TEST METHODOLOGY FOR EVALUATION OF FIREWORTHY AIRCRAFT SEAT CUSHIONS

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Abstract

Aircraft seat materials were evaluated in terms of their thermal performance. The materials were evaluated using (a) thermogravimetric analysis, (b) differential scanning calorimetry, (c) a modified NBS smoke chamber to determine the rate of mass loss and (d) the NASA T-3 apparatus to determine the thermal efficiency. In this paper, the modified NBS smoke chamber will be described in detail since it provided the most conclusive results. The NBS smoke chamber was modified to measure the weight loss of materials when exposed to a radiant heat source over the range of 2.5 to 7.5 W/cm^2. This chamber has been utilized to evaluate the thermal performance of various heat blocking layers utilized to protect the polyurethane cushioning foam used in aircraft seats. Various kinds of heat blocking layers were evaluated by monitoring the weight loss of miniature seat cushions when exposed to the radiant heat. The effectiveness of aluminized heat blocking systems was demonstrated when compared to conventional heat blocking layers such as neoprene. All heat blocking systems showed good fire protection capabilities when compared to the state-of-the-art, i.e., wool-nylon over polyurethane foam.

Introduction

One of the major fire threat potentials in commercial passenger aircrafts is the nonmetallic components in the passenger seats. The major components of aircraft passenger seats are the polymeric cushioning material and, to a lesser degree, the textile fabric covering; together they represent a large quantity of potentially combustible material. Each aircraft coach type passenger seat consists of about 2.37 kg of non-metallic material, the major component being the seat cushion. Since modern day wide-body passenger aircraft have from 275 to 500 passenger seats, the total amount of combustible polymeric material provides a severe threat to the environment in the cabin in case of either on-board interior fire or post-crash type fire which in addition involves jet fuel.

A major complication in research to develop fire resistant aircraft passenger seats, is to assure the laboratory method chosen simulates real life conditions in case of a fire scenario onboard an aircraft or a post-crash fire. In this study a non-flaming heat radiation condition was simulated. 7.6 cm x 7.6 cm samples made to resemble full-size seat cushions were tested for weight loss when exposed to different heat fluxes from an electrical heater. The measurements were conducted in a modified NBS smoke density chamber.

It has been shown (1,2,3,4) that the extremely rapid burning of aircraft seats is due to the polyurethane cushions of the seats. In order to protect the urethane foam from rapid degradation when exposed to heat, three different heat blocking layers were tested. Two were aluminized fabrics and one was neoprene type of material in two thicknesses. In all cases urethane foam was enveloped in a wool-nylon fabric.

Fabrics and foams put under a thermal load show a very complex behavior. Figure 1 illustrates the thermal behavior of a seat cushion with a heat blocking layer. When a heat blocking layer is introduced between the fabric and the foam, the complexity is expected to increase, especially if the heat blocking layer is an aluminized one as in some cases in this study. The protective mechanism for the urethane foam involves both conduction of the heat along the aluminum surface and heat re-radiation.

Description of Equipment

The test equipment for recording and processing of weight-loss data is shown in Figure 2. It consists of an NBS smoke chamber modified by the installation of an internal balance (ARBOR model #1206) connected to a HP5150A thermal printer, providing simultaneous print-outs of weight remaining and time elapsed. Data recorded on the printer was manually fed into a HP 9835 computer, processed and eventually plotted on a HP 9872 plotter (i.e. weight remaining versus time elapsed). Also used was a HP3455A millivoltmeter for the calibration of the chamber.

The NBS smoke chamber was modified two fold: (a) to permit a heat flux of 2.5-7.5 W/cm^2 and (b) to monitor weight loss of a sample on a continuous basis.

The NBS test procedure (5) employs a nichrome wire heater to provide a nominal exposure on the specimen surface of 2.5 W/cm^2 which corresponds to the radiation from a black-body at approximately 540°C. To simulate thermal radiation exposure from higher temperature sources, a heater capable of yielding a high radiant flux on the face of the sample was utilized. This heater is available from Deltech Inc. This heater is capable of providing a heat flux of 2.5-10 W/cm^2.

Two burning conditions are simulated by the chamber: radiant heating in the absence of ignition, and flaming combustion in the presence of supporting radiation. During test runs, toxic effluents may be produced; therefore an external exhaust system was connected to the chamber. In order to provide protection against sudden pressure increases the chamber is equipped with a safety blowout panel. Also, for added safety, a closed air breathing system was installed for use while operating and cleaning the chamber.

In this study, only the radiant heating condition was being simulated, using this electrical heater as the radiant heat source. The heater was calibrated at least once a week using a water-cooled calorimeter connected to a millivoltmeter. Using the calibration curve provided by the manufacturer, the voltages which provided the desired heat fluxes (2.5, 5.0 and 7.5 W/cm^2), were determined.

When the chamber was heated up to the desired temperature (and heat flux), an asbestos shield was slid in front of the heater. This prevented the adjacent chamber wall from over-heating and thus affecting the data. As mentioned earlier this NBS smoke chamber was modified for recording of weight loss data by the installation of an electronic balance. The balance was mounted on top of the chamber with its weighing "hook" entering the chamber through a small opening. The chamber was then resealed by enclosing the balance in a metal container which was tightly fitted to the chamber roof. This balance was well suited to perform this particular task, because of several of its features. It provides a digital output to allow weighing results to be transferred to external electronic equipment (in this case the thermal printer), below the balance weighing, which was essential, since the severe conditions inside the chamber during test runs were likely to corrode or otherwise destroy any weighing apparatus mounted inside the chamber. Also, the fact that it ascertains weight by measuring the electrical energy required to maintain equilibrium with the weight of the mass being measured,instead of by measuring mechanical displacement, makes it well suited to measure a continuous weight loss.

A desktop computer was used for data acquisition and storage. It provided an enhanced version of BASIC which includes an extensive array of error messages to simplify programming. The computer was equipped with an 80 by 24-character CRT (Cathode Ray Tube) display and a 16-character thermal printer for hard-copy printouts. One program written and used during the weight loss testing was PLOT wt. The program collected data from any test run stored on a data-file (the computer has a tape cartridge which reads the files from cassette tapes), calculated the weight remaining in %, and plotted the results versus time on a plotter hooked up to the computer.

Description of Materials

The materials used in this study are shown in Tables 1 and 2. Three types of foams were used and four types of heat blocking layers. The densities of the foams and the fire blocker layers are also shown in Tables 1 and 2, with an estimate of the seat weight when constructed from these materials. Two flexible polyurethane foams were used, a fire-retarded and a non-fire retarded. The composition of the non-fire retarded was as follows:

Component	Parts by weight
Polyoxypropylene glycol (3000 m.w.)	100.0
Tolylene diisocyanate (80:20 isomers)	105
Water	2.9
Silicone surfactant	1.0
Triethylenediamine	0.25
Stannous octoate	0.35

The composition of the fire retarded was not known but it may have contained an organo-halide compound as a fire-retardant. The composition of the polyimide foam used has been described previously (6).

The fire blocking materials used are shown in Table 3.

The Norfab® 11 HT-26-A is a woven mixture of poly(p-phenylene terephthalamide), an aromatic polyamide and a modified phenolic fabric. The fabric was aluminized on one side. The Preox® 1100-4 was based on heat stabilized polyacrylonitrile which was woven and aluminized on one side.

