surveys. The purpose defines the limits of the survey and must maintain the focus of the experts.

As presented in Appendix A, the purpose of the example survey is to predict the structural integrity of two barrier configurations; a floor/ceiling assembly without membrane protection and another with membrane protection and varying live and fuel loads. The unprotected assembly does not have a ceiling, exposing the floor joists directly to the room beneath, while the protected assembly has a gypsumboard ceiling.

Experts are asked to assign probabilistic values at incremental time steps, based upon whether the assembly has failed. Probabilistic values are assigned based upon expected fire growth and the corresponding impact on the assembly, until there is 100% certainty that total collapse has occurred. Total collapse is reached mean when the assembly has reached a condition where it can no longer support load. This clearly defines the endpoint of the exercise.

10.2.2. Establish the scenarios.

Step #2 - Create an adequate number of scenarios to represent the possible combinations of controlling factors.

An adequate number of scenarios are developed to cover the range of factors which influence performance of the assembly. Since expert surveys are intended to fill voids in data or modelling, the scenarios should be representative of real life configurations, including fuel loads, structural loads, openings and construction details. Data, where available, can be used to develop the appropriate range, as in the case of the low and high values for live and fuel loads. Where data does not exist, information can be provided from reference material, as in the case of the furniture arrangement.

For the example survey, two sets of four scenarios are developed to determine the effect on time to failure when gypsumboard is attached to the underside of the floor joists. Eight scenarios in all are established; Scenarios #1-4 without gypsum board and scenarios #5-8 with 1/2" gypsum board as the ceiling in the room of fire origin.

Details of the room settings are also provided. The room of origin is a ground floor sleeping room with a window entirely above finished grade. A single door into the room from the adjoining space is assumed to be open. The contents of the sleeping room represent the fuel load. Directly above the sleeping room is the living room. The living room is furnished, with the contents being supported by the floor joists which are exposed to the fire.

10.2.3. Variables and constants

Step #3 - Identify all variables and constants which the experts will use in

their substantiation.

VARIABLES

Selection of the variables is important to achieving the goal of the exercise. The variations between scenarios should consist of factors which, when considered by the experts, will influence probabilities assigned to failure. The more sensitive the outcome is to the variable, the more likely a broad range of responses will be given.

Following is a discussion of the variables and their importance to the outcome of the exercise.

Dead Load - The dead load of the assembly is the actual weight of the building materials. Dead load is given in lbs/ft^2 and for the assembly it consists of the weight of the joists, plywood subfloor, linoleum or hardwood finished floor and the gypsum board for the protected assembly. ASCE 7 [13] was used to determine the weights of the construction materials.

Live Load - The live load is the actual weight of the contents of living room. Two different furnishing packages were selected, one with sparse contents representing a low live load and other with dense contents representing a high live load. The combination of dead and live load represent the total load on the assembly.

Fuel Load - The fuel load is calculated from the mass and type of the contents in the sleeping room. Two bedroom configurations were selected to represent typical layouts. The low fuel load setting consists of sparse accommodations where ignition of the various pieces would not occur rapidly. The high fuel load setting consists of a densely arranged package of furnishings.

Ceiling - The ceiling of the sleeping room was selected to measure the effect of a gypsumboard membrane on delaying structural failure. Gypsumboard is a good barrier to the prevention of spread of fire to the framing members, although eventually it will fail if the fuel load is significant.

The following table illustrates the combinations of variables that the experts evaluated.

TABLE 10.1

DESCRIPTION OF ROOM SCENARIOS

SCEN-ARIO	UNPROTECTED W/O GB	PROTECTED W/ GB	LOW FUEL LOAD	HIGH FUEL LOAD	LOW LIVE LOAD	HIGH LIVE LOAD
1	x		x		x	
2	x			x	x	
3	x		x			x
4	x			x		x
5		x	x		x	
6		x		x	x	
7		x	x			x
8		x		x		x

CONSTANTS

Certain aspects are held constant to allow the experts to focus on the factors having greatest impact on the expected performance. The following constants are critical to the exercise; room dimensions, ceiling height, wall construction, door and window opening dimensions and whether they are opened or closed. Varying these parameters complicates the exercise.

10.2.4. Evaluate the available models.

Step #4 - Utilize current methods or models for the prediction of time to failure of the scenarios.

The experts should be provided with as much empirical data as possible, establishing common understanding and eliminating subjectivity. The most appropriate prediction techniques applicable to the scenarios should be selected. The results produced by the models are used by the experts as guides to assist in assigning probabilities. It is not necessary that the expert's assigned time to failure matches that of the methodology. If it does match, this is sign that there may be a misunderstanding in the instructions. The failure point of the selected methodology may not match the failure point described in the purpose. It is important that the instructions provide a clear description of the methodology, allowing the experts to rationalize their results against the theory and the calculated or predicted time.

