NATIONAL BUREAU OF STANDARDS REPORT

10 497

HEAT RELEASE AND IGNITION CHARACTERISTICS
OF
FLOOR COVERINGS USED IN THE NBS CORRIDOR TESTS

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

NATIONAL BUREAU OF STANDARDS

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HEAT RELEASE AND IGNITION CHARACTERISTICS OF FLOOR COVERINGS USED IN THE NBS CORRIDOR TESTS

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1.0 INTRODUCTION

Since most institutional and private dwellings use some form of floor covering, the Fire Research Section in conjunction with the Office of Flammable Fabrics is conducting a study on a group of these coverings in a fire environment. These tests are being conducted in several phases. The primary phase deals with the testing of a particular covering in a simulated 30 foot by 8 foot corridor which was constructed for this specific purpose. This report covers tests conducted to determine the heat release rate, the total heat released and the critical irradiance for the different types of floor coverings.

The information on the heat release rate was needed to give an indication as to the rate and the amount of heat which is given off by these materials in a fire environment. The critical irrandiance indicates the radiation levels required to cause spontaneous and piloted ignition. This data is supplementary information to be used in calculating the overall heat flow in the full scale corridor test.

These tests were performed in the heat release rate calorimeter. They were conducted at the National Bureau of Standards' Fire Research Section during the time period between May and August, 1971.

2.0 MATERIALS TESTED

The floor coverings tested included three different carpets and one vinyl asbestos floor tile. The first carpet tested was a brown 100% acrylon acrylic pile type. The pattern type was designated as VC 79-16. The nappe was approximately 6.4 mm (.25 inch) in length. The back of the carpet was made from a burlap-material with some type of adhesive material on it. The samples were taken from lot numbers VXP29 and XK.

The second covering tested was a blue high-low acrylic pile carpet. The pattern on this type of carpet was made by making part of the nappe higher or longer than the other parts. The length of the longer portion was 8 mm (.31 inch); whereas the length of the lower portion was 1.6 mm (.06 inch). It had a burlap back with no adhesive material on it.

The third covering tested was a gold rubber-backed low nylon pile carpet. The nappe of this carpet, which was 3.2 mm (.125 inch) in length was attached to a solid rubber back. The rubber back was 4 mm (.16 inch) thick.

Further descriptions of the carpets are included in Table I. A rubberized animal hair and jute pad was used with the samples which required it.

The final material tested was terraflex vinyl asbestos floor tile. Its thickness was 3.2 mm (.125 inch). All coverings were cut into 11.4 cm (4.5 inch) by 15.2 cm (6.0 inch) samples before testing.

3.0 TEST PROCEDURE

The heat release rate calorimeter was put into operation and allowed to equilibriate at a control temperature of 410°C. This device, designed to determine the heat release rate of various materials, consists of a combustion chamber, a mixing chamber and a control chamber. The combustion chamber has three gas fired panels and a door on which the samples are mounted. The ignition pilot is also mounted in the door below the sample holder. The irradiance levels are adjusted by varying the amount of gas going to the panels. The hot gases are cooled to a more manageable temperature by adding forced air in the control chamber.

The control chamber has a propane burner located approximately in its center. The flow of propane is regulated by a pneumatic valve which operates automatically in response to a temperature controller in order to keep the flue gases at a constant temperature. When a sample gives off heat the temperature tends to rise, however, this is prevented by the valve reducing this propane flow. The amount of heat which is given off by a sample is determined by measuring the decrease in the flow of propane. Changes in flow are recorded on a strip chart recorder. Using the heat of combustion of propane, the flow values are converted to heat values. For a more detailed description, see Reference 1.

The irradiance was measured by using a copper disk calorimeter placed in the sample holder. The levels ranged from 2.7 to 6.1 watts/cm^2 for carpet and from 2.5 to 8.4 watts/cm^2 for the tile. The carpet samples were mounted in a frame which consists of two brackets with an asbestos cement board back. See Figure 1. At each irradiance level the brown and blue acrylic samples were tested under four different conditions:

1. ignition pilot off, using no pad;
2. ignition pilot off, with pad;
3. ignition pilot on, no pad;
4. ignition pilot on, with pad.

The samples were placed into the sample holder of the calorimeter. The ignition times were determined by using a stop watch which was started when the door was closed and stopped when the flames were first observed through an observation window in the door. The maximum deflection of the recorder pen was measured in volts and multiplied by the proper factor to yield the peak heat release rate value in watts/cm^2.

The gold nylon carpet was tested under only conditions one and three. No jute pad was used with this particular carpet because it was manufactured with an integral rubber back. The tile was tested in the same manner as the gold carpet because no padding was required.

