Canada Mortgage and Housing Corporation
Société canadienne d'hypothèques et de logement

IMPACT OF MANDATORY SPRINKLERING OF MULTI-UNIT RESIDENTIAL BUILDINGS

FINAL REPORT

DECEMBER 1993

IBI GROUP

In Association with
Larden Muniak Consulting Inc.

DISCLAIMER

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Executive Summary

This report summarizes the investigation of the cost-effectiveness of installing automatic fire sprinklers in new low-rise and high-rise apartment buildings. The study is intended to supplement the findings of the Joint Task Group on Mandating Sprinklering of the Part 3 Standing Committees of the National Building Code of Canada. The study also considers additional changes proposed in conjunction with implementation of mandatory sprinklers.

The subject study provides a detailed statistical analysis and draws on a wide range of expert opinions to estimate levels of risk of loss of life, injury and property damage before and after installation of sprinklers.

The Building Code Assessment Framework, developed under the direction of the Buildings Branch of the Ontario Ministry of Housing, forms the primary tool for carrying out the analysis. This tool assists in the examination of impacts of change to the Building Code as incremental costs and benefits to society as a whole. Evaluation assumes that sprinklers are mandated and is based on incremental costs/savings for construction of all low-rise and high-rise apartment buildings constructed in a single year. The analysis includes the net present value of incremental costs/savings for construction of all high rise and low rise apartment buildings erected in a single year and the total annual operating cost/savings to the end of the useful life of those buildings. This assumes that timely maintenance is carried out on the fire sprinkler systems, so that their life span coincides with the length of building life.

Information sources have included the Provincial Fire Marshals' offices for fire statistics from 1988 to 1991 inclusive, Statistics Canada and Canadata Construction Statistics information on housing stock from 1988 to 1991 inclusive, review of selected literature, discussions with sprinkler contractors, cost consultants, underwriters, and building department officials.

The analysis used risk estimates from literature on sprinkler applications as well as those from the Delphi Panel. For most parameters, mean as well as limiting values were used to test sensitivity. The limiting values were produced to estimate upper limits for cost effectiveness of sprinkler use in multi-unit residential buildings. Alternative property loss reductions were used to test the sensitivity of this important benefit of sprinklers. It is considered less likely that limiting values for **all** parameters would simultaneously apply as compared to the mean values selected.

Findings from all three analysis scenarios are displayed graphically in Exhibits S1 and S2. Using a variety of sources, the range of willingness to pay per year-of-life saved (in 1993 Cdn $) is $4,000 to $48,000, with a base line value (applied in a U.S. study on sprinklers) of $24,000. Mandatory sprinklers for the example buildings in our analysis will impose a cost of $159,000 to $606,000 per year-of-life saved in low-rise buildings and $252,000 to $1,212,000 per year-of-life and in high-rise buildings. The lower range is the result of applying all limiting values. For a relatively small number of low-rise buildings towards the larger end of the permissable size range, this cost may be reduced somewhat if other proposed code changes relating to mandatory sprinklering are taken into account. The impact of these changes relate primarily to site design and choices for roof construction for which there is no statistical data.

The figures suggest that the cost per year-of-life saved for sprinklers in low-rise and high-rise apartment buildings is beyond what society appears willing to pay for safety features. One reason is that the risk of death by fire in recently-built apartment buildings is relatively low. Even assuming that, as the buildings age the fire risks will increase, the mean and limiting values of the base case risk rate are assumed to remain relatively low. With relatively few deaths as a base, the reductions in fatalities and property damage made possible by sprinklers are not great enough to offset the incremental costs for construction and maintenance.

Another area that could affect the economic viability of mandating sprinklering is the possible contribution to municipal fire suppression cost reduction by downsizing fire department staff and in new development facilities. CMHC is proposing to conduct a study in this regard which may or may not show a reduction in the overall cost to society if mandatory sprinklers were incorporated in **all** new buildings.

Pending the results of that study, from the above results we conclude that by comparison to what society has invested for other life safety practices, it is not cost-effective to make automatic fire sprinklers mandatory for multi-unit residential buildings in Canada.

Résumé

Le rapport résume l'analyse des coûts-avantages de l'installation d'extincteurs automatiques dans les nouveaux immeubles d'appartements de faible et de grande hauteur. Cette étude est censée compléter les résultats obtenus par le Groupe de travail mixte sur l'installation obligatoire d'extincteurs automatiques à eau des comités permanents sur la partie 3 du Code national du bâtiment du Canada. L'étude tient également compte des changements additionnels proposés conjointement avec l'installation obligatoire des extincteurs.

L'étude fournit une analyse statistique détaillée et s'en remet à toute une gamme d'opinions de spécialistes pour évaluer les risques de pertes de vie, de blessures et de dommages matériels avant et après l'installation des extincteurs.

Le document Building Code Assessment Framework, rédigé sous la conduite de la direction du bâtiment du ministère du Logement de l'Ontario, constitue l'outil principal ayant servi à mener l'analyse. Cet outil facilite l'examen des conséquences de modifier le code du bâtiment en ce qui a trait aux coûts marginaux et aux avantages pour la société dans son ensemble. Dans le cadre de l'évaluation, on tient pour acquis que les extincteurs sont obligatoires. L'évaluation est basée sur les économies et les coûts marginaux relatifs à la construction de tous les immeubles d'appartements de faible et de grande hauteur dans une seule année. L'analyse inclut la valeur actuelle nette des coûts marginaux et des économies liés à la construction de tous les immeubles d'appartements de faible et de grande hauteur produits en une seule année ainsi que les coûts et les économies d'exploitation annuels jusqu'à la fin de la vie utile de ces immeubles. On présume que les extincteurs sont entretenus régulièrement de sorte que leur durée de vie correspond à celle des immeubles.

L'information provenait des bureaux provinciaux des commissaires aux incendies pour les statistiques de 1988 à 1991 inclusivement, de Statistique Canada et des statistiques de construction de

CanaData sur le parc de logements de 1988 à 1991 inclusivement, de l'examen de la documentation choisie, des discussions avec des entrepreneurs, de consultants en matière de coûts, de souscripteurs et de responsables des services de construction.

Pour l'analyse, on a utilisé les estimations des risques tirées de la documentation sur les applications des extincteurs ainsi que des estimations du panel Delphi. Pour la plupart des paramètres, la valeur moyenne et les valeurs limites étaient utilisées pour en éprouver l'à-propos. Les valeurs limites étaient produites pour évaluer les limites supérieures de l'efficacité par rapport aux coûts de l'utilisation des extincteurs dans les collectifs d'habitation. Des réductions de pertes matérielles ont été utilisées pour vérifier l'importance de cet avantage considérable. Par rapport aux valeurs moyennes choisies, l'on considère qu'il est peu probable que les valeurs limites de **tous** les paramètres s'appliquent simultanément.

Les résultats des trois scénarios d'analyse sont présentés en S1 et S2. Selon diverses sources, la fourchette du prix que l'on est prêt à payer par vie épargnée (en dollars canadiens de 1993) varie entre 4 000 $ et 48 000 $, avec une valeur de base de 24 000 $ (appliquée dans une étude américaine sur les extincteurs automatiques). L'installation obligatoire d'extincteurs automatiques dans les immeubles utilisés pour nos analyses imposera des coûts allant de 159 000 $ à 606 000 $ par année de vie épargnée dans les bâtiments à faible hauteur et de 252 000 $ à 1 212 000 $, dans les bâtiments de grande hauteur. La fourchette la moins élevée résulte de l'application de valeurs limites. Pour un nombre relativement petit de bâtiments de faible hauteur situés à la limite supérieure des dimensions permises, ces coûts peuvent être réduits si l'on tient compte d'autres changements proposés au code relativement à l'installation obligatoire d'extincteurs automatiques. Les conséquences de ces changements sont liées principalement à la conception du site et aux choix de constructions du toit pour lesquelles aucune donnée statistique n'existe.

Les chiffres indiquent que le coût des extincteurs dans les immeubles de faible et de grande hauteur par année de vie épargnée est supérieur à ce que la société est prête à payer pour des mesures de sécurité. L'une des raisons étant que les risques de mortalité due aux incendies sont relativement bas dans les immeubles de faible hauteur de construction récente. Même en tenant pour acquis que les risques d'incendie augmenteront à mesure que l'immeuble vieillira, les valeurs moyennes et limites du taux de risques du cas de base devraient demeurer assez basses. Comme le nombre de pertes de vie est plutôt bas au départ, la diminution possible du nombre de décès et des pertes matérielles rendue possible grâce aux extincteurs automatiques ne suffit pas à compenser les coûts marginaux de construction et d'entretien.

La possibilité de diminuer les coûts liés à la maîtrise des incendies en réduisant le nombre d'employés dans les services municipaux de lutte contre l'incendie et les installations dans les nouveaux quartiers constitue un autre domaine qui pourrait avoir un effet sur la viabilité économique de l'installation obligatoire des extincteurs. La SCHL propose de mener une étude à ce sujet qui pourrait révéler, ou non, pour la société, une réduction du coût global de l'installation obligatoire des extincteurs automatiques dans **tous** les immeubles neufs.

En attendant les résultats de cette étude, en fonction des résultats susmentionnés, nous concluons que comparativement à ce que la société a investi pour d'autres mesures de sécurité, il n'est pas efficient de rendre l'installation d'extincteurs automatiques à eau obligatoire dans les collectifs d'habitation du Canada.

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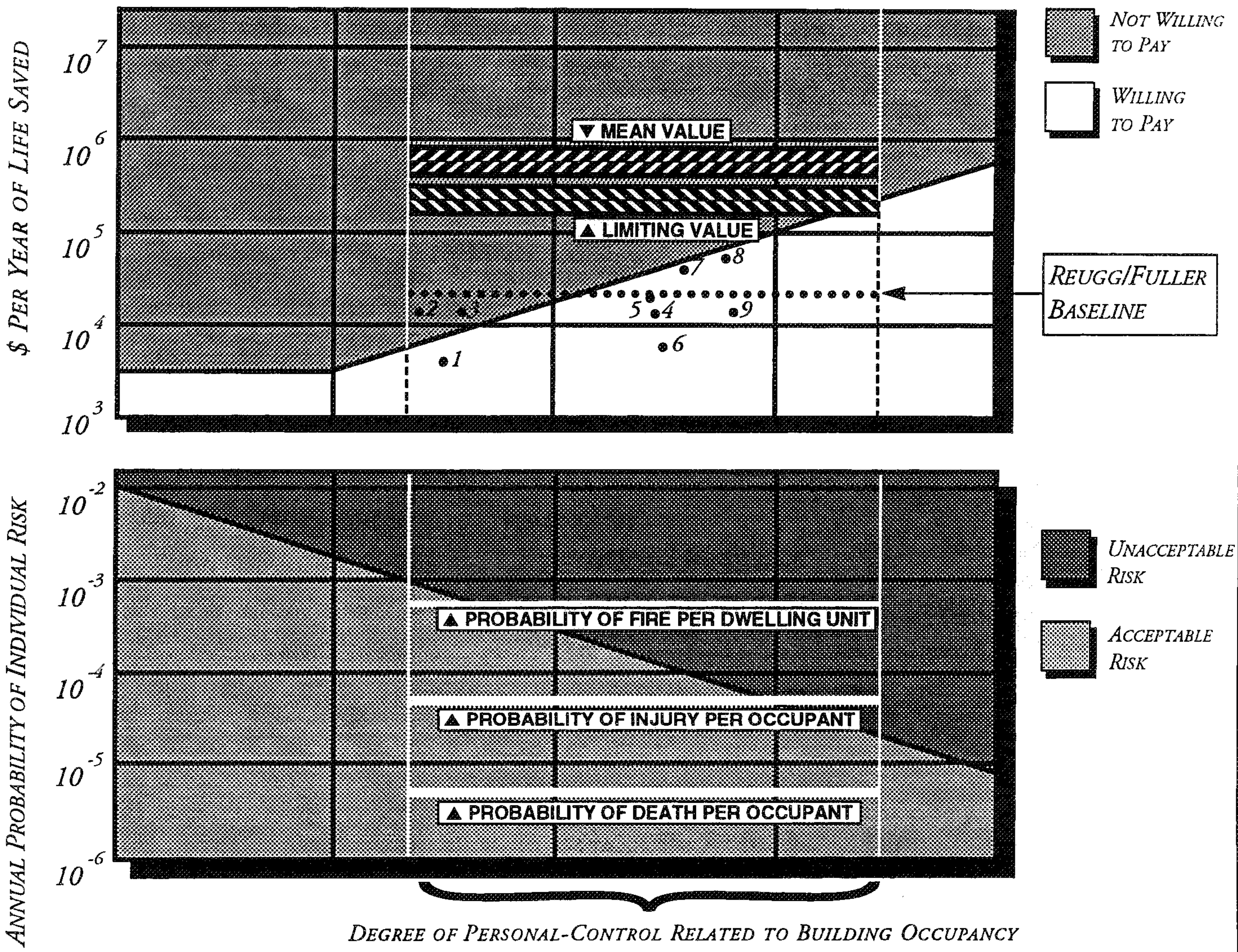
S1

Comparative Risk Assessment

Extent of Individuals' Personal Control Over Their Activities and Physical Environment			
Category 1	Category 2	Category 3	Category 4
"Voluntary"	Large Degree of Personal-Control	Small Degree of Personal-Control	"Involuntary"
Windsurfing	*Automobile*	*Public Transportation*	*Nuclear Power*



Cost-Effectiveness of Automatic Sprinklers in Low-Rise Apartments
(///) Range of $ per year of life saved using mean values for parameters
(\\\\\\) Range of $ per year of life saved using limiting values for parameters

Cost-Effectiveness of Other Mandated Safety Features		
Automobile Safety	Aircraft Safety	House / Fire Safety
1. Steering Column Protection 2. Passive Restraints / Belts 3. Fuel System Integrity	4. Cabin Fire Protection 5. Seat Cushion Flammability	6. Unvented Space Heaters 7. Children's Sleepwear Flammability 8. Smoke Detectors 9. Matches Safety Boxes

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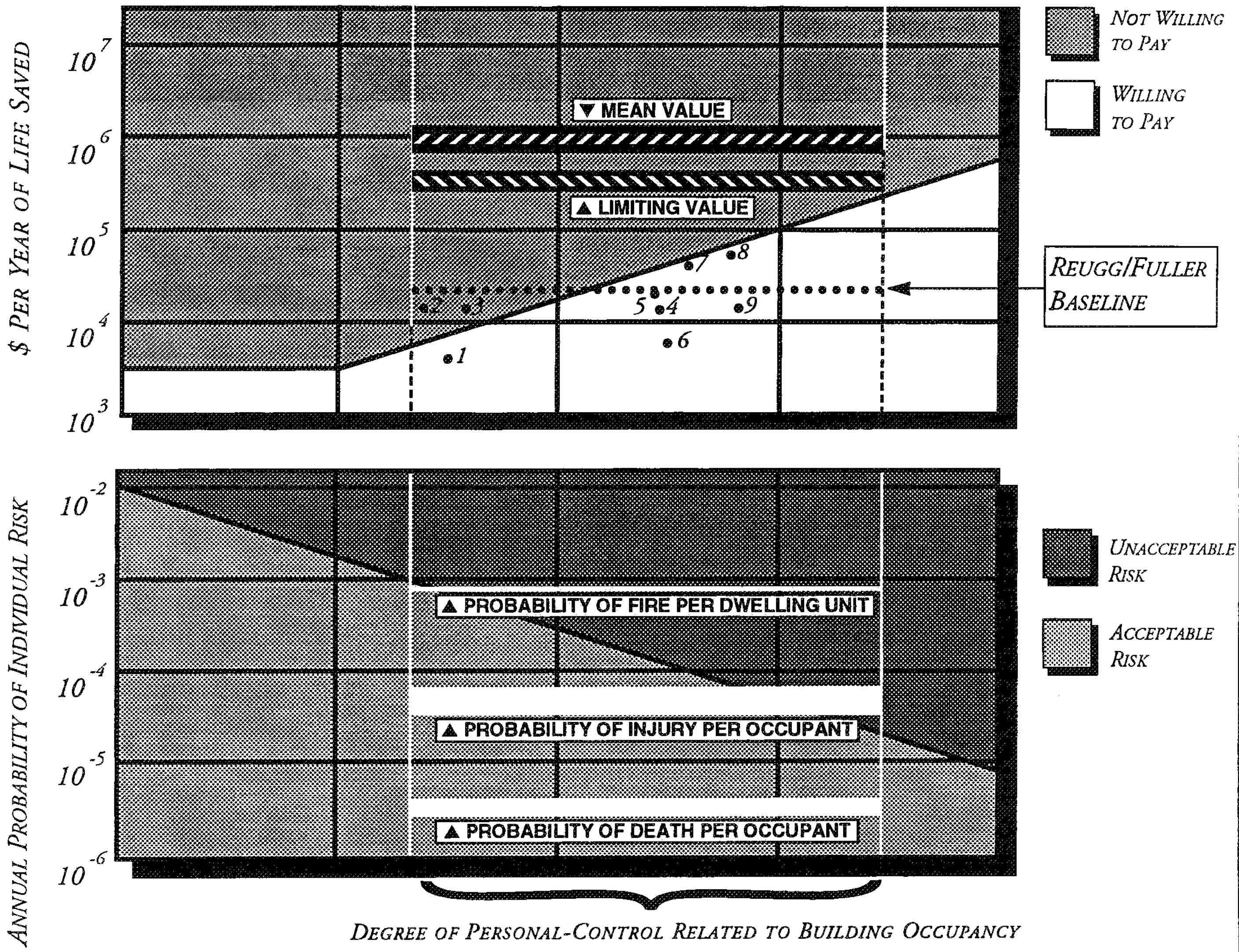
COMPARATIVE RISK ASSESSMENT

EXTENT OF INDIVIDUALS' PERSONAL CONTROL OVER THEIR ACTIVITIES AND PHYSICAL ENVIRONMENT			
CATEGORY 1	CATEGORY 2	CATEGORY 3	CATEGORY 4
"VOLUNTARY"	LARGE DEGREE OF PERSONAL-CONTROL	SMALL DEGREE OF PERSONAL-CONTROL	"INVOLUNTARY"
WINDSURFING	*AUTOMOBILE*	*PUBLIC TRANSPORTATION*	*NUCLEAR POWER*



COST-EFFECTIVENESS OF AUTOMATIC SPRINKLERS IN HIGH-RISE APARTMENTS

- RANGE OF $ PER YEAR OF LIFE SAVED USING MEAN VALUES FOR PARAMETERS
- RANGE OF $ PER YEAR OF LIFE SAVED USING LIMITING VALUES FOR PARAMETERS

COST-EFFECTIVENESS OF OTHER MANDATED SAFETY FEATURES

AUTOMOBILE SAFETY	AIRCRAFT SAFETY	HOUSE / FIRE SAFETY
1. STEERING COLUMN PRROTECTION 2. PASSIVE RESTRAINTS / BELTS 3. FUEL SYSTEM INTEGRITY	4. CABIN FIRE PROTECTION 5. SEAT CUSHION FLAMMABILITY	6. UNVENTED SPACE HEATERS 7. CHILDREN'S SLEEPWEAR FLAMMABILITY 8. SMOKE DETECTORS 9. MATCHES SAFETY BOXES

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Impact of Mandatory Sprinklering of Multi-Unit Residential Buildings

This report summarizes the findings of the study of the effectiveness of proposed building code changes relating to the mandatory installation of automatic fire sprinklers to be installed in all **new** multi-unit residential buildings. This building type includes high-rise apartment buildings as well as low-rise (four storeys or less) buildings. The study is intended to supplement the findings of the Joint Task Group on Mandatory Sprinklering of the Part 3 Standing Committees of the National Building Code of Canada.

We first introduce the purpose and scope of the study. We then indicate the need for measuring effectiveness in applying safety measures in buildings. We follow this by describing the study approach and methods. We then discuss the analysis parameters. Finally, we present the findings and conclusions. Appendices contain discussion and further information on selected aspects to provide the reader with additional details.

NEED FOR COST EFFECTIVENESS IN FIRE SAFETY MEASURES

One of the primary objectives in the National Building Code is to help ensure public health and safety. Reduction of the risk of fire has always been one of the central objectives of the code. This is achieved through mandating preventative measures, means for containment, techniques for suppression, means of egress, and provision for means of fighting fires by fire department personnel. Many of the fire safety measures mandated in building codes are highly effective and have been in place for many years. Introducing a major new fire measure such as automatic fire sprinklers in apartment buildings with significant capital costs, should be examined with respect to long term benefits.

MEASURES OF EFFECTIVENESS

In current conditions of global trade competition it can be argued that regulations should be in keeping with what society feels it can afford. This approach will help maintain and enhance our competitive position with respect to our trading partners. In the case of reducing fire risk, society must ask what are the most cost-effective means. This attitude can be extended to all forms of public regulation.

Measuring effectiveness of reducing fire risk must include the extent of reduction in loss of life, reduction of cost of injuries, and reduction of property damage. To these measurements the cost of maintaining these features to reduce risk over their useful life must be noted so as to compare the benefits with the costs. As a matter of principle, we must understand that above certain costs, the benefits obtained may not be worthwhile.

This study takes the view of evaluating overall costs to society and comparing these to benefits to society. The analysis does not address the extent to which the benefits arising from the use of automatic fire sprinklers accrue directly to the persons or groups who incur the incremental capital and operating costs associated with this fire safety measure. Any attempt to relate benefits to payers of the costs for features, such as sprinklers, which make the benefits possible, will quickly demonstrate that the vast majority of payees (ie. the building owners and tenants) often do not receive any direct benefit because of the low incidence of fire risk.

AUTOMATIC FIRE SPRINKLERS HELP REDUCE FIRE RISK

In recent years, in both Canada and the U.S., there has been considerable support for the expansion of the use of sprinklers in buildings. This support has been led in large part by the fire sprinkler manufacturing industry, with the encouragement of fire departments and in some cases, provincial, state and local governments.

Fire sprinklers can be highly effective because:

- They are **fast-acting** in suppressing/fighting fires.
- They can **confine the fire** to the compartment of origin and may prevent flashover; and
- They can greatly **reduce** or even **eliminate the build-up of smoke** before it spreads.

However, sprinklers cannot fully eliminate the effects of a fire. In some fire situations heat build-up generates large amounts of smoke but is not sufficient to cause sprinkler heads to release water. Water from the sprinkler system will cause property damage, although generally not as much as that caused by smoke, flames and water in an established fire fought with conventional fire hoses.

INCREMENTAL BENEFITS OF SPRINKLERS OVER SMOKE ALARMS: A CRITICAL ISSUE

Smoke alarms have already demonstrated significant positive impacts in reducing the hazards of fire in buildings. Studies (2, 10) have shown that the significant reduction in fire deaths and injuries during the 1980's coincides with introducing the requirement of wired-in-place smoke detectors in new buildings and with retrofitting them (commonly battery-operated) in older buildings. Other studies have estimated the impact of retrofitting all buildings with reliable wired-in-place (not battery-operated) smoke alarms.

Battery-operated smoke alarms have demonstrated a significant unreliability due to lack of power source because batteries have been removed or are non-functioning; all new construction since the early 1980's has been required by code to have built-in-place smoke detectors. This equipment is far mor reliable mainly because it ensures the power source (other than those instances when power to the dwelling is interrupted). Although smoke detectors cannot directly help contain or suppress a fire, the wired-in-place variety has demonstrated a very high degree of dependability as a warning device.

Because this study focuses on construction conforming to the most recent codes, we are dealing with a highly reliable fire warning system as base equipment for the subject buildings. Few statistics are available which indicate precisely what the reduced level of fire risk (death, injury, property losses) are for buildings built to today's standards of materials and equipment including smoke alarms. However, statistics from 1988-91 inclusive for B.C., Alberta, Manitoba and Quebec generally indicate significant reduction in risk as statistics progress from buildings constructed in 1970 or earlier, to those constructed 1971 to 1980 to those built in 1981 to 1991 (see Appendix A).

In this study the critical issue is: does the mandatory introduction of sprinklers in apartment buildings reduce the remaining fire risk sufficiently to justify the additional cost that this measure places on shelter? The study addresses this issue for both low-rise (four storeys or less) and high-rise apartment buildings. (Note that a different approach is suggested by NFPA in the U.S.; this approach highlights the benefits of sprinklers and points out that the capital cost increases add only 1 or 2% to the building cost; it therefore recommends sprinkler use (15)).

FOCUS ON COSTS/BENEFITS TO SOCIETY

Measuring the effectiveness of mandatory fire sprinklering and reduced risks should be carried out as indicated above, and must be considered over the assumed life of the sprinkler system. Operating costs and other important costs must be taken into account to produce a net present value. Other code changes proposed to accompany the requirement for mandatory sprinklering may also affect overall costs of construction and operations.

This study does not place a value on human life in order to compare the reduction in lives lost with the increase in capital and operating costs. The difficulty of placing a value on a human life can be avoided by focusing on what society has indicated and continues to indicate it is willing to pay to reduce risk to save lives.

The cost of measures to reduce the effect of hazards is somewhat like insurance. The amount paid out for the insurance premium must bear some relation to:

a. the likelihood of the occurrence that is being insured against (ie. the risk of the hazard occurring); and

b. the benefit derived in the event that the hazard occurs.

We describe our approach in greater detail below.

ANALYSIS DRAWS ON STATISTICS, EXPERT KNOWLEDGE AND LIFE CYCLE COSTING

Our approach to the analysis is structured around the Building Code Assessment Framework (BCAF), already used to evaluate selected changes proposed for the 1990 Ontario Building Code. The BCAF, as part of that work, was used to analyze the impact of mandatory sprinklering of single family houses.

The BCAF was developed by IBI Group and Trow Consulting Engineers under the direction of the Buildings Branch of the Ontario Ministry of Housing (see Appendix K). The BCAF contains data on design and construction details of 21 reference buildings representing 85% of Canadian construction during the 1980's. Included in that database are fire event/risk tree probabilities for each building type forming base case values. The BCAF contains a complete financial model for life cycle costs and an acceptable/unacceptable risk and willingness-to-pay graphs which help compare changes in mortality figures with incremental life cycle costs.

Consistent with the methods and information used in the BCAF, our analysis method contains the following elements:

- Two apartment building types as reference buildings - a high-rise apartment building (14 storeys, 137 units) and low-rise apartment building (3 storeys, 30 units).

- Estimate of life cycle length for each apartment type.

- Tracking of initial and ongoing incremental costs and savings for the dwelling units in high-rise and low-rise buildings constructed in the reference year over their life cycle. The number of dwelling units and their areas for each building type are based on annual averages over 1988-91 inclusive.

- Focus on incremental costs and benefits as a result of the proposed code changes.

- Statistics on deaths, injuries and property damage for apartment fires by province for both types of buildings from 1988-1991 inclusive.

- Estimate of fire risk based on new construction - apartments built according to present codes considering the base case risk as demonstrated from recent construction, with a factor for increasing the risk as the building ages.

- Base case fire event/risk trees with base values developed from other statistics (1983-1987).

- Delphi Panel of 25 experts across Canada to provide probability estimates of risks of each event of the fire event/risk trees, used to compute changes to number of deaths, and injuries and to amount of property damage (see Appendix G for names and qualifications of Delphi Panel members).

- Cost to society as a whole (not just to selected members of society).