For the purpose of the example survey the following models were selected:

Weoste/Schaffer model

The model, developed by Woeste and Schaffer [42] to predict the fire endurance of exposed wood joists, was used to approximate the time to failure in scenarios #1 -4. This model is sensitive to the live load, but not to the effect of varying the fuel load. The fire used in the development of the model was the ASTM E 119 exposure. The room fire growth curves were not expected to follow time vs. temperature curve given in ASTM E 119. The engineering judgment of the experts was critical in converting the results of the model to the results expected from the room conditions.

Component Additive Method

As discussed, the CAM method is derived from an evaluation of a series of ASTM E 119 fire tests involving gypsumboard membranes. The time assigned by CAM is not necessarily associated with structural failure of the assembly, but may be due to heat or flame transmission. Thus, the CAM predicted time to failure is only a relative value used by the experts as rationale for their answers. It is correct, however, to assume that the structural elements used in the derivation of CAM were loaded to create maximum allowable stresses in the floor joists.

10.2.5. Documentation.

Step #5 - Develop complete written instructions, with substantiating data to support the failure times assigned.

Providing clear and concise instructions to the experts is necessary to establish a common understanding of the exercise. The instructions must state the purpose of the survey and its intended application. Complete details of the scenarios including graphics are essential. The experts should be given a means to contact the surveyor with questions.

For the example survey, a complete set of instructions with illustrations were provided. Detailed drawings showing the sleeping room furniture packages and the living room contents are provided. A section of the floor/ceiling assembly and the wall assembly is also provided. The open door and window location are identified. Appendix A contains the complete set of instructions provided to the experts.

The experts are asked to complete a worksheet containing 8 identical time lines vs. probability of failure, for each of the scenarios. A sample time line was provided to give the experts direction in how to phrase the questions needed to complete the exercise. There is no time limit imposed for a response and the experts are encouraged to contact the author with questions.

10.2.6. Choosing and surveying experts

Step #6 - Survey those experts who are knowledgeable and comfortable in assigning probabilities.

Predicting the performance of a floor/ceiling assembly under fire exposure requires an understanding of both structural and fire protection engineering. A structural engineer might define performance in terms of the structural integrity of the assembly. A heat transfer expert might define performance as the assembly's ability to transfer energy and a fire service professional might define it in terms of containing the fire to the originating side of the assembly. Each of these expectations are appropriate when designing or evaluating a barrier for fire performance. The ASTM E 119 fire test failure criteria incorporates each of these failure modes in determining an assembly's fire endurance rating.

Experts for the example survey were selected from Governmental Agencies, academic institutions and industry. Most had a good to excellent understanding of the behavior of wood when exposed to fire. Overall, their knowledge of structural behavior was not as great, although it was more than adequate. Thirteen individuals in the United States and Canada were identified as having a good background in the combination of disciplines. Of these, six responded to the survey. Of the six, four appeared to understand the directions and showed logical answers. There was apparently some misinterpretation on the part of the other two experts. A compilation of the six responses is provided in Appendix B.

10.2.7. Re-survey.

Step #7 - Refine the question and repeat the exercise if probabilities assigned indicate a misunderstanding.

The process of a probability analysis utilizing expert judgment often requires more than one iteration of questioning. Ideally, the experts would be centrally located so that a number of meetings could be held to discuss questions. This would assure that everyone had a common understanding of the purpose and expected results.

It is likely, particularly in the case where the experts cannot meet as a group, that a re-survey is appropriate. If assigned probabilities are inconsistent within an expert's response or if large discrepancies appear between experts, a re-survey is warranted.

Because of the time commitment required of the experts to fairly and accurately complete the survey, a second iteration could not be performed. The intent of the example survey was to aid the author in developing a procedure, executing it and determining appropriate improvements. It is not the intent to analyze the results provided by the experts.

CONCLUSIONS

The task requested of the experts was challenging. It is likely that the many scenarios presented demanded an excessive time commitment on the part of the experts. A total of four scenarios would possibly have been more manageable and still have permitted the development of a logical response.

In the absence of a group meeting to unify understanding of the purpose, more detailed instructions should have been provided for clarification. An example specific to the exercise and containing the reasoning for assigning each probability to the time interval, may have resulted in more consistent results.

A further complication of the survey was that both models were based upon ASTM E 119 fire rather than the real fire. This conversion may have been easier had a fire growth curve been provided from a current computer model. This would have permitted a side-by-side comparison between the ASTM E 119 curve and the real fire curve.

