7}$$

where,

$c(s,f)$ = predicted fractional reduction in indirect fire costs,

CV_{pc} = estimated average value of out-of-pocket indirect costs per fire under the prior protection state, pc, and

$P(F)$ and

$UPW^*_{d,n,e}$ as defined previously.

The present value benefit of a discount in insurance premiums due to sprinklers ($\overline{IN}$) can be modeled as follows:

$$\overline{IN} = id(in \cdot IS) \cdot UPW^*_{d,n,e} \quad , \tag{8}$$

where,

id = the fractional discount in premiums for homeowner's insurance for a sprinklered house,

in = the insurance rate per $1,000 of homeowner's coverage,

IS = the amount of insurance coverage, in $1,000's, and

$UPW^*_{d,n,e}$ as defined previously.

(Equation 8 is elaborated upon in section 3.2.4 to take into account the presence or absence of discounts related to smoke detectors and to distinguish owner-occupied and rental housing.)

The present value benefits accruing to the homeowner from a pass-through of municipal reductions in costs of collective fire protection services ($\overline{MTS}$) can be modeled as follows:

$$\overline{MTS} = \left[\frac{\Delta S + \Delta L + \sum_{j=1}^{n} \frac{\Delta O_j + \Delta M_j + \Delta N_j + \Delta OS_j}{(1+\hat{d})^j} \cdot UCR_{\hat{d},n} \cdot UPW_{d,n}}{H} \right] (1-t_f) \quad (9)$$

where,

$\overline{MTS}$ is modeled mainly for fire station cost reductions or cost avoidance, and

Δ denotes reduction in costs attributable to sprinklered houses,

ΔS = reduction in fire station structure costs,

ΔL = reduction in fire station land costs,

$UCR_{\hat{d},n}$ = uniform capital recovery formula for amortizing the structure land, operating, maintenance, staffing, and other costs at the estimated municipal discount rate, $\hat{d}$, over n years,

$UPW_{d,n}$ = uniform present worth formula for finding the total present value over n years of the amortized cost at the homeowner's discount rate, d,

O_j = operating cost of the fire station in year j,

M_j = maintenance cost of the fire station in year j,

N_j = staffing costs to provide fire protection services in year j,

OS_j = costs in year j of other collective fire protection services,

H = number of households sharing the cost reductions or cost avoidances for collectively provided fire protection services and

t_f = homeowner's marginal federal income tax rate.

Other present value benefits to the homeowner of having a sprinkler system ($\overline{OB}$) might include lower construction and materials costs due to lessened code requirements for fire resistance, and lower land costs due to increased density allowances or smaller land set-aside requirements. These other potential benefits are neither modeled in detail nor included in the benefits estimates of this paper. As mentioned before, benefits represented by $\overline{MTS}$ and $\overline{OB}$ are likely to arise only if the individual homeowner buying a sprinkler system is part of a large, geographically significant bloc of sprinkler owners.

Purchase and installation costs can be adjusted to a present value basis ($\overline{PI}$), taking into account financing of the system as part of the house mortgage[1], as well as related tax effects, as follows:

$$\overline{PI} = (PI \cdot DP) + [PI \cdot (1-DP) \cdot (UCR_{i,\ell}) \cdot (UPW_{d,\ell/n})] - \sum_{j=1}^{n} [(t) \cdot (RP_j) \cdot (i) \cdot (SPW_{d,j})] - \overline{TC} - \overline{DTS}, \quad (10)$$

where,

PI = contract cost of system purchase and installation,

DP = fraction of PI placed as a downpayment,

$UCR_{i,\ell}$ = uniform capital recovery discount formula for amortizing the amount borrowed at mortgage loan interest rate, i, over ℓ loan payment periods,

$UPW_{d,\ell/n}$ = uniform present worth discount formula for finding the present value of the mortgage payments over the study period, where the UPW is based on ℓ periods if $\ell<n$ and on n periods if $\ell>n$ (if $\ell>n$, such that the UPW is based on n, the estimate of resale value should deduct any remaining loan costs owed at the time of resale),

