FIRE TESTS AND FLOORING MATERIALS

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INTRODUCTION

It was recognized during the early part of this century that flooring materials can be a critical player in fire growth and propagation. This national concern lead to regulations being written which quantified the behavior of flooring materials in fire tests. The first attempts to regulate flooring materials used the existing Stiener Tunnel, a test for flame spread developed at Underwriter's Laboratory [1], and the Pill Test was developed to identify easily ignited flooring materials [2,3]. The Pill Test continues to be used because it is simple and provides acceptable ignitibility information. Although used initially, the Stiener Tunnel did not provide the type of fire test data necessary for evaluating flooring materials in part because the tunnel was originally designed for testing ceiling and wall products. It was subsequently replaced by the Flooring Radiant Panel Test. In this paper, test method precision for the Flooring Radiant Panel Test is reviewed from the early days of test development to the present. It is shown that precision and test performance has improved over the years and that the test procedure can be used to quantify the flame propagation characteristic of critical radiant flux over a specified range. The performance of flooring products is discussed as it relates to the influence of aging and use. The Flooring Radiant Panel Test procedure and others are discussed as tools for input to computer models on fire growth and hazard analysis of flooring materials. The need for further development of the Flooring Radiant Panel Test is discussed.

BRIEF HISTORY OF THE FLOORING RADIANT PANEL

The flooring radiant panel was originally developed by Zabawsky at Armstrong Cork Company during the mid-1960's. (Table 1) Its development continued under a cooperative program between Armstrong and the National Bureau of Standards (NBS) in the early 1970's [3,4,5]. Research work carried out by Denyes and Quintiere demonstrated that radiant flux from a room fire which extended into a corridor was a significant factor related to the propagation of flames on floors [6]. Figure 1 exhibits plots made by Benjamin and Adams which show this flame propagation relationship [4]. Of the four corridor heat flux profiles shown in figure 1, the 10.7 kg/m^2 (2.2 lbs/ft^2) most closely represents the high end of the flux range used in the Flooring Radiant Panel Test procedure. L.G. Hartzell, an Armstrong Cork Research Associate at NBS, followed through on the test's development using the room/hallway fire scenario. The finished test procedure uses critical radiant flux as its scale of measurement. Critical radiant flux is defined as the level of incident radiant heat energy on a material's surface at the point of self flame extinction and is reported in units of, radiant heat energy/unit area [7]. Figure 2 shows the principal elements of the Flooring Radiant Panel Test Apparatus and gives an example of a typical radiant heat flux calibration curve for the apparatus.

The critical radiant flux test procedure was adopted by the American Society for Testing and Materials (ASTM)[7] and the National Fire Protection Association (NFPA)[8]. Various codes or regulating authorities have set fire test classification ratings for flooring materials based on the test method. In current regulations, acceptable flooring materials are rated as Class I and Class II. These critical radiant flux ratings are shown graphically as horizontal lines in figure 1.

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Since the early developmental work, the Carpet and Rug Institute (CRI) has worked with the National Institute of Standards and Technology (NIST), formally NBS, to improve the test procedure. Much of this research has been conducted to further standardize the procedure and improve precision.

Table 1: HISTORY OF THE FLOORING RADIANT PANEL

Mid-1960's	Original development by Armstrong Cork Company
1972	Cooperative program between Armstrong and the National Bureau of Standards to develop the test.
1972 - 75	Model Corridor Experimental and Analytical Studies for Floor Coverings at NBS.
1975	Proposed Critical Radiant Flux Test Method published by NBS
1978	Flooring Radiant Panel Test adopted by ASTM and NFPA
1984	ASTM and NFPA Flooring Radiant Panel Test methods revised.
1987	National Voluntary Laboratory Accreditation Program (NVLAP) noted reproducibility results exceeding a coefficient of variation of 35 %.
1987	The Carpet and Rug Institute (CRI) began an interlaboratory study (ILS)
1988-89	CRI and The National Institute of Standards and Technology (NIST) cooperative study on the Flooring Radiant Panel.
1991	ASTM revised the Flooring Radiant Panel test procedure based on the CRI/NIST study of 1988-89.
1991	Work by Briggs et al, questions the use of the Flooring Radiant Panel test for predicting hazard or for use in fire growth models.
1992	CRI/NIST/ASTM interlaboratory study