At each irradiance level several sets of runs were made and an average value was taken. The total heat for a specimen was determined by integrating a representative curve from each test condition at each irradiance. This yields the total heat passing out through the front face of the specimen. It does not include the heat that would be conducted into the floor.

The critical irradiance level, which is the lowest irradiance at which ignition occurs was determined from the plotted and tabulated data. Irradiance was plotted against the reciprocal of the square root of the ignition time. The point at which the graph joined the Y axis provided an upper limit for the critical irradiance. The highest irradiance at which ignition did not occur served as a lower limit. The equation used as a basis for determining the upper limit comes from solution of the problem of the heat conduction in a semi-infinite solid with a constant heat flux passing through its surface. The temperature of the front surface is given by Carslaw and Jaeger (Reference 2) as:

$$T=(2H/K)\left(\frac{\alpha t}{\pi}\right)^{\frac{1}{2}}$$

where T is the temperature, K is the thermal conductivity, t is the time and α is the thermal diffusivity. Rearranging the above equation,

$T=2H\left(\frac{t}{\pi K\rho C}\right)^{\frac{1}{2}}$ since $\alpha=K/\rho C$ where ρ is the density and C is the heat capacity. Therefore $H=(T/2)(\pi K\rho C)^{\frac{1}{2}}/\sqrt{t}$. Let $(T/2)(\pi K\rho C)^{\frac{1}{2}}=M$. Then $H=M(1/\sqrt{t})$.

If the surface temperature at the time of ignition is constant M has a fixed value at that time. This yields a linear relationship between the irradiance and the reciprocal of the square root of the ignition time. As the ignition time increases, $1/\sqrt{t}\rightarrow 0$. Therefore all points lie on the Y axis until ignition occurs.

There is a forced air flow of approximately 1 foot/sec past the specimen surface. The magnitude of this air flow could have some effect on the value of the critical irradiance.

4.0 RESULTS AND DISCUSSION

4.1 Brown Acrylic Carpet

It was found that the brown acrylic carpet gave two peak heat release rates at exposure levels of 4.1 watts/cm^2 and above for all four conditions. This in all probability was caused by the heat release from the smoldering or burning of a portion of the carpet nappe. The second peak was caused by the heat release of the remaining nappe, carpet back and the pad when used. See Figure 2. The largest heat release rate, 35.7 watts/cm^2, occurred at an irradiance level of 6.1 watts/cm^2 using both pad and pilot. This was the highest irradiance used. The ignition time under these conditions was 6.1 sec and the total heat released was 8100 joules/cm^2.

In addition to increased heat release the application of the pad played a significant part in the ignition time. When the pad was used the ignition time decreased. For example, at an irradiance of 4.1 watts/cm^2 with no pilot, the carpet with the pad ignited in 117 seconds whereas a carpet sample with no pad did not ignite. The heat release rates were higher in all cases when a pilot was used. When the heat release rates were plotted against irradiance the graphs were linear in the range where burning occurred. The carpet with the pad and the pilot had the lowest critical irradiance. The value was in the range between 1 and 2 watts/cm^2 and in this range the heat release rate was 18.4 watts/cm^2. See graphs and tabulated data.

4.2 Blue Acrylic Carpet

The blue acrylic carpet, which had a thicker nappe than that of the brown carpet, also gave two peaks. However, in most cases the second peak was lower than that of the first. Upon inspection of the carpet, it was observed that the backing was made from a loosely woven material whereas the brown carpet's back was more tightly woven. The brown carpet also had some type of adhesive material covering its back. The loosely woven back seemed to account for the decrease in the second peak heat release rate. The use of a pad did not seem to have as much influence on the ignition time as it did with the brown carpet. However, the pad influence was still observed at irradiance level of 5.1 watts/cm^2.

The highest peak heat release rate was 24.7 watts/cm^2 which occurred at an irradiance of 6.0 watts/cm^2 when the pad and the pilot were used. The ignition time was 7.3 seconds and the total heat was 6500 joules/cm^2. The heat release rate versus irradiance curves were again linear in the burning region. Again the heat release rates were higher for piloted samples than for non-piloted cases. The critical irradiances for all testing conditions ranged from 4.1 to 5.0 watts/cm^2.

4.3 Gold Nylon Carpet

The gold nylon carpet behaved differently than the first two types. This type only experienced one peak. This peak release rate was recorded at 5.9 watts/cm^2 and had a value of 56.5 watts/cm^2. At this level the ignition time was 29.7 seconds and the total heat was 4810 joules/cm^2. In general all of the ignition times were longer than those for the other group. The use of the pilot had a significant effect only at an irradiance level of 4.6 watts/cm^2. At this level the sample, not exposed to the pilot, required 133 seconds compared to 42 seconds when the pilot was used. The lowest critical irradiance occurred between 1 and 2 watts/cm^2 with the pilot. This type of carpet had the greatest flame intensity. The heat release rates for the piloted samples were higher than for the non-piloted samples. The fact that this type of carpet gave off a large amount of black smoke also distinguished it from the other two.