The mechanism of fire protection of these materials depends previously on heat re-radiation and thermal conduction along the aluminum layer. The Vonar® 2, and 3 layers used, are primarily transpirational-cooling heat blocking layers. This compound is a neoprene foam with added $Al(OH)_3$ as a fire retardant, attached to a cotton backing. The mechanism by which the foam works is based on the heat of vaporization of the foam absorbed, thereby cooling its surroundings.

Thermal Characterization

In order to thermally characterize the materials tested, Thermogravimetric Analysis (TGA) and Differential Scanning Calorimetry (DSC) were performed.

In TGA the samples are heated at a constant heating rate in either oxygen or nitrogen atmosphere and the weight loss recorded. The polymer decomposition temperature (PDT), the temperature where the mass loss rate is the highest (max $\frac{d\,(wt)}{dt}$), the temperature of complete pyrolysis and the char yield in % are then determined as shown in Figure 4. The results are shown in Table 4.

In DSC the electrical energy required to maintain thermal equillibrium between the sample and an inert reference, is measured. By calculating the peak area on the chart, the endo- or exothermity of transitions can be determined. This was done automatically on the analyzer used which was equipped with a micro-processor and a floppy-disc memory. One analysis is shown in Figure 5 and the results in Table 5.

Both TGA's and DSC's were performed on DuPont® thermal analyzers.

Radiant Panel Test Results

All of the configurations shown in Table 1 were tested in the modified NBS smoke chamber to determine the rate of mass loss. Prior to performing the weight loss experiments (radiant panel tests) on the complete sandwich cushions, weight loss experiments on individual components such as fabric, heat blocking layer and foam, were made. No detailed results of these tests will be reported in this paper, but a few observations might be worthwhile to report.

When, assuming that fire performance of the components were additive phenomena, the total weight loss of the components were added together and compared with a sandwich tested under the same conditions, no correlation was found. In some cases, testing with the highly flammable foam actually improved the performance of the sample compared to testing the heat blocking layer alone. The decorative fabric proved to have little influence on the performance of the heat blocking layer. Heat readily went through and the fabric burned off rapidly.

After performing these initial experiments, it was clear that the weight loss profile of the samples could not alone provide a good criteria to determine the efficiency of the heat block. The criteria chosen was the amount of gas originating from the urethane foam injected into the air. The possible steps for the thermal degradation of the flexible urethane foam are shown in Figure 6.

After extensive initial testing, it was determined to test the sandwich configurations shown in Tables 1 & 2. Configuration #367 represents the state-of-the-art, i.e. the seat configuration presently used in the commercial fleet.

All samples shown in Tables 1 & 2, were sandwich structures made up as miniature seat cushions. The sandwiches consisted of a cushioning foam inside a wrapping of a heat blocking layer and a wool-nylon fabric as shown in Figure 3. To simplify the assembly, the heat blocking layer and the fabric were fixed together with a stapler followed by wrapping them around the foam and then fixed in place by sewing the edges together with thread.

Prior to assembly, the individual components were weighed on an external balance and the results, together with other relevant data were recorded. The samples were mounted in the chamber as shown in Figure 3. In order to prevent the heat from the heater from reaching the sample before the start of the test, a special asbestos shield was made. The shield slides on a steel bar and can be moved with a handle from the outside which also enables the operator to terminate the test without opening the chamber door and exposing himself to the toxic effluents.

The test was initiated by pushing the asbestos shield into its far position, thus exposing the sample to the heat flux from the heater and by starting the thermal printer. The test then ran for the decided length of time (1,2,3,4 or 5 minutes) and was terminated by pulling the asbestos shield in front of the sample. When a stable reading on the printer was obtained (indicating that no more gases originating from the foam were injected into the chamber from the sample), the printer was shut off. After the chamber was completely purged from smoke the sample was taken out and allowed to cool down to room temperature.

The burned area on the side of the sample facing the heater was subsequently measured in order to standardize the test. This area was normally around 5 cm x 5 cm and since the sample size was 7.5 cm x 7.5 cm, this was thought to minimize edge effects (that is changes in the heat spread pattern through the sample caused by the heat blocking layer folded around the sides of the foam cushion).

Finally, the sample was cut open and the remainder of the foam scraped free from the heat blocking layer and weighed on the external balance. This was done to determine the amount of foam that had been vaporized and injected into the surroundings.

Results and Discussion

The samples shown in Tables 1 and 2 were exposed to heat flux levels of 2.5, 5.0 and 7.5 W/cm^2. After the weight loss of the urethane foam was determined, as described previously, the specific mass injection rate was calculated as follows:

$$\dot{m} = \frac{\text{(weight loss)}}{\text{(area of sample exposed to heat) x (time elapsed)}} \left[\frac{g}{cm^2, s}\right]$$

The area exposed to heat was brought into the equation in an effort to standardize the test runs in terms of how much radiant energy that had actually been absorbed by the sample.

Then the figure of merit was calculated as follows:

$$\varepsilon = \frac{\text{(heat flux)}}{\text{(specific mass injection rate)}} \left[\frac{W, s}{g}\right]$$

The objective was to determine a heat blocking system showing equal or better performance than the Vonar® 3 system. Therefore, the ε-value at every test condition for Vonar® 3 was assigned to be ε_o. Then the relative figure of merit was calculated as follows:

$$\varepsilon_{rel} = \frac{\varepsilon}{\varepsilon_o}$$

The mass loss data for fire retarded and non-fire retarded urethane is shown in Tables 6 and 7, respectively.

The rationale for ranking materials at the 2 minute exposure time is related to full scale tests conducted previously (1, 2, 3, 4) and is a critical time at which evacuation must occur in an aircraft in case of a post crash fire.

In case of a post crash fire outside the passenger compartment (e.g., a fire in the fuel system), the seat system inside the cabin will be exposed to severe heat radiation. The foam cushions will start to inject toxic gases into the cabin as simulated in this study. 2 minutes is thought to be an accurate time limit for the survivability of the passengers exposed to these conditions. Data at 2 minutes are also displayed graphically in Figures 7 and 8. Figures 9 and 10 show the figure of merit as a function of heat flux at 2 minutes exposure. It can be seen in Figure 9 that the figure of merit at a heat flux of 2.5 W/cm^2 for the aluminized fabrics (Preox^R 1100-4 and Norfab^R 11HT-26-Al) is higher than either the Vonar^R 2 and 3, at 5.0 W/cm^2 they are approximately equal, and at 7.5 W/cm^2 that both Vonar^R 2 and 3 show a higher figure of merit than the aluminized fabrics.

The method of protection for the urethane foam changes as the heat flux increases whereby the transpirtational cooling effect of the Vonar^R is more effective at the higher heat flux range. The mode of urethane protection using the aluminized fabric is primarily due to re-radiation and thermal conduction. At 5 W/cm^2 all heat blocking materials were approximately equally effective, but, it should be remembered that the weight penalty of the Vonar^R materials is excessive as shown in Table 1. The aluminized fabrics were equally effective in protecting both the fire retarded and the non-fire retarded urethane foams as shown in Figures 9 and 10.

To obtain a general view of the heat blocking performance of different heat blocking layers, the average mass injection rates of experiments with 1, 2,3,4 and 5 minutes elapsed time was calculated and is shown in Tables 8 and 9. Figures 11 and 12 show the figure of merit as a function of heat flux at average exposure time.