- Societal attitudes to risk and willingness to pay per year of life saved.

- Consideration of the effect of new wired-in-place smoke alarms as a base case.

- Consideration of the combined impact of wired-in-place smoke alarms and automatic fire sprinklers.

- Inclusion of a wide range of risk costs and operating costs, and considering benefits of code changes relating to mandatory sprinklering.

- Review of selected literature.

- Canadian Housing Stock estimated by province for both apartment building types.

- Provision of two sets of parameter values:

  - **average** of likely ranges of values (mean values)
  - **other** values at the ends of the ranges that tend to favour the economics of sprinklers (limiting values)

This approach serves to provide for sensitivity testing and the possible range of impacts.

Further discussion of these parameters follows below.

ANALYSIS PARAMETERS

The following information summarizes the analysis parameters, values, and assumptions used in developing the risk estimates and financial analysis. The study assumes that all other current code changes proposed along with the adoption of mandatory sprinklers.

BASE CASE FIRE RISK

The primary underlying factor relating to the cost-effectiveness of sprinklers in new apartment construction is the **extent of fire risk**. It is only when a fire occurs that detection or suppression devices have an opportunity to demonstrate their effectiveness. Note however that sprinklers, like smoke alarms, do not reduce the risk of fires starting, since fire causes are not generally related to detection/alarm and suppression devices. However it is possible that smoke alarms may give sufficient early warning that some fires are extinguished by building occupants; this in turn may result in those fires never being reported.

Theoretically, occupants in high-rise buildings are at greater risk in the event of fire than occupants in low-rise buildings. The increased risk is due to the larger number of persons being exposed potentially to the fire in a high-rise building. Use of high-rise fire statistics to develop risk rates intrinsically take this factor into account.

Note that we have assumed limiting values to reflect how aging of the buildings constructed in the reference year may cause these risk factors to be higher on average over the building life cycle. See Exhibit 1 and Appendix A.

REDUCTION IN RISK OF DEATH, INJURY, PROPERTY DAMAGE

The most difficult factors to estimate in this analysis are the extent of reduction in deaths, injuries, and property damage due to the installation of automatic fire sprinklers. The main reason for this is that there is limited experience in use of residential fire sprinklers, and therefore statistics are not reliable. For example, B.C. statistics comparing these categories of risk in recently-built apartment buildings with and without sprinklers show no significant differences related to sprinkler use.

Therefore this investigation used a number of different approaches in dealing with this constraint as described in the analysis scenarios below.

A. **Delphi Panel.** The Delphi members provided estimates for each event in the risk trees for deaths, injuries and property damage, with smoke alarms as a base case, and with smoke alarms and sprinklers. However, time constraints did not permit iterations to refine panel opinions.

EXHIBIT 1

SUMMARY OF BASE CASE PARAMETER VALUES

Building Type and Parameters		Average Annual Risk/Loss	
		Mean Value	Limiting Value
Low rise	- deaths (deaths per occupant)	4.88×10^{-6}	5.87×10^{-6}
	- injuries (injuries per occupant)	4.0×10^{-5}	4.8×10^{-5}
	- property damage ($ loss per unit)	$16.68/unit	$24.6/unit
High rise	- deaths (deaths per occupant)	2.94×10^{-6}	4.64×10^{-6}
	- injuries (injuries per occupant)	3.3×10^{-5}	6.1×10^{-5}
	- property damage ($ loss per unit)	$6.72/unit	$10.08/unit

Unit = dwelling unit (apartment unit)

B. **Delphi Panel plus minimum property damage.** A second alternative in dealing with property damage is to assume that there is certain minimum damage caused by the activation of one or more sprinkler heads as a result of a fire, and deduct this amount from the statistical reported property damage (for those recently built buildings with wired-in-place smoke alarms). The minimum damage would involve replacing furniture and furnishings and repainting interior surfaces. The minimum amount of damage to a fire compartment in a high-rise building is assumed to be $1,500.00. For the corresponding space in a low-rise apartment building, this amount is assumed to be $2,000.00 to reflect the greater likelihood of water damage to the dwelling unit below, in addition to damage in the compartment of origin. These minimum property damage amounts represent a reduction of 92% in the case of fires in low-rise apartment buildings and 78% in the case of fires in high-rise apartment buildings. These figures are generally higher than estimates from the literature.

C. **Literature.** Reduction in risk to life, injury and property is taken from the literature, with mean and limiting values used. See Appendix J, Bibliography.

These values are summarized in Exhibit 2.

For the average age of fire victims, we draw on statistics from the Provincial Fire Marshals' offices, which are used to compute years of life lost. Based on the age distribution of fire fatalities and the average life expectancy, the number of years of life saved per one prevented death is 35.

APARTMENT BUILDING CONSTRUCTION

As indicated above the analysis focuses on building construction in a single Reference Year. The extent of building construction, in this case apartment buildings, was taken from a survey (Canadata - Southam Business Communications) of apartment building starts in each province across Canada in the years 1988-1991 inclusive. The annual average based on these four years was computed for low-rise apartment buildings, four storeys or less, and high-rise buildings, five storeys and higher.

For the low-rise construction the average annual number of units constructed is 30,012 in an average of 2,157 projects per year, with each unit having an average construction gross floor area of 1,012 square feet.

EXHIBIT 2

ALTERNATIVE RISK REDUCTION VALUES FOR DEATH, INJURY, PROPERTY DAMAGE, WIRED-IN-PLACE SMOKE ALARMS AND SPRINKLERS

Hazard Outcome	Risk Reduction Value by Analysis Scenario					
	Scenario A - Delphi Panel		Scenario B - Delphi Panel, Minimum Property Damage		Scenario C - Literature (Both Building Types)	
	Low Rise	High Rise	Low Rise	High Rise	Mean Value	Limiting Value
Deaths	57	57	57	57	33%	44%
Injuries	50	49	50	49	52%	74%
Property Damage	44	42	92% - low-rise 78% - high-rise		42%	55%

For high-rise apartments, the average annual total is 128 projects per year, containing 13,686 units per year with a construction gross floor area of 1,124 square feet per unit.

These figures form the description of construction in the Reference Year, which the proposed code change to mandatory sprinklering will affect. Impact calculations are computed using these unit numbers to estimate population, risk, incremental construction costs, and net present value.

POPULATION OF REFERENCE YEAR CONSTRUCTION

Statistics on the population of new construction, and of existing stock, are based on statistics on Canada's "dwellings and household data". Population statistics are used in assessing individual risks to occupants in new construction, and to determine risk levels and changes in those levels by age of building. Population data for the Reference Year of analysis and related construction were based on the population per apartment unit determined for apartment construction built in 1981-1990. For low-rise apartments the average is 2.1 persons per unit for a total of 63,025 persons in low-rise apartment units built in the reference year. We calculated that the average population per high-rise unit is 1.5 persons yielding a total of 20,529 persons living in high-rise accommodation built in the reference year.

LENGTH OF LIFE OF SPRINKLER SYSTEM

Because the buildings constructed in the reference year are examined for costs and benefits over the expected length of life of the sprinkler system, the length of life is very important in comparing benefits to costs. Several factors could terminate the useful life of the sprinkler system. These factors include deterioration of the piping system, and sprinkler valves, radical renovation of the building interior either for a reconfiguration of the dwelling unit spaces, or complete upgrading of the existing dwelling units including mechanical and electrical systems, or demolition of the building. In economic analyses of buildings of non-combustible construction it is customary to estimate a building life of 40 to 50 years.

It is assumed that with appropriate maintenance the sprinkler piping system and sprinkler heads will have a life of 50 years. However, for the other reasons mentioned above, the useful life of the system may be shorter.

For low-rise apartments of combustible construction, we estimate that an upper end of the life of the building or the dwelling unit within it will be 45 years. As a lower estimate, we believe that on average such buildings and dwelling units will have a life of 35 years. The combining of these averages produces a low-rise building life, and therefore that of the sprinkler system, of 40 years. Although this may be somewhat generous for combustible construction, for analysis purposes we assume that it is attainable on average.

For high-rise apartment buildings, more durable non-combustible construction could produce a slightly longer life. As an upper limit we assume 50 years for the life of the dwelling units and the sprinkler systems within them. As a lower estimate, we believe an average of 40 years is appropriate for the life of the dwelling units and the sprinkler systems within them. This produces an overall average of 45 years for the sprinkler systems within high-rise apartment buildings.

The limiting values of length of building life and therefore of sprinkler life in each building type can be taken as 45 years for low-rise and 50 years for high-rise. There is no basis to assume a longer life for the buildings; economic analyses of building life cycles, particularly for those of privately-owned structures, is usually shorter for reasons relating to uncertainty and pressures for redevelopment primarily for economic reasons. For example, in sprinkler studies for houses (8, 10), the life cycle was assumed to be 20 and 30 years.

CAPITAL COST OF SPRINKLERS

Helyar and Associates, Cost Consultants, were commissioned to undertake a study to provide realistic construction cost information for provisional automatic sprinkler systems in multi-unit residential buildings. M.V. Shore and Associates, Consulting Mechanical Engineers were also consulted. The consultants used quantity and cost estimating techniques that they normally employ for preliminary construction analysis. Separate analyses were carried out for high-rise construction and low-rise construction. Costs included sprinkler heads, bulk head pipe furring, extra-over costs for mechanical systems, electrical wiring for additional alarm and trouble zones and panel, with an electrical credit for heat detector, and all contractors' overhead and profit. This last item includes the mark-up (over and above the price paid to the sprinkler contractor) by the general contractor. Details of that analysis are provided in Appendix C.

These figures were used with other reported costs in 1993 dollars to produce a mean cost. The limiting costs are based on the average of the lower end reported sprinkler costs.

The mean costs for low-rise buildings is $1.80 per square foot and for high-rise buildings $2 per square foot. The limiting values are $1.30 and $1.50 per square foot respectively.

CAPITAL COST SAVINGS DUE TO INSTALLATION OF SPRINKLERS

Under the National Building Code, smoke control measures are mandatory for high-rise apartment buildings. The most cost-effective solutions for such measures has been installation of fans to pressurize shafts. With the installation of automatic fire sprinklers, such measures are no longer necessary. Consequently there will be a cost savings corresponding to the installed cost of the fans. We estimate the savings to be about $0.38 per square foot for the high-rise Reference Building.

Most buildings are constructed without balconies to reflect market preferences. Therefor the cost of that feature does not represent an alternative savings due to sprinklers.

ON-GOING COSTS FOR SPRINKLERS

Automatic fire sprinklers to ensure effectiveness and to comply with the proposed building code change will require annual inspection and testing, continuous monitoring at a control station and periodic repairs.

Annual Inspection/Testing

To ensure reliability, sprinkler systems must be inspected and tested once per year. In contact with Emiron Fire Protection Limited and Grinnell Fire Protection Systems, we have been informed of the following costs:

- For the 30 unit low-rise apartment Reference Building, a yearly inspection of alarms and supervised valves in accordance with the National Fire Code at a cost of $250.

- For the 137 unit high-rise apartment Reference Building, an average yearly inspection and testing cost of $750 and, a yearly sprinkler pump maintenance cost of $200.

These costs were converted to cost per sq.ft. for their respective building types.

Central Monitoring

The proposed code changes include the requirement for central monitoring. This is carried out through an electronic connection between the sprinkler system and a monitoring service organization, which in the event of sprinkler activation (or occasionally a fault in the system) will inform the fire department. This service involves a reported cost of about $600 for initial installation and $630 annually for ongoing monitoring. These costs do not vary according to building size.

These costs were converted to cost per sq.ft. for their respective building types.

Repairs/Maintenance

It is inevitable over the life span of the building that some interference or damage will occur to the sprinkler heads, requiring replacement. This could be caused in the course of redecorating where sprinkler heads are inadvertently painted, or in the course of moving furniture or furnishings and/or carrying out renovations, causing damage to sprinkler heads. This may be particularly likely because many of these dwelling units will be rental accommodation with higher turnover of occupants than for single family housing. Although there is no experience on which to base an estimate, we suggest that mean amount of 5% of the sprinkler component and installation costs be allocated for sprinkler system repairs in each of the 11th, 21st, 31st and 41st (in the cases where the system is presumed to have a life over 40 years). As a limiting value we suggest that 5% be allotted only in the 21st and 41st years. These amounts are intended to offset all repairs to the sprinkler systems and any related water damage.

With the above inspection, testing and maintenance it is assumed that sprinkler reliability will be 100% (ie. in the event of a fire where temperatures at the sprinkler heads reach the appropriate temperature, the sprinkler heads will be activated).

COSTS PER INJURY

Costs per injury were taken from a number of sources (1, 4, 5, 6, 8, 10) and adjusted to 1993 Canadian dollars. In addition, a further suggestion based on latest NFPA information was considered converting the most recent estimates for U.S. costs to reflect the much greater efficiency of the Canadian health care system and adjusting to Canadian dollars. The overall average obtained in this manner is $30,193.00 per injury.

It is worth noting that fire injuries span a wide range of types. Firefighter injuries account for some 30-40% of all fire injuries. A recent report from NFPA classifies injuries of fire fighters into categories of:

- burns
- smoke or gas inhalation
- other respiratory distress
- eye irritation
- wound, cut, bleeding, bruise
- dislocation, fracture
- heart attack or stroke
- strain, sprain, muscular pain
- thermal stress (frostbite, heat exhaustion)

- other

It is interesting to note that burns account for less than 10% of the reported injuries. By far the greater number, accounting for between 50-60% of all injuries, are wounds, cuts, bleeding, bruises, strains, muscular pain. Due to the nature of fire data recording, these injuries, particularly the more minor ones, may be reported more frequently for fire fighters than for civilians. Therefore the injury breakdown will likely differ for civilian injuries. However, it would appear that the very costly burn injuries account for a relatively small proportion of the total injuries.

IMPACT ON FIRE FIGHTING RESOURCES

Application of residential fire sprinklers is sometimes thought to be able to reduce the need for and costs of fire fighting services. This is assumed to be done by either reducing the size of the fire hall (and staff and equipment) for given residential dwelling population, or by spacing conventional fire halls further apart.

Recent examinations of time spent by fire departments, first in the U.S. (14) and later in Vancouver (13), suggest that this will not be possible. In the U.S. surveys indicated that fire stations spend only 22% of the time in responding to fires (the remainder of the time was spent in dealing with emergencies and promoting community fire safety). Of the time devoted to fighting fires, only 10% was directed at residential fires, thereby producing a total time requirement for residential fires of less than 3%. It has been assumed that Canadian results would be similar. In fact, the recent study in Vancouver found that only 1.5% of the emergency calls were for residential fires (and less than half of these were for multi-unit residential buildings).

On the assumption that the remaining time of fire fighters is **not** needed for essential duties, one could consider enlarging the service delivery area of individual fire stations serving new developments. This effectively reduces the level of service provided and can only be justified if **all** buildings in the development are equipped with automatic fire sprinklers, including single family houses, and office space and if response time for other emergency calls is within an acceptable time limit. This implies that the fire station is located at or near the centroid of a significantly larger service delivery area and therefore may require immediate extension of underground services to such a site. These notions are worthy of further investigation, preferably by examining what would be the precise make-up of such a fire station to service a large catchment area and the timing of residential growth to completely fill the new catchment areas. This is beyond the scope of the present study, but should be considered, at least using two or three specific major Canadian subdivisions as realistic applications. Any cost savings would of course contribute to the economic viability of mandatory sprinklering. We understand that such a study is proposed by CMHC to be carried out in the near future.

With the above very small amount of fire response effort directed at residential fires, and the fact that the proposed code changes do not deal with single family and semi-detached dwellings, mandated sprinklers in new apartment buildings would not permit any measurable degree of downsizing of fire fighting resources. Therefore, we are unable to justify any fire fighting cost savings attributable to the implementation of mandatory sprinklering in multi-unit residential buildings.

OTHER COSTS

There are a number of other cost/savings which this study considers. These are:

- **Design fees.** These are estimated by examining the recommended fee schedule of the Ontario Association of Architects for the low-rise and high-rise Reference Buildings. The resulting fee amounts from the schedule are reduced by 15-20% indicate the highly competitive nature of fees for building design services. The mean amounts used are 6.5% for low-rise building and 5% for the high-rise building. As a limiting value the fees would be 6% and 4.5% respectively, and are applied to the installed costs of the sprinkler system. The argument that the current economic climate would result in designers adding the sprinkler feature within present absolute fee budgets does not recognize the added professional responsibility that sprinkler design and contract documentation requires.

- **Plan checking and building inspection.** The cost for these activities is included in the building permit fee. Discussions with building departments in Vancouver, Calgary, Toronto, Scarborough and Halifax suggested that a 1% building permit fee would be applied against the construction value.

- **Property taxes.** Discussions were held with the municipalities of Vancouver, Calgary, Toronto, Scarborough and Halifax to develop the relationship between annual property taxes and construction value. Assuming an approach based on market value assessment and assuming that the construction portion of the assessment keeps pace with inflation over the life of the building, we have selected a value of 1% of the cost for sprinklers be applied on an annual basis throughout the life of the buildings.

- **Life insurance.** Estimates from underwriters indicate that 15 million persons in Canada are insured for a total of $1.3 trillion, for an average of $86,700 per person insured. However, only 55% of the population is insured and on the assumption that life insurance is purchased only for persons over 21 years of age, (about 70% of the fire fatality group) the value of the policy per death is about $33,400. Because the age of the average fatality is 41 years, as opposed to life expectancy of about 76 years, for purposes of calculation, this amount is assumed to be paid some 35 years in advance for each fatality.

- **Indirect costs.** Indirect costs due to residential fires include costs for temporary shelter, employment absence, additional meals, demolition, legal services, transportation, emotional counselling, child care and allowance for miscellaneous items. These costs are about 6.5% of the direct costs for property damage (5, 10). To estimate the reduction in these costs, we assumed the same percentage reduction as for property damage (ie. direct costs).

- **Discount or Interest Rate.** This is the rate of interest reflecting the real time value of money that is used to convert costs and benefits occurring at different time to equivalent values at a common time (or at present value). The discount or interest rate is used to calculate a discount factor as follows:

  - $\frac{1}{(1+i)^N}$ is the factor to determine the Single Present Value of a future sum of money at the end of N periods of time at *i* interest or discount rate.

  - $\frac{(1+i)^N - 1}{i(1+i)^N}$ is the factor to determine the Uniform Present Value of end-of-period payments (or receipts) in a uniform series over N periods at *i* interest or discount rate.

One set of calculations uses a real interest or real discount rate (excluding inflation) of 6%. To test sensitivity of using a lower rate, 4%, is applied in a parallel set of calculations. Note that these rates are much lower than are currently being used for real estate economic analyses; however, such analyses generally include land for which future value can vary widely. In the case of this analysis, because human lives are involved, we use lower rates.

SUMMARY OF ANALYSIS PARAMETERS

Exhibits 1, 2 and 3 summarize the parameters used in the analysis. Note that mean and limiting values are used in those significant areas where the costs and benefits of sprinklers will be most significantly effected.

ANALYSIS SCENARIOS

As explained on pages 6 and 7, three different analysis scenarios were used to take into account the different estimates on risk from the Delphi Panel and from the literature, with added examination for alternative approaches to deal with property loss. For all other economic parameters mean and limiting values and alternative discount rates were used for each of the three four scenarios.

The results produce ranges for cost per year of life saved for each building type.

FINDINGS AND CONCLUSIONS

The risk data in computation of net present values of costs/savings per year of life saved are shown in Exhibit 4. These values were placed on the comparative risk assessment graphs indicating acceptable/ unacceptable levels of risk and cost for safety features (Exhibits 5, 6). Also shown on the graph is the baseline willingness to pay value (adjusted to 1993 Cdn $) from the Ruegg Fuller report (4). The findings are summarized below:

1. Annual fire risk, as expressed by annual fires per unit for both low-rise and high-rise accommodation is primarily in the unacceptable range, even for those dwelling units in recently constructed buildings (see Exhibits 5 and 6 and Appendix A, Exhibit A1).

2. Risk of death for both low-rise and high-rise housing units is clearly in the acceptable range. (See Exhibit 5.) However, this should not imply that this risk should not be reduced.

3. Risk of injury is generally below the maximum acceptable risk.

4. The annual probability of fire per unit for new construction is slightly lower for high-rise than for low-rise accommodation. The risk of death is higher for low-rise but the risk of injury is lower for low-rise. (see Appendix A, Exhibit A1).

5. Exhibit 4 summarizes the findings from the net present value analyses of incremental costs/savings due to sprinklers. The dollar amounts are expressed as the cost per year-of-life saved.

EXHIBIT 3

SUMMARY OF ADDITIONAL PARAMETER VALUES

Parameter	Mean Value	Limiting Value
Length of useful life of sprinkler system		
low rise	40 years	45 years
high-rise	45 years	50 years
Capital savings due to installation of sprinklers	$.38/sq.ft.	$.38/sq.ft.
Capital costs for sprinklers		
low-rise	$1.80/sq.ft.	$1.30/sq.ft.
high-rise	$2/sq.ft.	$1.50/sq.ft.
On-going costs for sprinklers		
low-rise testing and inspection	$250 per year	$250 per year
high-rise testing and inspection	$950 per year	$950 per year
repair, replacement to sprinkler heads	5% of initial cost in the 11th, 21st, 31st and 41st year	5% of initial cost in the 21st and 41st year
Design fees (as a percent of construction costs)		
low-rise	6.5%	6.0%
high-rise	5%	4.5%
Plan checking and building inspection (building permit)	1% of incremental construction cost	
Property taxes	1% of incremental value increase due to sprinklers	
Average cost per injury	$30,193	
Average life insurance per person in fire fatality group	$33,400	
Average delay in life insurance payments due to sprinklers	35 years (difference between average fire death and life expectancy)	

Unit = dwelling unit (apartment unit)

EXHIBIT 4

ESTIMATED INCREMENTAL LIFE CYCLE COST FOR SPRINKLERS PER YEAR OF LIFE SAVED
(Values are shown for a 4% and a 6% discount rate)

ANALYSIS SCENARIO	LOW RISE				HIGH RISE			
	Parameter Mean Values		Parameter Limiting Values		Parameter Mean Values		Parameter Limiting Values	
	4%	6%	4%	6%	4%	6%	4%	6%
A	349,810	323,154	193,047	176,137	701,498	646,695	685,240	260,510
B	329,173	307,466	169,501	158,573	688,014	636,637	273,282	251,736
C	605,835	559,404	241,452	221,738	1,211,593	1,116,955	361,274	331,433

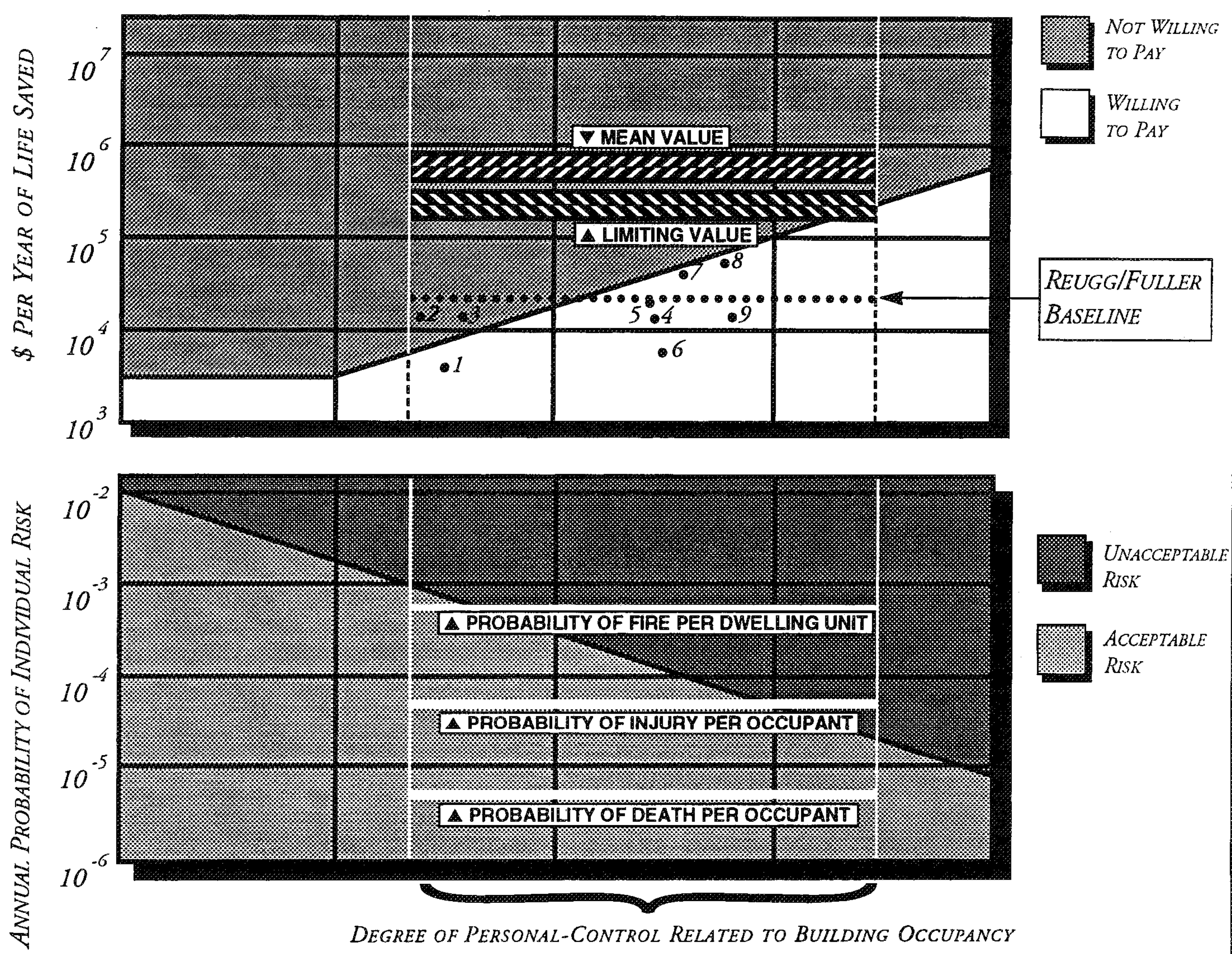
A: Changes in fire risk levels as estimated by the Delphi Panel.

B: Changes in fire risk levels as estimated by the Delphi Panel with one exception, savings in property losses, which are estimated based on comparison of statistical losses (no sprinklering) and estimated **minimum** losses when a sprinkler system is activated.

C: Change in fire risk levels, including property losses, are estimated based on values from the surveyed literature.

