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U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Decision Analysis of Strategies for Reducing Upholstered Furniture Fire Losses

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PREFACE

This report gives an evaluation of three representative alternatives for reducing upholstered furniture fire losses. The project, the purpose of which is to test the utility of decision analysis in evaluating fire safety policy, has been sponsored by the Center for Fire Research, National Bureau of Standards. The analysis was performed jointly by the Program for Information and Hazard Analysis, Center for Fire Research and the Decision Analysis Group, SRI International.

A preliminary project report was issued in November 1977 [1][1]. Since that time new data have become available which have been incorporated into the analysis. As this report goes to press more data are becoming available, which we will incorporate into any subsequent refinements of this analysis. Toward that end, we solicit comments from the reader on new data sources as well as criticisms of the methods used.

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[1] Numbers in brackets refer to references listed at the end of this report.

ABSTRACT

Decision analysis is used to evaluate alternative strategies for reducing residential upholstered furniture fire losses. Three alternatives are evaluated: no-action, mandatory smoke detector installation, and the proposed upholstered furniture standard under consideration by the Consumer Product Safety Commission. Quantitative models are developed to assess fire losses and costs under each alternative. The alternatives are evaluated on the basis of minimizing the total cost plus loss to society over time. Subject to the assumptions set forth in the report, the analysis shows that the detector alternative and the proposed standard are essentially equivalent and preferred to the no-action alternative. The proposed standard is more effective in saving lives, whereas the detector alternative is less costly to implement. The sensitivity of the results to key assumptions and input parameters is tested. The results are shown to be particularly sensitive to the cost of the proposed standard, the loss of life value assignment, and the upholstered furniture replacement pattern.

Key words: Building fires; cost-benefit analysis; costs; decision analysis; fire losses; furniture; hazard analysis; probability; residential buildings; sensitivity analysis; smoke detectors; standards; upholstered furniture.

SUMMARY

Fire is the second leading cause of accidental death in homes in the United States. Thousands of Americans are injured and killed and billions of dollars of property are lost to fire each year. Reducing these losses in a cost effective way requires the delicate balancing of many physical, social and economic factors. This report sets forth a decision analysis approach for accomplishing this balance in establishing fire safety policy.

The decision analysis method is demonstrated within the context of the upholstered furniture fire safety problem. Upholstered furniture fires account for more than 25 percent of all U.S. residential fire fatalities. Three representative intervention strategies are considered. The first is a policy of taking no formal action at all. The second is the implementation of federal legislation requiring smoke detectors in all U.S. residences. The third is the promulgation of the proposed upholstered furniture standard currently under consideration by the Consumer Product Safety Commission.

Quantitative models, constructed especially for the upholstered furniture fire problem, are developed to assess the time varying costs and losses that occur under each strategy. Historical statistics, supplemented by expert judgment, are used to develop probability assignments for the fire loss model. Explicit value assignments are used to convert casualty losses into economic terms. The most attractive strategy from the standpoint of society is that which minimizes total expected cost plus loss.

The analysis shows a gradual reduction in loss under the no-action alternative, due to the increased voluntary and locally required use of smoke detectors and a naturally evolving more smolder-resistant furniture population. The mandatory smoke detector alternative gives a rather substantial reduction in loss, but at the measurable cost of the required smoke detectors. The greatest loss reduction occurs under the proposed standard, but at a greater cost and longer implementation period than under the other two alternatives.

Table 1 gives a formal comparison of the alternatives. The alternatives are evaluated on a present value basis by discounting future expected losses and costs for each year considered and then summing. As shown in the table the present values of the cost plus loss under the three alternatives are equivalent to within 10 percent. To the extent that the alternatives are distinguishable, the proposed standard and smoke detector alternatives are essentially equal and preferred to the no-action alternative.

Table 1. Comparison of Three Alternatives

	Present Value at 8% from 1977 to 2010 (Billions of Dollars)		
Alternative	Loss	Cost	Cost Plus Loss
No-Action	$6.33	$0.00	$6.33
Detector Alternative	5.65	0.30	5.95
Proposed Standard	4.84	1.12	5.96

The sensitivity of the results to changes in the input parameters is tested. Table 2 summarizes three key sensitivity studies. The ranking of alternatives is sensitive to the cost of the proposed standard. A significantly lower cost makes the proposed standard superior to the other alternatives; a significantly higher cost makes it the least attractive alternative. The comparison of alternatives is also somewhat sensitive to furniture replacement patterns. Changing the time required to replace existing furniture from 30 years to 15 years makes the proposed standard about 10 percent more attractive than the next best option. The effect of changing the value assignment on the amount that society is willing to spend to save a single human life is also shown in table 2. Our analysis shows that the proposed standard is preferred for value assignments above our nominal value, whereas the detector alternative is preferred for most assignments below the nominal value.

Additional sensitivity analysis shows that except for the studies presented in table 2 it is difficult to produce a set of reasonable assumptions under which one alternative is substantially superior to the other two. Thus, on the basis of the information available for this analysis, the most attractive of the three alternatives is either the proposed standard or the smoke detector alternative. Further analysis shows that a combination of the smoke detector and proposed standard alternatives is slightly more attractive than either strategy alone, yielding a cost plus loss about $100 million less than either alternative separately.

Since some of the parameters upon which this analysis is based are difficult to estimate, the insights gained from this analysis must be interpreted with the understanding that they are subject to change as new information becomes available on this difficult fire problem.

Table 2. Selected Sensitivity Studies

Sensitivity Study	Present Value of Cost Plus Loss at 8% from 1977 to 2010 (Billions of Dollars)		
	No-Action Alternative	Smoke Detector Alternative	Proposed Standard
First Year Cost of Proposed Standard to Manufacturers			
$ 50 million	$ 6.3	$ 6.0	$ 5.2
$137 million (nominal)	6.3	6.0	6.0
$300 million	6.3	6.0	7.3
Estimated Time to Replace Existing Furniture			
15 years	6.3	5.9	5.6
30 years (nominal)	6.3	6.0	6.0
Loss of Life Value Assignment			
$ 100 000	4.0	3.9	4.2
$ 300 000 (nominal)	6.3	6.0	6.0
$ 500 000	8.7	8.0	7.7
$1 000 000	14.5	13.1	12.2

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Part One

RESULTS OF THE DECISION ANALYSIS

1. INTRODUCTION

In 1975 over 300 000 Americans were seriously injured in fires. Seventy-five hundred persons died. Direct property losses exceeded $4 billion [2]. Considerable work is being directed toward reducing these losses including basic research, community master planning, public education, data collection, hazard analysis, and development and improvement of product standards, building codes, and fire detection and supression devices.

This report documents the development and testing of a methodology for establishing rationally based fire safety policy. Motivation for the project derives from the fire community's need to focus its limited resources on loss reduction programs that provide the best balance between loss reduction and program costs.

The methodology is developed using the discipline of decision analysis. Decision analysis is used to evaluate complex decision problems involving uncertainty. It provides a structured approach for identifying decision alternatives, establishing outcome measures, and developing the necessary models to evaluate the decision alternatives in terms of the outcome measures selected. Probabilistic methods are used to address uncertainty and explicit value judgments are introduced to facilitate comparison of the alternatives. Decision analysis has been used to evaluate a wide variety of strategic decision problems in the public sector including nuclear safety [3], transportation safety [4], and research and development prioritization [5].

The methodology is applied to the upholstered furniture fire safety problem. Smoldering cigarettes which have been inadvertently dropped on furniture are a common cause of these fires. More than one-fourth of all U.S. residential fire deaths result from upholstered furniture fires [6]. Our analysis focuses on accidental fires in one- and two-family homes and apartments in which upholstered furniture is the first item to ignite. We consider only fires that are reported to fire authorities, since those are the fires which are responsible for most of the loss and for which incidence statistics are available.

There are many possible intervention strategies for reducing upholstered furniture fire losses, ranging from local public education efforts to federal product standards. To demonstrate the methodology, our analysis considers three representative intervention strategies. The first strategy is a policy of taking no formal action at all. This strategy provides the baseline against which the other decision alternatives are compared. The second alternative is a federal regulation requiring the installation of at least one smoke detector in every home. The third alternative is the proposed upholstered furniture standard currently under consideration by the Consumer Product Safety Commission (CPSC) [7]. The proposed standard sets forth criteria for eliminating combinations of fabric and furniture construction that are vulnerable to smoldering cigarette ignitions.

In demonstrating the methodology, we use a combination of fire loss data and expert judgment to estimate the input parameters. Although we use the best data available to the project team, there are significant uncertainties and omissions in those data. Since our analysis is directed toward distinguishing the clearly attractive alternatives from the less desirable ones, we direct little effort toward refining our estimates of parameters which do not significantly affect the comparison of the alternatives. Our assumptions and our estimates of the input parameters should be so interpreted.

The report is divided into two parts with a total of seven sections. The first part, Results of the Decision Analysis, is directed at the reader who is interested in the general methodology and principal analytical results. Section 1 describes the purpose of the project and introduces the upholstered furniture fire problem. Section 2 outlines the basic method of approach. Section 3 summarizes the principal results of the analysis giving a minimum of detail on their derivation.

The second part of the report, Detailed Derivation of Results, provides the additional detail necessary to completely document the input data and the model details, and provides additional results as well. Sections 4 through 6 and the appendix give the detailed derivation of the losses and costs under the different intervention strategies. Section 7 presents several sensitivity studies designed to test the validity of our results to changes in the input assumptions.

2. METHOD OF APPROACH

This section describes the basic approach and analytical tools used in evaluating the various intervention strategies. Although the models are elaborated upon in the following sections, this is the only section that presents an overview of our analytical approach.

2.1 Cost Plus Loss Criterion

The intervention strategies are evaluated from the standpoint of minimizing total societal cost plus loss. That is, each alternative is analyzed to determine its total fire-related losses and costs. The most attractive strategy from the standpoint of society is the one that minimizes the total cost plus loss.

It is important to note that the cost plus loss criterion does not account for distributional effects. That is, the measure does not address the question of who bears the costs and who enjoys the benefits of a particular intervention strategy. These distributional effects should ultimately be addressed, however, because the costs of the alternatives are not always borne in proportion to the benefits received. Nevertheless, this initial screening of the alternatives is limited to examining the alternatives from the standpoint of society as a whole.

Use of the cost plus loss criterion necessitates that assessments be made of the costs and the losses occurring under each alternative. We first describe our approach for assessing the losses and costs. We then describe our approach for converting non-monetary losses into monetary terms and for modeling the performance of the alternatives over time. The section concludes with a description of our approach for testing the sensitivity of the results to changes in the input assumptions.

2.2 Loss Assessment

Figure 1 gives a schematic of the model used to assess upholstered furniture fire losses. The model is given in the form of a probability tree. The model parameters are listed across the top of the figure. Each parameter can take on any one of several values represented by the branches under that parameter. Probabilities assigned to the branches represent the likelihood that the parameters will take on the particular values.

Each path through the tree represents a different type of upholstered furniture fire, defined by the values of the parameters making up the path. Associated with each path are expected losses, representing the average losses for that type of fire. The probability for each path is calculated by multiplying the probabilities of the branches making up the path. Combining the losses associated with each path with the path

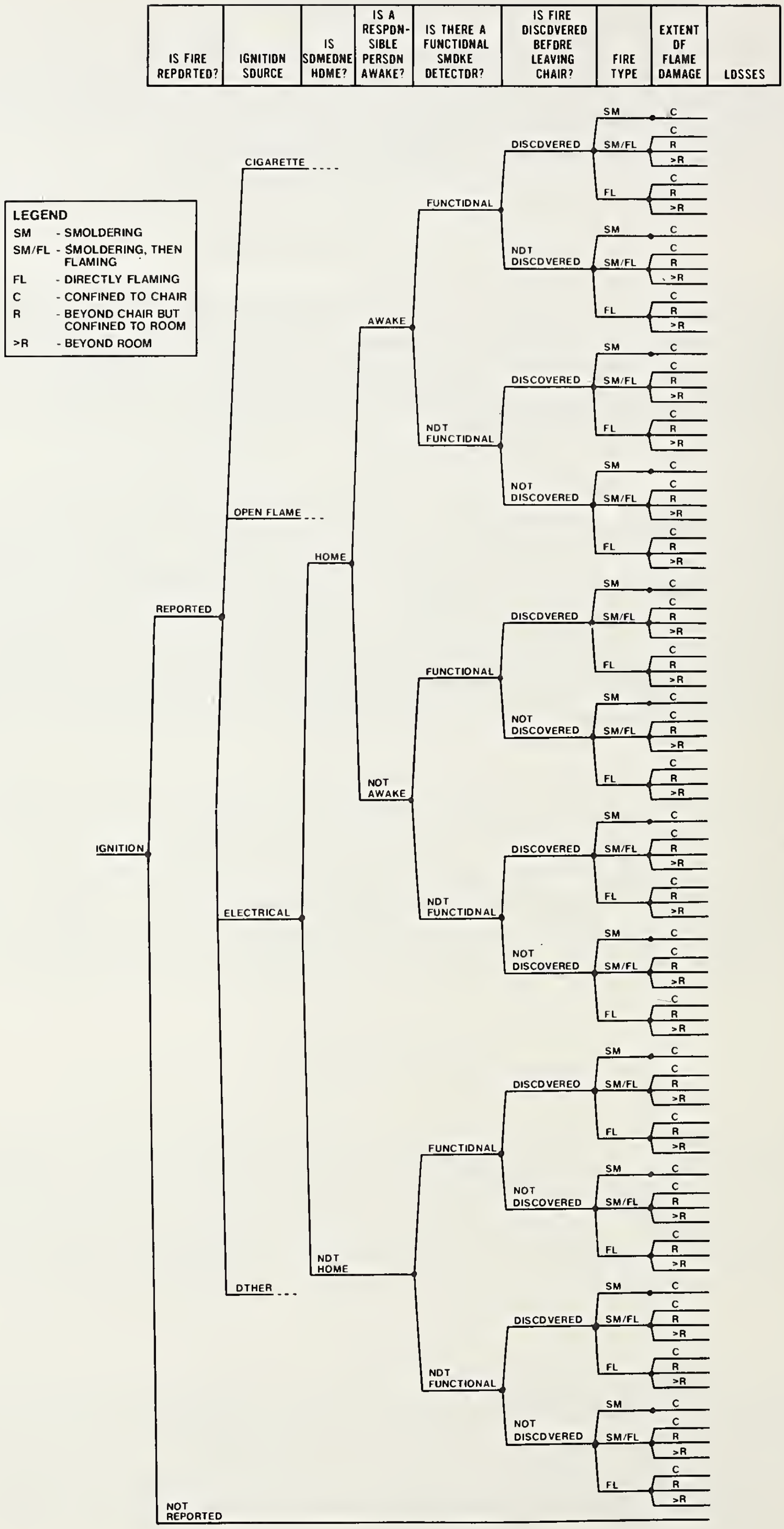

Figure 1. Probability Tree

probability allows us to construct the probability distribution of average losses resulting from a single reported upholstered furniture fire. The expected loss per reported fire is calculated by multiplying each path probability by its associated level of loss and then summing.

The model parameters are initially set to reflect current conditions. We then adjust the input probabilities to reflect the performance of the various intervention strategies. The expected losses for each path are kept the same for the various strategies since the type of fire represented by the path is unchanged. The model is exercised for each intervention strategy to obtain the average losses per reported fire. These results are then multiplied by the number of reported fires occurring under the alternative (determined in a separate calculation) to give the total annual U.S. losses under each intervention strategy.

The fire loss model serves as a vehicle for distinguishing the clearly attractive decision alternatives from the less desirable ones. The model is not intended to predict exactly how each of the alternatives will perform. Parameters are included in the model if they are judged to be important in comparing the alternatives or in making basic assessments of the overall loss. Thus, for example, a parameter for the heat release rate of the furniture is not included in the model because that parameter has little direct effect on the comparison of the alternatives.

2.3 Cost Assessment

Several categories of cost must be taken into account in determining the total societal cost of each intervention strategy. Some of the costs are market-based and others are non-market related. Obvious market costs are the added consumer expenditures imposed by the intervention strategy. These include the costs of the smoke detector purchases and higher prices paid for furniture produced under the proposed standard.

However, in addition to increased consumer expenditures, there are other market costs associated with the higher prices which occur under the proposed standard. These additional costs are due to the fact that certain consumers are forced out of the market as the price is increased. The fact that these consumers are no longer able to enjoy the benefits of new upholstered furniture constitutes a cost to society. We defer further discussion of how this cost is calculated until section 6.

Non-market costs are the societal costs not associated with consumer purchases. Government expenditures for research and development or enforcement are examples of non-market costs. Other costs include the societal cost of reduced market choice and the cost of less aesthetically pleasing furniture, should that be an effect of an intervention strategy.

The total cost to society of an intervention strategy is the sum of all costs incurred under that strategy.

2.4 Value Assignments

Since fire losses are measured in different units, e.g. numbers of fatalities, numbers of injuries, and dollars of property loss, it is desirable to transform these measures into common units to permit consistent comparison among alternative strategies. We convert numbers of fatalities into equivalent dollars for this purpose, based on value assignments representing the amount society is willing to spend to prevent a single fire fatality. We multiply the number of injuries by our estimate of the average cost of an upholstered furniture fire injury. The nominal value assignments used in our analysis are given in section 3.1.2.

2.5 Dynamic Considerations

Most intervention strategies require a number of years for full implementation. Thus, in analyzing the alternatives we must evaluate them over some period of time. Our approach is to evaluate each of the alternatives over the same time period, 1977 to 2010. We first evaluate the losses before any of the alternatives are implemented. Then, for each alternative we evaluate the losses for the year in which the alternative is fully implemented. Losses for the intervening years are found by interpolation according to the rate at which the alternative is implemented. Details on this process are given in section 5. For simplicity we assume a constant U.S. population and we use constant 1977 dollars throughout the analysis. These simplifications should not significantly affect the comparison of alternatives.

We use a present value method to compare the time varying patterns of cost and loss under the different alternatives. The future values of cost plus loss are discounted to the present time at a compound rate and then summed. The resultant sum is called the present value of the cost plus loss. The present value is a scalar measure that gives the present worth of the time stream of cost plus loss.

2.6 Sensitivity Analysis

An important step in our approach is sensitivity analysis. The alternatives are initially evaluated using nominal values or best estimates for each of the input parameters. We then reevaluate the alternatives using different values for the various input parameters. If a change in the ranking of the alternatives occurs over a reasonable range of a parameter, then additional effort may be required to refine the estimate of that parameter. Sensitivity analysis is important in guiding the model building and data gathering effort because it enables us to focus our attention on the factors that most critically affect the evaluation of alternatives.

3. PRINCIPAL RESULTS

This section gives the principal results of our analysis. The findings are presented with a minimum of derivation to emphasize the performance and comparison of alternatives. Details on the assumptions, data, and methodology are given in part two.

3.1 Current Losses

We first use the fire loss model to calculate upholstered furniture fire losses under current conditions. This exercise serves to partially validate the model and also provides a reference for comparing the performance of the alternatives.

3.1.1 Expected Loss Per Reported Fire

Table 3 gives the expected losses per reported fire as calculated from the model. We defer until section 4 a presentation of the input data for calculating current losses. The table shows that, on the average, 0.0276 persons are killed and 0.159 persons are injured in each reported upholstered furniture fire under current conditions.[2] The average property damage is $4,190 per fire, consisting of $3,640 for tangible property losses and $550 for intangible property losses. Intangible property losses are defined as other than real property losses, such as aesthetic damage, disruption of life style, and loss of family mementos.

3.1.2 Value Assignments

The various categories of fire loss are expressed in different units. The multi-dimensionality of these outcomes gives a comprehensive description of the loss, but makes it difficult to compare alternatives when there is a mixed ordering of the outcomes. For example, it is not apparent whether an alternative that results in one death and twenty serious burn injuries is preferable to one that results in two deaths and ten serious burn injuries.

To facilitate comparison of the alternatives and to ensure that they are compared in a consistent manner, we introduce a set of explicit value judgments. The value judgments assign a dollar equivalent to each unit of loss. They allow us to convert the several dimensions of loss into a single monetary equivalent. We recognize that determining a representative set of value assignments for all of society is a difficult task and that there is much disagreement among different individuals on how these assignments should be made. Ignoring the value judgments, however, will not obviate the problem, because value judgments are made,

[2] Both fire fighter and civilian casualties are included in these figures.

Table 3. Expected Losses Per Reported Fire Under Current Conditions

Category	Expected Loss[a] Number	Value Assignment	Monetary Equivalent[b]
Fatalities	0.0276	$300,000	$ 8,290
Injuries	0.159	10,000	1,590
Property			
Tangible			3,640
Intangible			550
Aggregate			$14,100

[a]Results in part one of this report are given to three significant figures or the nearest dollar.

[b]Calculations may not check because of rounding.

either implicitly or explicity, every time a choice among public safety alternatives is made. The value judgments are made explicit in this analysis to ensure a consistent evaluation of alternatives and to allow for an explicit examination of how the ranking of the alternatives depends on the value judgments.

Table 3 gives the nominal value judgments used in this analysis. We use $300,000 as the amount society is willing to pay to save a single life, and $10,000 as the cost of an average reported fire injury. The $300,000 figure is representative of amounts used in several public safety studies [8,9,10] but it should be pointed out that figures have been used ranging from $100 000 to $1 million per life saved [11,12,13]. The $10,000 injury figure is the amount cited by the Consumer Product Safety Commission in their assessment of the possible economic impact of the proposed standard [14]. We wish to emphasize that the value assignments used here are representative values only, and that the final decision should be based on a set of assignments deemed appropriate by the decision maker. Sensitivity studies are presented in subsequent sections showing how the results change with changes in the value assignments.

The aggregate loss, given in table 3, is the total of the monetary equivalents of the loss categories. The expected aggregate loss equals $14,100 per reported upholstered furniture fire. Loss of life is the major component of the loss, accounting for almost 60 percent of the total dollars. Tangible property loss is the second most important component, accounting for more than 25 percent of the total. Injuries represent only about 10 percent of the loss. We emphasize that the relative contributions of the different loss categories are dependent on the value assignments for death and injury. Using the nominal value assignments, table 3 shows that the greatest reduction in upholstered furniture fire losses would come from those alternatives which are most effective in reducing the number of fatalities.

Total annual losses are determined by multiplying the losses for a single reported fire by the annual number of reported upholstered furniture fires. As this important statistic is not reported directly, we derive it in the following section.

3.1.3 Annual Number of Ignitions

Clarke and Ottoson [6] have estimated the fraction of fire fatalities occurring in different categories of fires. Combining their estimates with the total number of fire fatalities estimated by the U.S. Fire Administration allows us to estimate the annual number of upholstered furniture fire fatalitites. These calculations are given in table 4.

Table 4. Development of Annual Number of Upholstered Furniture Fire Fatalities

Fire Category	Annual Number of Fatalities
U.S. total	7500
Residential 0.72 x 7500 =	5400
Residential and furnishings 0.54 x 5400 =	2920
Residential and upholstered furniture 0.50 x 2920 =	1460
One-and two-family homes and apartments and upholstered furniture 0.90 x 1460 =	1310

According to the U.S. Fire Administration there are currently 7,500 fire fatalities in the United States each year [2]. Multiplying by 0.72, the fraction of fire fatalities occurring in residences, as estimated by Clarke and Ottoson, gives an estimate of 5,400 residential fire deaths per year. Of these, Clarke and Ottoson estimate that 54 percent are the result of fires in which household furnishings are the first item ignited. Furthermore, they estimate that in approximately half of these cases, the first-to-ignite furnishings are pieces of upholstered furniture. Applying these percentages to the 5,400 residential fatalities gives 1,460 fatalities from upholstered furniture fires annually. Of these 1,460 fatalities about 90 percent, or 1,310 fatalities, occur in the occupancy classes considered in this analysis (one- and two-family homes and apartments).

We assume that essentially all fatalities occur in reported fires. Thus, dividing the 1,310 fatalities by 0.0276, the expected number of fatalities per reported upholstered furniture fire given in table 3, gives an estimated 47,500 reported upholstered furniture fires per year in one- and two-family homes and apartments under current conditions. Our estimates of the number of fatalities and the number of reported fires (1,460 and 47,500 respectively) are corroborated by recent testimony before the Consumer Product Safety Commission by the U.S. Fire Administration. Using their National Fire Incident Reporting System (NFIRS) data for 1977, they estimate 1,500 residential upholstered furniture fire fatalities and between 42,000 and 61,000 reported structural upholstered furniture fires in that year [15].

3.1.4 Total Annual Losses Under Current Conditions

Table 5 gives the total annual losses from reported upholstered furniture fires under current conditions. The results are obtained by multiplying the expected loss figures given in table 3 by 47,500, our estimate of the annual number of reported upholstered furniture fires. As shown, the total annual expected losses include 1,310 fatalities, 7,570 injuries, $173 million in tangible property loss, and $26 million in intangible property loss. The annual aggregate loss, which is the total of the monetary equivalents, is $668 million.

Table 5. Total Annual Reported Upholstered Furniture Fire Losses Under Current Conditions

Category	Total Annual Expected Losses[a] Number	Total Annual Expected Losses[a] Monetary Equivalent (Millions of Dollars)
Fatalities	1310	$394
Injuries	7570	76
Property		
Tangible		173
Intangible		26
Aggregate		$668

[a]Calculations may not check because of rounding.

3.2 The No-Action Alternative

One possible intervention strategy is to take no action at all. Even under this strategy, however, the losses will vary over time because of two important trends. The first is a change in the construction and composition of upholstered furniture. The second is the increased use of smoke detectors in residences. Both of these factors will tend to reduce upholstered furniture fire losses and must be taken into account if we are to properly model the losses under the no-action alternative.

In assessing the losses under the no-action alternative, we first define the trend we believe these forces will take. We then model the losses for a year in which these trends have reached their "steady state," or when the alternative has been "fully implemented." Finally, we interpolate, according to the rate at which these trends occur, to determine the losses for the intervening years. As discussed in section 2, we assume no growth in the U.S. population. This assumption should not significantly affect the relative comparison of alternatives. All of the results are given in 1977 dollars.

3.2.1 Losses Under the Fully Implemented No-Action Alternative

An important trend in the upholstered furniture industry is the replacement of cellulosic materials by thermoplastic fibers and urethane foam cushioning materials. This trend is important because thermoplastic upholstery materials tend to be more resistant to smoldering ignition. However, once ignited, synthetic materials tend to result in larger fires. For the purpose of this analysis, we assume that furniture manufacturers will continue to use man-made materials at current usage levels. Thus the furniture population will evolve toward a mix of furniture with the same flammability characteristics as current furniture production. Details on the fire characteristics of the currently produced furniture population are given in section 5.1.

A second phenomenon affecting upholstered furniture fire losses is the increased use of residential smoke detectors. The four model building codes in use throughout most of the United States now require that at least one smoke detector be installed in all new residential construction. Current retail sales of smoke detectors are also growing rapidly. We assume that eventually 60 percent of the households in the United States will have at least one smoke detector. However, the presence of a smoke detector does not guarantee that it will function properly. In addition to reliability problems, there are problems of lack of maintenance, such as battery replacement, as well as actual misuse. In this analysis we assume that at any point in time, 80 percent of the installed smoke detectors will be operating properly. Thus, for the no-action alternative we assume that eventually 48 percent (0.60 x 0.80) of U.S. households will have one or more functional smoke detectors. (The sensitivity of our results to the assumptions concerning the installation level and functional percentage is examined in section 7.3.)

Section 5.1 details how the fire loss model is adjusted to reflect the new furniture population and the increased use of smoke detectors. The resultant losses for the fully implemented no-action alternative are given in table 6. The table shows that total expected U.S. losses under the no-action alternative are estimated to be $486 million per year for a future year when the furniture population has been completely replaced with furniture of the type currently produced and when the smoke detector installation has leveled off at 60 percent. The aggregate loss is the total of the monetary equivalent of 878 fatalities and 4,900 injuries, as well as $149 million in tangible property loss and $24 million in intangible property loss. Again, the monetary value assigned to loss of life accounts for the majority of the aggregate loss (54 percent). Tangible property loss is again the second most significant contributor, at 31 percent.

Table 6. Total Annual Reported Upholstered Furniture Fire Losses Under Fully Implemented No-Action Alternative

	Total Annual Expected Losses[a]	
Category	Number	Monetary Equivalent (Millions of Dollars)
Fatalities	878	$263
Injuries	4900	49
Property		
Tangible		149
Intangible		24
Aggregate		$486

[a]Calculations may not check because of rounding.

The total expected loss of $486 million under the fully implemented no-action alternative compares with $668 million under current conditions. As detailed in section 5.1, the 27 percent loss reduction is primarily the result of the increased use of smoke detectors. A small part of the loss reduction is the result of the changes in the furniture population.

3.2.2 Losses Under the No-Action Alternative Over Time

The losses just calculated are for the case of the fully implemented no-action alternative. However, since it will take a number of years for the no-action alternative to become fully implemented, we must model the losses for the intervening years. Section 5.1.2 details how the losses are modeled over time. Our furniture replacement model predicts that it will take 30 years, or until 2005, to replace virtually all of the current furniture population with post-1975 furniture. For simplicity, we also assume that the smoke detector installation will reach its saturation level of 60 percent by 1980. The 1980 losses are determined in a separate calculation. Losses for the remaining years are found by interpolation based on the rates of smoke detector installation and furniture replacement.

Figure 2 shows the aggregate losses over time for the no-action alternative from 1975 to 2010, the time frame of our loss analysis. (The aggregate losses for the smoke detector alternative and the proposed standard alternative, detailed in sections 3.3 and 3.4, are also shown in the figure.) The current aggregate losses of $668 million per year decline under the no-action alternative to $492 million per year by 1980. This decline is primarily due to the increased level of functioning smoke detectors. The aggregate losses eventually level off at the $486 million annually cited in the previous section.

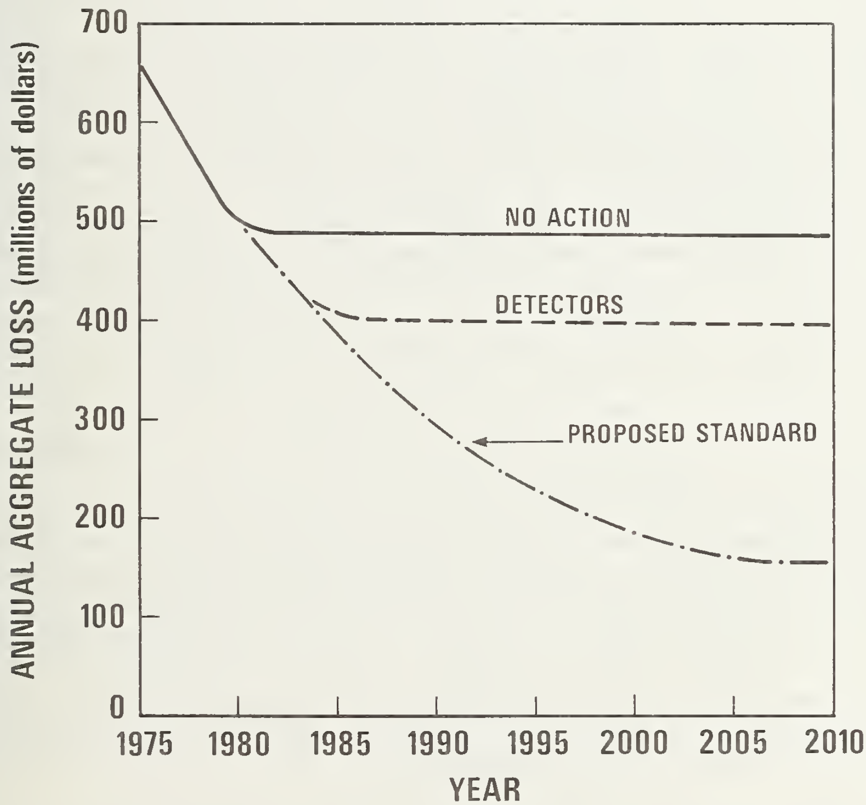

Figure 2. Annual Aggregate Loss Under Three Alternatives

3.3 The Smoke Detector Alternative

A second alternative for reducing upholstered furniture fire losses is to require the use of residential smoke detectors. Detectors are effective in providing early warning of fire. Thus, requiring their use in residences should increase the number of upholstered furniture fires that are discovered and contained while they are small and increase the time available for escape. Several intervention strategies are possible involving smoke detectors. However, to provide a reference on the general effectiveness of smoke detectors, we consider an alternative under which all U.S. residences are required to install at least one smoke detector. We are not aware of such a strategy being given active consideration at this time, but the alternative, as defined for this analysis, does provide a basis for comparing smoke detectors with other intervention strategies.

Our smoke detector alternative is directed toward requiring smoke detectors in all residences that do not currently have detectors. However, several communities already require detectors in existing dwelling units. For example at this writing, Montgomery County, Maryland; Minneapolis, Minnesota; San Carlos, California; and Farmer's Branch, Texas have legislated requirements for the installation of a smoke detector in all homes. Many other communities such as Chicago, Illinois, and Prince George's County, Maryland, are requiring smoke detectors in most multifamily dwellings. Still other communities, although not requiring detectors by law, have innovative plans for attaining high installation levels. For example, Rock Island, Illinois, is purchasing a smoke detector for each home to be installed by the local fire department. As noted earlier, smoke detectors are now required in the model building codes for new construction. Thus, requiring smoke detectors in all U.S. residences is a useful alternative for analysis.

3.3.1 Losses Under the Fully Implemented Smoke Detector Alternative

We assume that 90 percent of all U.S. homes will have smoke detectors under the fully implemented smoke detector alternative. As before, we assume that at any point in time 80 percent of the installed detectors will be working. Thus, under the fully implemented smoke detector alternative, we assume that 72 percent (0.9 x 0.8) of U.S. households will have a functional smoke detector. Also, as under the no-action alternative, we assume that the currently installed furniture population will be replaced with a population that has the same burning characteristics as the currently produced furniture.

The fire loss model is used to determine the losses under the fully implemented smoke detector alternative. The model parameters are adjusted to reflect the added smoke detectors and changed furniture population and the new numbers of ignitions and reported fire are computed. The expected annual losses from reported fires determined in this way are given in table 7.

Table 7. Total Annual Reported Upholstered Furniture Fire Losses Under Fully Implemented Smoke Detector Alternative

Category	Total Annual Expected Losses[a]	
	Number	Monetary Equivalent (Millions of Dollars)
Fatalities	678	$203
Injuries	3960	40
Property		
Tangible		131
Intangible		21
Aggregate		$396

[a]Calculations may not check because of rounding.

The table shows that the total annual upholstered furniture loss under the fully implemented smoke detector alternative is $396 million. This compares with a current loss of $668 million per year and an annual loss of $486 million under the fully implemented no-action alternative. There are 678 fatalities and 3,960 injuries expected annually as well as $131 million in tangible property loss and $21 million in intangible property loss. Once again, the dollar contribution of loss of life accounts for more than half of the aggregate total.

Whereas both the smoke detector and no-action alternatives offer significant long range loss reductions relative to current levels of loss, we note that the difference in loss between the two fully implemented alternatives is relatively small, $90 million. The reason is that a significant smoke detector installation level is assumed under the no-action alternative. The detector alternative addresses only the marginal detector installation beyond the no-action level, increasing the installation level of smoke detectors from 60 percent to 90 percent, thus resulting in an increase from 48 to 72 percent in the level of functional detectors.

3.3.2 Effectiveness of Smoke Detectors in Upholstered Furniture Fires

For use in later calculations, we also determine the maximum effectiveness of smoke detectors in reducing personal and property loss. The maximum effectiveness is determined by exercising the model twice: with the probability of a functional smoke detector first set at 0.0 and then set at 1.0. The difference in the two cases is 65 percent, 59 percent, and 45 percent reductions in deaths, injuries, and property loss, respectively. These differences provide upper bounds on the effectiveness of smoke detectors in reducing upholstered furniture fire losses, since they compare zero percent reliability of the detectors with 100 percent reliability. These results are used in section 6.2 to allow us to assign only a portion of the smoke detector cost to reducing upholstered furniture fire losses. These results are also useful as an indication of the validity of the model, since they agree well with predictions for upholstered furniture fire loss reductions made by experts in fire detection [16].

3.3.3 Losses Under the Smoke Detector Alternative Over Time

We assume that the smoke detector alternative will take effect in 1980, and that the 90 percent installation rate will be reached by 1985. Thus losses from 1975 through 1980 are identical to the losses under the no-action alternative. As in the case of the no-action alternative, the smoke detector alternative is not "fully implemented" until the year 2005 when the current furniture population is replaced with post-1975 furniture. Losses for the years from 1980 until full implementation is achieved in 2005 are found by interpolation according to the rates at which the furniture population is replaced and the smoke detectors are installed. The losses for the years after 2005 are constant since it is assumed that the furniture population and detector installation have reached their steady state.