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APPENDICES

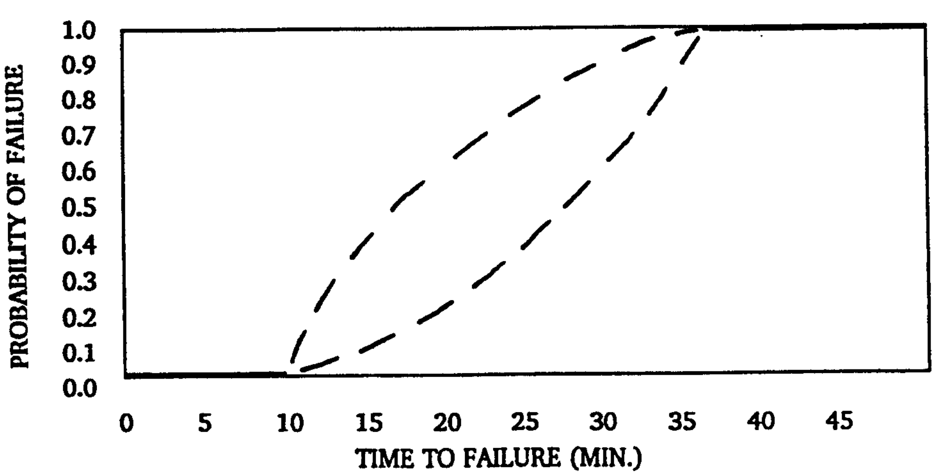
INSTRUCTIONS

INTRODUCTION

The *Building Firesafety Engineering Method*[1] combines engineering judgment with probability techniques to evaluate the expected fire performance of a room, space or building. An experienced fire protection engineer can, with the aid of available analytical methods, apply subjective reasoning to a given situation and assign probabilities associated with the outcome of the event. The probability value expresses a degree of belief and not a statistical frequency. The following exercise is intended to establish, through expert judgment, the zone of confidence in predicting the performance of a specific solid sawn joist, floor/ceiling assembly time to failure.

The following graph represents the expected range of results for this exercise. The scenario, times and probabilities indicated are for illustrative purposes only. **Please do not be bound by the values indicated.**

CONDITIONS: FUEL LOAD - LOW
LIVE LOAD - HIGH



GRAPH #1 - PROBABILITY ENVELOPE

FLOOR PLANS

In order to structure the opinions of the experts, a well defined set of scenarios must be presented. For this exercise, a typical single family dwelling provides the setting. A basement bedroom located beneath the living room is the room of fire origin. Figures 1 and 2 of Exhibit A illustrate two basement furniture arrangements representing somewhat different fuel loads. Figures 3 and 4 of Exhibit A illustrate somewhat different furniture live load arrangements of the living room, which is located above the bedroom. These specific conditions represent the environment for the scenarios. Figure 5 of Exhibit A is a cross-section of a typical exterior wall which encloses the room. A description of the furniture is provided.

ASSEMBLY CONSTRUCTION

Four (4) floor/ceiling assemblies have been selected as representative of single family construction. Both assemblies consist of 2" x 10" sawn joist with 19/32" tongue and groove plywood floor sheathing. The ceiling and floor coverings vary as shown in Table 1.

TABLE 1 - ASSEMBLIES

	WEIGHT (PSF)	FLOOR COVERING	CEILING
ASSEMBLY A	7.6	LINOLEUM	UNPROTECTED
ASSEMBLY B	10.1	HARDWOOD	UNPROTECTED
ASSEMBLY C	8.7	LINOLEUM	1/2" GYP. BOARD
ASSEMBLY D	11.3	HARDWOOD	1/2" GYP. BOARD

TIME TO FAILURE

Table 2 provides a summary of the eight combinations of live and dead load, fuel load and assembly construction. Times to failure are provided based upon the methodology cited. Information on the development of t_f can found in Exhibit B.

ASSIGNING PROBABILITIES

Utilizing the scenarios, assign probabilities of failure to the various times. A zero (0) represents your belief that it is certain that failure **will not** occur, and a one (1) represent your belief that failure **will** occur. Fire in the room has reached flashover at time zero (0). Using the time frames in Exhibit C, record your degree of belief that failure will have occurred at each of the time intervals presented. Failure is defined as the collapse of the floor/ceiling assembly and contents into the bedroom.

TABLE 2 - TIME TO FAILURE

SCENARIO	ASSEMBLY TYPE	FUEL LOAD	LIVE LOAD (PSF) (FLOOR ABOVE)	TOTAL LOAD (PSF) (FLOOR ABOVE)	MOMENT (IN/LBS) (DL+LL)	FAILURE TIME t_f	METHOD
#1	A	FIG. 1	1.4	9.0	3034	21.9	Woeste[2]
#2	A	FIG. 2	1.4	9.0	3034	21.9	Woeste[2]
#3	B	FIG. 1	12.0	22.1	7451	18.4	Woeste[2]
#4	B	FIG. 2	12.0	22.1	7451	18.4	Woeste[2]
#5	C	FIG. 1	1.4	10.1	3405	40	CAM[3]
#6	C	FIG. 2	1.4	10.1	3405	40	CAM[3]
#7	D	FIG. 1	12.0	23.3	7856	40	CAM[3]
#8	D	FIG. 2	12.0	23.3	7856	40	CAM[3]

EXAMPLE:

With each of the specific scenarios, ask yourself the following question; "Given a time of X minutes the probability that the assembly has failed is ___ (0 to 1)".

t_f (min.)	4	8	12	16	20	24	28	32	36	40
Probability of failure (0 to 1)	?	?	?	?	?	?	?	?	?	?