5 Comparative Risk Assessment

Extent of Individuals' Personal Control Over Their Activities and Physical Environment			
Category 1	Category 2	Category 3	Category 4
"Voluntary"	Large Degree of Personal-Control	Small Degree of Personal-Control	"Involuntary"
Windsurfing	*Automobile*	*Public Transportation*	*Nuclear Power*



Cost-Effectiveness of Automatic Sprinklers in Low-Rise Apartments
(////) RANGE OF $ PER YEAR OF LIFE SAVED USING MEAN VALUES FOR PARAMETERS
(\\\\) RANGE OF $ PER YEAR OF LIFE SAVED USING LIMITING VALUES FOR PARAMETERS

Cost-Effectiveness of Other Mandated Safety Features		
Automobile Safety	Aircraft Safety	House / Fire Safety
1. Steering Column Protection 2. Passive Restraints / Belts 3. Fuel System Integrity	4. Cabin Fire Protection 5. Seat Cushion Flammability	6. Unvented Space Heaters 7. Children's Sleepwear Flammability 8. Smoke Detectors 9. Matches Safety Boxes

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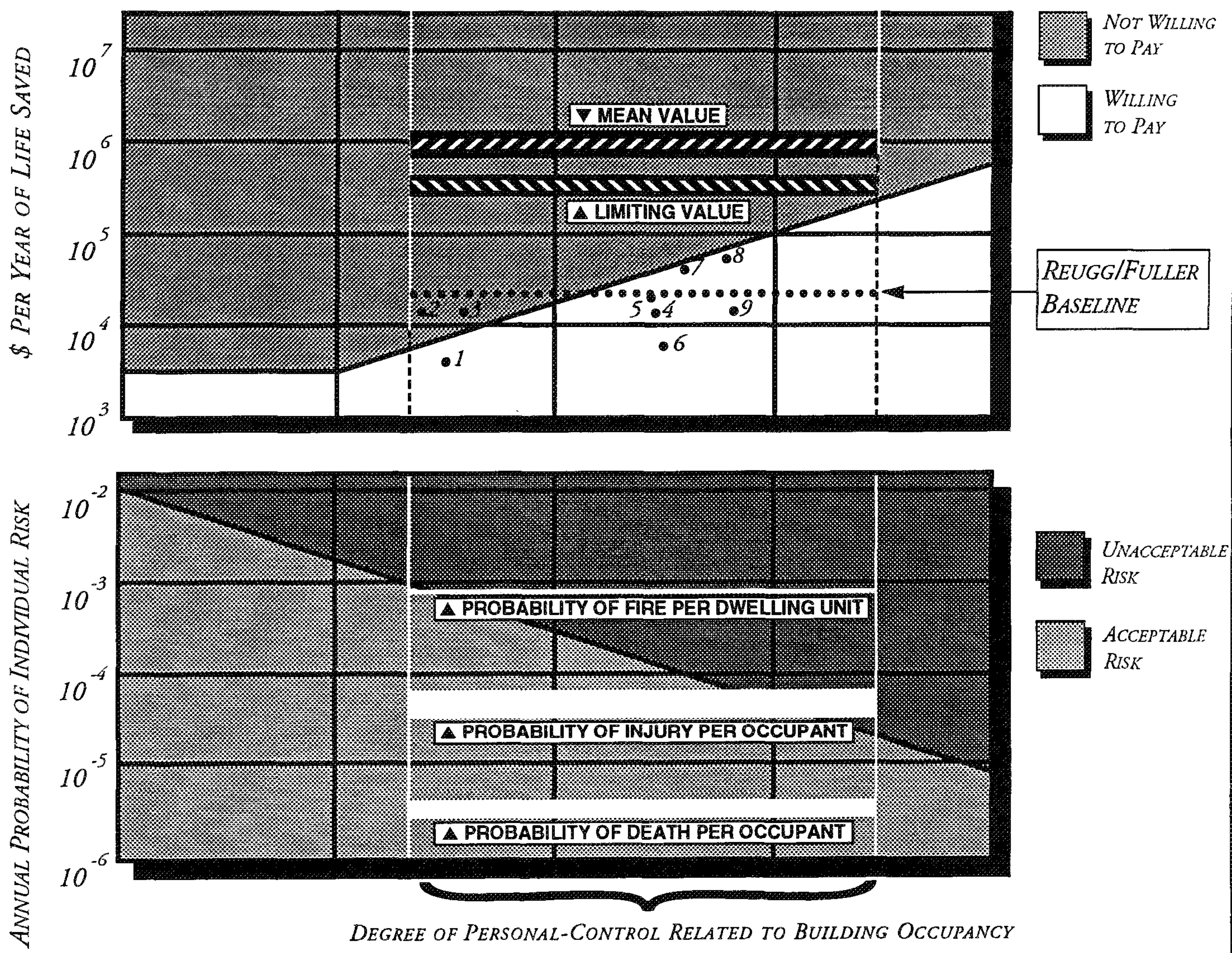
EXTENT OF INDIVIDUALS' PERSONAL CONTROL OVER THEIR ACTIVITIES AND PHYSICAL ENVIRONMENT			
CATEGORY 1	CATEGORY 2	CATEGORY 3	CATEGORY 4
"VOLUNTARY"	LARGE DEGREE OF PERSONAL-CONTROL	SMALL DEGREE OF PERSONAL-CONTROL	"INVOLUNTARY"
WINDSURFING	*AUTOMOBILE*	*PUBLIC TRANSPORTATION*	*NUCLEAR POWER*



COST-EFFECTIVENESS OF AUTOMATIC SPRINKLERS IN HIGH-RISE APARTMENTS

- (///) RANGE OF $ PER YEAR OF LIFE SAVED USING MEAN VALUES FOR PARAMETERS
- (\\\) RANGE OF $ PER YEAR OF LIFE SAVED USING LIMITING VALUES FOR PARAMETERS

COST-EFFECTIVENESS OF OTHER MANDATED SAFETY FEATURES

AUTOMOBILE SAFETY	AIRCRAFT SAFETY	HOUSE / FIRE SAFETY
1. STEERING COLUMN PROTECTION 2. PASSIVE RESTRAINTS / BELTS 3. FUEL SYSTEM INTEGRITY	4. CABIN FIRE PROTECTION 5. SEAT CUSHION FLAMMABILITY	6. UNVENTED SPACE HEATERS 7. CHILDREN'S SLEEPWEAR FLAMMABILITY 8. SMOKE DETECTORS 9. MATCHES SAFETY BOXES

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6. In all cases the incremental cost per year of life saved significantly exceeds the corresponding figures resulting from other mandatory safety measures imposed by authorities concerned with automobile, aircraft, and house/fire safety, and the Ruegg Fuller baseline.

7. Considerations of construction cost savings (Appendix I) would reduce the net cost increase of some upper end low-rise apartment buildings. Due to lack of statistics on detailed building size and site planning, it is not possible to give a precise estimate. However, due to the relatively small proportion of buildings involved and the value of cost savings, the amounts will not be sufficient to reduce cost per year-of-life saved to bring that amount into range of other mandated safety features.

Pending the results of the study to explore the cost savings for municipal fire suppression if sprinklers were to be mandated for all buildings, from the above, we conclude that the more limited application of mandatory residential automatic fire sprinklers in new low-rise and high-rise multi-unit residential buildings should be considered in the light of its significantly higher cost than other safety measures and relative to benchmarks for willingness to pay per year of life saved.

The *findings of this study do not imply that existing sprinklering* requirements could or should be eliminated. That would constitute an **increase** in risk from the status quo, which is a more sensitive issue than that of risk **reduction**.

It appears that hard-wired smoke alarms are playing an important role in risk reduction and will continue to do so, because they function independently of the need for the regular maintenance of battery-operated smoke alarms. With former devices already mandated, the required investment for sprinklering makes sprinkler systems significantly more costly than other recent important safety measures used in day-to-day living and working.

APPENDIX A

FIRE RISK TRENDS FOR APARTMENTS IN CANADA

Appendix A
Fire Risk Trends for Apartments in Canada

The following notes provide more information on the development of Base Case fire risks and mean and limiting values for the extent to which the introduction of sprinklers can reduce Base Case risks.

Guidelines for reporting fire across Canada have been established by the Fire Commissioner of Canada. Use of corresponding fire statistics in other countries is of less importance because of data available here.

OVERALL STATISTICS SHOW DECLINE

A recent examination [12] of Canadian fire statistics from 1977 to 1990 indicates a steady decline in fire death rates over that period. In the period of 1981 to 1990, the deaths per million people in fire across Canada declined from about 29 deaths per million to 17 deaths per million.

Another measure of fire impact also has shown a decline during that timeframe. Since 1981 dollar cost of fire damage as a percent of the gross domestic product in Canada has declined from 0.26% to 0.18%.

The reason for these declines can be attributed to several factors. The most likely reasons are improved fire safety education, and the adoption of smoke alarms across the range of dwelling unit types across Canada.

The significance of this trend in declining fire impact is that there is less opportunity for significant investments in fire safety in buildings to be cost effective.

AGE OF BUILDINGS, AN IMPORTANT FACTOR IN FIRE SAFETY

Following along from the above point regarding improved construction, it is interesting to note the pattern of fire statistics by age of building over the most recently available statistics, 1988 to 1991 inclusive. Fortunately, in the provinces of B.C., Alberta and Manitoba, fire statistics for high-rise and low-rise apartment buildings have been aggregated by age of building. Exhibit A1 shows the pattern for these three provinces with respect to fires per unit, deaths per occupant, injuries per occupant, and dollar loss per unit. Within each province, there is a clear trend toward a steady decline from buildings built prior to 1971, to buildings built in the period 1971 to 1980, to buildings built in the period 1981 to 1990.

This trend is also evident in Quebec where fire statistics according to building age are not disaggregated between high-rise and low-rise apartment buildings.

EXHIBIT A1

AVERAGE ANNUAL FIRE RISK BY BUILDING AGE 1988 - 1991

BUILDING TYPE	AVERAGE ANNUAL RISK/LOSS BY BUILDING AGE														
	FIRES/UNIT			DEATH/OCCUPANT			INJURIES/OCCUPANT			$ LOSS/UNIT, $ LOSS/FIRE					
	Up to 1970	1971-1980	1981-1991	Up to 1970	1971-1980	1981-1991	Up to 1970	1971-1980	1981-1991	Up to 1970		1971-1980		1981-1991	
LOW RISE															
British Columbia	$1x10^{-3}$	$9.9x10^{-4}$	$7.2x10^{-4}$	$1.4x10^{-6}$	$1x10^{-5}$	$5.7x10^{-6}$	$8.1x10^{-5}$	$1.2x10^{-4}$	$5.7x10^{-5}$	$24	$23,348	$20	$19,823	$21	$29,400
Alberta	$1.5x10^{-3}$	$1.2x10^{-3}$	$4.3x10^{-4}$	$1.8x10^{-5}$	$2.7x10^{-6}$	$5x10^{-6}$	$1.9x10^{-4}$	$1.7x10^{-4}$	$3x10^{-5}$	$22	$14,542	$36	$29,044	$20	$45,894
Manitoba	$3.2x10^{-3}$	$8.8x10^{-4}$	$7.6x10^{-4}$	$5.1x10^{-6}$	0	0	$3.3x10^{-4}$	$7.6x10^{-5}$	$1.7x10^{-5}$	$36	$11,280	$15	$17,314	$8	$10,399
3 Province Weighted Average	$2.1x10^{-3}$	$1.1x10^{-3}$	$6.1x10^{-4}$	$6.6x10^{-6}$	$6.1x10^{-6}$	$5x10^{-6}$	$1.3x10^{-4}$	$1.3x10^{-4}$	$4.5x10^{-5}$	$25	$16,548	$27	$22,598	$20	$23,705
HIGH RISE															
British Columbia	$7.7x10^{-4}$	$4.3x10^{-4}$	$5.2x10^{-4}$	0	$7.2x10^{-6}$	0	$1.6x10^{-4}$	$3.6x10^{-5}$	$6.3x10^{-5}$	$5	$6,462	$4	$9,367	$3	$5,630
Alberta	$2x10^{-3}$	$1.7x10^{-3}$	$5.8x10^{-4}$	$5.3x10^{-5}$	$8.8x10^{-6}$	0	$7.6x10^{-4}$	$2.6x10^{-4}$	$6.5x10^{-5}$	$76	$38,737	$23	$13,464	$3	$5,207
Manitoba	$2.1x10^{-3}$	$2.4x10^{-3}$	$1.6x10^{-3}$	$1.3x10^{-5}$	$3.5x10^{-5}$	0	$2x10^{-4}$	$1.6x10^{-4}$	$1.9x10^{-4}$	$20	$9,536	$12	$5,028	$9*	$7,960*
3 Province Weighted Average	$1.4x10^{-3}$	$1.3x10^{-3}$	$8.2x10^{-4}$	$1.7x10^{-5}$	$1.5x10^{-5}$	0	$3.3x10^{-4}$	$1.4x10^{-4}$	$9.6x10^{-5}$	$27	$19,839	$12	$9,153	$5	$6,697
LOW & HIGH RISE															
Quebec	$1.4x10^{-3}$	$1.4x10^{-3}$	$7.1x10^{-4}$	$1x10^{-5}$	$2.4x10^{-6}$	$1.9x10^{-6}$	$9.4x10^{-5}$	$7.6x10^{-5}$	$2.6x10^{-5}$	$40	$27,508	$30	$21,494	$12	$16,813

* Averages adjusted in Manitoba to exclude large losses in an apartment building garage.This loss involved not only structural damage but damage to vehicles in the garage. If this loss were to be included in the above statistical averages, the Manitoba dollar loss per unit will jump from $9 to $88, and the dollar loss from fire goes from $7,960 to $55,693. Similarly, there would be a jump in the 3 province weighted average for 1981-1990 from $5 per unit to $24 per unit and from $6,697 per fire to $30,563 per fire. It is therefore appropriate to exclude this figure because it arises from an unusual fire and it significantly skews the statistical averages.

Note that in Manitoba, fire statistics included a particularly serious fire in an open-air residential parking garage at the base of an apartment building. This garage in which this fire occurred had a ceiling assembly containing foamed plastic which was not properly protected. This foamed plastic ceiling material appeared to be a prime cause for the anomalous severity of the fire in the parking area. For this reason, this example is removed for statistical purposes. With this event removed, the pattern in Exhibit A1 showed a trend toward dollar loss per unit decline in recent years. Because of lack of statistics in fire deaths in British Columbia, Alberta and Manitoba, particularly, for high-rise buildings, the combined Quebec statistics for high-rise and low-rise buildings and the unavailable breakdown of statistics by building age for other Canadian provinces, we used a weighted average of the building stock's recorded risk considering age where possible.

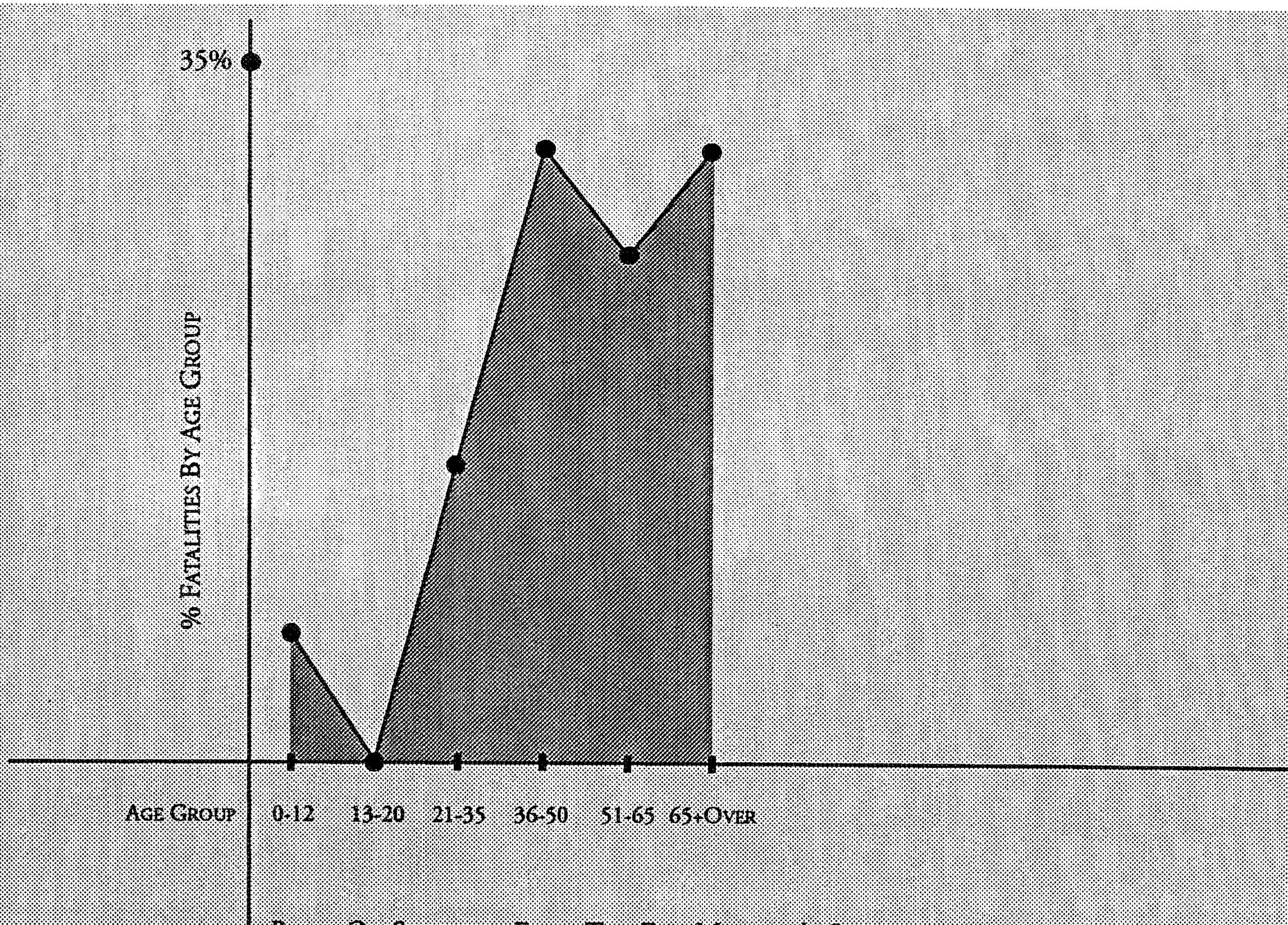
The above mean and limiting average figures are then assumed to be the Base Case mean risk factors for high-rise and low-rise apartment construction built to current code standards across Canada.

Statistics show that the three western provinces discussed above, plus Ontario and Quebec account for 92% of the high-rise dwelling units as well as the low-rise dwelling units. While Ontario accounts for 65% of the high-rise dwelling units, Quebec accounts for 54% of the low-rise units. In order to establish a mean and limiting value for deaths and injury risks, the 3-province weighted average, an adjusted Quebec figure based on the combined Quebec average ratio of low-rise to high-rise, and an adjusted Ontario figure (based on a comparison between the risk across all buildings in Ontario and in the 3 provinces where a risk by building age is available) were used and prorated to reflect the provinces' share of building stock. For each building type the **spread** between the risk value for the age group 1981-1991 and the risk value of stock of all ages was then determined. The risk for each building type across **all** stock produces a control maximum risk. To recognize that risk may increase for the new stock as the buildings age, we closed the gap between the current risk for those dwellings and the risk for dwellings of all ages by adding 1/8 and one quarter of the risk spread to produce the mean and limiting values for low-rise, and 20% and 40% of the risk spread (because it is larger) for the mean and limiting values for high-rise. A similar procedure was used to establish mean values for property loss. The limiting property loss value used for low-rise buildings is the national average while that for high-rise buildings is a value 50% higher than the mean. The resulting values are shown in Exhibit 1 of the report.

See Exhibit A2 for age distribution of fatalities.

EXHIBIT A2

CIVILIAN FATALITIES FROM APARTMENT FIRES, 1988-1991



BASED ON STATISTICS FROM THE FIRE MARSHAL'S OFFICES FROM MANITOBA, ALBERTA AND BRITISH COLUMBIA.

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TO-3594/MAHSHID/MAY/13/1993

COMMENT ON ALTERNATIVE APPROACH TO BASE CASE RISK

We considered an alternative point of view with respect to base case risk. An approach considered in the U.S. involves the notion that the average risk over the life of buildings will approach the national average, even for the newest construction built according to latest code standards. The reason for this is the assumption that the older a dwelling unit becomes, the lower the household income is of its inhabitants. Low income households in the U.S. are associated with significantly increased fire risk.

We have been unable to discover any studies for Canada that have produced statistical and technical evidence corroborating that a) the older the dwelling, the lower the income of its household, and b) risk increases significantly with low incomes (other than study by Ontario Housing Corporation which indicates 97% reliability for wired-in-place smoke alarms). Whatever the socio-economic and behavioural factors related to fire risk may operate in the U.S., the corresponding social and historical background in Canada is far different. In contrast to the U.S., Canada has a much broader social safety net, and no large visible urban minority groups with a history of low social and income status, and related high fire risk housing. Behavioural factors of lowest income groups in the two countries could be very different. Further Canada has a very different pattern of city building over time whereby older inner city neighbourhoods in Canadian cities have generally been preserved and enhanced. The notion that even the newest housing (ie. housing built over the past 10-12 years according to the most recent safety advances incorporated into building codes) will perform no better over its life than the national average (reflecting a large proportion of the older housing stock which has not been built according to recent code advances), does not appear logical.

On the contrary, the dramatic decline (over 40%) in the death rate in the residential fires in dwellings of all age in Canada in the 1980's corresponds directly to the availability of battery operated smoke alarms, and to a much lesser extent (because of the small proportion of the stock involved) the mandatory requirement for hard-wired smoke alarms in new construction. The fact that in fire situations, U.S. experience shows that only two thirds of dwellings have smoke alarms that are functioning (whereas hard-wired smoke alarms have been reported to be nearly 100% reliable in fires), only strengthens the notion that as new construction with mandatory hard-wired smoke alarms forms a larger proportion of the housing stock, the blended risk rate for all stock will continue to drop.

The above approach implies that provisions should be made for added costs of sprinkler and other related repairs due to vandalism and for reduced reliability of sprinkler systems that may be associated with poor management practices in housing accommodating the lowest economic/social stratum of society.

APPENDIX B

COMPARATIVE RISK AND COST GRAPHS

Appendix B
Comparative Risk and Cost Graphs

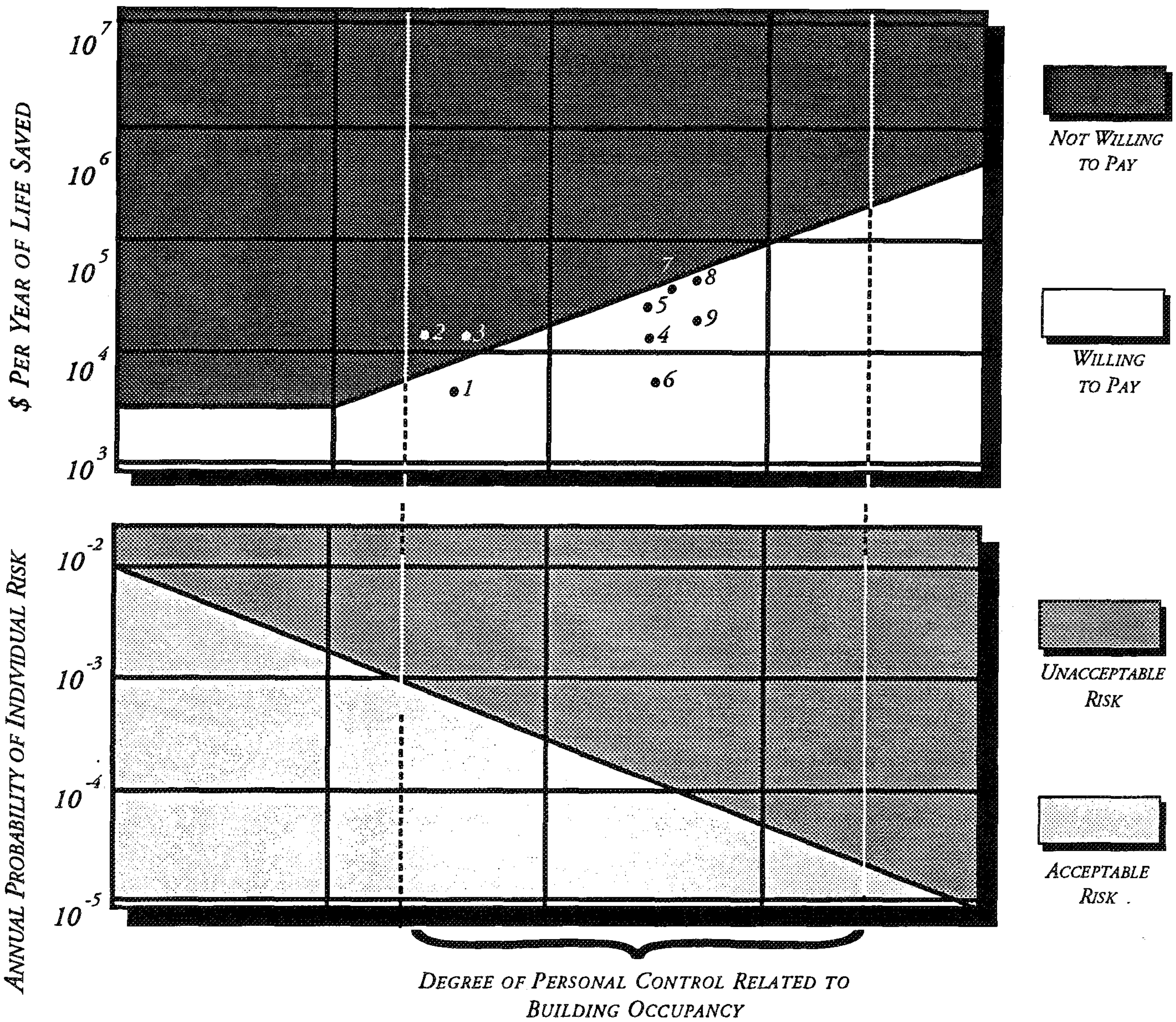
The Building Code Assessment Framework takes a societal view with respect to costs and benefits resulting from changes to the Building Code. Society in Western Europe and North America continually makes defacto judgements regarding acceptable risks and willingness to pay to save lives in developing regulatory devices to maintain public health and safety. Depending upon the degree of personal control of individuals, society has indicated that certain levels of risk probabilities are acceptable, but as the risk probability increases, it reaches a point that is unacceptable. Similarly, society, through regulatory measures, has deemed itself willing to pay to reduce life threatening risks to a certain level, but tends to stay away from imposing compliance costs that are very high. In this latter matter, society is indirectly placing a value on a human life without specifically stating what that value is.

The Building Code Assessment Framework draws on analyses developed in Europe, modified for use in Canada. The most useful indication of the above concepts can be illustrated by reference to Canadian and U.S. data.

With respect to investments imposed by regulations to save lives, the recent CMHC study on automatic fire sprinklers for one and two family houses, provided some statistics which supports the concept of the notion of limits to societal willingness to pay to save lives. The investment costs have been converted based on estimates of average age at death and life expectancy and are placed along the graph. It is interesting to note that these investments are either well within or close to the indicated limits of willingness to pay.

APPENDIX B COMPARATIVE RISK ASSESSMENT

Extent of Individuals' Personal Control Over Their Activities and Physical Environment			
Category 1	**Category 2**	**Category 3**	**Category 4**
"Voluntary"	Large Degree of Self-Control	Small Degree of Self-Control	"Involuntary"
Windsurfing	*Automobile*	*Public Transportation*	*Nuclear Power*



Cost Effectiveness of Other Mandated Safety Features

Automobile Safety	Aircraft Safety	House / Fire Safety
1. Steering Column Protection	4. Cabin Fire Protection	6. Unvented Space Heaters
2. Passive Restraints / Belts	5. Seat Cushion Flammability	7. Children's Sleepwear Flammability
3. Fuel System Integrity		8. Smoke Detectors
		9. Matches Safety Boxes

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APPENDIX C

COST ESTIMATES FOR RESIDENTIAL SPRINKLERS

Appendix C
Cost Estimates for Residential Sprinklers

The following report summarizes cost estimates for residential sprinklers. Note that the figures represent an overview of current practice and represent a range of use of copper, steel as well as plastic pipe for sprinkler lines.