Figure 2 shows the aggregate losses over time for the smoke detector alternative from 1975 to 2010. The current aggregate losses of $668 million per year eventually decline to $396 million annually. Almost all of this decrease occurs by 1985 when the projected level of smoke detector installation is reached. The continuing slight decline in losses between 1985 and 2005 is attributable to the continuing replacement of furniture.

3.4 The Proposed Standard Alternative

A third alternative considered for reducing upholstered furniture fire losses is the proposed upholstered furniture standard currently under consideration by the Consumer Product Safety Commission. The proposed standard is intended to reduce smoldering ignitions in upholstered furniture, primarily those caused by cigarettes. Combinations of upholstery and furniture construction that can be ignited by cigarettes would not be permitted under the proposed standard.

Under the proposed standard, upholstery fabrics would be separated, according to a stipulated flammability test, into four classes: A, B, C and D. Class A fabrics are those that are most resistant to cigarette ignition, and Class D fabrics are those that are least resistant. Some reasonably simple modifications in the furniture construction, many of which are now being implemented by the manufacturers voluntarily, would allow most furniture to meet the proposed standard with Class A, B, or C fabrics. These modifications include substituting vinyl welt cord for braided cellulose and twisted paper welt cord, treating cotton batting with boric acid, producing more smolder-resistant decking systems, and using various wrappings on cushions. These techniques, however, will not enable most constructions to comply with the proposed standard with the majority of Class D fabrics.

Class D fabrics, which account for about 40 percent of the upholstery fabrics now in use [17], are primarily heavyweight cellulosic fabrics such as jacquards and velvets. If the proposed standard is enacted, some manufacturers might cease using Class D fabrics, switching instead to currently produced Class A, B, or C fabrics. Other manufacturers might choose to add a needle punched aluminum foil barrier system to the arms, backs, and cushions of the furniture. Such a system has been shown to be effective at drawing heat away from the smoldering source, thereby reducing the likelihood of a smoldering ignition. Some Class D fabrics could be upgraded to Class A, B, or C by blending synthetic materials with the cellulosic fibers. Another as yet unproven technique is to apply a microencapsulated sulfur backcoating to the Class D fabric, thereby making it a Class A or B fabric. Other smolder inhibitors might also be used in this manner.

3.4.1 Losses Under the Fully Implemented Proposed Standard Alternative

For the purpose of this analysis we assume that the foil barrier method or a similar construction method will be used to make Class D fabrics comply with the proposed standard. Because of such factors as poor quality control in the manufacturing process, loss of ignition resistance due to soil and wear, use of slipcovers and noncompliant reupholstering, we assume that only 80 percent of the furniture population manufactured under the proposed standard will be in compliance. We also assume, as in the no-action case, that 60 percent of U.S. households will eventually have a smoke detector, of which 80 percent will be working at any one time. Details for modeling these assumptions are given in section 5.3. The resultant losses are given in table 8.

Table 8 shows that the total annual upholstered furniture loss under the fully implemented proposed standard is $157 million per year. There are 259 fatalities and 1,560 injuries annually as well as $55 million in tangible property loss and $9 million in intangible property loss. Once again, the principal loss component is loss of life, accounting for half of the total. The total annual loss under the proposed standard of $157 million is less than one-fourth of the $668 million current loss, less than one-third of the $486 million loss under the fully implemented no-action alternative, and less than one-half of the $396 million loss under the fully implemented detector alternative.

Table 8. Total Annual Reported Upholstered Furniture Fire Losses Under Fully Implemented Proposed Standard Alternative with 80 Percent Compliance

	Total Annual Expected Losses[a]	
Category	Number	Monetary Equivalent (Millions of Dollars)
Fatalities	259	$ 78
Injuries	1560	16
Property		
Tangible		55
Intangible		9
Aggregate		$157

[a]Calculations may not check because of rounding.

As shown in section 5.3, the losses under the fully implemented proposed standard can be partitioned into those losses which are attributable to furniture that is compliant with the proposed standard and those attributable to furniture that is not compliant. We find that $97 million or 62 percent of the total U.S. loss is due to the noncompliant portion of the population. Furthermore, 176 of the 259 total expected fatalities, or 68 percent, are from fires involving the 20 percent noncompliant furniture. Thus it appears that the compliance rate may significantly affect the overall effectiveness of the proposed standard. A sensitivity study on the compliance level is presented in section 7.3.4.

3.4.2 Losses Under the Proposed Standard Alternative Over Time

In modeling the losses under the proposed standard over time, we assume that the standard takes effect in 1980. As for the no-action alternative, we assume that 60 percent of all residences will have purchased smoke detectors by 1980. Thus, the losses from 1975 to 1980 are the same as for the no-action case. Our furniture replacement model predicts that it will take 30 years, from 1980 until 2010, to replace virtually all existing furniture with furniture manufactured under the proposed standard. The losses between 1980 and 2010 are found by interpolation, taking the appropriate weighted average of furniture that is compliant and noncompliant with the proposed standard.

The annual aggregate losses expected under the proposed standard alternative are shown in figure 2. The losses decline prior to 1980 because of the increased level of smoke detector installation and are identical to the no-action alternative losses. After 1980, the losses decrease as more and more furniture becomes compliant with the proposed standard, eventually reaching the level of $157 million annually.

Figure 2 shows that the proposed standard alternative is the most effective alternative for reducing fire losses. The detector alternative is the next most effective at loss reduction. However, both of these alternatives have measurable costs associated with the loss reduction. We address these costs in the following sections.

3.5 Cost of Implementing the Intervention Strategies

This section summarizes our cost estimates for implementing the various alternatives.

3.5.1 Cost of the No-Action Alternative

We assume that no costs are incurred under the no-action alternative. Although smoke detectors are purchased under this alternative, these purchases do not result from any action taken under this alternative. Therefore, we do not include the currently projected detector purchases as a cost. The zero cost of the no-action alternative provides a baseline for measuring the costs of the other alternatives.

3.5.2 Cost of the Smoke Detector Alternative

We assume that the effect of the smoke detector alternative is to increase the installation level of smoke detectors from 60 to 90 percent. Column 1 of table 9 gives the total consumer expenditures associated with this increase in installation level. The total costs are based on an average installed cost of $22 per detector[3] and an average operating cost of $1.80 per detector per year. We also assume a 10 percent annual replacement rate. As discussed previously, we assume that the installation requirement will become effective in 1980 and that the 90 percent installation level will be reached by 1985. Since we have assumed a constant U.S. population, we also assume that the number of U.S. households requiring detectors remains constant. Thus for the years 1985 and beyond, only operating and replacement costs are required, as shown in column 1.

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[3] Most of the detectors are assumed to be battery-operated with no associated installation cost.

Table 9. Cost of Smoke Detector Alternative

	Annual Cost[a] (Millions of Dollars)		
Year	All Required Smoke Detectors	Amount Allocated to Upholstered Furniture Fires (29% of col. 1)	Smoke Detector Alternative Total (Col. 2 plus $1 million)
1975-9	$ 0.0	$ 0.0	$ 0.0
1980	102.8	29.8	30.8
1981	120.1	34.8	35.8
1982	137.3	39.8	40.8
1983	154.6	44.8	45.8
1984	171.9	49.9	50.9
1985 & beyond	86.4	25.1	26.1

[a]All costs, as well as losses, in this report are given in 1977 dollars.

The costs in column 1 of table 9 are the total direct consumer expenditures associated with increasing the smoke detector installation level from 60 percent to 90 percent. However, it is not appropriate to assign all of these costs to the smoke detector alternative because the benefits of the detectors also apply to fires other than upholstered furniture fires.[4] As discussed in section 6.2, we assign 29 percent of the total detector costs to the upholstered furniture fire scenario based on the fraction of lives smoke detectors could save in upholstered furniture fires compared to all residential fires. The consumer expenditures allocated to the smoke detector alternative are given in column 2 of table 9.

Finally, implementation of the smoke detector alternative would result in costs to the government for enforcement and education. We include $1 million annually to reflect the portion of this cost attributable to upholstered furniture fires. The total annual cost of the

[4]An alternative and more comprehensive approach would be to compare the total costs of the required smoke detectors with the total benefits derived from their use, whether they occur in upholstered furniture fires or other types of fires. However, modeling the benefits of smoke detectors in other residential fires would require a considerably larger analytical effort than this project permits. Therefore we choose the simpler approach of only modeling the costs and benefits associated with upholstered furniture fires.

smoke detector alternative, obtained by adding $1 million to the upholstered furniture allocation, is shown in column 3 of table 9.

3.5.3 Cost of the Proposed Standard Alternative

The costing of the proposed standard alternative involves a number of detailed assumptions and calculations. This section summarizes the results of these computations. The reader is referred to section 6.3 for a detailed derivation of the cost estimates.

3.5.3.1 First-Year Cost of the Proposed Standard

For our initial analysis of the proposed standard alternative we assume that the standard will be met by the barrier method discussed earlier. As detailed in section 6.3, we estimate that about 38 million linear yards of Class D fabric would be underlaid with a foil barrier. Labor, material, and inventory for applying the barrier would total $103.7 million. We assign an additional $11.6 million for the necessary treating of the cotton batting. Testing, record-keeping, and research and development costs total an additional $21.3 million. Thus, we estimate the total first-year costs to the furniture manufacturer to be $136.6 million. This represents an average cost of $6.83 per piece when averaged over the total furniture production.

In a separate paper, C. Muehlhause [18] has calculated that due to commissions and other markup effects, the first-year manufacturing costs should be multiplied by a "market factor" of 1.5 to obtain the total cost to society. Thus, the total first-year cost of the proposed standard is $136.6 million x 1.5 + $1 million = $206 million, where $1 million is added to reflect enforcement costs. Although it is possible that the aluminum foil barrier may affect the aesthetic quality of the furniture, we assume that the barrier will be sufficiently well designed to overcome any aesthetic problems. Therefore, aesthetics costs are not included in this estimate.

3.5.3.2 Cost of the Proposed Standard Over Time

As discussed in section 6.3, we expect that the manufacturers' cost of the proposed standard will decline over time. This decline is anticipated because each Class D fabric must be separately tested with each construction, and because an additional step is required in the fabrication process when Class D fabrics are used. Many manufacturers are expected to avoid this additional effort by substituting fabrics of a higher class for Class D fabrics. We estimate that the usage of Class D fabrics will decline from 40 percent in 1980 to 20 percent in 1985. There will be a corresponding reduction in the cost of applying the barrier. We also assume that research and development will reduce the cost of the barrier material by 50 percent within 5 years, and we eliminate the research and development costs after 1985. Although we project a decline in the use of Class D fabrics, we assume that many of these fabrics will be replaced by similar fabrics of a higher class so that there would be no perceptible loss of market choice. Table 10 summarizes the initial and long-range costs of the proposed standard to the furniture manufacturer.

Table 10. Summary of Manufacturers' Cost of the Proposed Standard

	Annual Cost (Millions of Dollars)	
Component	Initial	Long Range
Barrier Installation		
Material	$ 39.9	$10.0
Labor and Handling	63.8	31.9
Cotton Batting Treatment	11.6	11.6
Testing and Recordkeeping	20.3	12.4
Research and Development	1.0	0.0
Total	$136.6	$65.9

We assume that the proposed standard takes effect in 1980 and that the cost reductions discussed above have occurred by 1985. The manufacturers' costs for 1981-1984 are found by linear interpolation. The manufacturers' cost for all years after 1985 are set equal to the 1985 costs.

The total annual societal cost of the proposed standard alternative using the barrier method is given in figure 3. As with the first year, the manufacturers' cost is multiplied by the market factor and then $1.0 million is added for the cost of enforcement. The market factor is assumed to be 1.5 for the first five years, and then, due to long term competitive adjustments in the upholstered furniture market, to decline linearly over the next 10 years to a constant level of 1.2.

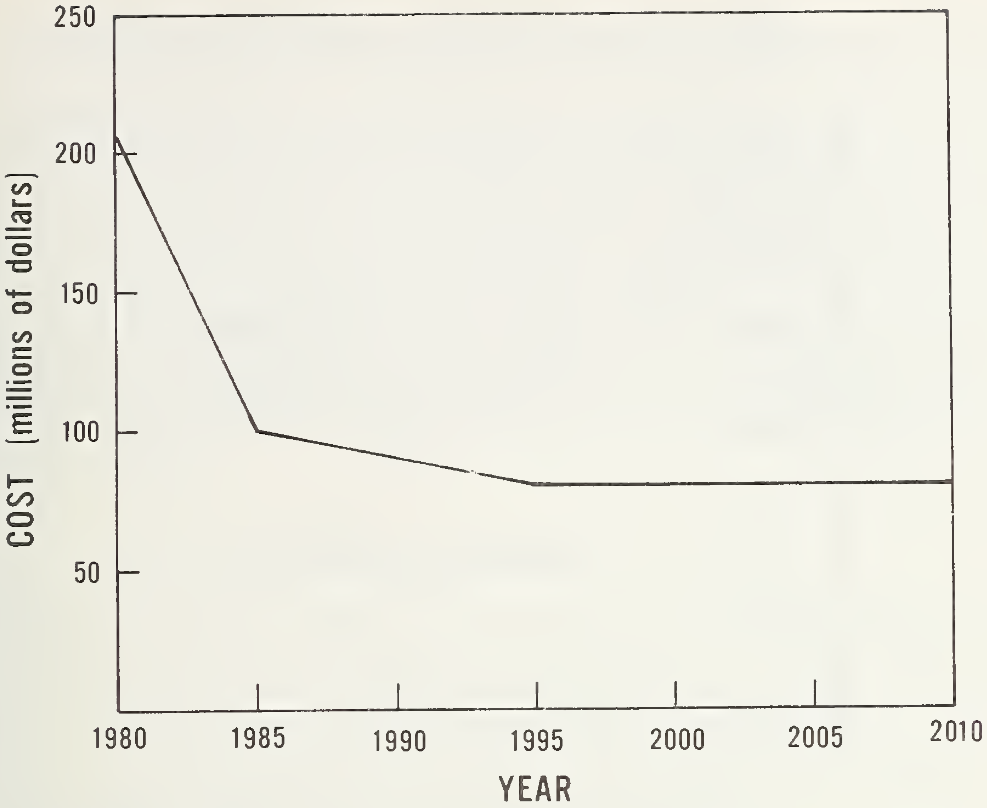

Figure 3. Annual Societal Cost of Proposed Standard Using the Barrier Method

3.6 Cost Plus Loss Evaluation of the Three Intervention Strategies

The cost and loss results of the previous sections are combined in this section to give the cost plus loss of each intervention strategy. The costs and losses are summed by year for each alternative and the results are given in figure 4. The cost plus loss criterion serves to identify the most attractive intervention strategy from the standpoint of society as a whole. Although distributional effects are not addressed by this criterion, as discussed in section 2, the cost plus loss criterion distinguishes the clearly promising alternatives from the less attractive alternatives.

3.6.1 Cost Plus Loss of No-Action Alternative

The cost plus loss of the no-action alternative is equal to the total loss incurred under that alternative, because we define our accounting basis so that no costs are incurred under that alternative. Thus, the cost plus loss declines from $668 million in 1975 to $492 million in 1980 and eventually levels off at $486 million per year after 2005. The

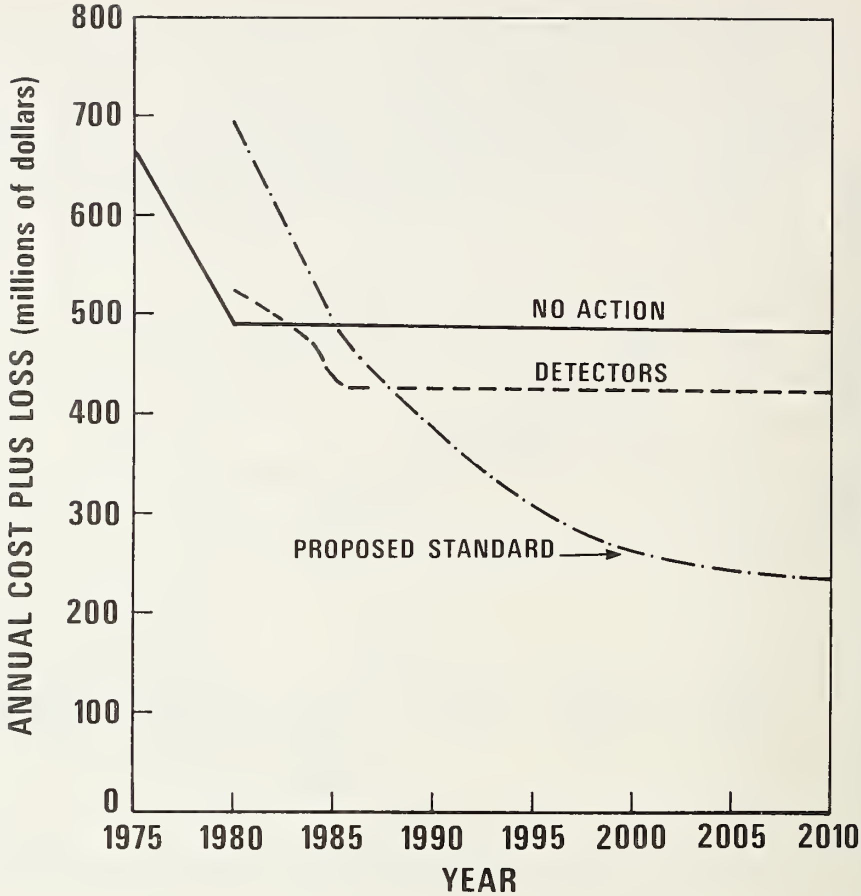

Figure 4. Annual Cost Plus Loss Under Three Alternatives

primary reason for the decline during the period 1975-1980 is the increased use of smoke detectors. After this period, when smoke detectors have reached their peak installation level, there is a slight decline in cost plus loss due to the changing (more smolder-resistant) furniture population.

3.6.2 Cost Plus Loss of Smoke Detector Alternative

The smoke detector alternative is assumed to take effect in 1980. Thus, prior to 1980 the cost plus loss is the same as for the no-action alternative. The cost plus loss curve for the detector alternative, as shown in figure 4, has a discontinuity in 1980, the first year that costs are incurred. Between 1980 and 1985 the increased cost is offset by the reduction in total losses, as evidenced by the "detector" curve crossing the "no-action" curve. After 1985 the two curves are essentially parallel with the smoke detector curve about $60 million below the "no-action" curve. The total cost plus loss to society under the smoke detector alternative eventually levels off at $422 million annually.

3.6.3 Cost Plus Loss of Proposed Standard Alternative

The proposed standard is also assumed to take effect in 1980. The cost plus loss under the proposed standard is coincident with the no-action alternative prior to 1980. There is a rather large increase in cost plus loss in 1980 because the large cost of implementing the standard is not offset by a significant loss reduction in that year. However, due to the decreasing cost of the standard and its increasing effectiveness as existing furniture is replaced by compliant furniture, loss reduction begins to exceed the cost of the standard by about 1985, and the "proposed standard" curve crosses the "no-action" curve. The total annual cost plus loss under the proposed standard alternative continues to decline--crossing the "detector" curve near 1988 and eventually leveling off at $235 million annually.

3.6.4 Comparison of the Three Alternatives

Figure 4 shows that in the long run the proposed standard is the most attractive strategy for reducing total societal cost plus loss. However, in the early years the proposed standard is the least attractive alternative because the cost exceeds the initial loss reduction. The selection of the most attractive alternative therefore depends on the issue of time preference--how much society is willing to pay today to partake of benefits tomorrow.

Time preference is a difficult social issue involving a value judgment on how much one generation should sacrifice to benefit succeeding generations. There is a vast literature on the issue of time preference [19,20], and although there is not a consensus on how the problem should be treated, many analyses have used discounting techniques to address time related trade-offs.

Using a discounting approach, a time stream of the various costs and losses is developed. Each of the future values of cost and loss is then discounted to the present time at a compound rate reflecting the decision maker's time preference. The resulting discounted values are summed and the sum is called the present value. The present value is a single number that summarizes the present worth of the particular time stream. By comparing the present values of different time streams, the time streams can be compared in a consistent manner. Discounting has long been used in business to compare different investment plans.

Table 11 gives the present value of the cost plus loss of the three alternatives discounted at an 8 percent real rate. We feel that this rate represents a reasonable opportunity cost for consumer related expenditures. The present values shown in the table are calculated over the period 1977-2010. The table shows that the present values of cost plus loss for the detector alternative and the proposed standard are essentially equal at approximately $6.0 billion. Both alternatives are preferred to the no-action alternative on the basis of a total present value of cost plus loss. The present value of the cost plus loss under the no-action alternative is approximately $6.3 billion.

Table 11. Comparison of Three Alternatives

	Present Value at 8% from 1977 to 2010 (Millions of Dollars)		
Alternative	Loss	Cost	Cost Plus Loss
No-Action	$6330	$ 0	$6330
Detector Alternative	5650	300	5950
Proposed Standard (Barrier Method)	4840	1120	5960

Although the proposed standard and detector alternatives result in approximately the same present cost plus loss, they achieve that result in different ways. The proposed standard achieves much greater loss reduction, but it also costs significantly more to implement. Relative to the no-action alternative, the proposed standard gives a loss reduction in present value terms of $6.3 - $4.8 = $1.5 billion at a cost of $1.1 billion. The smoke detector alternative gives a loss reduction of $0.7 billion at a cost of $0.3 billion. The ratio of benefits to costs is 1.3 for the proposed standard and 2.2 for the detector alternative. Thus, although the proposed standard gives a greater total loss reduction, the reduction is achieved at a rate which is less efficient than the rate under the detector alternative.

3.6.5 Reduction in Loss of Life Under the Three Alternatives

Table 12 gives the total expected number of upholstered furniture fire fatalities under each of the three alternatives, as calculated from the fire loss model. The numbers of fatalities are accumulated over the period 1977 to 2010 without discounting. Relative to the no-action case, the table shows that the smoke detector alternative saves 5,500 lives over this period while the proposed standard saves 12,900 lives.

Many analyses have evaluated public safety programs on the basis of dollars spent per life saved. This is a meaningful measure if the various expenditures and fatality reductions occur in the same period of time. However, as discussed earlier, the costs and benefits of the different upholstered furniture fire intervention strategies occur at different points in time; therefore, it is not methodologically sound to compare the total number of lives saved with the total program costs.

(One can calculate the present value of the program costs, and discount the value assigned to lives saved, but it is not meaningful to discount fatalities.) Nevertheless, as shown in table 13, it is possible to derive upper and lower bounds for dollars spent per life saved.

Table 12. Total Number of Fire Fatalities from 1977 thru 2010 Under Three Alternatives

Alternative	Number of Fatalities	Lives Saved Relative to No-Action
No-Action	30,800	---
Detector Alternative	25,300	5,500
Proposed Standard (Barrier Method)	17,900	12,900

Table 13. Calculation of Upper and Lower Bounds on Expenditure Per Life Saved Under Two Alternatives to No-Action from 1977 to 2010

	Detectors	Proposed Standard
Number of Lives Saved Relative to No-Action	5,500	12,900
Accumulated Costs	$881,000,000	$3,008,000,000
Accumulated Property & Injury Savings Relative to No-Action	$845,000,000	$2,980,000,000
Accumulated Fatality Directed Expenditures Relative to No-Action	$36,000,000	$28,000,000
Upper Bound on Expenditure per Life Saved[a]	$161,000	$234,000
Lower Bound on Expenditure per Life Saved	$6,500	$2,200

[a]Calculations may not check because of rounding.

Table 13 gives the total number of lives saved under the proposed standard and smoke detector alternatives relative to no-action from 1977 thru 2010. An upper bound on the total expenditure per life saved is obtained by dividing the total accumulated (undiscounted) cost of the alternative (also given in the table) by the number of lives saved. The table shows that the upper bound of the expenditure is $161,000 per life saved under the detector alternative compared to $234,000 under the proposed standard. However, because the entire costs of the alternatives are assigned to life safety, this method of calculation neglects the substantial reductions in injury and property losses, relative to no-action, which occur under the two alternatives. The monetary equivalents of these reductions, are also shown in the table. By subtracting these savings from the accumulated costs we obtain a lower bound on the expenditure per life saved. The lower bounds are $6500 per life saved for the detector alternative and $2200 per life saved for the proposed standard. These calculations provide upper and lower bounds on the cost of life safety. However, we emphasize that neither of these ratios addresses the issue of time preference, that is, the use of short-term expenditures for future life safety.

3.7 Selected Sensitivity Studies

The results just presented depend on many assumptions. This section examines the sensitivity of our results to changes in those assumptions. Additional sensitivity studies are presented in section 7.

3.7.1 Loss of Life Dollar Assignment

It is difficult to assign a value to the amount society is willing to spend to prevent a fire fatality, the so-called "value of life." Figure 5 shows how the comparison of alternatives is affected by this value. The figure shows that if no value is placed on preventing the loss of life, the most attractive alternative is the no-action alternative. At a value of approximately $60,000 per life saved, the smoke detector alternative becomes the most attractive strategy, and at approximately $300,000 per life saved, the proposed standard becomes the most attractive alternative. The proposed standard is the most attractive strategy for all values greater than $300,000 per life saved. At a value of $1 million per life saved the proposed standard results in a reduction in present value of cost plus loss of 7 percent over the detector alternative and 16 percent over no action. Thus, although the assignment of the value of life is a difficult one, our sensitivity studies show that the smoke detector alternative and proposed standard remain most attractive over a wide range of this parameter.

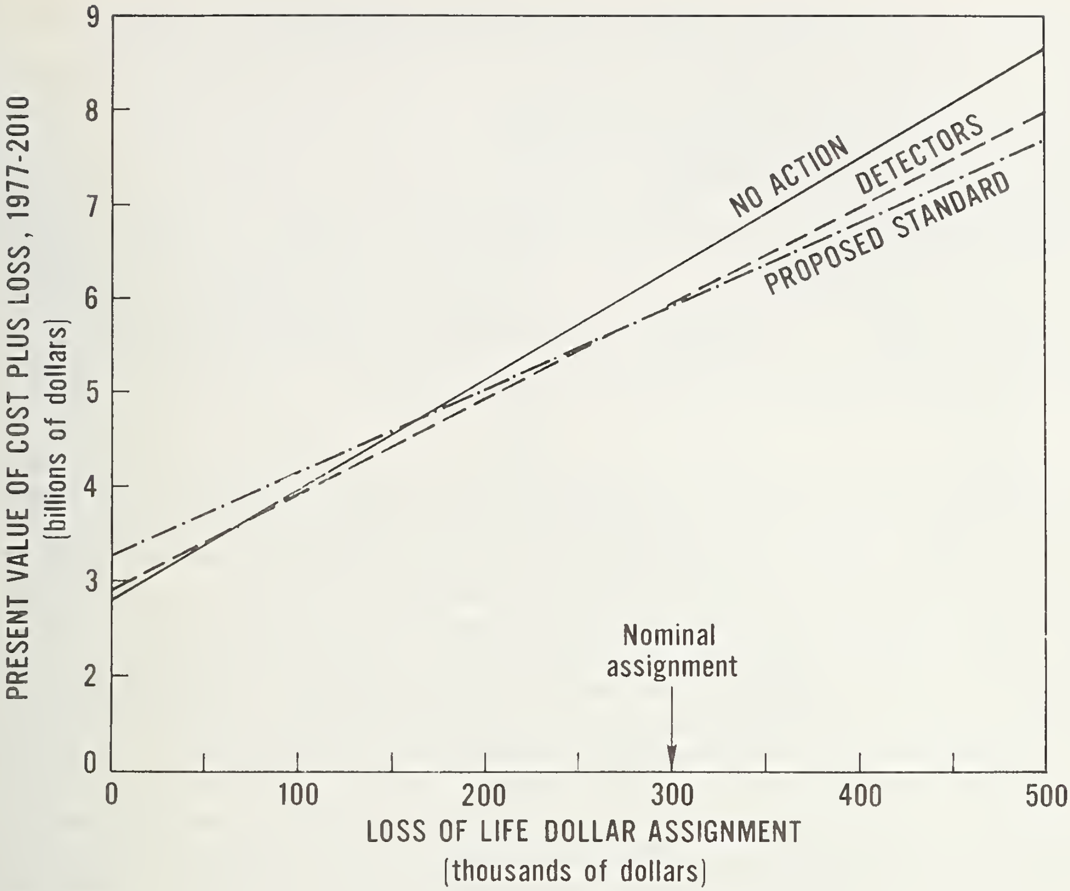

Figure 5. Sensitivity of Results to Dollar Assignment on Loss of Life

3.7.2 Proposed Standard Using the Backcoating Method

We have postulated that for Class D fabrics, compliance with the proposed standard would be achieved by using an aluminum foil barrier under the fabrics. However, there is uncertainty on the particular method or combination of methods that furniture manufacturers will actually use to meet the proposed standard. Conceptually, we could address our uncertainty on the method used to comply with the standard directly. However, since the uncertainties are changing rapidly, we have chosen to designate the barrier method as the basic method for complying with the proposed standard and to treat other compliance methods as sensitivity studies. In this section we discuss the effectiveness of a promising alternative to the barrier method, which we call the "backcoating method."

Two backcoating methods have been identified. Work at the Southern Regional Research Center of the U.S. Department of Agriculture has indicated that many cotton upholstery fabrics may be upgraded from Class D to Class B or C by proper choice of existing backcoating products [21]. The second backcoating method is based on research at the National Bureau of Standards showing that the application of sulfur to textile materials inhibits smoldering combustion. This method is still being developed, but based on current laboratory work, we assume that a smolder inhibitor such as microencapsulated sulfur could be applied to upholstery fabrics in a backcoating. The backcoating would upgrade Class D fabrics to either Class A or B. The backcoating method would also require the boric acid based treatment for the underlying cotton batting to enable constructions intended for use with Class B and C fabrics to meet the proposed standard. To illustrate the proposed standard alternative using the backcoating method we develop the losses and costs for the microencapsulated sulfur process in this report.

Because of the different flammability characteristics of the furniture manufactured under the backcoating and barrier methods, the losses under the backcoating method are separately modeled, as detailed in section 5.3.2. The losses under the backcoating method are somewhat larger than under the barrier method because the backcoating method is less effective at reducing ignitions from flaming sources. Moreover, if an ignition occurs, materials treated with a sulfur backcoating may tend to result in larger fires. The cost of the backcoating method, detailed in section 6.3, is significantly less than the barrier method cost primarily because of reduced labor, materials, and handling.

Table 14 gives the present value of the cost plus loss for the backcoating method, as well as for the other three alternatives already investigated. Using our nominal assumptions on the cost and effectiveness of this method, the table shows that the backcoating method of meeting the proposed standard is the most attractive option. Although the losses under the backcoating method are somewhat higher than under the barrier method, the lower cost of the backcoating method more than offsets this increase. However, we emphasize that a backcoating with microencapsulated sulfur has not yet been used commercially, and the results reported here are based on laboratory projections of effectiveness only.

The total cost plus loss to society of a combination of both the barrier method and the backcoating method using microencapsulated sulfur or a comparably priced backcoating product would be very attractive compared to any of the nominal alternatives. We regard the cost of the barrier method as an upper bound on the cost of the proposed standard and expect that other methods, more comparable in cost to the backcoating method, would be developed if the proposed standard is promulgated by the Consumer Product Safety Commission. Thus, the proposed standard alternative may be even more attractive than our nominal case suggests.

Table 14. Comparison of Proposed Standard (Backcoating Method) with Three Nominal Alternatives

Alternative	Present Value at 8% from 1977 to 2010 (Millions of Dollars)		
	Loss	Cost	Cost Plus Loss
Proposed Standard (Backcoating)	$5060	$ 510	$5570
Proposed Standard (Barrier)	4840	1120	5960
Detector Alternative	5650	300	5950
No-Action	6330	0	6330

3.7.3 Cost of the Proposed Standard Alternative

Our nominal cost estimate shows the barrier method to be a relatively expensive way of meeting the proposed standard. Figure 6 shows how the choice of alternatives is affected by the furniture manufacturers' initial cost for the barrier method. The figure shows that the cost of the proposed standard has a critical effect on the choice of alternatives. A 40 percent increase in the cost would make the barrier method the least attractive alternative, whereas a 30 percent decrease in the cost would make the barrier method the most attractive alternative--even better than our nominal estimate of the backcoating method. The sensitivity of our results to the cost of the backcoating method is discussed in section 7.4.1.

If further work is undertaken to refine our analysis, the cost of the proposed standard is a major area to be addressed.

3.7.4 Cost of the Smoke Detector Alternative

Since there is relatively little uncertainty on the cost of installing smoke detectors, we postpone until section 7 our analysis of how that cost affects the choice of alternatives. Instead, in this section we examine how the choice of alternatives depends on the fraction of the smoke detector costs allocated to the smoke detector alternative. The reader is reminded that we assigned only a portion of the smoke detector costs to upholstered furniture fires because smoke detectors are effective in detecting other types of fires as well.