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[1]The system is considered to be financed as part of the mortgage, since it is assumed to be installed in a newly constructed house.

t = marginal composite (Federal, State, and local) income tax rate of the homeowner,

RP_j = remaining principal outstanding on the loan in year j, where, for $j = 1$, $RP_1 = PI \cdot (1-DP)$, and for $j>1$, $RP_{j-1} - [(PI)\cdot(1-DP)\cdot(UCR_{i,\ell}) - (RP_{j-1})\cdot(i)]$,

i = interest rate on the mortgage loan,

$SPW_{d,j}$ = single present worth discount formula for finding the present value of the mortgage interest tax deduction in year j,

$\overline{TC}$ = present value of any available governmental tax credits to purchasers of home sprinkler systems,

$\overline{DTS}$ = present value of income tax savings due to depreciation of system acquisition costs if applicable (generally applicable only to rental housing).

The present value of resale proceeds realizable from selling the house prior to the end of the system's useful life ($\overline{S}$) are deducted from other costs, and can be modeled as follows:[1]

$$\overline{S} = S_n \cdot SPW^*_{d,n,e} \quad , \tag{11}$$

where,

S_n = selling price of system at the end of the study period, where S_n is adjusted for any outstanding balance on the mortgage loan, as well as applicable capital gains tax and, for a rental house, depreciation recapture tax, and

$SPW^*_{d,n,e}$ = single present worth formula, modified to include a constant rate of escalation over n years, for use in finding the present value of resale at the end of year n.

The expected present value of life-cycle operating costs ($\overline{OP}$), consisting of water costs, water damage costs, and, for systems with pumps, electricity costs, can be modeled as follows:

$$\overline{OP} = \overline{WC} + \overline{WD} + \overline{E} \quad , \tag{12}$$

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[1]As sprinkler systems become more widely used, it may be possible to refine the estimation of resale price by incorporating a sprinkler variable into residential hedonic price indices to reflect sprinklers as one of the attributes which may influence housing prices. See, for example, Michael G. Ferri, "An Application of Hedonic Indexing Methods to Monthly Changes in Housing Prices, 1965-1975," AREUER Journal, Vol. 5, 1977, pp. 455-465.

where,

$\overline{WC}$ = present value of water costs with the sprinkler system versus without it,

$\overline{WD}$ = present value of water damage costs with the sprinkler system versus without it, including costs from accidental discharge,

$\overline{E}$ = present value of electricity costs, for operating the system, if applicable.

Water consumption costs and water damage costs will be incurred only if the system is activated. There are two main types of activation that may be considered: (1) intended activation induced by fire and (2) inadvertent, or accidental, activation. The latter is likely the only significant type to evaluate, because water consumption and water damage that would result from having the fire department extinguish a fire are likely to far outweigh that resulting from sprinkler activation.

The present value water consumption costs ($\overline{WC}_{AD}$) for accidental discharge, though likely to be trivial in most cases, can be estimated using the following equation:

$$\overline{WC}_{AD} = P(DS|NF) \cdot (W \cdot U_{AD}) \cdot UPW^*_{d,n,e} \cdot [1 - (t \cdot A)] \qquad (13)$$

where,

$\overline{WC}_{AD}$ = present value of life-cycle water consumption cost for accidental discharge,

$P(DS|NF)$ = conditional probability of discharge (DS) given no fire (NF)

$$P(DS|NF) = \frac{P(NF\&DS)}{P(NF)},$$

W = cost per unit of water,

U_{AD} = units of water consumed during accidental discharge,

t = marginal income tax rate of the homeowner, and

A = 1 if rental unit,
0 if owner-occupied.

The water damage costs from accidental discharge ($\overline{WD}_{AD}$) can be modeled in a comparable way as follows:

$$\overline{WD}_{AD} = P(DS|NF) \cdot (D_{AD}) \cdot UPW^*_{d,n,e} \cdot [1 - (t \cdot A)] \qquad (14)$$

where,

D_{AD} = cost of repairing water damage in case of accidental discharge, and all other variables are as in equation (13).