4.4 Vinyl Asbestos Tile

The vinyl asbestos tile, had only one peak because of its homogeneity. The peak heat release rate at an irradiance of 6.3 watts/cm^2 with a pilot was 26.2 watts/cm^2. The ignition time was 28.8 seconds and the total heat was 2870 joules/cm^2. The critical irradiance when the pilot used was in the range between 3.5 and 4.5 watts/cm^2. The heat release rate versus irradiance curve for the piloted samples was linear for irradiances greater than the critical irradiance. The heat release rate curve for the non-piloted samples seemed to approach a constant value of approximately 15.5 watts/cm^2. The value was probably the maximum heat release rate for smoldering tile. When exposed in the calorimeter the samples had a tendency to warp and blister. When tested in the corridor it again started to warp upon being exposed to the heat. This allowed the adhesive material to be exposed and ignite, adding some additional heat to the fire.

The tables included in this report summarize the results from testing. Table II lists the material tested along with the results at each test condition. Table III lists the critical irradiance, maximum heat release rate and total heat for samples at an irradiance of around 6.0 watts/cm^2.

As a means of comparison, the heat release rates and ignition times for various other materials at irradiance of 6.2 watts/cm^2 are given as follows:

1. Pine 16.3 watts/cm^2, 13.5 seconds, 19 mm (3/4 inch) thick
2. Oak 19.1 watts/cm^2, 41.7 seconds, 19 mm (3/4 inch) thick
3. Plywood 17.6 watts/cm^2, 18.1 seconds, 19mm (3/4 inch) thick
4. Redwood 19.1 watts/cm^2, 16.3 seconds, 19mm (3/4 inch) thick

5.0 CONCLUSIONS AND RECOMMENDATIONS

The gold rubber backed nylon pile carpet might be the most dangerous in case of fire since it had the lowest critical irradiance, below 2 watts/cm^2 with pilot, the highest heat release rate 56.5 watts/cm^2 and released a large amount of black smoke. The asbestos floor tile had less critical properties than the others, since it had a higher critical irradiance for non-piloted ignition compared to the carpets and longer ignition times. If a non-flammable or minimum amount of adhesive could be used to bond the tile to the floor it would be the most fire resistant of the floor coverings tested.

The fact that the heat release rates for piloted ignition were higher than those for non-piloted samples indicated that the pilot increased the irradiance on the sample significantly which could also decrease the ignition time. A pilot which uses an intermittent flame or spark might be used to alleviate this problem.

REFERENCES

1. W. J. Parker and M. E. Long, "Development of a Heat Release Rate Calorimeter at NBS," to be published in the proceedings of the ASTM Symposium on "Ignition, Heat Release and Noncombustibility of Materials," Washington, D.C., October 6, 1971.

2. Carslaw and Jaeger, "Conduction of Heat in Solids," Oxford University Press 1959, Second Edition, Page 75.

TABLE I

CARPET DESCRIPTION

Color	Construction	Face Fiber	Backing	Pile Wt. (Oz/Yd^2) Estimate	Pile Height	Stitches Per in.	Rows Per in.
Brown	Woven-Level Loop	Acrylic	Jute and Cotton	38	¼"	7.8	8.0
Blue	Tufted-High/Low Loop	100% Acrylic	Woven P.P./Jute	32	1/16-5/16"	8.0	6.6
Gold	Tufted-Level Loop	Nylon BCF	Non-Woven P.P./Foam Rubber	20	1/8"	8.0	6.8