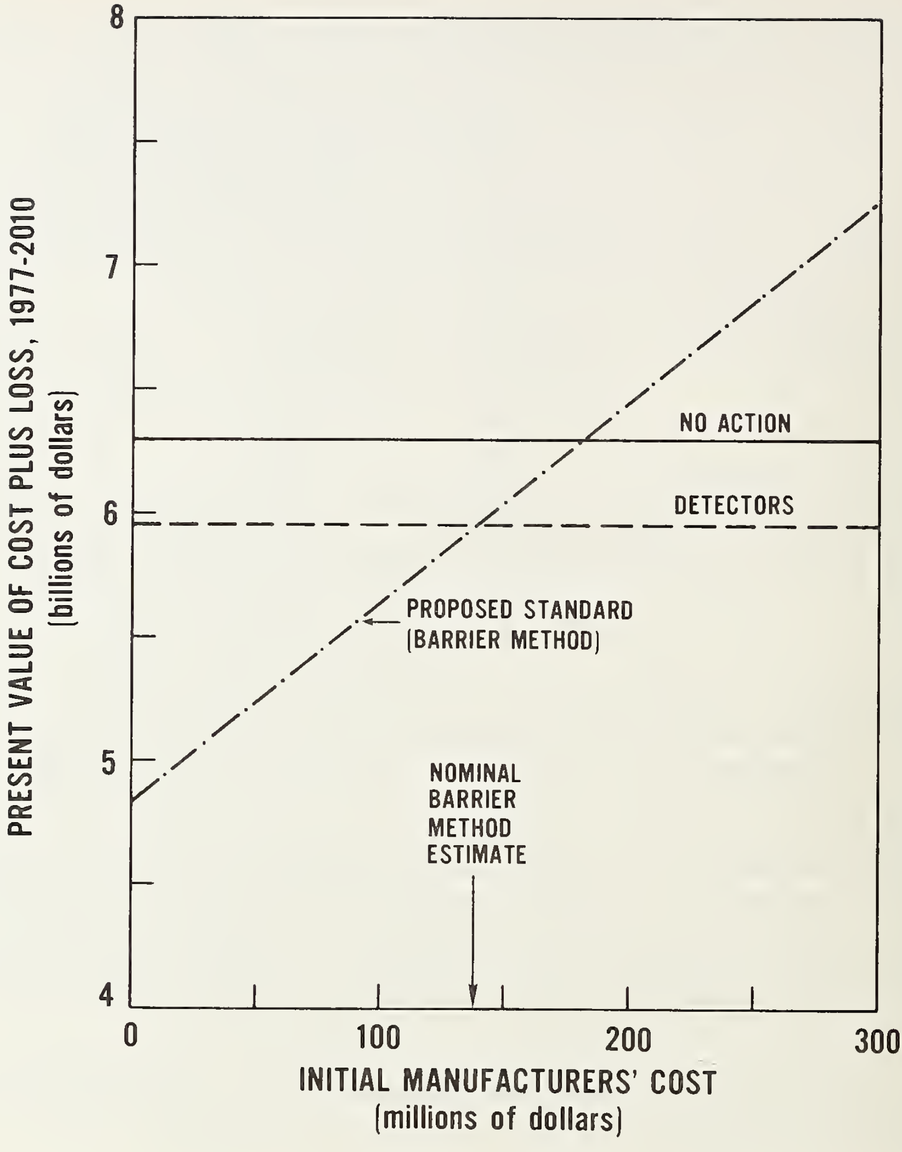

Figure 6. Sensitivity of Results to Manufacturers' Cost of Proposed Standard Using the Barrier Method

Figure 7 shows how the choice of alternatives is affected by the percentage of smoke detector costs assigned to upholstered furniture fires. As discussed in section 6.2, our nominal calculation assigns 29 percent of the costs to the upholstered furniture fire scenario based on our estimate that 29 percent of the lives saved by detectors would be in upholstered furniture fires. That calculation is based in part on the assumption that smoke detectors could reduce loss of life in all residential fires by 60 percent. If detectors would reduce life loss in all residential fires by only 40 percent, then a larger percentage of the fatalities avoided would be in upholstered furniture fires; hence the allocation of costs would increase to 44 percent. Increasing the detector

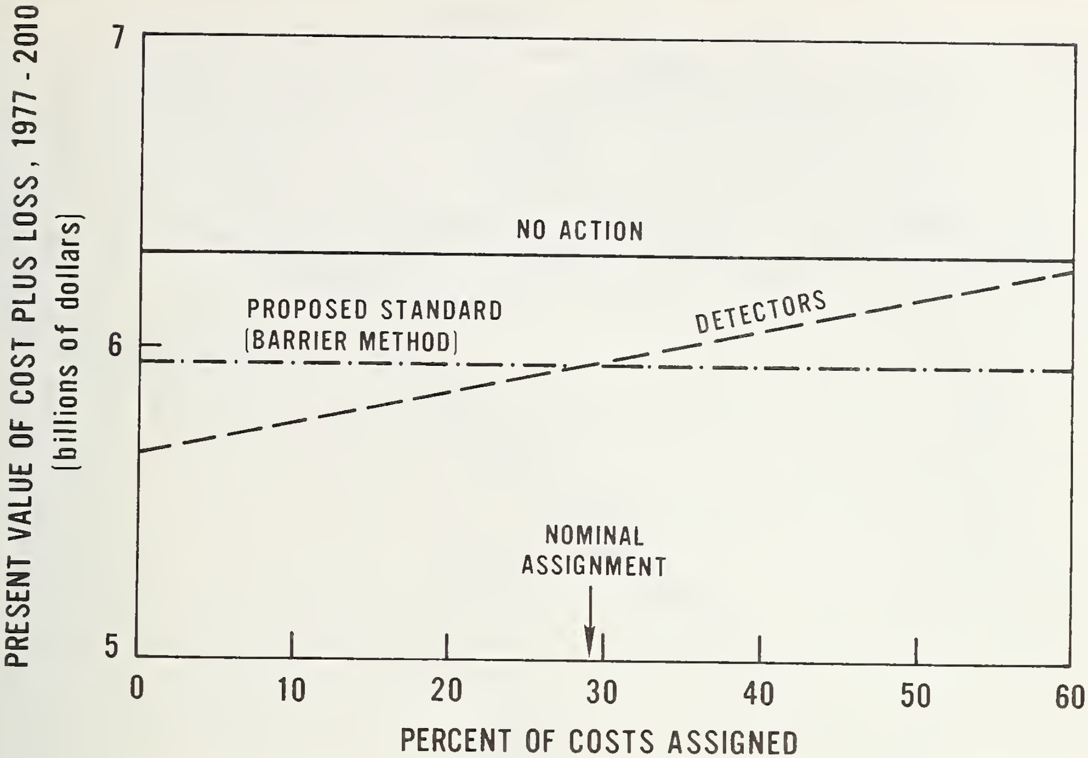

Figure 7. Sensitivity of Results to Percentage of Smoke Detector Costs Assigned to Upholstered Furniture Fires

effectiveness to 70 percent would reduce the upholstered furniture fire allocation of costs to 25 percent. The figure shows that over this range of allocated costs, the smoke detector alternative is slightly more or less attractive than our nominal evaluation of the proposed standard using the barrier method. However, there is not enough difference between those two alternatives to make one alternative clearly superior to the other.

3.7.5 Annual Number of Ignitions and Fatalities

From table 4 we estimate that upholstered furniture fires currently result in 1460 residential fire deaths per year of which 1310 are in one- and two-family homes and apartments. Other estimates on the magnitude of the problem have been cited. Figure 8 shows how the comparison of alternatives depends on the current magnitude of the problem. The abscissa in the figure represents the total number of upholstered furniture fire fatalities in all residential occupancies because that is the quantity most commonly estimated. (Another quantity frequently estimated is the number of residential upholstered furniture fire fatalities involving smoking, which account for about 70 percent of the 1,460 residential fatalities or 1,020 fatalities.)

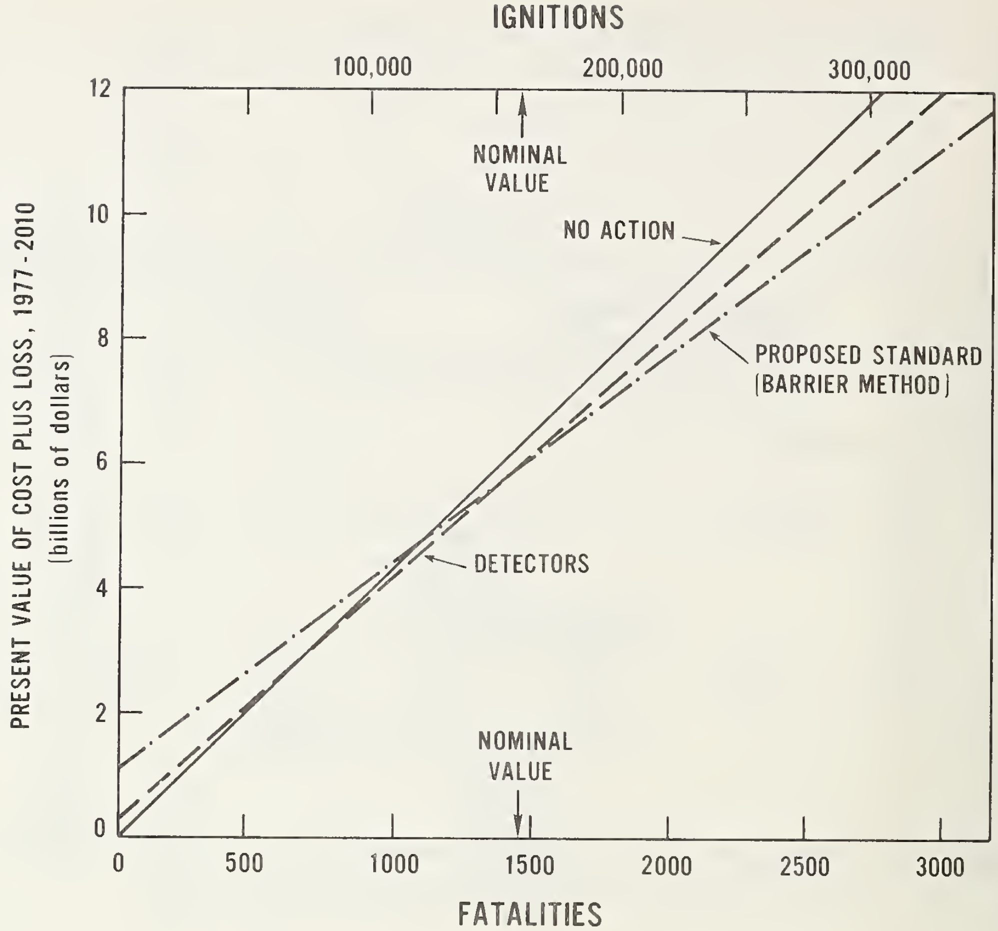

Figure 8. Sensitivity of Results to Changes in the Total Annual Number of Residential Upholstered Furniture Fatalities and the Annual Number of Upholstered Furniture Ignitions in Residences

Figure 8 shows that the no-action alternative is the most attractive if the current number of fatalities is less than 600. If the number of fatalities is between 600 and 1,500, the smoke detector alternative is preferable. The proposed standard is the preferred alternative if there are more than 1,500 deaths per year. The figure also shows the effect of changing our estimate on the number of upholstered furniture ignitions, since in our analysis the number of ignitions is directly proportional to the number of fatalities. Thus, large changes in the numbers of fatalities or ignitions can change the choice of alternatives. However, as discussed in section 3.1.3, our estimate has been well corroborated and we do not expect it to change significantly.

3.8 Combination of Alternatives

Thus far we have examined how the smoke detector alternative and proposed standard perform when implemented separately. Table 15 gives the present value of the cost plus loss for the two alternatives implemented together. The cost of the combination program is the sum of the costs of the two elements. The losses under the combination alternative are calculated using the fire loss model. The table shows that the combination alternative is preferable to any of the alternatives implemented singly. For both the barrier method and the backcoating method of complying with the proposed standard, the present value of the cost plus loss is about $100 million less under the combination alternative than under the next best alternative.

Table 15. Comparison of Combination Alternatives

	Present Value at 8% from 1977 to 2010 (Millions of Dollars)		
Alternative	Loss	Cost	Cost Plus Loss
Combination (Barrier)	$4440	$1420	$5860
Proposed Standard (Barrier)	4840	1120	5960
Detector Alternative	5650	300	5950
No-Action	6330	0	6330
Combination (Backcoating)	4640	810	5450
Proposed Standard (Backcoating)	5050	510	5560

Part Two

DETAILED DERIVATION OF RESULTS

4. DEVELOPMENT OF CURRENT LOSSES FROM FIRE LOSS MODEL

This section provides a detailed description of the upholstered furniture fire loss model. The use of the model is demonstrated by employing it to calculate losses under current conditions. Loss model results for the various intervention strategies are given in section 5.

4.1 Description of Fire Loss Model

4.1.1 Model Overview

Figure 9 gives a schematic of the fire loss model. As outlined in section 2, the model describes a number of different types of upholstered furniture fires. The model parameters are listed across the top of the figure. Beneath each input parameter are sets of branches representing the different possible values of that parameter. Each path through the tree represents a different type of upholstered furniture fire. The tree is actually four times as large as it appears since the portion of the tree associated with electrical ignition source is repeated for each of the other three ignition sources. As shown, the model allows for more than 300 different kinds of upholstered furniture fires.

Associated with each path is a level of loss, represented by four output variables on the right-hand side of the figure. Probabilities are assigned to each branch representing the relative frequency of occurrence of the branch values. Each branch probability assignment is conditional on the values of the parameters preceding that branch. The probability of a particular path through the tree is obtained by multiplying the probabilities of the branches making up the path. Combining the path probability with the losses associated with the particular path provides a probability distribution on losses resulting from a single reported upholstered furniture fire. The expected losses per reported fire are calculated directly from the probability distribution by multiplying each path probability by its associated loss values and then summing over all paths through the tree.

The model is used by first setting the input parameters to reflect current conditions. Then the model parameters are adjusted to reflect the performance of the different intervention strategies. However, in this section we will only be concerned with modeling the losses under current conditions.

4.1.2 Model Parameters

The model parameters are introduced according to the basic sequence of ignition, fire development, and resultant loss. The model begins by assuming that an ignition has occurred and then addresses whether the fire is reported to the fire authorities. Since this analysis is only

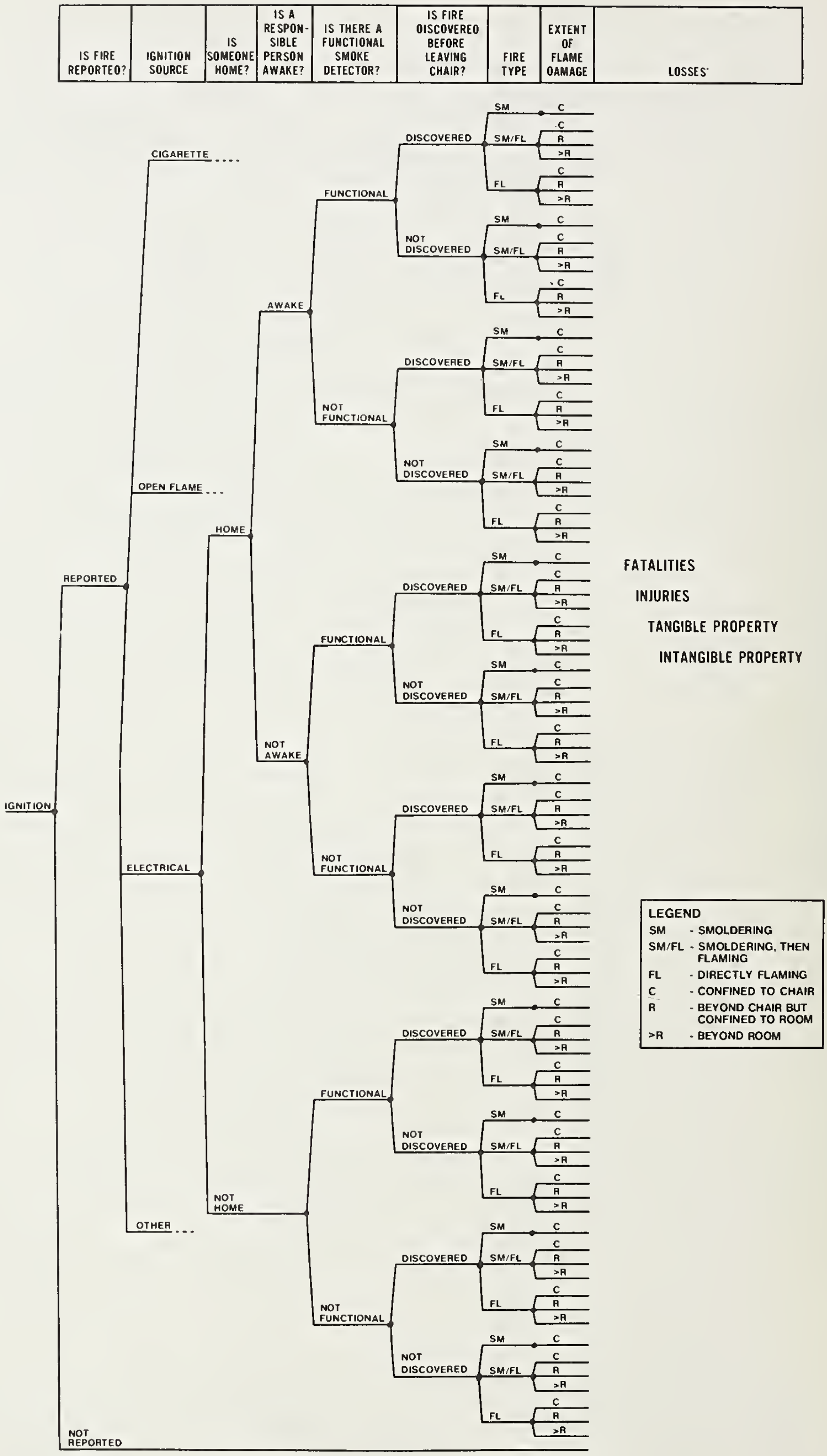

Figure 9. Probability Tree for Assessing Losses Per Upholstered Furniture Fire

concerned with reported fires, we consider only the losses that emanate from the "reported" branch. The model then considers the ignition source. For simplicity, the model delineates three of the most common ignition sources: cigarettes (including pipes, cigars, and unspecified smoking material), open flame, and electrical devices. All other ignition sources are grouped into a fourth category called "other."

The second portion of the model characterizes the development of the fire, given a reported ignition from a particular source. The model first addresses whether anyone is at home at the time of ignition. If someone is at home, then the model addresses whether at least one individual is both conscious and physically capable of discovering and responding to the fire. If the individual is so capable, then he is classified as "awake;" otherwise, he is classified as "not awake." The model also considers whether there is at least one functional smoke detector in the residence. Then, depending on whether someone is at home and awake and on whether there is a functional smoke detector, the model addresses whether the fire is discovered before or after it leaves the chair.[5]

A fire is defined as "discovered" if its presence is observed before it leaves the chair by someone who is physically capable of responding to the fire. If the fire is observed after spreading from the chair or it self-extinguishes, then it is classified as "not discovered."

The fire is further characterized according to the fire type and final extent of flame damage. The fire type gives the ignition and fire sequence. Three fire types are considered: smoldering only, smoldering then flaming and directly flaming (denoted by SM, SM/FL, and FL, respectively). For simplicity, three levels of flame damage are considered: confined to the chair, beyond the chair but confined to the room, and beyond the room (denoted by C, R, and >R, respectively).

The third section of the model defines the losses for each path through the tree. Four categories of loss are considered: loss of life, injury, tangible property loss, and intangible property loss. The various categories of loss are made dependent on extent of flame damage, on whether the fire is discovered before leaving the chair, and on whether someone is at home at the time of ignition.

4.2 Probability Assignments for Current Conditions

The use of the fire loss model is best demonstrated by using it to calculate losses for current conditions. Input data for the calculations are derived from several sources. Wherever possible, we use statistical

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[5] We use "chair" to refer to any piece of upholstered furniture.

data, such as provided by the U.S. Fire Administration's National Fire Incident Reporting System (NFIRS), to develop the necessary probability assignments. However, where statistical data are not available, we use expert judgment as that is the best information currently available.

The NFIRS data base is a key source of data for our analysis. At the time we were carrying out the analysis, the data base consisted of two years of reporting experience from parts of Ohio for 1976 and California for 1975. The data include 2,742 incidents in one- and two-family homes and apartments in which upholstered furniture was the first item to ignite. Incendiary and suspicious fires were excluded from consideration. It is clear that as more data become available or as the understanding of upholstered furniture fires improves, it may be necessary to revise our probability assignments and carry out a new evaluation of the alternatives.

4.2.1 Ignition Source Probabilities

The probabilities on ignition source, given a reported ignition, are taken directly from the NFIRS data base. Table 16 lists these probabilities.

Table 16. Ignition Source Statistics from 2742 Upholstered Furniture Fires

Ignition Source	Number of Occurrences	Probability of Occurrence[a]
Cigarette	1771	0.7031
Open Flame	326	0.1294
Electrical	131	0.0520
Other	291	0.1155
Unknown	223	--

[a]Based on 2519 fires for which the ignition source is unknown

4.2.2 Probabilities Leading to Discovery and Fire Type

The probability of a fire being discovered before leaving the chair depends on a variety of factors including the type of fire and the presence of individuals capable of discovering the fire. For the purpose of this analysis, we make the probability of the fire being discovered before leaving the chair dependent on the ignition source, whether someone is at home and awake, and whether there is a functional smoke detector.

Statistical data do not exist on most of these parameters and so expert judgment must be used to assign the probabilities. The desired probabilities are all conditional on the fire being reported. However, most experts are inclined to assess the probabilities independently of whether the fire is reported. We therefore introduce a second probability tree to assist in translating the probability assignments from the class of all fires (reported and unreported) to the class of reported fires only. The new probability tree is called the auxiliary tree.

A schematic of the auxiliary tree is given in figure 10. The auxiliary tree appears quite similar to the original probability tree introduced in figure 9 except that two of the input parameters have been dropped from the tree and the parameter designating whether the fire is reported has been moved to the end of the auxiliary tree. In this manner, the input parameters are made independent of whether the fire is reported, yet the required probabilities can be derived for the class of reported fires only. The ignition source and flame spread parameters are not needed in the auxiliary tree because they are determined directly from the NFIRS data base and are already conditional on the fire being reported. We defer an example of the calculation of these probabilities until all the probabilities for the auxiliary tree have been introduced.

As discussed in the following sections, separate auxiliary trees are developed for each ignition source since many of the probabilities are dependent on the ignition source. Figure 11 (A, B, C, and D) summarizes the probability assignments for the auxiliary trees.

4.2.2.1 Is Someone Home?

The probability of at least one person being at home, given an ignition, is made dependent on the ignition source. To determine this probability, we first estimate the probability of at least one person being at home at a random time and then adjust the probability to reflect the fact that there was an ignition of a particular type. From a separate calculation not given here we estimate the probability of at least one person being at home at a random time to be about 0.75. However, the probability of someone being at home, given that there is an upholstered furniture ignition, is somewhat higher than this value because most furniture ignitions are caused by direct human activity. Thus, we set the probability of someone being at home at 0.95 and 0.99 for cigarette and open flame ignitions, respectively, because nearly all those ignitions occur when someone is at home. Electrical and other ignitions are less dependent on someone being at home, so we set the probability of someone being at home, given those ignition sources, at 0.80 and 0.85, respectively.

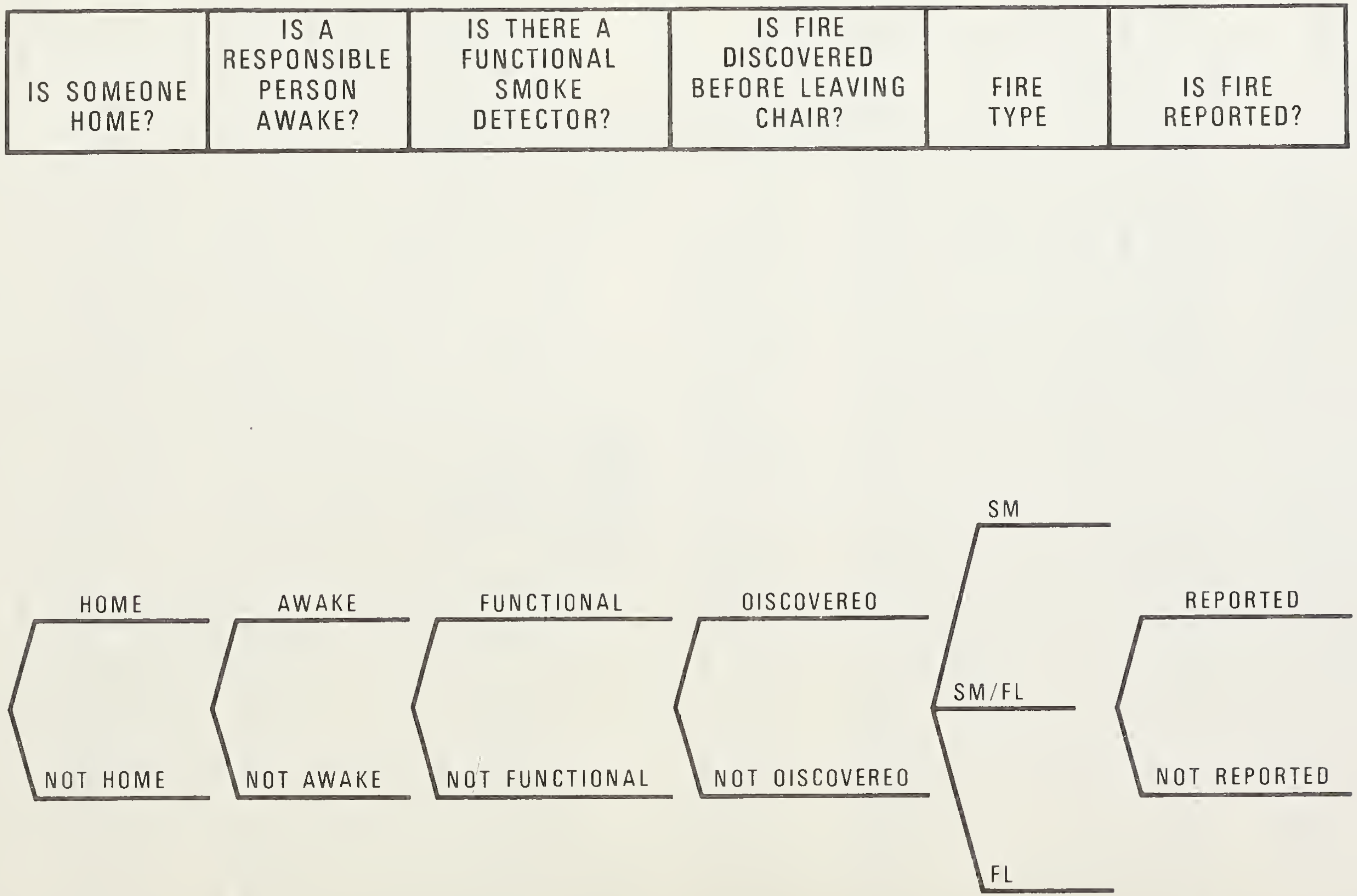

Figure 10. Schematic of Auxiliary Probability Tree

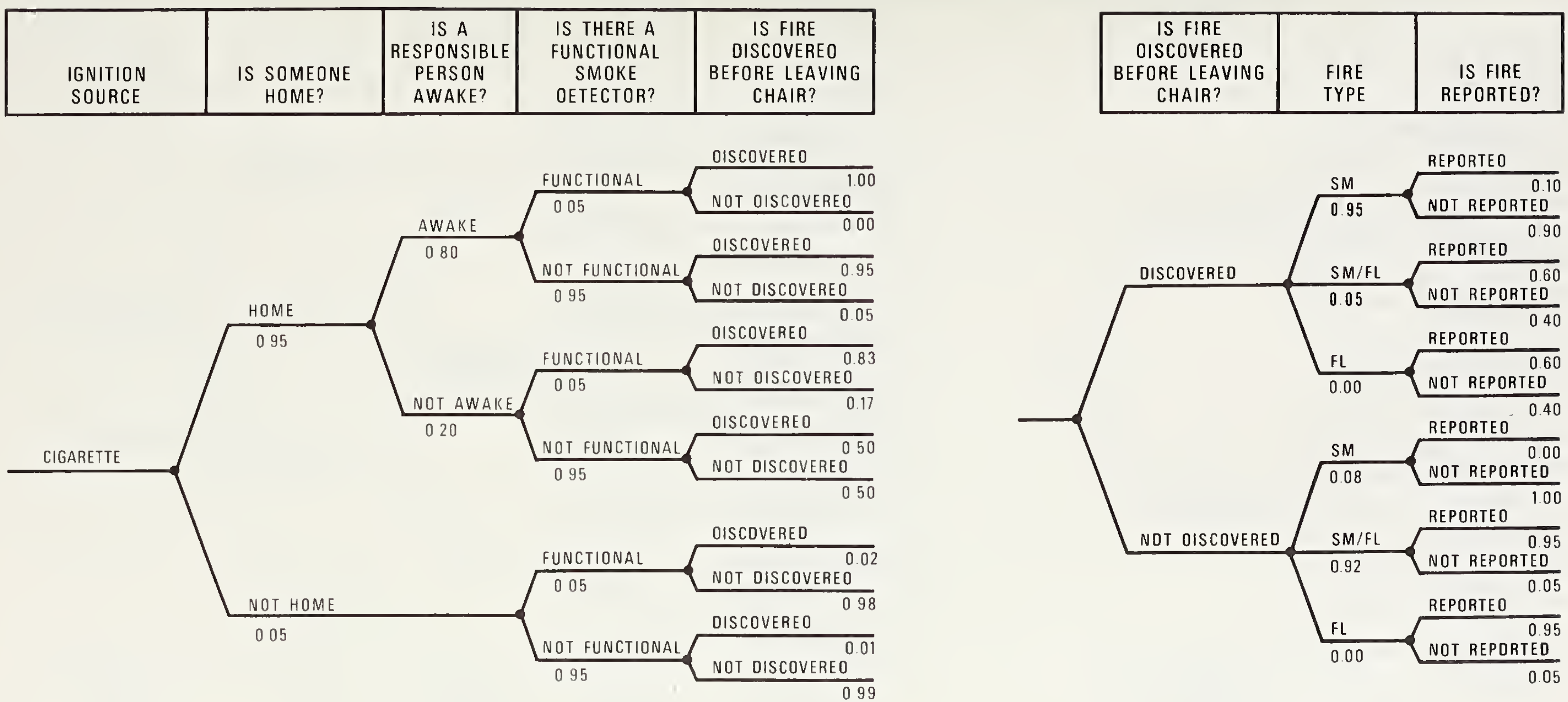

Figure 11A. Auxiliary Probability Tree for Cigarette Ignition Source Under Current Conditions

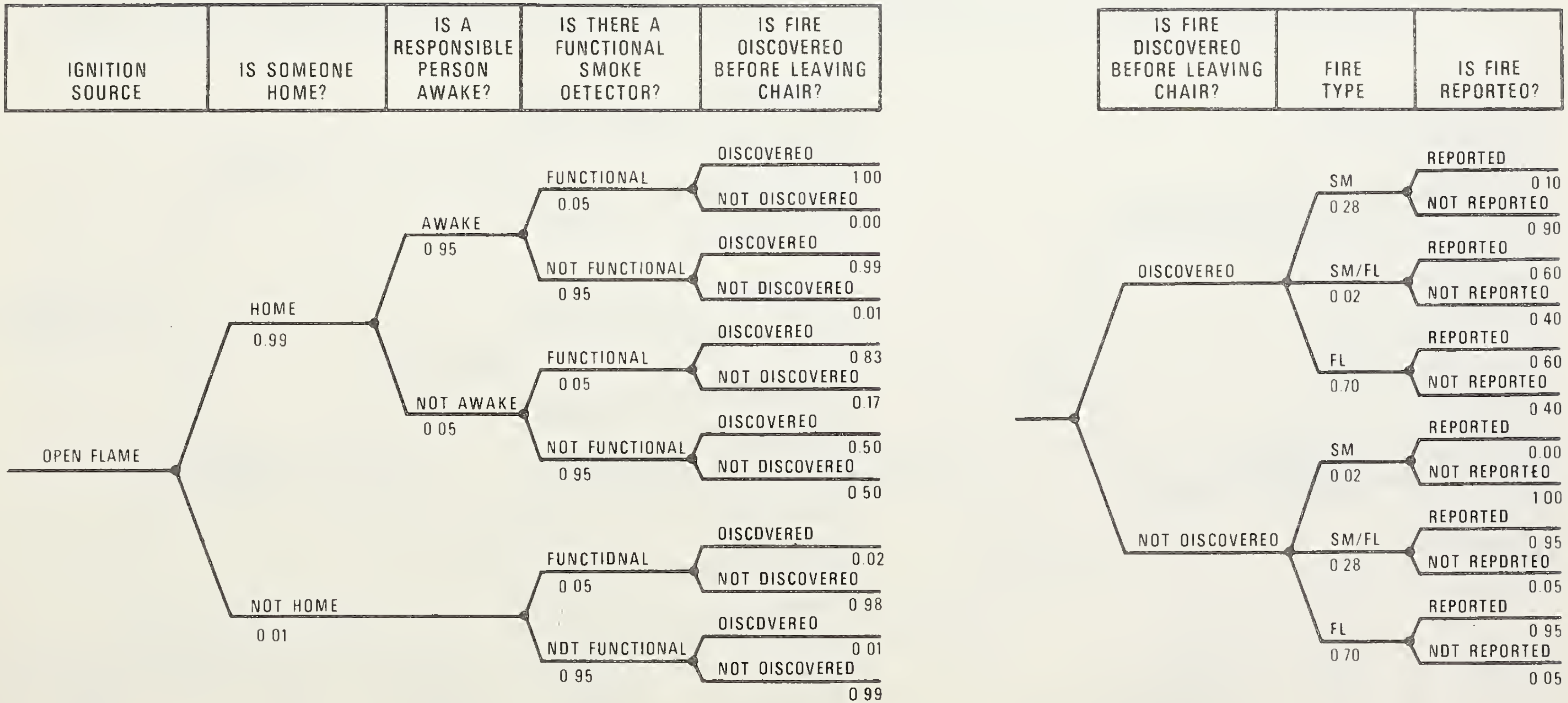

Figure 11B. Auxiliary Probability Tree for Open Flame Ignition Source Under Current Conditions

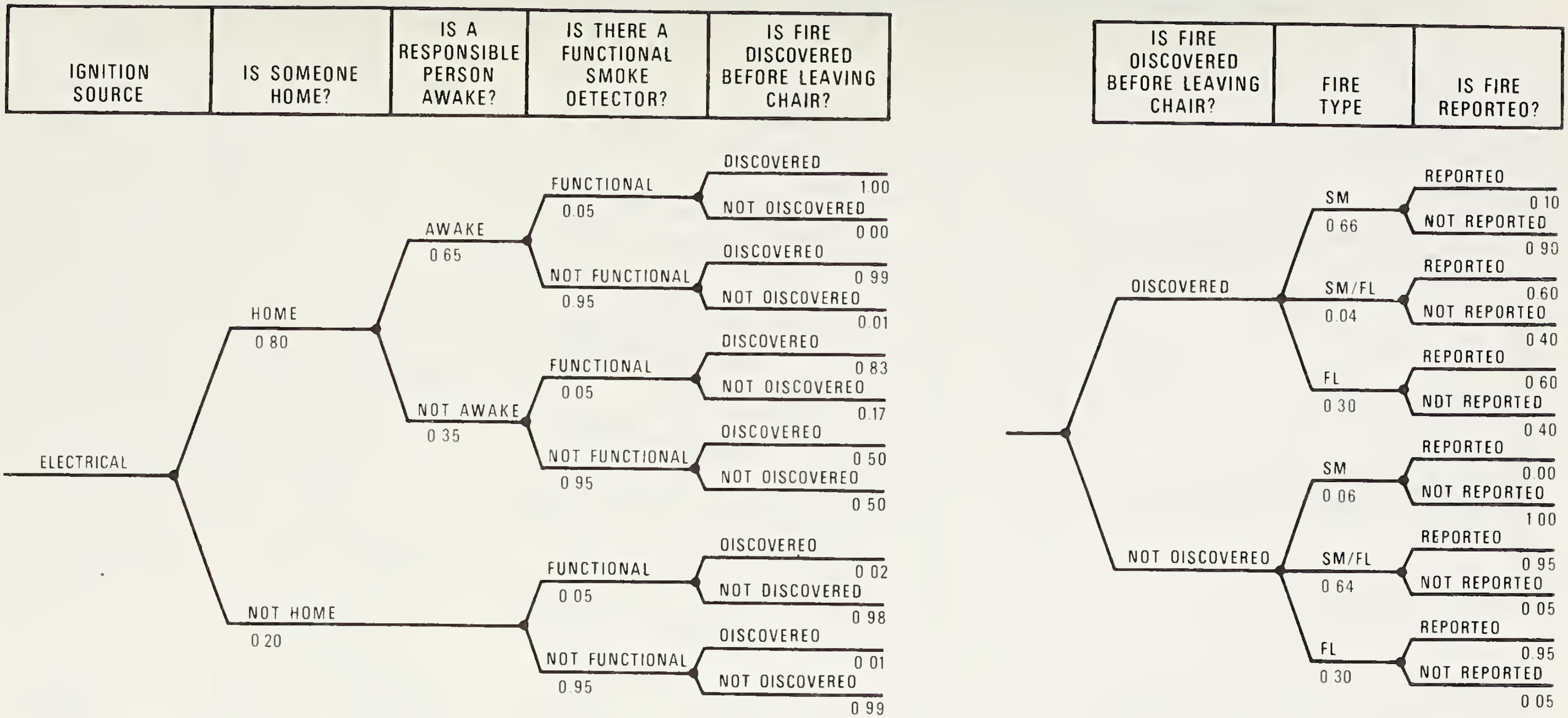

Figure 11C. Auxiliary Probability Tree for Electrical Ignition Source Under Current Conditions

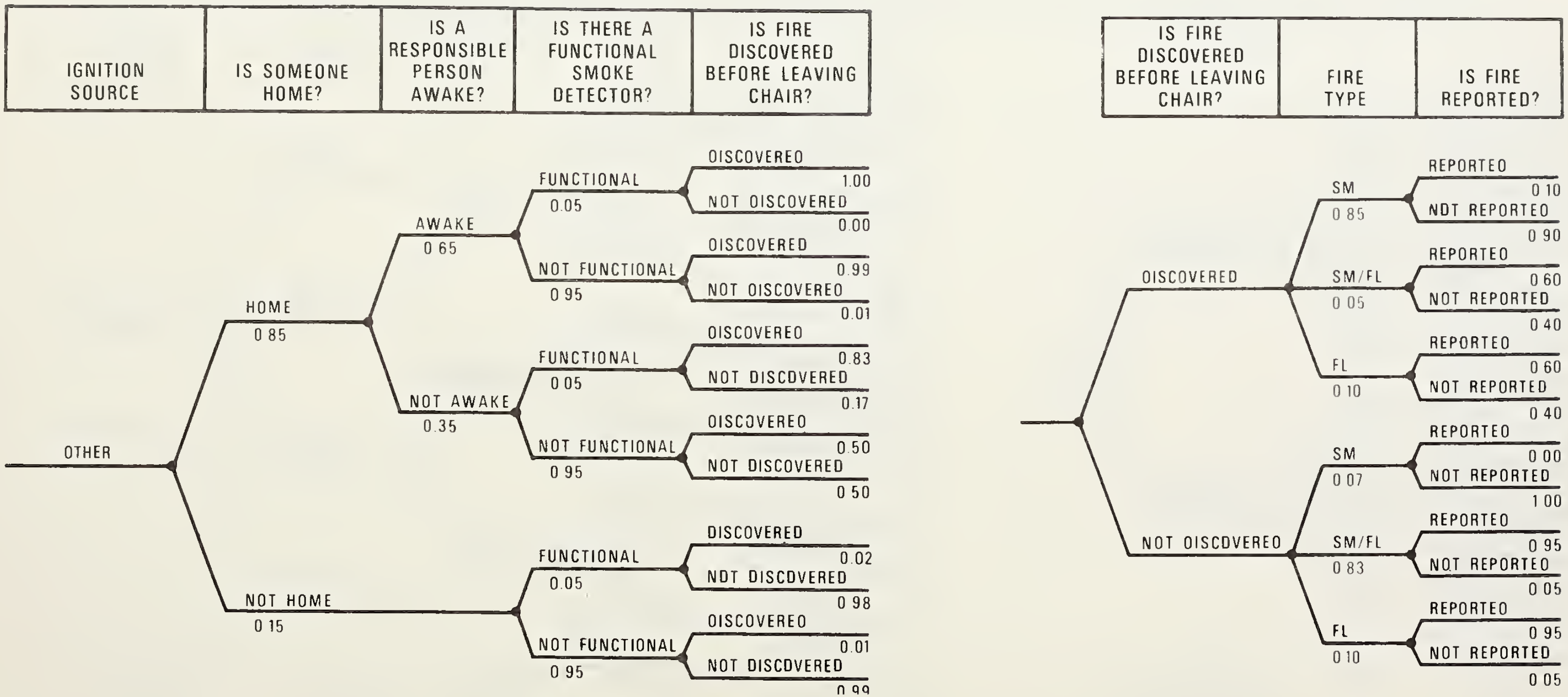

Figure 11D. Auxiliary Probability Tree for Other Ignition Source Under Current Conditions

4.2.2.2 Is a Responsible Person Awake?

Based on considerations of normal living patterns, we estimate in a separate calculation that the probability of at least one person being awake at a random time, given that someone is at home, is about 0.60. A person is defined to be "awake" if he is physically awake and capable of responding to a fire situation. Thus, young children, invalids, and intoxicated persons are not considered "awake." However, the estimate of this probability must be further conditioned to reflect the fact that there has been an ignition. Since most upholstered furniture fires are associated with human activity, we increase our nominal estimate of at least one person being awake to reflect the condition of an ignition having occurred. We set the probability of someone being awake, given an open flame ignition, at 0.95 because most of these ignitions are from matches and lighters resulting in immediate ignition. For cigarette ignition sources, we lower the probability of a responsible person being awake to 0.80 because the person who was smoking may be infirm, intoxicated, or may have fallen asleep before the smoldering furniture ignition occurred. Electrical and other ignitions are not as dependent on someone being awake, and so we set the probability of someone being awake, given one of these ignitions, at 0.65, which is slightly higher than our unconditional probability estimate of someone being awake. It should be recalled that all these estimates are conditional on someone being at home. If no one is at home, then the probability that a responsible person is awake is not defined.