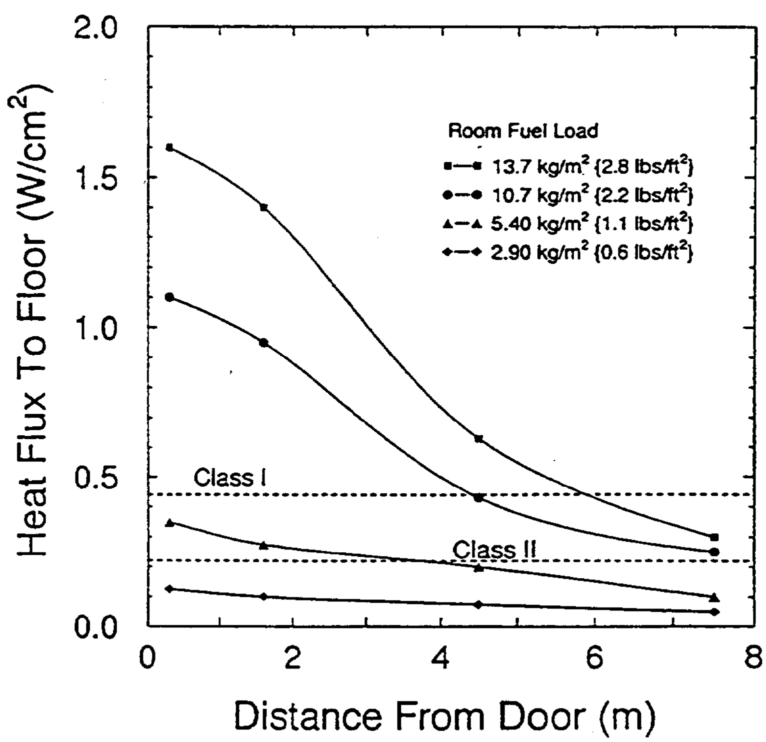

Figure 1. Radiant Flux to Corridor Floors Based on Room Fire Loads [4]

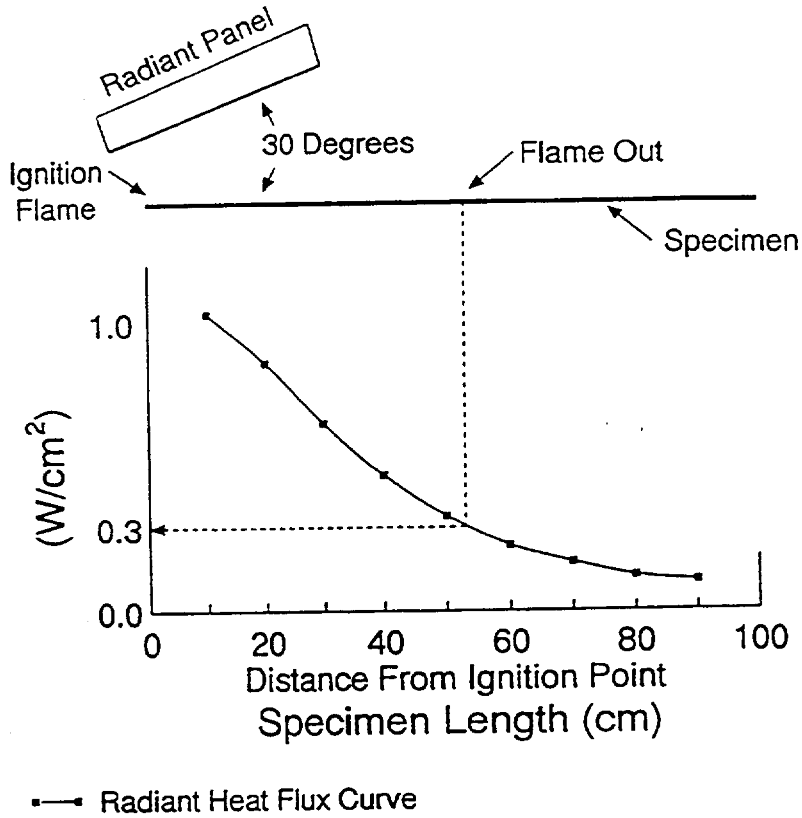

Figure 2. Flooring Radiant Panel Test Principals and Critical Radiant Flux Measurement

STANDARDIZATION OF THE TEST METHOD

As with other test procedures used for regulatory purposes, variability has always been a concern. In 1975, Benjamin and Adams reported the first interlaboratory test results for the Flooring Radiant Panel Test Method. The outcome of this study exhibited a within laboratory repeatability of about 20 percent and a between laboratory reproducibility of about 35 percent [4]. See table 2. In the fire test community, this level of precision is currently considered to be acceptable. However, organizations such as ASTM and NFPA are constantly working to improve their standards as new technology and knowledge allows.