The remaining element of operating costs is the present value of electricity costs, $\overline{E}$, for a system requiring a pump. This cost would be modeled similarly to $\overline{WC}_{AD}$, except that electricity price and quantity would be substituted for the price and quantity of water, W • U.

The present value of maintenance, repair, and replacement costs ($\overline{M}$) over the life cycle can be modeled as follows:

$$\overline{M} = \left[(w_m \cdot h_m \cdot UPW^*_{d,n,e}) + \sum_{j=1}^{n} [(w_{rrj} \cdot h_{rrj}) + m_{rrj}] \cdot SPW^*_{d,j,e} \right] \cdot [1-(t \cdot A)], \qquad (15)$$

where,

w_m = wage rate per hour for routine maintenance,

h_m = length of time in hours required for annual routine maintenance,

$UPW^*_{d,n,e}$ = uniform present worth discount formula modified to allow for escalation of the wage rate at rate e,

w_{rrj} = wage rate per hour for repair and replacements in year j,

h_{rrj} = average length of time in hours required for repair and replacement in year j,

m_{rrj} = materials cost for repair and replacement in year j,

$SPW^*_{d,j,e}$ = single present worth discount formula modified to allow for escalation of prices at rate e,

t = marginal composite income tax rate of the homeowner, and

A = 1 if a rental unit,
0 if owner-occupied.

The present value of increased property taxes ($\overline{P}$) over the life cycle can be modeled as follows, based on a straight-line obsolescence rate:

$$\overline{P} = \sum_{j=1}^{n} [PI \cdot (1 - j/n) \cdot t_p \cdot SPW^*_{d,j,e} \cdot (1 - t)], \qquad (16)$$

where,

PI = contract purchase and installation cost of the sprinkler system,

$1-j/n$ = obsolescence factor, designed to result in a zero remaining tax base at the end of the system life, and

t_p = effective property tax rate.

$SPW^*_{d,j,e}$ = single present worth formula, modified to include a constant rate of escalation over j years, for use in finding the present value of increased property taxes, and

t = marginal composite income tax rate of the homeowner.

The investment in the sprinkler system is estimated to be economically efficient if the present value of expected net benefits is positive, i.e. if NB>0. The assumptions are that the investor is risk-neutral and other things remain equal. Other factors which may in fact not remain equal and which are not incorporated in the model include such things as valuation of aesthetic effects, consumer willingness to use new technologies, availability of system sales and system maintenance service in the marketplace, and local codes governing the use of sprinklers.

It should also be noted that an estimate of positive net benefits for sprinklers does not necessarily mean that homeowners will purchase them, even disregarding noneconomic considerations. Previous studies have shown, for instance, that a homeowner's decision to purchase analogous kinds of new housing technologies have depended critically on other economic factors such as the relative size of the initial cash outlay, the particular pattern of cash flows, or the perceived value of the investment as a status symbol.[1]

Further complicating the prediction of a homeowner's investment decision based on expected value results is variable risk preference. Homeowners may be risk-seeking, risk-indifferent, or risk-averse, as reflected in the shape of their utility functions. The criterion described above of maximizing the expected value of net benefits is relevant only if the decisionmaker's

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[1]See, for example, Arthur J. Reiger, Marketplace Realities and Solar Economics. (U.S. Department of Housing and Urban Development Report, distributed by the National Solar Heating and Cooling Information Center), June 1978.

utility function is linear, which it may or may not be. If it is not linear (i.e., the decisionmaker is not risk neutral), then preferred acts of investments can only be identified by converting expected values to expected utilities. This is possible for individuals, but there is no well-founded procedure for combining individual utility functions to obtain a group utility function, and, in fact, it may even be impossible to do so.[1]

A further limitation is the static nature of the model. It fails to capture fully the dynamic interactions of community, developer, and homeowner decisions. For example, community cost avoidance, which is modeled as a lower property tax to the homeowner, may simultaneously affect the conditional probabilities of fire loss and changes in insurance rates. Developer cost reductions from building more densely may alter the incidence of fire, and affect the homeowner in ways not captured by the model.