Essentially the same results are observed as the measurements indicated at 2 minutes.

The usage of a heat blocking layer in aircraft seats, significantly improves the performance of the seat when exposed to heat radiation. This is true at all heat flux ranges tested. Samples representing the state-of-the-art (#367) were completely burned after only a short exoosure time and it was not possible to test these samples at 7.5 W/cm^2. When it comes to ranking between the different heat blocking layers, the results are more ambiguous. It is true that Vonar^R R performed better at the higher heat flux level (7.5 W/cm^2) but at the heat level of most interest (5.0 W/cm^2) it was approximately equal to the other heat blocking layers. The heat flux of 5.0 W/cm^2 is considered an average heat flux level in the interior of the aircraft as shown in simulated full scale fire tests conducted previously (2). There was no signfiicant differences observed in the fire blocking efficiency of the layers whether a non-fire retarded or a fire retarded urethane foam was used. At 5.0 W/cm^2 the efficiency of the Vonar^R 3 was higher with the non-fire retarded foam while the aluminized fabric showed a higher efficiency with the same foam at 7.5 W/cm^2 as shown in Figures 9 and 10. It is not precisely known whether this difference is due to the differences between the two foams or is due to the different mechanism of the heat blocking layers, i.e. transpiration or re-radiation cooling. Neither one of the two aluminized fabrics show outstanding performance in comparison with each other. When the complexities of the effect of the underlying foam are taken into consideration, it is reasonable to rank them as giving equal fire protection. For example, in the case of the fire-retarded foam, the Norfab^R gives excellent fire protection at the low (2.5 W/cm^2) heat flux in comparison with the Preox^R 1100-4 fabric as shown in Figure 11. At 5.0 W/cm^2, they are equal and at 7.5 W/cm^2 the situation is reversed when using the non-fire retarded urethane foam. The Norfab^R

11HT-26-AL fabric exhibited better performance at all heat flux levels when tested with the non-fire-retarded foam as shown in Figure 12.

The 181-E glass fabric indicated the lowest fire protection at 5.0 W/cm^2 when the exposure time is averaged over 5 min as shown in Figure 10. At the (2) minutes interval, its performance was approximately the same as the other fabrics as shown in Figure 9.

A study of the cost/weight penalty of different heat blocking systems (7) shows that the re-radiation-cooling systems or aluminized fabrics provide far better cost-efficiency than the transpirational-cooling systems such as Vonar^R 3. These results and the equality in fire protection performance shown in this study, points in favor of aluminized fabrics for possible use as a cost efficient heat protection system for the urethane foam.

Several difficulties were encountered when conducting the radiant panel tests. The major complications were: (a) the experiments were designed to measure the amount of gas, originating from the urethane foam, injected into the air. To really detetmine how much gas due to urethane decomposition that is produced, the gases need to be analyzed (preferably by GC-MS methods). This could not be done at the time of this study, (b) some of the gas produced from combustion of urethane foam may be trapped in the heat blocking layer. The amount of gas trapped is extremely difficult to measure. The initial experiments showed that, in some cases, the difference in the weight loss of the HBL (with and without a urethane foam core) was greater than the weight of foam lossed; hence the weight of gas trapped could not be measured. This problem was corrected by perforating the fabric on the back surface to allow venting of the gas and, (c) there was a problem with the quenching period. At 7.5 W/cm^2 this might well be the dominant mechanism for weight loss of the urethane foam for shorter tests runs. It is desirable that a method to instantly quench the sample be developed for testing at heat fluxes of 7.5 W/cm^2 and higher.

Thermal Efficiency

The NASA-Ames T-3 thermal test (8) was used to determine the fire endurance of the seat configurations shown in Tables 1 and 2. In this test, specimens measuring 25 cm x 25 cm x 5.0 cm thick were mounted in the chamber and thermocoupled on the backface of the specimen. The flames from an oil burner supplied with approximately 5 liters/hour of JP-4 jet aviation fuel provided heat flux to the front face of the sample in the range of 10.4 - 11.9 W/cm^2. The test results were inconclusive since the temperature rise in most of the specimens was extremely rapid and it was very difficult to determine small differences in fire blocking efficiency of the various layers. Additional work will be performed to reduce the level of heat flux in the chamber in order to be able to differentiate easier among the samples.

Conclusions

It is understood that a great number of mechanisms govern the performance of fabrics and foams when exposed to heat radiation. Finding these mechanisms and measuring their individual parameters, is extremely difficult. In this study efforts were directed towards determining the heat protection provided by different heat blocking layers, relative to one another.

Some specific conclusions may be drawn from this study:

(a) Modified NBS smoke chamber provides a fairly accurate method for detecting small differences in specimen weight loss over a range of heat fluxes and time

(b) Aluminized thermally stable fabrics provide an effective means for providing thermal protection to flexible urethane foams

(c) Vonar^R 2 or 3 provided approximately equal thermal protection to F.R. urethane than the aluminized fabrics but at a significant weight penalty

(d) No significant differences were observed in the use of F.R. or N.F. urethane when protected with a fire blocking layer

(e) The efficiency of the foams to absorb heat per unit mass loss when protected with the heat blocking layer decreases significantly in the heating range of 2.5 - 5.0 W/cm^2, but remains unchanged or slightly increases in the range of 5.0 - 7.5 W/cm^2.

The results showed that the heat blocking systems studied provides significant improvement of the fire protection of aircraft seats compaired to the state-of-the-art (i.e. the seats presently used in the commercial fleet).

The results indicated that transpirtation- and re-radiation-cooling systems provided approximately equal fire protection. However, the high weight/cost penalty of the transpiration system favored the re-radiation systems (7).

The T-3 test is not suitable at its present operation to detect minor differences in heat blocking efficiency. Additional methods must be utilized in evaluating these and similar materials in order to establish a good correlation between these weight loss experiments and other more established or standard test methodologies.

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TABLE 1 COMPOSITE AIRCRAFT SEAT CONFIGURATIONS WITH F.R. URETHANE

SAMPLE NO. (1)	FIRE BLOCKING MATERIAL	AREAL DENSITY, Kg/m^2	FOAM	DENSITY, Kg/m^3	SEAT WEIGHT, g (2)	% Δ
367	NONE		F.R. URETHANE	29.9	2374	0
17	VONAR 3® COTTON	0.91	F.R. URETHANE	29.9	3935	+66
11	VONAR 2® COTTON	0.67	F.R. URETHANE	29.9	3525	+48
373	PREOX® 1100-4	0.39	F.R. URETHANE	29.9	3039	+28
376	NORFAB® 11HT-26-AL	0.40	F.R. URETHANE	29.9	3055	+29
377	181 E-GLASS	0.30	F.R. URETHANE	29.9	2888	+22

(1) ALL CONFIGURATIONS COVERED WITH WOOL-NYLON FABRIC, 0.47 Kg/m^2

(2) ESTIMATED WEIGHT OF COACH SEAT CONSISTING OF BOTTOM CUSHION (50.8 × 55.9 × 10.2 cm), BACK CUSHION (45.7 × 50.8 × 5.1 cm) AND HEAD REST (45.7 × 20.3 × 12.7 cm)