TABLE II

TEST DATA

Sample	Irradiance (watts/cm²)	Test Condition	Average Peak Heat Release Rates: 1st Peak (watts/cm²)	Average Peak Heat Release Rates: 2nd Peak (watts/cm²)	Average Ignition Time (sec)	Total Heat Released (joules/cm²)
Brown Acrylic Carpet	2.7	1) No pad, no pilot	4.75		None	1023
		2) Pad, no pilot	14.4		None	8140
		3) No pad, pilot	4.2		None	475
		4) Pad, pilot	21.0		156.2	8000
	3.4	1) No pad, no pilot	5.05		None	1570
		2) Pad, no pilot	11.4		None	2565
		3) No pad, pilot	7.23		None	505
		4) Pad, pilot	22.2		126.0	4060
	4.1	1) No pad, no pilot	8.4	9.25	None	3046
		2) Pad, no pilot	9.73	27.7	116.5	5523
		3) No pad, pilot	6.72	8.40	None	1760
		4) Pad, pilot	11.6	29.7	79.0	5287
	5.2	1) No pad, no pilot	19.8	17.5	45.3	3468
		2) Pad, no pilot	23.1	30.7	15.3	4680
		3) No pad, pilot	12.9	19.3	22.5	3436
		4) Pad, pilot	18.9	30.7	11.1	4817
	6.1	1) No pad, no pilot	21.4	20.6	34.4	2751
		2) Pad, no pilot	23.3	32.8	6.3	7860
		3) No pad, pilot	21.0	21.0	19.2	3100
		4) Pad, pilot	20.6	35.7	6.1	8200
Blue Acrylic Carpet	2.8	1) No pad, no pilot	10.1	4.0	None	1613
		2) Pad, no pilot	9.3	11.8	None	4500
		3) No pad, pilot	8.4	4.7	None	2108
		4) Pad, pilot	8.1	10.1	None	3710
	4.1	1) No pad, no pilot	9.9	6.5	None	1539
		2) Pad, no pilot	11.3	13.4	None	2730
		3) No pad, pilot	9.8	5.5	None	1455
		4) Pad, pilot	11.2	14.2	None	5407
	5.1	1) No pad, no pilot	13.1	9.6	125.5	3879
		2) Pad, no pilot	22.8	16.9	81.0	5890
		3) No pad, pilot	17.1	9.0	18.5	2213
		4) Pad, pilot	24.1	23.0	16.3	7530
	6.0	1) No pad, no pilot	24.3	20.2	12.5	3067
		2) Pad, no pilot	24.4	24.0	10.5	6198
		3) No pad, pilot	23.1	16.4	8.0	2941
		4) Pad, pilot	24.3	24.7	7.3	6493
Gold Nylon Carpet	2.8	1) No pilot	4.7		None	3889
		2) Pilot	27.4		168.3	4311
	3.8	1) No pilot	29.2		183.9	3710
		2) Pilot	36.2		131.0	5080
	4.6	1) No pilot	38.3		131.3	4406
		2) Pilot	48.8		42.7	5028
	5.9	1) No pilot	56.0		34.0	4342
		2) Pilot	56.5		29.7	4901
Vinyl Asbestos Tile	2.5	1) No pilot	5.2		None	675
		2) Pilot	5.2		None	885
	3.5	1) No pilot	6.6		None	1318
		2) pilot	4.3		None	812
	4.6	1) No pilot	9.6		None	1170
		2) Pilot	17.4		63.5	2045
	5.3	1) No pilot	15.7		None	1128
		2) Pilot	22.7		68.2	2582
	6.3	1) No pilot	13.8		None	3120
		2) Pilot	26.2		28.8	2856
	7.2	1) No pilot	16.6		None	1982
		2) Pilot	32.8		22.4	1476
	8.4	1) No pilot	15.1		8.9	1539

TABLE III

SUMMARY OF RESULTS

Sample	Critical Irradiance Pilot watts/cm^2	Critical Irradiance No Pilot watts/cm^2	Max. Heat Release Rate watts/cm^2 No Pilot	Total Heat Released Pilot joules/cm^2	Total Heat Released No Pilot joules/cm^2
Brown Acrylic	4.3	4.6	21 @ 6.1 watts/cm^2	3100	2751
Brown Acrylic with pad	<2.7	3.6	33 @ 6.1 watts/cm^2	8200	7860
Blue Acrylic	4.2	4.7	24 @ 6.0 watts.cm^2	2941	3067
Blue Acrylic with pad	4.1	4.6	24 @ 6.0 watts.cm^2	6493	6198
Gold Nylon	1.5	3.1	56.0 @ 5.9 watts/cm^2	4901	4342
Asbestos Tile	3.8	7.2	14 @ 6.2 watts.cm^2	2856	3120

