NISTIR 89-4191

EXAMINATION OF THE VARIABILITY OF THE ASTM E 648 STANDARD WITH RESPECT TO CARPETS

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U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
Center for Fire Research
Gaithersburg, MD 20899

Sponsored by:
The Carpet and Rug Institute
Dalton, GA 30722

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EXECUTIVE SUMMARY

PURPOSE AND SCOPE

The objectives of this research program were to investigate the variability of the ASTM E 648 Standard with respect to carpets and to make recommendations for revising the standard to improve the repeatability and reproducibility of the measured results. The need for such a study arose from NVLAP's concerns about the high coefficients of variation resulting from proficiency rounds carried out as part of the Carpet LAP.

One carpet was studied to investigate the ignitability and flame propagation problem experienced by CRI in the summer of 1987. Several ignition sources and procedural variations were investigated to assure that flame propagation would occur; the most significant finding was that a propane line burner gave a more uniform burn pattern than the propane torch point source pilot burner and seemed to insure propagation away from the ignition area provided the critical radiant flux was less from the maximum flux from the panel.

Eight carpets of varying fibers and constructions were examined using the standard procedure to determine which would result in the lowest coefficient of variation. One was chosen for a parametric study of the test variables. Based on the findings of this study, a "proficiency round" was carried out using this carpet and recommendations were made to ASTM Committee E05 on Fire Standards for revision of ASTM E 648.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions resulted from this study:

- Replacement of the point ignition source by a line burner improves the likelihood of flame propagation and provides more even burn patterns.
- The rate of air flow through the apparatus has a significant effect on test results.
- Contrary to previous experience with NVLAP proficiency rounds, good reproducibility can be achieved by paying closer attention to prescribed procedures.
- Conditioning time up to at least 12 days appears to increase critical radiant flux values.
- Imposing a time limit on the test is not a viable means for determining critical radiant flux of a carpet.

- Use of 100 lb, or smaller, bottles of commercial propane can influence operating conditions during the course of the day if proper attention is not paid to making adjustments in the gas flow rate to maintain the panel operating temperature and flux profile.

- The radiant panel requires 1 1/2 hours to approach equilibrium when propane is used for the fuel; equilibrium was achieved in only 1 hour with natural gas.

Specific recommendations for further work which need to be addressed are as follows:

- Carry out a round robin with a wide selection of carpets, including as many laboratories as are willing to participate.

- All future NVLAP proficiency rounds should be performed using the same adhesive supplied from a single source.

- Determine the effect of specimen location on the carpet to assess variation in the product and determine the effect of carpet aging on critical radiant flux.

Additional consideration should be given to the following in order to further the development of the Flooring Radiant Panel Test.

- Determine whether electric radiant panels could be substituted for the gas-fired panels.

- Determine whether perforated ceramic tile panels are equivalent to the porous refractory panels currently specified in the standard.

- Determine the practicability of installing automatic gas controls and feedback systems for operating gas-fired panels to maintain desired operating conditions.

- Determine the optimal requirements for bulk storage of propane and provide guidance in the test method for maintaining desired panel operating temperature and flux profile.

- Determine the need for tighter specifications for the free air space between the specimen holder and the chamber walls.

- Determine the importance of specifying the weight (and type) of adhesive used to bond carpets to substrates; lot-to-lot variation in adhesive should be examined. Study the effect of conditioning time for different adhesives using a wider selection of carpets.

- Determine the feasibility and accuracy of reducing the test time for finding the critical radiant flux by moving the line burner forward.

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EXAMINATION OF THE VARIABILITY OF THE ASTM E 648 STANDARD WITH RESPECT TO CARPETS

Sanford Davis, J. Randall Lawson, and William J. Parker

ABSTRACT

The objectives of this research program were to investigate the variability of the ASTM E 648 Standard with respect to carpets and to make recommendations for revising the standard to improve the repeatability and reproducibility of the measured results. Several ignition sources and procedural variations were studied to assure that flame propagation away from the point of ignition would occur if the critical radiant flux of the carpet was less than the maximum flux from the panel. This resulted in the replacement of the propane torch point source pilot burner by a propane line burner. A coefficient of variation study was carried out to select one carpet for a parametric study of the test variables. As a result of the parametric study and a subsequent "proficiency round", recommendations were made to ASTM Committee E05 on Fire Standards for revision of ASTM E 648. The most significant changes were the use of the line burner for ignition and a tighter control of the air flow through the chamber.

Keywords: ASTM E 648 Flooring Radiant Panel Test; carpets; critical radiant flux; flammability; floor coverings; National Voluntary Laboratory Accreditation Program; parametric study; proficiency rounds.

1. INTRODUCTION/BACKGROUND

1.1 HISTORY - ORIGIN OF ASTM E 648

The need for regulation of flooring systems used in health care facilities (and in other regulated occupancies) had been anticipated and acted on by the U.S. Public Health Service as early as 1965 when a directive was issued regulating the use of carpets in hospitals receiving financial aid under the

Hill-Burton Act [1].[1] The directive established a tentative flame spread limit of 75 by the ASTM E 84 Tunnel Test [2] for carpeting and other floor covering materials used in patient occupied areas. The tentative qualification is supported by a 1967 critique of E 84 [3] in which it was concluded "... Use of the test method for this purpose can be justified only on the basis that a suitable fire test for floor covering does not exist."

In order to understand the testing and measurement of the behavior of flooring systems in a fire situation, it is necessary to consider fire in three distinct stages. Stage 1 is the ignition and initial growth. For example, this could be the first sign of a flame in a wastebasket or on an upholstered chair. A fire will be considered as being in Stage 1 while the fire remains in the area of ignition. Stage 2 is the growth to full involvement - or flashover - of the room or space of origin. The fire has progressed through Stage 2 when everything in the room is burning. Stage 3 is after the time of flashover when the fire spreads beyond the room of origin and spills over into the corridor and fire begins to spread along the passageway.

Since April 1971, Federal regulations have required that all carpet manufactured and sold in the United States pass the Pill Test (FF 1-70) [4]. The test screens out carpet easily ignited by a small incendiary source; it measures the response of carpet exposed to a timed burning tablet in the absence of an imposed external radiant field. Subsequent room tests conducted at the National Bureau of Standards showed [5] that carpet that passed the Pill Test also will not spread flame during a Stage 1 fire.

The National Bureau of Standards conducted an evaluation of fire incidents in which flame spread was reported to have occurred in, or to have involved, carpet. Several multiple fatality fires occurred in the early 1970's in which carpet installed in corridors was concluded to be responsible for the spread of the fire. In these cases, such as the Harmer House fire in Marietta, Ohio, with 21 fatalities, and the Baptist Towers for the Elderly fire in Atlanta, Georgia, with nine fatalities, the carpets passed the Pill Test. Analysis of the corridor fire incidents revealed that carpet that passed the Pill Test would not propagate during a Stage 1 exposure, but when installed in a corridor, flame propagation would occur over the carpet when exposed to a fully developed room fire (Stage 3).

The following questions then needed to be addressed: What level of flame spread resistance is necessary to prevent the floor covering from contributing to the spread of a Stage 3 fire to other parts of the building? To answer this question, studies were conducted at the National Bureau of Standards [6,7], as well as at other organizations [8,9], to develop the understanding of the mechanisms by which fire spreads along carpeted corridors under the influence of a Stage 3 fire. In these studies, fire from a room which has passed flashover extended into a corridor through an open door. The test program led to the following three conclusions:

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[1] Numbers in brackets refer to the literature references in Section 7.

1) The amount of energy radiated onto the flooring system is a significant determinant as to whether or not a carpet system will propagate flame.

2) To radiate sufficient energy onto the floor to propagate flame, the fire source (in the room) must be large enough to heat the smoke layer and ceiling in the corridor to a critical level.

3) Flammable materials mounted on the walls or ceiling have greater effect on flame spread that similar materials installed on the floor.

In 1969, the Department of Health and Human Services (formerly the Department of Health, Education, and Welfare) undertook the development of a suitable test by sponsoring work at Underwriters Laboratories, which culminated in the development of the UL 992 Chamber Test [10]. While this test generates an index, it was shown that the test environment relates to the potential hazard of fire growth in a full-scale corridor. Full-scale corridor fire experiments at the National Bureau of Standards [6,7] and research with the NBS Model Corridor [11], essentially an extension of the UL work, led to the concept of critical radiant flux, the basis for ranking floor covering systems in the Flooring Radiant Panel Test [12,13].

Since neither the Tunnel Test [2] nor the Chamber Test [10] were considered to be adequate for evaluating flooring materials, a new test was proposed. During the period from 1966 to 1974, a radiant panel test for floor coverings had been under study at the Research and Development Laboratories of Armstrong World Industries (formerly Armstrong Cork Company). The test concept was developed further at the National Bureau of Standards and resulted in the Flooring Radiant Panel Test [14]. This test was designed to simulate a likely set of conditions which might lead to fire spread in a carpet system. The Flooring Radiant Panel Test concept evolved from information obtained from the full-scale corridor fire test program at the National Bureau of Standards. This test method determines a critical radiant flux, incident on the flooring, measured in watts per square centimeter. The critical radiant flux is the lowest level of radiant energy necessary for a fire to continue to burn and spread.

The Flooring Radiant Panel Test is different from other fire test methods for flooring systems in that it measures an actual property of the carpet system and is not based on an arbitrary scale. The test yields data correlated to the relative performance of materials in actual installations. In this test, the floor covering system is installed on the "floor" of the test chamber similar to a "real world" situation. The test can accommodate floor system assemblies, such as carpet with a separate underlayment. The basic elements of the test procedure and the test hardware, as they are currently used, are described in ASTM E 648 [15]. The horizontally mounted 1000 mm long floor covering test specimen receives energy from an air-gas fuel radiant panel mounted above the specimen and inclined at an angle of 30° to the horizontal. A pilot burner provides a source of open flame ignition of the specimen. The gas panel generates a flux profile along the length of the specimen ranging from a maximum of 1.1 W/cm^2 at the 100 mm location to 0.1 W/cm^2 at the 900 mm location. As the first step in carrying out the test, the floor covering system specimen is carefully mounted in the holding frame. With the chamber at equilibrium conditions, the specimen is moved into the test position and the chamber is closed. Following a two-minute preheat of the specimen by the radiant panel, the pilot burner is applied. The test continues until the specimen flaming goes out. The maximum distance burned is converted to the corresponding radiant flux level from the calibrated flux profile graph and the result is reported as critical radiant flux.