Table 2 COMPOSITE AIRCRAFT SEAT CONFIGURATIONS WITH N.F. URETHANE AND POLYIMIDE

SAMPLE NO. (1)	FIRE BLOCKING MATERIAL	AREAL DENSITY, Kg/m^2	FOAM	DENSITY, Kg/m^3	SEAT WEIGHT, g (2)	% Δ
15	VONAR 3® COTTON	0.91	N.F. URETHANE	16.0 (23.2)	3205 (3583)	+35 (+51)
372	PREOX® 1100-4	0.39	N.F. URETHANE	16.0 (23.2)	2309 (2686)	-2.7 (+13)
375	NORFAB® 11HT-26-AL	0.40	N.F. URETHANE	16.0 (23.2)	2325 (2703)	-2.1 (+14)
289	NONE		POLYIMIDE	19.2	1812	-24

(1) ALL CONFIGURATIONS COVERED WITH WOOL-NYLON FABRIC, 0.47 Kg/m^2

(2) ESTIMATED WEIGHT OF COACH SEAT CONSISTING OF BOTTOM CUSHION (50.8 × 55.9 × 10.2 cm), BACK CUSHION (45.7 × 50.8 × 5.1 cm) AND HEAD REST (45.7 × 20.3 × 12.7 cm)

TABLE 3 **CANDIDATE HEAT BLOCKING LAYERS FOR SEAT CUSHIONS**

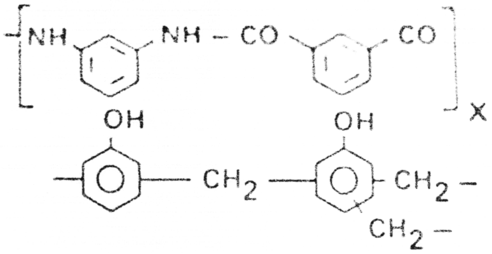
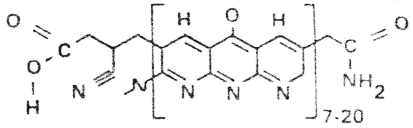
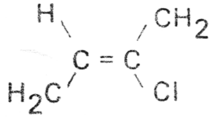
FIRE BLOCKER	AREAL DENSITY kg/m²	COMPOSITION	TYPICAL STRUCTURE
NORFAB® 11HT 26 AL ALUMINIZED	0.40	70% KEVLAR® 25% NOMEX® 5% KYNOL®	POLY (p-PHENYLENE TEREPHTHALAMIDE) 
PREOX® 1100-4 ALUMINIZED	0.39	HEAT STABILIZED POLYACRYLONITRILE	
VONAR 2® COTTON	0.67	POLYCHLOROPRENE	
VONAR 3® COTTON	0.91		
181 E-GLASS FABRIC, SATIN WEAVE	0.30	GLASS	SiO_2

TABLE 4

THERMOGRAVIMETRIC ANALYSIS

SAMPLE NAME	PDT, °C		MAX $\frac{d\,(wt)}{dt}$ °C		COMPL. PYROLYSIS, °C		CHAR YIELD, %	
	AIR	N^2	AIR	N^2	AIR	N^2	AIR	N^2
WOOL-NYLON	272	273	405	339	538	440	3	23
PREOX® 1100-4	276	315	610	350	657	447	8	58
NORFAB® 11HT-26-AL	440	440	590	560	612	610	34	61
VONAR® 2, 3	278	276	385	352	600	517	36	47
N.F. URETHANE	278	263	320	338	340	410	2	5
F.R. URETHANE	268	250	331	380	381	401	11	6
POLYIMIDE	384	450	563	585	659	596	8	48

TABLE 5 DIFFERENTIAL SCANNING CALORIMETRY

SAMPLE NAME	AIR		N_2	
	ΔH, J/G	PEAK TEMP., °C	ΔH, J/G	PEAK TEMP., °C
WOOL-NYLON	137 48	200 299	273	199
PREOX® 1100-4	188	356	174	351
NORFAB® 11HT-26-AL	—	—	—	—
VONAR® 2, 3	-300 317	350 377	-666 122	333 363
N.F. URETHANE	4970	386	2105	408
F.R. URETHANE	2264	356	—	—
POLYIMIDE	366	386	—	—

COMMENTS: POSITIVE ΔH-VALUES INDICATE EXOTHERMIC REACTIONS (i.e. HEAT EVOLVED IN THE TRANSITION), NEGATIVE ΔH-VALUES INDICATE ENDOTHERMIC REACTION (i.e. HEAT ABSORBED IN THE TRANSITION)

"—" INDICATES THAT NO TRANSITIONS WERE OBSERVED WITHIN THE RANGE OF THIS DSC-CELL (0-550°C)

TABLE 6. MASS LOSS DATA OF F.R. URETHANE AT 2 min FROM RADIANT PANEL TEST

CONFIGURATION NUMBER	DESCRIPTION OF SAMPLE	SPECIFIC MASS INJECTION RATE $\dot{M}\ \frac{10^{-5}\,g}{cm^2\,sec}$			FIGURE OF MERIT $\epsilon = \dot{q}/\dot{M}\ \frac{10^4\,W\,sec}{g}$			RELATIVE FIGURE OF MERIT (1) $\epsilon/\epsilon_0 \times 100\%$		
		2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2	2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2	2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2
367	WOOL-NYLON/F.R. URETHANE	13	61	∞	1.9	0.8	N/A	32	42	N/A
17	WOOL-NYLON/VONAR 3® COTTON/F.R. URETHANE	4.1	27	28	6.0	1.9	2.7	100	100	100
11	WOOL-NYLON/VONAR 2® COTTON/F.R. URETHANE	4.0	21	50	6.3	2.3	1.5	105	121	56
373	WOOL-NYLON/PREOX® 1100-4/F.R. URETHANE	3.3	29	59	7.7	1.7	1.3	128	89	48
376	WOOL-NYLON/NORFAB® 11HT-26-AL/F.R. URETHANE	2.7	24	66	9.4	2.1	1.1	155	111	0.41
377	WOOL-NYLON/181 E-GLASS/ F.R. URETHANE	4.0	25	∞	6.3	2.0	N/A	105	105	N/A

(1) SCALED RELATIVE TO ϵ_0 FOR VONAR 3® HEAT BLOCKING LAYER WITH A VALUE OF ϵ_0 AS 100

TABLE 7. MASS LOSS DATA OF N.F. URETHANE AT 2 min FROM RADIANT PANEL TEST

CONFIGURATION NUMBER	DESCRIPTION OF SAMPLE	SPECIFIC MASS INJECTION RATE $\dot{M}$ $\frac{10^{-5}\ g}{cm^2\ sec}$			FIGURE OF MERIT $\epsilon = \dot{q}/\dot{M}$ $\frac{10^4\ W\ sec}{g}$			RELATIVE FIGURE OF MERIT (1) $\epsilon/\epsilon_0 \times 100\%$		
		2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2	2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2	2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2
15	WOOL-NYLON/VONAR 3® COTTON/N.F. URETHANE	1.5	27	28	19	1.9	2.7	317	100	100
372	WOOL-NYLON/PREOX® 1100-4/N.F. URETHANE	3.3	20	52	7.7	2.5	1.4	128	132	52
375	WOOL-NYLON/NORFAB® 11HT-26-AL/N.F. URETHANE	1.2	11	20	21	4.5	3.8	350	240	140
289	WOOL-NYLON/POLYIMIDE	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A