There figures are included in costs from other sources to obtain the mean value and limiting values for sprinkler installation costs.

HELYAR

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Fax: 416/864-1668

April 19th, 1993

Larden Muniak Consulting Inc.
2490 Bloor Street West
Toronto, Ontario
M5C 1R4

Attention: Mr. J. Mallovy

Dear Sir,

Re: **<u>RESIDENTIAL SPRINKLER STUDY</u>**

We enclose a copy of our report for the C.M.H.C. Study on the cost effect of providing sprinklers in multi-unit residential buildings.

If you have any questions please contact the writer or Mr. Dennis Smith.

Yours truly,

HELYAR & ASSOCIATES

M.A. Barker, P.Q.S.
Vice President

REF: MS(93044)

C.M.H.C. STUDY ON THE COST EFFECT OF PROVIDING SPRINKLERS IN MULTI-UNIT RESIDENTIAL BUILDINGS

PURPOSE

Helyar & Associates have undertaken this study to provide realistic construction cost information for the provision of automatic sprinkler systems in multi-unit residential buildings.

In all provinces except British Columbia we have relied on current cost data for comparable building occupancies, ie: hotels. In British Columbia we have used cost data for multi-unit residential buildings.

In all cases the sprinkler system unit prices provided are in dollars per square foot of gross liveable area, and do not include parking areas, storage areas, meeting rooms, etc. Please refer to the price build-up for information on how the unit prices are developed.

A price based on gross liveable area was selected for the ease of application. As indicated in the price build-up provided, the costs for fire protection systems normally required in multi-unit residential are not included.

All construction costs provided are inclusive of trade mark-ups, general contractor overhead's and profits and provincial taxes. G.S.T. is not included.

ANALYSIS

We provide the following price build-up for two types of multi-unit residential buildings in the Toronto market.

Model #1 - High-rise Construction

We have based this Model on a 14 storey, reinforced concrete structure building with 145 apartment units. The total liveable area is 120,000 SF. A mix of one, two and three bedroom apartments has been allowed. It is assumed sidewall spray heads will be utilized where possible to reduce branch piping and bulkhead work. Furthermore, where practical, the architectural design will allow for provision of the least number of sprinkler heads ie: limited use of winding circulation space.

The three bedroom apartment used in this model has approximately 850 square feet of liveable area. It would require approximately 14 sprinkler heads for complete coverage. This includes provision of a sprinkler head in the storage/utility room but not the bedroom closets.

The two bedroom apartment used in this model has approximately 600 square feet of liveable area. It would require approximately 10 sprinkler heads.

In both cases there would be roughly one sprinkler head per 60 square feet of liveable area, based on light hazard coverage.

Circulation space would require approximately one sprinkler head per 100 square feet of area.

ANALYSIS (cont'd)

Model #1 - High-rise Construction (cont'd)

Generally circulation space is limited to approximately 15 percent of liveable area in multi-unit residential buildings.

Our analysis will be based on a blended cost per square foot of liveable area.

Calculation of Sprinklers to Liveable Space

Apartments:	85% of total area, 1 head/60 SF
Circulation:	15% of total area, 1 head/100 SF
Average:	100% of total area, 1 head/64 SF

or .015 heads per S.F. of liveable area

Cost Build-Up - High-rise - Toronto

	Item	Cost/SF
1)	SPRINKLERS .015 heads @ $90.00/head	$1.35
2)	BULKHEADS - PIPE FURRING	.30
3)	EXTRA-OVER COSTS FOR MECHANICAL - increased incoming fire water service - increased main header, BFP, etc. - increased main riser - increased fire pump size - increased diesel generator size	.25
4)	ELECTRICAL WIRING FOR ADDITIONAL ALARM AND TROUBLE ZONES & PANEL	.10
5)	ELECTRICAL CREDIT FOR HEAT DETECTOR	0.10
	TOTAL HIGH-RISE SPRINKLERS...	**$1.90**

ANALYSIS (cont'd)

Model #2 - Low-Rise Construction

For purposes of this analysis the size of the apartments is similar. The low rise apartment block model is as follows. A three storey wood frame building with thirty apartments. The total liveable area is 25,000 SF. The coverage for the sprinkler system would be the same. The number of sprinkler heads required in each unit would also be the same.

The only difference would be in the cost of construction. Low-rise work is slightly more economical due to the height. Low-rise combustible construction would require all construction spaces ie: attics, utility tunnels, crawl-spaces, etc., be sprinklered also.

For this analysis all construction spaces other than attics should be costed at 75% of the comparable liveable area rate. These areas would generally utilize an open grid distribution and would not require furring. Attic spaces should be costed at 50% of the comparable liveable area rate. While more difficult to install, attic sprinklers are typically extended upwards from the upper most liveable area sprinkler system distribution.

No credit for a heat detector has been included in the low rise residential cost build-up. Heat detectors are not presently required in this type of building. An example based on a one storey building of 20,000 SF with a full attic and a full crawlspace in the Toronto market is as follows.

Total Liveable Area	20,000 SF
Total Crawl Space (20,000 x .75 (75%))	15,000 SF
Total Attic Space (20,000 x .50 (50%))	10,000 SF
Total Area for Sprinkler Calculation	**45,000 SF**

Total Area - 45,000 SF x $1.90 (from table) = $85,500

CONCLUSION

The following table includes the total cost for providing sprinkler systems to both high-rise and low-rise multi-unit residential building for various construction centres in Canada. Included are current (1993) costs and approximate 1991 costs.

The budget costs provided are in dollars per square foot of liveable floor area. This is generally assumed to be all floor areas above grade, including circulation areas, but not including storage areas, utility rooms, machine rooms or parking.

These costs do not include or replace the cost of fire protection work presently required in high-rise construction hence are over and above these costs.

As indicated in the analysis section, we believe we have included for all new work necessary, any over sizing of previously required components and any credit for deletion of components no longer required, in the build-up of these unit prices.

COST OF SPRINKLER SYSTEMS IN VARIOUS GEOGRAPHIC CENTRES OF CANADA
COST PER SQUARE FOOT OF GROSS LIVEABLE AREA

LOCATION	HIGH-RISE RESIDENTIAL		LOW-RISE RESIDENTIAL	
	1991	1993	1991	1993
Halifax	1.95	1.95	1.95	1.95
Montreal	1.95	1.95	1.95	1.95
Toronto	1.90	1.90	1.90	1.90
Edmonton	2.40	2.45	2.35	2.40
Vancouver	2.35	2.40	2.30	2.35
Canada (Average)	2.10	2.15	2.10	2.15

- Above prices included Provincial Sales Tax where applicable
- Above prices do not include G.S.T.

APPENDIX D

REFERENCE BUILDINGS

Appendix D
Reference Buildings

The Building Code Assessment Framework contains a database of 21 Reference Buildings corresponding to building types representing approximately 85% of building construction across Canada during the 1980s. The database consists of complete construction drawings and specifications for each Reference Building.

The construction drawings and specifications are used to assist in measuring the construction and cost implications of changes to the Building Code as these may affect each building type.

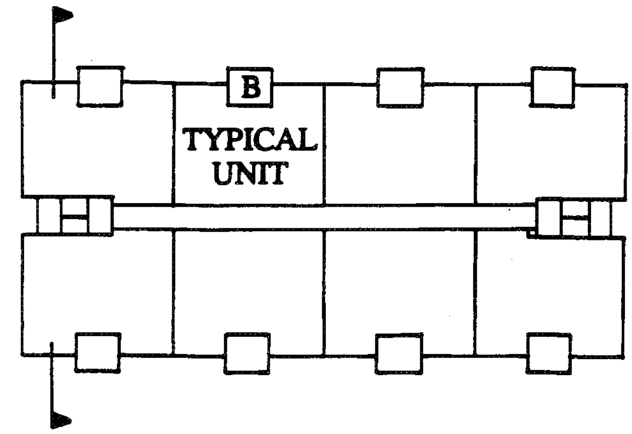
For purposes of this study the Reference Buildings representing low-rise and high-rise apartments were used by the Delphi Panel to appreciate the significance of changes in the Code and by Helyar Associates, Chartered Quantity Surveyors, in their estimate of sprinklering costs.

For reference, outline plans and sections for each of these buildings, taken from the Building Code Assessment Framework database, are included following these notes.

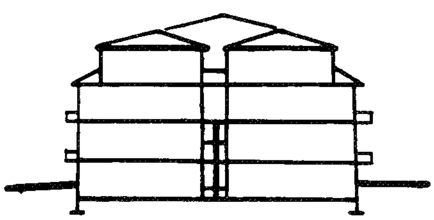
It is interesting to note that the average area per dwelling unit in the Reference Buildings, as compared to the statistical analysis of new construction across Canada in the period 1988-1991 inclusive is as follows:

	LOW RISE APARTMENT BUILDING	HIGH RISE APARTMENT BUILDING
• Reference building	1,004 sq. ft.	1,100 sq. ft.
• New construction statistics	1,012 sq. ft.	1,124 sq. ft.

The low-rise apartment building has 30 units on three floors; the high-rise apartment building has 137 units on fourteen floors.



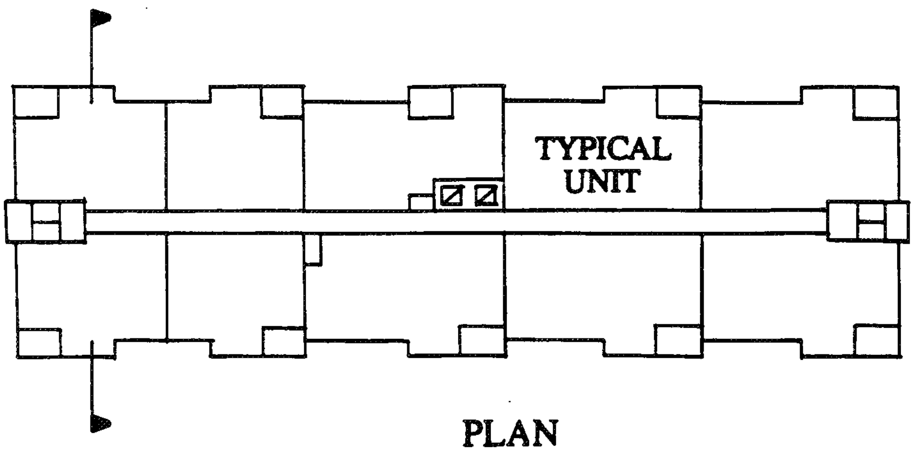
PLAN



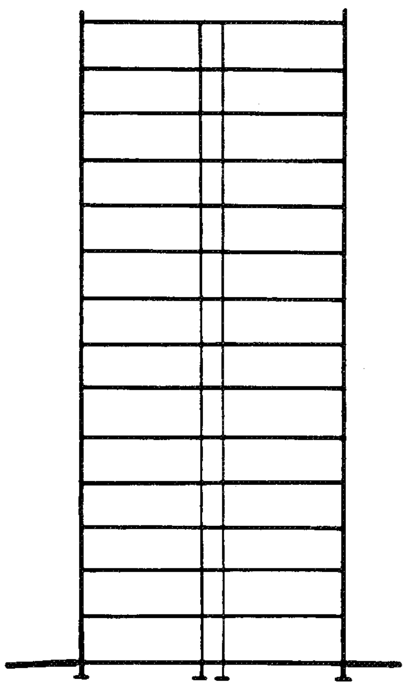
SECTION

MAIN FLOOR AREA 700m^2

project title BUILDING CODE ASSESSMENT FRAMEWORK		**sheet title** 3. APARTMENT BUILDING LOW-RISE	
no.	REFERENCE BUILDINGS		
Trow IBI GROUP		**scale** 0 5 10m	**sheet no.** 3
		date MARCH 1989	
		drawn by	



PLAN



SECTION

MAIN FLOOR AREA 975m²

project title	BUILDING CODE ASSESSMENT FRAMEWORK REFERENCE BUILDINGS
no.	
sheet title	4. APARTMENT BUILDING HIGH-RISE
scale	0 5 10m
date	MARCH 1989
drawn by	
sheet no.	4

Trow IBI GROUP

Hughes-Owens Geofilm

APPENDIX E

CANADIAN HOUSING AND FIRE STATISTICS 1988 - 1991:

MULTIPLE UNIT RESIDENTIAL BUILDINGS

Appendix E
Canadian Housing and Fire Statistics 1988-1991: Multiple Unit Residential Buildings

The following figures are organized by province. Statistics Canada provides consistent information for all provinces for number of units, population and inventory of stock by age.

Fire statistics, however, vary in level of detail depending upon the province. Because of changes in code requirement affecting fire safety, it is important to be able to examine risk levels for newer buildings and compare these with those of older buildings. Only B.C., Alberta and Manitoba break out fire statistics by high-rise and low-rise apartment buildings and age. From Quebec, we are able to get fire statistics by age of dwelling for all types of dwellings combined and for each high-rise and low-rise apartment building for all building ages combined.

The average of these numbers and estimates for the limiting value are applied to all provinces across Canada for purposes of the risk analysis.

A. STOCK AS OF 1990

(Source: Dwellings and Households, 93-311; Statistics Canada)

STRUCTURAL TYPE	NO. OF UNITS	% UNITS OF TOTAL STOCK
Apts. 5 storeys and over	810	N/A
Apts. less than 5 storeys	8,098	N/A
Total apts.	8,908	5
Single detached	133,130	76
Total Dwellings	174,495	100%

B. POPULATION

(Source: Dwellings and Households, 93-311; Statistics Canada)

STRUCTURAL TYPE	POPULATION	% OF POP. IN APTS.
Apts. 5 storeys and over	1,275	N/A
Apts. less than 5 storeys	21,865	N/A
Total apts.	23,140	4
Total population of province	568,474	100%

C. INVENTORY OF STOCK BY AGE OF BUILDING

(Source: Occupied Private Dwellings, 93-314; Statistics Canada, 1991)

STRUCTURAL TYPE	UP TO + 1970	1971 - 80	1981 - 90
Apts. 5 storeys and over	325	350	145
Apts. less than 5 storeys	3,885	2,273	1,859
Total apts.	4,210	2,623	2,004

Note: Table A totals are not equal to Table C totals as sources are different.

D. FIRE STATISTICS: 1988–91

Source: Fire Marshal's Office for the Province of Newfoundland

Structural Type: Under 5 Storeys

YEAR	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
1988	0	0	0	0
1989	3	2	1	25,000
1990	4	1	0	35,700
1991	3	0	0	4,700

A. STOCK AS OF 1990

(Source: Dwellings and Households, 93-311; Statistics Canada)

STRUCTURAL TYPE	NO. OF UNITS	% UNITS OF TOTAL STOCK
Apts. 5 storeys and over	35	N/A
Apts. less than 5 storeys	5,010	N/A
Total apts.	5,045	11
Single detached	32,475	73
Total Dwellings	44,475	100%

B. POPULATION

(Source: Dwellings and Households, 93-311; Statistics Canada)

STRUCTURAL TYPE	POPULATION	% OF POP. IN APTS.
Apts. 5 storeys and over	50	N/A
Apts. less than 5 storeys	10,520	N/A
Total apts.	10,570	8
Total population of province	129,765	100%

C. INVENTORY OF STOCK BY AGE OF BUILDING

(Source: Occupied Private Dwellings, 93-314; Statistics Canada, 1991)

STRUCTURAL TYPE	UP TO + 1970	1971 - 80	1981 - 90
Apts. 5 storeys and over	20	0	10
Apts. less than 5 storeys	2,482	1,058	1,403
Total apts.	2,502	1,058	1,413

Note: Table A totals are not equal to Table C totals as sources are different.

D. FIRE STATISTICS: 1988–91

Source: Fire Marshal's Office for the Province of Prince Edward Island

Structural Type: Apartment, Tenement, Flat

YEAR	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
1988	18	0	0	156,661
1989	41	3	0	123,009
1990	22	2	0	102,097
1991	12	0	0	204,855

A. STOCK AS OF 1990

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	NO. OF UNITS	% UNITS OF TOTAL STOCK
Apts. 5 storeys and over	12,095	N/A
Apts. less than 5 storeys	36,518	N/A
Total apts.	48,613	15
Single detached	219,630	68
Total Dwellings	324,375	100%

B. POPULATION

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	POPULATION	% OF POP. IN APTS.
Apts. 5 storeys and over	19,560	N/A
Apts. less than 5 storeys	80,340	N/A
Total apts.	99,900	11
Total population of province	899,942	100%

C. INVENTORY OF STOCK BY AGE OF BUILDING

(Source: Occupied Private Dwellings, 93-314; Statistics Canada, 1991)

STRUCTURAL TYPE	UP TO + 1970	1971 - 80	1981 - 90
Apts. 5 storeys and over	4,455	5,575	2,075
Apts. less than 5 storeys	20,028	7,289	8,630
Total apts.	24,483	12,864	10,705

Note: Table A totals are not equal to Table C totals as sources are different.

D. FIRE STATISTICS: 1988–91

Source: Fire Marshal's Office for the Province of Nova Scotia

Structural Type: Apartment, Tenement, Flat

YEAR	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
1988	105	2	21	992,611
1989	144	4	13	1,580,347
1990	127	5	17	962,796
1991	114	3	25	932,347

A. STOCK AS OF 1990

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	NO. OF UNITS	% UNITS OF TOTAL STOCK
Apts. 5 storeys and over	3,600	N/A
Apts. less than 5 storeys	27,727	N/A
Total apts.	31,327	12
Single detached	181,650	72
Total Dwellings	253,710	100%

B. POPULATION

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	POPULATION	% OF POP. IN APTS.
Apts. 5 storeys and over	5,290	N/A
Apts. less than 5 storeys	61,000	N/A
Total apts.	66,290	9
Total population of province	723,900	100%

C. INVENTORY OF STOCK BY AGE OF BUILDING

(Source: Occupied Private Dwellings, 93-314; Statistics Canada, 1991)

STRUCTURAL TYPE	UP TO + 1970	1971 - 80	1981 - 90
Apts. 5 storeys and over	1,050	2,120	380
Apts. less than 5 storeys	17,787	5,508	4,341
Total apts.	18,837	7,628	4,721

Note: Table A totals are not equal to Table C totals as sources are different.

D. FIRE STATISTICS: 1988–91

Source: Fire Marshal's Office for the Province of New Brunswick

Structural Type: Apartment, Townhouse

YEAR	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
1988	Not available	-	-	-
1989	91	24	43	891,347
1990	93	13	71	442,907
1991	111	11	40	1,252,122

PROVINCIAL PROFILE OF STOCK AND FIRE HISTORY Province: Quebec

A. STOCK AS OF 1990

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	NO. OF UNITS	% UNITS OF TOTAL STOCK
Apts. 5 storeys and over	137,105	N/A
Apts. less than 5 storeys	891,586	N/A
Total apts.	1,028,691	39
Single detached	1,175,085	45
Total Dwellings	2,634,300	100%

B. POPULATION

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	POPULATION	% OF POP. IN APTS.
Apts. 5 storeys and over	219,790	N/A
Apts. less than 5 storeys	1,961,490	N/A
Total apts.	2,181,280	32
Total population of province	6,895,963	100%

C. INVENTORY OF STOCK BY AGE OF BUILDING

Based on Stock as of 1990; Statistics Canada

STRUCTURAL TYPE	UP TO + 1970	1971 - 80	1981 - 90
Apts. 5 storeys and over	53,655	44,755	38,055
Apts. less than 5 storeys	570,002	149,406	172,469
Total apts.	623,657	194,161	210,524

Note: Table A totals are not equal to Table C totals as sources are different.

D. FIRE STATISTICS: 1988–91

Source: Fire Marshal's Office for the Province of Quebec

Structural Type: All Apartment Buildings

Year: 1988

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	984	SEE 1990	SEE 1990	25,805,697
1971 - 80	337			7,335,230
1981 - 90	185			3,932,819
Unknown	121			2,343,947
TOTAL	1,627			39,417,693

Year: 1989

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	946	SEE 1990	SEE 1990	25,692,275
1971 - 80	272			7,658,827
1981 - 90	137			1,875,262
Unknown	95			1,354,110
TOTAL	1,450			36,580,474

Year: 1990

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS*	NO. OF INJURIES*	$ LOSS
Up to and including 1970	896	69	623	26,743,580
"Average casualty/year"		13.8	124.6	
1971 - 80	237	5	157	4,254,334
"Average casualty/year"		1	31.4	
1981 - 90	129	4	54	2,201,430
"Average casualty/year"		0.8	10.8	
Unknown	88	10	49	3,800,168
"Average casualty/year"		2	9.8	
TOTAL	1,350	88	883	36,999,512

* Based on 5 year totals: 1987–91

PROVINCIAL PROFILE OF STOCK AND FIRE HISTORY	Province: Quebec

Year: 1991

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	769	SEE 1990	SEE 1990	20,569,398
1971 - 80	246			4,222,948
1981 - 90	110			1,405,697
Unknown	95			2,413,608
TOTAL	1,220			28,611,651

A. STOCK AS OF 1990

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	NO. OF UNITS	% UNITS OF TOTAL STOCK
Apts. 5 storeys and over	595,385	N/A
Apts. less than 5 storeys	284,116	N/A
Total apts.	879,501	25
Single detached	2,094,970	58
Total Dwellings	3,638,365	100%

B. POPULATION

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	POPULATION	% OF POP. IN APTS.
Apts. 5 storeys and over	1,131,820	N/A
Apts. less than 5 storeys	710,290	N/A
Total apts.	1,842,110	18
Total population of province	10,084,885	100%

C. INVENTORY OF STOCK BY AGE OF BUILDING

(Source: Occupied Private Dwellings, 93-314; Statistics Canada, 1991)

STRUCTURAL TYPE	UP TO + 1970	1971 - 80	1981 - 90
Apts. 5 storeys and over	260,145	213,355	118,290
Apts. less than 5 storeys	170,238	68,598	47,514
Total apts.	430,383	281,953	165,804

Note: Table A totals are not equal to Table C totals as sources are different.

D. FIRE STATISTICS: 1988–91

Source: Fire Marshal's Office for the Province of Ontario

Structural Type: 5 Storeys and over

YEAR	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
1988	1,396	7	193	6,069,107
1989	1,292	8	164	6,201,898
1990	1,367	9	222	9,836,763
1991	1,324	8	192	6,913,854

Structural Type: Under 5 Storeys

YEAR	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
1988	570	11	97	8,338,791
1989	557	11	110	4,653,576
1990	587	5	116	8,815,381
1991	524	5	111	11,794,493

A. STOCK AS OF 1990

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	NO. OF UNITS	% UNITS OF TOTAL STOCK
Apts. 5 storeys and over	35,675	N/A
Apts. less than 5 storeys	43,080	N/A
Total apts.	78,755	19
Single detached	275,915	68
Total Dwellings	405,120	100%

B. POPULATION

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	POPULATION	% OF POP. IN APTS.
Apts. 5 storeys and over	53,105	N/A
Apts. less than 5 storeys	90,470	N/A
Total apts.	143,575	13
Total population of province	1,091,942	100%

C. INVENTORY OF STOCK BY AGE OF BUILDING

(Source: Occupied Private Dwellings, 93-314; Statistics Canada, 1991)

STRUCTURAL TYPE	UP TO + 1970	1971 - 80	1981 - 90
Apts. 5 storeys and over	13,120	14,265	8,230
Apts. less than 5 storeys	23,335	12,478	7,035
Total apts.	36,455	26,743	15,265

Note: Table A totals are not equal to Table C totals as sources are different.

D. FIRE STATISTICS: 1988-91

Source: Fire Marshal's Office for the Province of Manitoba

Structural Type: 5 Storeys and over

Year: 1988

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	32	0	4	196,552
1971 - 80	27	1	3	391,450
1981 - 90	12	0	5	30,800
Unknown	9	0	0	23,700
TOTAL	80	1	12	642,502

Year: 1989

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	20	0	6	550,490
1971 - 80	41	1	3	90,504
1981 - 90	14	0	4	177,200
Unknown	12	0	4	72,149
TOTAL	87	1	17	890,343

Year: 1990

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	23	1	2	243,875
1971 - 80	38	0	5	92,300
1981 - 90	9	0	0	2,000,500
Unknown	12	0	1	49,988
TOTAL	82	1	8	2,386,663

Year: 1991

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	32	0	4	39,050
1971 - 80	33	1	2	129,665
1981 - 90	16	0	0	687,550
Unknown	15	0	4	120,114
TOTAL	96	1	10	976,379

D. FIRE STATISTICS: 1988–91

(Source: Fire Marshall's Office for the Province of Manitoba)

Structural Type: Under 5 Storeys

Year: 1988

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	108	1	31	1,623,885
1971 - 80	18	0	4	581,812
1981 - 90	4	0	0	30,500
Unknown	55	0	8	635,423
TOTAL	185	1	43	2,871,620

Year: 1989

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	70	0	14	1,068,617
1971 - 80	13	0	3	38,950
1981 - 90	6	0	0	6,450
Unknown	55	0	11	600,249
TOTAL	144	0	28	1,714,266

Year: 1990

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	69	0	12	529,736
1971 - 80	6	0	1	81,700
1981 - 90	5	0	1	12,350
Unknown	57	0	9	441,814
TOTAL	137	0	23	1,065,600

Year: 1991

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	52	0	8	161,845
1971 - 80	10	0	0	59,374
1981 - 90	6	0	0	158,680
Unknown	57	0	7	255,612
TOTAL	125	0	15	635,511

A. STOCK AS OF 1990

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	NO. OF UNITS	% UNITS OF TOTAL STOCK
Apts. 5 storeys and over	10,085	N/A
Apts. less than 5 storeys	35,742	N/A
Total apts.	45,827	13
Single detached	275,935	76
Total Dwellings	363,150	100%

B. POPULATION

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	POPULATION	% OF POP. IN APTS.
Apts. 5 storeys and over	13,235	N/A
Apts. less than 5 storeys	67,910	N/A
Total apts.	81,145	8
Total population of province	1,009,613	100%

C. INVENTORY OF STOCK BY AGE OF BUILDING

(Source: Occupied Private Dwellings, 93-314; Statistics Canada, 1991)

STRUCTURAL TYPE	UP TO + 1970	1971 - 80	1981 - 90
Apts. 5 storeys and over	2,515	3,980	3,660
Apts. less than 5 storeys	16,035	10,192	9,725
Total apts.	18,550	14,172	13,385

Note: Table A totals are not equal to Table C totals as sources are different.