FINAL STEP

Please return the results of Exhibit B to me. I will inform you of the results of the group analysis when it is completed. Thank you.

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EXHIBIT A

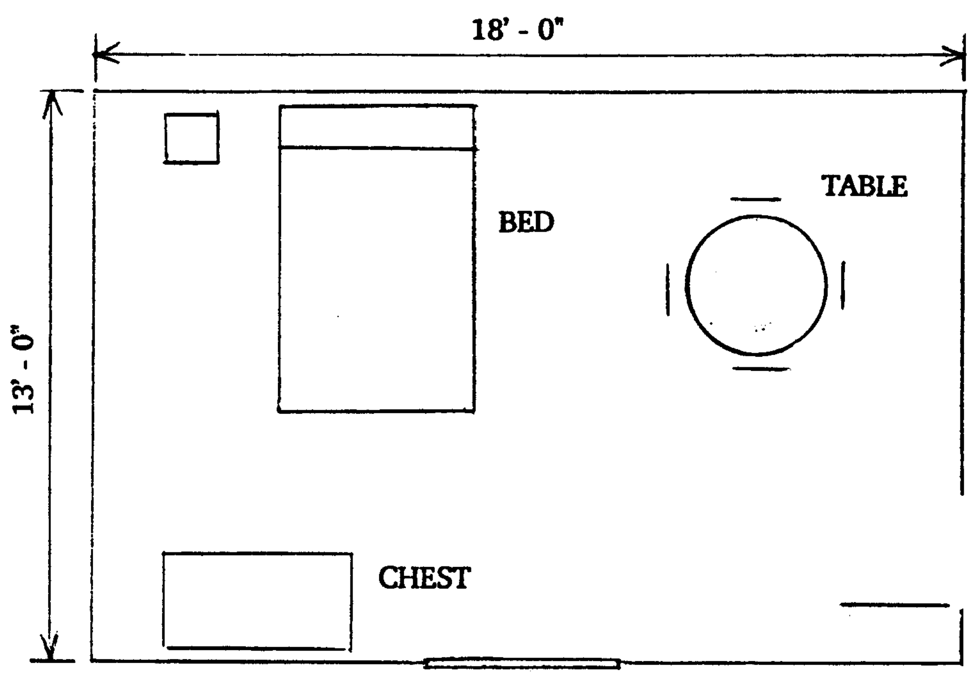

FIGURE #1 - BEDROOM