(1) SCALED RELATIVE TO ϵ_0 FOR VONAR 3® HEAT BLOCKING LAYER WITH A VALUE OF ϵ_0 AS 100

TABLE 8 MASS LOSS DATA OF F.R. URETHANE AVERAGED OVER TIME FROM RADIANT PANEL TEST

CONFIGURATION NUMBER	DESCRIPTION OF SAMPLE	SPECIFIC MASS INJECTION RATE $\dot{M}$ $\frac{10^{-5}\,g}{cm^2\,sec}$			FIGURE OF MERIT $\epsilon = \dot{q}/\dot{M}$ $\frac{10^4\,W\,sec}{g}$			RELATIVE FIGURE OF MERIT (1) $\epsilon/\epsilon_0 \times 100\%$		
		2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2	2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2	2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2
367	WOOL-NYLON/F.R. URETHANE	50	66	N/A	0.48	0.76	N/A	8	35	N/A
17	WOOL-NYLON/VONAR 3® COTTON/F.R. URETHANE	4.2	23	27	5.9	2.2	2.8	100	100	100
11	WOOL-NYLON VONAR 2® COTTON/F.R. URETHANE	3.9	21	47	6.4	2.3	1.6	108	104	57
373	WOOL-NYLON/PREOX® 1100-4/F.R. URETHANE	3.3	17	35	7.6	3.0	2.1	128	136	75
376	WOOL-NYLON NORFAB® 11HT-26-AL/F.R. URETHANE	2.2	16	55	11	3.1	1.4	186	141	50
377	WOOL-NYLON/181 E-GLASS/ F.R. URETHANE	3.5	33	N/A	7.1	1.5	N/A	120	68	N/A