1.2 RECENT PROBLEM

1.2.1 NVLAP Concerns

The National Institute of Standards and Technology (NIST) administers the National Voluntary Laboratory Accreditation Program (NVLAP), which was created by the Department of Commerce in 1976 [16]. NVLAP provides an unbiased third party evaluation and recognition of performance, as well as expert technical assistance to upgrade laboratory performance for conducting specific tests or types of tests in specified fields of testing. In addition to requests from the private sector for establishing a Laboratory Accreditation Program (LAP), any federal, state, or local governmental agency responsible for regulatory or public service programs established under statute or code, which has determined a need to accredit testing laboratories within the context of its programs, may request the Director of NIST to establish a LAP. In 1979, the Department of Housing and Urban Development (HUD) requested the establishment of a LAP for carpets; included in this LAP is ASTM E 648, the Flooring Radiant Panel Test. This method was one of several chosen by NVLAP for proficiency testing, which provides a means of checking laboratory testing performance by means of interlaboratory tests.

Proficiency testing (a limited interlaboratory program in which each laboratory in the LAP performs a test on the same material) is an integral part of the NVLAP accreditation process. Demonstration of appropriate facilities, equipment, personnel, etc. is essential, but may not be sufficient for the evaluation of laboratory competence. The production of test data using special test samples in each proficiency round provides NVLAP with a way to determine the overall competence of the laboratory. Proficiency rounds are performed periodically to identify problems in a laboratory, or with a test method, which NVLAP, working with the laboratory staff, attempts to solve.

During the early years of the carpet LAP, the proficiency rounds carried out by NVLAP were inconclusive because of the materials chosen for each round and the way the data were reported. Data from NVLAP for Rounds 6 through 10 were more definitive; however, coefficients of variation (COV) as determined by the ASTM E 691 standard practice for conducting interlaboratory studies [17] varied from 21.6 to 40.2 percent. Revising these results to account for laboratories reporting outliers, and eliminating the outliers, provided the following results:

Proficiency Round	No. of Participating Laboratories	Coefficient of Variation, %
6	11	22.6
7	12	33.1
8	11	18.0
9	13	35.5
10	11	30.3

Round 11 also was inconclusive with five of the 12 participating laboratories reporting results where the flames did not propagate beyond the initial ignition point. This round was repeated using the same carpet, only all of the specimens were prepared using an adhesive supplied by NVLAP; again, the results were inconclusive, only this time, nine of the 11 participating laboratories reported that at least one of the three specimens (and in eight cases, all of the specimens) did not propagate flames beyond the ignition point.

In Round 12, all of the specimens were prepared in one laboratory by the same technician using the same adhesive for all and were distributed to the other laboratories. The data from eight (of 11) laboratories experiencing no ignition problems resulted in a COV of 23.7 percent.

A special proficiency round was carried out using the standard reference material developed by NIST. In this case, for 10 laboratories (the 11th was an outlier), the COV was only 6.4 percent, although the average was about 14 percent lower than the certified value.

The large range in the laboratory test results created difficulties in determining the competence of laboratories through the use of proficiency testing. At this point in time, early 1987, a decision was made by NVLAP to discontinue proficiency testing for ASTM E 648, although the method was permitted to stay in the accreditation program. This prompted the Carpet and Rug Institute (CRI) to embark upon a program with several selected laboratories to attempt to resolve the problem (see Section 1.2.2). As will be described below, this program was unsuccessful, resulting in a notification to CRI late in 1987 that NVLAP intended to announce in the Federal Register the intent to eliminate ASTM E 648 from the Carpet Laboratory Accreditation Program. As a consequence, CRI, together with the American Textile Manufacturers Institute and the American Fiber Manufacturers Association, contracted with the Center for Fire Research to make an in-depth study of the test method and to make recommendations for revisions to ASTM E 648.

1.2.2 CRI Program - Ignitability Problem

In the summer of 1987, CRI initiated a program with five laboratories experienced in the use of ASTM E 648 to attempt to resolve the problems with ignition and variability in test results. A 32 oz cut pile nylon 6,6 staple fiber carpet having an expected critical radiant flux (CRF) of about 0.5 W/cm^2 (about 40 cm burn distance) was selected by CRI, specimens were cut to the required size and randomized, and 40 specimens were sent to each of the five laboratories participating in this program. The intent was that each laboratory would test four specimens per week for a period of 10 weeks. However, the program was aborted after the second week because it was apparent that there still was a wide variation in test behavior. Eighteen of the 40 specimens tested up to that time did not propagate flames beyond the immediate region of the point of application of the igniter flame, while four specimens did burn beyond the point of ignition up to the 20 cm point. The 18 remaining specimens gave results ranging in CRF from 0.46 to 0.89 W/cm^2 (average CRF of 0.692 ± 0.165 W/cm^2 with a coefficient of variation of 23.8 percent).

It was at this time that the three organizations mentioned above agreed to sponsor the program at NIST in order to study the problems with carpet flammability using ASTM E 648 and to make recommendations for appropriate revision to the standard for consideration by ASTM Committee E05 on Fire Standards.

1.3 APPROACH

For the purposes of this study, the ASTM E 648-88 Standard Test Method for Critical Radiant Flux of Floor-Covering Systems Using a Radiant Heat Energy Source [15] was chosen as the starting point. The basic elements of the test chamber are: an air-gas fueled radiant energy panel inclined at approximately 30° to and directed at a horizontally mounted floor covering system specimen. The radiant panel generates a radiant energy flux distribution ranging along the 100 cm length of the test specimen from a nominal maximum of 1.0 W/cm^2 at the 10 cm point to a minimum of 0.1 W/cm^2 at the 90 cm point. The test is initiated by open flame ignition from a pilot burner. The distance burned to flame-out is converted to watts per square centimeter from the calibration flux profile curve and reported as critical radiant flux, W/cm^2.

The research program was divided into five phases.

- Study of the ignitability problem
- Selection of a carpet having a low coefficient of variation using the ASTM E 648 test
- Parametric study of the test variables
- "Proficiency Round"
- Revision of the ASTM E 648 standard for submission to ASTM

An attempt would be made to resolve the problem with erratic ignitability and flame propagation using the same nylon carpet which was used in the CRI program carried out in the summer of 1987. Consideration was given to replacing the propane torch igniter burner, increasing the imposed radiant flux on the specimen, and imposing a longer preheat time. In addition, visits were made to several testing laboratories, to assess their procedures for sample preparation and conditioning and for carrying out the test.

For the coefficient of variation study, a number of carpets selected by the sponsors would be evaluated by the standard procedure to determine which would

would result in the lowest coefficient of variation based on the testing of six specimens. One carpet then would be selected for further testing in the parametric study of test variables.

The objective of the parametric study was to evaluate the effect on test results, using one carpet, of a number of test specimen preparation variables and test procedure variables. For the specimen, the variables considered were the mounting board (simulated concrete substrate as specified in the standard), the adhesive used in gluing the carpet specimen to the mounting board, and conditioning of the mounted specimen. For the test procedure, the variables to be considered were the radiant flux profile, specimen preheat time, the type of gas used for the radiant panel, the backing board for the system assembly, the orientation of the specimen in the sample holder (machine direction vs. 180° to the machine direction), air flow at the specimen surface, air flow through the chamber exhaust stack, and chamber operating temperature.

Based on the results of the parametric study, appropriate changes would be made in the ASTM E 648 standard reflecting the information obtained from this study. A "proficiency round" would be carried out with a number of laboratories to evaluate the changes in the standard and finalize the document before submitting it to ASTM Committee E05 on Fire Standards for processing through the consensus standards process. It was not the intent of this current research to conduct a full interlaboratory program with the proposed changes; however, this option remains open for future consideration.

2. EXPERIMENTAL PROCEDURES

2.1 MATERIALS

The carpet used in the CRI program carried out in the summer of 1987 was identified as a 32 oz cut pile nylon 6,6 staple fiber carpet. Cut specimens from this carpet were made available to CFR for the ignitability study.

Eight different carpets were chosen by the sponsors to carry out the coefficient of variation study. The information supplied to CFR concerning the identification of these carpets is summarized in Table 1. Sufficient cut specimens were supplied to CFR by CRI and ATMI to perform these tests.

Based on the results of the coefficient of variation study presented in Section 3.2 and subsequent discussions with the sponsors, Carpet C was chosen for the parametric study. This carpet was described as a 50 oz nylon 6,6 cut pile carpet made with a staple yarn. The same carpet was used in the "proficiency round" carried out to evaluate the proposed changes in the test method.

2.2 METHODS OF INVESTIGATION

2.2.1 Ignitability Study

Unburned specimens of the carpet described in the CRI program (Section 1.2.2) were obtained from several of the participating laboratories for our investigation. During this phase of the study, and all subsequent phases, all of the test specimens evaluated by CFR were prepared by the same technician. Each carpet specimen was bonded to 1/4 in thick Sterling[2] board (high density inorganic fiber reinforced cement board) using about 1 3/4 oz (50 g) of Supra STIX 90 Adhesive[2], both supplied by the sponsors; the adhesive was applied with a 1/16 in square-notched trowel following a typical field application procedure. (It was later learned that most field applications are made using a 1/8 in V-notched trowel.) In order to distribute the adhesive uniformly, a 20 lb (9.1 kg) steel roller was rolled along the specimen two or three times. The bonded specimens then were placed vertical racks to ensure good air circulation in a conditioning room at 23 ± 3 °C and 50 ± 5 percent relative humidity for at least 48 h prior to testing and, in most cases, at least two weeks, unless noted otherwise. Field experience has shown that it is sometimes necessary to "dead stack" the specimens to prevent separation of the carpet and the substrate before the adhesive sets. The foregoing sample preparation procedure was proposed for inclusion in the standard as a guide to good practice (see Section 5).