4.2.2.3 Is There a Functional Smoke Detector?

We assume that approximately 5 percent of U.S. residences had functional smoke detectors in 1975 and 1976, the "current" period modeled. We therefore set the probability of there being a functional smoke detector at 0.05.

4.2.2.4 Is Fire Discovered Before Leaving Chair?

The probability of a fire being discovered before it spreads beyond the initial piece of furniture ignited is made dependent on the ignition source, on whether there is a functional smoke detector, and on whether someone is at home and awake. If there is no functional smoke detector, but someone is at home and awake, then the probability of the fire being discovered before leaving the chair is set at 0.99 for open flame, electrical, and other ignition sources, and 0.95 for cigarettes. If someone is at home but not awake, then the probability of the fire being discovered before leaving the chair is set at 0.50 for all ignition sources. If no one is at home, then the discovery probability is set at 0.01 for all ignition sources, reflecting the small chance that a neighbor or passer-by will discover the fire before it leaves the chair.

If there is a functional smoke detector, the probabilities of the fire being discovered before leaving the chair are the same for all ignition sources. If someone is at home and awake, we assign a probability of 1.0 to the fire being discovered before leaving the chair. If the detector is functional and if someone is at home but not awake, then as shown in figure 12 we calculate the probability of the fire being discovered before leaving the chair to be 0.83. As shown, this assessment considers the probability that the person is either not responsible (e.g., young or infirm) or intoxicated. If there is a functional smoke detector, but no one is at home, we assign a 0.02 probability that the fire will be discovered before it leaves the chair, reflecting the small chance of the smoke detector alerting a neighbor or passer-by.

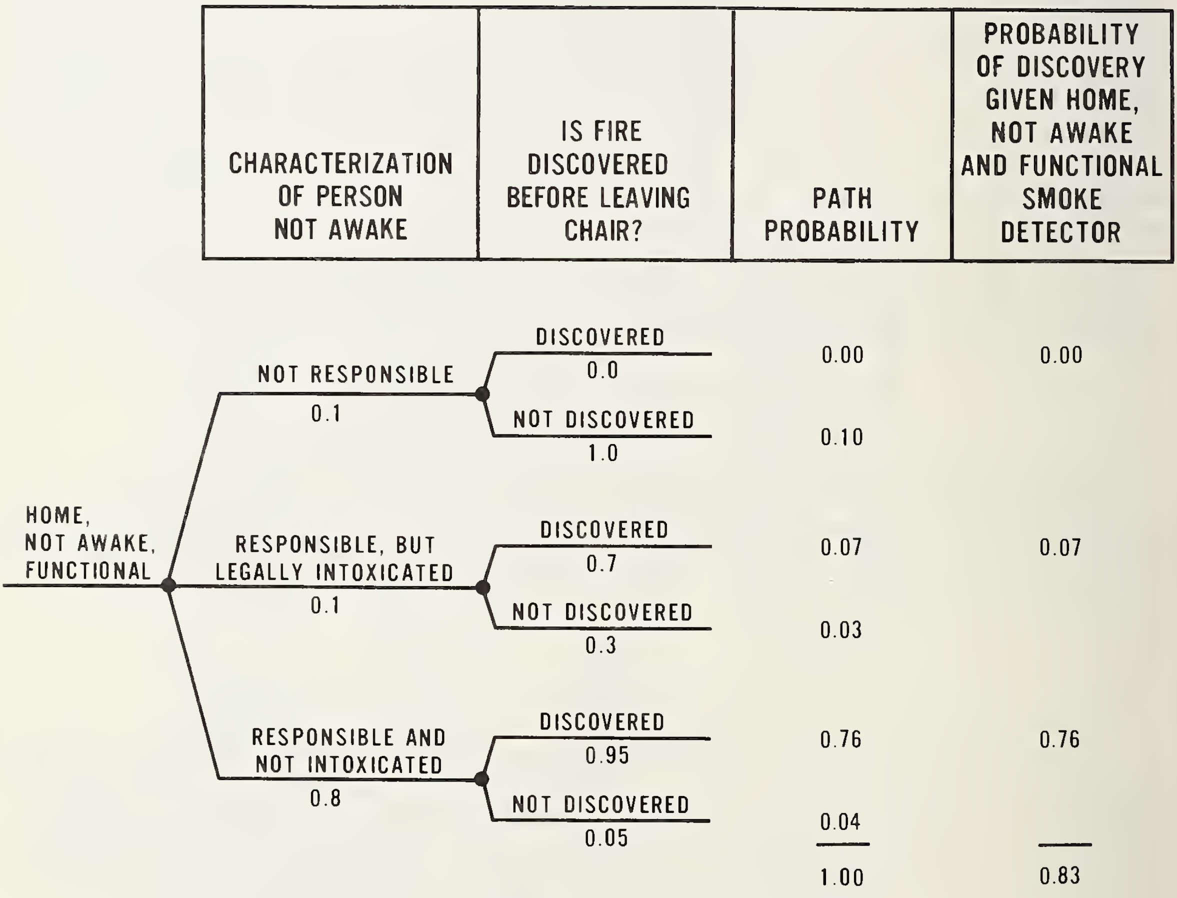

Figure 12. Calculation of Discovery Probability Conditional on Home, Awake, and Functional Parameters

4.2.2.5 Fire Type

The fire type probability gives the likelihood that the fire only smolders (SM), smolders and then flames (SM/FL), or flames only (FL). To calculate the fire type probabilities, we introduce an intermediate variable to characterize the initial ignition class. As shown in table 17, ignitions are classed as either initially smoldering or flaming. The table shows that 100 percent of cigarette ignitions, 30 percent of open flame ignitions, 70 percent of electrical ignitions, and 90 percent of other ignitions are assumed to begin in a smoldering stage. The remaining ignitions are assumed to begin in a flaming state.

Table 17. Probability Assignments on Ignition Class as Function of Ignition Source

Ignition Source	Ignition Class	Ignition Class Probability
Cigarette	Smoldering	1.00
	Flaming	0.00
Open Flame	Smoldering	0.30
	Flaming	0.70
Electrical	Smoldering	0.70
	Flaming	0.30
Other	Smoldering	0.90
	Flaming	0.10

As shown in figure 13, the fire type probabilties are made dependent on ignition class and on whether or not the fire was discovered before leaving the chair. A flaming ignition is assumed always to lead to a fire of type FL. A smoldering ignition, if discovered, leads to a fire of type SM with probability 0.95 and of type SM/FL with probability of 0.05. If the fire is not discovered, then the SM probability is set at 0.08 and the SM/FL probability at 0.92.

To eliminate the intermediate parameter, ignition class, we combine the information in figure 13 and table 17. For example, to calculate the probability that a discovered fire resulting from an electrical ignition source will smolder only, we first observe from table 17 that there is a 70 percent chance of the ignition beginning in a smoldering

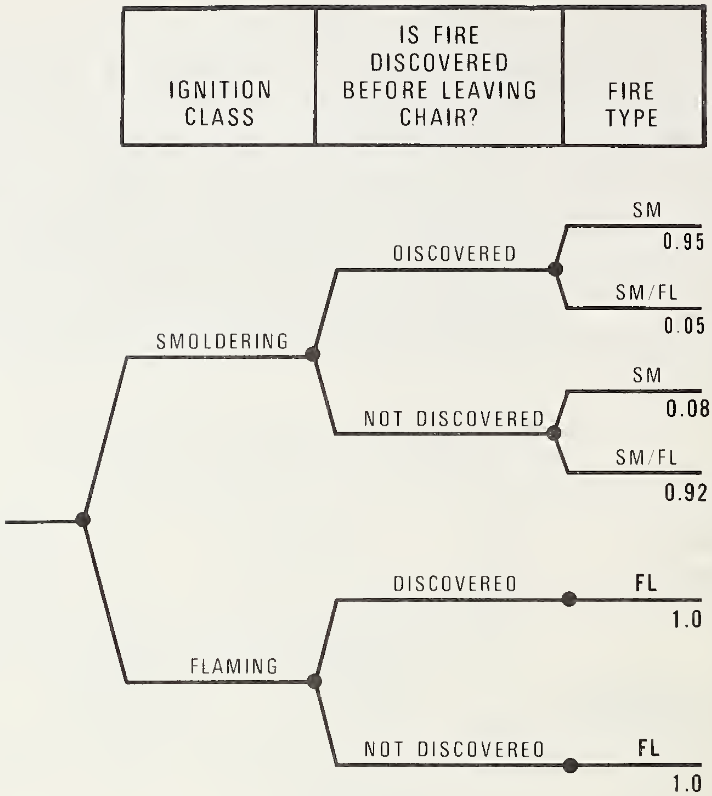

Figure 13. Probability Assignments on Fire Type as Function of Discovery and Ignition Class

state. From figure 13, we note that there is a 95 percent chance that a smoldering ignition will terminate in a smoldering state (SM) if the fire is discovered before it leaves the chair. Therefore, the probability that a fire type SM results from an electrical ignition source, given discovery, is 0.70 x 0.95 = 0.66.[6] Similarly, the probability that the fire will smolder and then flame (SM/FL), given that it is discovered, is 0.70 x 0.05 = 0.04. If a smoldering ignition from an electrical source is not discovered, the probability of fire type SM is 0.70 x 0.08 = 0.06; the probability of SM/FL, given that it is not discovered, is 0.70 x 0.92 = 0.64. The probability of the fire type FL is the probability that it begins flaming, or 0.30. Similar calculations are made for the other ignition sources, the results of which are shown in the second parts of figures 11A, B, C, and D.

[6] Input probabilities are rounded to two decimal places subject to the constraint that they sum to one.

4.2.2.6 Is Fire Reported?

The terminal branches on the auxiliary tree are the probabilities that the fire is reported to the fire department. These probability assignments are based on expert judgment and, for all ignition sources, they are made dependent only on the fire type and whether the fire is discovered before leaving the chair. Thus, for example, the probability of the fire being reported is assumed to be only 0.10 if the fire was discovered and only smoldered. But the probability of the fire being reported is set at 0.95 if the fire ultimately flamed and was not discovered before leaving the chair.

4.2.2.7 Calculation of Conditional Probabilities from Auxiliary Probability Trees

The probabilities required for the original probability tree of figure 9 are conditional on the fire being reported. The calculation of these probabilities from the auxiliary tree is a multistep process based on the definition of conditional probability.

As an example of how the conditional probabilities are calculated, figure 14 is used to calculate, for cigarette ignitions, the probability of someone being "not awake," given a reported fire with someone at home. As shown, the probability of the fire being reported with someone at home is found to be 0.214596.[7] The probability of someone being at home and not awake and of the fire being reported is the sum of the path probabilities that comprise that event, or 0.092557. Thus, from the definition of conditional probability, the probability of someone being "not awake," given a reported cigarette ignition with someone at home, is 0.092557/0.214596, or 0.431308. Similar calculations are made to determine the other conditional probabilities. The resulting probabilities are given in the appendix.

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[7] Intermediate calculations in part two of this report are shown to as many as 6 significant figures to maintain the relative differences among the small probabilities and to minimize round-off errors. Final results, however, are given in three significant figures. The exact calculations shown in figure 14, as well as the other figures and tables in part two, may not check because of rounding. For a more complete explanation of "round-off" see appendix.

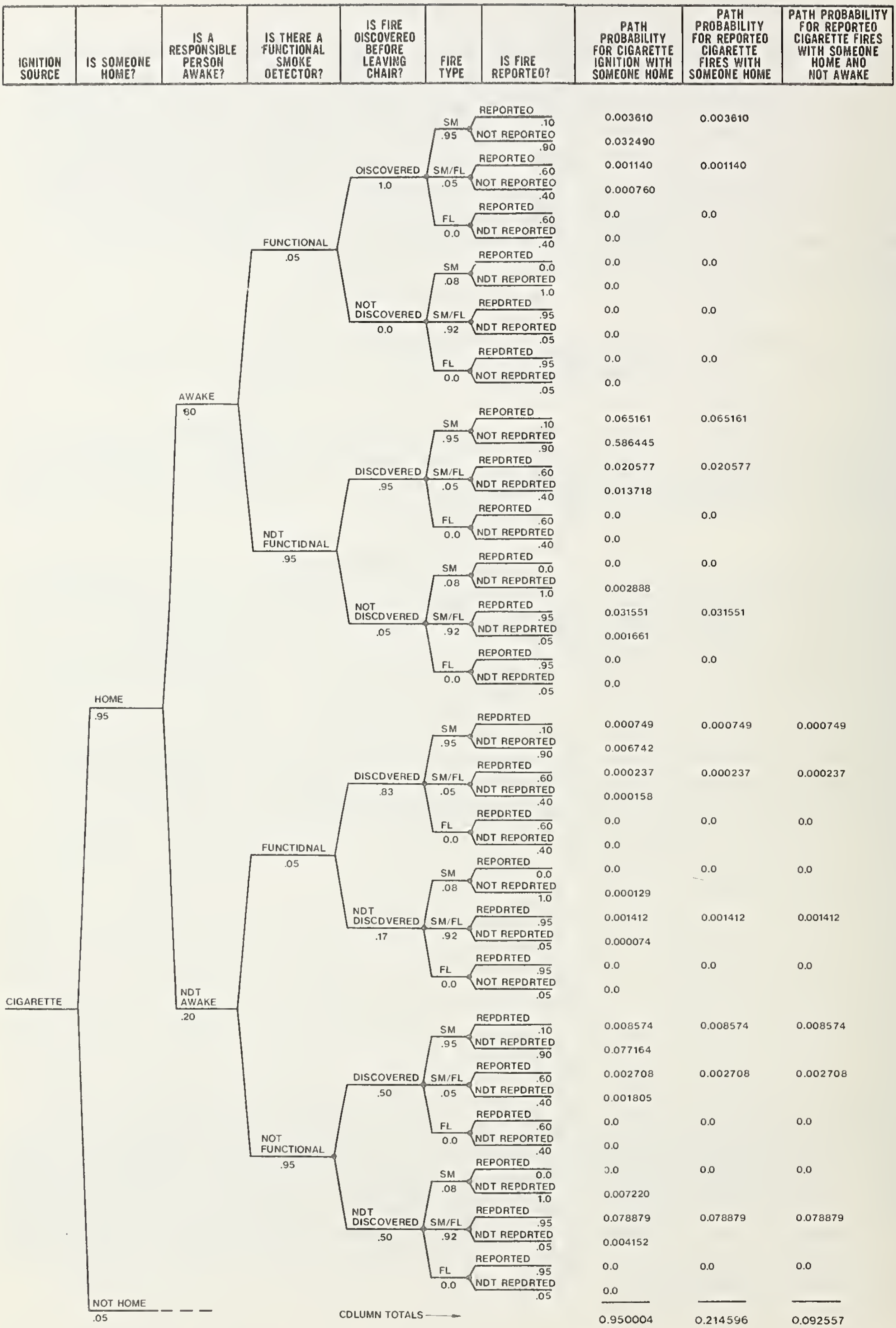

Figure 14. Portion of Auxiliary Tree for Cigarette Ignition Source Used in Sample Conditional Probability Calculation

4.2.3 Extent of Flame Damage Probabilities

Statistics on the extent of flame damage for upholstered furniture fires are taken directly from the NFIRS data base. However, the NFIRS statistics are not conditioned on fire type or on whether the fire is discovered before leaving the chair. Since the latter two considerations are important in the comparison of alternatives, the statistics must be adjusted to make them dependent on fire type and the discovery parameter.

First, we consider the effect of fire type. If the fire type is SM (smoldering only), we assume that the flame damage is confined to the chair regardless of whether the fire is discovered. Therefore, as shown in figure 15, we set the probability of the flame damage being confined to the chair (C) at 1.0 for the fire type SM.

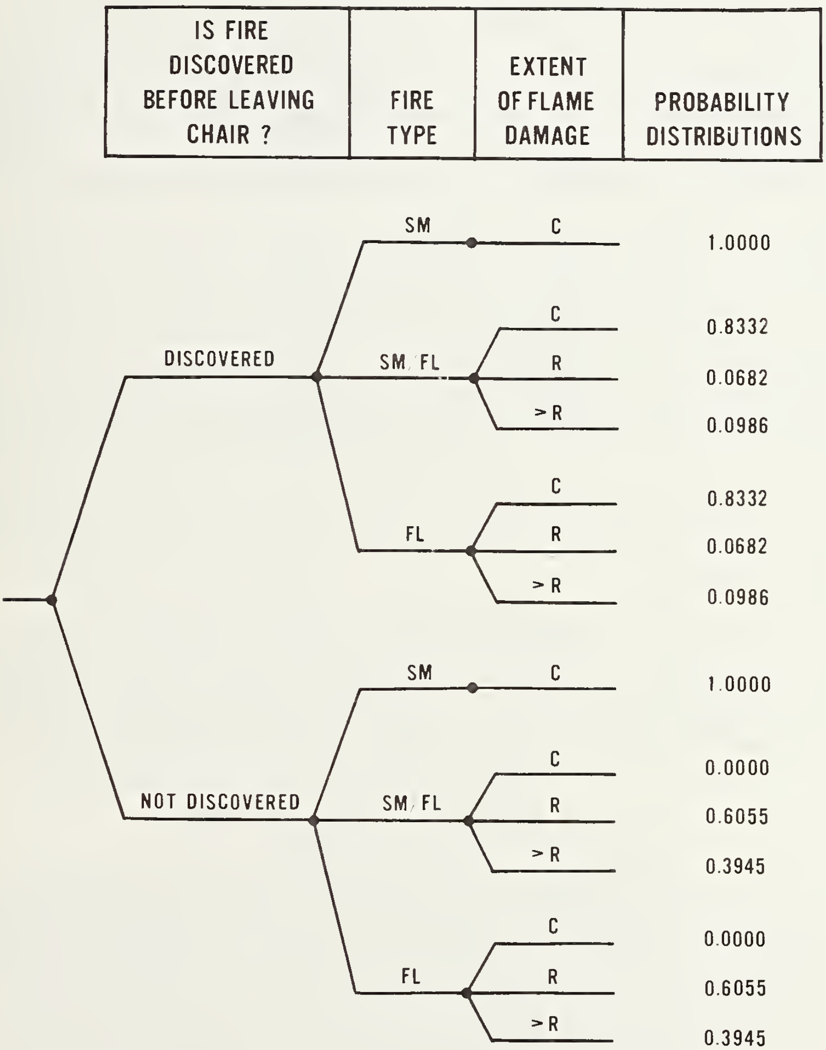

Figure 15. Probability Distributions on Extent of Flame Damage Conditional on Discovery and Fire Type

Table 18 gives the extent of flame damage for 2,497 of the 2,742 upholstered furniture fires contained in the NFIRS data base. The fires in the data base include fires that only smoldered as well as fires that ultimately flamed. The extent of flame damage for fires that ultimately flamed can therefore be determined by adjusting the statistics to account for the fires that never flamed. From the auxiliary trees (figure 11A-D), we calculate that 24.3 percent of the reported fires, or approximately 606 of the 2,497 fires, never progress beyond the smoldering stage. Subtracting the smoldering only fires from the "C" fires in the first column of table 18 then gives the distribution on extent of flame damage for fires that ultimately flame, as shown in the table.

Table 18. Statistics on Extent of Flame Damage for 2742 Upholstered Furniture Fires

Extent of Flame Damage	Number of Fires	Number of Fires That Ultimately Flamed	Frequency of Fires That Ultimately Flamed[a]
C	1048	442	0.2337
R	860	860	0.4548
>R	589	589	0.3115
Unknown	245	---	--
Total	2742	1891	1.0000

[a]Based on an estimated 1891 fires with known extent of flame damage that ultimately flamed

Table 18 gives estimated frequencies on extent of flame damage for reported fires that ultimately flame. However, the frequencies must be further adjusted to account for their dependency on whether the fire is discovered before leaving the chair. To calculate the required conditional probabilities we introduce the following notation:

$P(x)$ = probability event x occurs

$P(x_1,\ldots,x_n)$ = probability events x_1 thru x_n all occur

$P(x/y)$ = probability event x occurs, given that event y occurs

rep = fire is reported

flame = fire ultimately flames

C = flame damage is confined to chair

R = flame damage extends beyond chair but is confined to room

$>R$ = flame damage extends beyond room

dis = fire is discovered before leaving the chair

$\overline{dis}$ = fire is not discovered before leaving the chair

Using the rules of conditional probability, we write:

$$P(C/rep,flame) = P(C/dis,rep,flame)\ P(dis/rep,flame) + P(C/\overline{dis},rep,flame)\ P(\overline{dis}/rep,flame) \tag{1}$$

$$P(R/rep,flame) = P(R/dis,rep,flame)\ P(dis/rep,flame) + P(R/\overline{dis},rep,flame)\ P(\overline{dis}/rep,flame) \tag{2}$$

$$P(>R/rep,flame) = P(>R/dis,rep,flame)\ P(dis/rep,flame) + P(>R/\overline{dis},rep,flame)\ P(\overline{dis}/rep,flame) \tag{3}$$

Also, because the categories of flame damage have been defined to be mutually exclusive and collectively exhaustive, we can write:

$$P(C/dis,rep,flame) + P(R/dis,rep,flame) + P(>R/dis,rep,flame) = 1 \tag{4}$$

Equations (1), (2), (3), and (4) provide four equations in six unknowns. They can be solved uniquely if two more linearly independent equations involving the unknown variables can be generated. To develop two such equations, we assume that the flame damage must extend beyond the chair if a flaming fire is not discovered before leaving the chair. We also assume that the probability of a fire spreading beyond the room is four times as great for undiscovered fire as for discovered fire.

Therefore, we can write:

$$P(C/\overline{dis},rep,flame) = 0 \tag{5}$$

$$P(>R/\overline{dis},rep,flame) = 4P(>R/dis,rep,flame) \tag{6}$$

From the auxiliary trees, we calculate

$$P(dis/rep,flame) = 0.280$$

$$P(\overline{dis}/rep,flame) = 0.720$$

Substituting these values, together with the values given in table 18, into equations (1) through (6), we obtain the probability distributions shown in figure 15. As shown in the figure we assume that these probabilities on flame damage are valid for all fires that ultimately flame--that is, for fires of types SM/FL and FL. (We further assume that these probabilities are valid for each of the ignition sources.)

4.3 Loss Assignments

Associated with each type of fire, or path through the tree, is an average level of loss. In this section we develop loss estimates for each type of fire represented by the tree. The loss estimates are given in terms of deaths, injuries, and tangible and intangible property loss. In most cases, the loss estimates are developed from historical statistics, adjusted by judgment to reflect dependencies not recorded in the statistics.

As a first approximation, we assume that the level of property loss is dependent on whether the fire is discovered before leaving the chair and on extent of flame damage. We assume that the level of injury and death depends on whether anyone is at home, whether the fire is discovered before leaving the chair, and on the extent of flame damage. It is possible to construct a more detailed estimate of loss by introducing more variables on which to condition the losses, but the variables selected here are sufficient for a preliminary comparison of alternatives.

Table 19 gives the average personal and tangible property losses recorded for the 2742 fires in the NFIRS data base as a function of extent of flame damage. Project team estimates for intangible property losses are also given in the table. In order to make the values usable under the assumptions made for the analysis, the fatality and injury loss numbers must also be made dependent on whether someone is at home and on whether the fire is discovered before leaving the chair. Since statistical data do not exist for this dependency, expert judgment is used to characterize it.

For example, we consider the number of fatalities from fires with extent of flame damage beyond the room. Table 19 shows that on the average 0.08489 persons were killed in a fire of this class. We would expect this loss figure to be higher for fires in which someone was at home and lower if no one was at home at the time of ignition. But averaging over whether anyone was at home or not, the expected mortality rate must be 0.08489 fatalities per fire. Thus,

$$P(\text{home}/\text{rep},>R)\ L(\text{home},\text{rep},>R) + P(\overline{\text{home}}/\text{rep},>R)\ L(\overline{\text{home}},\text{rep},>R) = L(\text{rep},>R) = 0.08489 \qquad (14)$$

where

$L(x_1,\ldots,x_n)$ = average loss given that events x_1 thru x_n all occur

home = someone is at home when ignition occurs

$\overline{\text{home}}$ = no one is home when ignition occurs

Table 19. Loss Statistics for 2742 Upholstered Furniture Fires

Extent of Flame Damage	Average Number of Fatalities Per Fire[a]	Average Number of Injuries Per Fire[a]	Average Tangible Property Loss Per Fire	Average Intangible Property Loss Per Fire[b]
C	0.00477	0.0429	$ 323	$ 20
R	0.01628	0.1395	$ 2 312	$ 200
>R	0.08489	0.3956	$11 480	$2000

[a]Both firefighter and civilian casualties are included

[b]Project team estimates

The probabilities $P(\text{home/rep,>R})$ and $P(\overline{\text{home}}\text{/rep,>R})$ are calculated from the fire loss model (probability tree). Thus, equation (14) is a single equation in two unknowns, and it can be solved if one more independent equation involving $L(\text{home,rep,>R})$ and $L(\overline{\text{home}}\text{,rep,>R})$ can be developed. To provide this equation, we assume that the loss of life for fires of class ">R" is 10 times greater for fires in which someone is at home than in which no one is at home.

That is,

$$L(\text{home,rep,>R}) = 10L(\overline{\text{home}}\text{,rep,>R}) \tag{15}$$

From the fire loss model, we calculate that

$$P(\text{home/rep,>R}) = 0.7010$$

$$P(\overline{\text{home}}\text{/rep,>R}) = 0.2990$$

Substituting these values into equations (14) and (15), we obtain

$$L(\text{home,rep,>R}) = 0.11614$$

$$L(\overline{\text{home}}\text{,rep,>R}) = 0.01161$$

These values must now be adjusted to reflect whether the fire is discovered before leaving the chair. Thus, we write

$$P(\text{dis/home,rep,>R})\ L(\text{dis,home,rep,>R}) + P(\overline{\text{dis}}\text{/home,rep,>R})\ L(\overline{\text{dis}}\text{,home,rep,>R}) = L(\text{home,rep,>R}) \tag{16}$$

$$P(\text{dis/}\overline{\text{home}}\text{,rep,>R})\ L(\text{dis,}\overline{\text{home}}\text{,rep,>R}) + P(\overline{\text{dis}}\text{/}\overline{\text{home}}\text{,rep,>R})\ L(\overline{\text{dis}}\text{,}\overline{\text{home}}\text{,rep,>R}) = L(\overline{\text{home}}\text{,rep,>R}) \tag{17}$$

To uniquely solve (16), another relationship between $L(\text{dis,home,rep,>R})$ and $L(\overline{\text{dis}}\text{,home,rep,>R})$ is required.

We assume that

$$L(\overline{\text{dis}}\text{,home,rep,>R}) = 10L(\text{dis,home,rep,>R}) \tag{18}$$

From the fire loss model, we calculate

$$P(\text{dis/home,rep,>R}) = 0.1265$$

$$P(\overline{\text{dis}}\text{/home,rep,>R}) = 0.8735$$

Substituting these values into (16) and solving simultaneously with (18), we obtain

$$L(\text{dis},\text{home},\text{rep},>R) = 0.01311$$

$$L(\overline{\text{dis}},\text{home},\text{rep},>R) = 0.13107$$

If no one is at home at the time ignition occurs, we assume that the expected loss of life is the same for all fires whether or not the fire is discovered before leaving the chair. Thus

$$\begin{aligned} L(\text{dis},\overline{\text{home}},\text{rep},>R) &= L(\overline{\text{dis}},\overline{\text{home}},\text{rep},>R) \\ &= L(\overline{\text{home}},\text{rep},>R) \\ &= 0.01161 \end{aligned}$$

Similar calculations are made for loss of life in fires of flame extent "R" and for injuries in fires of flame extent "R" and ">R". Loss of life for fires of flame extent "C" is only conditioned on whether someone is home. For a fire that is not discovered before leaving the chair, we assume that the probability that the flame damage is confined to the chair is zero for reported fires, or $P(\overline{\text{dis}}/\text{rep},C) = 0$. Tables 20 and 21 list the assumptions used in subdividing the loss statistics into finer categories.

Table 20. Assumptions Used to Condition Expected Fatality Losses on Occupancy, Discovery and Extent of Flame Damage

Extent of Flame Damage	Relationship Between Fatality Loss Categories
C	$L(\text{home},\text{rep},C) = 20L(\overline{\text{home}},\text{rep},C)$
R	$L(\text{home},\text{rep},R) = 20L(\overline{\text{home}},\text{rep},R)$
	$L(\overline{\text{dis}},\text{rep},\text{home},R) = 5L(\text{dis},\text{rep},\text{home},R)$
	$L(\overline{\text{dis}},\text{rep},\overline{\text{home}},R) = L(\text{dis},\text{rep},\overline{\text{home}},R)$
>R	$L(\text{home},\text{rep},>R) = 10L(\overline{\text{home}},\text{rep},>R)$
	$L(\overline{\text{dis}},\text{rep},\text{home},>R) = 10L(\text{dis},\text{rep},\text{home},>R)$
	$L(\overline{\text{dis}},\text{rep},\overline{\text{home}},>R) = L(\text{dis},\text{rep},\overline{\text{home}},>R)$

Tangible and intangible property losses are made dependent on whether the fire is discovered before leaving the chair, using a method similar to that outlined above. In subdividing the losses, we assume that property losses in discovered fires with extent of flame damage "R" and ">R" are 80 percent of the losses incurred in not-discovered fires.

Table 21. Assumptions Used to Condition Expected Injury Losses on Occupancy, Discovery and Extent of Flame Damage

Extent of Flame Damage	Relationship Between Injury Loss Categories
C	$L(\text{home},\text{rep},C) = 10L(\overline{\text{home}},\text{rep},C)$
R	$L(\text{home},\text{rep},R) = 10L(\overline{\text{home}},\text{rep},R)$
	$L(\overline{\text{dis}},\text{rep},\text{home},R) = 2L(\text{dis},\text{rep},\text{home},R)$
	$L(\overline{\text{dis}},\text{rep},\overline{\text{home}},R) = L(\text{dis},\text{rep},\overline{\text{home}},R)$
>R	$L(\text{home},\text{rep},>R) = 5L(\overline{\text{home}},\text{rep},>R)$
	$L(\overline{\text{dis}},\text{rep},\text{home},>R) = 5L(\text{dis},\text{rep},\text{home},>R)$
	$L(\overline{\text{dis}},\text{rep},\overline{\text{home}},>R) = L(\text{dis},\text{rep},\overline{\text{home}},>R)$

Table 22 gives the resultant loss figures for each category of loss.

4.4 Value Assignments

The fire loss model provides estimates for four categories of loss: deaths, injuries, tangible property loss, and intangible property loss. In comparing the alternatives, we must compare the various units of loss with the costs of implementing the alternatives. It is possible to simultaneously compare the costs with the different units of loss, but to facilitate the evaluation of the alternatives and to ensure that they are compared on a consistent basis, this section introduces the explicit value assignments for use in reducing the different outcome measures to a common monetary scale. The monetary equivalent of the different categories of loss may be interpreted as the amount society is willing to pay to prevent a single loss of the particular category.

As discussed in section 3.1.2, we use a nominal value of $300 000 per life saved for our analysis. A sensitivity study to determine how the choice among alternatives varies with this assignment is given in section 3.7.1.

Injuries incurred during upholstered furniture fires cover a wide range of types and severity. In a report commissioned by the Consumer Product Safety Commission, Battelle Columbus Laboratories estimates the cost of an average upholstered furniture fire injury at $8700 [22]. This figure represents the average costs of hospital and physicians, rehabilitation, work loss, and legal fees for injuries to civilians (as opposed to firefighters). Burn injuries, smoke inhalation, and other injuries are averaged in this cost estimate. In this analysis we use a

Table 22. Expected Loss Assignments as Function of Occupancy, Discovery and Extent of Flame Damage

Extent of Flame Damage	Is Someone Home?	Is Fire Discovered Before Leaving Chair?	Average Number of Fatalities Per Reported Fire	Average Number of Injuries Per Reported Fire	Average Property Loss Per Reported Fire (Dollars)	
					Tangible	Intangible
C	Yes	Yes	0.00477	0.0430	$ 323	$ 20
		No	0.00477	0.0430	323	20
	No	Yes	0.00024	0.0043	323	20
		No	0.00024	0.0043	323	20
R	Yes	Yes	0.00488	0.1003	1 865	161
		No	0.02441	0.2007	2 332	202
	No	Yes	0.00116	0.0195	1 865	161
		No	0.00116	0.0195	2 332	202
>R	Yes	Yes	0.01311	0.1157	9 352	1 629
		No	0.13107	0.5785	11 690	2 036
	No	Yes	0.01161	0.1040	9 352	1 629
		No	0.01161	0.1040	11 690	2 036

value approximately equal to this estimate, $10,000 per average fire injury, although we recognize that this figure may not include an adequate allowance for such indirect costs as pain and suffering. A sensitivity study on this value assignment is given in section 7.1.2.

Tangible property losses are valued at the cost of the real property involved as reported in the NFIRS data base. Intangible property losses are valued at the average dollar amount one would be willing to pay to forego such losses as aesthetic damage, disruption of life style, and loss of family mementos. The tangible property losses, shown in table 19, are obtained directly from the NFIRS data base. For each extent of flame damage class, the figure is the average direct property loss estimated by the fire service for all upholstered furniture fires in that class. The intangible property loss figures are project team estimates. Both sets of figures, adjusted to make them dependent on the discovery parameter, are shown in table 22.

Table 23 gives the monetary equivalents for each of the categories of loss. The table is constructed by multiplying the average number of fatalities and injuries per fire (table 23) by their associated value assignments. By construction, the losses are made dependent on extent of flame damage, whether anyone is at home, and the discovery parameter. The aggregate loss shown in the table is the sum of the monetary losses associated with a particular category. There are 10 possible aggregate loss levels, ranging from $458 to $58,832 per fire, depending on the particular combination of conditioning variables.