D. FIRE STATISTICS: 1988–91

Source: Fire Marshal's Office for the Province of Saskatchewan

Structural Type: All Apartment Buildings

YEAR	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
1988	Not available	-	-	-
1989	Not available	-	-	-
1990	39	1	4	619,970
1991	62	1	10	544,384

A. STOCK AS OF 1990

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	NO. OF UNITS	% UNITS OF TOTAL STOCK
Apts. 5 storeys and over	45,635	N/A
Apts. less than 5 storeys	104,527	N/A
Total apts.	150,162	16
Single detached	569,430	63
Total Dwellings	**910,390**	**100%**

B. POPULATION

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	POPULATION	% OF POP. IN APTS.
Apts. 5 storeys and over	67,475	N/A
Apts. less than 5 storeys	229,960	N/A
Total apts.	297,435	13
Total population of province	2,365,825	100%

C. INVENTORY OF STOCK BY AGE OF BUILDING

Based on Stock as of 1990; Statistics Canada

STRUCTURAL TYPE	UP TO + 1970	1971 - 80	1981 - 90
Apts. 5 storeys and over	15,755	19,405	10,430
Apts. less than 5 storeys	38,403	43,314	23,128
Total apts.	54,158	62,719	33,558

Note: Table A totals are not equal to Table C totals as sources are different.

D. FIRE STATISTICS: 1988–91

Source: Fire Marshal's Office for the Province of Alberta

Structural Type: 5 Storeys and over

Year: 1988

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	28	1	6	218,951
1971 - 80	31	0	3	94,598
1981 - 90	6	0	2	31,716
Unknown	7	0	3	71,566
TOTAL	72	1	14	416,831

Year: 1989

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	33	1	37	3,551,593
1971 - 80	37	0	21	265,657
1981 - 90	6	0	0	9,607
Unknown	9	0	2	17,679
TOTAL	85	1	60	3,844,536

Year: 1990

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	40	2	13	371,263
1971 - 80	33	1	4	484,860
1981 - 90	4	0	0	8,250
Unknown	6	0	2	5,187
TOTAL	83	3	19	869,560

Year: 1991

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	22	1	14	453,226
1971 - 80	29	0	1	84,069
1981 - 90	6	0	2	20,162
Unknown	10	0	1	122,807
TOTAL	67	1	18	680,264

D. FIRE STATISTICS: 1988–91

Source: Fire Marshal's Office for the Province of Alberta

Structural Type: Under 5 Storeys

Year: 1988

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	78	1	6	427,358
1971 - 80	84	0	13	942,739
1981 - 90	13	0	1	86,958
Unknown	14	1	6	50,519
TOTAL	189	2	26	1,507,574

Year: 1989

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	92	1	24	1,131,021
1971 - 80	72	0	8	441,651
1981 - 90	16	0	3	233,603
Unknown	27	0	11	330,524
TOTAL	207	1	46	2,136,799

Year: 1990

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	82	3	22	2,146,970
1971 - 80	70	0	23	2,230,800
1981 - 90	13	0	1	2,134,228
Unknown	18	0	1	68,633
TOTAL	183	3	47	6,580,631

Year: 1991

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	70	1	11	1,006,349
1971 - 80	82	1	18	5,330,600
1981 - 90	23	1	1	115,289
Unknown	20	0	2	121,197
TOTAL	195	3	32	6,573,435

A. STOCK AS OF 1990

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	NO. OF UNITS	% UNITS OF TOTAL STOCK
Apts. 5 storeys and over	69,060	N/A
Apts. less than 5 storeys	191,998	N/A
Total apts.	261,058	21
Single detached	728,745	59
Total Dwellings	1,243,895	100%

B. POPULATION

(Source: Dwellings and Households, 93-311; Statistics Canada, 1991)

STRUCTURAL TYPE	POPULATION	% OF POP. IN APTS.
Apts. 5 storeys and over	101,585	N/A
Apts. less than 5 storeys	403,195	N/A
Total apts.	504,780	18
Total population of province	2,883,367	100%

C. INVENTORY OF STOCK BY AGE OF BUILDING

Based on Stock as of 1990; Statistics Canada

STRUCTURAL TYPE	UP TO + 1970	1971 - 80	1981 - 90
Apts. 5 storeys and over	29,700	23,260	15,665
Apts. less than 5 storeys	80,750	56,746	52,039
Total apts.	110,450	80,006	67,704

Note: Table A are not equal to Table C totals as sources are different.

D. FIRE STATISTICS: 1988–91

(Source: Fire Marshall's Office for the Province of British Columbia)

Structural Type: 5 Storeys and over

Year: 1988

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	17	0	2	14,719
1971 - 80	9	1	2	63,486
1981 - 90	6	0	1	25,500
Unknown	19	0	4	58,320
TOTAL	51	1	9	162,025

Year: 1989

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	29	0	10	319,497
1971 - 80	7	0	0	36,832
1981 - 90	5	0	1	31,503
Unknown	12	0	0	49,549
TOTAL	53	0	11	437,381

Year: 1990

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	30	0	10	132,367
1971 - 80	16	0	2	120,615
1981 - 90	13	0	2	72,440
Unknown	14	0	2	64,274
TOTAL	73	0	16	389,696

Year: 1991

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	16	0	6	127,920
1971 - 80	8	0	1	153,770
1981 - 90	5	0	1	28,197
Unknown	16	0	2	64,888
TOTAL	45	0	10	374,775

D. FIRE STATISTICS: 1988–91

(Source: Fire Marshall's Office for the Province of British Columbia)

Structural Type: Under 5 Storeys

Year: 1988

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	94	0	14	2,219,858
1971 - 80	56	2	11	544,033
1981 - 90	23	0	3	369,447
Unknown	93	0	15	3,018,790
TOTAL	266	2	43	6,152,128

Year: 1989

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	80	0	10	639,479
1971 - 80	54	1	8	1,420,824
1981 - 90	28	1	6	1,825,775
Unknown	80	1	5	840,313
TOTAL	242	3	29	4,726,391

Year: 1990

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	95	0	20	3,859,918
1971 - 80	51	1	21	1,617,678
1981 - 90	28	1	4	460,374
Unknown	90	0	13	1,557,789
TOTAL	264	2	58	7,495,759

Year: 1991

AGE OF STOCK	NO. OF FIRES	NO. OF DEATHS	NO. OF INJURIES	$ LOSS
Up to and including 1970	58	1	11	938,774
1971 - 80	63	1	21	857,930
1981 - 90	42	0	6	872,478
Unknown	91	1	10	2,590,858
TOTAL	254	3	48	5,260,040

APPENDIX F

DELPHI PANEL MEMBERS

Appendix F
Delphi Panel Members

The following highlights the relevant expertise of the Delphi Panel members who have participated on this study. About two thirds of the Panel members have expertise in the fields of building and fire code development and in fire protection engineering and research. The remaining participants have extensive experience in fire prevention and/or firefighting.

Graham Adams, Adams Consulting Services Inc., 110 Eglinton Avenue East, Toronto, Ontario, M4P 2Y1

Graham Adams, Principal of Graham Adams Consulting Services Inc. is an architect and community planner with extensive experience as a manager and advisor on building codes and industry standards at the provincial and national levels. He is presently a member of Part 9 Building Committee and the Canadian Construction Research Board.

Randal Brown, Randal Brown and Associates, Suite #105, 6 Lansing Square, Willowdale, Ontario, M2J 1T5

Randal Brown has a Bachelor of Science degree in Fire Protection and Safety Engineering and has been employed in the fire protection engineering field since 1976. Mr. Brown has been a principal of Randal Brown and Associates Limited, Fire Protection Engineers, since 1984. Mr. Brown has been a member of various committees on fire safety including the NFPA Foam Water and Sprinkler Committee and the ULC Committee on Fire Alarm Equipment and Systems, and is currently the Canadian representative on the SFPE Architectural and Building code Liaison Committee.

Harry Caulfield, Alberta Labour, 207-4920 - 51st Street, Edmonton, Alberta, T4N 6K8

Harry Caulfield is the Central Director for Alberta Labour. He has extensive experience in fire safety including 12 years as Deputy Fire Commissioner. He has also worked as a City of Calgary firefighter, technical systems officer, regional supervisor and director.

William G. Burton, City of Winnipeg Fire Department, 5th Floor, Public Safety Building, 151 Princess Street, Winnipeg, Manitoba, R3B 1L1

Bill Burton is the Director of Fire Prevention for the City of Winnipeg Fire Department. He has over 17 years of firefighting experience and for the past four years has worked as a fire prevention officer with the City.

A.W. Tony Chow, City of Etobicoke Building Department, Etobicoke City Hall, 399 The West Mall, Etobicoke, Ontario, M9C 2Y2

Tony Chow has been the Building Commissioner with the City of Etobicoke, Ontario since 1985. Mr. Chow was the Assistant Chief of Technical Research and Consulting Services with the Ontario Fire Marshal's Office between 1977 and 1985. In addition to the 30 years of experience in the building and construction fields, Mr. Chow has been involved in advisory committees with the Canadian Standards Association, Ontario building code and the Ontario Fire Code.

Bruce Clemensen, Clemensen & Associates Ltd., 17 Oakland Avenue, Weston, Ontario, M9M 2H9

Bruce Clemensen, Principal of Clemensen and Associates Limited, is a member of the Executive Committee of the Canadian Commission on Building and Fire Codes and Chairman of the Technical Research Committee of the CHBA.

Peter Colquhoun, Arencon Inc., 1401 Captain Court, Mississauga, Ontario, L5J 1A9

Peter Colquhoun has been practising architecture since 1973. since 1986 he has worked as a building code consultant and established his own practice in building code and fire safety consulting in 1992.

Walter Miller, Arencon Inc., 1401 Captain Court, Mississauga, Ontario, L5J 1A9

W.G. Miller, Principal of Arencon Inc. has been involved with the building and fire safety industry for over 30 years. His experience includes contracting, manufacturing and consulting for the industry.

Chris Fillingham, Dunlop Farrow Architects, 450 Front Street West, Toronto, Ontario, M5V 1B6

Chris Fillingham has been a partner with Dunlop Farrow Architects since 1983. Mr. Fillingham's expertise includes involvement with building code development on the Provincial and National levels as well as the technical committees of the homebuilding associations. He has also coauthored a number of technical papers relating to the building code and high rise residential buildings.

John Frye, Plan Examination Branch, City of Winnipeg, 395 Main Street, Winnipeg, Manitoba, R3B 3E1

John Frye is the Superintendent of Plan Examination with the City of Winnipeg. He participated on numerous professional committees including the Automatic Sprinkler System Task Group of the Building Standards Board and Fire Advisory Council of Manitoba. He has also published various papers on building and fire safety.

Syl Allard, City of Sault Ste. Marie, 99 Foster Drive, Civic Centre - Building Department, Sault Ste. Marie, Ontario, P6A 5N1

Syl Allard has been a Senior Plans Examiner with the City of Sault Ste. Marie since 1984. Prior to 1984, Mr. Allard worked as a Senior Architectural Technologist and Plans Examiner with the City of Elliot Lake.

Harold Locke, 811 Beach Avenue, Suite 309, Vancouver, British Columbia, V6Z 2B5

Harold Locke, Principal and President of Locke MacKinnon Domingo Gibson & Associates Ltd., specializes in fire protection systems and building code analysis. Mr. Locke has experience in all aspects of fire testing of building materials, the development and application of life safety codes. He has current committee memberships on ASTM E-5 on Fire Standards, ULC on Fire Standards, ACNBC on Fire Performance of Building Materials, among others.

Sarah Maman, Gerling Global General Insurance Co., 480 University Avenue, Toronto, Ontario, M5G 1V6

Sarah Maman is Assistant Vice President of the Loss Prevention Department at Gerling Global General Insurance. Her past experience includes working as a special risk representative with the Insurance Advisory Organization, a loss control engineer with Reed Stenhouse and a Fire Protection Engineer and Building Code Consultant with Rolf Jensen and Associates. Ms Maman was an Assistant Director of Fire Research with the Canadian Wood Council.

Dennis Beacham, Manitoba Labour, Suite #510, 401 York Street, Winnipeg, Manitoba, R3C 0P8

Dennis Beacham is a Codes and Standards Engineer with the City of Winnipeg, Fire Commissioner's Office. For the past 18 years, Mr. Beacham has been involved with the development and application of building and fire codes.

Jim Mehaffey, Forintek Canada, 800 Montreal Road, Ottawa, Ontario, K1G 3Z5

Jim Mehaffey is a Fire Research Scientist with the Eastern Laboratory of Forintek Canada Corp. Dr. Mehaffey worked between 1980 and 1987 as a Research Officer with the National Fire Laboratory and the National Research Council. Dr. Mehaffey is presently the Vice Chairman of the ASTM committee on fire standards, member of several task groups reporting to the ULC and member of the Canadian Advisory Committee on Fire Tests on Building Material.

Don Pilling, Edmonton Fire Department, #2 Fire Hall, 10221 - 107th Street, Edmonton, Alberta, T5J 1K1

Don Pilling is a Fire Protection Engineer with the City of Edmonton Fire Department. His work involves plan and building inspections, and the inspection of large loss fires. Mr. Pilling also provides technical expertise in all aspects of fire department operations.

Les McMillan, City of Calgary Fire Department, 4124 - 11th Street SE, Calgary, Alberta, T2G 3H2

Les McMillan joined the City of Calgary Fire Department as an active firefighter in 1963. In 1970, he transferred into the Fire Prevention Bureau and held various positions prior to becoming the Fire Marshal of the Calgary Fire Department.

Jonathan Rubes, Leber/Rubes Inc., 34 Ross Street, Toronto, Ontario, M5T 1Z9

Jonathan Rubes is President of Leber/Rubes Inc. and has over 15 years of fire protection and building code consulting experience. Mr. Rubes is Chairman of the National Fire Code of Canada Standing Committee on Fire Safety in Buildings. Mr. Rubes is also a member of the Canadian Commission on Building and Fire Codes.

Larry Spiess, Sherwood Park Fire Department, 1933 Sherwood Avenue, Sherwood Park, Alberta, T8A 3R3

Larry Spiess is the Fire Marshal of Strathcona's Emergency Services. He is responsible for the inspections, investigations and public education branch of the emergency services. Mr. Spiess has over 20 years experience in fire prevention.

Bill Sproule, 33 Elmhurst Avenue, Suite 609, Willowdale, Ontario, M2N 6G8

Bill Sproule has worked for 35 years in fire prevention with the City of Toronto Fire Department. He has recently retired as Deputy Chief of Fire Prevention and has been a Director with both the Canadian Fire Safety Association and the Society of Fire Protection Engineers. He is presently a member of the NBC Standing Committee on Occupancy and Chairman of the ULC Fire Alarm Committee.

Andrew Zdanowicz, 3 Tullis Drive, Toronto, Ontario, M4S 2E2

Andrew Zdanowicz is the Director of Customer and Departmental Services of the Building Department, City of Scarborough. Mr. Zdanowicz also worked as the Manager of Research and development with the Ontario Ministry of Housing for 10 years. He also carried out research related to smoke alarms with the Ontario Housing Corporation.

Carroll Kimball, Office of the Fire Marshall, P.O. Box 6000, Fredericton, New Brunswick, E3B 5H1

Carroll Kimball is the Manager of Regional Services, Office of New Brunswick Fire Marshal. For the past 19 years with the Fire Marshal's Office, Mr. Kimball has been dealing with inspections and building plan reviews. Mr. Kimball served on the Part 4 Committee of the National Fire Code of Canada from 1980 to 1990 and is presently a member of the Standing Committee on Fire Protection on Part 3 of the NBC.

Dorel Feldman, Concordia University, Centre for Building Studies, 1455 Des Maisonneuve West, Montreal, Quebec, H3G 1M8

Dorel Feldman has been with the Centre for Building Studies at Concordia University since 1978. Dr. Feldman is Manager of Polymerization Department of the research institute of macromelecular chemistry. He is also a professor of polymer chemistry and presents a course on smoke spread and control in buildings.

Don Livingston, Code Development Section, Ontario Ministry of Housing, 777 Bay Street, Toronto, Ontario, M5G 2E5

Don Livingston is a Senior Building Code Advisor with the Ontario Ministry of Housing, Buildings Branch. Mr. Livingston has participated on various committees on building fire safety and code development.

APPENDIX G

BACKGROUND INFORMATION FOR DELPHI PANEL

Appendix G - Background Information for Delphi Panel

PURPOSE OF STUDY

The purpose of this study is to assess the feasibility, from a societal point of view, of mandating automatic fire sprinklers in new multiple unit residential buildings. These buildings include elevator apartments and walk-up apartments falling within the scope of Part 9 of the National Building Code (NBC). This study will also serve as input to decisions being made by the Institute for Research in Construction and the Building Code Branch of the Ontario Ministry of Housing in modifying the NBC and the Ontario Building Code (OBC).

ANALYSIS PROCEDURES

The analysis will follow procedures and will use software developed by IBI Group for the Building Code Assessment Framework, prepared for the Buildings Branch, Ontario Ministry of Housing. The approach to analysis is based on the premise that society has limited funds to invest in reducing risk of death, injury and property damage from a wide variety of hazards, including fires. By its actions with respect to other investments to reduce risks, society has implied that there are limits to which it is willing to invest in reducing existing risks. These limits have been estimated and are an integral part of the Building Code Assessment Framework database.

DELPHI APPROACH

The Delphi approach is mainly concerned with the utilization of experts' opinions in a structured communication process which ensures a high degree of anonymity for individual responses.

The Delphi approach has been used in risk estimation as part of the Building Code Assessment Framework. Delphi panel findings helped evaluate proposed changes to the 1990 Ontario Building Code.

The panel consists of 25-30 experts who will review the base case fire risk trees for high rise and low rise buildings as developed earlier for the Building Code Assessment Framework. Each panel member will estimate the probability of fire events assuming:

1. provision of fully functioning hard-wired smoke detectors (with a reliability of 97%) with no sprinklers (except in those areas of the building where required by NBC); and

2. provision of fully functioning hard-wired smoke detectors (with a reliability of 97%) and automatic sprinklers.

It is estimated that for the Base Case for each building type, 66 to

It is estimated that for the Base Case for each building type, 66 to 75% of the dwelling units have operating smoke detectors. This assumes a mix of battery operated and hard-wired smoke detectors.

A statistical analysis of the estimates will then be carried out, and additional iterations may be necessary to achieve acceptable consensus among panel members.

TYPICAL REFERENCE BUILDINGS

As part of the Building Code Assessment Framework, typical reference buildings have been selected based on their representation of new Canadian building construction and susceptibility to fire hazards. Two reference buildings are briefly described below in the hope that this will assist members of the Delphi panel in visualizing scenarios more easily, and in estimating fire event probabilities for the two assumptions A and B described above, for each of the two single use building types.

LOW RISE APARTMENT BUILDING

A three and a half (3½) storey wood frame walk-up apartment building with a total building area of approximately 3,000 m² (750 m² typical floor area), and of typical combustible construction with rated wood joist floors and roof. Each floor has eight (8) units along a double-loaded corridor with exit stair on each end.

HIGH RISE APARTMENT BUILDING

A fourteen (14) storey apartment building of a total building area of approximately 14,400 m² (1,000 m² typical floor area), and of typical non-combustible poured concrete construction. There are ten (10) units per floor with smoke alarms and heat detectors in units and corridors. (Experience with the Ontario Housing Corporation housing indicates a reliability of 97% for wired-in smoke alarms.) Service spaces and public areas (laundry room, exercise room, lobby) are sprinklered.

BASE CASE FIRE RISK TREES

Exhibits 1 and 2 (see Delphi Panel Questionnaire) present fire risk trees for a low rise building and a high rise building respectively. Base case probabilities were developed earlier for the Building Code Assessment Framework.

Events leading to a certain consequence are organized as branches which in turn form a tree structure. Parallel branches on the tree represent mutually independent events and each branch is assigned a probability. The percent figure at each of the end branches on the right hand side of the risk tree exhibits represents the probability of that consequence occurring along the complete path in question; ie.

- the percent probability of death (civilians and fire fighers)
- the percent probability of fire fighter injury
- the percent probability of civilian injury
- the percent probability of **major** property damage.

The sum of probabilities of any two parallel branches starting from the same node is equal to 1 (or 100%). The sum of probabilities of any four end branches, dealing with the exposure-leading-to-consequence, is **not** necessarily equal to 1 (or 100%).

DEFINITION OF FIRE EVENTS

The first branch of the tree deals with the probability of ignition as the starting point of the fire in a compartment. This probability is derived from statistics and is not to be estimated by the panel members.

The second set of branches are concerned with the progress of fire (within the area of origin), after ignition. Two mutually exclusive events are defined and considered for purposes of risk analysis (as with all other branches); the fire may remain in the pre-flashover stage or progress to post-flashover.

Given that the fire does not progress beyond pre-flashover, the tree structure considers the possibility of manual or automatic extinguishment (certain building areas will have sprinklers as required by code). Occupant and/or fire fighter injuries may result from exposure to such conditions, and even death in some cases due to smoke inhalation and/or burns. Property damage to building elements and components may also result from these paths.

If the fire progresses to the post-flashover stage, it can either remain confined to the compartment of origin, or spread by convection or destruction (assuming either a predominantly convective or a predominantly destructive spread). Furthermore, this spread may result in smoke only or in fire and smoke in the areas it occurs in.

Spread is assumed to occur to either of two zones: means of egress or adjacent compartments/buildings. Therefore, any building may be schematically described as having three zones: compartment of origin, means of egress, and adjacent compartments and buildings.

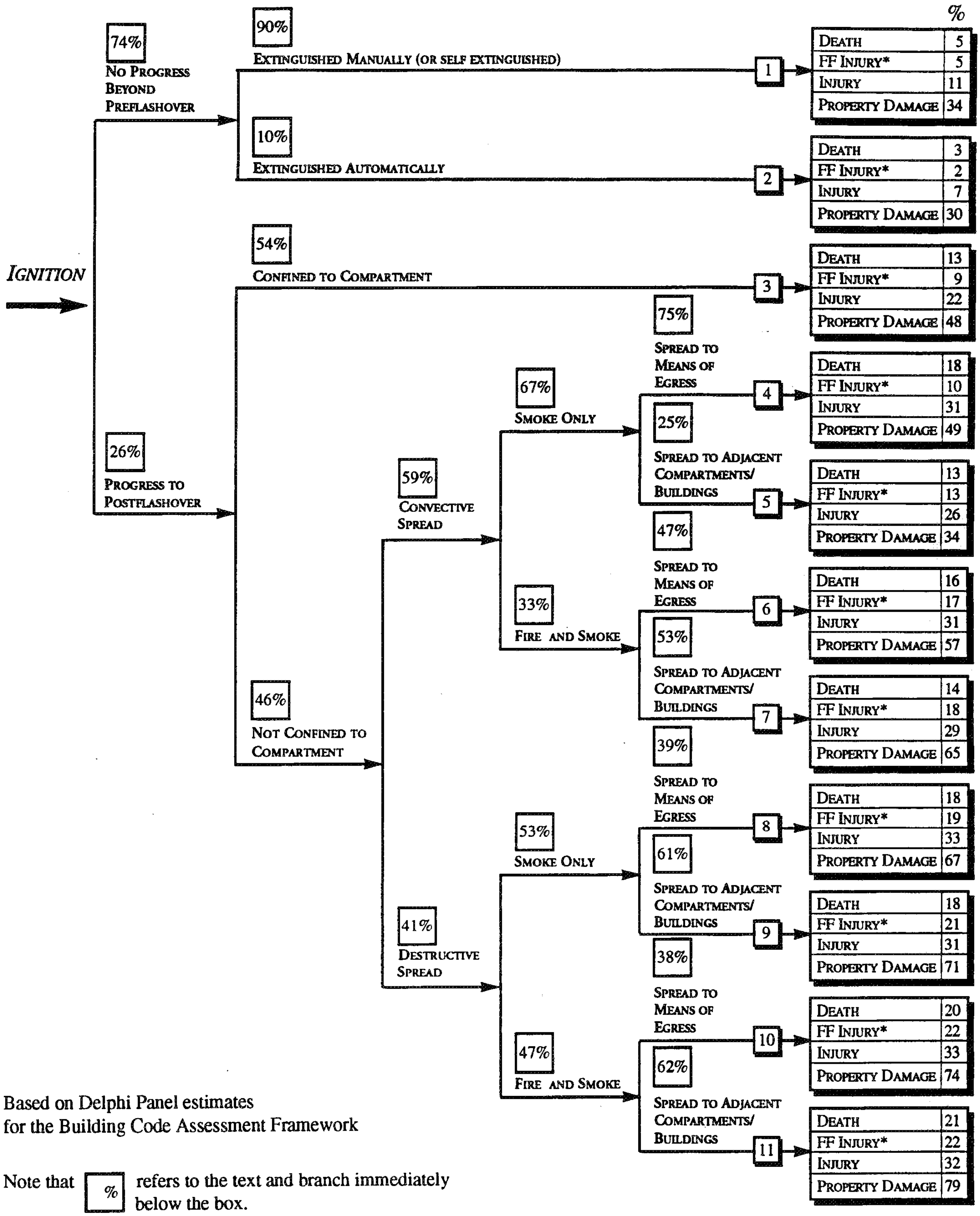
All paths in the fire risk tree lead to four consequences: deaths, civilian injuries, fire fighter injuries and property damage.

EXHIBIT 1

FIRE RISK ANALYSIS TREE

BASE CASE PROBABILITY FOR A LOW RISE APARTMENT BUILDING

(66% - 75% of the units have functioning smoke detectors)



Based on Delphi Panel estimates for the Building Code Assessment Framework

Note that [%] refers to the text and branch immediately below the box.

* FIREFIGHTER INJURY

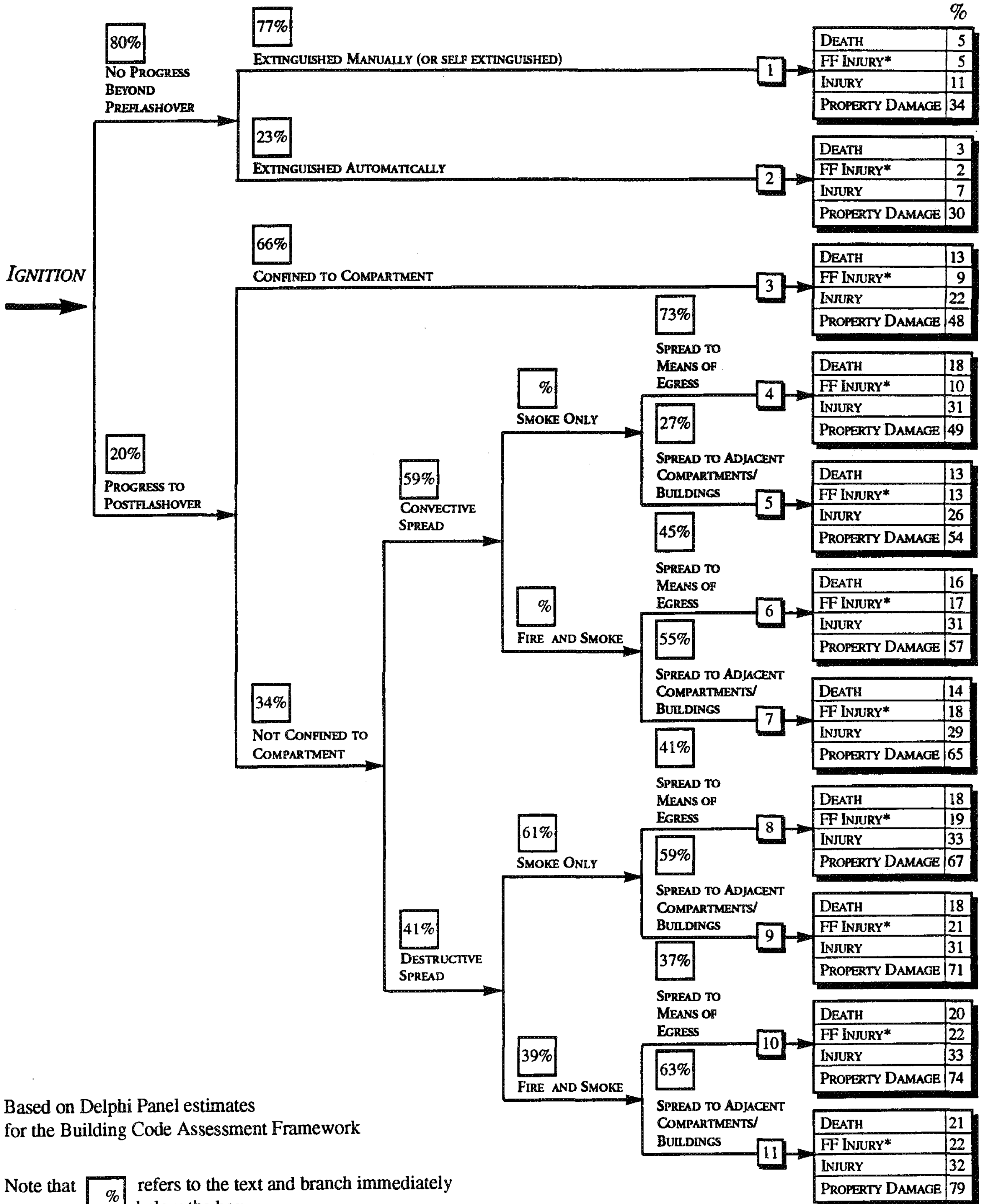
IBI GROUP

EXHIBIT 2

FIRE RISK ANALYSIS TREE

BASE CASE PROBABILITY FOR A HIGH RISE APARTMENT BUILDING

(66% - 75% of the units have functioning smoke detectors)



Based on Delphi Panel estimates
for the Building Code Assessment Framework

Note that [%] refers to the text and branch immediately below the box.