ROOM OF ORIGIN, BASEMENT FLOOR

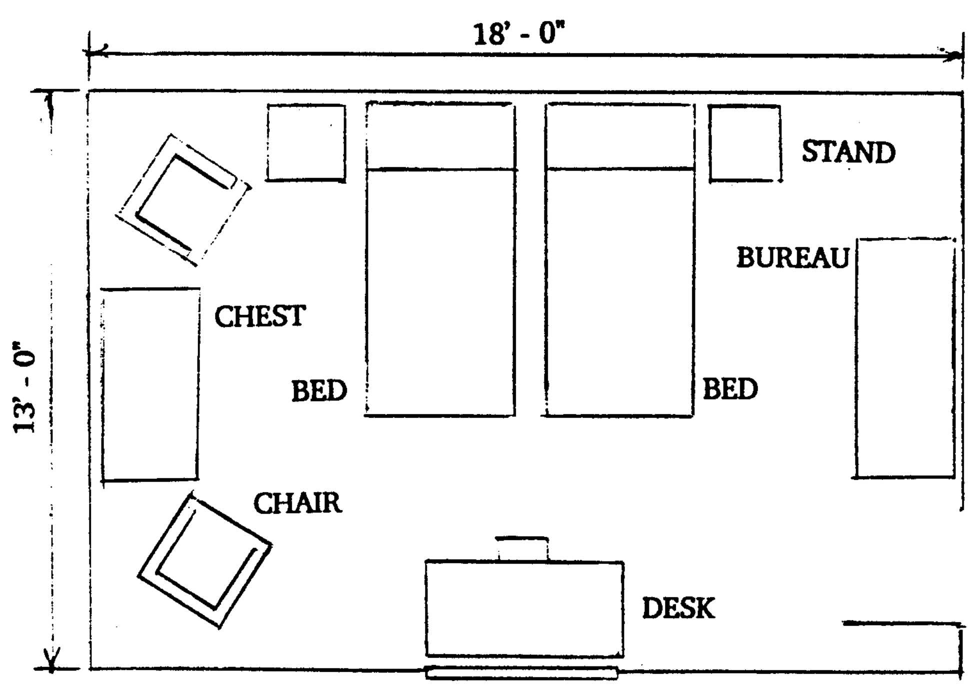

FIGURE #2 - BEDROOM
ROOM OF ORIGIN, BASEMENT FLOOR

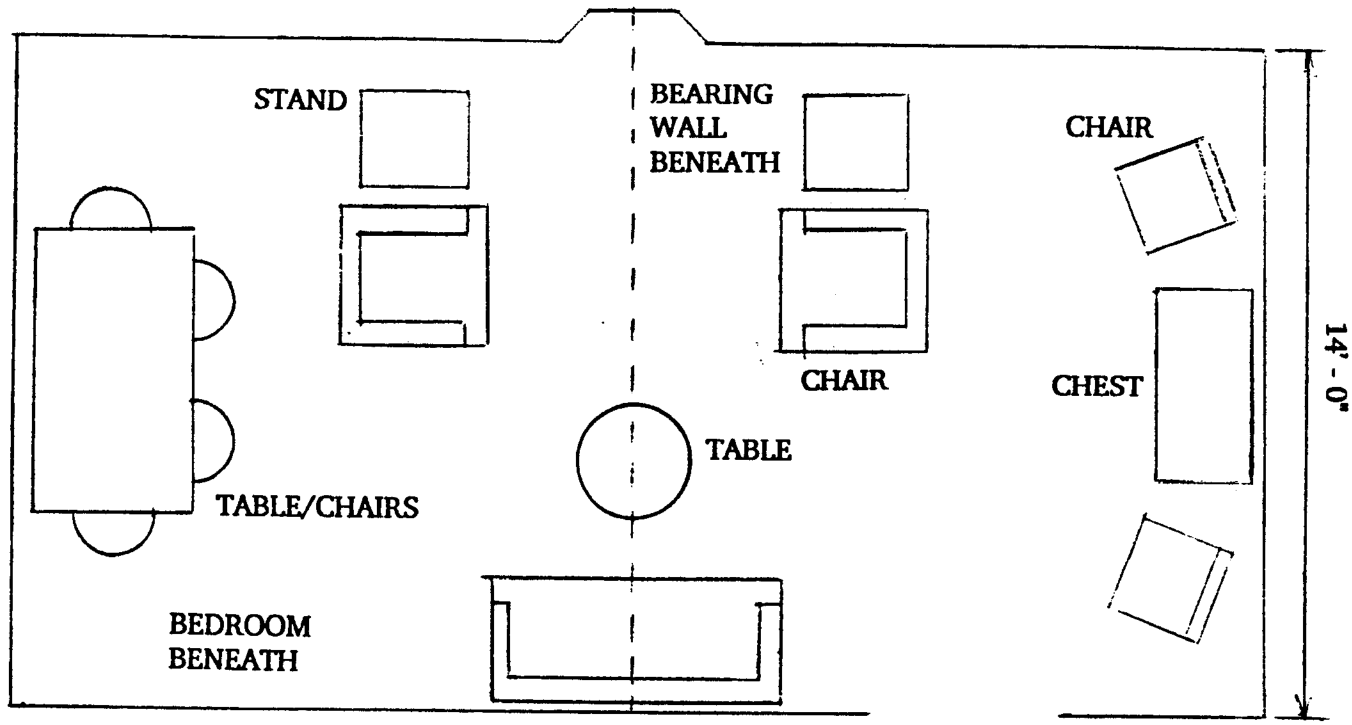

FIGURE #3 - LIVINGROOM
ROOM ABOVE FIRE ROOM

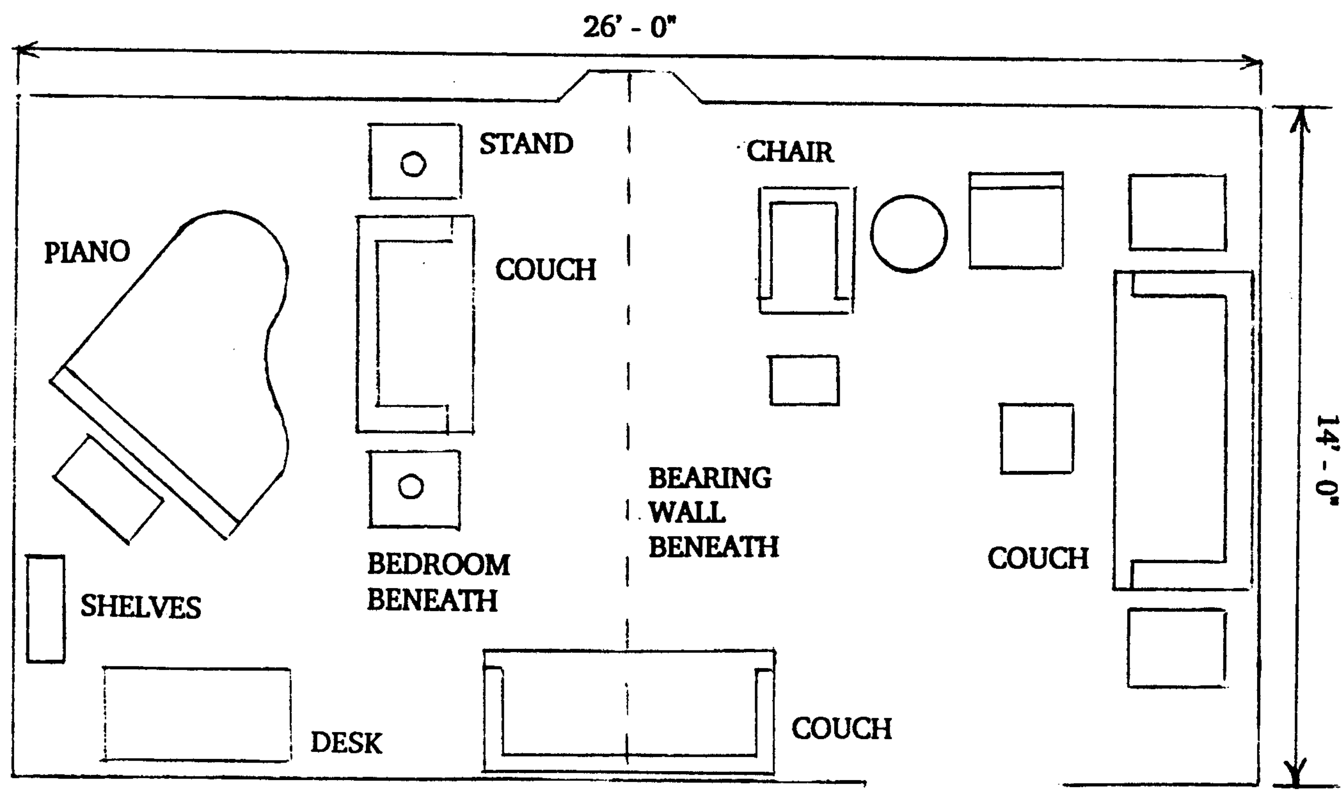

FIGURE #4 - LIVINGROOM
ROOM ABOVE FIRE ROOM