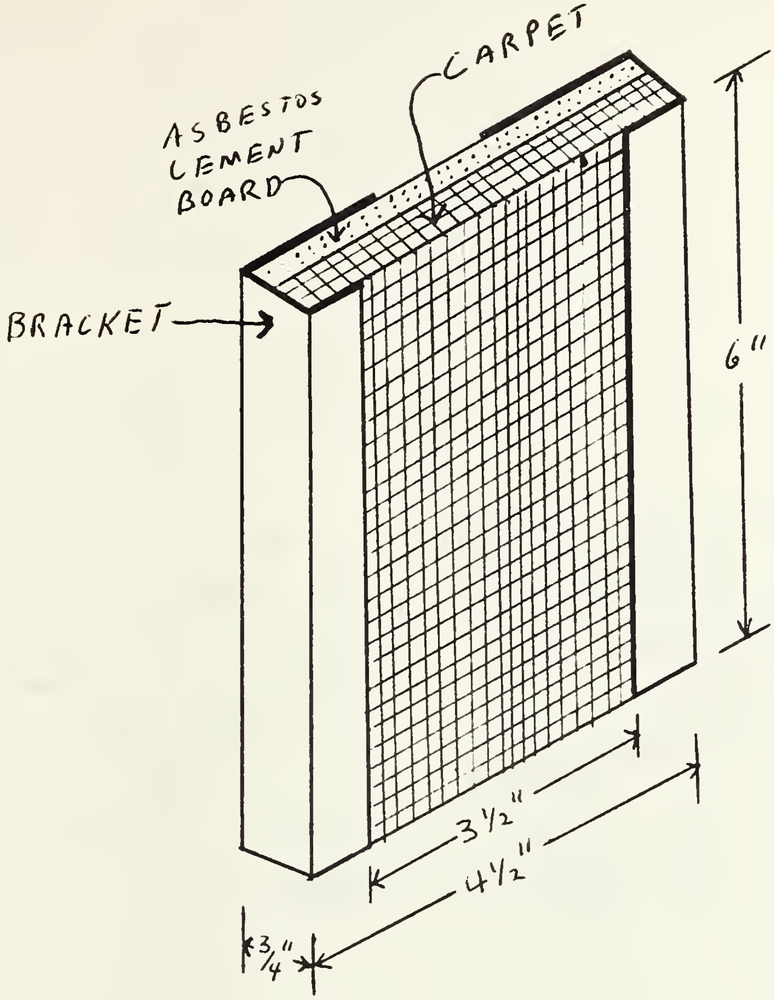


FIGURE 1 - CARPET HOLDER