* FIREFIGHTER INJURY

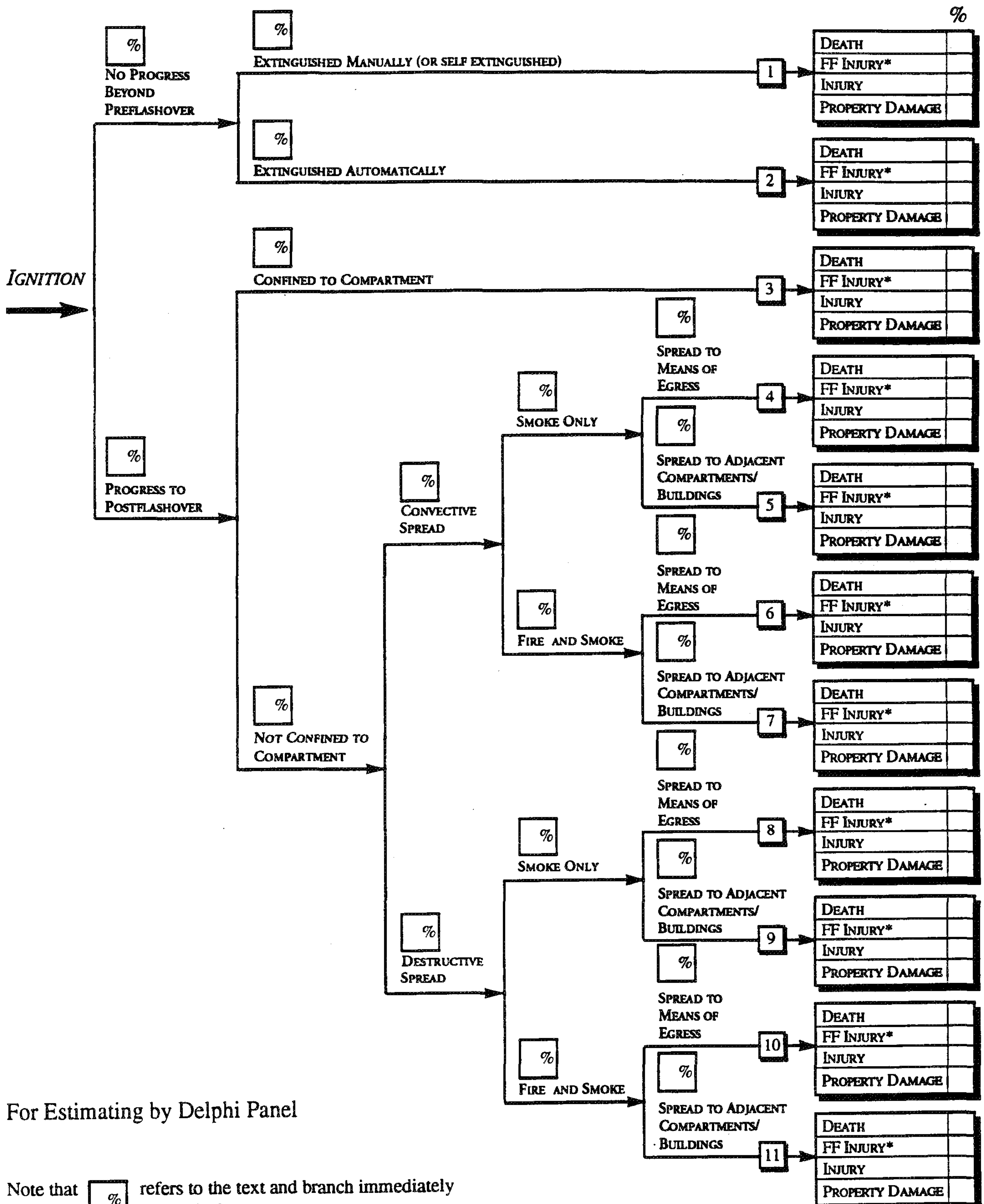
IBI GROUP

EXHIBIT 3

FIRE RISK ANALYSIS TREE

NEW PROBABILITIES FOR A LOW RISE APARTMENT BUILDING

ASSUME: PROVISION OF FULLY FUNCTIONING HARD-WIRED SMOKE ALARMS AND NO SPRINKLERS



For Estimating by Delphi Panel

Note that [%] refers to the text and branch immediately below the box.

* Firefighter Injury

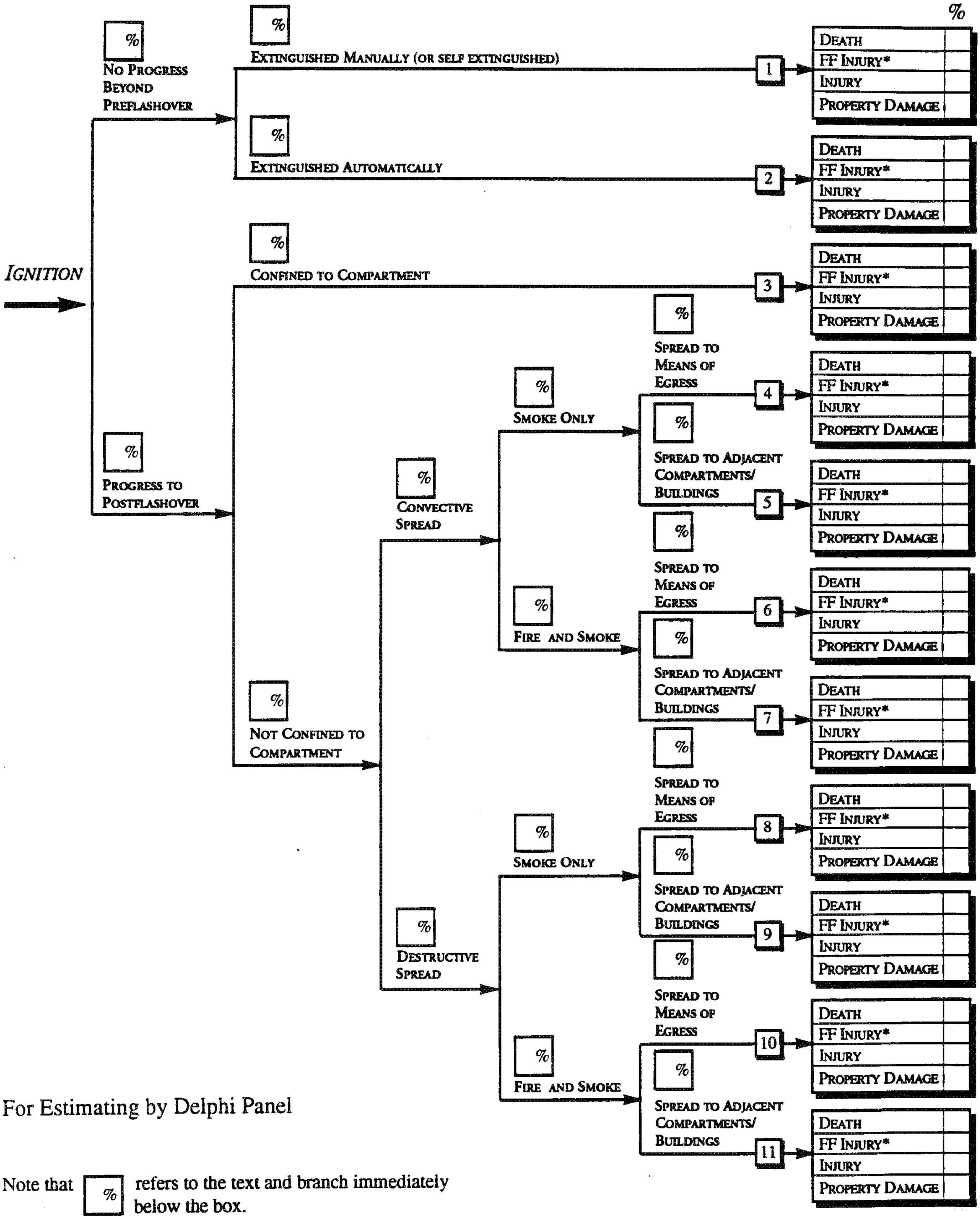
IBI GROUP

EXHIBIT 4

FIRE RISK ANALYSIS TREE

NEW PROBABILITIES FOR A LOW RISE APARTMENT BUILDING

ASUME: PROVISION OF FULLY FUNCTIONAL HARD-WIRED SMOKE ALARMS PLUS **FULL SPRINKLERS**



For Estimating by Delphi Panel

Note that [%] refers to the text and branch immediately below the box.

* Firefighter Injury

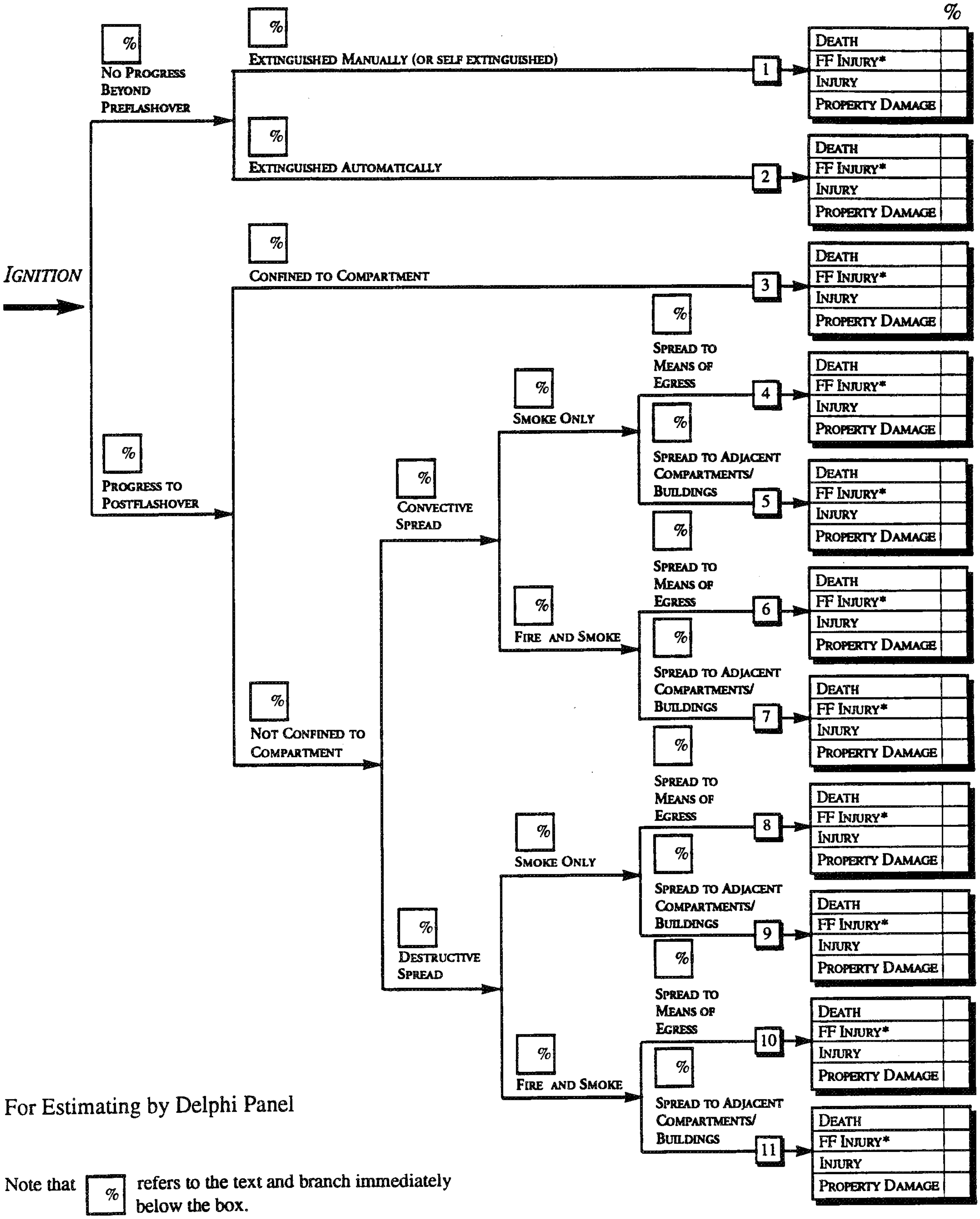
IBI GROUP

EXHIBIT 5

FIRE RISK ANALYSIS TREE

NEW PROBABILITIES FOR A HIGH RISE BUILDING

ASSUME: PROVISION OF FULLY FUNCTIONAL HARD-WIRED SMOKE ALARMS AND NO SPRINKLERS



For Estimating by Delphi Panel

Note that [%] refers to the text and branch immediately below the box.

* Firefighter Injury

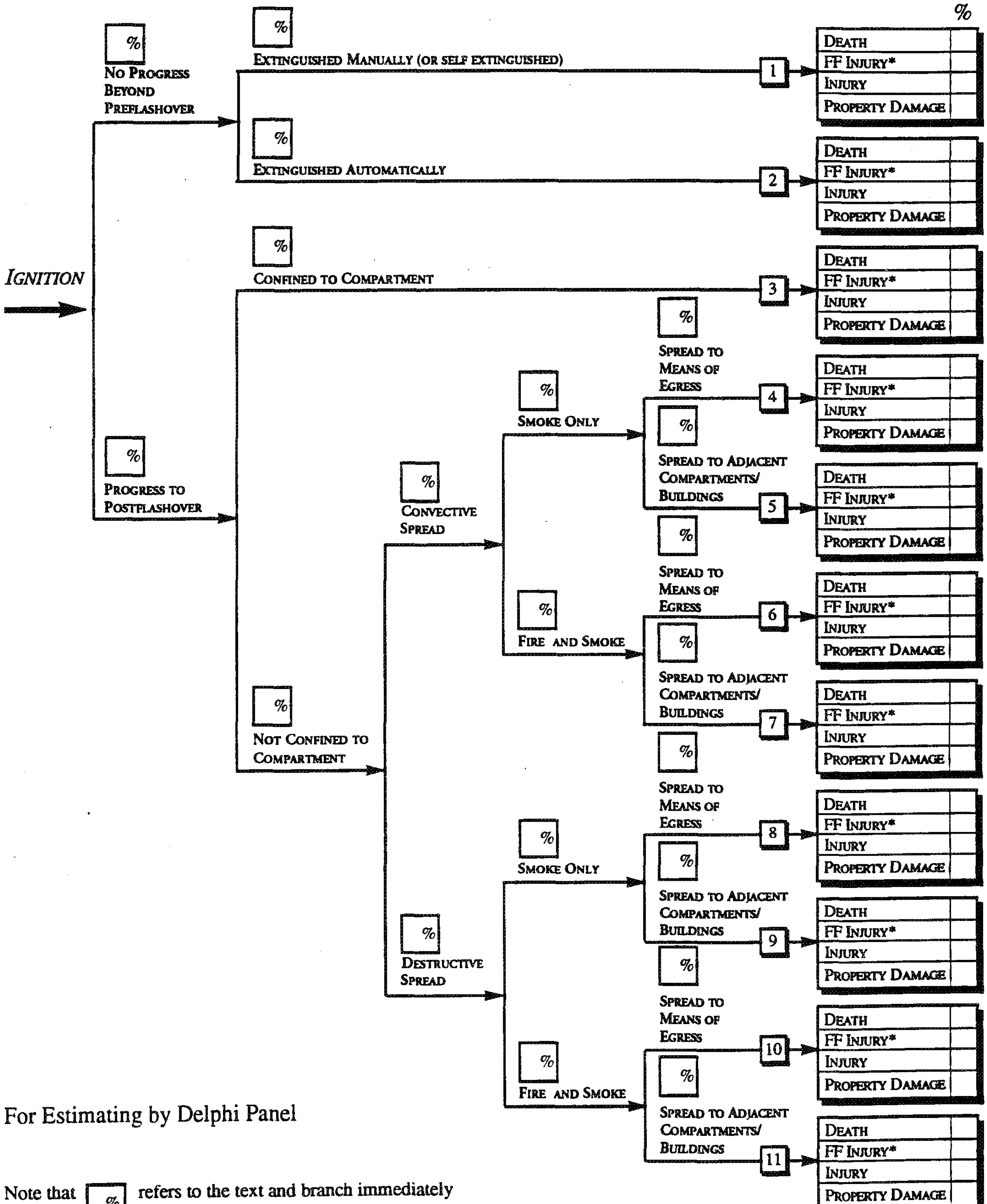
IBI GROUP

EXHIBIT 6

FIRE RISK ANALYSIS TREE

NEW PROBABILITIES FOR A HIGH RISE BUILDING

ASSUME: PROVISION OF FULLY FUNCTIONAL HARD-WIRED SMOKE ALARMS PLUS FULL SPRINKLERS



Note that [%] refers to the text and branch immediately below the box.

* Firefighter Injury

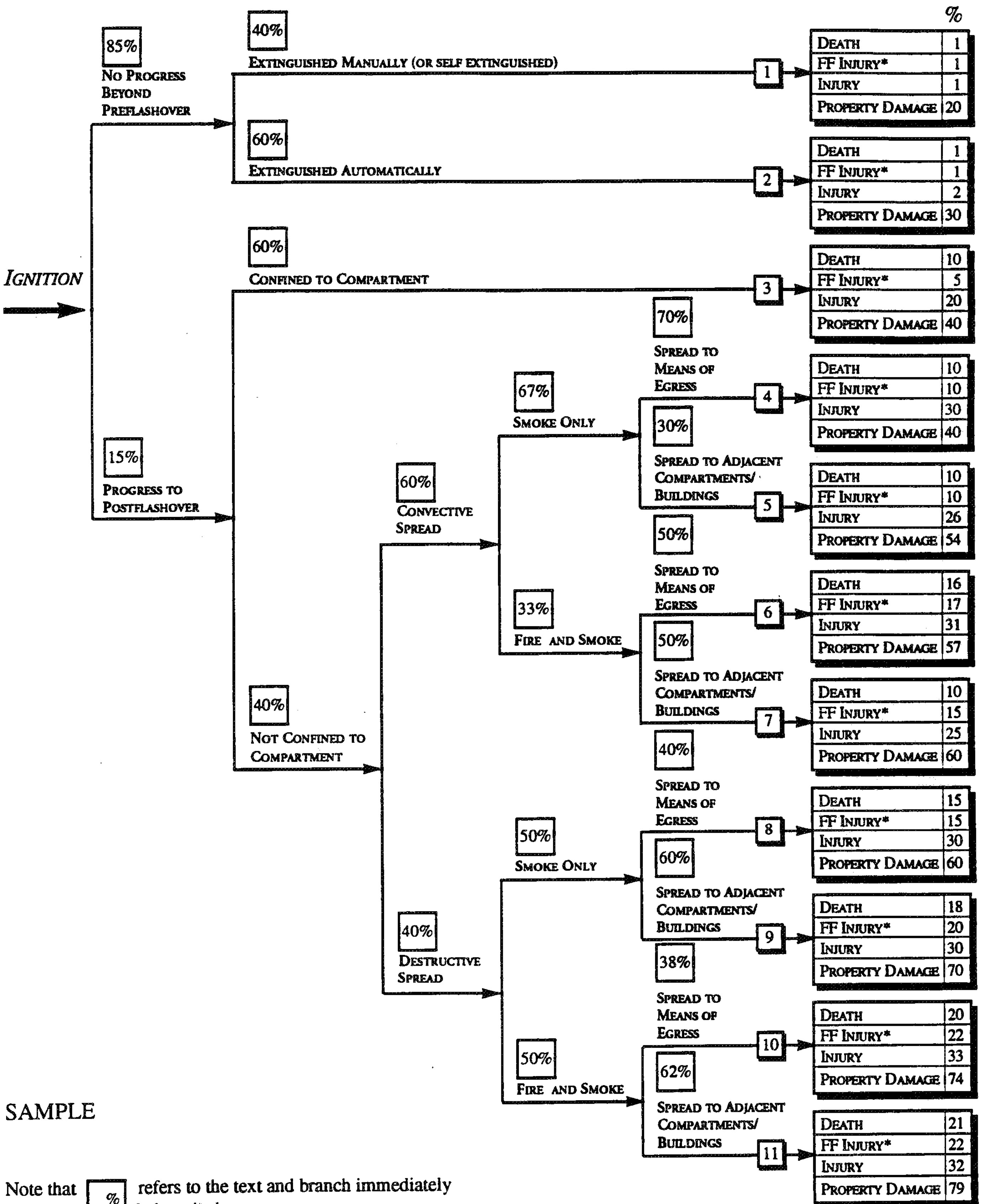
IBI GROUP

EXHIBIT 7

FIRE RISK ANALYSIS TREE

SAMPLE: COMPLETED RISK TREE WITH NEW BRANCH PROBABILITY

(percent probabilities are illustrative only)



SAMPLE

Note that [%] refers to the text and branch immediately below the box.

* FIREFIGHTER INJURY

APPENDIX H

REVIEW OF MINUTES AND REPORT OF PART 3 JOINT TASK GROUP ON AUTOMATIC SPRINKLER SYSTEMS

Appendix H
Review of Minutes and Report of Part 3 Joint Task Group on Automatic Sprinkler Systems

As background to this study, we reviewed the minutes and report of the Part 3 Joint Task Group on Automatic Sprinkler Systems of the Standing Committee on Fire Protection and the Standing Committee on Occupancy. The following notes present the highlights of this material noting their relevance for this study and its method.

APPENDIX H

Review of first 4 meetings and March 1993 report of Part 3 Joint Task Group on Automatic Sprinkler Systems of the Standing Committee on Fire Protection and the Standing Committee on Occupancy.

The Part 3 Joint Task Group on Automatic Sprinkler Systems began its work after an earlier Task Group, a Joint Task Group on mandatory installation of sprinklers in houses, reviewed the potential for mandatory sprinklering of house-form construction in 1988 and 1989. The main conclusion in that Task Group was that mandatory sprinklering should not be imposed on most house-form construction. Included in the material considered by this previous Task Group were independent studies demonstrating construction costs of up to 38 million dollars per potential life saved due to sprinklering of houses.

The second Task Group, the Part 3 Joint Task Group on Automatic Sprinkler Systems (herein referred to as the Task Group) was constituted in late 1990. It had a membership of 11, apart from IRC staff. The chairman was president of a firm active in the design of fire safety systems. Other members included an associate of an architectural firm, employee of a property management firm, employee of a management group for provincial housing, two representatives of materials interests, two representatives of municipal and provincial fire services, a building official and two persons from firms providing fire safety equipment and/or systems.

A significant difference between the scopes of the Task Group and of this study is that the Task Group were to consider the potential for mandatory sprinklers in all occupancy classifications whereas as this project is concerned only with multi-unit residential buildings. However, statistics demonstrate that the greatest number of deaths and injuries occur in residential occupancies.

The Task Group performed no cost benefit studies but relied on conclusions of studies from other sources. The documentation of the Task Group demonstrated no critical review of cost benefit analysis of other sources.

The Task Group recommended a number of changes for implementation in the Building Code as well as future consideration of additional reductions in Building Code requirements beyond those currently in the National Building Code where sprinklers are mandated for such buildings. Although these additional trade-offs would lessen construction costs, no quantification of such reduction has been made by the Task Group.

In general, the Task Group documentation emphasizes the benefit of sprinklering in terms of reduced loss of life and injury and reduced property losses. These benefits are not conclusively compared to cost. Emphasis is placed on trends in other jurisdictions.

The Task Group met as follows:

(1) 08 March 1991,
() 19, 20, 21 November 1991,
(3) 7, 8, 9 April 1992,
(4) 15, 16, 17 September 1992,
(5) 20, 21, 22 January 1993.
Report (prepared by A.J.M. Aikman) March 1993.

The terms of reference of the Task Group were presented at the first meeting. These were:

(1) Review existing NBC requirements for the mandatory installation of automatic sprinkler systems to determine if they are still feasible.
(2) Consider the degree to which the installation of automatic sprinkler systems can permit a designer to modify or waive other requirements of the NBC.
(3) Review regulations or jurisdictions that have additional requirements for the installation of automatic sprinkler systems in buildings and analyze the differences.
(4) Analyze available data utilizing the results of studies and experiences from those jurisdictions who have regulations effecting automatic sprinkler system requirements in one or more categories of buildings to determine if the NBC should make any additions to the requirements for the installation of automatic sprinkler systems.
(5) Review the practice of installing partial sprinkler systems in buildings and determine if this practice should continue to be accepted in the NBC in lieu of complete sprinklering of a building.
(6) Examine the cost and reliability aspects of various smoke control measures for high buildings in relation to the cost and effectiveness for Measure A - a fully sprinklered building - taking into account modified requirements that affect other areas of the building.
(7) Examine the benefits of other fire suppression and compartmentation techniques in comparison to automatic sprinkler systems to determine those that provide an equivalent level of safety for building occupants.

The minutes of the first four meetings and the report of the Task Group were reviewed to ascertain the relevance for the purposes of this study - i.e. the cost impact of mandatory sprinklering of multi-unit residential buildings in consideration of derived benefits.

Much of the content of the Task Group meeting documentation is not directly relevant to the purposes of this study. Material deemed to be of relevance included data on deaths and injuries due to fire in residential occupancies, number and frequency of fire in different types of residential buildings and the cost of sprinkler systems relative to lives saved, injuries prevented or other benefits.

Of the data which were relevant, not all of them were accompanied by reference sources.