4.5 Calculation of Losses Under Current Conditions

The probability estimates, loss outcomes, and value assignments outlined above are used with the probability tree of figure 9 to calculate the possible losses from a single reported upholstered furniture fire. The calculations are made by determining the probability and losses associated with each path through the tree. The probability of the path is the product of the probabilities of the branches making up the path. The losses are found from tables 22 and 23, depending on the level of flame extent, occupancy, and discovery parameters. The probabilities of the paths leading to the same loss are summed, and the results are presented in the form of a probability distribution on loss.

Table 24 gives the resultant probability distributions on aggregate loss for a single reported upholstered furniture fire. The cumulative probability is the probability that the expected losses will be less than or equal to the amount shown. The cumulative probability distribution is also shown in graphical form in figure 16.

Measured in monetary terms, the average aggregate loss ranges from approximately $460 to $58,800 per fire. There is a 54 percent chance that the fire will have expected losses less than $4,500, and a 14 percent

Table 23. Dollar Loss Assignments as Function of Occupancy, Discovery and Extent of Flame Damage

Extent of Flame Damage	Is Someone Home?	Is Fire Discovered Before Leaving Chair?	Average Dollar Loss Per Reported Fire			
			Fatality	Injury	Property	Aggregate
C	Yes	Yes	$ 1 431	$ 430	$ 343	$ 2 204
		No	1 431	430	343	2 204
	No	Yes	72	43	343	458
		No	72	43	343	458
R	Yes	Yes	1 464	1 003	2 026	4 493
		No	7 323	2 007	2 534	11 864
	No	Yes	348	195	2 026	2 569
		No	348	195	2 534	3 077
>R	Yes	Yes	3 933	1 157	10 981	16 071
		No	39 321	5 785	13 726	58 832
	No	Yes	3 483	1 040	10 981	15 504
		No	3 483	1 040	13 726	18 249

Table 24. Probability Distributions on Aggregate Losses Under Current Conditions

Aggregate Loss (Dollars)	Probability	Cumulative Probability
$ 458	0.00031	0.00031
2 204	0.41939	0.41970
2 569	0.00001	0.41971
3 077	0.10823	0.52794
4 493	0.01447	0.54241
11 864	0.22170	0.76412
15 504	0.00001	0.76413
16 071	0.02092	0.78505
18 249	0.07051	0.85556
58 832	0.14444	1.00000

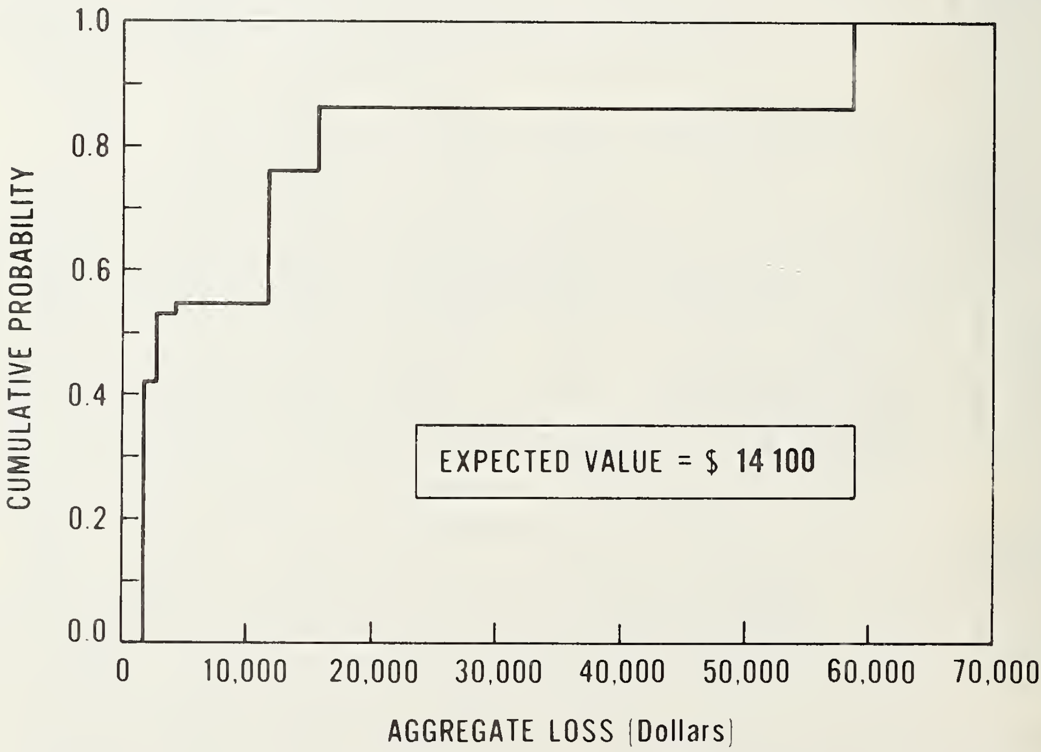

Figure 16. Cumulative Distribution on Aggregate Losses Under Current Conditions

chance that losses will be $18,000 or more. The expected value of the probability distribution is $14,100. Similar probability distributions can also be constructed for each of the loss components. In this analysis, however, our focus is on the expected values of these losses.

Table 25 gives the expected loss in each category. The table shows that loss of life is the largest component of the aggregate loss accounting for 59 percent of the total. Tangible and intangible property losses are the second most important component, together accounting for 30 percent of the expected loss. Injuries account for only 11 percent of the expected aggregate loss. It should be recalled that these results are dependent on the value assignments made for death and injury, and that changing the assignments could change the relative importance of the different loss categories. The expected loss per reported fire is multiplied by 47,500, the annual number of reported fires derived in section 3.1, to obtain the total annual U.S. losses also shown in table 25.

Table 25. Reported Upholstered Furniture Fire Losses Under Current Conditions

	Expected Loss Per Fire		Total Annual Expected Losses[a]	
Category	Number	Monetary Equivalent	Number	Monetary Equivalent (Millions of Dollars)
Fatalities	0.0276	$ 8,290	1312	$394
Injuries	0.159	1,590	7570	76
Property				
Tangible		3,640		173
Intangible		550		26
Aggregate		$14,100		$668

[a]Obtained by multiplying the expected loss per fire by 47,500, the annual number of reported upholstered furniture fires

4.6 Number of All Upholstered Furniture Fires Under Current Conditions

In this section we derive the number of "all" upholstered furniture fires (both reported and unreported) under current conditions and the corresponding ignition source distribution. These results are used in section 5 to model the expected losses under the three alternatives.

We first calculate the probability that an upholstered furniture fire is reported. From the definition of conditional probability, we can write

$$P(cig/rep) = \frac{P(cig,rep)}{P(rep)} \tag{7}$$

and also

$$P(rep/cig) = \frac{P(cig,rep)}{P(cig)} \tag{8}$$

where

cig = ignition source is cigarette

Rearranging (8) we obtain

$$P(cig) = \frac{P(cig,rep)}{P(rep/cig)} \tag{9}$$

and substituting (7) into (9) yields

$$P(cig) = \frac{P(cig/rep)\ P(rep)}{P(rep/cig)} \tag{10}$$

To determine the probability of an upholstered furniture fire being reported, P(rep), we note that equations similar to (10) can be written for the other ignition sources. Then, because the four ignition sources are defined to be mutually exclusive and collectively exhaustive, we can write

$$P(cig) + P(open) + P(elec) + P(other) = 1 \tag{11}$$

or

$$\frac{P(cig/rep)\ P(rep)}{P(rep/cig)} + \frac{P(open/rep)\ P(rep)}{P(rep/open)} + \frac{P(elec/rep)\ P(rep)}{P(rep/elec)} + \frac{P(other/rep)\ P(rep)}{P(rep/other)} = 1 \tag{12}$$

or

$$\left[\frac{P(cig/rep)}{P(rep/cig)} + \frac{P(open/rep)}{P(rep/open)} + \frac{P(elec/rep)}{P(rep/elec)} + \frac{P(other/rep)}{P(rep/other)}\right] P(rep) = 1 \tag{13}$$

where

open = ignition source is open flame

elec = ignition source is electrical

other = ignition source is other

The probabilities for each of the ignition sources conditional on the fire being reported are obtained directly from the NFIRS data base as shown in table 16. The probabilities of the fire being reported, given a particular ignition source, are determined from the auxiliary probability trees. Substituting these values into equation (13), we obtain

$$\left[\frac{0.7031}{0.2579} + \frac{0.1294}{0.4801} + \frac{0.0520}{0.4807} + \frac{0.1155}{0.3858}\right] P(\text{rep}) = 1$$

or

$$P(\text{rep}) = 0.2938$$

The probability that the fire is reported is used to obtain the total number of all upholstered furniture fires (both reported and unreported). As detailed in section 3.1, based on the annual number of fire fatalities, we estimate that there are 47,500 reported upholstered furniture fires annually. Dividing this estimate by 0.2938, the probability that the fire is reported, we obtain 161,600 upholstered furniture ignitions annually under current conditions.

For use in later calculations it is also useful to calculate the unconditional ignition source probabilities, that is, the probabilities of ignition source unconditional on whether the fire is reported. The unconditional ignition source probabilities are obtained by substituting the required values into equation (10) and similar equations for the remaining ignition sources. We obtain the unconditional ignition source probabilities given in table 26. Multiplying each of the ignition source probabilities by 161,600, the total number of ignitions, we obtain the total number of all fires (both reported and unreported) for each ignition source shown in table 26.

Table 26. Ignition Source Distribution for All Fires Under Current Conditions

Ignition Source	Probability	Current Number of Ignitions
Cigarette	0.8010	129 442
Open Flame	0.0792	12 799
Electrical	0.0318	5 139
Other	0.0880	14 221
Total	1.0000	161 600

5. DERIVATION OF LOSS RESULTS UNDER THREE ALTERNATIVE INTERVENTION STRATEGIES

This section provides a detailed derivation of the losses under the three intervention strategies. Many of the results have already been summarized in section 3. They are repeated here along with the underlying input data and assumptions to provide complete documentation of the results and their derivation.

5.1 Losses Under the No-Action Alternative

One intervention strategy for reducing upholstered furniture fire losses is for the government to take no formal action at all. However, even under this strategy it is likely that upholstered furniture fire losses will decline over time because of the increased installation of smoke detectors and the current use of more smolder resistant materials in furniture production. Since it will take a number of years for these changes to take place, we model the losses under the no-action alternative at a number of points in time. We begin by modeling the losses for the case in which the projected smoke detector level has been reached and the current furniture population has been completely replaced with new furniture. We call this the "steady state" or "fully implemented" case. We then develop the losses for the intermediate years.

5.1.1 Steady-State Losses Under the No-Action Alternative

To model the steady-state losses under the no-action alternative, we first address the smoke detector installation. We assume that eventually 60 percent of the homes in the United States will install at least one smoke detector because of either concern for fire safety or local ordinances. Thus, in modeling the steady-state losses under the no-action alternative we revise the probability of there being a functional smoke detector, in the fire loss model. The second trend addressed in modeling the steady-state losses under the no-action alternative is a shift in the composition of upholstered furniture. Current (1975) fire losses, developed in section 4, depend upon the flammability characteristics of the furniture currently in our homes, "the current furniture population" or "pre-1975 furniture." Considerable quantities of cellulosic upholstery and cellulosic stuffing materials were used in the construction of this furniture in past years. Many of these cellulosic upholstery materials and fillings have now been replaced by thermoplastic materials and polyurethane foam cushioning in current furniture production. This is important since the thermoplastic materials tend to be more smolder resistant. However, once ignited, the furniture being produced now is likely to develop a larger fire because of the increased use of polyurethane foam. We assume that under the no-action alternative the current furniture population, of pre-1975 construction, will be replaced by a new furniture population, of post-1975 construction, similar in flammability characteristics to furniture being produced now. Thus in modeling the steady-state losses under the no-action alternative, we adjust the probabilities of ignition source, fire type, and extent of flame damage to reflect the different flammability properties of the post-1975 furniture. The other input probabilities, such as the probability of at least one person being home, remain the same as for current conditions. The losses associated with a particular path through the tree also remain the same as for current conditions.

5.1.1.1 Revised Functional Smoke Detector Probability

We assume that smoke detector usage will increase from the current level of 5 percent functional to 48 percent functional, based on a 60 percent installation level with 80 percent of the detectors operational.

5.1.1.2 Revised Ignition Source Probabilities

Fire technology experts have estimated that smoldering ignitions will be reduced by one-third when the current furniture population has been completely replaced with new furniture, and also that there will be a 10 percent reduction in the number of flaming ignitions. Using these estimates, the revised number of ignitions and ignition source probabilities are calculated as shown in table 27. The table shows the different combinations of ignition source and ignition class. The column labeled "current number of ignitions" gives the number of fires by source and initial ignition type for current conditions, derived from tables 17 and 26. The second column gives the fraction of ignitions that would still occur under the reduction factors discussed above. The third column, the product of the first two columns, gives the number of ignitions by source and type under the fully implemented no-action alternative.

The table shows that the total number of ignitions is projected to decrease from 161,600 to approximately 111,000 ignitions per year. The primary reason for the decrease in the total number of ignitions is the projected one-third reduction in smoldering ignitions. (The assumption of a constant U.S. population at the 1975 level is important to this projection. Otherwise, the reduction would be in the same ratio 111,000: 161,600 but would have to be handled on a per capita basis.)

5.1.1.3 Revised Fire Type Probabilities

The fire type probabilities are the probabilities that the fire never leaves the smoldering state (SM); that the fire smolders and then flames (SM/FL); or that it begins in a flaming state (FL). As before, we assume the fire type probabilities depend on the ignition class

Table 27. Calculation of Revised Ignition Source Probabilities Under No-Action Alternative

Ignition Source	Ignition Class	Current Number of Ignitions	Fraction of Ignitions Occurring After Population is Replaced	Annual Number of Ignitions by Class Occurring After Population is Replaced	Revised Ignition Class Probabilities	Annual Number of Ignitions by Source Occurring After Population is Replaced	Revised Ignition Source Probabilities
Cigarette	Smolder	129 442	0.67	86 737	1.0000	86 737	0.7812
	Flame	0	--	0	0.0000		
Open Flame	Smolder	3 840	0.67	2 573	0.2419	10 636	0.0958
	Flame	8 959	0.90	8 063	0.7581		
Electrical	Smolder	3 597	0.67	2 410	0.6345	3 798	0.0342
	Flame	1 542	0.90	1 388	0.3655		
Other	Smolder	12 799	0.67	8 575	0.8701	9 855	0.0888
	Flame	1 422	0.90	1 280	0.1299		
Total		161 600		111 026		111 026	1.0000

(whether the fire begins smoldering or flaming) and on whether the fire is discovered before leaving the chair. Using the fire type dependencies given in figure 13, the revised ignition class probabilities from table 27 are used to obtain revised fire type probabilities under the steady-state no-action alternative. The calculations are given in figure 17. (No calculations are given for cigarette ignition source since there is no change from current conditions.)

5.1.1.4 Revised Probabilities for Extent of Flame Damage

Although the currently produced or "new" furniture is less likely to ignite, there is evidence that once ignited, a larger fire than we expect under current conditions is likely. To model this phenomenon we assume, based on discussions with fire research experts at the Center for Fire Research, National Bureau of Standards, and the California Department of Consumer Affairs, that only 60 percent of those fires currently confined to the room will remain so confined. Using these assumptions we compute the revised probability distribution on extent of flame damage as shown in table 28. The intermediate distribution is found by multiplying the current "C" probability by 0.6 and assuming that the remaining fires are "R" and ">R" in the same proportion as before. The revised probabilities are found by retaining the "C" probability just calculated, multiplying the intermediate "R" probability by 0.6, and then normalizing to find the probability of ">R." As shown, the probability of a discovered fire that ultimately flames being confined to the chair declines from 0.83 to 0.50. The probability of such fires spreading beyond the room increases from 0.10 to 0.38.

5.1.1.5 Calculation of Steady-State Losses Under No-Action Alternative

The fire loss model is used to calculate the steady-state losses under the no-action alternative. Except for the ignition source, fire type, extent of flame damage, and functional smoke detector probabilities, the input probabilities to the fire loss model are the same as for current conditions. The outcome assignments for a particular path through the tree are kept the same as for current conditions since we are using constant dollars throughout the analysis.

The revised input probabilities are used with the original auxiliary trees of figure 10 to recalculate the required loss model probabilities conditional on the fire being reported. The revised probability of a fire being reported, also determined from these calculations (described in section 4), is found to be 0.272 compared to 0.294 for current conditions. The revised conditional probabilities, along with the revised flame extent probabilities, are used with the main tree of figure 9 to calculate the steady-state losses resulting from a single reported upholstered furniture fire under the fully implemented no-action alternative.

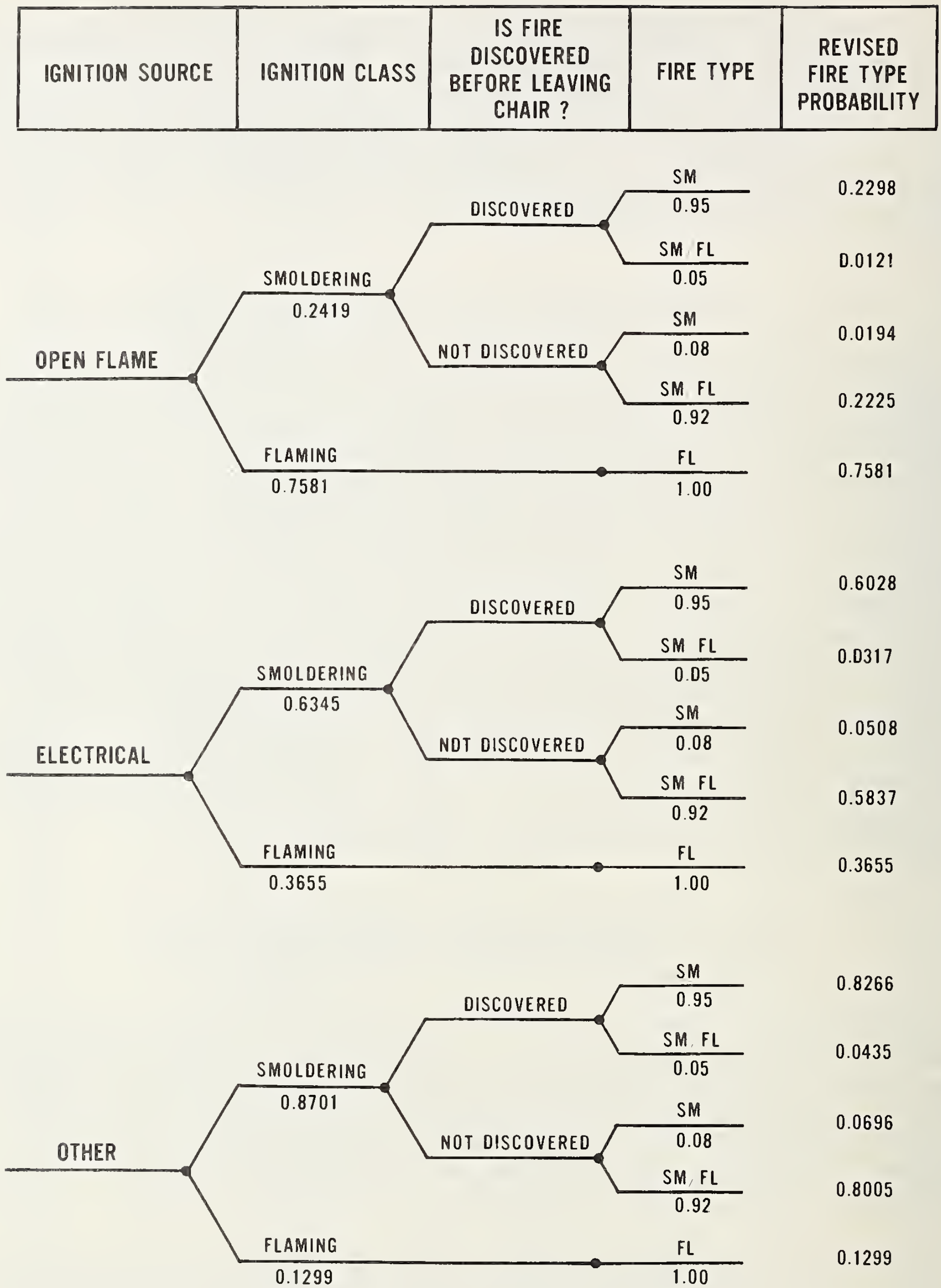

Figure 17. Calculation of Revised Fire Type Probabilities Under No-Action Alternative

Table 28. Calculation of Revised Extent of Flame Damage Probabilities Under No-Action Alternative

Is Fire Discovered Before Leaving Chair?	Extent of Flame Damage	Extent of Flame Damage Probabilities Under Current Conditions	Fraction of Fires Confined to Chair Under No-Action Alternative	Intermediate Extent of Flame Damage Distribution	Fraction of Fires Confined to Room Under No-Action Alternative	Revised Extent of Flame Damage Probabilities Under Steady-State No-Action Alternative
Discovered	C	0.8332	0.6	0.4999	---	0.4999
	R	0.0682	---	0.2045	0.6	0.1227
	>R	0.0986	---	0.2956	---	0.3774
Not Discovered	C	0.0000	0.6	0.0000	---	0.0000
	R	0.6055	---	0.6055	0.6	0.3633
	>R	0.3945	---	0.3945	---	0.6367

Table 29 gives the resultant probability distributions on aggregate loss for a single reported upholstered furniture fire under the fully implemented no-action alternative. A graph of the cumulative probability distribution is given in figure 18. The range of possible losses is the same as under current conditions, from $460 to $58,800, but the likelihood of the different values has changed. Whereas there is 0.14 probability of the total losses per fire exceeding $58,800 under current conditions, there is a 0.17 probability of that occurring under the steady-state no-action alternative. The expected aggregate loss, given a reported ignition, is $16,100 compared to $14,100 for current conditions.

Table 29. Probability Distributions on Aggregate Losses Under No-Action Alternative

Aggregate Loss (Dollars)	Probability	Cumulative Probability
$ 458	0.00041	0.00041
2 204	0.40808	0.40849
2 569	0.00003	0.40852
3 077	0.06962	0.47814
4 493	0.03412	0.51227
11 864	0.09470	0.60697
15 504	0.00009	0.60706
16 071	0.10498	0.71204
18 249	0.12201	0.83404
58 832	0.16596	1.00000

Table 30 gives the expected losses by category. To obtain the total annual losses, the number of reported fires is calculated as the product of the number of ignitions and the probability of the fire being reported, or 111 000 x 0.272 = 30,200. By multiplying this number by the loss per reported fire, the total expected losses are obtained. The table shows that total annual U.S. losses under the steady-state no-action alternative are $486 million, compared to $668 million under current conditions. More than half of the $486 million in aggregate loss is due to loss of life. The total number of fatalities under the fully implemented no-action alternative is 878 compared to 1312 under current conditions. Thus the combined effect of the increased smoke detector installation level and the more smolder-resistant furniture population is to reduce total expected U.S. losses occurring in residential upholstered furniture fires by $182 million per year.

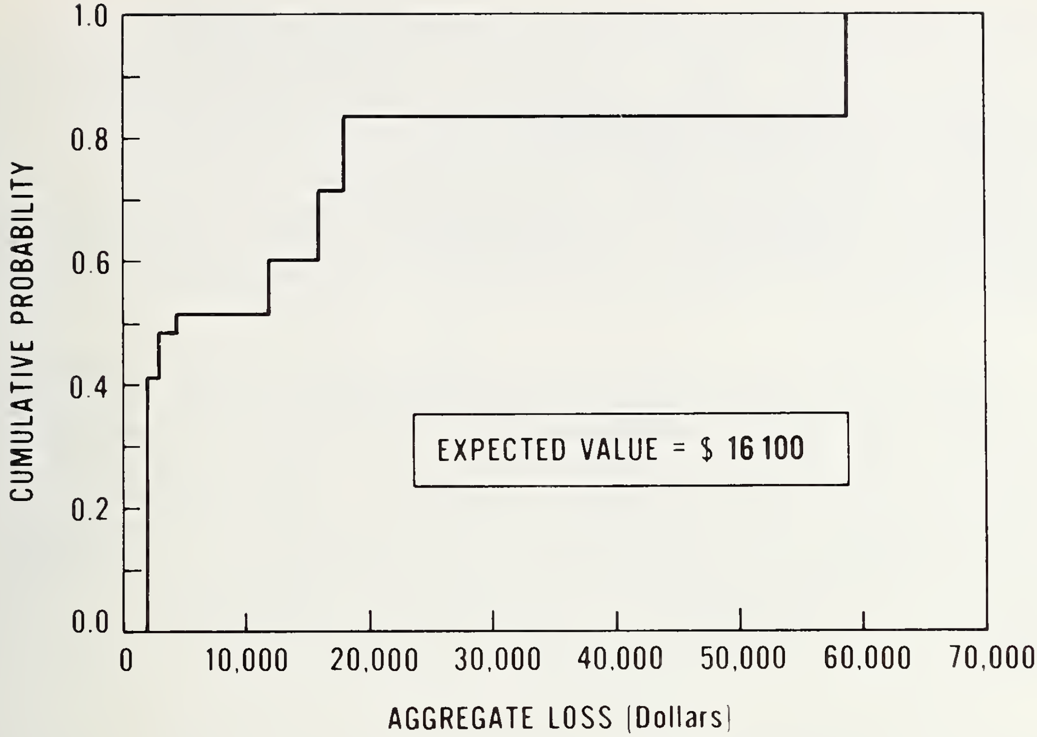

Figure 18. Cumulative Distribution on Aggregate Losses Under No-Action Alternative

Table 30. Reported Upholstered Furniture Fire Losses Under Fully Implemented No-Action Alternative

	Expected Loss Per Fire		Total Annual Expected Losses[a]	
Category	Number	Monetary Equivalent	Number	Monetary Equivalent (Millions of Dollars)
Fatalities	0.0291	$ 8 720	878	$263
Injuries	0.162	1 620	4900	49
Property				
Tangible		4 930		149
Intangible		800		24
Aggregate		$16 100		$486

[a]Obtained by multiplying the expected loss per fire by 30,200, the annual number of reported upholstered furniture fires

5.1.2 No-Action Alternative Losses Over Time

It will take a number of years for the losses under the no-action alternative to reach the steady-state level just calculated. We assume that the smoke detector installation level will increase from its 1977 level of 5 percent functional to the steady-state level of 48 percent functional by 1980. It will take many more years for the furniture population to be completely replaced. Both of these effects must be modeled if we are to model the losses over time under the no-action alternative.

Our approach is to calculate the losses for an intermediate year and then to obtain the losses in the intervening years by interpolation. We choose 1980 as the intermediate year because that is when the voluntary smoke detector level is assumed to reach its steady-state value. In calculating the losses for 1980 we divide the 1980 furniture population into furniture that was made before and after 1975 (i.e., currently installed furniture and currently produced furniture). The expected losses in 1980 can therefore be calculated by determining the losses for each population group with the smoke detector level at its steady-state value and then averaging according to the relative size of each group.

We have already calculated the losses for the post-1975 population (currently produced furniture) in which the smoke detector installation is at the steady-state level (table 30). The losses for the pre-1975 furniture population are calculated by using the fire loss model to determine the losses for the case in which the furniture population is the currently installed population and in which the smoke detector installation rate has reached its ultimate level of 60 percent (48 percent functional). This is done by using the fire loss model with the probability and outcome assignments developed for current conditions in section 4 except that the probability of a functional smoke detector is set to 0.48. The losses resulting from these calculations are given in table 31.

In order to determine the relative fraction of pre-and post-1975 furniture in 1980 we need to model the upholstered furniture replacement pattern. Based on work done at the University of Maryland, we assume that furniture lifetimes are normally distributed [22]. We assume a mean lifetime of 17 years and standard deviation of 3.3 years.

Using a constant annual future production, based on our constant population assumption, and past production data, we derive the resultant furniture replacement pattern shown in figure 19. Since upholstered furniture production will likely increase in the years to come, the mix of furniture may change more rapidly than predicted by this model. A sensitivity study on the furniture replacement pattern is given in section 7.2.1.

Table 31. Total Annual Losses for Currently Installed Furniture Population Assuming 60 Percent Installation Level of Smoke Detectors

Category	Total Annual Expected Losses	
	Number	Monetary Equivalent (Millions of Dollars)
Fatalities	932	$280
Injuries	5590	56
Property		
Tangible		138
Intangible		21
Aggregate		$495

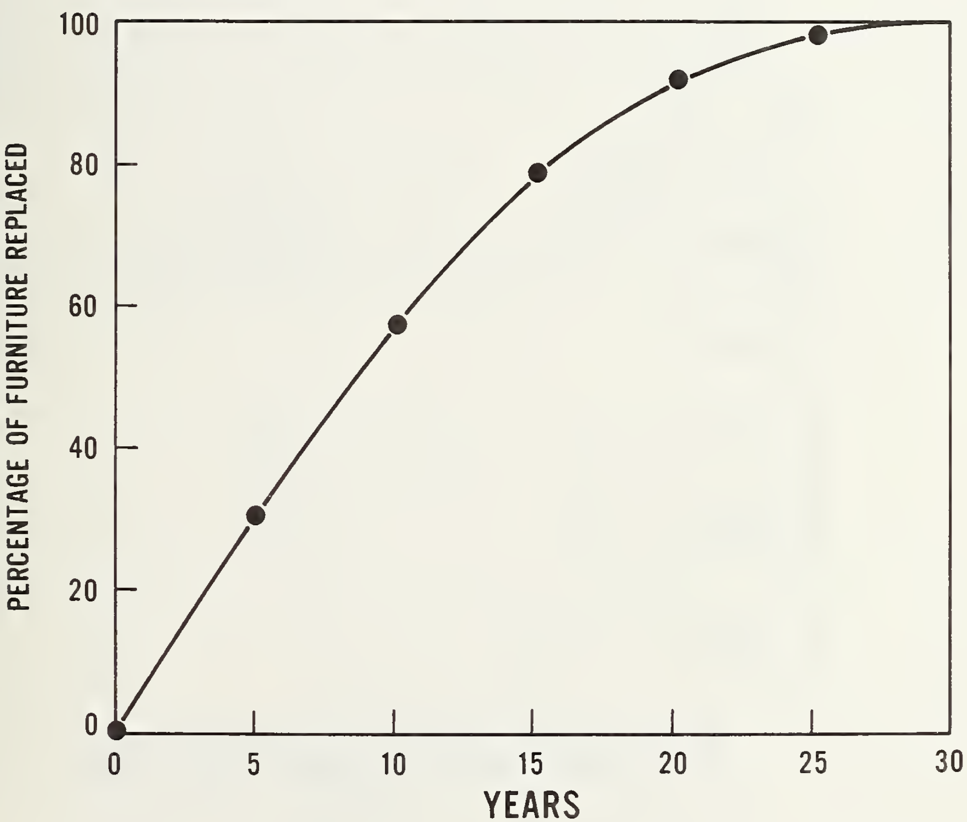

Figure 19. Furniture Replacement Rate Curve

The figure shows that according to our replacement model 30 percent of the 1975 furniture population will be replaced by post-1975 vintage furniture by 1980. Taking a weighted average of the losses for the pre- and post-1975 populations as given in tables 30 and 31 gives the expected losses for the year 1980. The calculations are shown in table 32.

Losses for the years 1981 through 2004 are found by interpolation, by obtaining the fraction of pre- and post-1980 furniture for each year from figure 19 and then taking the appropriate weighted average of the corresponding losses. The expected losses for the years between 1975 and 1980 are estimated by simple linear interpolation. Losses for the year 2005 and all subsequent years are set equal to the steady-state losses (table 30).

Figure 20 gives the resultant losses over time. The figure shows the current losses of $668 million declining to $492 million by 1980 and finally leveling off at $485 million per year by 2005. The steep decline in the early years is due to the installation of smoke detectors during the period 1975 to 1980.

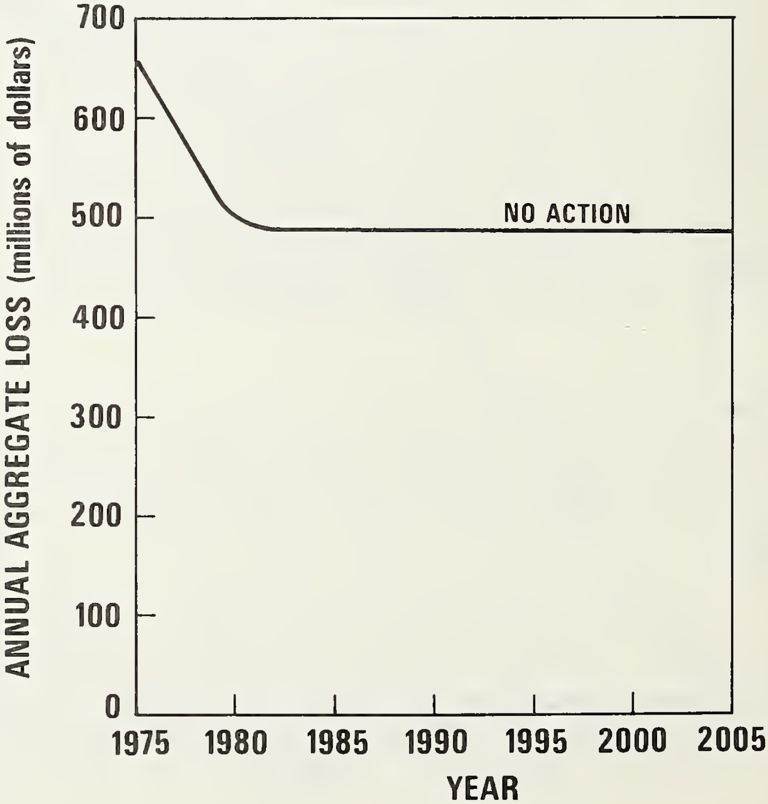

Figure 20. Annual Aggregate Loss Under No-Action Alternative

Table 32. Calculation of Total Expected 1980 Losses

Loss Category	Total Annual Expected Losses with Probability of Functional Smoke Detector Equal to 0.48				
	Pre-1975 Furniture Losses	70% of Pre-1975 Furniture Losses	Post-1975 Furniture Losses	30% of Post-1975 Furniture Losses	1980 Losses
Number of Fatalities	932	652	878	263	916
Number of Injuries	5,587	3,911	4,902	1,471	5,382
Property (Thousands of Dollars)					
Tangible	$138,400	$96,880	$148,950	$44,685	$141,565
Intangible	20,745	14,522	24,301	7,290	21,812
Aggregate (Thousands of Dollars)	$494,645	$346,252	$485,690	$145,707	$491,959

5.2 Losses Under the Smoke Detector Alternative

A second intervention strategy for reducing upholstered furniture fire losses is the enactment of federal legislation requiring smoke detectors in all U.S. residences. The effect of this strategy would be to increase the steady-state smoke detector installation level from our assumed 60 percent rate to some higher installation rate, depending on the level of compliance. Therefore, our approach in modeling the losses under this alternative is to assume a new steady-state installation level and to change the functional smoke detector probability accordingly. Since this alternative has no impact on the furniture itself, we assume the same furniture evolution under this alternative as under the no-action alternative. Thus, the probability assignments for loss model parameters related to upholstered furniture fire behavior are the same as for the no-action case.

5.2.1 Revised Input Probabilities

We assume that 90 percent of all residences will eventually comply with the smoke detector requirement. Even though the requirement is for all residences to have detectors, we assume that a small fraction, 10 percent, will never comply because of ignorance, lack of concern, or out-right disobedience. We also assume that 80 percent of the installed detectors will be operational. Thus, the steady-state probability of there being a functional smoke detector is set at 0.90 x 0.80 = 0.72.

The furniture population under the smoke detector alternative is the same as for the no-action alternative. Therefore, the probabilities of ignition source, fire type, and extent of flame damage are as given in tables 27 and 28 and figure 17. The probability assignments for the other parameters as well as the outcome assignments remain unchanged.

5.2.2 Calculation of Steady-State Losses Under Smoke Detector Alternative

The revised probabilities are used as inputs to the fire loss model to obtain the steady-state losses under the detector alternative. The method used is the same as for the no-action alternative as described in section 5.1.1.5. The resultant probability distributions of losses per reported upholstered furniture fire are given in table 33. A graph of the cumulative distribution is given in figure 21. The figure shows that there is a 0.13 probability of the losses per fire exceeding $58,800 compared to a 0.17 probability under the fully implemented no-action alternative. The expected aggregate losses are $13,900 per reported fire. The revised probability that the fire is reported, also calculated from the fire loss model, is 0.256 compared to 0.272 for the no-action alternative.