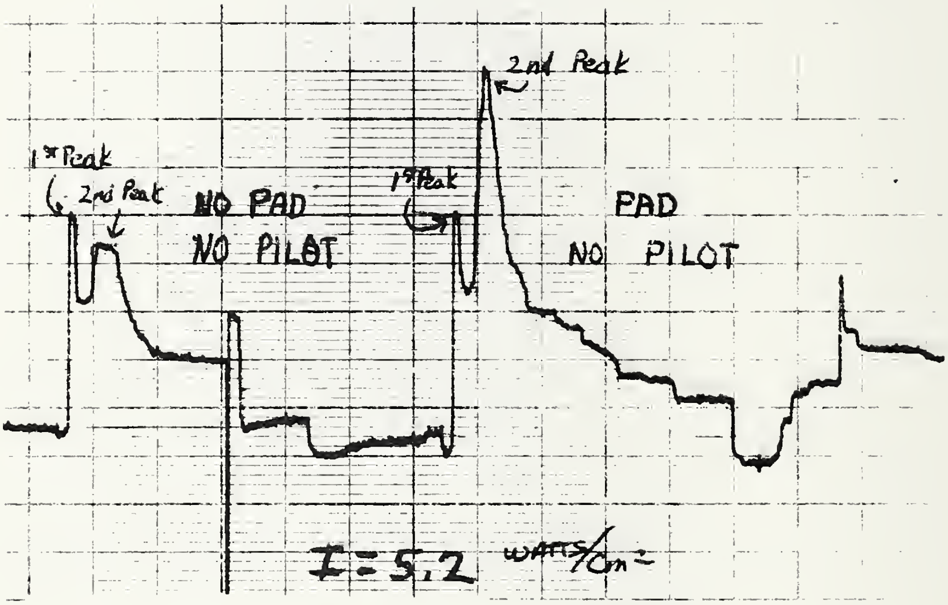
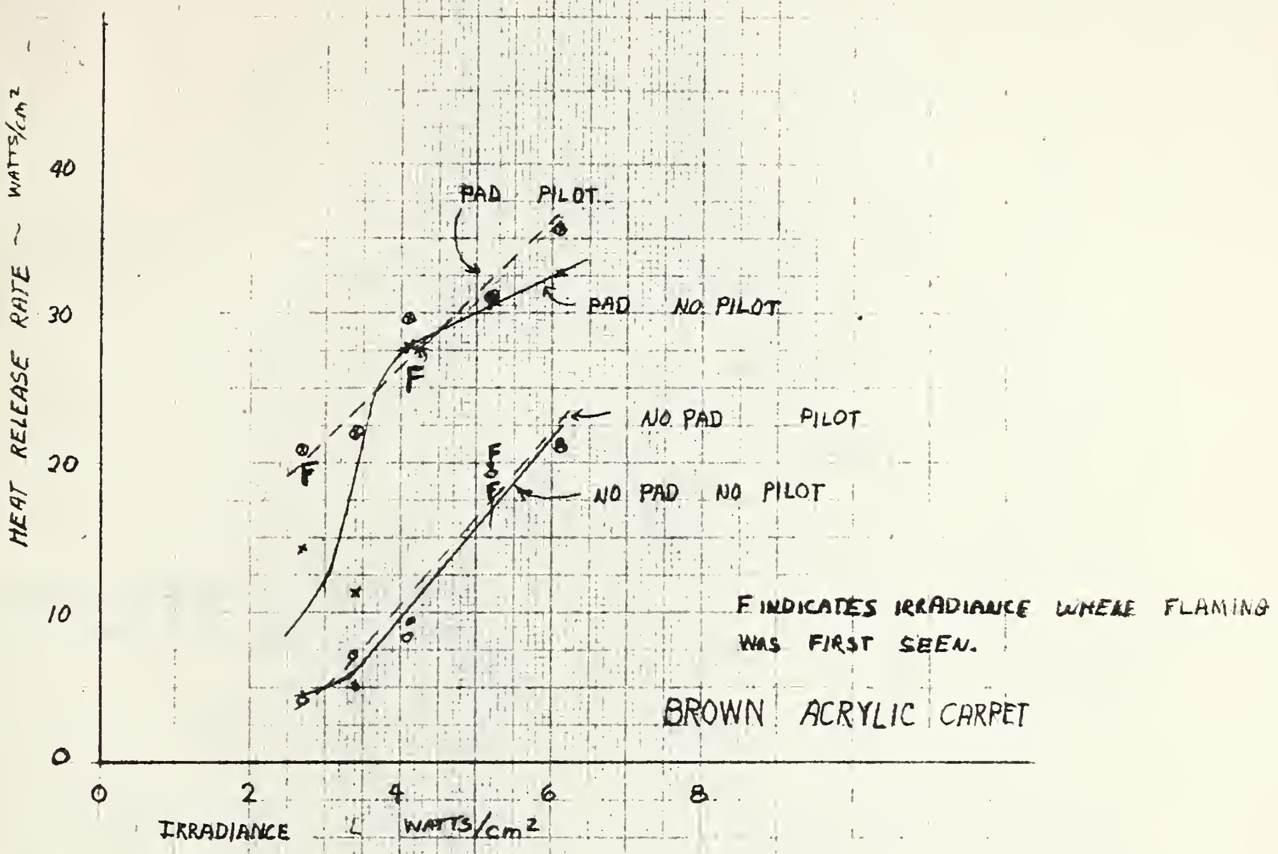