A brief synopsis of some potentially relevant material from the Task Group documents is provided as follows:

Meeting No. 1

Page I-2: There is a report and an extract from minutes of the 6 meeting of the Standing Committee and Fire Protection, 23, 24 February 1987 regarding an overview of automatic sprinkler systems by Mr. J.K. Richardson of IRC. Points made include the following:
- estimated possible 50% reduction in lives lost if sprinklers installed in residential buildings (no source quoted)

- the reliability of sprinkler systems install in accordance with NFPA 13 is in excess of 96%, could be increased to 99% with proper inspection testing and maintenance (no source quoted)
- reduction in insurance rates can generally allow owners to recoup cost of installation in less than 5 years (no source quoted)
- cost of automatic sprinkler systems are approximately 1% of the cost of a new building (no source quoted)
- for 1 or 2 family dwellings there are virtually no insurance benefits to be gained by installing sprinklers (no source quoted)

Appendix M

This appendix is a committee paper on automatic sprinkler protection in buildings regulated by the National Building Code of Canada prepared by A.J.M. Aikman and John F. Berndt for the Standing Committees on Occupancy and Fire Protection in February 1987. There are statistics which are relevant to the purposes of this study. They include material extracted from the annual report of the Fire Commissioner of Canada based on reports from provincial authorities. Table 1 of the report indicates number of fires in Canada for a period of 1974 to 1983 according to the occupancy classification system in the NBC. (Although the author states that there is no major trend indicating the number of fires as being reduced substantially in this time frame, a linear regression of the numbers shows a decrease in the number of fires of about 1.7% per year or 15.6% over 10 years. If the fact that the number of residential units increased over this time and that these statistics included all residential housing are included in the analysis, the yearly reduction of fires is significant.) Table 2 indicates property loss in dollars in Canada for the same period of time. Table 3 indicates the number of fires, injuries and deaths in buildings in Canada in 1980 to 1983 and demonstrates a continuing decline in residential fire deaths over this period. Table 4 specifically identifies the number of fires, injuries and deaths in residential property in Canada in 1980 to 1983.

Second Meeting

Appendix F

This is a reproduction of a summary report on a capital, commissioning and maintenance cost comparison study of alternate smoke control measures for high rise buildings prepared for the Alberta Department of Labour in November 1983.

Appendix J

This is a copy of a report on residential fire sprinkler systems prepared for Alberta Department of Labour, January 1989. Numbers of fires, fire deaths and property losses in Alberta were examined for an 8 year period ending in 1987.

Appendix L

This appendix contains statistics for the years 1986 to 1990 respecting a comparison of fire losses of sprinklered versus unsprinklered buildings. These were sourced from the Alberta Ministry of Labour, Fire Commissioner's Office.

Appendix P

This appendix consists of a copy of speech notes for presentation to the Task Group in November 1991 in Edmonton. Points made include the following:

- Page 5 — It is indicated that Labour Canada's fire losses in Canada for Alberta for 1985 to 1989 inclusive included death from burns or asphyxia from a vehicle fire as well as potentially suicide or murder results in a 35% discrepancy between provincial statistics for building fire death versus the Labour Canada statistics.

- Page 7 — John Hopkins study mentioned other sources and attributing 90% effectiveness to combined sprinkler smoke alarm systems is mentioned. The speaker also indicated that the particular study, to his recollection, attributed 80% of the benefit to smoke alarm system alone and estimated the cost of smoke alarms at about 2% to 3% of the cost of sprinklers.

Appendix R

This is a document titled "*Cost Study for Sprinkler Installations for Senior Citizen Housing*" prepared in September 1991 for Alberta Municipal Affairs. Three types of multi-unit residential buildings, not exceeding 3 storeys in height, were considered. The general conclusion was that the cost of sprinkler systems greatly exceeded the savings potential realizable from permitted reduction in construction material or systems. It was also concluded the additional cost of sprinklers was so large that sprinkler systems could not be justified.

Although insurance cost was reviewed, the buildings analyzed were covered by government insurance and no cost savings were available for the projects. It was indicated that the Insurers Advisory Group (IAG) had noted a generally recommended 10% to 30% reduction in premiums for sprinklered buildings but that, in consideration of market driven premiums, actual reductions offered maybe in the order of 10%. In summary, it was concluded that residential sprinklers cannot be justified in terms of savings from reduced construction cost.

Meeting No. 3

Appendix G

Statistics were presented for the province of Quebec for fires in the period of 1984 to 1989. Data related to numbers of fire deaths and dollar losses and to comparisons made between fires limited to the room of origin and those that spread beyond room of origin.

Appendix H

Appendix H is titled "*Review of Automatic Sprinkler Protection for Buildings in Canada*" prepared for the Canadian Automatic Sprinkler Association and the Corporation of Master Fire Protection Contractors in the Province of Quebec by Professional Loss Control Ltd. 04 February 1992.

The review describes itself as "an overview rather than a detailed study of a specific building" and indicates that it provides "a realistic, supportable summary of sprinkler performance."

In general the report does not include its own or original cost/benefit data; rather, it references a variety of other sources of statistics.

- Page H22 It was indicated that as Canadian data on reduction of loss of life and property in sprinklered and unsprinklered buildings are limited, USA data were used on the assumption that USA data would likely be applicable to Canadian circumstances.

- Page H23 It was indicated that since the introduction of smoke alarm requirements in the late 1970's, fire deaths in Canada have decreased from more than 800 in 1980 to approximately 500 in 1989. It was also indicated that in the past 3 years there has been little subsequent improvement.

- Page H26 Tabular data demonstrating 1989 fire losses in Canada for property classification are presented; these are further broken down for different types of residential occupancies.

- Page H27 Suggested reduction of life lost in different properties shown for Alberta and British Columbia on the basis of assumed benefits of sprinklering based on USA data. It is indicated that life loss reduction in different occupancies in the USA varies from 37% to 57%.

- Page H33 Anticipated percentage reduction in property lost in different occupancies is projected to be 52% based on data taken from sprinklered and unsprinklered buildings over 500 m^2 in the province of Alberta 1986 to 1990.

- Page H40 Different sources of reliability data indicating sprinkler reliability of from 95.7% to 98.4% are listed.

- Page 511 In a position paper of the Canadian Association of Fire Chief's titled "*Where is the Fire Service Going*" it is indicated that (in Vancouver) sprinklers are being installed for less than a $1.54 per sq. ft. in single family houses.

- Pages T17 to T26
In an April 1992 committee paper on automatic sprinkler systems application in Part 3 of the National Building Code of Canada 1990, A.J.M. Aikman provides statistical data derived from annual reports issued by Labour Canada, Office of the Fire Commissioner respecting a period from 1974 to 1989.

Meeting No. 4

The minutes of the fourth meeting contain no information of a statistical nature which could be considered in cost benefit evaluation.

March 1993 Report of the Part 3 Joint Task Group

This report summarized the recommendations that automatic sprinklers systems be required in the great majority of buildings constructed under Part 3 and in many buildings constructed under Part 9. The report also summarized the Task Group's understanding of costs of installing sprinkler systems and data respecting sprinkler systems reliability.

The discussion on costs is based largely on comparative cost studies conducted for the Alberta Labour in 1992. No other reference is made to specific content of other studies.

It was also reported that the Task Group considered that there were a number of potential cost reduction factors which are dependant on sprinklering. These include, for example, potential elimination of requirements for buildings to face 2 and 3 streets (resulting in simplifying servicing and site development), reduction in fire insurance costs, reduction in initial development charges based in part on reduction municipal fire fighting costs and reduced frontage, reduced fire-related deaths and injuries, reduced property losses, saving in loss of income to building occupants forced out of work due to a fire, etc. None of these additional potential benefits were quantified in terms of cost by the Task Group.

A number of specific proposals were contained in Appendix B of the Task Group report for further trade-offs in consideration of mandatory sprinklering. These proposals were largely reflected in the eventual proposed changes put out for public comment in August 1993. Comment on actual proposed changes which are in addition to the basic whole building sprinklering proposals is contained in Appendix I.

APPENDIX I

DISCUSSION OF PROPOSED CODE CHANGES RELATING TO MANDATORY SPRINKLERS

Appendix I - Discussion of Proposed Code Changes Relating to Mandatory Sprinklers

This Appendix discusses the proposed changes to NBC Subsection 3.2.2 which will mandate sprinklers for all residential buildings under Part 3. Other proposed changes which are contingent upon mandatory sprinklers are also discussed.

SUBSECTION 3.2.2. CONSTRUCTION

National Building Code (NBC) Subsection 3.2.2. establishes construction requirements for buildings. These requirements include restrictions on combustibility of construction (a building is either permitted to be of combustible or noncombustible construction or is required to be of noncombustible construction) and structural fire-resistance. These requirements vary depending on occupancy type, building height in storeys and building area. A building of a given height is permitted to be built with an incrementally larger building area if it faces two or three streets, as opposed to facing only one street. Additionally, although buildings of a particular occupancy classification which meet the most severe limitations on fire-resistance may be built to any height or area, a building possessing a lesser degree of fire-resistance may typically have its maximum allowable building area doubled if it is sprinklered.

It is proposed to modify the Subsection 3.2.2. Articles dealing with residential buildings to mandate sprinklers in all cases. Additionally, it is proposed to allow a building with a given type of construction and fire-resistance to be built to the limits previously permitted for facing three streets in all siting situations (i.e. even when the building would face less than three streets) when the building is sprinklered with an electrically-supervised sprinkler system and there is a connection through a fire alarm system to a central station monitoring facility. The disadvantage to building owners and builders with this proposal is the denial of the previous ability to build unsprinklered buildings. There is the possible advantage (compared to previous sprinklered construction) of larger allowable floor areas for buildings not deemed to face at least three streets where building height does not exceed 6 storeys. The potential impact of these proposals is discussed below.

According to available statistics, the average number of suites per floor in recently constructed Canadian multi-storey apartment buildings is typically in the range of 8 to 12[1]. Assuming an average area per suite of about 1000 m^2 (including common elements), this equates to a typical floor area of about 800 to 1200 m^2.

On this basis, the ability to double permissible floor plate sizes due to mandatory sprinklering may not be significant on many sites. The number of suites which can be constructed on a given site is ultimately determined by zoning allowances. It frequently happens that, where the site could be developed with one large floor plate building, it is actually developed with two separate buildings for marketing purposes. According to comment obtained from building industry sources, the preferred number of suites per floor is in the 10-14 range for elevator-equipped condominium buildings.

LOW-RISE COMBUSTIBLE CONSTRUCTION - 1990 NBC 3.2.2.34.

This is the most lenient article for construction of NBC Part 3 residential buildings. Combustible construction may be used. Floor assemblies require a 45 min fire-resistance rating; no rating is required for the roof assembly.

1990 NBC 3.2.2.34. size limits are as follows:

Table 3.2.2.E
Forming Part of Sentence 3.2.2.34.(1)

No. of Storeys	Unsprinklered Maximum Area, m^2		
	Facing 1 street	Facing 2 streets	Facing 3 streets
1	1800	2250	2700
2	900	1125	1350
3	600	750	900
Column 1	2	3	4

Under the proposed change, height and area limits under (re-numbered) Article 3.2.2.33. would be as follows:

1 storey 5400 m^2
2 storeys 2700 m^2
3 storeys 1800 m^2

For a 1 storey design where the building could face only 1 or 2 streets, the proposed change offers the advantage of a larger allowable area. Whether such advantage would be acceptable in consideration of the cost penalty of electrically supervised sprinklering and an upgraded fire alarm system, is questionable.

It is reasonable to assume that for economies of construction most low-rise developments will have at-grade parking. This usually entails driveways leading from the street to such parking areas. Most designs will require a driveway for service access at least along one side of the building if the building faces only one street. These driveways, as well as aisles between parking rows, may be used as fire access routes considered equivalent to streets. In this situation, a building could readily be considered to face 2 or 3 streets.

Whether the ability to build a larger floor plate with supervised sprinklered construction is frequently advantageous, is also questionable. For 1 storey, 2 storey and 3 storey buildings, available statistics[2] demonstrate an average number of suites per floor as 16, 9 and 10 respectively and therefore suggests an approximate typical floor area of 1600 to 1000 m^2. If the rationale respecting access routes as equivalent to streets described in the preceding paragraph is accepted, it appears most 2 and 3 storey designs could be built under NBC 3.2.2.34. For designs at the high end, construction must use a more stringent Section 3.2.2. article, or incorporate a fire wall to reduce building area for the portions of the building on either side of the fire wall to not more than the maximum permitted under 3.2.2.34.

Depending on locale, a masonry fire wall subdividing a 3 storey apartment building will cost approximately $10,000.00 - $13,000.00. At $1.50/ft^2 ($16.15/m^2), a 3 storey plus basement apartment building having a building area of 1200 m^2 would cost about $58,000.00 to sprinkler. In general, for low-rise residential buildings of combustible construction, it appears more economical to build a fire wall under 1990 NBC allowances, given a choice between a fire wall or sprinklers.

As it is not clear from the statistics what proportion of buildings will have side driveways, thereby eliminating the need for a fire wall under present code requirements, it is not possible to compute the average savings from not having to provide a fire wall.

It seems clear that there will be some savings for some 3 storey apartment buildings. However, we believe that the given preference for side driveways to keep the front of buildings free of cars and since vehicles and the average building size, the savings over the full annual production of low-rise units will be small.

LOW-RISE COMBUSTIBLE CONSTRUCTION - 1990 NBC 3.2.2.35.

This Code article permits combustible construction. Floor and roof assemblies require a 1 h fire-resistance rating.

1990 NBC 3.2.2.35. size limits are as follows:

Table 3.2.2.H.
Forming Part of Sentence 3.2.2.37.(1)

No. of Storeys	Unsprinklered Maximum Area, m^2		
	Facing 1 street	Facing 2 streets	Facing 3 streets
1	2400	3000	3600
2	1200	1500	1800
3	800	1000	1200
Column 1	2	3	4

Under the proposed change, Articles 3.2.2.35. and 3.2.2.36. (the latter applying to 4 storey sprinklered buildings) would be amalgamated with the following modified height and building area limits, relative to the 1990 NBC:

1 storey	7200 m^2
2 storeys	3600 m^2
3 storeys	2400 m^2
4 storeys	1800 m^2

Under the proposed Code change, electrically supervised sprinklering allows the roof assembly not to have a fire-resistance rating.

A 1 h rated combustible roof assembly for a combustible wood-framed building constructed under 1990 NBC 3.2.2.35. would likely have structural members spaced such that 15.9 mm drywall would be used to avoid sag between supports. On the basis of Chapter 2 of the Supplement to the National Building Code, one layer of 15.9 mm Type X drywall will provide not more than a 45 min fire-resistance rating. On this basis, a double layer of 15.9 mm Type X drywall would have to be used. As of November 1993, the cost of installing an additional layer of untaped 15.9 mm drywall was in the \$0.70/$ft.^2$ (\$7.53/m^2) range in the Toronto area.[3]

Relative expenses and savings in applying the proposed Code article versus the existing Article 3.2.2.35. will vary depending on building area and siting conditions. As an example, a 3 storey building with basement facing 3 streets and having a building area of 1200 m^2 could be built under 1990 NBC 3.2.2.35., unsprinklered, with a 1 h rated roof/ceiling assembly. Under the proposed change, mandatory sprinklering would cost approximately $77,500.00 extra although there would be a cost reduction of approximately $9,000.00 due to elimination of the rating for the roof/ceiling assembly.

It is worth noting that there are very few listed roof ceiling assemblies utilizing wood framing. This may be due to a lack of market demand or to doubts about return in investment in testing when assemblies are variable. Where a combustible residential building is of a size which would require a rated roof, it is likely that a fire wall would be utilized to enable construction under 1990 NBC 3.2.2.34.

For buildings permitted to be of 1 h rated combustible construction, the proposed provisions mandating sprinklering are of varying benefit, depending on intended building area and height.

For example, previously the allowable building area for a 2 storey building facing 1, 2 or 3 streets would exceed the statistical average number of suites per floor; in this case mandatory sprinklering would afford no advantage respecting area limits.

In another instance, a 3 storey building facing 1 street could not exceed a building area of 800 m^2 unsprinklered or 1600 m^2 voluntarily sprinklered; under the proposed change, the building could have a building area of up to 2400 m^2 with mandatory sprinklering. While the possibility of floor plates larger than permitted by voluntary sprinklering under the 1990 NBC is convenienced by the proposed change, the proportion of buildings designed to have such large floor plates will likely be relatively small if statistics respecting the size of buildings previously erected represent preferred or typical building sizes.

MID-RISE NONCOMBUSTIBLE CONSTRUCTION - 1990 NBC 3.2.2.37.

This Code article requires noncombustible construction and limits building height to 6 storeys. Floor and roof assemblies require a 1 h fire-resistance rating.

1990 NBC 3.2.2.37. size limits are as follows:

Table 3.2.2.H
Forming Part of Sentence 3.2.2.37.(1)

No. of Storeys	Unsprinklered Maximum Area, m^2		
	Facing 1 street	Facing 2 streets	Facing 3 streets
1	unlimited	unlimited	unlimited
2	6000	unlimited	unlimited
3	4000	5000	6000
4	3000	3750	4500
5	2400	3000	3600
6	2000	2500	3000
Column 1	2	3	4

Under the proposed change, height and area limits under (re-numbered) Article 3.2.2.35. would be as follows:

3 storeys	12000 m^2
4 storeys	9000 m^2
5 storeys	7200 m^2
6 storeys	6000 m^2

The requirements for mid-rise buildings (represented by proposed Article 3.2.2.35.) cover buildings up to six storeys in height. Even on a site affording access to only 1 street, a 6 storey building could be constructed with considerably more suites per floor than average under the 1990 NBC 3.2.2.37. provisions.

HIGH-RISE NONCOMBUSTIBLE CONSTRUCTION - 1990 NBC 3.2.2.38.

Proposed Article 3.2.2.36. dealing with all residential buildings exceeding six storeys in height offers no cost or design benefit due to mandatory sprinklering compared to 1990 NBC Article 3.2.2.38. Construction remains noncombustible and 2 h ratings are required. The additional cost of fully-supervised sprinklering is extra compared to the 1990 NBC; the cost of above-grade mechanical smoke control would, however, be deleted for a building not equipped with balconies where building height exceeds 18 m.

3.2.3.14. WINDOWS IN MUTUALLY EXPOSED WALLS

The proposed changes would delete Article 3.2.3.14. which places a limit on the proximity of windows in adjacent fire compartments where the exterior walls of such fire compartments meet at an exterior angle of 135° or less. The minimum dimension between such windows is 1 m; in practice, this requirement often imposes separation requirements in the 2.5 m - 3.0 m range.

The proposed allowance in sprinklered buildings will convenience some designs, although it will not be a significant factor in fundamental building layouts. It is not possible to quantify this convenience in cost terms.

The likely imposition of more stringent energy conservation requirements will tend to limit the portion of an exterior wall devoted to windows.

3.2.4.1. FIRE ALARM SYSTEMS

The 1990 NBC exempted apartment buildings not exceeding three storeys in height where each dwelling unit is served by an exterior exit facility leading to ground from being required to have a fire alarm system. The proposed changes delete this allowance. The change is represented as being intended to facilitate monitoring of a mandatory sprinkler system and it is further indicated that the cost increase above that of a sprinkler panel will not be substantial.

Although this requirement would not affect the low-rise building used as one of the costing examples in the study, it would impose an additional cost on other buildings not exceeding three storeys in height where each dwelling unit is served by an exterior exit facility leading to ground level. This could include rows of townhouses or apartments served by exterior exit passageways.

3.2.4.11. HEAT DETECTORS

The requirement for heat detectors in residential suites is deleted in that mandatory sprinklers are substituted in lieu of heat detectors.

3.2.4.17. PULL STATIONS

The proposed revisions to this Article would allow a manual pull station not to be installed at an exterior egress doorway from a suite that does not lead to an interior second means of egress in a building not exceeding three storeys in height.

This appears to be of advantage in a relatively small proportion of building designs. It will not apply to conventional apartment buildings with interior access corridors and no direct exterior egress from suites. On this basis, it has not been considered.

3.2.5. DELETION OF STANDPIPE AND HOSE SYSTEMS IN SMALL RESIDENTIAL BUILDINGS

The proposed change to standpipe and hose system requirements would delete the requirement for standpipe and hose systems in any residential building not more than three storeys in building height. This would have the effect of deleting the 1990 NBC requirement for standpipe and hose systems in one storey buildings exceeding 2,000 m^2 in building area, two storey buildings exceeding 1,500 m^2 in building area, and three storey buildings exceeding 1,000 m^2 in building area. The example low-rise building considered in the study, with a building area of 700 m^2 would not have required a standpipe and hose system under the 1990 NBC and therefore the cost of adding sprinklers to such a building would not be reduced by elimination of a standpipe and hose system. Most 2 and 3 storey apartment buildings with an average of 8 to 12 units per floor would see no change in consideration of the relaxation of standpipe requirements.

In consideration of 1990 NBC requirements, it is possible for low-rise developments to utilize a fire wall to limit building size to that permitted under 1990 NBC 3.2.2.34. This would also have the effect of enabling such buildings to be built without standpipe and hose systems. This may reduce costs in some 3 storey buildings, for example, by $15,000 to $20,000 depending on design and location.

3.2.5. UTILIZATION OF NFPA 13R

NFPA 13R is a standard for the installation of sprinkler systems in residential occupancies up to and including 4 storeys in height. It has been suggested that utilization of this Standard in the design of low rise multi-unit residential buildings may effect savings in comparison with utilization of NFPA 13.

NFPA 13R does allow economies in the design and installation of sprinkler system relative to NFPA 13. The primary advantages come from fewer design sprinklers (a maximum of 4 in a compartment), potential use of a common supply main to the building serving both the sprinkler system and domestic uses, lesser water supplies and generally a number of other simplifications compared to standard systems.

The costing data which have been used in the study do not differentiate between systems conforming to NFPA 13 versus systems conforming to NFPA 13R. The costing data are based on market activity and reflect the ability of the market to utilize 13R systems in low rise applications. In our research the lowest net cost for sprinklering to a developer (ie. does not include mark-up to purchaser) of low rise combustible multi-unit buildings has been $1.40 per sq. ft., a figure which includes the offsetting savings realized by the installation of sprinkler systems. Other sources indicated somewhat higher costs.

3.2.6. HIGH RISE REQUIREMENTS

The proposed changes respecting Subsection 3.2.6. would mandate Measure A Sprinklering as the only smoke control measure in high-rise apartment buildings. The cost of the sprinkler system is additive; the cost of mechanical smoke control systems is deleted.

In practice, for high-rise apartment buildings, Measures F or G, Pressurized Air Shafts and Elevator Shafts, are typically utilized to comply with the smoke control requirements of Subsection 3.2.6. Most buildings utilize Measure G which involves pressurization of stairwells and fire fighters elevator shafts. These measures require the presence of fans and, possibly, shafts located adjacent to stairwells for injection of pressurizing air at various heights in the building to modulate pressure throughout the height of the stair shaft. Whether or not such additional shaft is required is dependent on building height and the location of the fan. (A fan located near the bottom of the building may not require this additional shaft.)

There are no specific requirements for ongoing testing of mechanical smoke control. Such ongoing testing can be done by the building superintendent simply by activating fans and observing air flow.

3.2.6 ELIMINATION OF BALCONY-BASED SMOKE CONTROL ALLOWANCES

The allowance whereby above-grade mechanical smoke control measures may be eliminated for apartment buildings where each suite has an accessible exterior balcony is of little effect except in the loss of a design option.

The presence of balconies is not a determining factor in marketing high-rise dwelling units. Many new developments are built without open-air balconies. In this case, mechanical shaft pressurization techniques (typically Measure G) are used to achieve the requirements of smoke control in NBC 3.2.6.

Balconies are regarded as being an element of choice in terms of marketing and are not fundamental purposes of complying with smoke control provisions. (Note that the high-rise example used in the study does have balconies. The imposition of mandatory sprinklering in this case would not entail a compensatory cost reduction due to the elimination of pressurization for shafts as such pressurization would not be required.)

3.3.1.7. PROTECTION ON FLOOR AREAS WITH A BARRIER-FREE PATH OF TRAVEL

The proposed changes to this Article would mandate sprinklering as the only means of providing protection on floor areas with a barrier-free path of travel. The 1990 NBC allows four options for protection of such floor areas in multi-storey residential buildings: sprinklering, a fire fighters type elevator (with protection against smoke when the building exceeds three storeys), subdivision of the floor area into 2 zones or utilization of balconies for refuge.

For buildings not equipped with an elevator, mandatory sprinklering would offer no cost saving in respect of this code requirement as it is likely that no barrier-free path of travel would exist above or below the first storey.

For buildings equipped with an elevator, the requirement would most likely be met by appropriately rating the elevator shaft and closures at elevator door openings and the provision of a 1 h rated separation for public corridors and the 1 h protection of electrical conductors for the elevator. The cost of complying with this requirement is expected to be minimal, compared to whole building sprinklering.

3.3.1.20. JANITOR'S ROOMS

This proposed Article would delete the requirement for a fire-rated separation around a janitors room in a fully-sprinklered building. The cost savings are expected to be minuscule or nonexistent, given that if the janitors room is adjacent to suites or a public corridor, separation requirements for these other entities will ensure the provision of a rated separation at any rate. Additionally, there are relatively few janitors rooms in most multi-unit residential buildings.

3.3.1.23. LAUNDRY ROOMS

On a similar basis to janitors rooms, the rated separation requirements for laundry rooms are deleted from fully-sprinklered buildings. The cost saving to this allowance again is likely to be insignificant for the reasons stated respecting the proposed deletion of a rated assembly around janitors rooms.

3.3.4.2. FLOOR ASSEMBLIES WITHIN A MULTI-LEVEL DWELLING UNIT

The 2 h fire-resistance rating required for floor assemblies within a dwelling unit where the building is not sprinklered and is more than six storeys in height, is deleted. This would allow 1 h rated floor assemblies within (not between) dwelling units in buildings where 2 h rated floor assemblies are required between dwelling units.

This allowance is of relatively little practical application as there is no relief for the requirement for noncombustible construction of the floor assembly. Although within a building where the primary structure has a 2 h rating, it may be possible to utilize 1 h rated steel joist systems for floor assemblies within a multi-level dwelling unit, this is not frequently done. The interior floor assemblies are usually constructed in accordance with the method used for the floor assemblies between suites.

Multi-level apartment suites are infrequently used as an apartment unit design type.

3.4.2.1. SINGLE EXIT FROM A FLOOR AREA

The maximum floor area for a residential building not exceeding two storeys in height served by one exit is increased from 100 m^2 to 150 m^2 and the maximum permissible travel distance to an exit measured from a suite door is increased from 15 m to 25 m on the basis of mandatory sprinklering.

This change will have negligible application in the design of multi-unit residential buildings. A 150 m^2 floor area will not accommodate more than 2 or 3 one-bedroom suites. This compares to the previous allowance whereby the 100 m^2 maximum floor area might accommodate two small one-bedroom suites. The increase in travel distance is not likely to be of consequence given the small size of the floor area. Additionally, it is not likely that such small floor areas would be constructed under Part 3 of the NBC, although on rare occasions, a small second storey may be erected above a much larger first storey. Constructed under Part 9, they would not fall under the mandatory sprinklering requirements.