The next time period when test method precision was evaluated occurred around 1987. These studies resulted from certification rounds conducted by the National Voluntary Laboratory Accreditation Program (NVLAP). From six certification rounds over a three year period, with each round using a different flooring material and multiple replicates, it was found that the within laboratory repeatability remained at 20 percent. However, the between laboratory reproducibility was found to be as high as 40 percent with one carpet. This level of reproducibility was considered to be unacceptable and resulted in attempts by the industry to determine its cause. The initial industry interlaboratory study (ILS) attempted to look at this variability. But, the study was terminated after it was found that the selected test material did not always propagate flames far enough away from the ignition point to allow proper measurement. This difficulty with the initial study lead to an agreement between CRI and NIST to pursue the study together.

Table 2: MEASURES OF VARIABILITY

Year Reported	Within Lab Repeatability (%)*	Between Labs Reproducibility (%)*
1975 10M/14L/3R* NBS/MMFPA*/CRI	20	35
1987 6M/11L/6R NVLAP	20	32 - 40
	New Test Method:	
1989 1M/10L/3R CRI/NIST	8	13
1992 5M/7L/3R	2 - 20	4 - 25
2M/7L/3R CRI/NIST	26 & 36	32 & 50
1992 1M/11L/3R NVLAP	11	12

*Note: Values represent the coefficients of variation for repeatability and reproducibility. M = number of materials, L = number of laboratories, R = number of replicates. The values for repeatability and reproducibility reported in this table are obtained from standard statistical methods for calculating precision. The most current standard is ASTM E691. MMFPA = Man Made Fiber Producers Association

The second study began about nine months after the start of the first study. The initial step in this program was to evaluate the original flooring material used in the first study. NIST and several of the laboratories participating in the first study tested some 51 carpet specimens which were retained by the laboratories when the first program was halted. During the time period between the initial industry study and the study begun by NIST, the original carpet lots were maintained in conditioned storage at the testing laboratories. The untested carpet specimens from the original lot were used in the study which followed. See details in references 9 and 10. Results from this investigation were surprising. There was a marked change in critical radiant flux with a majority of the 51 carpet specimens tested. The mean critical radiant flux had dropped from 0.69 W/cm^2 to 0.44 W/cm^2 [9]. See table 3. This nine month difference in time between the first and second study resulted in the same carpet lot being rated as a Class I flooring, and then rated as a Class II flooring in the second study. The only thing at this point that seems to explain this unexpected change was that the flame spread resistance properties of the carpet specimens degraded while in the laboratories conditioning rooms. With this question of changes in product fire performance being unresolvable at the time, the project moved on to address the issues which appeared to be causing test result variability in the NVLAP studies.

Table 3: 1987 CRI CARPET STUDY VS. 1988 CRI/NIST CARPET RESULTS

Year/Number of Tests	Range (W/cm^2)	No. of Values ≥1.1 (W/cm^2)	Mean for Values <1.1 (W/cm^2)	CoV* (%)
1987/48 CRI Study	0.46 - >1.1	20	0.69	24
1988/51 CRI/NIST Study	0.33 - >1.1	1	0.44	21
	Difference between mean values:		0.25	

* CoV = Coefficient of Variation

The second phase of the Flooring Radiant Panel research program looked at defining points of variability in the test procedure. The following were identified as needing improvement:

- specimen preparation and conditioning
- adhesive variability and gluing of carpets
- test chamber temperature and air flow control
- specimen ignition technique

Research conducted on these variables and others is reported in reference 9. As a result of these studies the following changes were made in the test procedure:

- Specimen preparation and conditioning sections of the test procedure were tightened.
- Tolerances for air flow through the test chamber were set.
- Preheat time of the test chamber was lengthened to better stabilize temperature.
- A new full length line burner replaced the torch used to ignite specimens.
- The preheat time of test specimens was extended as an aid to ignition.