Some limitations are imposed not by the model itself but by the unavailability of data. It is difficult or impossible to obtain for all components of the model reliable and consistent data.

Despite these limitations, the above model can be helpful in predicting the market potential of residential sprinkler systems. The cost effectiveness of a new technology is an important determinant of its market rate of diffusion.

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[1]See Arrow's impossibility theorem in K.J. Arrow, Social Choice and Individual Values, second ed., New Haven, Connecticut: Yale University Press, 1963.

[Decision models for the builder/developer and of the municipal government are developed and presented in the appendix. These show how the elements of the models are interrelated.]

2.3 Evaluation Techniques Used in the Model

This section gives a brief reference to some of the techniques employed in the benefit-cost model for the convenience of the reader who is unfamiliar with the techniques.[1] The reader who does not require this background may wish to go directly to section 3.

Life-Cycle Approach. When first costs are relatively high and related benefits accrue over time, an economic evaluation method that employs a life-cycle approach, accounting for benefits and costs over the investor's time horizon, is generally appropriate. "Life-cycle costing" is a method for summing the stream of an investment's costs over time, where these costs are adjusted to a time-equivalent basis by a technique called discounting.[2] The same type of approach can be applied to benefits, whereby the stream of benefits over time is also discounted and summed. By subtracting discounted

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[1]For a general reference to benefit-cost analysis, see E. J. Mishan, Cost-Benefit Analysis, New York: Praeger, 1982.

[2]For a further description of life-cycle costing, see Rosalie Ruegg and Harold Marshall, "Economics of Building Design," Solar Age, July 1981, pp. 22-27; Rosalie T. Ruegg, Stephen R. Petersen, and Harold E. Marshall, Recommended Practice for Measuring Life-Cycle Costs of Buildings and Building Systems, National Bureau of Standards, NBSIR 80-2040, June 1980; Rosalie T. Ruegg, Harold E. Marshall, and Porter Driscoll, "Life-Cycle Costing," Architectural Graphics Standards, 7th Edition, February 1981; Rosalie T. Ruegg, Life-Cycle Cost Manual for the Federal Energy Management Program, National Bureau of Standards, Handbook 135 (Revised), May 1982; and Louis P. Clark, A Life-Cycle Cost Analysis Methodology for Fire Protection Systems in New Health Care Facilities, National Bureau of Standards, NBSIR 82-2558, July 1982.

costs from discounted benefits, the net benefits (or net losses) measured in either present value or annual value dollars can be determined. By dividing discounted benefits by discounted costs, a benefit-cost ratio can be calculated. By accumulating future discounted benefits (less future discounted costs) on a year-by-year basis and comparing the result to the initial investment cost, the time to payback can be found. And, by solving for the interest rate that, when used in the appropriate discounting formulas, will equate benefits and costs, the internal rate-of-return on the investment can be determined.

Discounting[1]

To an individual the value of a specific sum of money depends on precisely when it is to be received. Given the existence of interest rates and the opportunity of borrowing and lending, benefits in hand afford reinvestment opportunities, and it is generally preferable to receive benefits earlier than later. Costs deferred afford opportunities for interim uses of funds for other purposes, or the avoidance of borrowing costs; hence, it is generally preferable to defer costs. The "investment opportunity cost" can be accounted for by charging an interest rate for using resources over the relevant period of time. This procedure is usually called "discounting," and is accomplished through the use of compound interest formulas, or factors computed from the formulas, which can be used to convert differently timed cash flows to a time-equivalent basis, e.g., the present value, or annual value. The formulas and factors incorporate the investor's opportunity cost in terms of an

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[1]A more detailed treatment of the discounting process may be found in Harold E. Marshall and Rosalie T. Ruegg, Simplified Energy Design Economics, National Bureau of Standards, NBS Special Publication 544, 1980, pp. 16-20.

interest rate, usually referred to as the "discount rate." Discount rates may be expressed in either "nominal" or "real" terms. Nominal rates include both the opportunity cost of postponed receipts of money and the effects of inflation. Real rates reflect only the opportunity cost, not inflation.