Table 33. Probability Distributions on Aggregate Losses Under Smoke Detector Alternative

Aggregate Loss (Dollars)	Probability	Cumulative Probability
$ 458	0.00051	0.00051
2 204	0.44489	0.44540
2 569	0.00004	0.44543
3 077	0.07394	0.51937
4 493	0.03693	0.55631
11 864	0.07280	0.62911
15 504	0.00012	0.62922
16 071	0.11362	0.74284
18 249	0.12958	0.87242
58 832	0.12758	1.00000

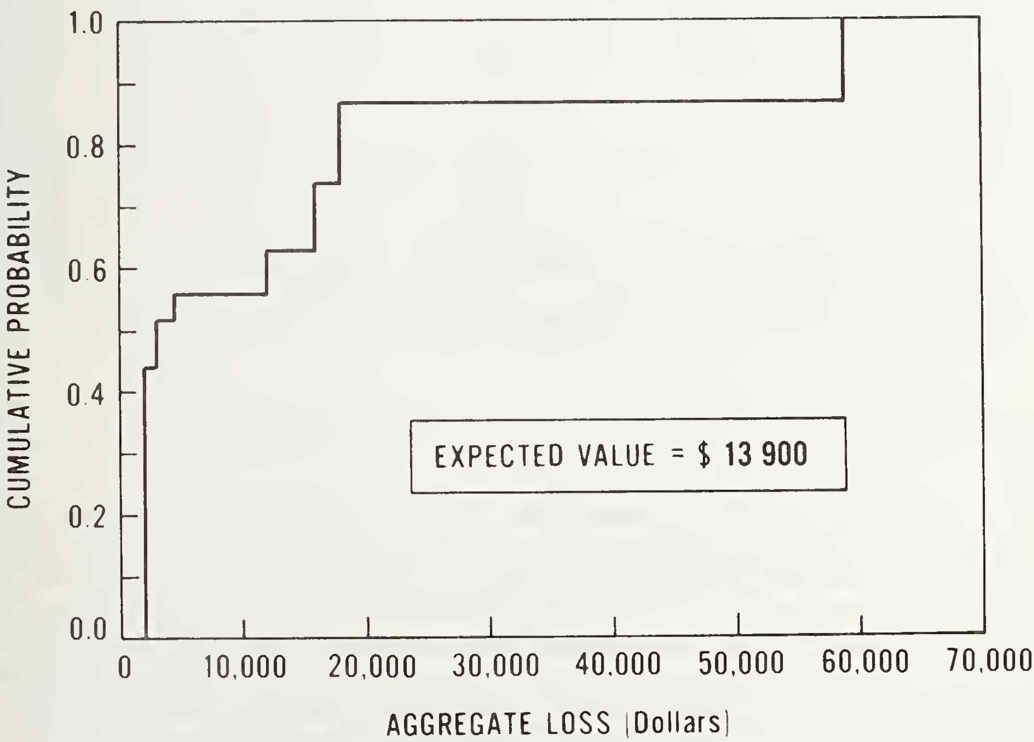

Figure 21. Cumulative Distribution on Aggregate Losses Under Smoke Detector Alternative

Table 34 gives the expected loss by category. The total number of reported fires, 28,400, is obtained by multiplying the number of ignitions expected in the steady-state no-action alternative furniture population, 111,000, by the probability that the fire is reported, 0.256. This is again used to obtain the total annual expected losses of $396 million as shown in the table. The loss of life component again accounts for more than half of the aggregate losses. There are 678 fatalities annually compared to 1312 under current conditions and 878 under the steady-state no-action alternative. The total U.S. losses of $396 million compare to $486 million under the steady-state no-action alternative and $668 million under current conditions. Thus the effect of increasing the smoke detector installation level from 60 to 90 percent is to reduce total U.S. losses occurring in residential upholstered furniture fires by about $90 million per year.

Table 34. Reported Upholstered Furniture Fire Losses Under Fully Implemented Smoke Detector Alternative

	Expected Loss Per Fire		Total Annual Expected Losses[a]	
Category	Number	Monetary Equivalent	Number	Monetary Equivalent (Millions of Dollars)
Fatalities	0.0239	$ 7,160	678	$203
Injuries	0.139	1,390	3960	40
Property				
Tangible		4,630		131
Intangible		750		21
Aggregate		$13,900		$396

[a]Obtained by multiplying the expected loss per fire by 28,400, the annual number of reported upholstered furniture fires

5.2.3 Losses Under the Smoke Detector Alternative Over Time

In modeling the losses over time for the smoke detector alternative we assume that the program takes effect in 1980 and that it takes until 1985 for the detector installation to reach its projected level of 90 percent. Losses for the years 1977 to 1980 are the same as for the no-action alternative. Losses for the years between 1985 and 2005 are based on the changing furniture population (figure 19) and are found in the same manner as those for the no-action alternative. The calculations for the years from 1980 through 1985 take into account both the changing furniture population and the increased level of smoke detector installation. The losses for the years after 2005 are constant and equal to the 2005 steady-state losses (table 34).

Figure 22 gives the resultant losses over time for the smoke detector alternative. The figure shows total U.S. losses declining from the current level of $668 million per year to $396 million. Most of the loss reduction occurs by 1985 when the projected level of smoke detector installation has been reached. The continuing slight decline in losses between 1985 and 2005 is attributable to the continuing replacement of the furniture population.

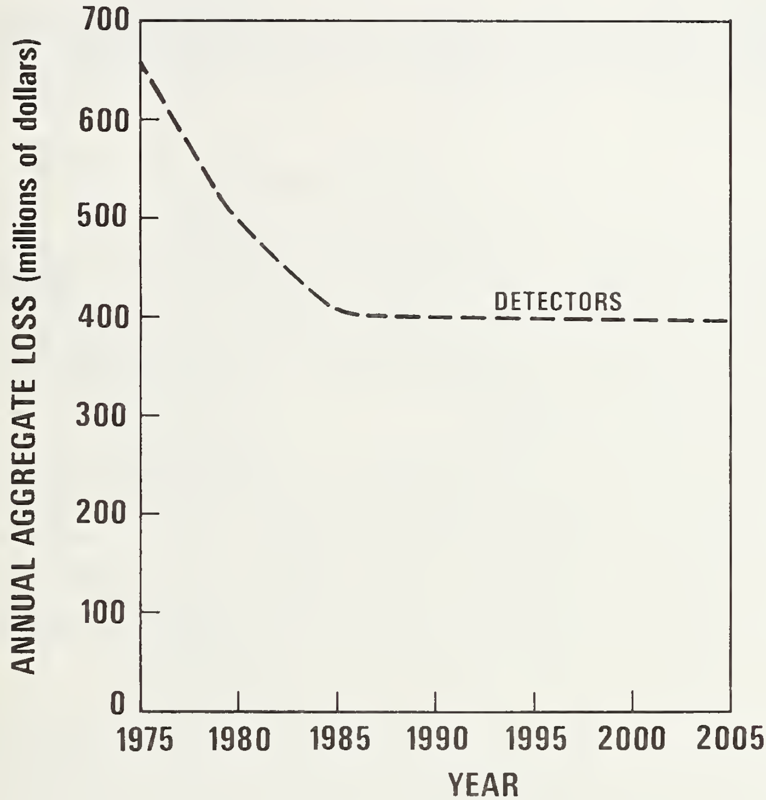

Figure 22. Annual Aggregate Loss Under Smoke Detector Alternative

5.3 Losses Under the Proposed Upholstered Furniture Standard

A third intervention strategy is the proposed upholstered furniture standard currently under consideration by the Consumer Product Safety Commission. The proposed standard, described in detail in section 3, is intended to eliminate combinations of fabric and furniture construction that are vulnerable to cigarette ignition. We consider two methods for meeting the proposed standard. We first consider the use of a needle-punched aluminum foil barrier for use in dissipating the heat build-up from dropped cigarettes. We then consider the use of a backcoating containing microencapsulated sulfur to make upholstery fabrics more smolder resistant. The backcoating method is considerably less expensive than the barrier method, but has yet to be tested and demonstrated under commercial conditions. Our purpose in modeling a second method of compliance with the standard is to give some consideration to new technology which might allow compliance at a lower cost.

5.3.1 The Barrier Method for Meeting the Proposed Standard

We first evaluate the effectiveness of the barrier method under full compliance and then we assume a level of compliance for evaluating the losses under this alternative.

5.3.1.1 Full Compliance

The primary effect of the proposed standard is to reduce smoldering ignitions from cigarettes and other ignition sources. Since the barrier has been designed to prevent cigarette ignitions, we assume that all cigarette ignitions will be eliminated if full compliance is obtained. We assume that smoldering ignitions from electrical and other sources will be reduced by 80 percent.

The treated cotton batting used in conjunction with the aluminum foil barrier provides some protection from flaming ignitions. We assume that flaming ignitions from open flame and electrical sources will be reduced by 30 percent. However, since open space heaters, a major component of "other" ignition sources, are a relatively large heat source, we assume that flaming ignitions from other sources will be reduced by only 20 percent under the barrier method.

The revised ignition source probabilities are calculated as shown in table 35. The calculations are analogous to the calculations for the no-action alternative, except that we have used the reduction factors appropriate for the proposed standard. The table shows that the probability of the ignition source being a cigarette declines from 0.80 under current conditions to 0.0 under the barrier method with full compliance. The total number of ignitions is projected to decline from the current level of 161,600 ignitions per year to approximately 11,800 ignitions per year under the barrier method with full compliance.

Table 35 also provides the basis for computing the new fire type probabilities. These calculations are also analogous to those for the no-action alternative. The results for three ignition sources are summarized in table 36. No results are shown for cigarette ignitions since that ignition probability is zero.

Table 35. Calculation of Revised Ignition Source Probabilities Under Proposed Standard (Barrier Method)

Ignition Source	Ignition Class	Current Number of Ignitions	Fraction of Ignitions Occurring After Population is Replaced	Annual Number of Ignitions by Class Occurring After Population is Replaced	Revised Ignition Class Probabilities	Annual Number of Ignitions by Source Occurring After Population is Replaced	Revised Ignition Source Probabilities
Cigarette	Smolder	129 458	0.0	0	---	0	0.0000
	Flame	0	---	0	---		
Open Flame	Smolder	3 840	0.0	0	0.000	6 271	0.5329
	Flame	8 959	0.7	6 271	1.000		
Electrical	Smolder	3 597	0.2	719	0.3999	1 799	0.1529
	Flame	1 542	0.7	1 079	0.6001		
Other	Smolder	12 799	0.2	2 560	0.6923	3 697	0.3142
	Flame	1 422	0.8	1 138	0.3077		
Total		161 600		11 767		11 767	1.0000

Table 36. Probability Distributions on Fire Type Under Fully Implemented Proposed Standard (Barrier Method) with 100 Percent Compliance

Ignition Source	Is Fire Discovered Before Leaving Chair?	Fire Type	Probability Under Standard
Open Flame	Discovered	SM SM/FL FL	0.0000 0.0000 1.0000
	Not Discovered	SM SM/FL FL	0.0000 0.0000 1.0000
Electrical	Discovered	SM SM/FL FL	0.3799 0.0200 0.6001
	Not Discovered	SM SM/FL FL	0.0320 0.3679 0.6001
Other	Discovered	SM SM/FL FL	0.6577 0.0346 0.3077
	Not Discovered	SM SM/FL FL	0.0554 0.6369 0.3077

Since most of the construction materials will be similar under both the proposed standard and the steady-state no-action alternatives, we use the same extent of flame damage probabilities for the two cases. Thus, the extent of flame damage probabilities under the proposed standard with full compliance are as given in table 28. We also use the same 0.48 functional smoke detector probability for the two cases, because the proposed standard has no special provision for enhancing the installation of smoke detectors. The other probability assignments remain the same as those for current conditions.

The revised probability assignments as just presented are used in the fire loss model to calculate the loss distributions for a single reported upholstered furniture fire under the proposed standard using the barrier method with full compliance. The results are given in table 37. A graph of the cumulative distribution is given in figure 23. Although the possible values of loss are the same as those for current

Table 37. Probability Distributions on Aggregate Losses Under Proposed Standard Using the Barrier Method with 100 Percent Compliance

Aggregate Loss (Dollars)	Probability	Cumulative Probability
$ 458	0.00044	0.00044
2,204	0.39957	0.40001
2,569	0.00008	0.40009
3,077	0.04946	0.44955
4,493	0.08931	0.53886
11,864	0.03614	0.57500
15,504	0.00025	0.57525
16,071	0.27474	0.84999
18,249	0.08668	0.93667
58,832	0.06333	1.00000

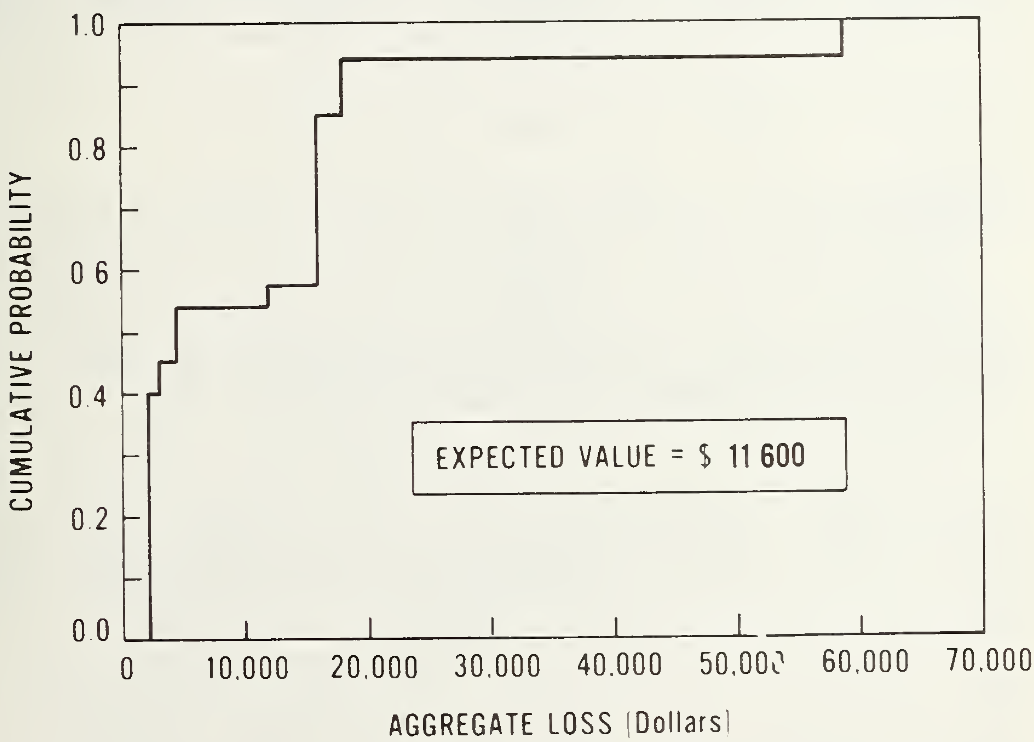

Figure 23. Cumulative Distribution on Aggregate Losses Under Proposed Standard Using the Barrier Method

conditions, ranging from $460 to $58,800, the figure shows that the likelihoods of the different outcomes have changed substantially under the proposed standard. Whereas there was a 0.14 probability of a fire with expected losses exceeding $58,800 under current conditions, there is only a 0.063 probability of such a fire occurring under the proposed standard. The expected aggregate loss, given a reported ignition, is $11,600, compared to $14,100 under current conditions.

Table 38 gives the expected losses per reported fire for the proposed standard using the barrier method with full compliance. The expected fatalities per reported fire are now 0.0162 compared to 0.0276 under current conditions. The table shows that the monetary value of the expected fatality loss is approximately equal to the expected tangible property loss, each accounting for about 42 percent of the aggregate losses.

Table 38. Reported Upholstered Furniture Fire Losses Under Fully Implemented Proposed Standard (Barrier Method) with 100 Percent Compliance

	Expected Loss Per Fire		Total Annual Expected Losses[a]	
Category	Number	Monetary Equivalent	Number	Monetary Equivalent (Millions of Dollars)
Fatalities	0.0162	$ 4,860	104	$31
Injuries	0.112	1,120	719	7
Property				
Tangible		4,820		31
Intangible		790		5
Aggregate		$11,600		$74

[a]Obtained by multiplying the expected loss per fire by 6,430, the annual number of reported upholstered furniture fires

Although the total number of ignitions declines under the proposed standard using the barrier method with full compliance, the probability of an ignition being reported increases. The reason is that a higher percentage of fires that do occur under the proposed standard are serious. The probability that the fire is reported is calculated to be 0.546. Thus an expected 6,430 of the 11,800 fires under the barrier method with full compliance will be reported. Total expected annual losses are found by multiplying the expected loss per reported fire by the expected number of reported fires. The results, also shown in table 38, give an expected total annual loss of $74 million under the fully implemented proposed standard using the barrier method with full compliance.

5.3.1.2 Partial Compliance

Several factors, including the use of slipcovers, noncompliant upholstering, poor manufacturing quality control, and loss of ignition resistance due to soil and wear, make it unlikely that the proposed standard will ever achieve full compliance. Therefore, in this section we investigate the effectiveness of the barrier method assuming that only 80 percent compliance is achieved.

In modeling the partially compliant case, we assume that the non-compliant furniture is equivalent in burning characteristics to the currently produced furniture assumed under the no-action alternative. Thus the expected losses for a particular compliance level are found by taking a weighted average of the losses from the fully compliant proposed standard furniture population and the no-action furniture population. The calculations are shown in table 39.

The table shows that the total annual losses are $157 million for the 80 percent compliant case, compared to $74 million for the fully compliant case. Furthermore, the 20 percent noncompliant furniture population contributes 62 percent of the aggregate loss, 68 percent of the fatalities, 63 percent of the injuries, and 55 percent of the property loss as well as 54 percent of the reported fires and 70 percent of the ignitions. Thus achieving a better compliance level than 80 percent would appear to affect the expected losses. A sensitivity study on the compliance level is presented in section 7.4.3.

5.3.1.3 Losses Over Time

It will take a number of years for the proposed standard to become fully implemented, even at the 80 percent compliance level. The reason is that, according to our furniture replacement model shown in figure 19, it takes about 30 years for essentially all of the furniture to be replaced.[8] The losses over time are modeled in the same way for the proposed standard as for the no-action alternative. The only difference is that the furniture replacement is assumed to begin in 1980 when the standard takes effect, rather than in 1975 when the currently produced or post-1975 furniture replacement begins. Also, at any point in time only 80 percent of the post-standard furniture is assumed to be compliant.

Figure 24 gives the losses over time for the proposed standard using the barrier method with 80 percent compliance.

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[8] The furniture replacement model used for post-1975 furniture in modeling the no-action alternative is also used for post-1980 furniture produced under the proposed standard.

Table 39. Calculation of Total Annual Expected Losses, Number of Ignitions, and Number of Reported Fires for Proposed Standard (Barrier Method) with 80 Percent Compliance

Loss Category	Total Annual Expected Losses				
	No-Action	20% of No-Action	Proposed Standard with 100% Compliance	80% of Proposed Standard with 100% Compliance	Proposed Standard with 80% Compliance
Number of Fatalities	878	176	104	83	259
Number of Injuries	4 902	980	719	575	1 556
Property (Thousands of Dollars)					
Tangible	$148 950	$29 790	$30 985	$24 788	$54 578
Intangible	$ 24 301	$ 4 860	$ 5 097	$ 4 078	$ 8 938
Aggregate (Thousands of Dollars)	$495 690	$97 138	$74 490	$59 592	$156 730
Number of Ignitions	111 000	22 200	11 767	9 414	31 614
Number of Reported Fires	30 225	6 045	6 427	5 142	11 187

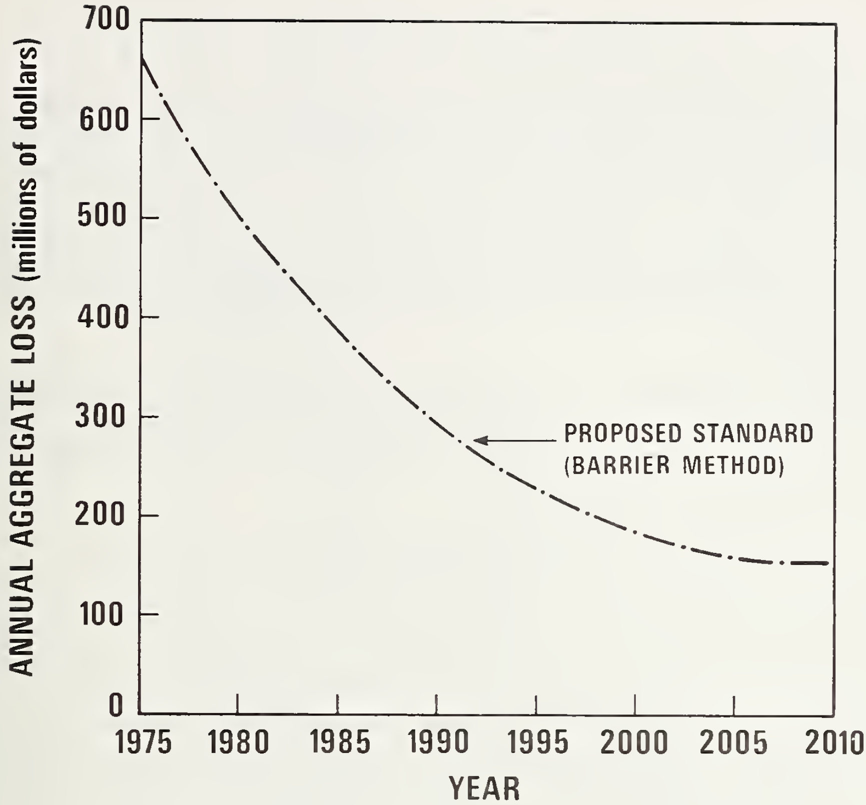

Figure 24. Annual Aggregate Loss Under Proposed Standard Alternative Using the Barrier Method

5.3.2 The Backcoating Method for Meeting the Proposed Standard

A second possible method for meeting the proposed standard is to apply a backcoating to upholstery fabrics. As discussed in section 3.7.2 it is possible that existing backcoating products could be used; however, in this section we consider the use of a backcoating containing microencapsulated sulfur. Although this method has been demonstrated in the laboratory, it has not been tested under field conditions and there is some question as to whether it is a feasible alternative. We investigate the effectiveness of the sulfur backcoating method, assuming that it performs as demonstrated under laboratory conditions.

As with the barrier method, we investigate the effectiveness of the backcoating method assuming full compliance with the proposed standard before considering the case of partial compliance.

5.3.2.1 Full Compliance

The primary effect of the sulfur backcoating is to reduce the incidence of smoldering ignitions. Based on laboratory experience accumulated to date, we assume that all smoldering ignitions from cigarettes, open flame and electrical sources are eliminated. We assume a 50 percent reduction in smoldering ignitions from other sources. The reason is that many of the "other" ignition sources, such as space heaters with a sustained heat source, may eventually volatize the sulfur in the backcoating.

Laboratory experience to date indicates that sulfur treated fabric may be slightly more susceptible to flaming ignitions than untreated fabrics. To reflect this phenomenon, we *increase* the incidence of flaming ignitions by 10 percent.

The revised ignition source probabilities using the above assumptions on likelihood of ignition are calculated as shown in table 40. The calculations are analogous to those performed for the barrier method. Also given in the table is the annual number of ignitions occurring under the proposed standard using the sulfur backcoating method with full compliance. The table shows that the expected number of ignitions under the backcoating method with full compliance is approximately 19,500 ignitions per year, compared to 11,800 under the barrier method and 111,000 under the steady-state no-action alternative. The revised probability distributions on fire type are shown in table 41. Since smoldering ignitions are expected only for the "other" category, only this category is shown. Again, the method of computation parallels that previously presented.

In modeling the proposed standard using the barrier method, we assume that the extent of flame damage probability distributions are the same as under the steady-state no-action alternative, since the furniture populations in both cases have similar constructions using similar amounts of polyurethane foam. However, the extent of flame damage probabilities must be adjusted to model the backcoating method, because of the propensity of sulfur-backed materials to burn more intensely. We use the same adjustment method as used for the no-action alternative (shown in table 28). However, in this case we use adjustment factors of 0.5 instead of the 0.6 factor used for the no-action alternative. Table 42 gives the distributions on extent of flame damage for current conditions, no-action and the proposed standard using the backcoating method.

The probability of a functional smoke detector is set at 0.48, the same as that for the no-action alternative and the barrier method of meeting the proposed standard. All of the other probability assignments are the same as those for current conditions.

Table 40. Calculation of Revised Ignition Source Probabilities Under Proposed Standard (Backcoating Method)

Ignition Source	Ignition Class	Current Number of Ignitions	Fraction of Ignitions Occurring After Population is Replaced	Annual Number of Ignitions by Class Occurring After Population is Replaced	Revised Ignition Class Probabilities	Annual Number of Ignitions by Source Occurring After Population is Replaced	Revised Ignition Source Probabilities
Cigarette	Smolder	129 458	0.0	0	---	0	0.0000
	Flame	0	---	0	---		
Open Flame	Smolder	3 840	0.0	0	0.0000	9 855	0.5050
	Flame	8 959	1.1	9 855	1.0000		
Electrical	Smolder	3 597	0.0	0	0.0000	1 696	0.0869
	Flame	1 542	1.1	1 696	1.0000		
Other	Smolder	12 799	0.5	6 400	0.8036	7 964	0.4081
	Flame	1 422	1.1	1 564	0.1964		
Total		161 600		19 515		19 515	1.0000

Table 41. Probability Distributions on Fire Type Under Fully Implemented Backcoating Method of Compliance with Proposed Standard

Ignition Source	Is Fire Discovered Before Leaving Chair?	Fire Type	Probability Under Backcoating Method
Other	Discovered	SM	0.7634
		SM/FL	0.0402
		FL	0.1964
	Not Discovered	SM	0.0643
		SM/FL	0.7393
		FL	0.1964

Table 42. Probability Distributions on Extent of Flame Damage for Current Conditions, No-Action, and Fully Implemented Proposed Standard (Backcoating Method)

Is Fire Discovered Before Leaving Chair?	Extent of Flame Damage	Extent of Flame Damage Probability		
		Current Conditions	No-Action	Proposed Standard (Backcoating)
Discovered	C	0.8332	0.4999	0.4166
	R	0.0682	0.1227	0.1193
	>R	0.0986	0.3774	0.4641
Not Discovered	C	0.0000	0.0000	0.0000
	R	0.6055	0.3633	0.3028
	>R	0.3945	0.6367	0.6972

The above assumptions on ignition, fire type, and extent of flame damage are used in conjunction with the fire loss model to calculate the possible losses resulting from a single reported upholstered furniture fire under the proposed standard using the backcoating method with full compliance. The resulting distributions are given in table 43.

Table 43. Probability Distributions on Aggregate Losses Under Proposed Standard Using the Backcoating Method

Aggregate Loss (Dollars)	Probability	Cumulative Probability
$ 458	0.00039	0.00039
2,204	0.33848	0.33887
2,569	0.00007	0.33895
3,077	0.04279	0.38174
4,493	0.08431	0.46605
11,864	0.03240	0.49845
15,504	0.00029	0.49874
16,071	0.32811	0.82684
18,249	0.09854	0.92539
58,832	0.07461	1.00000

The expected losses per fire are given in table 44. The probability of an ignition being reported is calculated to be 0.528. Thus an expected 10,300 of the 19,500 fires under the backcoating method with full compliance will be reported. As shown in the table, the total annual expected losses under the backcoating method with full compliance are calculated to be $13 100 x 10 300 = $135 million.

5.3.2.2 Partial Compliance

As with the barrier method, we assume that in practice only 80 percent of furniture will be compliant with the proposed standard using the backcoating method. Total expected losses for this case of partial compliance are found by taking a weighted average of the results for the fully compliant case and the no-action alternative. The computations are given in table 45. As shown in the table, total annual losses for the 80 percent compliant case are $205 million, compared to $97 million for the fully compliant case.

Table 44. Reported Upholstered Furniture Fire Losses Under Fully Implemented Proposed Standard (Backcoating Method) with 100 Percent Compliance

Category	Expected Loss Per Fire		Total Annual Expected Losses[a]	
	Number	Monetary Equivalent	Number	Monetary Equivalent (Millions of Dollars)
Fatalities	0.0181	$ 5,430	186	$ 56
Injuries	0.122	1,220	1250	13
Property				
Tangible		5,540		57
Intangible		920		10
Aggregate		$13,100		$135

[a]Obtained by multiplying the expected loss per fire by 10,300, the annual number of reported upholstered furniture fires

5.3.2.3 Losses Over Time

Losses over time under the backcoating method are calculated exactly as for the barrier method. The resulting aggregate loss is given in figure 25. The figure also shows how these losses compare with the losses under each of the three nominal alternatives.

Table 45. Calculation of Total Annual Expected Losses, Number of Ignitions, and Numbers of Reported Fires for Proposed Standard (Backcoating Method) with 80 Percent Compliance

Loss Category	Total Annual Expected Losses				
	No-Action	20% of No-Action	Proposed Standard with 100% Compliance	80% of Proposed Standard with 100% Compliance	Proposed Standard with 80% Compliance
Number of Fatalities	878	176	186	149	324
Number of Injuries	4 902	980	1 254	1 003	1 984
Property (Thousands of Dollars)					
Tangible	$148 950	$29 790	$57 052	$45 642	$75 432
Intangible	$ 24 301	$ 4 860	$ 9 509	$ 7 607	$12 467
Aggregate (Thousands of Dollars)	$485 690	$97 138	$135 028	$108 022	$205 160
Number of Ignitions	111 000	22 200	19 515	15 612	37 812
Number of Reported Fires	30 225	6 045	10 302	8 242	14 287

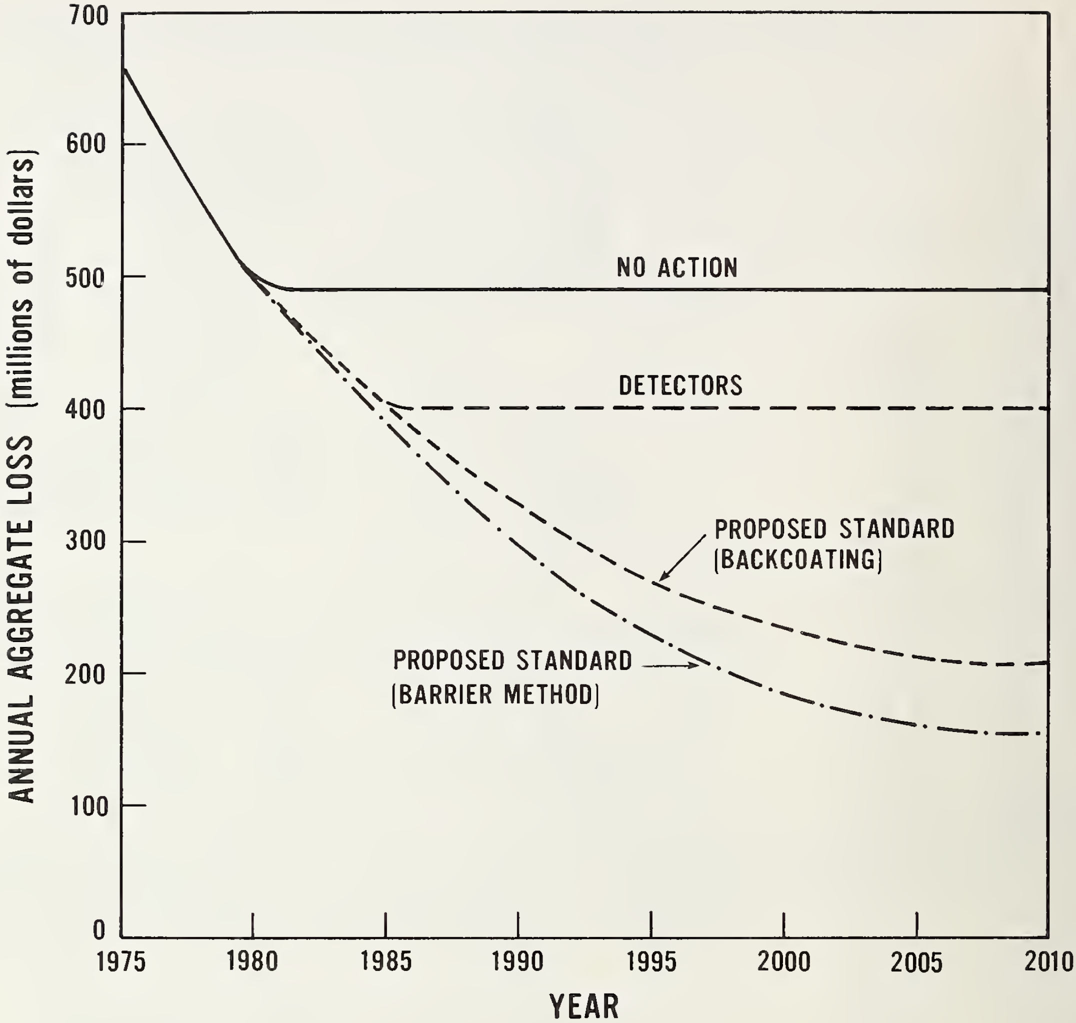

Figure 25. Annual Aggregate Losses Under Proposed Standard Using the Backcoating Method and Three Nominal Alternatives

6. DERIVATION OF COST RESULTS

This section gives a detailed derivation of the costs of implementing each intervention strategy. The basic cost estimates were summarized in section 3, but without detail on the individual cost elements. This section provides that detail.

6.1 No-Action Alternative

We define the costs of the no-action alternative to be zero, since it is the baseline against which the other alternatives are compared. Actually costs are incurred under this alternative, such as expenditures for voluntary and locally required purchases of smoke detectors. But since these expenditures are made under all of the alternatives, we set the costs equal to zero to keep the cost accounting simple. This simplification does not affect the relative evaluation of the alternatives.

6.2 Smoke Detector Alternative

The principal costs of the smoke detector alternative are the costs of purchasing and maintaining the required smoke detectors. We assume that the impact of this intervention strategy will be to increase the detector installation level from 60 to 90 percent over a five year period. Assuming a constant population of 72 million households during the time frame of this analysis [23], we calculate that 0.30 x 72 = 21.6 million first time purchases will be made under the detector alternative. We assume that detectors have an average lifetime of ten years and thus we assume that 10 percent of the installed detectors will be replaced in any given year.

We assume that the average purchase cost of a detector is $20.[9] We assume an average $2 installation cost for all detectors, based on $20 installation costs for house-wired detectors and zero installation costs for battery operated detectors, the latter of which are expected to make up 90 percent of all detectors by 1980. We also assume an annual maintenance cost of $1.80 per detector based on battery replacement costs or an equivalent amount of electricity for house current detectors. (Although some detectors now require the considerably more expensive mercury batteries, the $1.80 figure is based on the expectation that essentially all smoke detectors manufactured after 1980 will use the less expensive 9 volt alkaline batteries.)

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[9] All cost estimates are in 1977 dollars.

Table 46 gives the costs of the required smoke detector purchases for several selected years. The costs include initial year purchases as well as replacement and maintenance costs. The table shows that the annual costs begin at $102.8 million, reach a maximum of $171.9 million in 1984, and then level off at $86.4 million for 1985 and beyond.

Table 46. Annual Cost of Required Smoke Detectors

	Cost (Millions of Dollars)				
Year	Initial Installation	Operation and Maintenance	Replacement	Total	Upholstered Furniture Fire Allocation
1975-9	$ 0.0	$ 0.0	$ 0.0	$ 0.0	$ 0.0
1980	95.0	7.8	0.0	102.8	29.8
1981	95.0	15.6	9.5	120.1	34.8
1982	95.0	23.3	19.0	137.3	39.8
1983	95.0	31.1	28.5	154.6	44.8
1984	95.0	38.9	28.0	171.9	49.9
1985 & beyond	0.0	38.9	47.5	86.4	25.1

The total costs associated with the required smoke detector purchases are given in column 4 of table 46. However, it is not appropriate to assign all these costs to the smoke detector intervention strategy for reducing upholstered furniture fires, because smoke detectors impact on many types of residential fires. We allocate a fraction of the total costs according to the relative impact that smoke detectors have in upholstered furniture fires compared to other residential fires.