Four other commercially available adhesives were evaluated during this phase of the study. In addition, several pilot ignition sources other than the one specified in the standard were examined. Two specimens were tested using an imposed external irradiation about 17 percent lower (measured at the 10 cm point) than specified in the standard to determine whether this carpet would still ignite and propagate flames away from the ignition source for reduced incident fluxes.

During the course of this phase of the program, visits were made to three of the independent testing laboratories to assess the variations in their procedures which could be responsible for the variability in test results.

2.2.2 Coefficient of Variation Study

Cut specimens of the eight carpets described in Table 1 were bonded to the reinforced cement board substrate using two different adhesives and stored in a conditioning room. Six specimens of each, bonded with Nu Broadlok II Adhesive[2] were used to determine the coefficient of variation; specimens were tested according to the standard procedure. In addition, other specimens

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[2] Certain commercial products are identified in this report in order to adequately specify the materials used. Such identification does not imply recommendation by the National Institute of Standards and Technology, nor does it imply that these materials identified are the best available for the purpose.

bonded with Supra STIX 90 Adhesive were tested with the following variations: imposed external irradiation 36 percent higher than the standard, with a five minute preheat as compared to the standard two minutes, and the use of two different cement board substrates. Based on this study, one carpet was chosen for the parametric study of test variables.

2.2.3 Parametric Study

Sufficient information had been obtained from the ignitability and coefficient of variation phases of the program to establish a baseline set of test conditions from which to deviate in order to study what we felt were the critical test variables. The baseline conditions were as follows:

- Carpet C (50 oz cut pile nylon 6,6 made with a staple yarn);
- Sterling board for mounting;
- Supra STIX 90 Adhesive;
- Minimum 48 h curing and conditioning;
- Millboard backing board;
- Standard flux range (1.1 W/cm^2 at 10 cm; 0.1 W/cm^2 at 90 cm);
- Two minute preheat;
- Propane line burner (see Figure 1); and
- Five minute pilot application.

A number of variables were identified for examination in the parametric study of the ASTM E 648 test procedure. These included:

- Fiber reinforced cement board substrate for mounting the specimen (previously considered during the coefficient of variation phase);
- Choice of adhesive for bonding the carpet specimen to the substrate;
- Choice of inorganic backing board for mounting the bonded specimen in the sample holder;
- Type of gas used for the radiant panel (the standard permits the use of either natural gas or propane);
- Radiant flux profile;
- Preheat time of the specimen prior to applying the pilot ignition source;
- Air flow across the specimen surface during the test;
- Air flow through the chamber exhaust stack; and
- Specimen orientation.

Each of these factors was considered separately. Those which appeared to have little or no effect on test behavior were passed over quickly, while those which did show a significant effect, were studied in greater depth. It should be pointed out that the effects observed were obtained with only one carpet product and that other carpets may respond in a different manner. A future planned interlaboratory program using a variety of carpets could uncover some unforeseen behavior.

2.2.4 "Proficiency Round"

The results of the parametric study became the basis for a preliminary revision of the ASTM E 648 standard. Using the same C carpet used in the parametric study, 10 laboratories participated in an unofficial "proficiency round". Each of these laboratories agreed to install a line burner, which was provided by CFR, in their apparatus and to follow a set of guidelines for sample preparation and conditioning. Each laboratory was visited by Mr. Lawson, during which time he observed their start-up, calibration, and testing procedures; three specimens were tested during these one-day visits.

Based on the results of this phase of the program, and after consultation with the ASTM task group having responsibility for E 648, a final revision of the standard was submitted to ASTM Committee E05 on Fire Standards for promulgation.

3. RESULTS

3.1 IGNITABILITY STUDY

A mapping diagram of the carpet specimens which were supplied to the five laboratories in the CRI program was provided to us for use in attempting to resolve the problem of ignitability and flame propagation. (The numbers around the periphery of the table refer to the specimen numbers.) The individual data points obtained by these laboratories during the summer of 1987 are shown for each carpet specimen at the left side of the bold lines (low specimen numbers) in Table 2; the remainder of the values on the right side of the table were obtained by CFR and several of the other laboratories when tested in the spring of 1988. It should be noted that only two specimens (No. 86 tested by CFR and No. 160 tested by one of the laboratories, both using the standard procedure) failed to propagate beyond the 20 cm point, while the remainder burned at least 30 cm. Of the 19 specimens tested by CFR using the standard conditions, only specimen No. 86 did not propagate beyond the immediate region of the pilot flame application; the other 18 specimens averaged 0.43 W/cm^2 with a coefficient of variation (COV) of 18.6 percent.

Duplicate specimens prepared by CFR with Touchdown 780 Adhesive[2] gave an average of 0.45 W/cm^2; with Touchdown 760 Adhesive[2], 0.39 W/cm^2; and with Taylor 295 Adhesive[2], 0.39 W/cm^2. Five specimens (a sixth was an outlier) prepared with Nu Broadlok II Adhesive[2] gave an average of 0.41 W/cm^2 with a COV of 14.0 percent.

Nine other specimens prepared by CFR with Supra STIX 90 Adhesive were tested using some minor variations in the test procedure, primarily the ignition source (line burner vs diffusion flame vs methenamine pills). Included also were lower flux profile (17 percent lower at the 10 cm point) and a five minute preheat. These specimens gave an average of 0.42 W/cm^2 with a COV of 14.0 percent.

3.2 COEFFICIENT OF VARIATION STUDY

The results obtained for the coefficient of variation (COV) study are summarized in Table 3. Carpets A and E did not propagate flames and, therefore, were excluded from further consideration as a choice for the parametric study. This does not mean, however, that these carpets have in inherent ignitability problem. They have a well-defined critical radiant flux above the maximum incident flux used in the standard test. These values are listed in Table 4. Carpet F had the lowest COV (7.1 percent); however, the time to flameout was very short and it was thought that this product would not be discriminating enough to show the effect of procedural variables. Carpet B had the next lowest COV (10.4 percent); however, this carpet exhibited poor stability during the test (shrinkage, splitting, etc.) and was considered to be a poor choice for the parametric study. Hence, Carpet C became the product of choice (COV = 11.8 percent); the average burn time in this case was about 70 minutes.

During this phase of the project, additional data were obtained for each of the carpets, using the variables noted in Section 2.2.2. Although these results did not relate to the COV study, they are summarized in Table 4, primarily for information.

3.3 PARAMETRIC STUDY

The results obtained for the parametric study are summarized in Table 5. The average critical radiant flux (CRF) for the six specimens tested using the baseline conditions (see Section 2.2.3) was 0.44 W/cm^2, with a coefficient of variation of 10.0 percent.

Two other adhesives (Taylor 295 and Nu Broadlok II) used for bonding the specimen to the substrate resulted in CRF values of 0.45 and 0.41 W/cm^2, respectively. A specimen of a calcium silicate board was used to replace the millboard currently specified in the standard; the CRF in this case was 0.45 W/cm^2.

Several auxiliary tests were carried out with thermocouples imbedded in the surface of the carpet at various distances from the ignition source. This work led to the conclusion that the likelihood of flame propagation beyond the point of ignition would be enhanced by increasing the preheat time from two minutes to five minutes. The result in this case was minimal; the CRF was 0.48 W/cm^2. Subsequently, it was proposed to include this change in the standard (see Section 5). A modest enhancement of the flux profile (10 percent measured at the 10 cm point) also was evaluated; the resulting CRF was

0.46 W/cm^2. Reversing the specimen orientation in the chamber (180° from the machine direction) also showed minimal effect for this carpet.

During the course of the visits to the testing laboratories, it was observed that one of the laboratories had a very high air flow through the chamber stack, resulting in high air flow across the surface of the specimen. It was observed during the tests that some of the small flamelets had a tendency to extinguish, while the overall effect was to increase the total burn length on the specimen. Three specimens were tested under conditions of high air flow and low air flow through the chamber stack and across the surface of the specimen; a summary of the results, compared to normal air flow, is in given in Table 6. Low air flow results in an increase in CRF to 0.51 W/cm^2, while high air flow reduces the average CRF to 0.36 W/cm^2.

3.3.1 Gas Study

The ASTM E 648 standard permits the use of either natural gas or propane for the radiant panel. The various testing laboratories use one or the other, depending on the specific apparatus design (CFR uses natural gas); however, the apparatus design does not permit easy replacement of one by the other. The effect on chamber and test conditions comparing natural gas to commercial grade propane and to chemically pure (CP) propane was examined.

In order to make these comparisons, another flooring radiant panel apparatus was used to evaluate test conditions with the bottled gases. The CFR test apparatus was used to obtain similar data using natural gas. The bottled gas tests were run at the Consumer Product Safety Commission (CPSC) Engineering Laboratory located in Gaithersburg, MD. Two full 100 lb bottles of propane were obtained, one containing commercial grade propane and the other containing CP propane. Based on discussions with personnel at several testing laboratories using bottled propane, it was decided to run the tests with the gas bottles chilled in an ice bath. This was done to simulate cold weather conditions which appeared to have caused difficulties at some laboratories.

The purpose of this work was to determine how apparatus operating conditions would change as the bottled propane was consumed and to compare these results with natural gas supplied from a commercial pipeline. Two areas of interest were monitored during each of the tests, (1) pyrometer output which provides an indication of change in radiant panel blackbody temperature and (2) air temperature in the test chamber which provides information on the stability of the test environment.