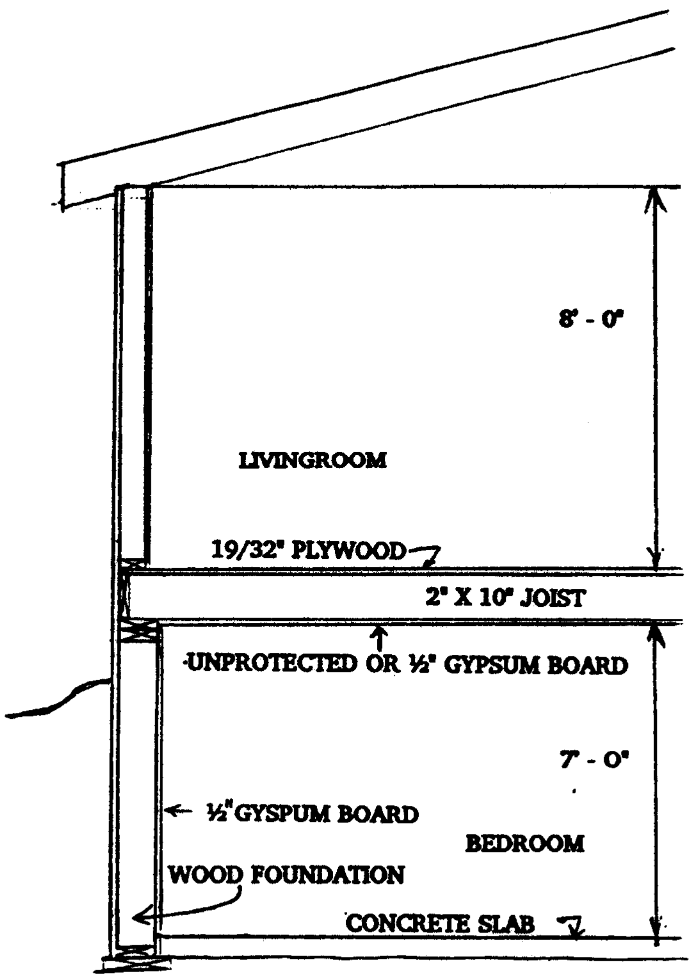

FIGURE #5 - SECTION

FURNISHING DESCRIPTION

Mattress	-	polyurethane foam padding, polyolefin fabric, wood frame.
Chairs	-	polyurethane foam padding, cotton fabric, wood frame.
Tables/chairs	-	wood frame.
Chest/desk	-	wood frame.