Annual values and present values are equally valid ways of adjusting amounts to a common time basis for comparison and either can be used to compute measures of net benefits. Annual values express all costs and benefits as though they occurred in uniform yearly amounts over the study period, whereas present values express all costs and benefits as though they occurred in a lump sum at the beginning of the study period. Annual values and present values are time equivalents. This analysis expresses final dollar amounts as present values, but uses annual values in certain intermediate calculation steps.

Treatment of Inflation. A valid economic analysis requires that a common unit of measure be used for evaluating benefits and costs. This means that dollars of equal purchasing power (constant dollars) be used to indicate the various benefits and costs occurring over time, rather than dollars of changing purchasing power (current dollars). If benefits and costs are stated in current dollars, that is, in terms of the particular values of the dollar that are expected to hold in the years the benefits or costs occur, their value must be converted to constant dollars in a benefit-cost analysis. Current dollars may be converted to constant dollars prior to the discounting

operation through the application of a price deflator index, followed by discounting with a real discount rate, that is, one that does not include purely inflationary or deflationary change. Alternatively, current dollars may be converted to constant dollars in the discounting operation through the use of a nominal discount rate, that is, one that does include a projection of the inflationary or deflationary rate of change. As a variation of the first approach, most prices and values used at the beginning of the study period may be assumed to remain the same over the study period when measured in constant dollars, and only those prices estimated to change at a rate faster or slower than the rate of general price inflation need be adjusted through the use of differential price escalation rates. Since benefits and costs are already in constant dollars when this approach is used, a real discount rate should be used.

The discounting factors used in the models are the Single Present Worth Factor (SPW), the Uniform Present Worth Factor (UPW), the Uniform Capital Recovery Factor (UCR); the Uniform Present Worth Factor modified to incorporate a constant rate of escalation (UPW*), and the Single Present Worth Factor also modified to incorporate a constant rate of escalation (SPW*). The SPW and SPW* factors are used to convert a single future amount to an equivalent present value. The UPW and UPW* factors are used to convert amounts recurring over some specific number of periods to present values. The UCR factor is used to convert a present value to a series of uniformly recurring amounts.

The incorporation of SPW* and UPW* factors in the model developed in section 2.2 allows for differential price escalation rates if the analyst chooses. However, in the case illustrations in this report all values are assumed to escalate at the general rate of inflation, i.e., a zero differential rate is used.

Expected Value Analysis. Even though the occurrence of future fires is not known with certainty, there is a known probability distribution based on fire statistics which can be used to calculate expected values of related benefits and costs.

In this study, sprinkler benefits in terms of reduced property losses, indirect costs, and fewer deaths and injuries are calculated as expected values by multiplying percentage loss reductions (based on sprinkler effectiveness test data) by estimated values of loss associated with a fire in the absence of sprinklers, and multiplying the result by the probability of fire occurrence. The expected value of benefits in future years can be discounted to a present value equivalent by multiplying each year's expected value by the appropriate single-amount discount factor and summing across years or, if annual benefits are uniform or change at a constant rate, simply by multiplying the initial year's expected value by the appropriate UPW or UPW* factor.

Sensitivity Analysis. By testing the responsiveness of benefit-cost results to variations in values assigned to different parameters, sensitivity analysis allows the identification of those parameters that are most important to the economic success of residential sprinklers. Additionally, sensitivity analysis is useful in assessing the consequences of uncertainty in data and in assumptions. It does not tell the decision maker the values that should be used, but it shows the impact of using different values.

Break-Even Analysis. Another approach that can provide useful information to decisionmakers in the face of uncertainty is break-even analysis. By setting benefits equal to costs, and leaving the value of one of the parameters unspecified, it is possible to solve for the minimum or maximum value which it must take in order for the system to be minimally cost effective.