Before the tests were conducted, the apparatus was calibrated to determine the normal operation settings for gas and air flow rates to the radiant panel and normal chamber conditions. Each test was planned to take a full six hours. A general overview of the test procedure follows: a 100 lb bottle of commercial or CP propane was placed in a 40 gal steel trash container which was filled with water and ice. The ice bath, which was located outside of the laboratory building, was left overnight with outdoor temperatures approaching the freezing mark. The tests were run the following morning. Tests were conducted by adjusting the air and gas flow rates to the radiant panel to a fixed flow rate after igniting the panel and these flow rates were maintained throughout the six hour test period. The pyrometer output and chamber temperature were recorded throughout the period. Also, a log was kept on gas pressure in the 100 lb bottle throughout the test. Ice was added to the ice bath, as needed, to maintain bottle temperature and the gas flow valve was adjusted, as needed, to maintain the desired flow rate as the bottle pressure dropped during the day. Tests were conducted in the following order:

1. Full bottle of commercial propane
2. Second day test with above propane bottle
3. Full bottle of CP propane
4. NIST test with natural gas

Figures 2 through 6 show results from these tests conducted at CPSC using bottled propane and NIST using room temperature natural gas. Figures 2 and 3 show pyrometer output values obtained during the study. Note in Figure 2 that there appears to be some difficulty with stabilizing blackbody temperature between the 30 min and one hour time periods. This is due in some degree to the fact that the control valve and piping was being heated by conduction from the radiant panel. From this plot, it is clear that the radiant panel did not stabilize until about two hours after it was lit. Also, note that the apparent heating value, based on identical gas flow settings, for CP propane is slightly higher than for commercial propane. This higher heating value is expected with CP propane. Compare the results from Figure 2 with Figure 3. The scales are different because the pyrometers have different calibration constants. Note that the room temperature natural gas gives a more predictable blackbody temperature from the radiant panel. Figure 4 shows a comparison of chamber temperatures between the three bottled propane tests. Again, it should be noted that the chamber did not appear to stabilize until about two hours. Figure 5 shows temperature data obtained from the chamber and stack of the NIST apparatus. Again, the natural gas apparatus appears to be more stable than that using the bottled gases. Figure 6 shows plots of propane tank pressures from tests 1 and 2. Note the steady fall off of pressure throughout each of the two days with a significant pressure drop over the first two hour period on the first day. This pressure drop may explain some of the difficulties in controlling the apparatus experienced by laboratories that are using only a 100 lb or smaller gas bottle for operating the radiant panel.

3.4 <u>"PROFICIENCY ROUND"</u>

Three randomly selected specimens of the C carpet were provided to each of the 10 laboratories participating in the "proficiency round". Each laboratory agreed to follow the details of the test procedure as provided in the revised version of the standard being proposed at that time. The specimens were bonded to the substrates in each laboratory and conditioned for a minimum of two days prior to testing. On the day of the testing a review was made of the sample preparation procedure. Observations were also made of the laboratory procedure from early morning start-up, through calibration checks, to final testing of the carpet specimens.

The results of this "proficiency round" are given in Table 7. The overall average critical radiant flux was 0.50 W/cm^2 with a coefficient of variation of 11.5 percent.

Table 8 summarizes the procedural variations noted during the interlaboratory investigation. It is apparent from this summary that most of the laboratories deviated in one way or another from the directions provided for carrying out this experiment. One laboratory used Flexboard II[2] as the substrate rather than Sterling board. Only four laboratories used a roller which came close in weight to the one specified for smoothing the carpet on the substrate after applying the adhesive. Seven of the 10 laboratories stacked the bonded specimens under a dead load for periods up to 72 hours before conditioning the specimens, contrary to instructions. (The option for dead loading specimens for up to 24 hours prior to conditioning has since been included in the proposed revision to the standard.)

4. DISCUSSION

During the CRI study in the summer of 1987, about one-half of the specimens tested before the program was terminated failed to propagate beyond the point of pilot flame application. When retained specimens of this same carpet were tested by CFR and the other laboratories the following spring, there did not seem to be any problem with flame propagation. The initial specimens tested in CFR were taken from the other end of the carpet (high specimen numbers). At first, it was thought that the carpet was variable from one location to another; however, based on the results obtained for those specimens near the low-numbered end (e.g., 52, 55, 57, etc.), it appears that there may be an aging problem with the carpet. This subject should be investigated further.

During the course of the ignitability study, a number of different ignition sources were examined. Although there did not appear to be any problems with ignitability and flame propagation away from the point of pilot flame application, it was concluded that a line burner covering the width of the specimen provided more reproducible ignition and more uniform burn patterns. The line burner was not used in the coefficient of variation study because we wanted to test under standard conditions, but was chosen as one of the baseline conditions for the parametric study and was subsequently used by all of the laboratories during the "proficiency round". Replacement of the point source propane torch by the line burner was recommended for inclusion in the standard (see Section 5).

Of the six carpets that gave measurable results in the coefficient of variation study, the coefficients of variation ranged from 7.1 to 15.9

percent. As stated earlier in Section 3.2, Carpet C (COV = 11.8 percent) was chosen for the parametric study.

Most of the variables examined in the parametric study had little effect. From the work during the ignitability phase of the program, it was concluded that the choice of adhesive had no effect on whether flames would propagate. A more in-depth investigation during this phase demonstrated also that the adhesive choice had little effect on the critical radiant flux (CRF) values. Both the Taylor 295 and the Nu Broadlok II gave results well within the expected range of variability of the test method. (However, it has been reported by one laboratory that adhesive appearance and consistency varies from lot to lot.) Similar conclusions can be drawn from the variants of using a calcium silicate backing board, using a five minute preheat prior to pilot flame application, using a 10 percent higher flux profile, or reversing the specimen orientation. The most significant effect was brought about by varying the air flow across the specimen surface and through the chamber. Increasing the air flow lowered the CRF about 18 percent, while decreasing the air flow increased the CRF about 16 percent. Consequently, tighter control of air flow through the chamber was written into the revised standard (see Section 5).

The gas study showed that room temperature natural gas supplied from a commercial pipeline has benefits for controlling the chamber environment. This type of control also may be experienced with bulk propane storage which exceeds the 100 lb bottle size, but this has not been investigated. Further study should be conducted to determine the optimal propane bulk storage requirements needed to reduce control problems related to pressure loss in the system. Of course, pressure regulators on the piping system will have an impact on chamber operations, but the changes in tank pressure may affect the way that propane is vaporizing and result in changes in gas quality. This idea has not been studied in this project and should be examined carefully in future work related to fire testing.

As a result of the gas study, it was concluded that a longer heat-up time was required prior to calibration, particularly when bottled propane is used for the radiant panel. This factor was included in the proposed revisions to the standard (see Section 5).

During the course of this project, we were asked by the independent testing laboratories to consider imposing a time limit on the test rather than wait for complete flameout. Some carpets burn out quickly, while others may take as long as two hours. Their motivation was to limit the test time so that better control of costs and scheduling could be maintained. Analysis was made of the available data for tests which burned for more than an arbitrarily chosen 60 minutes. Table 9 summarizes the results of this analysis. Based on seven test series, the average increase in radiant flux was 14.2 percent, ranging from 4.6 to 31.3 percent. For purposes of product development, any test can be terminated prior to flameout if it is determined that the critical radiant flux is lower than the desired value. However, for qualification and regulatory purposes, specimens should be permitted to self- extinguish.

The "proficiency round" demonstrated that, at least with one carpet, the testing laboratories have the capability of performing an interlaboratory program resulting in a low coefficient of variation (11.5 percent). It appears that the deviations from the specified procedure had little overall effect on the performance in this round. Two major changes were made in the standard: (1) the allowable range for air flow through the chamber was defined and (2) a line burner was used in place of the propane torch point source for igniting the specimen.

Examination of the data from the "proficiency round" (Table 8) shows that there is a definite trend in critical radiant flux values, at least for this carpet and adhesive combination, as the conditioning time is increased. It appears that the bond strength between the specimen and the substrate increases with time up to about 12 days; one laboratory conditioned their specimens for 26 days with no further increase in critical radiant flux. These results are shown graphically in Figure 7.

The ASTM E 648 standard requires that (a minimum of) three specimens per sample be tested. It has been proposed that if the coefficient of variation of these three specimens is more than 20 percent, then three additional specimens shall be tested and the average of all six specimens shall be reported. Provision should be made to account for the outlier which is definitely not representative of the actual critical radiant flux for that carpet.

In addition to the proposed changes in the standard which have been discussed above in Section 4, a number of other changes are being proposed, based on our experiences in this program, which should have little impact on critical radiant flux but are included in an attempt to reduce variability in test results. These changes are based only on work performed with a limited number of carpets. It should be pointed out that only one product was used in the "proficiency round". Once the NVLAP program is resumed for carpets, experience will determine whether these changes are effective. No work was done with flooring systems other than carpets, such as resilient floor coverings, vinyl tiles, and hardwood floors. Experience, again, will determine whether the changes are applicable to other types of floor coverings and flooring systems.

5. SUMMARY AND CONCLUSIONS

This research has demonstrated that conduct of the Flooring Radiant Panel Test has resulted in somewhat less than pristine performance by the in-house and independent laboratories. Experience has shown poor agreement in test results among the laboratories participating in the NVLAP program. On the other hand, it has been shown that modifications to the standard and close attention to control of laboratory environment, sample preparation and conditioning, and operating procedures can result in marked improvement in reproducibility of test results. Based on this research, the following conclusions can be made:

1. Replacement of the point ignition source by a line burner improves the likelihood of flame propagation and provides more even burn patterns.

2. The rate of air flow through the apparatus has a significant effect on the test results.

3. Contrary to previous experience with NVLAP proficiency rounds, good reproducibility can be achieved by paying closer attention to prescribed procedures.

4. Conditioning time up to at least 12 days appears to increase critical radiant flux values.

5. Imposing a time limit on the test is not a viable means for determining critical radiant flux of a carpet.

6. Use of 100 lb, or smaller, bottles of commercial propane can influence operating conditions of the apparatus during the course of the day if proper attention is not paid to making adjustments in the gas flow rate to maintain the panel operating temperature and flux profile.

7. The radiant panel required 1 1/2 hours to approach equilibrium on one apparatus using propane for the fuel; equilibrium was achieved in only 1 hour, on another apparatus using natural gas. Therefore, a minimum of 1 1/2 hours should be required for warming up the panel.

The proposed changes in the ASTM E 648 standard are as follows:

- Apply a 20 lb roller across the top of the specimen after gluing it to the substrate; permit stacking the specimens under a dead load for no more than 24 hours; condition the specimens for a minimum of 72 hours in a manner which allows for good air circulation.

- Replace the pilot burner with a stainless steel line burner covering the width of the specimen having two rows of holes evenly spaced along its length. Make provision for moving the burner forward in case of specimen burnout in the ignition area.

- Add dimensional tolerances to the chamber exhaust stack and control the laboratory exhaust so that the air flow through the chamber stack is between 200 and 300 ft/min.

- Allow the chamber to heat up for 1 1/2 hours before calibrating and testing.

- Preheat the specimen in the chamber for five minutes before applying the pilot burner.