FIGURE 2 - HEAT RELEASE RATE CURVES FOR BROWN ACRYLIC CARPET



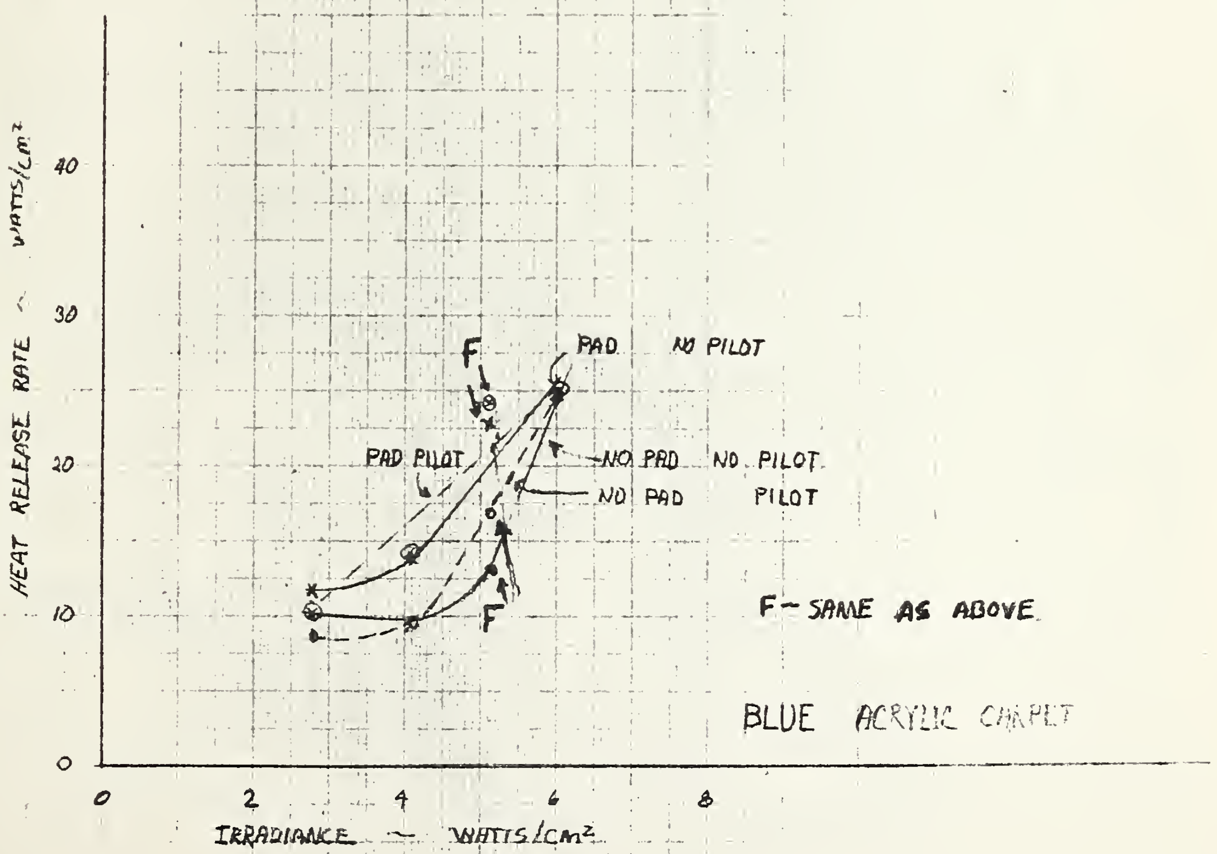


FIGURE 3 - HEAT RELEASE RATES FOR ACRYLIC CARPETS

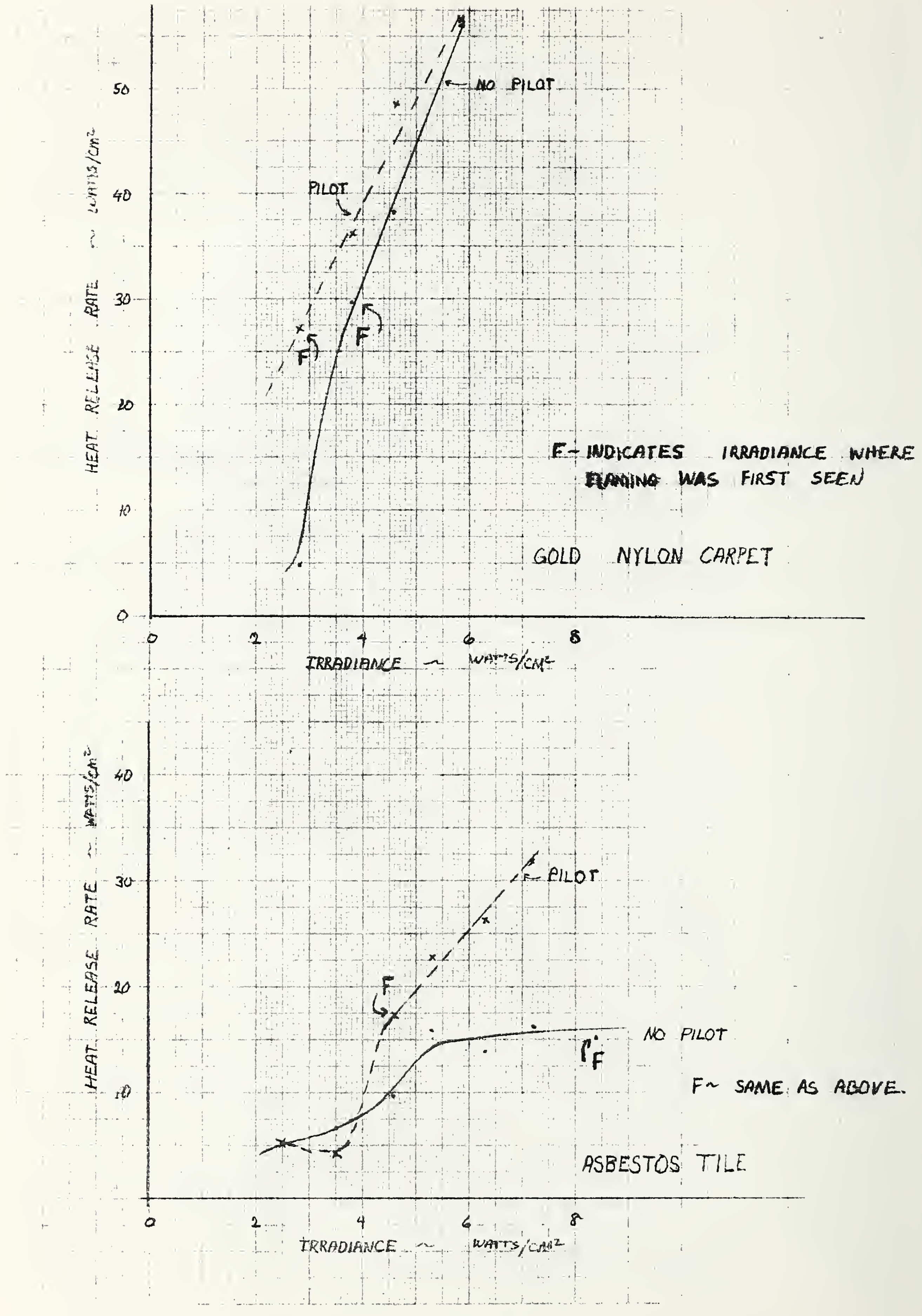