(1) SCALED RELATIVE TO ϵ_0 FOR VONAR 3® HEAT BLOCKING LAYER WITH A VALUE OF ϵ_0 AS 100

TABLE 9. MASS LOSS DATA OF N.F. URETHANE AVERAGED OVER TIME FROM RADIANT PANEL TEST

CONFIGURATION NUMBER	DESCRIPTION OF SAMPLE	SPECIFIC MASS INJECTION RATE $\dot{M}\ \frac{10^{-5}\ g}{cm^2\ sec}$			FIGURE OF MERIT $\epsilon = \dot{q}/\dot{M}\ \frac{10^4\ W\ sec}{g}$			RELATIVE FIGURE OF MERIT (1) $\epsilon/\epsilon_0 \times 100\%$		
		2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2	2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2	2.5 W/cm^2	5.0 W/cm^2	7.5 W/cm^2
15	WOOL-NYLON/VONAR 3® COTTON/N.F. URETHANE	2.8	22	28	8.9	2.3	2.7	1.49	105	96
372	WOOL-NYLON/PREOX® 1100-4/N.F. URETHANE	4.9	29	30	5.1	1.7	2.5	86	77	89
375	WOOL-NYLON/NORFAB® 11HT-26-AL/N.F. URETHANE	3.0	12	19	8.4	4.1	3.9	142	186	140
289	WOOL-NYLON/POLYIMIDE	0	0	0	N/A	N/A	N/A	N/A	N/A	N/A

(1) SCALED RELATIVE TO ϵ_0 FOR VONAR 3® HEAT BLOCKING LAYER WITH A VALUE OF ϵ_0 AS 100

FIGURE 1 BEHAVIOR OF ALUMINIZED FABRIC/FOAM ASSEMBLY UNDER ~~NORMAL~~ THERMAL LOADS

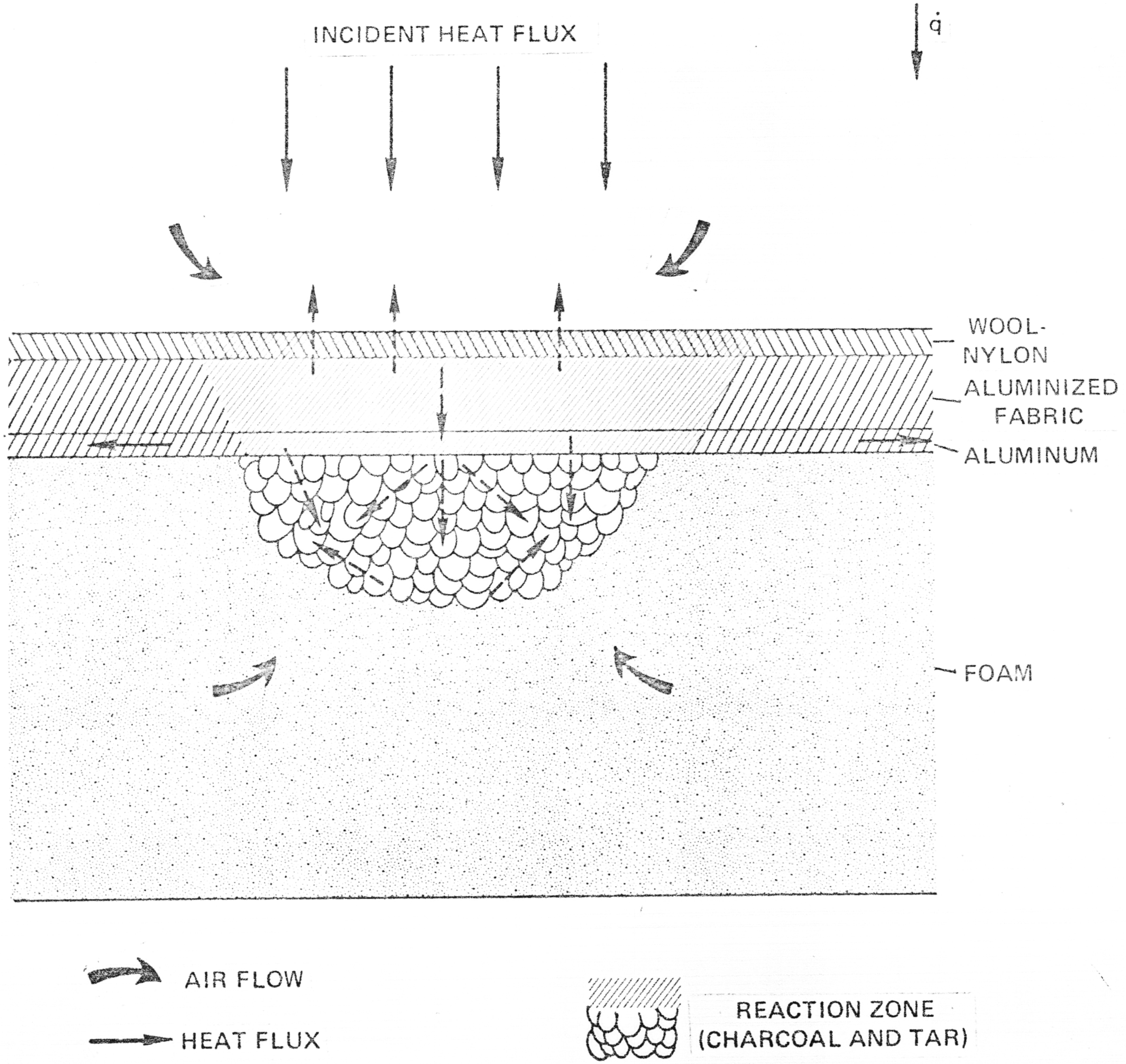
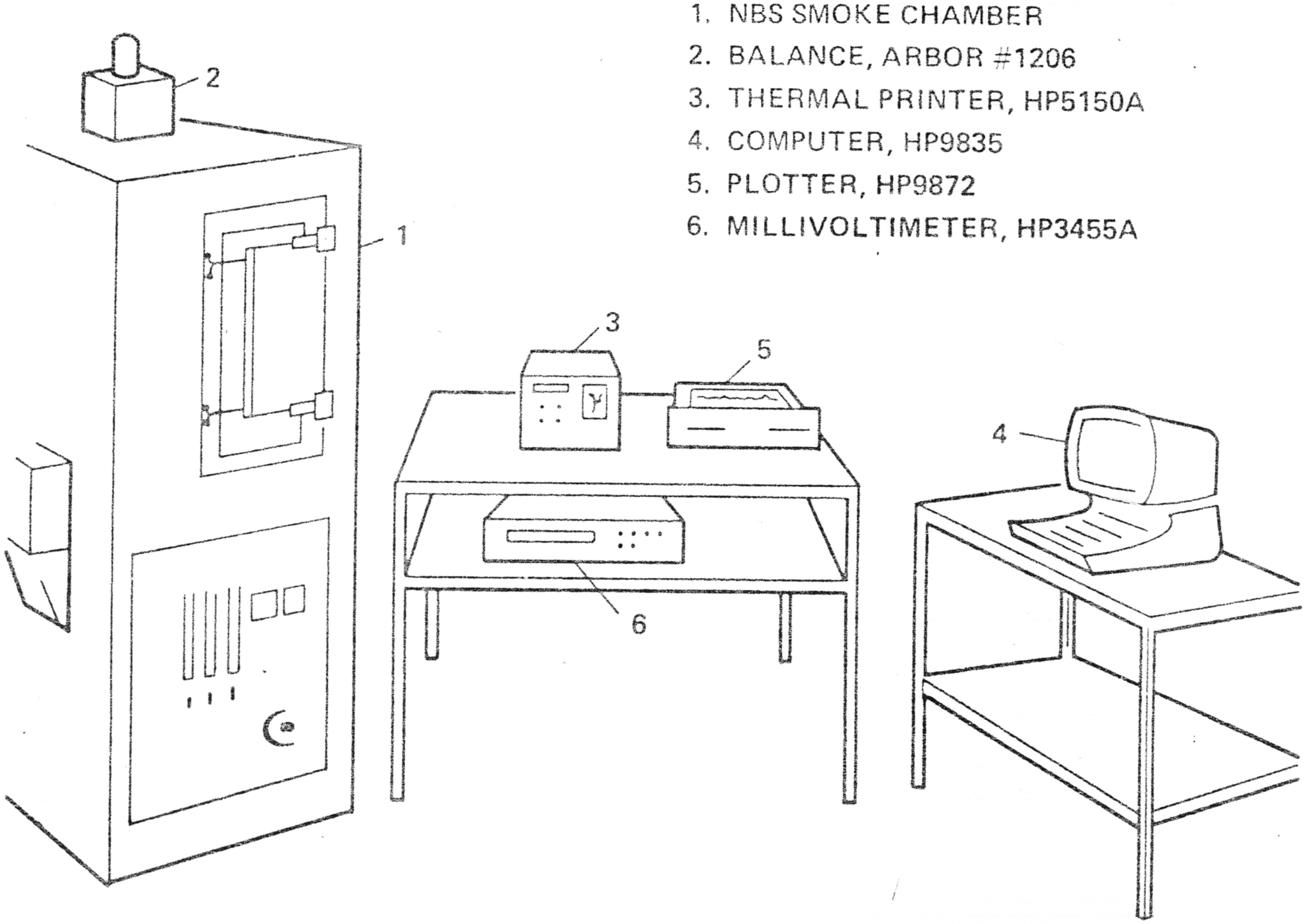