- Remove the pilot burner and terminate the test if flames do not propagate within five minutes.

- Test three additional specimens and report all values if the coefficient of variation for the first three is more than 20 percent.

The revised standard has been submitted to ASTM Committee E05 for consideration and balloting. This is the first major revision in the standard since it was originally published in 1978.

6. RECOMMENDATIONS FOR FURTHER WORK

The specific recommendations for further work which need to be addressed are as follows:

1. Carry out a round robin with a wide selection of carpets, including as many laboratories as are willing to participate. This will provide an assessment of the recommended changes to the test standard.

2. Although the adhesives used in this study had little or no effect on the test results, it is perceived in the field that adhesives can vary from lot to lot. Therefore, all future NVLAP proficiency rounds should be performed using the same adhesive supplied from a single lot.

3. Determine the effect of specimen location on the carpet to assess variation in the product and determine the effect of carpet aging on critical radiant flux. This will address the unanswered question of why the results of the CRI program carried out in 1987 were so different from the NIST results and those from several of the laboratories on the same carpet tested in 1988.

In addition to the specific recommendations listed above, this study has revealed several other considerations which should be investigated in order to further the development of the Flooring Radiant Panel Test. These are as follows:

1. Determine whether electric radiant panels could be substituted for the gas-fired panels.

2. Determine whether perforated ceramic tile panels are equivalent to the porous refractory panels currently specified in the standard.

3. Determine the practicability of installing automatic gas controls and feedback systems for operating gas-fired panels to maintain desired operating conditions.

4. Determine the optimal requirements for bulk storage of propane and provide guidelines in the test method for maintaining desired panel operating temperature and flux profile.

5. Determine the need for tighter specifications for the free air space between the specimen holder and the chamber walls.

6. Determine the importance of specifying the weight (and type) of adhesive used to bond carpets to substrates; lot-to-lot variation in adhesive should be examined. Study the effect of conditioning time for different adhesives using a wider selection of carpets.

7. Determine the feasibility of reducing the test time for finding the critical radiant flux by moving the line burner forward.

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8. ACKNOWLEDGEMENTS

The authors would like to acknowledge our sponsors, The Carpet and Rug Institute, American Textile Manufacturers Institute, and American Fiber Manufacturers Association, without whose support and patience, this project would not have been carried out. In addition, we would like to thank those carpet manufacturers who so graciously provided the materials used in this study.

We would especially like to thank Roy McLane, who prepared all of the test specimens, and Gary Roadarmel and Angel Perez, who untiringly tested all of the specimens in the E 648 flooring radiant panel test.

Acknowledgement should be given to the Consumer Product Safety Commission laboratory personnel who made their facilities available to us for carrying out the study of the type of gas used for the radiant panel.

We also would like to thank the testing laboratories that participated in the "proficiency round" and permitted us to examine their test procedures.

Table 1. Test Carpets for Coefficient of Variation Study

Carpet Identification	Fiber Weight, oz.	Style	Fiber Type	Yarn
A	28	Cut Pile	Nylon 6,6	BCF*
B	24	Loop Pile	Polypropylene	BCF
C	50	Cut Pile	Nylon 6,6	Staple
D	28	Cut Pile	Nylon 6,6	Staple
E	28	Loop Pile	Nylon 6,6	BCF
F	50	Cut Pile	Wool	Staple
		Light vs Dark Color		
G (Light)	24	Loop Pile	Nylon 6	BCF
H (Dark)	24	Loop Pile	Nylon 6	BCF

* BCF - Bulk Continuous Filament

Table 2. Specimen Location Map for Carpet Used in CRI Program

Critical Radiant Flux, W/cm^2

Specimen Numbers	14	28	42	56	70	84	98	112	126	140	154	168	182	196	
14	0.90	0.48			0.38	0.41	0.35				0.38	0.45			196
13	0.49	0.49	1.08	0.43		0.49						0.41	0.40		195
12	0.84	0.89	0.83			0.55					0.37		0.43	0.37	194
11	1.1	0.46	1.08	>1.1	0.47					0.55	0.35		0.43		193
10	1.08	0.61	0.88	0.37	0.67					0.54	0.48	0.38		0.41	192
9	0.71	1.1	0.82						0.37	0.40			0.47	0.49	191
8	1.08	1.1		0.88								0.48		0.37	190
7	1.1	0.84	1.1				0.39					0.60	0.45		189
6	1.1	0.77	0.88		0.44						0.34	0.84*	0.51	0.53	188
5	0.86	1.16	1.1	0.97				0.43				0.39			187
4	0.64	1.1	1.1	>1.1				0.39	0.52		0.49		0.40		186
3	1.1	0.98	1.1		0.86	0.34						0.43	0.33	0.37	185
2	0.76	0.92	1.1	0.82	0.95		>1.1		0.39						184
1	0.96	0.52	0.51	1.08	0.38							0.43		0.33	183
	1	15	29	43	57	71	85	99	113	127	141	155	169	183	

Specimen Numbers

* Laboratory reported 0.84 W/cm^2; reversing the specimen machine direction gave 0.42 W/cm^2.

Table 3. Coefficient of Variation Study

Carpet Identification	Time to Flameout, min	Critical Radiant Flux, W/cm^2	Average CRF, W/cm^2	Std. Dev., W/cm^2	Coefficient of Variation, %
A	--	>1.1 (4 specimens)	--	--	--
B	48	0.32			
	31	0.33			
	31	0.36			
	40	0.28			
	42	0.29			
	55	0.28	0.31	± 0.03	10.4
C	55	0.56			
	57	0.56			
	74	0.45			
	78	0.43			
	74	0.48			
	90	0.45	0.49	± 0.06	11.8
D	79	0.27			
	82	0.25			
	78	0.30			
	64	0.33			
	65	0.36			
	87	0.33	0.31	± 0.04	13.5
E	--	>1.1 (5 specimens)	--	--	--
F	10	0.71			
	9	0.67			
	9	0.67			
	9	0.69			
	10	0.63			
	11	0.58	0.66	± 0.05	7.1
G	72	0.37			
	73	0.38			
	103	0.30			
	94	0.27			
	109	0.26			
	71	0.31	0.32	± 0.05	15.9
H	74	0.29			
	91	0.27			
	45	0.40			
	64	0.33			
	71	0.27			
	67	0.32	0.31	± 0.05	15.7

Table 4. Additional Data for the Carpets in the Coefficient of Variation Study

Carpet Identification	Substrate	Adhesive	Flux Profile	Preheat Time, min	Pilot	Critical Radiant Flux, W/cm^2
A	Sterling Board	Nu Broadlok II	High	2	Std.	1.85
	Sterling Board	Nu Broadlok II	High	5	Line	1.50
B	Sterling Board	Supra STIX 90	High	2	Std.	0.29
	Sterling Board	Supra STIX 90	High	2	Std.	0.27
	Sterling Board	Supra STIX 90	High	2	Std.	0.29
C	Ultra Board	Supra STIX 90	Std.	2	Std.	0.47
	Ultra Board	Supra STIX 90	Std.	2	Std.	0.48
	Eter Board	Supra STIX 90	Std.	2	Std.	0.50
	Eter Board	Supra STIX 90	Std.	2	Std.	0.47
	Sterling Board	Supra STIX 90	High	2	Std.	0.43
	Sterling Board	Supra STIX 90	High	2	Std.	0.44
	Sterling Board	Supra STIX 90	High	2	Std.	0.49
	Sterling Board	Supra STIX 90	High	2	Std.	0.50
	Sterling Board	Supra STIX 90	High	2	Std.	0.45
	Sterling Board	Supra STIX 90	High	2	Std.	0.47
	Sterling Board	Supra STIX 90	High	5	Std.	0.37
	Sterling Board	Supra STIX 90	High	5	Std.	0.38
	Sterling Board	Supra STIX 90	High	5	Std.	0.40
	Sterling Board	Supra STIX 90	High	5	Std.	0.51
	Sterling Board	Supra STIX 90	High	5	Std.	0.43
	Sterling Board	Supra STIX 90	High	5	Std.	0.48
D	Sterling Board	Supra STIX 90	High	2	Std.	0.26
	Sterling Board	Supra STIX 90	High	2	Std.	0.33
	Sterling Board	Supra STIX 90	High	2	Std.	0.31
E	Sterling Board	Nu Broadlok II	High	5	Line	1.75
F	Sterling Board	Supra STIX 90	High	2	Std.	0.66
	Sterling Board	Supra STIX 90	High	2	Std.	0.68
	Sterling Board	Supra STIX 90	High	2	Std.	0.58

Table 5. Parametric Study

Baseline Conditions	Critical Radiant Flux, W/cm^2	Average CRF, W/cm^2	Std. Dev., W/cm^2	Coefficient of Variation, %	Remarks
Yes	0.39				
	0.43				
	0.43				
	0.52				
	0.43				
	0.42	0.44	± 0.04	10.0	
No	0.42				
	0.42				
	0.51	0.45	± 0.05	11.6	Taylor 295 Adhesive
No	0.41				
	0.44				
	0.37	0.41	± 0.04	8.6	Nu Broadlok II Adhesive
No	0.45				
	0.46				
	0.45	0.45	± 0.01	1.3	Calcium silicate backing board
No	0.52				
	0.46				
	0.46	0.48	± 0.04	7.3	5 min preheat
No	0.39				
	0.51				
	0.45				
	0.46				
	0.48	0.46	± 0.04	9.7	10% increase in flux
No	0.41				
	0.44				
	0.42	0.42	± 0.02	3.6	Specimen orientation reversed
No	0.37				
	0.36				
	0.35	0.36	± 0.01	2.3	High air flow through chamber stack
No	0.48				
	0.43				
	0.51	0.51	± 0.03	5.0	Low air flow through chamber stack

Table 6. Effect of Air Flow on Critical Radiant Flux

Air Flow	Stack Flow, fpm	Specimen Surface Centerline fpm	Specimen Surface 90 degrees fpm	Average CRF, W/cm^2	Std. Dev., W/cm^2	COV, %
Low	150	15 - 20	15 - 23	0.51	± 0.03	5.0
Normal	200 - 300	13 - 19	19 - 35	0.44	± 0.04	10.0
High	400 - 800	18 - 35	28 - 50	0.36	± 0.01	2.8