FIGURE 4 - HEAT RELEASE RATES FOR NYLON CARPET AND ASBESTOS TILE

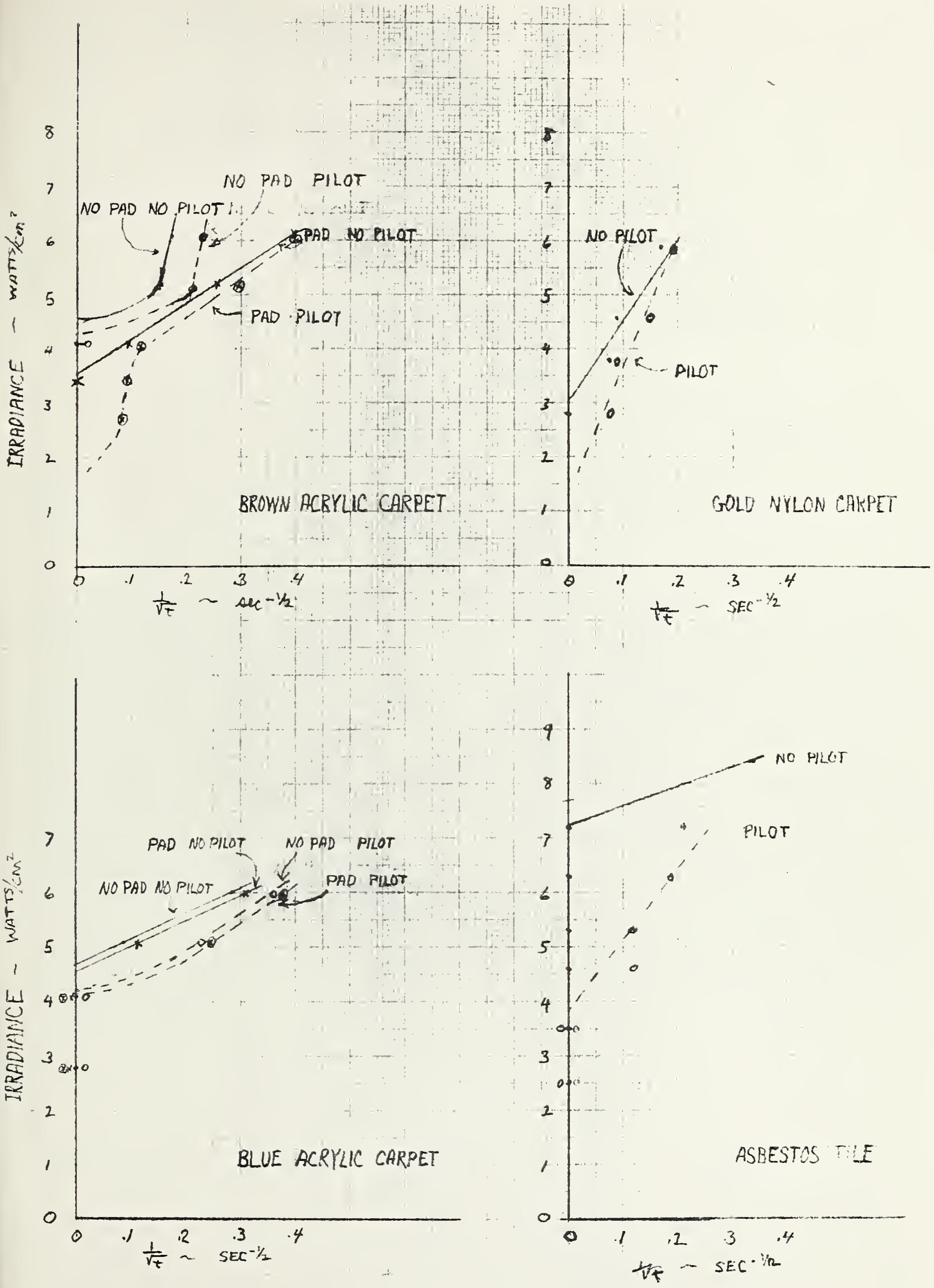


FIGURE 5 - PLOTS FOR ESTIMATING CRITICAL IRRADIANCE

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