After these changes were made, a single carpet interlaboratory study was conducted to assess the new test procedure. This study also provided a means for comparing performance between the old pilot burner and the new line burner. Just prior to beginning the interlaboratory study, NIST ran a series of Flooring Radiant Panel tests, using the old pilot burner to ignite carpet specimens from the lot distributed for the ILS. The ILS followed with its specimens being ignited by the new line burner. Results from the comparison are shown in table 4. The test data shows that there is no statistical difference in critical radiant flux between the carpets ignited with either pilot burners. This indicates that the new line burner would not be expected to cause a change in a materials classification. However, the new burner is expected to provide greater opportunities for test specimen ignition. Overall results from the interlaboratory study are shown in table 2, under the heading 1989. As can be seen, within laboratory repeatability was 8 percent and between laboratory reproducibility was 13 percent. This indicated an improvement over earlier interlaboratory results. At this point, the test method changes evaluated during the ILS were submitted to ASTM, and they soon became a part of the current standard.

Table 4: OLD VS. NEW PILOT BURNER

Burner Type	Labs/ Replicates	Mean (W/cm^2)	s (W/cm^2)	CoV (%)
OLD	1/6	0.49	0.06	11.8
NEW	10/3	0.50	0.06	11.5

Note: All tests conducted with carpet cut from the same roll. The mean, sample standard deviation (s) and coefficient of variation (CoV) reported here are based on the cumulative sum of all data points, not using cell averaging.

With support from CRI, a full interlaboratory study was planned which would provide data for a new precision statement for the new test method. Flooring manufacturers supplied test materials for the study. NIST planned the interlaboratory study with cooperation from ASTM Committee E5, managed the program, reduced and analyzed the data, and prepared the test report [10]. Results from this study are presented in Figure 3 and table 2. Materials A through F were all carpeting products. Material G was a resilient flooring product. When viewing data generated for five of the seven materials tested, results indicate that the test procedure is performing well. It is significant that between laboratory reproducibility is closely approaching the values for within laboratory repeatability. This implies that the test procedure is exhibiting control over its variables. Values for reproducibility can not be less that those for within laboratory repeatability. For five of the materials repeatability ranged from 2 to 20 percent while reproducibility ranged from 4 to 25 percent. For fire test methods, this level of variability is considered to be acceptable, and it shows that the test procedure can produce meaningful results which may be use for regulation purposes. However, the data also shows that two carpet products exhibited significantly high values. From the graph, it is apparent that B and C did not behave as the other five. Materials B and C were carpets produced from the same basic components and differed only in backing construction. For detailed descriptions of these carpets and the study, see reference 10. Table 2 shows that repeatability and reproducibility values for these two materials (1992, 2M/7L/3R) are unacceptably high. Extensive evaluation of the laboratory data and test specimens suggest that this variability is probably associated with product uniformity. At this time, no other data have been presented to alter this assumption. It is interesting to note that carpets B and C are similar in weight and were generally constructed from the same materials as the variable carpet reported in the 1987 CRI study. The earlier carpet exhibited notable variability and indicated that product aging may have an impact on fire performance. More work is needed in order to understand the fire performance properties of this style of carpeting.