2.4 Economic Parameters and Assumptions

This section discusses establishing values for the discount rate, inflation rate, real price changes, system life, study period, and tax rates.

The discount rate, a compound rate of interest used to convert benefits and costs occurring at different times to a common time, should reflect the investor's opportunity cost of capital. The higher the rate, the lower will be the present value of future costs and benefits.

There is no single rate that is appropriate for all investors, but in a "generic type" of study such as this, it is desirable to choose a rate that will be representative "on the average" for the subject group of investors. There is a wide disparity among homeowners as to their discount rate, since at any given time some will be in net debt positions at interest rates ranging from low to high, and some will be in credit positions at yields also ranging from low (in some cases yields may be negative after taxes and inflation) to high.

As background to selecting a discount rate for the case studies, the average of real, after-tax rates of return to investors in all grades of nonfinancial common stock and long-term corporate bonds over the 1947-1975 period was examined, and was found to be 7 percent.[1] Additionally, discount rates by income class, as derived by Hausman for individuals purchasing energy-using durable goods, were considered. In the late 1970's, the implicit discount rates for homeowners with incomes between $35,000 and $50,000 ranged from 5.1 percent to 8.9 percent.[2] With this general guidance, a rate of 6 percent was selected for use in the case studies. The 6 percent rate is defined as a real rate, after taxes.

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[1]See description of approach and data analysis in Rosalie T. Ruegg, et. al., Economic Evaluation of Solar Energy Systems in Commercial Buildings; Methodology and Case Studies, National Bureau of Standards NBSIR 82-2540, pp. 87-89, as based on historical trends in rates of return to investors published by Daniel M. Holland and Steward C. Meyers, Trends in Corporate Profitability and Capital Costs, WP 937-77, Alfred P. Sloan School of Management (Cambridge, Mass: Massachusetts Institute of Technology), 1977.

[2]Jerry A. Hausman, "Individual Discount Rates and the Purchase and Utilization of Energy-Using Durables," Bell Journal of Economics, Vol. 10, No. 1, 1979.

Because there is little basis for projecting differential rates of inflation for most of the categories of costs and benefits of sprinkler systems, most of them are assumed to inflate at the rate of general price inflation. The rate of general price inflation is set at 5 percent per annum. In the case of interest expense and depreciation expense--both items which are based on historical costs and are not variable with inflation (variable rate mortgages are not treated)--it is necessary to convert the costs to their constant dollar equivalents. This is done by discounting the nominal cash flows with a nominal discount rate which is adjusted to reflect the assumed 5 percent inflation rate. The inflation-adjusted, market rate is 11.3 percent; i.e., $0.06 + 0.05 + (.06)\ (.05) = 0.113$ or 11.3 percent.[1]

The study period is the length of time over which costs and benefits from the sprinkler system are calculated. The length of the study period need not coincide with the length of the system life. The model allows for system replacements and resale or disposal values to reconcile the two. However, for the purpose of the case studies, the study period is selected to coincide with the assumed system life.

There is no empirically validated life for fast-response residential sprinkler systems. However, system components are similar to components for which there is some experience with durability. Plumbing systems in houses generally have long lives; sprinkler apparatus in commercial buildings appear to have relatively long lives. A study period and system life of 30 years are assumed.

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[1]The market rate is equal to the real rate plus the inflation rate plus the product of the two rates.

Marginal Federal income tax rates range among homeowners from a low of about 10 percent to a high of about 50 percent. To the Federal income tax rate can be added any applicable State and local income tax rates, taking into account the deductibility of one from the other. For the case studies, a composite marginal income tax rate of 40 percent is used to evaluate tax effects.

Effective property tax rates in the U.S. range from about 0.82 percent to 7.46 percent.[1] The national average effective rate in U.S. cities of 2.15 percent is used in the case studies to evaluate property tax effects.

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[1]U.S. Bureau of the Census, Statistical Abstract of the United States 1980, Washington, D.C.

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