EXHIBIT B

DEVELOPMENT OF TIME TO FAILURE (t_f)

Two methods are utilized in the development of t_f. For unprotected assemblies, the equation developed by Schaffer and Woeste[2] was utilized. Since a correlation has not been developed for protected assemblies, the Component Additive Method[3] was selected. The Schaffer/Woeste equation requires various input parameters for determining the time to failure. It should be noted that the CAM does not require numerical inputs, but bases results upon the actual materials utilized in the assembly.

The species of wood selected is Douglas Fir West Inland which has a Modulus of Rupture (3) of 7713 psi. It is appropriate to reduce the MOR for size factor and seasoning. The size factor (F) in accordance with the NDS (4) is:

$$F = \left(\frac{2}{d}\right)^{\frac{1}{9}}$$

For a 2"x10" with an actual depth of 9.25 inches, F = 0.8435. The seasoning adjustment factor in accordance with the ASTM (3) permits a 25% increase in the published MOR. Therefore, the assumed MOR for the purpose of predicting fire endurance is:

$$MOR_{adj} = 7713 \text{ psi} \times 0.8345 \times 1.25 = 8135 \text{ psi}$$

The clear span of the floor joist from the exterior wall to the interior bearing wall is assumed to be 13'-0". The flexural formula:

$$M = \frac{wl^2}{8}$$

is used to calculate the actual moments presented in Table 2.

UNPROTECTED ASSEMBLIES

The values of t_f presented in Table 2 for unprotected floor/ceiling assemblies were calculated from the following equation developed by Schaffer and Woeste[2].

$$t_f = \frac{2Cd(d+b)+6MK\gamma/B-\sqrt{2Cd(d+b)+6MK\gamma/B^2-4V^2(b+d)(bd^2-6M/B)}}{2C^2(b+4d)}$$

where:

$$K = \frac{(b+2d)}{bd}$$

M =	applied bending moment (ft-lb)
d =	joist depth (in.)
C =	char rate (in./min.)
t_f=	time duration of fire (min.)
B =	joist MOR (psi)
b =	initial joist width (in.)
γ =	fire performance factor

The value for char rate was selected as 0.03 in/min. The fire performance factor, γ, is 0.17.

COMPONENT ADDITIVE METHOD

The Component Additive Method was developed as an alternative to full scale assembly ratings. Prior to the acceptance of the CAM in the model building codes, all assemblies required testing in accordance with ASTM E 119. This is prohibitively expensive given the number of possible combinations of components. The following tables are utilized in the development of the Time to Failure values.

TIME ASSIGNED TO PROTECTIVE MEMBRANES	
Description of Finish	Time (min)
⅜ inch douglas fir plywood, phenolic bonded	5
½ inch Douglas fir plywood, phenolic bonded	10
⅝ inch Douglas fir plywood, phenolic bonded	15
⅜ inch gypsum board	10
½ inch gypsum board	15
⅝ inch gypsum board	20
½ inch Type X gypsum board	25
⅝ inch Type X gypsum board	40
Double ⅜ inch gypsum board	25
½ + ⅜ inch gypsum board	35
Double ½ inch gypsum board	40

TIME ASSIGNED TO WOOD-FRAME COMPONENTS	
Description of Frame	Time (min)
Unprotected wood studs, 16 inches on center	20
Unprotected wood joists, 16 inches on center	10
Wood roof and floor truss assemblies, 24 inches on center	5

For the scenarios presented in Table 2, the t_f value was determined as follows:

Floor joist, 16" OC	10 min.
1/2" gypsum board	15 min.
	25 min.

EXHIBIT C

SCENARIO #1 - ULFLLLL (Unprotected, low fuel load, low live load)

t_f (min.)	4	8	12	16	20	24	28	32	36	40
Probability of failure										

SCENARIO #2 - UHFLLLL (Unprotected, high fuel load, low live load)

t_f (min.)	4	8	12	16	20	24	28	32	36	40
Probability of failure										

SCENARIO #3 - ULFLHLL (Unprotected, low fuel load, high live load)

t_f (min.)	4	8	12	16	20	24	28	32	36	40
Probability of failure										

SCENARIO #4 - UHFLHLL (Unprotected, high fuel load, high live load)

t_f (min.)	4	8	12	16	20	24	28	32	36	40
Probability of failure										

SCENARIO #5 - PLFLLLL (Protected, low fuel load, low live load)

t_f (min.)	6	12	18	24	30	36	42	48	54	60
Probability of failure										

SCENARIO #6 - PHFLLLL (Protected, high fuel load, low live load)