Our approach is to allocate the costs according to the relative fraction of deaths prevented in upholstered furniture fires versus other types of residential fires. We assume that a properly installed and operating smoke detector in every residence could reduce the loss of life in all residential fires by about 60 percent. The 60 percent figure is based on estimates of a 41 percent reduction in fatalities by McGuire and Roscoe [25], a 71 percent reduction in fatalities by Halpin, Dinan and Deters [26], and a report from the Ontario Housing Corporation [26] that smoke detectors "discovered" 85 percent of the fires which occurred in their dwellings. We calculate in table 2 that there are currently 4860 fire deaths in one- and two-family dwellings and thus we estimate that detectors could save about 0.60 x 4,860 = 2,920 lives per year. We also calculate in section 3.3.1 that smoke detectors would reduce the loss of life in upholstered furniture fires by about 65 percent. Based on our current estimate of 1310 upholstered furniture fire fatalities per year, we therefore estimate that detectors would save about 0.65 x 1310 = 850 lives per year in upholstered furniture fires. We therefore estimate that 850/2920 = 29 percent of the smoke detector life savings will be from upholstered furniture fires. Therefore, as shown in column 5 of table 46, we assign 29 percent of the total smoke detector costs to the smoke detector alternative.

The total societal cost of the smoke detector alternative must include governmental costs for enforcement and education. We include annual costs of $1 million to reflect the portion of this cost attributable to upholstered furniture fires. The total annual cost of the smoke detector alternative is therefore obtained by adding $1 million to column 5 of table 46.

6.3 Proposed Upholstered Furniture Standard

We assume that regardless of the compliance mechanism, the proposed standard will result in an increase in the cost of manufacturing upholstered furniture. This increased cost will in turn be passed on to the consumer, augmented to a certain extent by the effects of commissions and other middleman costs. To the extent that consumer purchases are sensitive to upholstered furniture prices, some consumers will be forced out of the market. The costs of the proposed standard, therefore, include the increased manufacturing and marketing costs as well as the societal costs of forcing certain consumers out of the market.

6.3.1 Cost of the Barrier Method

6.3.1.1 Initial Cost to Furniture Manufacturers

The costs of the barrier method to the furniture manufacturers in the first year are summarized in table 47. A primary cost of this method is the cost of the labor and materials for installing the aluminum foil barrier. We estimate that about 190 million linear yards of upholstery fabric will be used in 1980, the first year the standard is assumed to be in effect. We assume that about 40 percent, or 76 million linear yards, will be Class D fabric, the fabric type requiring the barrier. We assume that the barrier will be used only on those portions of the furniture where a cigarette might fall-- about 50 percent of the furniture's covered area. Therefore, about 38 million linear yards of aluminum foil barrier will be required to meet the standard. At an estimated cost of $1.05 per linear yard, we calculate the total cost of the barrier material to be $39.9 million the first year the standard is in effect.

Table 47. Manufacturers' First Year Cost of the Proposed Standard Using the Barrier Method

Component	Initial Cost (Millions of Dollars)
Barrier Installation	
Material	$ 39.9
Labor	55.8
Handling	8.0
Cotton Batting Treatment	11.6
Testing	
Furniture Manufacturers	15.2
Fabric Manufacturers	2.7
Recordkeeping	
Furniture Manufacturers	1.5
Fabric Manufacturers	0.9
Research and Development	1.0
Total	$136.6

Based on discussions with furniture manufacturers we estimate that the labor costs for installing the barrier may range from $3.50 to $10.30 for sofas and $2.50 to $6.70 for chairs. Taking a weighted average of the midpoints of these estimates, according to the relative fraction of sofas and chairs, gives an average labor cost of $5.37 per piece of upholstered furniture. To account for employer payroll expenses such as social security and insurance contributions, we use a factor of 1.3 to give an effective labor cost of $6.98 per piece of upholstered furniture. Assuming an annual upholstered furniture production of 20 million pieces, of which 40 percent are made from Class D fabrics, we obtain a total annual labor cost of $55.8 million for the first year the standard is in effect.

Added inventory and handling costs will be incurred as a result of using the barrier method to meet the proposed standard. We assume that these costs equal 20 percent of the materials costs, or $8.0 million the first year the standard is in effect.

In addition to the costs of applying the barrier, there are the costs of treating the cotton batting with a boric acid based material. The cotton batting must be so treated to make furniture with Class B, C, and D fabrics meet the standard. We assume that it will be more efficient to treat all of the cotton batting with boric acid than to keep two separate inventories, one for Class A fabrics and another for the other fabrics. At an annual volume of 116 million pounds of batting and at a treatment cost of 10 cents per pound, we therefore estimate the initial year cotton batting treatment costs at $11.6 million per year.

Testing costs are also imposed by the proposed standard. The tests involve both mock-up tests and fabric tests. For furniture construction to be used with Class A, B, or C fabrics, mock-up tests must be conducted using the least ignition-resistant fabric to be used with that construction. The mock-up tests may be pooled by the manufacturers. We assume an average of 12 mock-up tests per year for each of the 1,369 furniture manufacturers [28] for use with their Class A, B, and C fabrics. At an average mock-up testing cost of $50 per test, we therefore calculate the mock-up testing costs for Class A, B, and C fabrics to be $0.8 million the first year the standard is in effect.

Class D fabrics entail more mock-up testing. Each fabric must be tested with each furniture construction. We assume that 72 000 Class D fabrics will be tested on an average of four mock-up constructions. At $50 per test, the Class D fabric mock-up testing costs are therefore $14.4 million for the first year the standard is in effect.

The total mock-up testing costs are the sum of the testing costs for all four fabric classes, or $15.2 million. We assume an additional record-keeping cost to the furniture manufacturer of $5 per test or $1.5 million in the first year.

The fabric manufacturers must also test their fabrics to determine their classification. We assume an annual volume of 180,000 fabric tests per year. At an average cost of $15 per test, we obtain a fabric testing cost of $2.7 million. We assume an additional record-keeping cost to the fabric manufacturers of $5 per test, or $0.9 million annually.

We assume that industry will invest in research and development to reduce the costs of meeting the standard. We assign $1 million per year to reflect these costs.

The total cost of using the barrier method to meet the proposed standard is the sum of the above costs, or $136.6 million the first year the standard is in effect. Dividing $136.6 million by 20 million, our estimate of the number of furniture pieces produced in one year, we obtain an average cost of $6.83 per piece. However, the average cost for a furniture piece upholstered with Class D fabric is $15.81, whereas the average cost for a piece upholstered with Class A, B, or C fabric is only $0.84.

6.3.1.2 Adjustment for Market Effects

We have estimated that the upholstered furniture industry will incur an additional cost of $136.6 million per year to meet the proposed standard using the barrier method. In a simple economic world, we could assume that these costs are the total societal costs of the proposed standard. However, the real economic world is more complicated and there are more costs to be taken into account before a truer measure of the total societal cost is obtained. In particular, several factors combine to make the price increase of the furniture in the short run greater than the per-unit cost of the added manufacturing costs. These factors include inventory and financing charges incurred by distributors and commissions to salesmen. As the manufacturing costs increase, so do these other costs. Coupled with the higher price of the furniture is a reduction in demand and loss of benefit to persons who no longer participate in the market. The total societal cost of the proposed standard is the net of the increase in price and the loss of consumer benefit. Economists term this cost the change in social surplus.

C. Muehlhause of the National Bureau of Standards has prepared a detailed paper relating the change in social surplus to the change in manufacturers' costs [18]. A result of this work is that the total societal costs of the proposed standard are equal to 1.5 times the initial increase in manufacturing costs. Multiplying the $136.6 million cost increase by 1.5 and adding an additional $1 million per year for enforcement we obtain $206 million for the total societal cost of the proposed standard in the first year.

6.3.1.3 Cost of the Barrier Method Over Time

We calculate that the barrier method will cost $206 million the first year the standard is in effect. However, due to adjustments in the furniture market, we believe that these costs will decrease over time. There has been a shift away from the use of Class D fabrics over the last few years. Because of the considerably higher cost of using Class D fabrics under the proposed standard as shown above, we believe this trend away from Class D fabrics would be accelerated by the proposed standard as manufacturers shift to fabrics that do not require the barrier underlay. Also, there would be competitive adjustments in the marketplace, resulting in lower mark-ups of the manufacturers' costs.

To model the changing costs over time, we assume that the use of Class D fabrics will decrease from 40 percent of the total upholstery fabric market in 1980 to 20 percent in 1985. We assume that this shift results in no loss of consumer choice because much of it represents natural evolution in the marketplace or changes in the fabrics that are imperceptibly small to the casual user. We also assume that research and development will result in new barrier materials that cost half as much as the first-year barrier materials.

Table 48 gives the initial and long-run manufacturing costs of the barrier method. As shown, the long-run cost of the barrier material is reduced by 75 percent because of lower usage and lower unit cost. The labor, handling, mock-up testing, and manufacturers' record-keeping costs are also reduced because of the decreased use of Class D fabrics. The cotton batting treatment costs and the fabric manufacturers' testing and record-keeping costs remain unchanged in the long run because these activities must still be performed. We eliminate the long-range research and development costs because we assume that the early efforts were successful in developing less expensive barrier materials.

Table 48. Manufacturers' Annual Cost of Proposed Standard Using the Barrier Method

Component	Cost (Millions of Dollars) Initial	Long Range
Barrier Installation		
Material	$ 39.9	$10.0
Labor	55.8	27.9
Handling	8.0	4.0
Cotton Batting Treatment	11.6	11.6
Testing		
Furniture Manufacturers	15.2	8.0
Fabric Manufacturers	2.7	2.7
Record-keeping		
Furniture Manufacturers	1.5	0.8
Fabric Manufactuers	0.9	0.9
Research and Development	1.0	0.0
Total	$136.6	$65.9

Table 48 shows that the long-run manufacturers' costs are less than 50 percent of the initial year cost, $65.9 million versus $136.6 million. The primary reason for the cost reduction is the decreased use of Class D fabrics, which results in significantly lower material and labor costs.

We assume that the initial year manufacturers' costs will occur in 1980 and that the long-run costs will be reached by 1985. The costs for the intermediate years, 1981-1984, are found by linear interpolation. As before, we must adjust the manufacturers' cost to account for subsequent marketplace adjustments. We use the same market factor of 1.5 to make this adjustment for the first 5 years. We then linearly reduce the market factor to a long-range value of 1.2 over the next 10 years to represent the long-run competitive adjustments of the producers and sellers.

Table 49 gives the total societal cost of using the barrier method to meet the proposed standard for four selected years. Costs for intermediate years are found by linear interpolation. The total societal costs are calculated by multiplying the manufacturers' costs by the market factor for the particular year and adding $1 million for the cost of enforcement. The table shows that the total initial year cost of $206 million decreases to a long-range value of $80 million.

Table 49. Total Annual Societal Cost of Proposed Standard (Barrier Method)

Year	Cost (Millions of Dollars)
1980	$206
1985	100
1990	90
1995 & beyond	80

6.3.2 Backcoating Method for Meeting the Proposed Standard

A second possible method for meeting the proposed standard is to apply a smolder inhibiting backcoating to Class D fabrics. The technique has yet to be used commercially but it appears promising on the basis of laboratory work. In this section we develop the cost of the "backcoating method" under the assumption that a microencapsulated sulfur backcoating could be used to inhibit smoldering combustion. We expect that this cost is similar to the cost of using other types of backcoating products to upgrade Class D fabrics.

The principal costs for this method are the backcoating costs and sulfur treatment. Many of the Class D fabrics are already backcoated for reasons not related to flammability. However, we estimate that about 45 percent or 34.2 million linear yards of the Class D fabrics must be backcoated in order to utilize the sulfur process. Backcoating costs average $0.30 per linear yard, giving a cost of $10.3 million for additional backcoating.

Based on discussions with industry sources we estimate that adding microencapsulated sulfur to the backcoating will cost about 14 cents per linear yard of treated fabric. This must be added to the backcoating of all Class D fabrics. We therefore estimate the sulfur treatment cost for the 76 million yards of Class D fabrics to be $10.6 million.

We use the same cotton batting treatment costs as those for the barrier method, because the same treatment is used and the same amount of batting is treated under both methods.

Application of the sulfur backcoating to Class D fabrics will transform them into Class A or B fabrics. Under this method there would no longer be any Class D fabrics. Thus the mock-up testing costs to the furniture manufacturer are simply the costs of testing the furniture constructions with prototype fabrics A, B, and C -- or $0.8 million, as previously calculated. As before, record-keeping costs are assumed to be $5 per test. However, because there are fewer mock-up tests conducted under the backcoating method, record-keeping costs are reduced to $0.1 million.

We assume that the fabric testing and record-keeping costs for the backcoating method will be the same as for the barrier method because each fabric must still be tested. Therefore, we use the same $2.7 million fabric-testing and $0.9 million record-keeping costs.

Table 50 summarizes the annual manufacturers' cost of the backcoating method. The table shows a total annual manufacturers' cost of $37.0 million, compared to an initial cost of $136.6 million for the barrier method. The primary reason for the lower cost is the reduced cost of materials, labor, and testing.

Table 50. Manufacturers' Annual Cost of Proposed Standard Using the Backcoating Method

Component	Cost (Millions of Dollars)
Sulfur Treatment	$10.6
Additional Backcoating	10.3
Cotton Batting Treatment	11.6
Testing	
Furniture Manufacturer	0.8
Fabric Manufacturer	2.7
Record-keeping	
Furniture Manufacturer	0.1
Fabric Manufacturer	0.9
Total	$37.0

We assume that the backcoating method costs to the furniture manufacturers are constant over time. As with the barrier method, we apply a market factor to the manufacturers' cost to determine the total societal cost of the sulfur method. We use the same market factors: 1.5 during the first 5 years declining to 1.2 over the next 10 years.

Table 51 gives the total annual societal cost of both the backcoating and barrier methods of meeting the proposed standard. The total annual societal costs are calculated by multiplying the manufacturers' cost by the appropriate market factor and adding $1 million per year for enforcement. The table shows that the backcoating method costs are significantly less than the barrier method costs, although the difference decreases in time. In the long term, the total annual societal costs are $80.1 million for the barrier method and $45.4 million for the backcoating method.

Table 51. Annual Societal Cost of Proposed Standard

	Cost (Millions of Dollars)	
Year	Barrier Method	Backcoating Method
1980	$ 205.9	$ 56.5
1985	99.9	56.5
1990	90.0	51.0
1995 & beyond	80.1	45.4

7. SENSITIVITY ANALYSIS

Our nominal results are based on several key assumptions. This section tests the sensitivity of our results to changes in those assumptions. Some sensitivity studies have already been reported in section 3. This section summarizes those results as well as a number of other more detailed studies not yet reported.

7.1 Sensitivity to Value Assignments and Time Preference

Key to the evaluation of benefits are the value assignments and discounting parameters used to convert benefits into present monetary terms. This section tests the sensitivity of our results to changes in these parameters. In these sensitivity studies, as in the rest of the section, we only vary the value of the parameter in question. All other parameters are kept at their nominal values. (We also have the capacity to perform multi-variate sensitivities if they are deemed useful.)

7.1.1 Value of Life

In section 3 we examine the sensitivity of our results to changes in the amount society is willing to spend to save a human life. Although it is very difficult to assign a value to this parameter, the sensitivity analysis shows that the smoke detector and proposed standard alternatives are the most attractive alternatives over a rather broad range of values, from $60,000 to $400,000 per life saved. At values above $400,000 per life saved, the proposed standard is clearly the most attractive alternative. However, at values close to zero, the no-action alternative is the favored strategy.

7.1.2 Cost of a Fire Injury

Based on work by the Consumer Product Safety Commission, our nominal results assume a $10,000 cost for an average fire injury. One might argue that a higher value should be used since the $10,000 figure does not include such indirect losses as pain and suffering. Figure 26 shows how our results depend on the cost assigned to an average fire injury. At value assignments close to zero, the three alternatives are essentially equivalent. At values in the range of our nominal assignment, $10,000, the smoke detector and proposed standard alternatives are the most attractive. As the value increases significantly above $40,000 per fire injury, the proposed standard increasingly becomes the most attractive option.

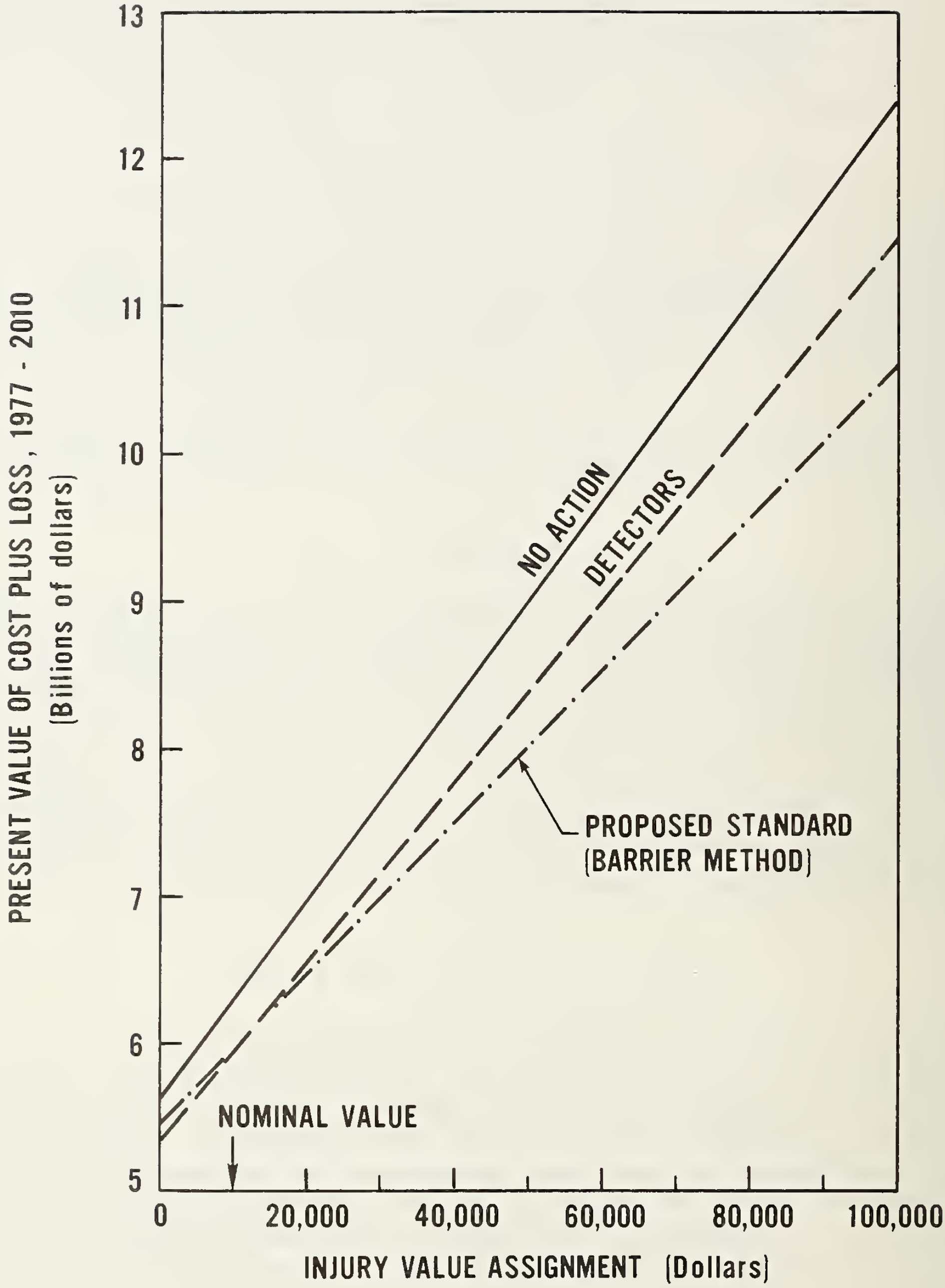

Figure 26. Sensitivity of Results to Injury Value Assignment

7.1.3 Discount Rate

In comparing future benefits and costs with present benefits and costs we use a discounting approach to discount future values to their present equivalents. The discount rate is the compound rate at which the future benefits and costs are discounted. The higher the discount rate, the more current benefits are valued relative to future benefits.

Figure 27 shows how our results depend on the discount rate. At low discount rates, close to zero, the proposed standard is definitely the most attractive alternative. The reason is that the early implementation costs of the proposed standard are offset by the future benefits, since these benefits are discounted very little. But as the discount rate increases to our nominal value of 8 percent and higher, the smoke detector alternative becomes the most attractive alternative because it offers benefits almost as soon as the costs are incurred.

7.1.4 Planning Interval

Our nominal analysis is limited to a 34-year planning interval, 1977 to 2010. We terminate the analysis at 2010 because all of the alternatives would be fully implemented by that time. However, extending the analysis beyond 2010 would increase the total accumulated benefits at relatively little additional cost for each alternative.

Figure 28 shows the present value of the cost plus loss at 8 percent plotted against the final year of the planning interval. Although the total cost plus loss depends on the planning interval, the comparison of the alternatives is little changed by varying the final year over a rather broad range from 2000 to 2030.

7.2 Furniture Population Parameters

The rate at which the furniture population is replaced and its flammability properties are important factors in evaluating the effectiveness of the different alternatives. This section examines the sensitivity of our results to these parameters.

7.2.1 Furniture Replacement Pattern

Our nominal results depend on the assumption that the furniture lifetimes are normally distributed with a mean and standard deviation of 17 and 3.3 years, respectively. Using past production data and a constant annual future production, we obtain the curve shown in figure 29. Subsequent to the completion of our work, Lane and Koecher of the University of California have developed a different furniture replacement curve [28]. Their curve, which is also reproduced in figure 29, is

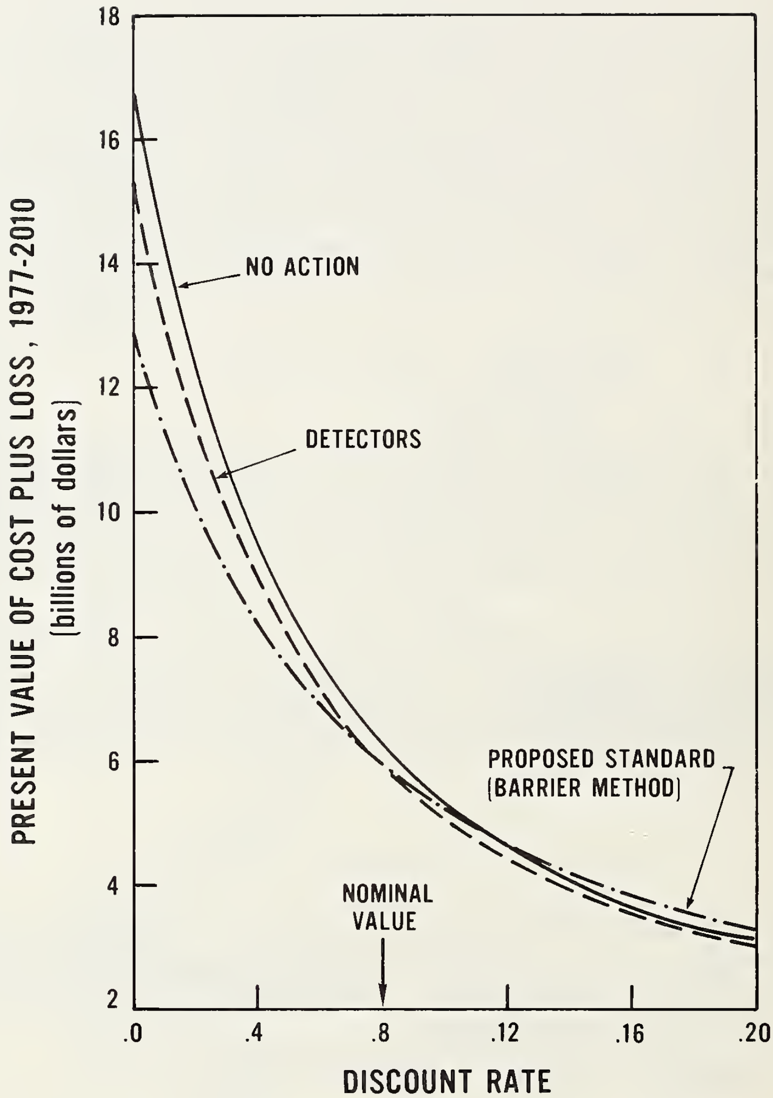

Figure 27. Sensitivity of Results to Choice of Discount Rate

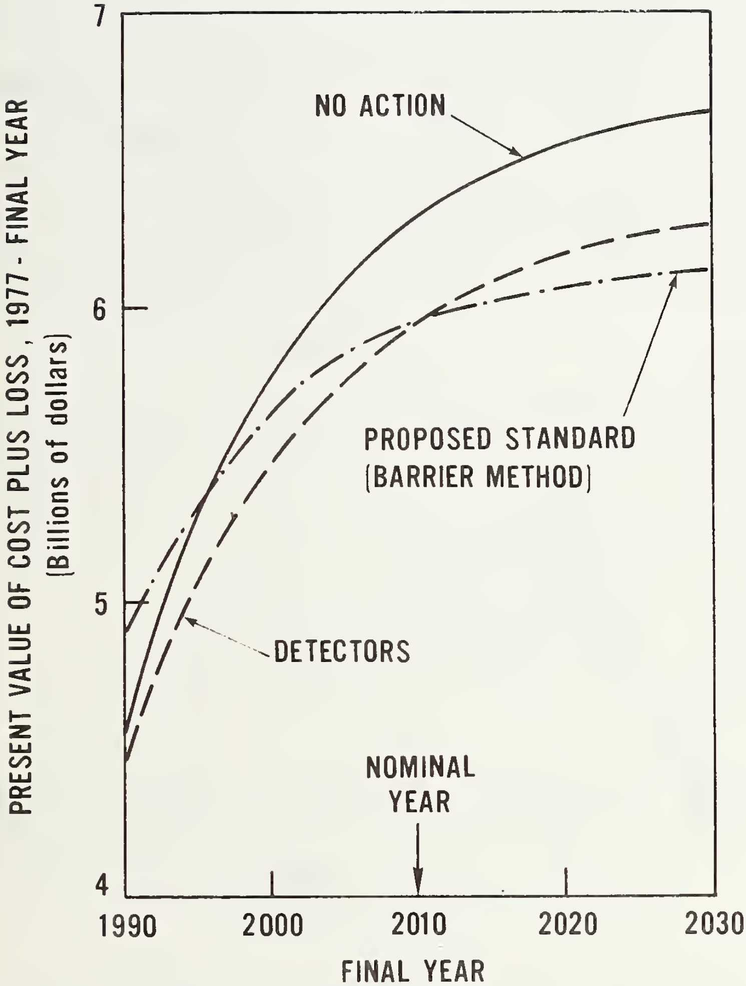

Figure 28. Sensitivity of Results to Planning Interval

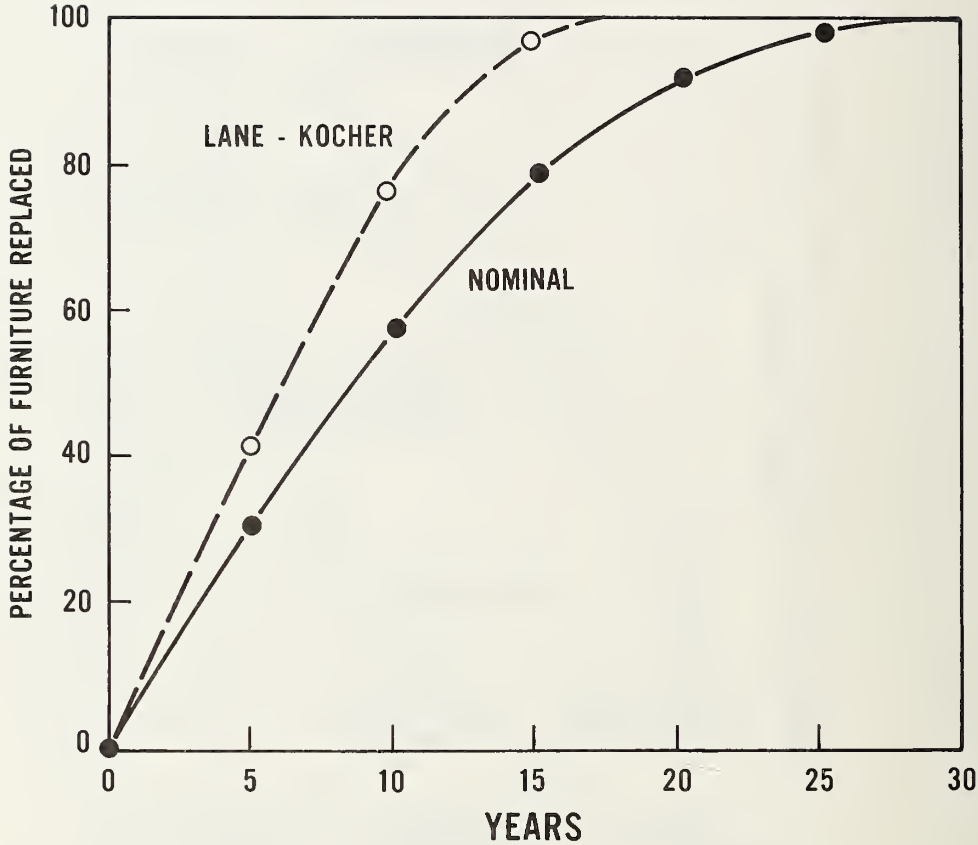

Figure 29. Comparison of Lane-Kocher and Nominal Furniture Replacement Curves

based on past production data and future demand predicted by their model. The figure shows that essentially all of the furniture population is expected to be replaced in about 15 years compared to 30 years under our nominal assumptions.

Table 52 gives the comparison of alternatives using the two different furniture replacement curves.[10] The table shows that the comparison of alternatives is quite sensitive to the assumptions concerning furniture replacement rate. Our nominal results show that the smoke detector and proposed standard alternatives are approximately equivalent. But if we assume that the population is replaced according to the Lane-Kocher model, then the proposed standard is clearly the most attractive strategy. The reason is that the benefits from the proposed standard are realized much earlier, thereby offsetting the early implementation costs. The results of this sensitivity study indicate that further research directed toward determining the appropriate furniture replacement model should be included in any refinements of this analysis.

Table 52. Comparison of Nominal Results with Results Obtained Using Lane-Kocher Furniture Replacement Curve

Alternative	Present Value at 8% from 1977 to 2010 (Millions of Dollars)			
	Using Lane-Kocher Curve			Nominal Case
	Loss	Cost	Cost Plus Loss	Cost Plus Loss
No-Action	$6310	$ 0	$6310	$6330
Detector Alternative	5640	300	5940	5950
Proposed Standard (Barrier Method)	4480	1120	5600	5960

[10] To model our three alternatives we make the simplifying assumption that the curve Lane and Kocher developed for replacement of pre-1979 furniture with post-1979 furniture is valid for both pre- and post-1975 furniture and pre- and post-1980 furniture.

7.2.2 Smolder Resistance of Currently Produced Furniture

In modeling the natural evolution of the furniture population under the smoke detector and no-action alternatives, we assume that the population would evolve toward a mix of materials equivalent in fire properties to the currently produced furniture population. We further assume that the incidence of cigarette ignitions would be reduced by one third when the furniture population was completely replaced. This latter assumption is a critical one because it governs the extent to which upholstered furniture fires will be reduced under the no-action alternative.

Figure 30 shows how varying the estimated reduction in cigarette ignitions alone affects the choice of alternatives. The sensitivity study is conducted over a range from 50 to 90 percent of the cigarette ignitions remaining, compared to our nominal value of 67 percent. If some unforeseen technology in furniture manufacturing would take the parameter out of this range, then the cost of the proposed standard would have to be reassessed. The figure shows that the smoke detector alternative is the most attractive for remaining fractions less than our nominal two thirds value. For larger values the proposed standard is most attractive. The findings are reasonable since the proposed standard would be much more cost effective in replacing easily ignited furniture than in replacing furniture that is already resistant to cigarette ignition.

7.3 Parameters Governing the Smoke Detector Alternative

The performance of the smoke detector alternative depends on the number of detectors installed as well as the fraction of installed detectors that are operational. This section examines the sensitivity of our results to changes in these parameters, as well as changes in the purchase cost of the smoke detectors themselves.

7.3.1 Smoke Detector Installation Level Under No-Action

Our nominal analysis assumes that voluntary and locally mandated installation of smoke detectors would reach an ultimate level of 60 percent. Figure 31 shows how the comparison of alternatives is changed by varying this installation level from 40 to 70 percent. The figure shows that even at a 70 percent installation level, the proposed standard and smoke detector alternatives are superior to the no-action alternative. Of course, the lower the voluntary and locally mandated installation level, the less attractive the no-action alternative becomes.

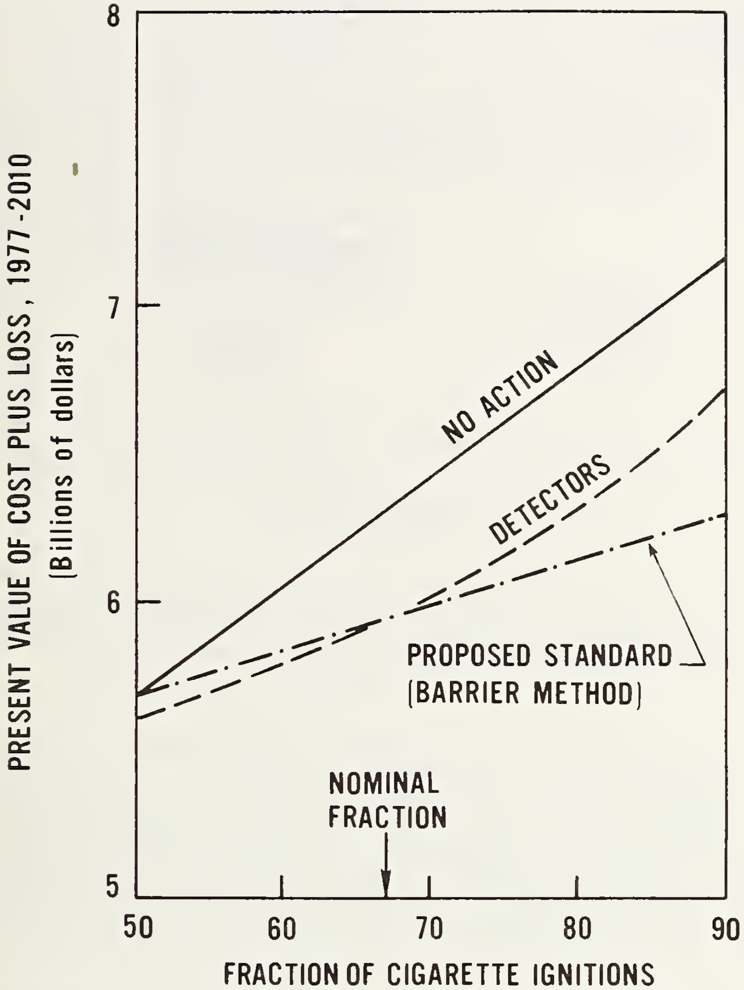

Figure 30. Sensitivity of Results to Reduction in Cigarette Ignitions Under No-Action

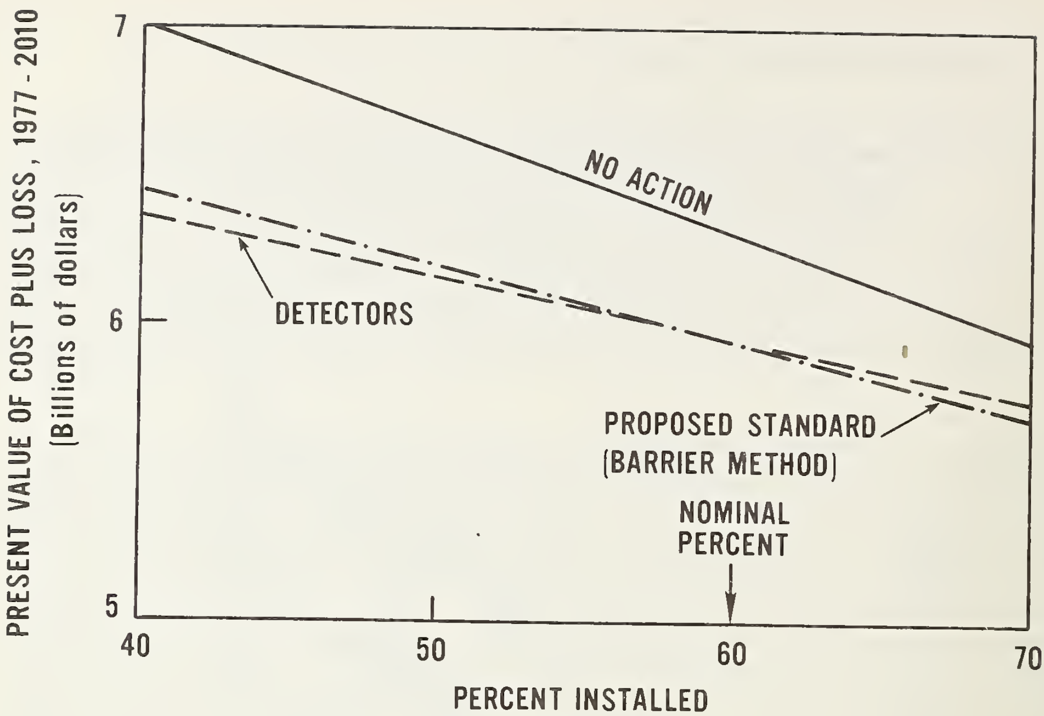

Figure 31. Sensitivity of Results to Smoke Detector Installation Level Under No-Action

Although this sensitivity analysis assumes a fixed installation level of 90 percent under the mandatory smoke detector alternative, the figure shows that the cost plus loss of the smoke detector alternative varies with the no-action installation level. The reason is that as we vary the level of voluntary and locally mandated installation, the costs and loss reduction attributable to the mandatory smoke detectors also vary.