FIGURE 2. **EQUIPMENT FOR WEIGHT-LOSS DATA**



1. NBS SMOKE CHAMBER
2. BALANCE, ARBOR #1206
3. THERMAL PRINTER, HP5150A
4. COMPUTER, HP9835
5. PLOTTER, HP9872
6. MILLIVOLTIMETER, HP3455A

FIGURE 3 **SAMPLE CONFIGURATION**

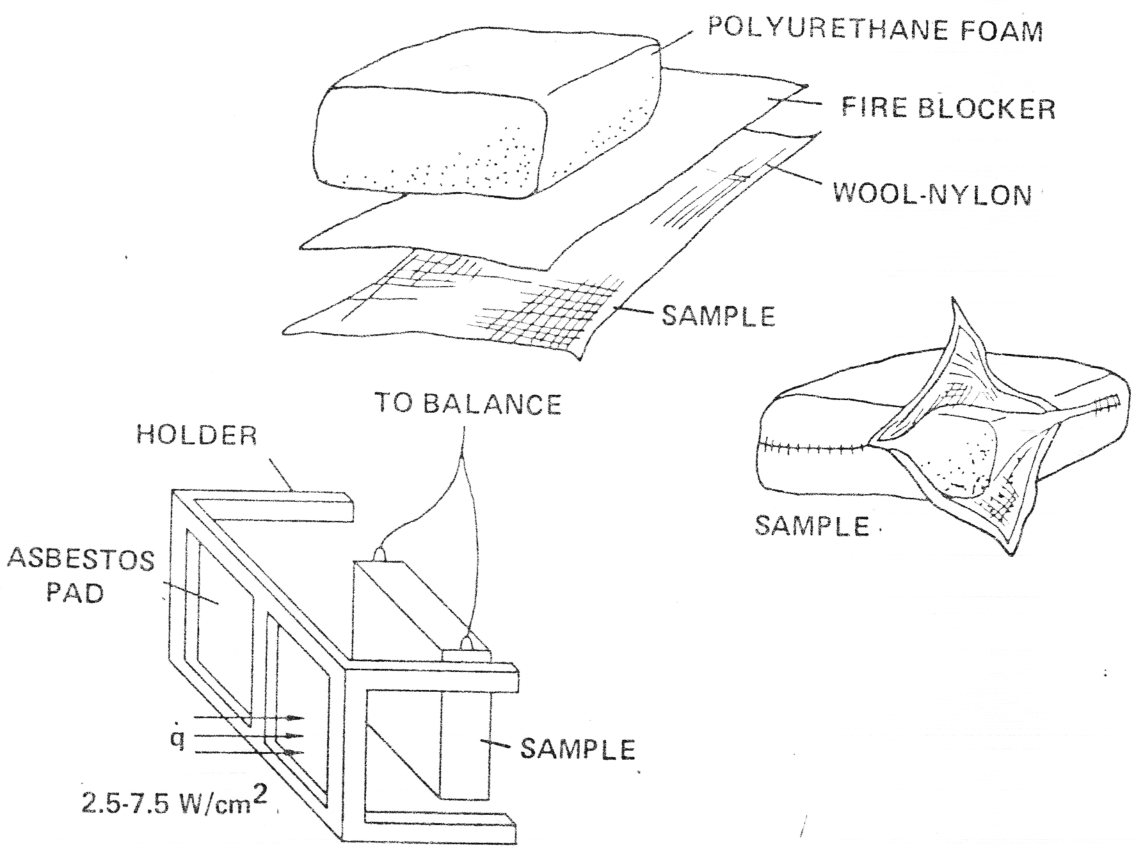


FIGURE 4. **TYPICAL THERMOGRAM**

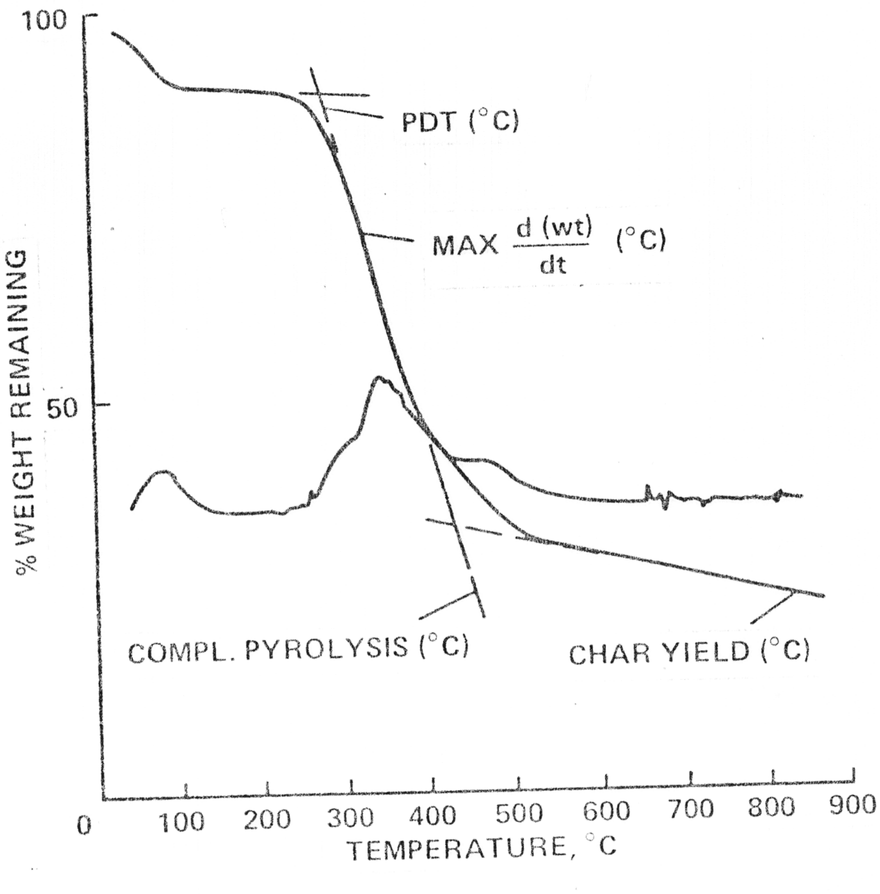


FIGURE 5.

DIFFERENTIAL SCANNING CALORIMETRY OF VONAR® 2

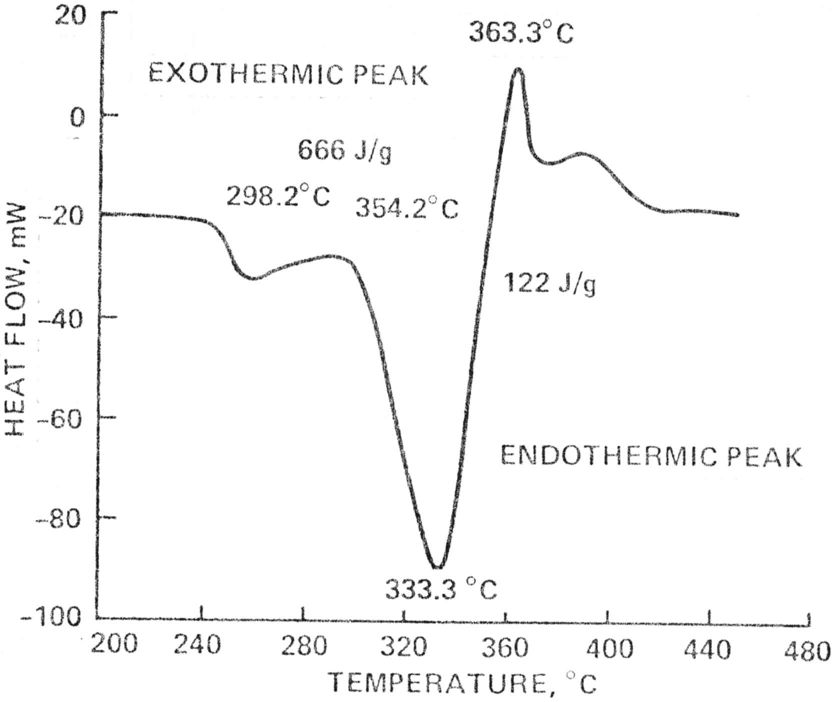
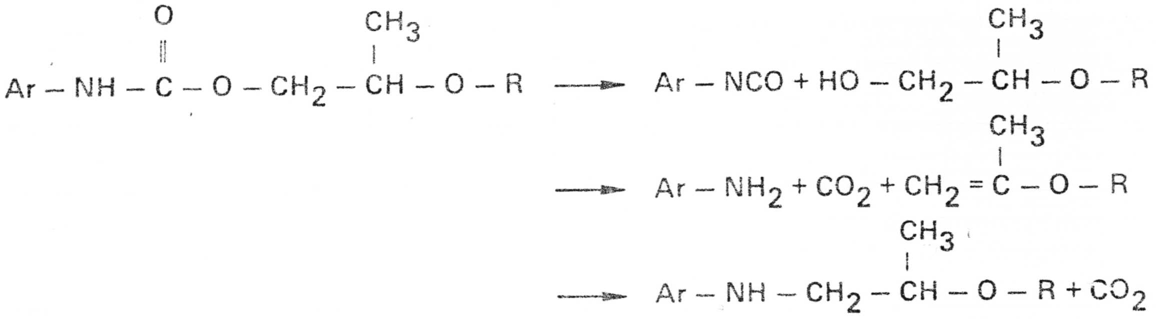


FIGURE 6. **THERMAL DEGRADATION OF FLEXIBLE POLYURETHANE FOAMS**



$$\mathrm{Ar-NH-\overset{\overset{O}{\|}}{C}-O-CH_2-\overset{\overset{CH_3}{|}}{CH}-O-R \longrightarrow Ar-NCO+HO-CH_2-\overset{\overset{CH_3}{|}}{CH}-O-R} \quad (1)$$

$$\mathrm{\longrightarrow Ar-NH_2+CO_2+CH_2=\overset{\overset{CH_3}{|}}{C}-O-R} \quad (2)$$

$$\mathrm{\longrightarrow Ar-NH-CH_2-\overset{\overset{CH_3}{|}}{CH}-O-R+CO_2} \quad (3)$$