t_f (min.)	6	12	18	24	30	36	42	48	54	60
Probability of failure										

SCENARIO #7 - PLFLHLL (Protected, low fuel load, high live load)

t_f (min.)	6	12	18	24	30	36	42	48	54	60
Probability of failure										

SCENARIO #8 - PHFLHLL (Protected, high fuel load, high live load)

t_f (min.)	6	12	18	24	30	36	42	48	54	60
Probability of failure										

APPENDIX B

SCENARIO #1 - UNPROTECTED, LOW FUEL LOAD, LOW LIVE LOAD										
	Time to Failure, tf (min.)									
	4	8	12	16	20	24	28	32	36	40
1	0	0	0	.2	.3	.4	.4	.4	.4	.4
2	0	0	0	0	.1	.2	.6	.8	1	1
3	0	0	0	.1	.3	.7	.9	1	1	1
4	0	0	0	0	1	1	1	1	1	1
5	0	0	0	0	0	1	1	1	1	1
6	0	0	0	0	0	.5	.95	1	1	1

SCENARIO #2- UNPROTECTED, HIGH FUEL LOAD, LOW LIVE LOAD										
	Time to Failure, tf (min.)									
	4	8	12	16	20	24	28	32	36	40
1	0	0	.2	.4	.6	.8	1	1	.4	.4
2	0	0	0	.1	.3	.7	1	1	1	1
3	0	0	0	.1	.3	.7	.9	1	1	1
4	0	0	0	1	1	1	1	1	1	1
5	0	0	0	0	0	1	1	1	1	1
6	0	0	0	0	0	.5	1	1	1	1

SCENARIO #3 - UNPROTECTED, LOW FUEL LOAD, HIGH LIVE LOAD										
	Time to Failure, tf (min.)									
	4	8	12	16	20	24	28	32	36	40
1	0	0	.2	.4	.45	.5	.5	.5	.5	.5
2	0	0	0	.1	.15	.5	.7	1	1	1
3	0	0	.1	.3	.9	.9	1	1	1	1
4	0	0	1	1	1	1	1	1	1	1
5	0	0	0	1	1	1	1	1	1	1
6	0	0	0	0	.5	.95	1	1	1	1

SCENARIO #4- UNPROTECTED, HIGH FUEL LOAD, HIGH LIVE LOAD										
	Time to Failure, tf (min.)									
	4	8	12	16	20	24	28	32	36	40
1	0	.2	.4	.6	.8	1	1	1	1	1
2	0	.1	.3	.7	.9	1	1	1	1	1
3	0	0	.1	.3	.7	.9	1	1	1	1
4	0	1	1	1	1	1	1	1	1	1
5	0	0	0	1	1	1	1	1	1	1
6	0	0	0	0	.14	.99	1	1	1	1

SCENARIO #5-PROTECTED, LOW FUEL LOAD, LOW LIVE LOAD										
	Time to Failure, tf (min.)									
	6	12	18	24	30	36	42	48	54	60
1	0	0	.1	.1	.1	.1	.1	.1	.1	.1
2	0	0	0	0	0	0	0	0	.1	.3
3	0	0	0	.2	.4	.8	1	1	1	1
4	0	0	0	0	0	1	1	1	1	1
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	.95	1	1	1

SCENARIO #6 -PROTECTED, HIGH FUEL LOAD, LOW LIVE LOAD										
	Time to Failure, tf (min.)									
	6	12	18	24	30	36	42	48	54	60
1	0	0	0	.2	.4	.6	.8	1	1	1
2	0	0	0	0	0	0	0	.1	.3	.5
3	0	0	0	.3	.5	.9	1	1	1	1
4	0	0	0	0	1	1	1	1	1	1
5	0	0	0	0	0	0	0	1	1	1
6	0	0	0	0	0	.39	1	1	1	1

SCENARIO #7-PROTECTED, LOW FUEL LOAD, HIGH LIVE LOAD										
	Time to Failure, tf (min.)									
	6	12	18	24	30	36	42	48	54	60
1	0	0	.11	.11	.11	.11	.11	.11	.11	.11
2	0	0	0	0	0	.1	.3	.5	.7	.9
3	0	0	0	.3	.5	.9	1	1	1	1
4	0	0	0	1	1	1	1	1	1	1
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	.5	1	1	1	1

SCENARIO #8 - PROTECTED, HIGH FUEL LOAD, HIGH LIVE LOAD										
	Time to Failure, tf (min.)									
	6	12	18	24	30	36	42	48	54	60
1	0	0	.2	.4	.6	.8	1	1	1	1
2	0	0	0	0	0	.1	.3	.5	.7	1
3	0	0	0	.4	.9	1	1	1	1	1
4	0	0	0	1	1	1	1	1	1	1
5	0	0	1	0	0	0	1	1	1	1
6	0	0	0	0	0.03	.98	1	1	1	1