7.3.2 Smoke Detector Installation Level Under Federal Mandate

Our nominal analysis of the smoke detector alternative assumes that a 90 percent installation level would ultimately be achieved under the mandatory smoke detector program. Figure 32 shows how the comparison of alternatives changes by varying the assumed installation level under the mandatory program from 70 to 100 percent. The figure shows that the smoke detector alternative is slightly preferred at ultimate installation levels above 90 percent, but the proposed standard is most attractive at lower levels. However, there is little significant difference between these two alternatives over the range of installation levels investigated.

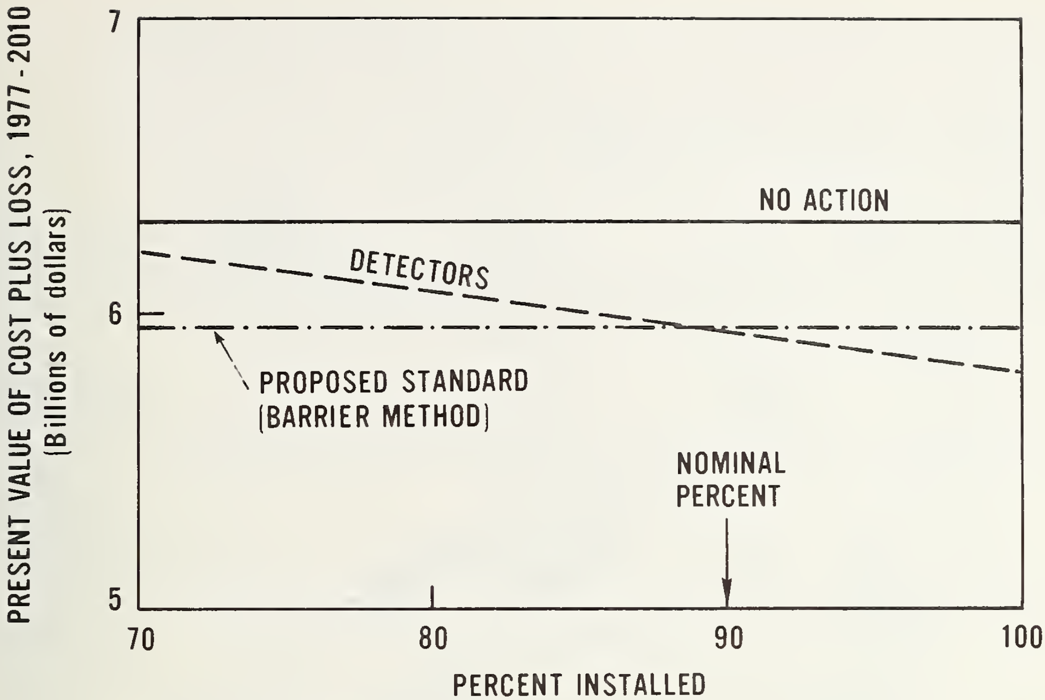

Figure 32. Sensitivity of Results to Smoke Detector Installation Level Under Detector Alternative

7.3.3 Fraction of Operational Smoke Detectors

Figure 33 shows how the fraction of smoke detectors that is assumed to be operational affects the comparison of alternatives. Our nominal assumption is that 80 percent of all detectors would be properly operating. The figure shows that the smoke detector alternative is the most attractive if the fraction of operational detectors rises much above 80 percent. For operational percentages much less than 80 percent the proposed standard is the most attractive. However, in none of the cases is there such a significant difference among the alternatives that one is clearly the most attractive.

7.3.4 Smoke Detector Purchase Cost

In section 3 we estimate the installed cost of a typical smoke detector to be $22 per unit. Table 53 shows the comparison of our nominal results with two values of cost per installed detector. The table shows that varying the cost from $10 to $30 per installed detector, has essentially no effect on the comparison of alternatives. As in our nominal analysis, these sensitivity results assume that 29 percent of the total smoke detector costs are assigned to the smoke detector alternative.

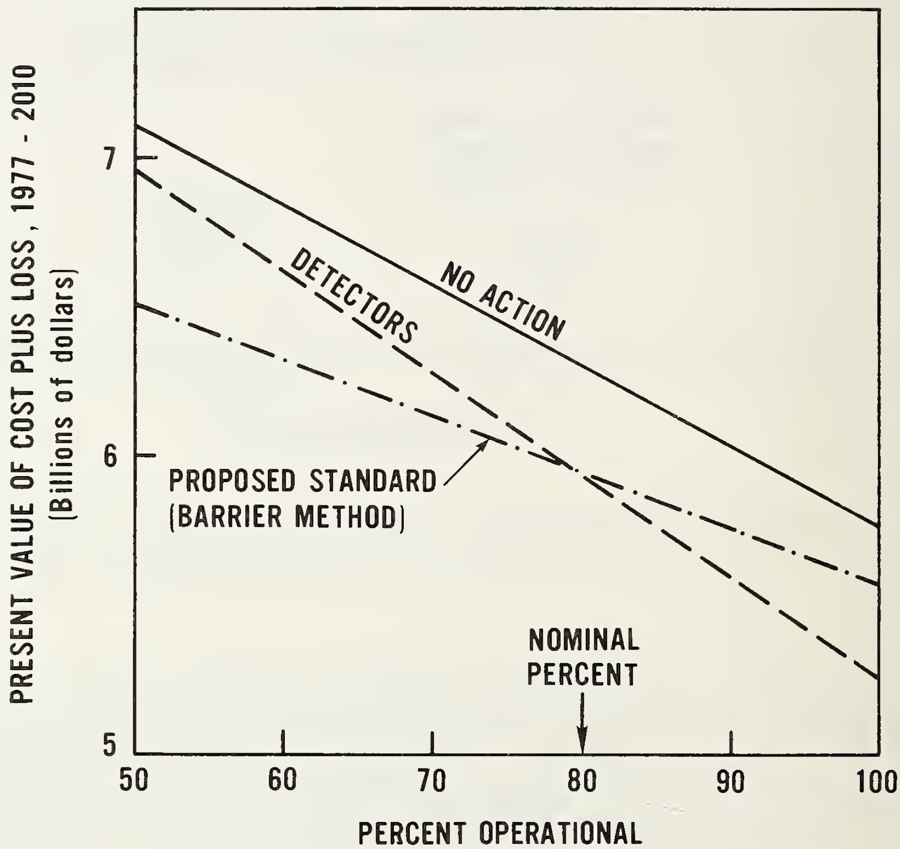

Figure 33. Sensitivity of Results to Percentage of Properly Operating Smoke Detectors

Table 53. Sensitivity of Results to Cost Per Installed Smoke Detector

Alternative	Cost Per Detector (Dollars)	Present Value at 8% from 1977 to 2010 (Millions of Dollars)		
		Loss	Cost	Cost Plus Loss
Detector Alternative	$10	$5650	$ 190	$5840
	22[a]	5650	300	5950
	30	5650	370	6020
No-Action		6330	0	6330
Proposed Standard (Barrier)		4840	1120	5960

[a]nominal cost

7.4 Parameters Affecting the Proposed Standard

The performance of the proposed standard is dependent on the cost of the standard and the ultimate level of compliance. This section presents several sensitivity studies to explore the dependence of our results on these factors.

7.4.1 Manufacturers' Cost of the Proposed Standard

Figure 34 shows how the choice of alternatives is affected by the furniture manufacturers' initial cost for both the barrier method and the backcoating method. As discussed in section 3.7.3, the figure shows that the comparison of alternatives is quite sensitive to the manufacturers' cost for the barrier method. If the cost is greater than our nominal value of $136 million for the first year, then the smoke detector alternative is most attractive. On the other hand, if the manufacturers' cost is less than our nominal value, then the proposed standard is clearly most attractive. On the other hand, figure 34 shows that the initial manufacturers' cost of $37.0 million for the backcoating method would have to more than double to make this compliance method less attractive than no-action.

We wish to point out that the difference in the vertical intercepts in figure 34 is due to the different expected losses under the two compliance methods. The difference in the slopes of the two lines is due to the different assumptions concerning the behavior of the manufacturers' costs over time.

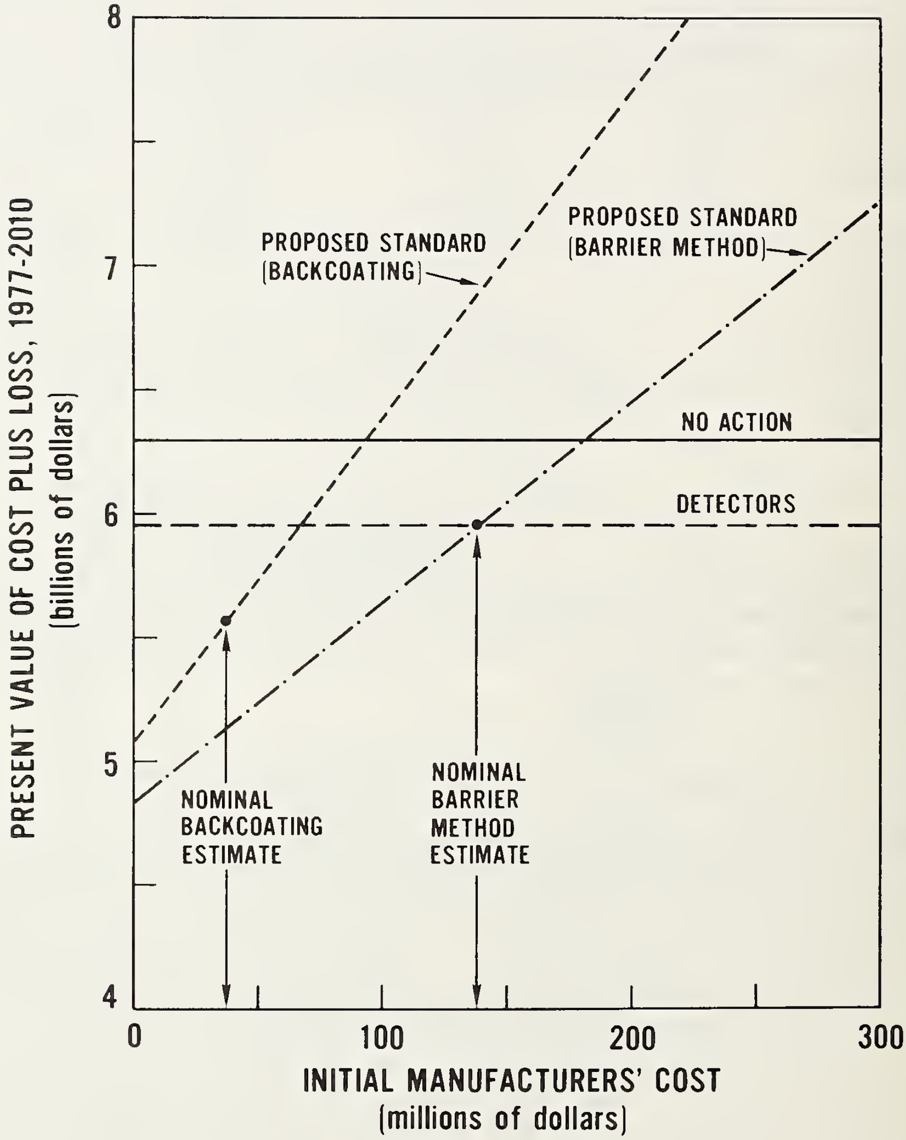

Figure 34. Sensitivity of Results to Manufacturers' Cost of Proposed Standard Under Two Compliance Methods

7.4.2 Market Factor for Assessing Total Societal Cost of Proposed Standard

In assessing the total societal cost of the proposed standard we multiply the manufacturers' cost by a market factor. The market factor was derived to account for the effects of middleman charges and decreased consumer participation in the market. Table 54 shows how the comparison of alternatives depends on the market factor. The market factor of 1.7 corresponds to the mark-up currently being applied to the total manufacturing cost of the upholstered furniture. The 1.2 factor represents the mark-up associated with such fixed costs as sales commissions. Although the absolute value of the cost plus loss of the proposed standard varies with the market factor, the table shows that the choice of alternatives is not significantly affected by the value of the market factor.

Table 54. Sensitivity of Results to Market Factors

	Market Factors		Present Value at 8% from 1977 to 2010 (Millions of Dollars)		
Alternative	Initial	Long Range	Loss	Cost	Cost Plus Loss
Proposed Standard (Barrier)	1.2	1.2	$4840	$ 960	$5800
	1.5[a]	1.2[a]	4840	1120	5960
	1.5	1.5	4840	1200	6040
	1.7	1.2	4840	1230	6070
	1.7	1.7	4840	1360	6200
No-Action			6330	0	6330
Detector Alternative			5650	300	5950

[a] nominal values

7.4.3 Compliance Level

Our nominal analysis assumes that 80 percent of the furniture manufactured under the proposed standard would be compliant. Reasons for non-compliance include the use of slipcovers, aging, the use of improper materials or techniques, or outright disregard for the standard. Figure 35 shows how the performance of the barrier method of meeting the proposed standard depends on the compliance level. Two curves are given in the figure. One assumes that the total cost of attempting to meet the standard is constant, and only the compliance varies. This curve would correspond to the case where aging or deteriorated materials have affected the complaince level. The other curve assumes that the total

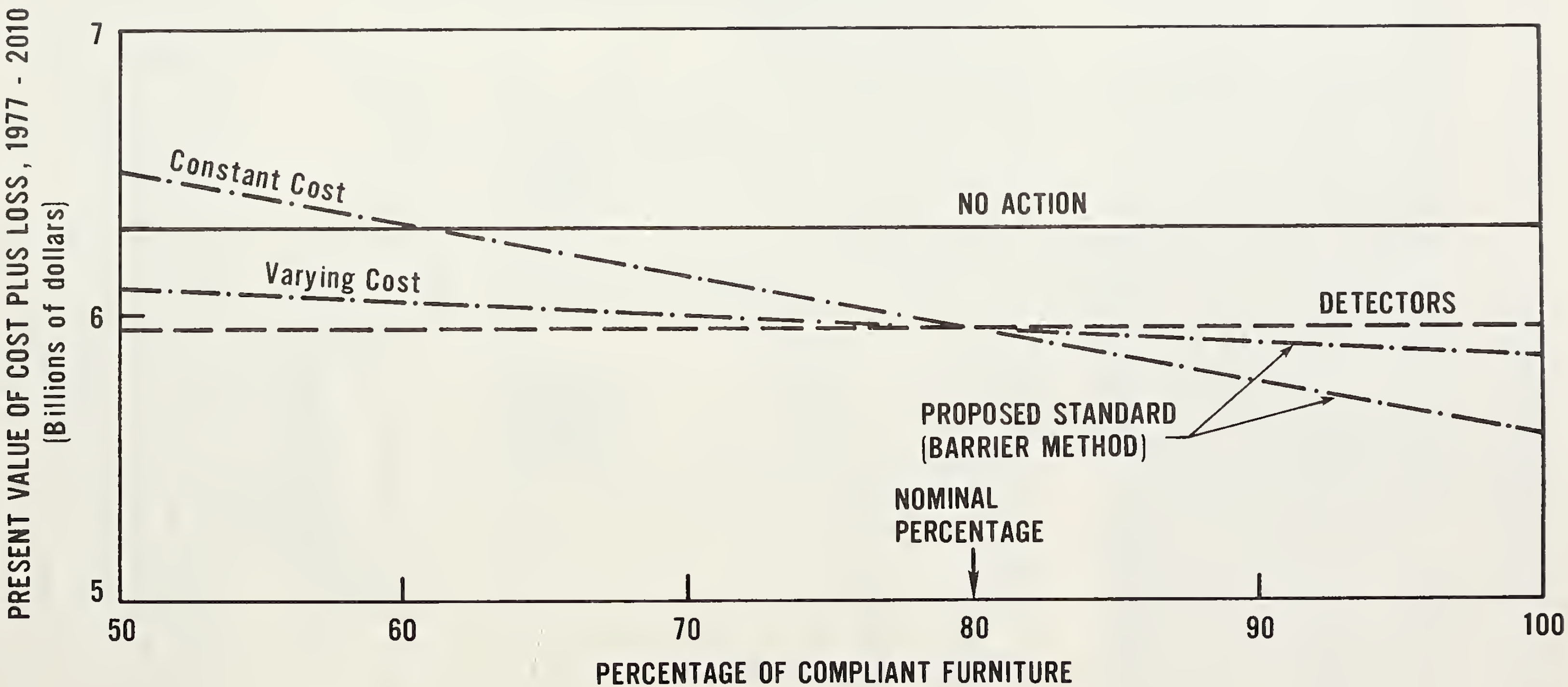

Figure 35. Sensitivity of Results to Percentage of Compliant Furniture Under Proposed Standard

costs of the standard vary with the compliance level. This curve would correspond to the situation where there has been no attempt at all to meet the standard. In the fixed cost case, for compliance levels higher than 80 percent the proposed standard is most attractive, while the detector alternative is most attractive for compliance levels less than 80 percent. On the other hand, for the varying cost case the proposed standard and detector alternatives are essentially equal and preferred to no action.

7.5 Summary of Sensitivity Results

We have examined the sensitivity of our results to many different assumptions and parameter values in this section and also in section 3.7. We have seen that under a great variety of conditions the differences between the proposed standard and detector alternative are small. Within reasonable ranges on most parameters they remain together more attractive than no action.

Two sensitivity studies indicate areas where future attention should be focused. The first is the cost of the proposed standard (section 3.7.1 and 7.4.1) and the second is the furniture replacement pattern (section 7.2.1). If the cost of the proposed standard should prove to be significantly higher than our nominal estimate, then the smoke detector alternative is the most attractive alternative followed by no action. However, we expect that such a significant increase in this cost estimate is unlikely. On the other hand, if the cost of the proposed standard proves to be significantly lower than our nominal estimate or the furniture replacement is considerably faster than our model predicts, then the proposed standard is the most attractive alternative. With regard to the furniture replacement pattern, if essentially all existing furniture could be replaced in 15 years, compared to our nominal estimate of 30 years, then the proposed standard is the most attractive strategy.

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APPENDIX

Conditional Probabilities for Current Conditions

This appendix is provided for the convenience of the reader who wishes to work through the fire loss calculations detailed in sections 4 and 5.

Figure 36, A, B, C, and D, gives the fire loss model probabilities for each ignition source under current conditions. These probabilities, conditional on the fire being reported to the fire service, are calculated from the auxiliary trees (figure 11) as described in section 4.2.2.7. Together with the probabilities given in table 16 and figure 15 and the loss assignments given in tables 23 and 24 the probabilities shown in the figure are input to the fire loss model (figure 9) to determine the current losses per reported upholstered furniture fire.

To the reader who is working through the details of the calculations, we wish to point out that there may be some very minor discrepancies in our reported values on some parameters. Calculations were performed by full scale computer, hand calculator, and pencil and paper with varying numbers of significant figures. Intermediate roundoffs were made when the calculation mode was changed. None of the resulting discrepancies have any significance in the final results of the analysis presented in this report.

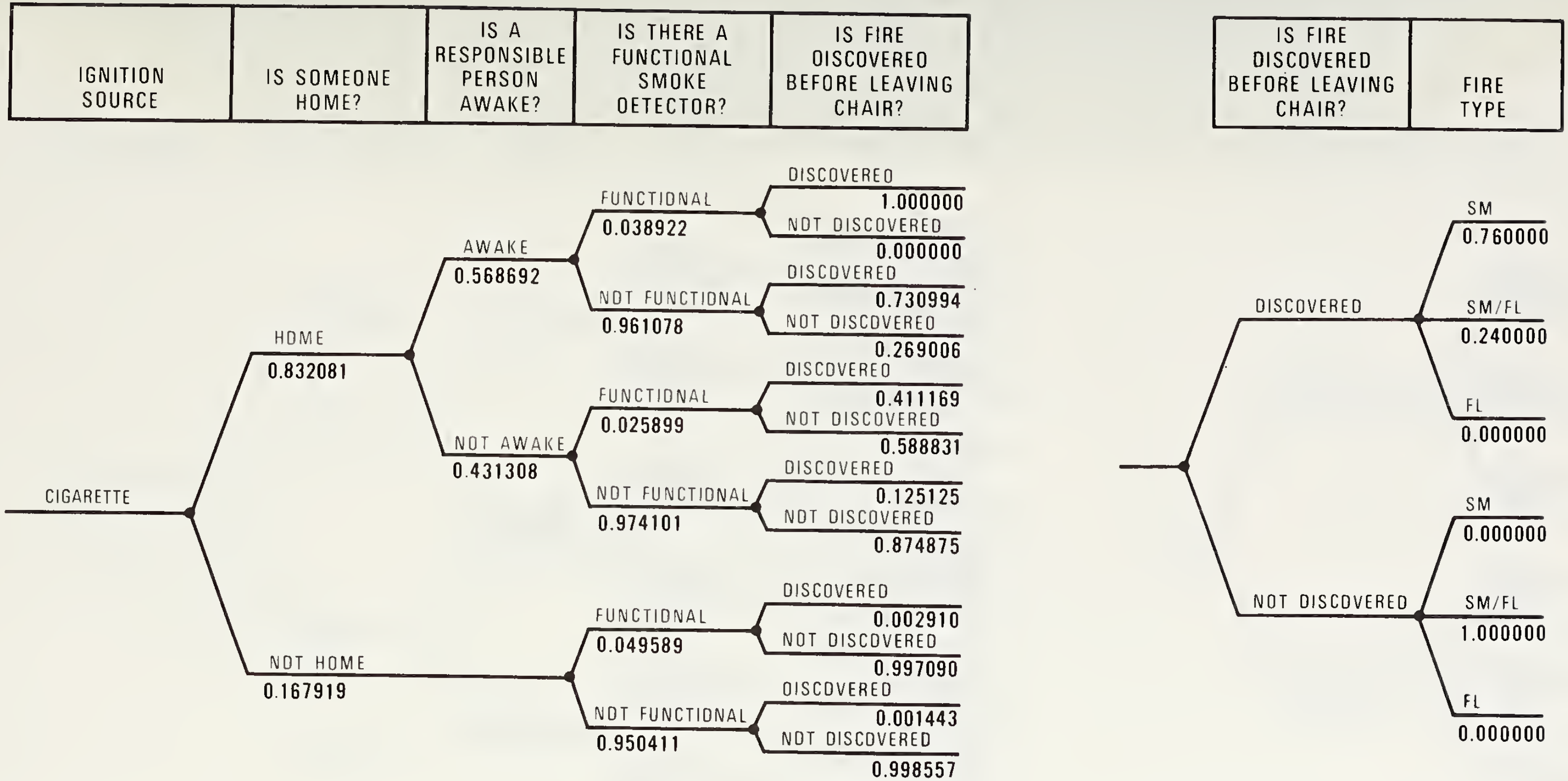

Figure 36A. Fire Loss Model Probabilities for Cigarette Ignition Source for Current Conditions Conditional on the Fire Being Reported as Calculated from Figure 11A

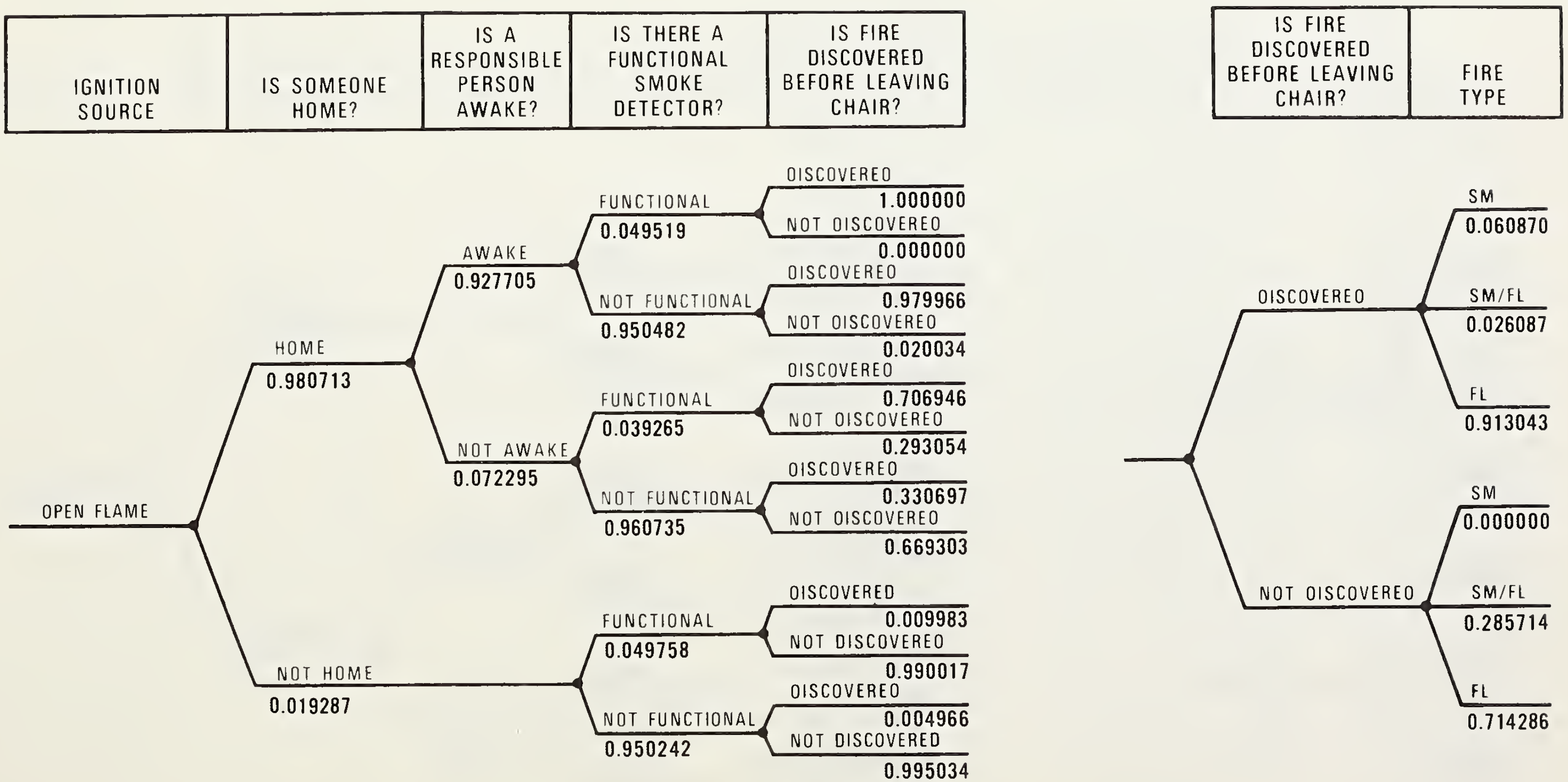

Figure 36B. Fire Loss Model Probabilities for Open Flame Ignition Source for Current Conditions Conditional on the Fire Being Reported as Calculated from Figure 11B

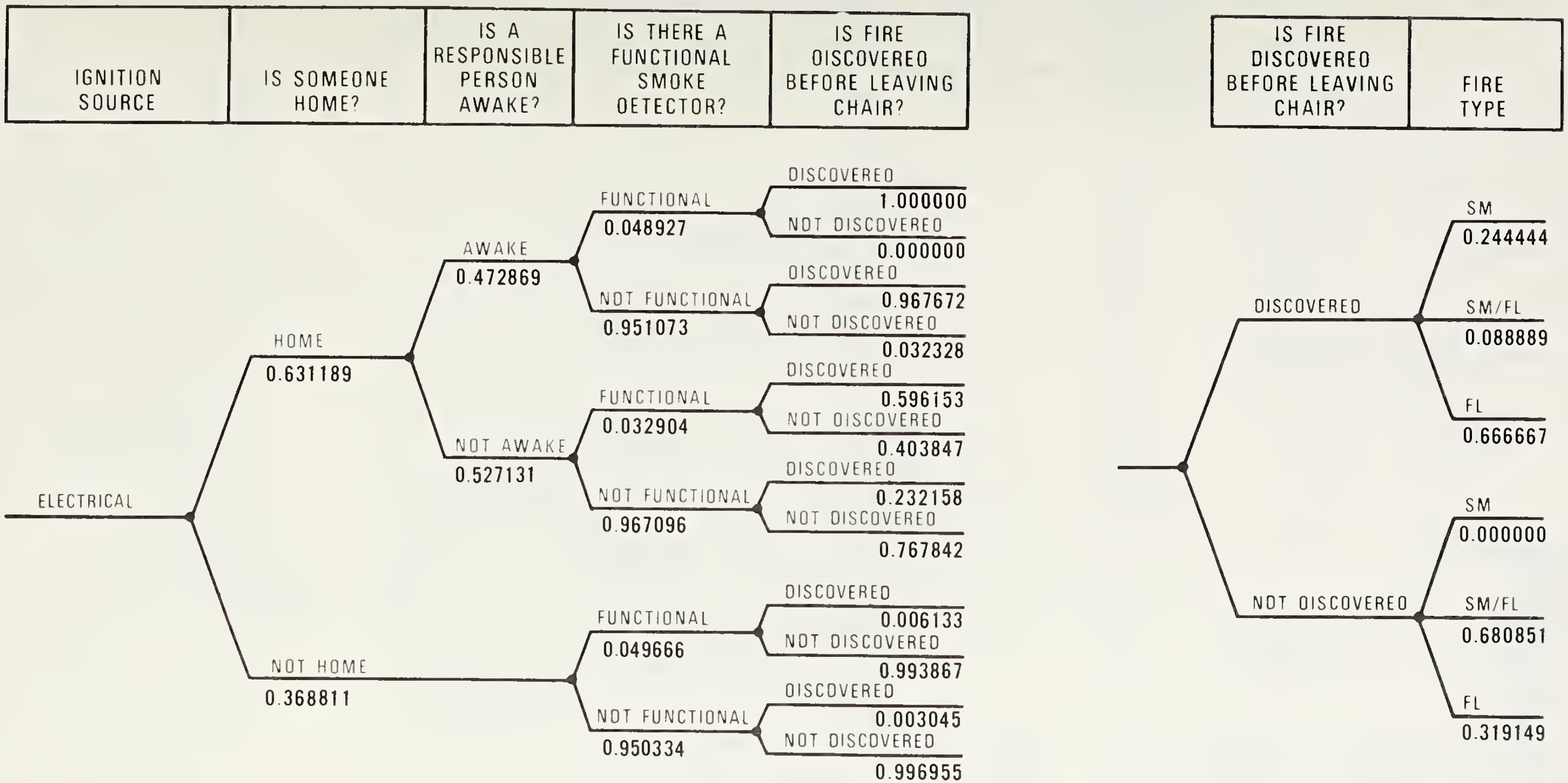

Figure 36C. Fire Loss Model Probabilities for Electrical Ignition Source for Current Conditions Conditional on the Fire Being Reported as Calculated from Figure 11C

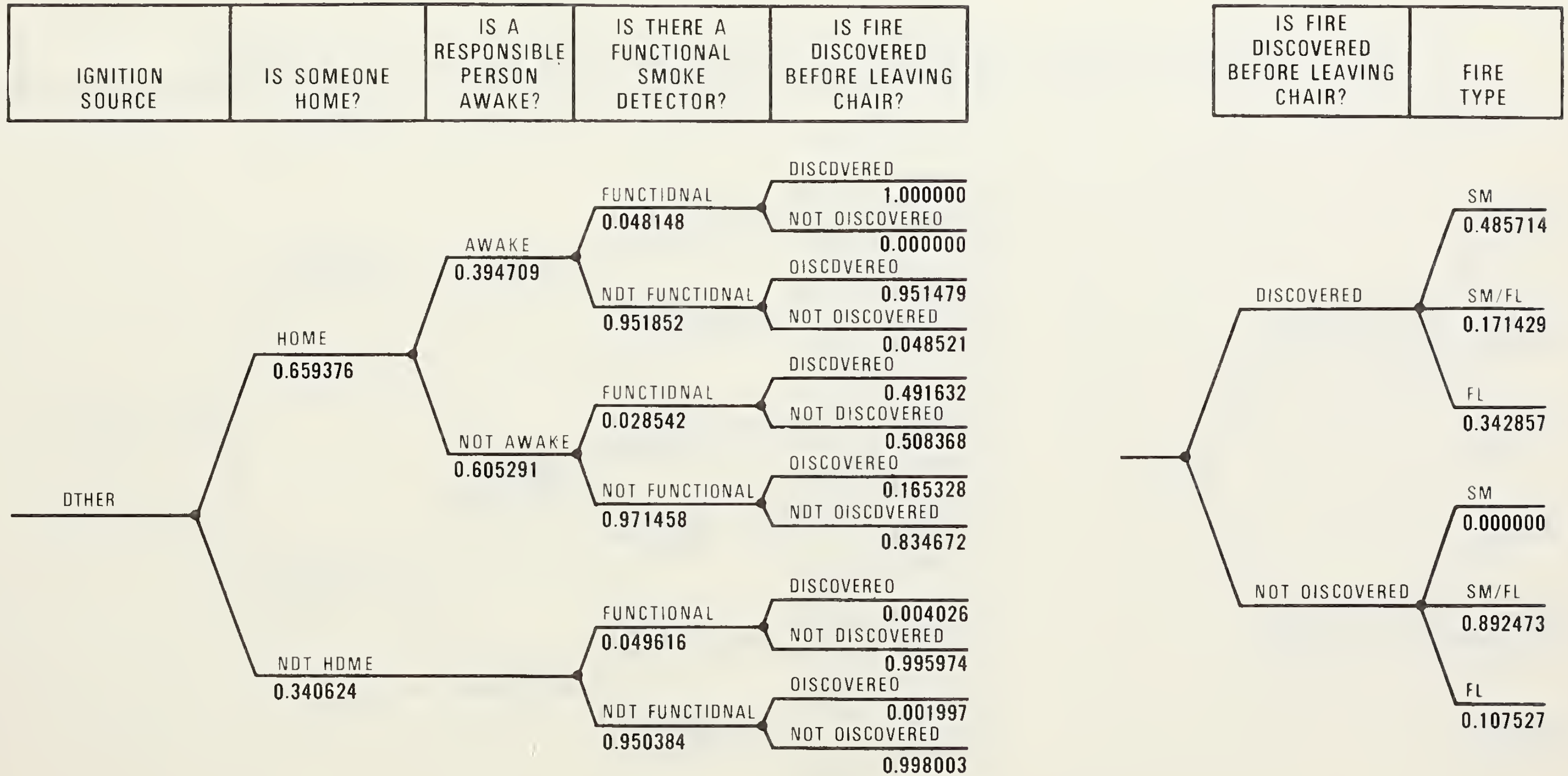

Figure 36D. Fire Loss Model Probabilities for Other Ignition Source for Current Conditions Conditional on the Fire Being Reported as Calculated from Figure 11D

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Decision analysis is used to evaluate alternative strategies for reducing residential upholstered furniture fire losses. Three alternatives are evaluated: no-action, mandatory smoke detector installation, and the proposed upholstered furniture standard under consideration by the Consumer Product Safety Commission. Quantitative models are developed to assess fire losses and costs under each alternative. The alternatives are evaluated on the basis of minimizing the total cost plus loss to society over time. Subject to the assumptions set forth in the report, the analysis shows that the detector alternative and the proposed standard are essentially equivalent and preferred to the no-action alternative. The proposed standard is more effective in saving lives, whereas the detector alternative is less costly to implement. The sensitivity of the results to key assumptions and input parameters is tested. The results are shown to be particularly sensitive to the cost of the proposed standard, the loss of life value assignment, and the upholstered furniture replacement pattern.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Building fires; cost-benefit analysis; costs; decision analysis; fire losses; furniture; hazard analysis; probability; residential buildings; sensitivity analysis; smoke detectors; standards; upholstered furniture.

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