Table 7. Results of the "Proficiency Round"

Laboratory	Critical Radiant Flux, W/cm^2	Average CRF, W/cm^2	Std. Dev., W/cm^2	Coefficient of Variation, %
1	0.53			
	0.48			
	0.51	0.51	± 0.03	5.0
2	0.65			
	0.57			
	0.49	0.57	± 0.08	14.0
3	0.53			
	0.47			
	0.47	0.49	± 0.03	7.1
4	0.43			
	0.43			
	0.42	0.43	± 0.01	1.4
5	0.58			
	0.49			
	0.56	0.54	± 0.05	8.7
6	0.59			
	0.56			
	0.47	0.54	± 0.06	11.6
7	0.49			
	0.46			
	0.47	0.47	± 0.02	3.2
8	0.44			
	0.45			
	0.45	0.45	± 0.01	1.3
9	0.43			
	0.38			
	0.43	0.41	± 0.03	7.0
10	0.56			
	0.56			
	0.58	0.57	± 0.01	2.0
All labs		0.50	± 0.06	11.5

Table 8. Interlaboratory Investigation

Lab	Average CRF	Adhesive Mass Used	Substrate*	Roller Weight	Dead Weight	Time Weight Applied	Conditioning Environment		Time Conditioned	Observed Bond	Chamber Stack Air Flow Rate		Heat Flux Gauge Comparison	Chamber Temp.	Average Flameout Time
											Mean	Range			
	W/cm^2	g		kg	kg	h	°C	% RH	days		ft/min		W/cm^2 ▼	°C	min
1	0.51	86	s/b	3.2	none	--	25	50	4	spotty	200	150-285	n/a	160	36
2	0.57	114	s/b	none	18.2	24	23	55	12	total	270	170-290	-0.02	140	77
3	0.49	170	s/b	21.0	24.1	20	21	49	7	spotty	250	190-310	-0.03	<180	41
4	0.43	112	s/b	0.6	68.1	16	24	47	2.75	spotty	250	170-320	-0.02	n/a	38
5	0.54	152	s/b	45.4	10.5	24	22	49	26	total	225	175-325	0.0	173	78
6	0.54	149	s/b	none	10.4	24	22	53	7	spotty	200	150-230	-0.02	n/a	30
7	0.47	227	s/b	9.1	28.4	16	20	51	5	spotty	225	160-350	0.0	n/a	38
8	0.45	272	f/b	9.1	none	--	23	50	2	total	-	-	-0.01	180	66
9	0.41	113	s/b	11.4	none	--	24	37	2	spotty	260	180-300	-0.03	†	42
10	0.57	61	s/b	10.9	16.9	72	23	52	9	total	240	200-280	0.0	185	54
Test parameters specified by CFR for this project.			s/b	9.1	none	0	21±3	50±5	≥2		250	200-300	0.48-0.52	≈180	

* s/b = Sterling Board, f/b = Flexboard II

† Lab did not have or use a chamber thermocouple to normalize chamber between tests. Also, the radiation pyrometer was not hooked up or used.

▼ Lab flux gauge was compared to CFR flux gauge at 40 cm point on calibration board. Data column shows the difference in values as compared to the CFR flux meter.

n/a - not available

Table 9. Effect of Imposing a Time Limit on Reported Radiant Flux Values

Study	Carpet	Adhesive*	Aver. RF at 60 min	Aver. CRF	Aver. Burn Time	Incr. in CRF
			W/cm^2	W/cm^2	min	%
COV	C	B II	0.54	0.49	71	10.2
COV	D	B II	0.38	0.31	76	18.4
COV	G	B II	0.42	0.32	87	31.3
COV	H	B II	0.35	0.31	69	12.9
Parametric	C	SS 90	0.46	0.44	65	4.6
Parametric	C	T 295	0.52	0.46	80	13.0
Parametric	C	B II	0.48	0.44	74	9.1
					aver.	14.2