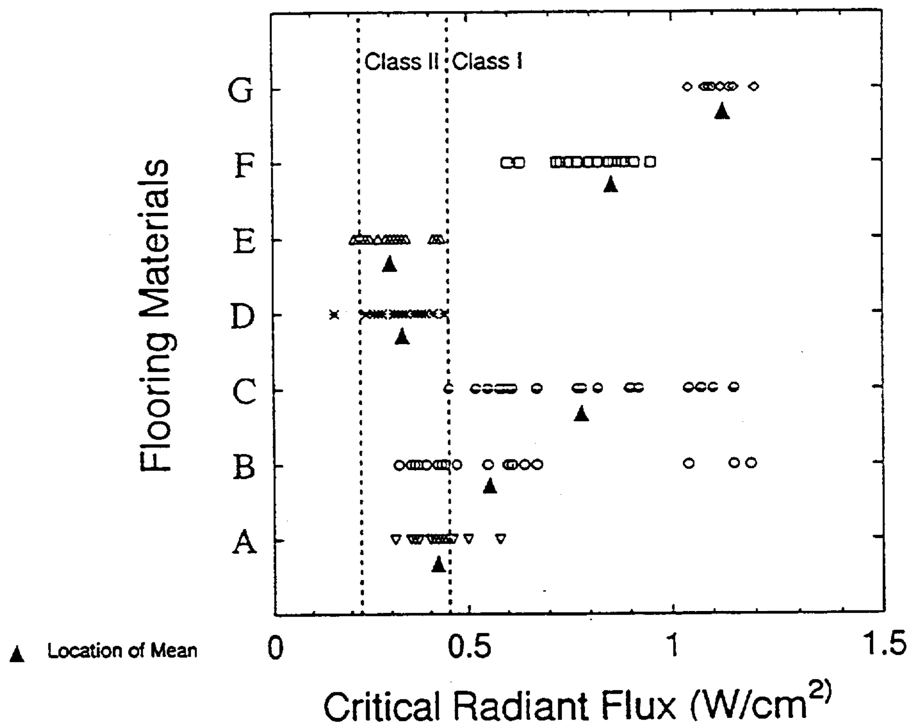

Figure 3. Data from the 1992 Interlaboratory Study [10]

FIRE PERFORMANCE OF MATERIALS

With questions raised concerning the possibility of aging having an impact on product resistance to flame spread, a number of other questions come into focus:

- Do all flooring materials lose their fire resistive properties through aging?
- How does wear influence fire performance of flooring materials?
- Does soil increase or reduce the fire performance of flooring materials?

Currently, all products being used in the market place are fire tested while in its unused state. Generally, fire behavior for these products is unknown in their used state. Since the simple aging of certain flooring products appears to influence fire performance, it would be necessary to study changes in fire performance of flooring materials which result from use to understand their contribution to the fire hazard in buildings.

HAZARD ASSESSMENT AND CRITICAL RADIANT FLUX

Since the introduction of the Flooring Radiant Panel test and use of Class I and Class II flooring materials, there appears to have been an improvement in carpeting materials fire resistance. Currently, this improvement in fire resistance is not quantifiable in relationship to hazard assessment. However with the increased effort to use small-scale tests to predict full-scale fire performance, some have considered using results from the Flooring Radiant Panel Test for hazard assessment. Work done by Briggs, et al [11], indicates that, in its present state, the Flooring Radiant Panel does not yield a correlation suitable for full-scale fire predication or hazard assessment with large fires. Also, hazard assessment as it relates to fire growth requires the measurement of rate of flame spread. As used in North America, the Flooring Radiant Panel Test does not provide data on the rate of flame front propagation which is a critical factor in accessing fire hazard. From the work of Briggs and a review of the original work by Quintiere, it can be seen that the Flooring Radiant Panel does not provide an opportunity for hazard assessment, especially with fires larger than about 500 kW. When information concerning the limits of the Flooring Radiant Panel are evaluated in relation to modern building fires, even if the element of rate can be measured, it is indicated that results may not give useful predictions of hazard assessment where fuel loads exceed 10.7 kg/m^2 (2.2 lbs/ft^2).

Fuel loads found in occupancies where flooring is regulated appear to be much higher than those originally used for preparing the current fire performance standards. It is reported by Robertson and Gross that combustible contents in single occupancy hospital rooms range from 15 to 110 kg/m^2 (3 to 22 lbs/ft^2)[12]. The average load of combustible contents for office spaces was 92 kg/m^2 (18.4 lbs/ft^2) with a range of 35 to 215 kg/m^2 (7 to 43 lbs/ft^2)[12]. The work by Quintiere provides data on fires with fuel loads as high as 14.4 kg/m^2 (2.9 lbs/ft^2) in a 2.4 x 2.6 m (7.9 x 8.6 ft) room with one opening into a 2.4 m (7.9 ft) wide 9.1 m (30 ft) long corridor [13,14]. See figure 4. On this plot, the Class I and Class II certification ranges for flooring have been marked for the readers convenience. It is clear that a 600 kW fire could cause a Class I flooring to propagate flames more than 6 m (20 ft) down a corridor. The rate of flame front travel is unknown in this scenario since the test method does not evaluate rate of fire spread. Putting furniture heat release rates into perspective, it is not uncommon to find a single chair of ordinary construction producing heat release rates in excess of 600 kW [15,16]. Based on the fuel loads in buildings reported by Robertson and Gross, it is expected that much larger fires exceeding 2000 kW for fully furnished rooms can occur [12].