3.4.2.5.(1) INCREASED TRAVEL DISTANCE

With mandatory sprinklering, maximum travel distance to an exit from a suite entrance increases to 45 m from the 30 m previously required without sprinklers. Assuming a simple rectangular plan shape with exits at the extreme ends of the central corridor, in an unsprinklered building a public corridor could be at least 60 m long. A 60 m long public corridor design could readily accommodate up to 16 suites - possibly 22 suites if 6 m dead-end corridors extend beyond the stairwell exit doors. Marketing constraints usually restrict the number of suites per floor to 10-14, according to design[4] and developer[5] sources. According to statistics for recently constructed apartment buildings, the average number of suites per floor typically ranges from 8 to 12.

While the change to a 45 m maximum travel distance with mandatory sprinklering would do away with the necessity of a third exit stairwell in the occasional very large floor plate, it is not likely that such advantage would frequently be utilized due to overriding design and marketing constraints regarding the desirable number of suites on a floor area.

1. Canadata Construction Statistics, 1988 - 1991

2. *Ibid.*

3. Mr. R. Mercer, Canadian Gypsum Company 29/11/93

4. Mr. S. Wassermuhl, Page + Steele Architects 25/11/93

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APPENDIX J

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APPENDIX K

INTRODUCTORY PAPER* ON BUILDING CODE ASSESSMENT FRAMEWORK

* Delivered at Sixth International Fire Conference, Interflam '93, Oxford, England, March, 1993.

FIRE RISK ANALYSIS AND ASSESSMENT FOR THE CANADIAN BUILDING CODE ASSESSMENT FRAMEWORK

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ABSTRACT

The Building Code Assessment Framework (BCAF) is an analytical tool which systematically evaluates changes to the National and Provincial Building Codes in Canada. It is intended to provide strategic advice to officials setting or modifying building regulations. This paper discusses the fire risk analysis and assessment approach that is part of the BCAF. This approach is a strategic one that provides a systematic and rational method for comparing trade-offs between risk changes and incremental costs due to code changes. A fire risk analysis event tree provides a structure at a macro level to optimize the use of existing fire hazard statistics and estimates of fire risk event probabilities by a Delphi Panel. The use of both fire hazard statistics and the Delphi Panel in the analysis is described. The use of the Delphi Panel has proven viable and necessary for applying the BCAF to more than 40 changes to the Ontario Building Code (OBC). The results of analyzing a proposed code change to the OBC (mandating of sprinklers in low rise dwellings) are presented.

INTRODUCTION

Canada now has an analytical tool to systematically evaluate changes to the National Building Code (NBC) and provincial building codes. This tool, called the Building Code Assessment Framework (BCAF) was developed by IBI Group and Trow Inc. under the sponsorship of the Ministry of Housing of the Province of Ontario. The BCAF analyzes any proposed code change, addition or deletion in relation to the building code objectives; and assesses economic and social impacts, including fire and other risks. It performs these analyses in consideration of 19 to 22 building types representative of the full range of building construction in recent years in each of the provinces across Canada.

This paper is concerned with the fire risk analysis and assessment approach that is part of the BCAF. The paper describes the BCAF in general terms and then discusses in detail the fire risk analysis and assessment approach in terms of its main characteristics: the fire risk analysis tree; the analysis process; and the assessment method. Reference to an application is made.

THE BUILDING CODE ASSESSMENT FRAMEWORK

The National Building Code (NBC) and its equivalent provincial building codes are updated and modified through various committees subject to a public review process. The varying make-up of these committees and the lack of a rational and systematic approach to evaluating proposed code changes limit the extent of objectivity that can be applied to these changes.

Amid a growing climate of regulatory reform, the Buildings Branch of the Ontario Ministry of Housing undertook a number of projects to rationalize the building industry in the province, which has the largest building construction dollar volume of all provinces in Canada. Included was the development of the BCAF; a framework and procedure to more rationally and systematically evaluate proposed changes to the NBC and the OBC. The BCAF has been primarily designed as a strategic tool for use by experts with responsibilities for code development at the Provincial and Federal levels. Since its development it has already been applied in assessing selected changes to the latest edition of the OBC. It is currently being applied to new code development issues related to fire safety provisions in apartment buildings.

STRUCTURE OF THE BCAF

The BCAF has two components; the Code Analysis Component (CAC) and the Impact Analysis Component (IAC). The CAC essentially identifies the objectives and requirements of a proposed code change. These objectives are fundamentally related to ensuring fire safety, structural sufficiency, and/or public health and welfare through the control of related hazards and risks. The CAC contains an automated relational database that organizes articles in the building code according to code objectives, code requirements and building spaces involved.

The IAC identifies the type and nature of potential cost and risk impacts of a proposed change and quantitatively measures and assesses these impacts. Any proposed change may alter the level of risk associated with hazards addressed by building codes. In order to estimate this change in risk, the IAC employs a risk analysis and assessment procedure focusing on four major hazards and their consequences:

- Fire (deaths, injuries, property damage);
- Structural Failure/Collapse (deaths, injuries, property damage);
- Indoor Air Contamination (deaths, illnesses);
- Personal Accidents (deaths, injuries).

The IAC contains various databases including sets of typical Reference Buildings (RB) representative of the volume of annual new construction of all building types in each province and susceptibility to fire hazards (i.e., share of fire losses); existing building stock and new building construction; hazard statistics; and expert risk estimates by Delphi Panel members. Most databases and the IAC processes are automated, and enable modifications to be made on a modular basis as new statistics become available and as judgements and opinions evolve. In fact scientific and statistical information on structural failure/collapse, indoor air contamination and personal accidents is limited relative to that for the incidence of fire and its consequences. It is accepted that modifications and additions with respect to all hazards will be made as knowledge expands, thereby enhancing the BCAF. These kinds of modifications and additions are fully anticipated and that is why the BCAF is referred to as a "framework", i.e. a structure to which updated knowledge and techniques can be added.

A STRATEGIC APPROACH TO RISK ANALYSIS AND ASSESSMENT

The IAC's strategic approach to risk analysis and assessment provides a systematic and rational approach for comparing trade-offs between fire risk increase/reduction and cost increase/reduction. The costs and benefits resulting from this approach focus on society as a whole because often the benefactors of a code requirement are not necessarily those who pay for it. The approach essentially looks at the net overall costs per benefit. Regardless of which hazard is being considered, the approach to assessing the risk impact (including that of fire risk) of a proposed code change consists of the following characteristics:

- An overall society viewpoint is taken;

- With respect to users of a specific building, (i.e. the group at risk), there may be a need to identify the size of this group on a provincial or national basis;

- Most causes (or group of causes) of risks are considered, thereby enabling differentiation between as-built causes and in-use causes, including human error. This in turn permits a focus on those causes that can be affected by Canadian building codes.

- Data and expert judgement are used to develop base case (i.e. existing code) probabilities of exposure, and to develop information on the extent of a hazard for each building type in the RB set for each province.

- The overall building stock is used in estimating risk impacts in new building construction relative to average annual risk.

- Risk probabilities are developed on an annual basis relating to hazard statistics, adjusted to relate to the volume of building construction in the reference year. Changes in probabilities of each hazard cause and subsequent events are estimated. Note that as a conservative measure, no allowance is made for the relation of hazard and building age, condition, and level of design and construction standards applied at the time of construction. Although the evaluation is done based on new construction conditions and new code requirements, and although conditions worsen over time, the fire risk database is continually updated and would necessarily reflect the change in levels of risk due to the volume of new construction.

- For each hazard, the difference between the overall risk before the code change and after the code change is applied to the base case incidence of death, injury and property damage to determine the overall impact of the code change on new building construction in the reference year.

FIRE RISK ANALYSIS TREE

Risk for purposes of this work is defined as the possibility of occurrence of adverse consequences for the building (i.e., fire damage) and its occupants (i.e., deaths and injuries). In order to systematically analyze fire risks, a fire risk analysis tree is provided. See Figure 1. This forms a simple fire event model.

Events leading to a certain consequence are organized as branches which in turn form a tree structure. Parallel branches on a tree represent mutually independent events and each branch is assigned a probability. End branches represent exposure-leading-to-consequence events, i.e., exposure-leading-to-death event or to injury, et cetera. End branches representing no-deaths, no-injuries or no-property damages are **not** shown on the tree. The end branches dealing with the possibility of exposure leading to losses are superimposed and therefore the sum of probabilities of any four end branches is not necessarily equal to one. The sum of probabilities of any other two parallel branches starting from the same node is equal to one.

The product of a series of dependent branch probabilities results in a **hazard path probability**. The product of a given **hazard path probability** and the **expected loss** associated with that path that gives the **path risk**. The sum of risks due to all paths in a tree represents the **total risk** due to fire. For fire, (or any other given hazard) each building type may have a unique set of probability values comprising its tree.

FIRE RISK TREE AS SIMPLE FIRE EVENT MODEL

It should be remembered that the nature of a building fire will not lend itself to useful probabilistic analysis at the level required by the IAC without some simplification. For this reason, it is assumed that fire spread is either **predominantly** by destruction or **predominantly** by convection.

Above all, it must be remembered that the BCAF is a strategic tool. The changes in risk probability are compared with broad estimates (on a logarithmic scale) of acceptable and unacceptable risk probabilities and willingness to pay per year of life saved (see Figure 2). This permits a wide "factor of safety" in the calculations while maintaining an acceptable level of credibility in decision making.

DESCRIPTION OF FIRE EVENTS

The first branch of the tree deals with the probability of ignition as the starting point of the fire in a compartment (the basic building space addressed by the building code).

The second set of branches is concerned with the progress of fire, after ignition, within the area of origin. Two mutually exclusive events are defined and considered for purposes of risk analysis (as with all other branches). The fire may remain in the pre-flashover stage or progress to post-flashover.

Given that the fire does not progress beyond pre-flashover, the tree structure considers the possibility of manual or automatic extinguishment. Occupant and/or fire fighter injuries may result from exposure to such conditions, and even death in some cases due to smoke inhalation and/or burns. Property damage to building elements and components may also result from these paths.

If the fire progresses to the post-flashover stage it can either remain confined to the compartment or origin or spread by convection or destruction (assuming either a predominantly convective or a predominantly destructive spread). Furthermore, this spread may result in smoke only or in fire and smoke in the areas it occurs in.

Spread was assumed to occur to either of two areas; means of egress or adjacent compartments/buildings. Therefore any particular building may be schematically described as having three zones: compartment of origin, means of egress, and adjacent compartments and buildings.

All paths in the fire risk analysis tree lead to four loss types (consequences) and therefore fire risk analysis deals with four risks.

- Risk of death to occupants, fire fighters and others.
- Risk of fire fighters' injuries (due to the fact that these injuries constitute on average approximately 40% of the total reported injuries).
- Risk of injury to occupants and others.
- Risk of property damage to building elements, components and structures.

METHOD OF FIRE RISK ANALYSIS AND ASSESSMENT

This section discusses the use of statistics and expert opinion as a data source in the fire risk analysis process; the method of application of the fire risk analysis process; the method of application of the fire risk analysis tree; and the assessment method and use of results in the IAC.

USE OF EXISTING STATISTICS AND EXPERT OPINION

There are two types of data that need to be obtained prior to the application of the fire risk trees:

- The probability of different branch events per building type that may depend on the design, construction and occupancy.

- The losses associated with a series of events (scenario). In the case of the fire tree these losses are deaths, fire fighters' injuries, occupant injury and property damage.

Published and unpublished provincial statistics for the different building types providing the probability of certain events such as ignition (all provinces) and confinement and/or extinguishment (a few provinces) may be obtained. Similarly, available statistics may provide the value of the total losses related to a given building type.

However, for a number of fire events along the tree, statistics are not available from Canadian sources. The share of each fire scenario of the total losses in a building type is also difficult to assess from statistics. In order to complement the statistical values available and to estimate the probabilities of events and loss shares, expert opinion is necessary. A Delphi approach is used to estimate the needed probability values. This approach is described in detail in the section below. Estimates from experts in the field are used as substitutes for unavailable statistics, until appropriate and reliable statistics are available for use in the IAC.

THE DELPHI METHOD

The Delphi Method can be defined as a method of "structuring a group communication process so that the process is effective in allowing a group of individuals, as a whole, to deal with a complex problem" [1].

This process is mainly concerned with the utilization of experts' opinions. The communication process is usually structured as to allow:

- Anonymity among the experts for their individual responses.

- Feedback of individual contributions of information and knowledge.

- An assessment of the views and opinions contributed by experts.

- Opportunity for individuals to revise judgement and views.

Note that the base case risk for each building type is computed only once. Also, for purpose of efficiency, panel member comments are obtained for a "batch" of proposed code changes (i.e., several changes are presented at once, each one being evaluated independently). The method is as follows:

- A panel of 30-35 fire experts is assembled. The types of backgrounds reflected in the participant group include fire service officials, building officials, building scientists and researchers, members of building industry associations, and private consultants. Regional representation is also a consideration in the selection process.

- For panel members with previous experience in the BCAF Fire Risk Process, little is needed by way of explanation. For new members of the panel and for review by experienced members, an interview guide is developed describing the overall process, mandate and components of the BCAF. The fire risk analysis approach and definition of the fire events in the fire risk tree are explained. The interview package also contains:

  - A description of the code change (i.e., existing article and changes as provided by the official code development agency).

  - Schematic drawings of the reference buildings affected by the change, and conceptual design and construction possibilities of how a change can be implemented.

  - Base case risk trees of the reference buildings affected, with the event and branch probabilities for the base case (consensus values) shown on them. Note that the base case risk estimates were developed by a similar process.

  - Tables corresponding to each fire event are provided for the reference building in question. The expert inputs his/her estimate in these tables.

  - Tables to allow the estimation of a particular scenario's (path) percentage share of fire losses for each reference building are also provided.

- Members of the Delphi panel are then interviewed on an individual basis. The purpose of these interviews is to provide the experts with the questionnaire and answer any questions related to its structure. During these meetings the approach to risk estimation is explained and the tables are discussed. The tables are then left with the participant to fill out. The estimates required are related to existing (or base case) risks in different building types. Experts are asked to give their best estimates based on knowledge, experience and typical characteristics of building types involved.

- A preliminary analysis of the results is carried out. This includes statistical analysis and qualitative assessment of participants' comments and suggestions. A consultation paper is then prepared incorporating a statistical summary (mainly the mean and standard deviation) and comments from the first round and sent back to the participants allowing for a second round of estimation. In order to assure anonymity, the statistical summary does not indicate any names and all comments are edited so as to maintain confidentiality.

- In a typical Delphi survey, before preparing a final analysis, the iterative process continues until consensus is reached. Consensus is assumed to have been reached when a certain percentage of 'votes' fall within a prescribed range (e.g. 2 units on a 10 unit scale) [3]. In this case a second round could be considered sufficient to reach an acceptable consensus between panel members on base case estimates. A standard deviation of less than 15% is considered satisfactory for purposes of the BCAF (See discussion below).

The statistical analysis is based on a population of 30 or more, and is therefore, carried out according to a large sample size.

For each estimate, the mean, standard deviation and median are calculated. The frequency and distribution of estimates is determined and plotted graphically. This allows noting large scattering of estimates and which participants may have contributed to this. Scattering is expected after the first round due to different backgrounds and views and to regional differences as well.

In addition to the above, a 95% confidence interval is determined for the mean based on maximum error of estimate. Based on this range, the percentage of estimates falling within is determined as another indication of reaching consensus. The degree of skewness of the results is also determined.

APPLICATION OF FIRE RISK ANALYSIS TREE

The following is a step-by-step description of the process used to determine a change in risk (**fire deaths** in this case) due to a proposed code change and for one particular building type.

- Base Case Risk Estimation

STEP 1: Assign base case branch probabilities based on statistics and/or expert opinion.

STEP 2: Calculate path probabilities for the base case; path probability is the product of branch probabilities along that path.

STEP 3: Knowing from statistics that on average there are, for example, 0.013 deaths occurring per fire in a certain RB type, the analyst distributes this risk among those paths ending with a death according to expert estimation.

- Loss Constants Calculation

STEP 4: Calculate loss constants for each death path. A loss constant equals the base case path risk (Step 3) divided by the base case path probability (Step 2).

- Code Change Risk Estimation

STEP 5: Assign new branch probabilities due to a code change as estimated by experts.

STEP 6: Calculate new path probabilities for each death path.

STEP 7: Calculate new path risks by multiplying the new path probabilities (Step 6) by the corresponding death path loss constants (Step 4).

STEP 8: Sum up all new path risks obtained from Step 7 to get the new death risk due to code change.

- Incremental Change in Risk

STEP 9: Calculate incremental change in death risk. This equals the difference between the base case risk of 0.013 (see Step 3) and a new risk determined from Step 8 (assume 0.0152). Therefore the incremental change in death risk due to the code change in this hypothetical example is an increase of 0.0022 deaths per average fire in that building type.

The changes in risks related to fire fighters injuries, occupants' injuries, and property damage are assessed in the same manner.

METHOD OF ASSESSMENT AND USE OF RESULTS IN IAC

The incremental changes in risks determined from Step 9 described above, is the value that is transferred and used in the IAC. Such a value is expressed in years of life gained/lost over the life cycle of the building based on the average age of a casualty in a building fire and the individual's average life span; and is then prorated to represent the total volume of new construction of a certain building type.

Other risks such as injuries are changed to monetary values, and with property damage, are prorated to total new construction.

In order to assess the socio-economic impacts in terms of overall societal expectations and standards, the results are applied to the Comparative Risk Assessment Graph (see Figure 2). This graph is based on fundamentals of risk appraisal developed by a Swiss Consulting Engineering Firm[2,3]. The fundamental concepts have been adapted to the Canadian context for purposes of the BCAF. Based on the graph, the dollar costs/savings per year of life saved/lost and the probability of individual risk can be assessed according to established societal standards corresponding to different risk categories and degree of an individual's control over his/her environment. This method enables a quantitative assessment of the results of the IAC.

APPLICATIONS

The BCAF has already been applied to more than 40 proposed changes to the OBC, and the results of the analysis taken into consideration by code development decision makers. More specifically, the BCAF evaluated the impact of requiring that all residential dwellings governed by Part 9 of the OBC have fire sprinklers designed and installed in conformance with NFPA 13D Standard for the Installations of Sprinkler Systems in One and Two Family Dwellings, and Mobile Homes. The analysis and assessment confirmed details arrived at in other studies and concluded that the cost was higher than society is willing to pay, given the benefits that would be achieved.

CONCLUSIONS

The BCAF approach to fire risk analysis and assessment provides a systematic and relatively rational approach at a macro level to assess the fire risk impacts of building code changes. The approach allows an optimum use of existing statistics and relies on a Delphi Panel to complement the statistical data and ultimately and to estimate fire event risk probabilities. The structure of the fire risk tree and the IAC allows for future integration of more statistical data to replace the Delphi values.

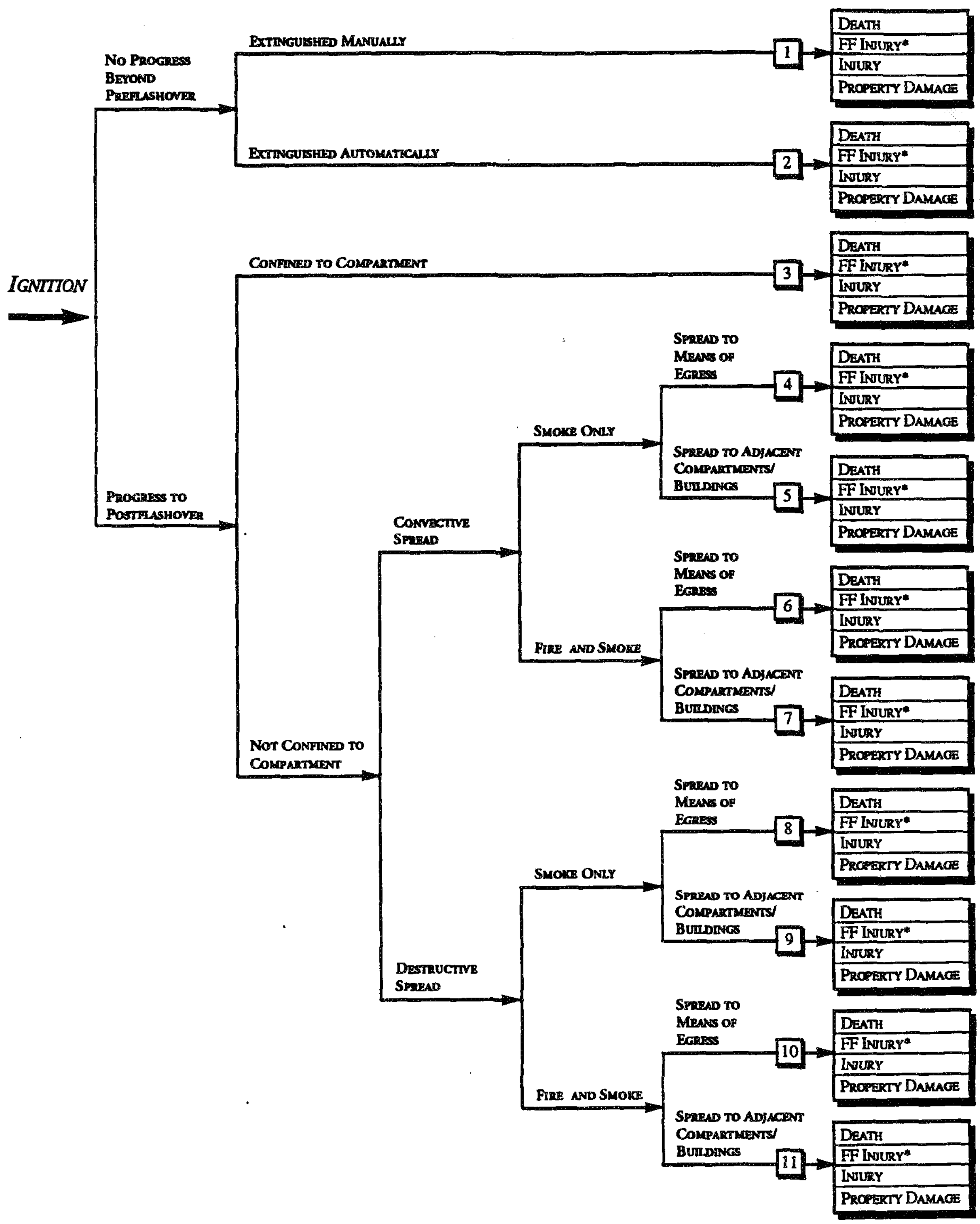
REFERENCES

1 Linestone, H.A. & Turoff, M. (Eds), The Delphi Method, Techniques and Applications, Addison-Wesley Publishing Company, Reading, Mass., 1975.

2 Merz, H.A. & Schneider Th., "Who is Afraid of Risk Criteria", Hazard Prevention, Jan./Feb. 1987, pp. 8 - 13.

3 Bohnenblust, H. & Schneider Th., "From Legal Principles to Engineering Decisions Where Do We Shift to Quantifications?", Paper presented at the V. International Safety Summer Symposium on Safety Science, Leuven, Belgium, 1983.

Figure 1: Fire Risk Analysis Tree



* Firefighter Injury

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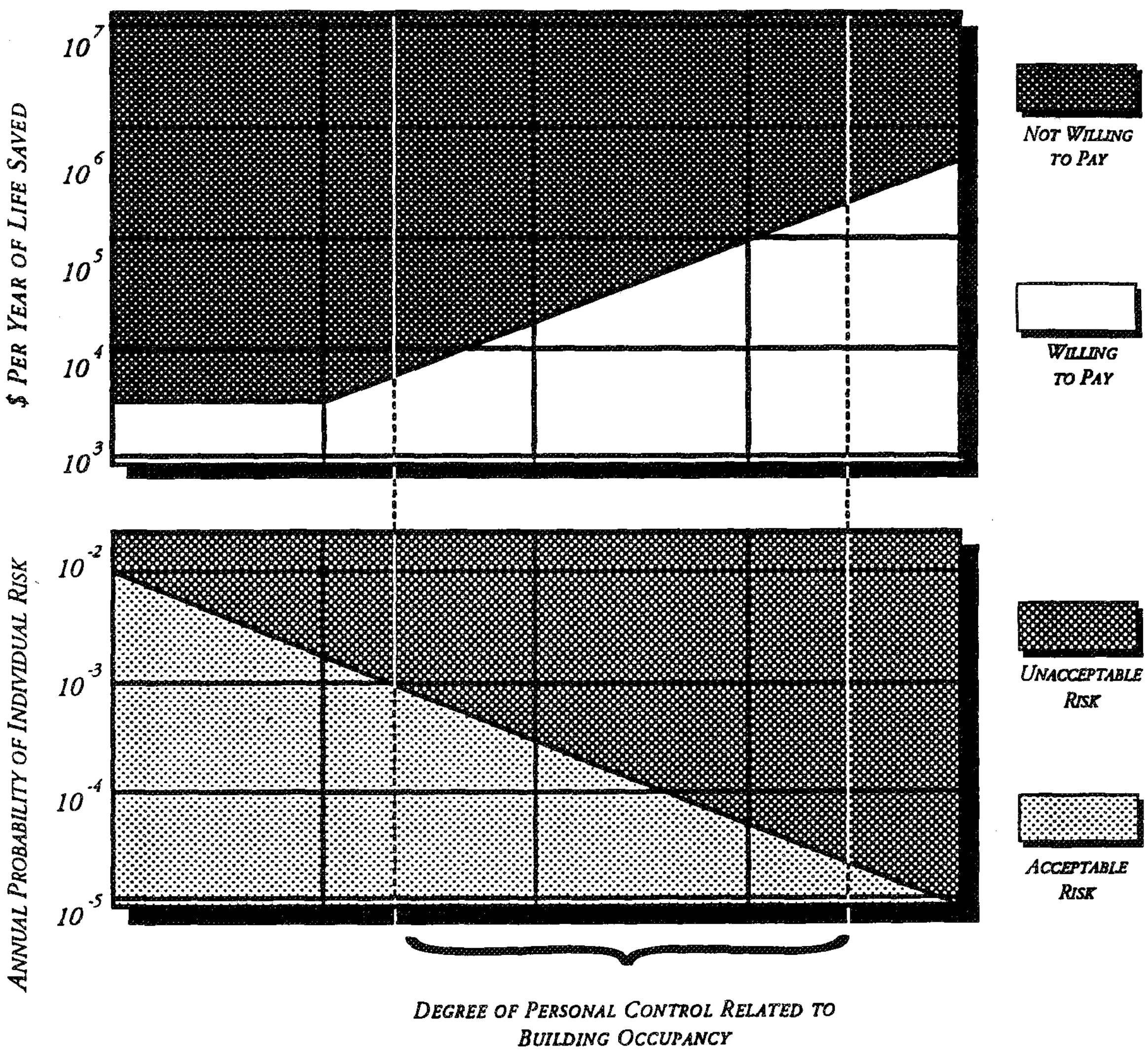
FIGURE 2: COMPARATIVE RISK ASSESSMENT

Extent of Individuals' Personal Control Over Their Activities and Physical Environment			
Category 1	Category 2	Category 3	Category 4
"Voluntary"	Large Degree of Self-Control	Small Degree of Self-Control	"Involuntary"
Windsurfing	*Automobile*	*Public Transportation*	*Nuclear Power*



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