* B II = Nu Broadlok II, SS 90 = Supra STIX 90, T 295 = Taylor 295

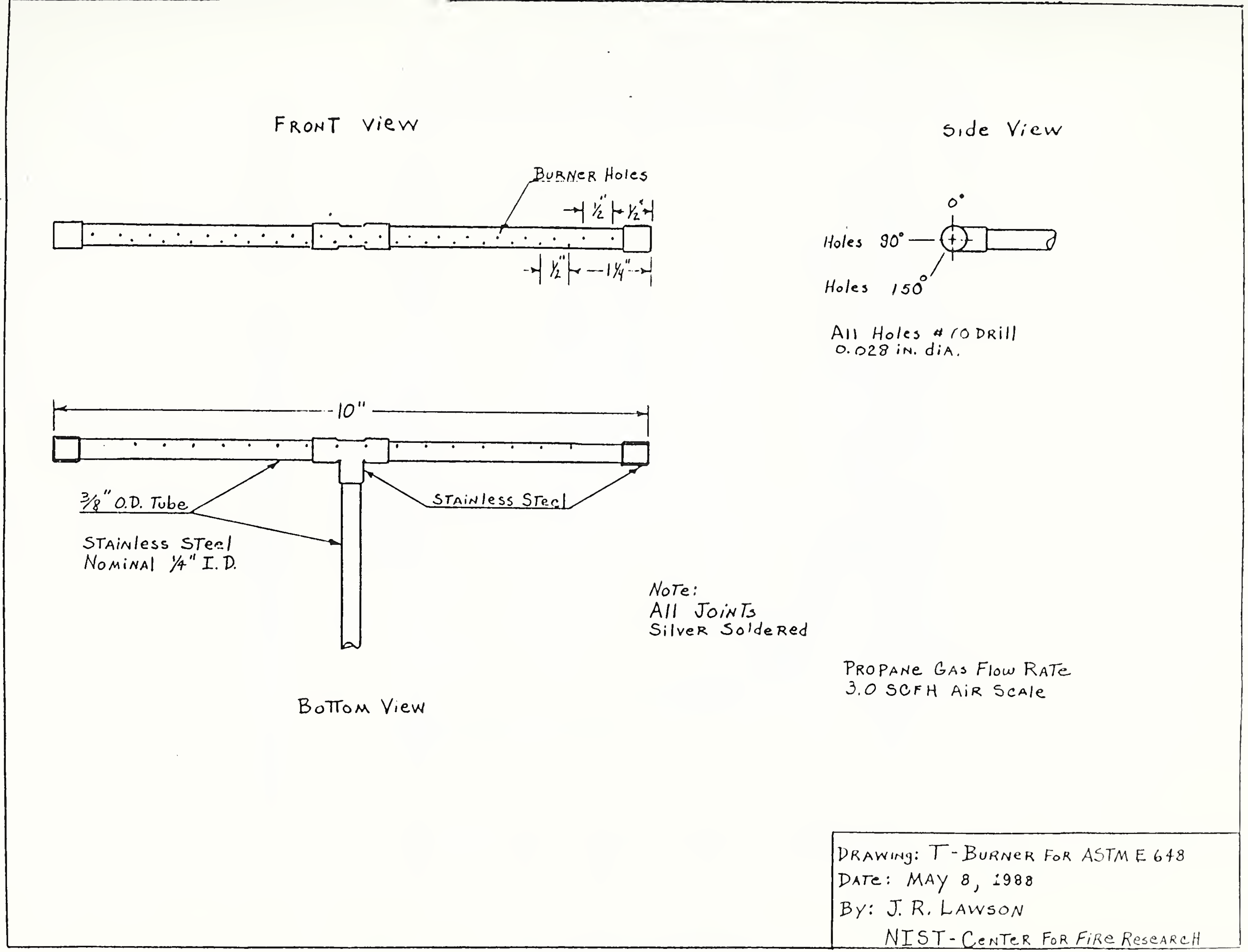

Figure 1. Line Burner for ASTM E 648

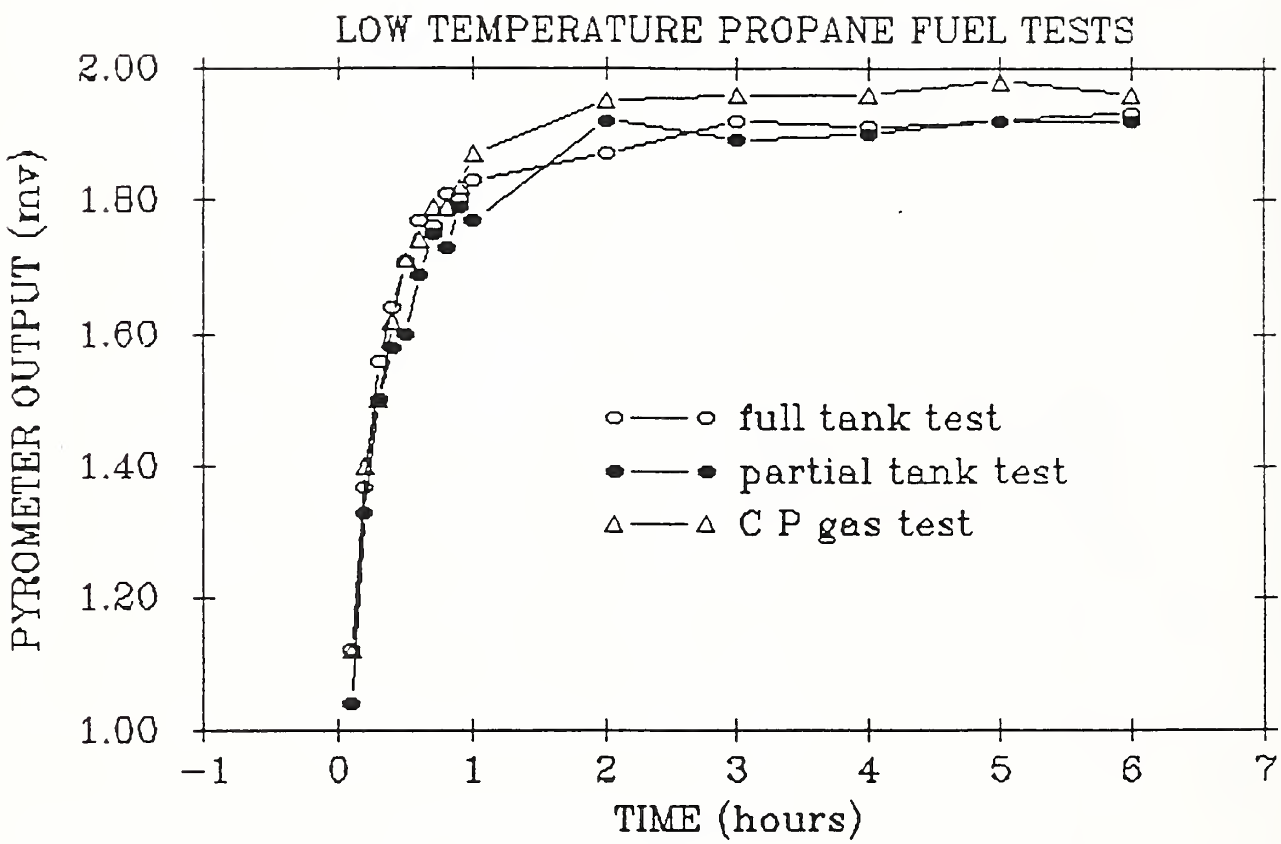

Figure 2. Low Temperature Propane Fuel Tests - Pyrometer Output

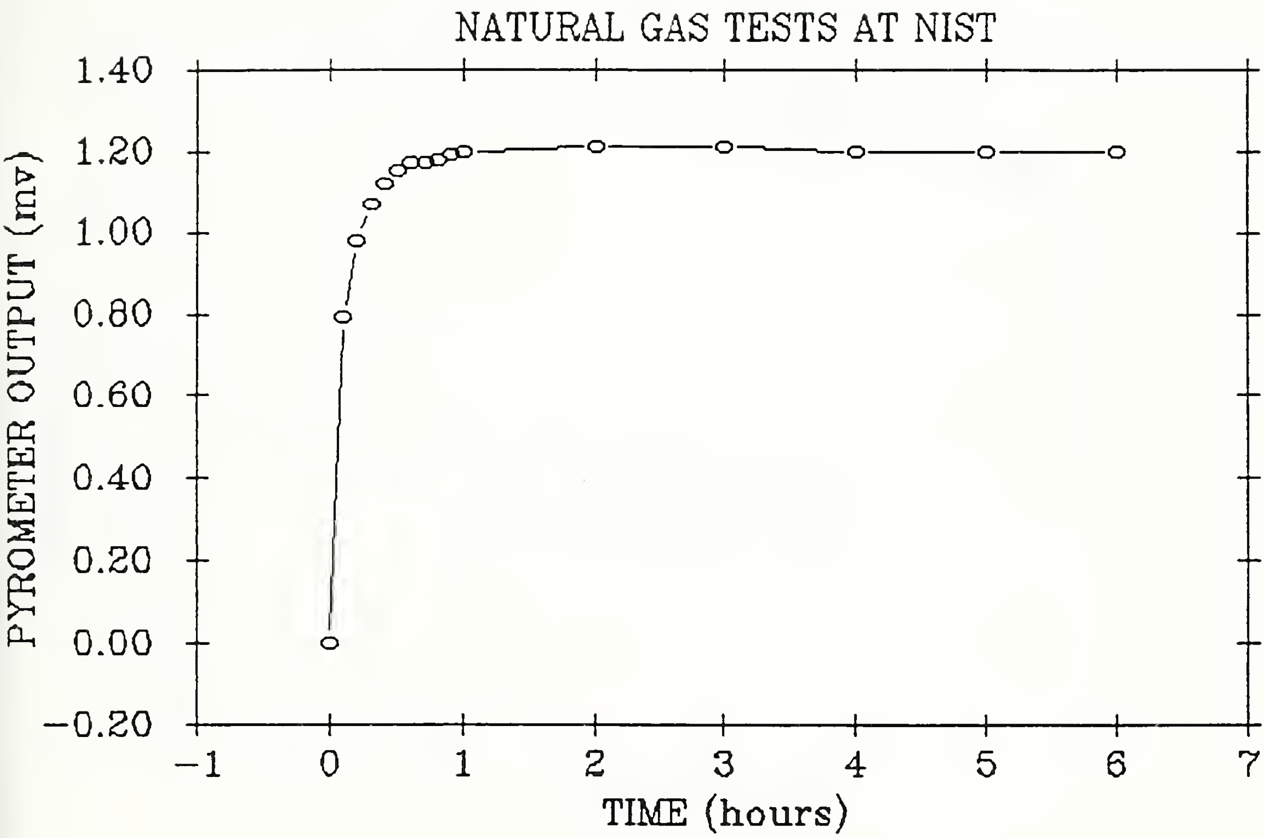

Figure 3. Natural Gas Tests at NIST - Pyrometer Output

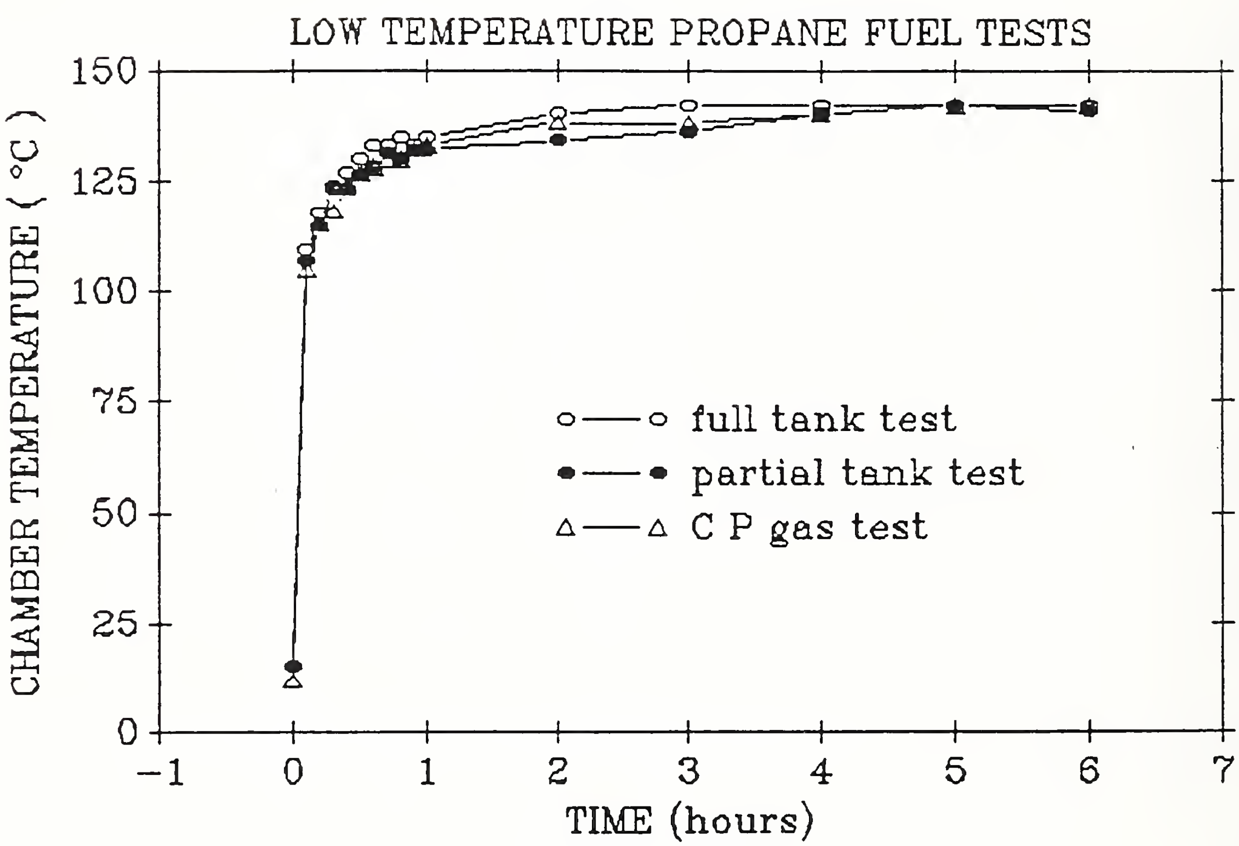

Figure 4. Low Temperature Propane Fuel Tests - Chamber Temperature

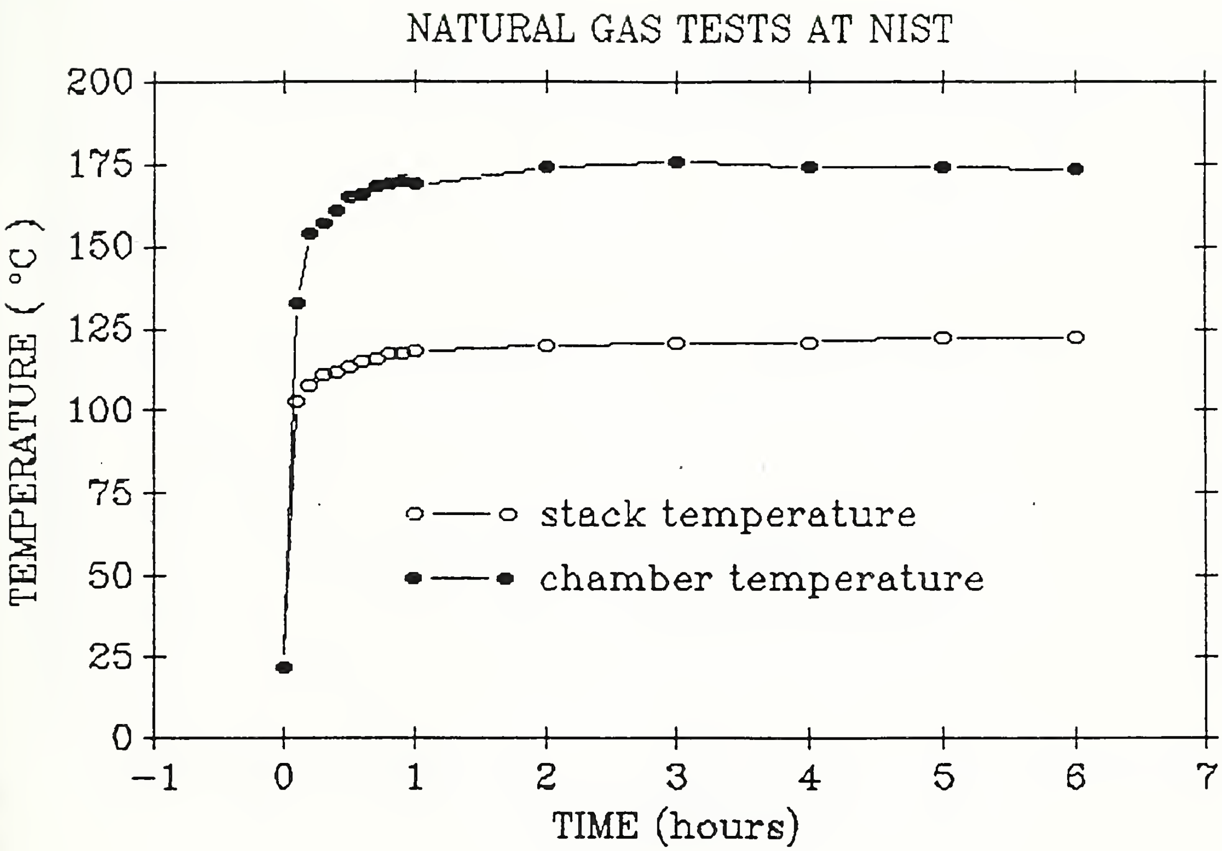

Figure 5. Natural Gas Tests at NIST - Temperatures

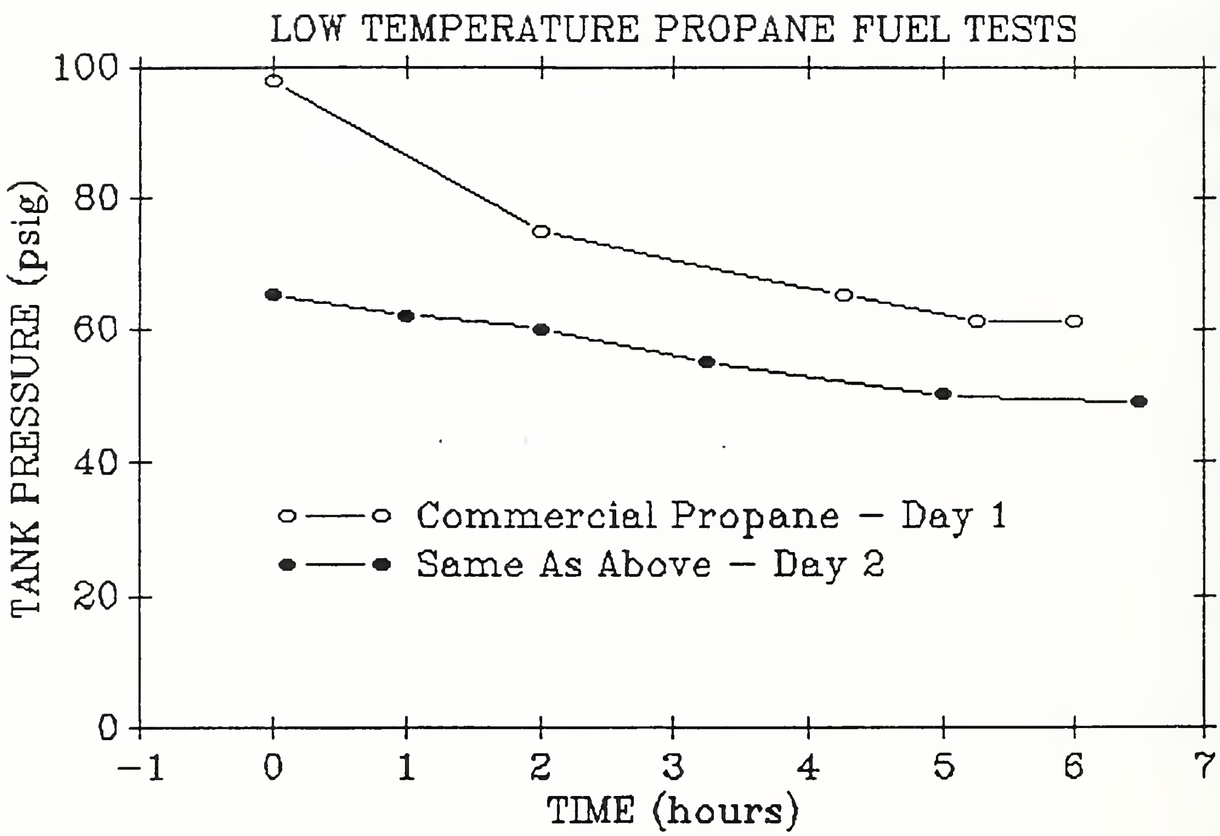

Figure 6. Low Temperature Propane Fuel Tests - Tank Pressure

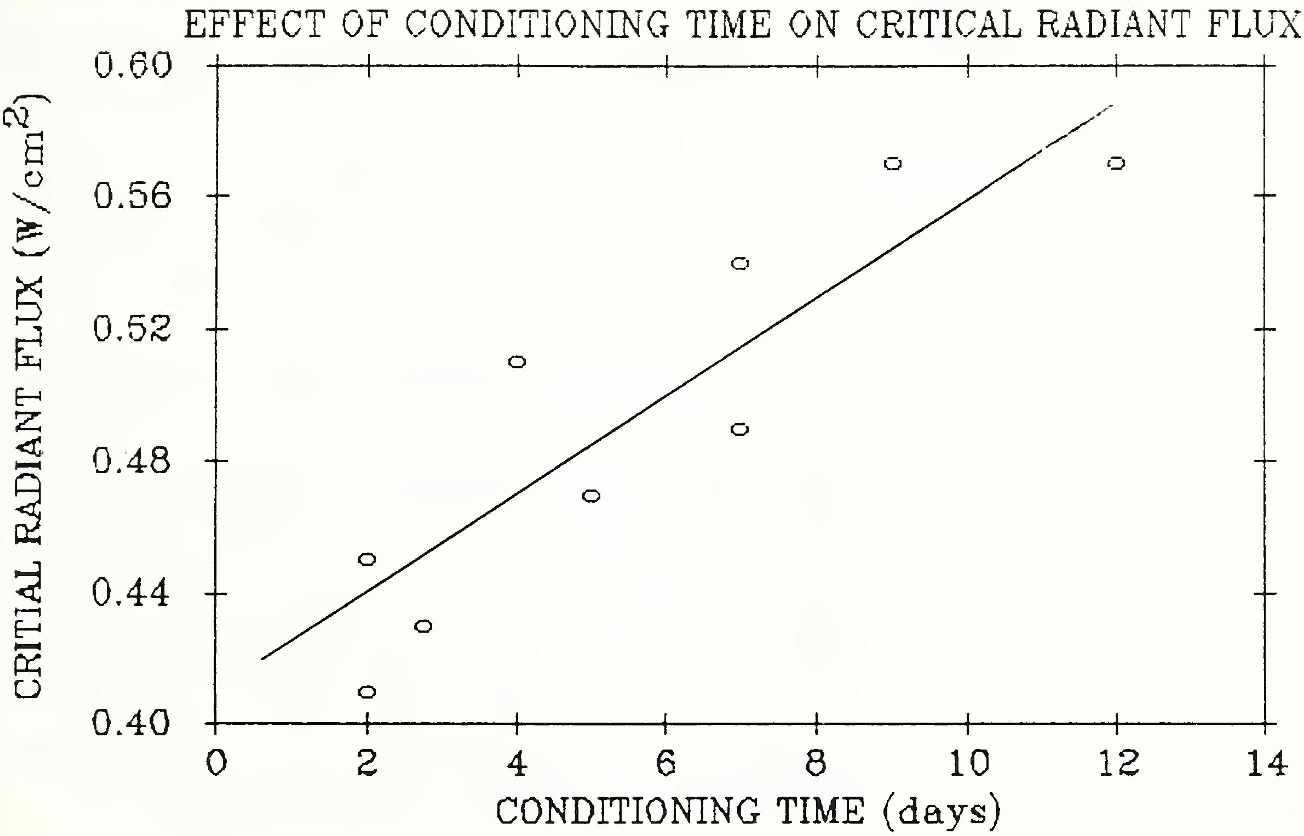

Figure 7. Effect of Conditioning Time on Critical Radiant Flux

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (*See instructions*)	1. PUBLICATION OR REPORT NO.	2. Performing Organ. Report No.	3. Publication Date
	NISTIR-89/4191		October 1989

4. TITLE AND SUBTITLE

Examination of the Variability of the ASTM E 648 Standard with Respect to Carpets

5. AUTHOR(S)

Sanford Davis, J. Randall Lawson, William J. Parker

6. PERFORMING ORGANIZATION (*If joint or other than NBS, see instructions*)

National Institute of Standards and Technology
~~NATIONAL BUREAU OF STANDARDS~~
U.S. DEPARTMENT OF COMMERCE
GAITHERSBURG, MD 20899

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (*Street, City, State, ZIP*)

The Carpet and Rug Institute Dalton GA 30722
American Textile Manufacturers Institute Washington, DC 20006
American Fiber Manufacturers Association Washington, DC 20036

10. SUPPLEMENTARY NOTES

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

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

The objectives of this research program were to investigate the variability of the ASTM E 648 Standard with respect to carpets and to make recommendations for revising the standard to improve the repeatability and reproducibility of the measured results. Several ignition sources and procedural variations were studies to assure that flame propagation away from the point of ignition would occur if the critical radiant flux of the carpet was less than the maximum flux from the panel. This resulted in the replacement of the propane torch point source pilot burner by a propane line burner. A coefficient of variation study was carried out to select one carpet for a parametric study of the test variables. As a result of the parametric study and a subsequent "proficiency round", recommendations were made to ASTM Committee E05 on Fire Standards for revision of ASTM E 648. The most significant changes were the use of the line burner for ignition and a tighter control of the air flow through the chamber.

12. KEY WORDS (*Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons*)

ASTM E 648; carpets; flammability; floor coverings

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14. NO. OF PRINTED PAGES

45

15. Price

A03

USCOMM-DC 6043-P80