Basic elements found useful in making fire hazard assessments for materials are generally considered to include:

- an ignition parameter which relates time to the thermo-physical and chemical characteristics of a material,
- a parameter for rate of flame spread and
- information on a material's heat of combustion and heat release rate

Presently, no one fire test provides information on each of these parameters. The Flooring Radiant Panel test does not relate its results to time. If time of flame front progress is added to the test procedure, spread rate data could be generated. Data obtained from the measurement of critical radiant flux may assist in predicting ignition of flooring materials. However, both ignition and flame spread rates for flooring materials can now be measured by ASTM test method E 1321[17]. This addresses two of the elements above. The Flooring Radiant Panel can not provide any information on heat release rate in its current design. Heat release rate must be obtained from a calorimeter. The Cone Calorimeter, as specified in ASTM E 1354[18], may be appropriate for obtaining heat release rate.

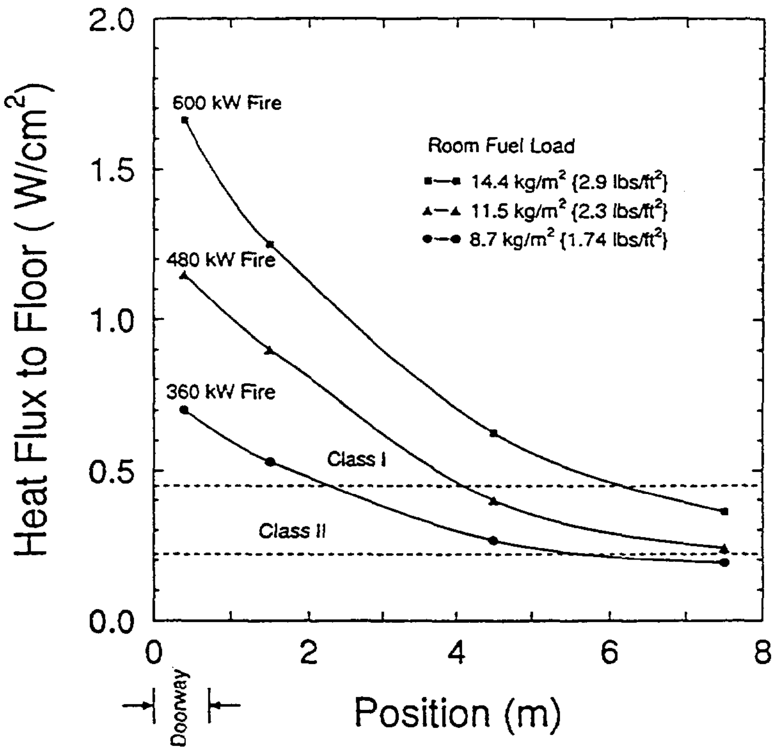

Figure 4. Radiant Flux to Corridor Floors Based on Room Fire Loads [13]

SUMMARY

Experience has shown over the years that use of the Pill Test and Flooring Radiant Panel Test standards have generally reduced losses with fires involving flooring, where the flooring materials are classified. Today, the Flooring Radiant Panel's test precision is considered to be equivalent to other fire test methods, with the exception of that experienced with a particular style of carpeting. At this point in time, no research results have been reported that explain the apparent changes in fire performance or the high variability found with this style of carpeting. Additional studies are required to develop an understanding of fire performance with these carpet products.

Questions regarding the use of the Flooring Radiant Panel in hazard assessment have been addressed. It is pointed out that time must be incorporated into the test method to obtain a rate of flame propagation. In addition, hazard analysis for flooring materials, as with other materials, must include information on properties controlling ignition and heat release rates. Today, other test methods exist which have been designed specifically to provide these input data for hazard analysis. The Flooring Radiant Panel test was not originally designed for making assessments of hazard but was developed to provide a reasonable means for regulating flooring materials. If it is to be used as a tool for hazard assessment, the Flooring Radiant Panel test must be developed further.

ACKNOWLEDGEMENT

I extend appreciation to Dr. Henry Mitler, of the Building and Fire Research Laboratory at NIST, for his input on the requirements for fire modelling and their use in hazard assessment.

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