FIGURE 7 **SPECIFIC MASS INJECTION RATE OF F.R. URETHANE AT VARIOUS HEAT FLUX LEVELS AT 2 min**

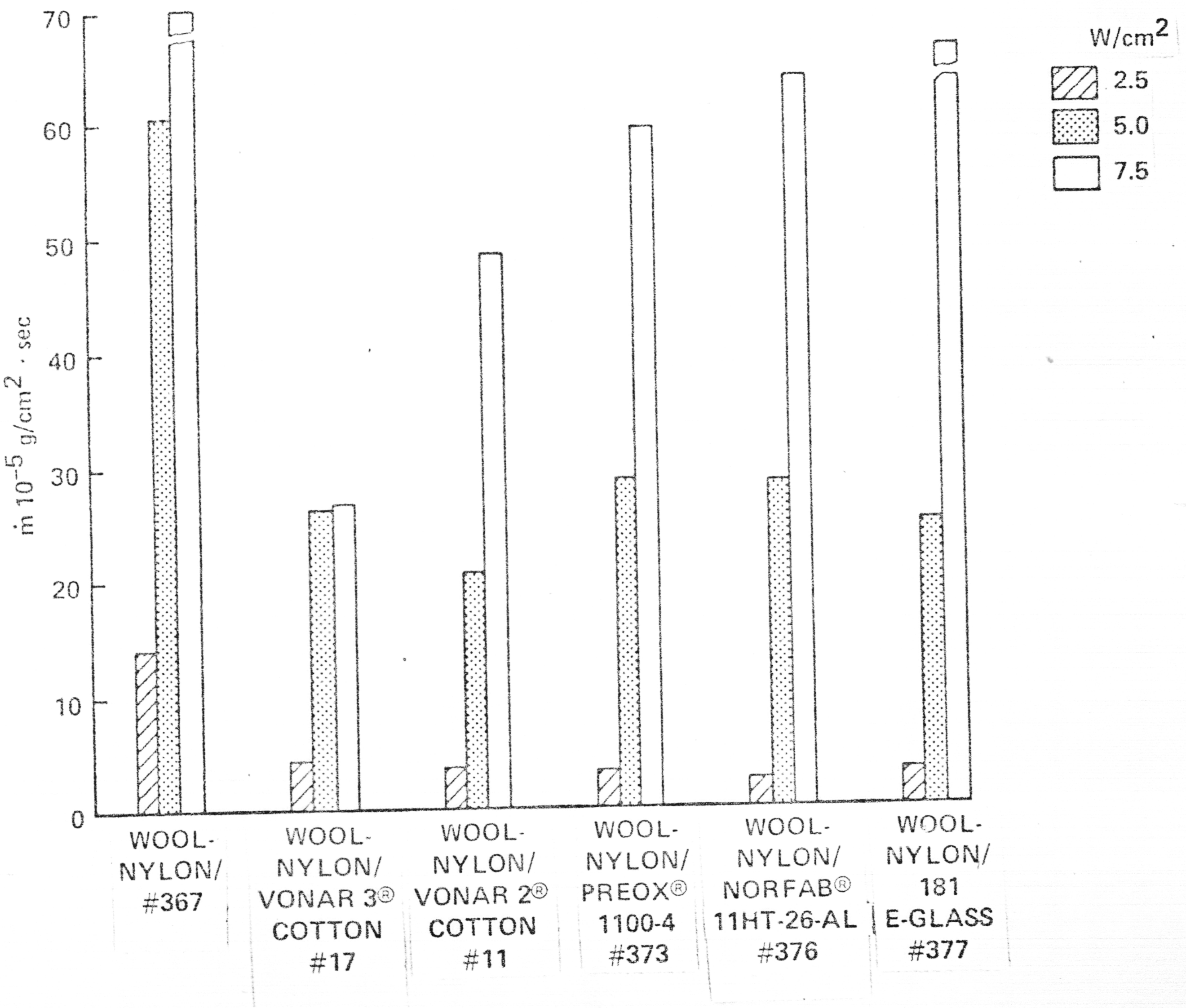


FIGURE 8. SPECIFIC MASS INJECTION RATE OF N.F. URETHANE AT VARIOUS HEAT FLUX LEVELS AT 2 min

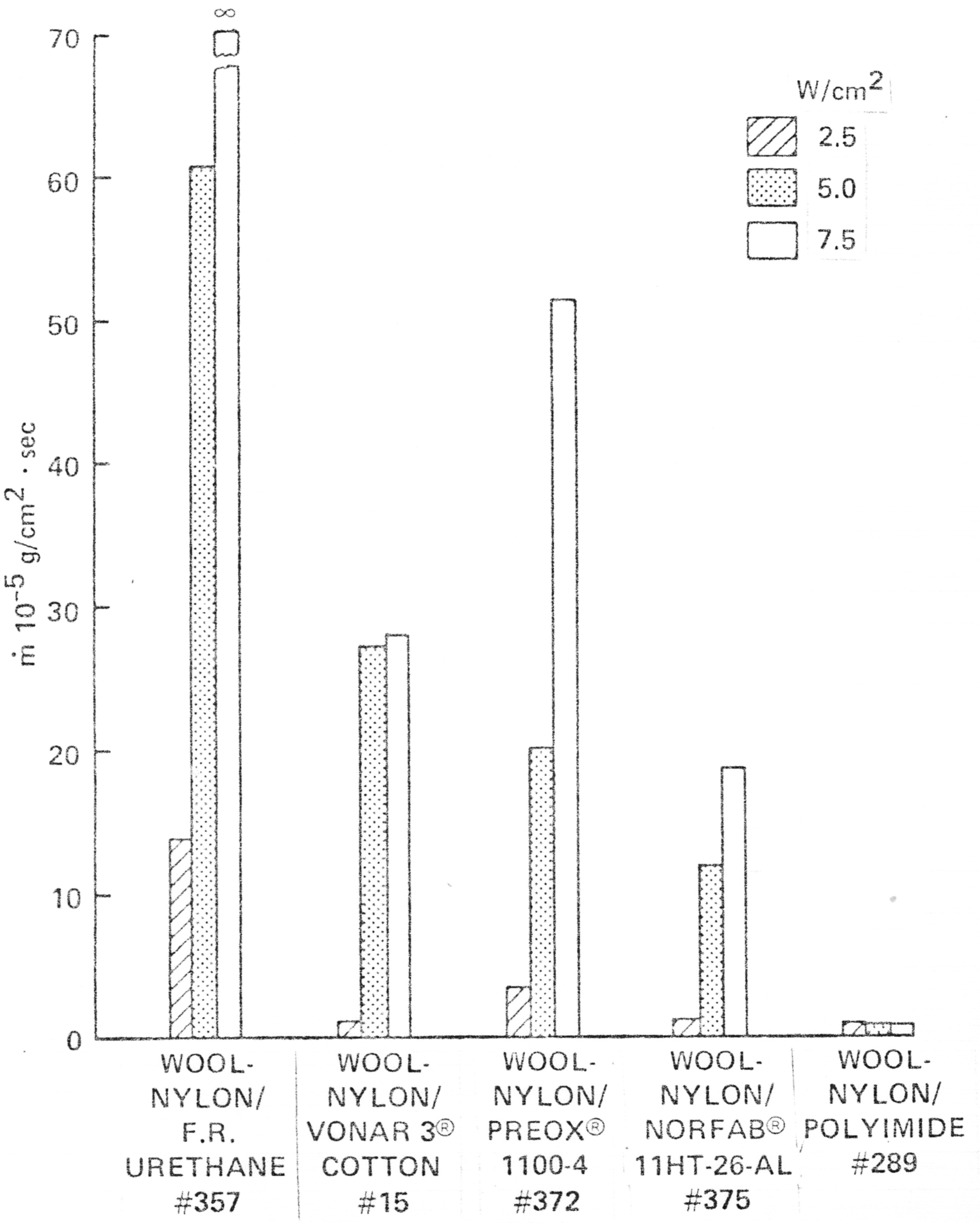
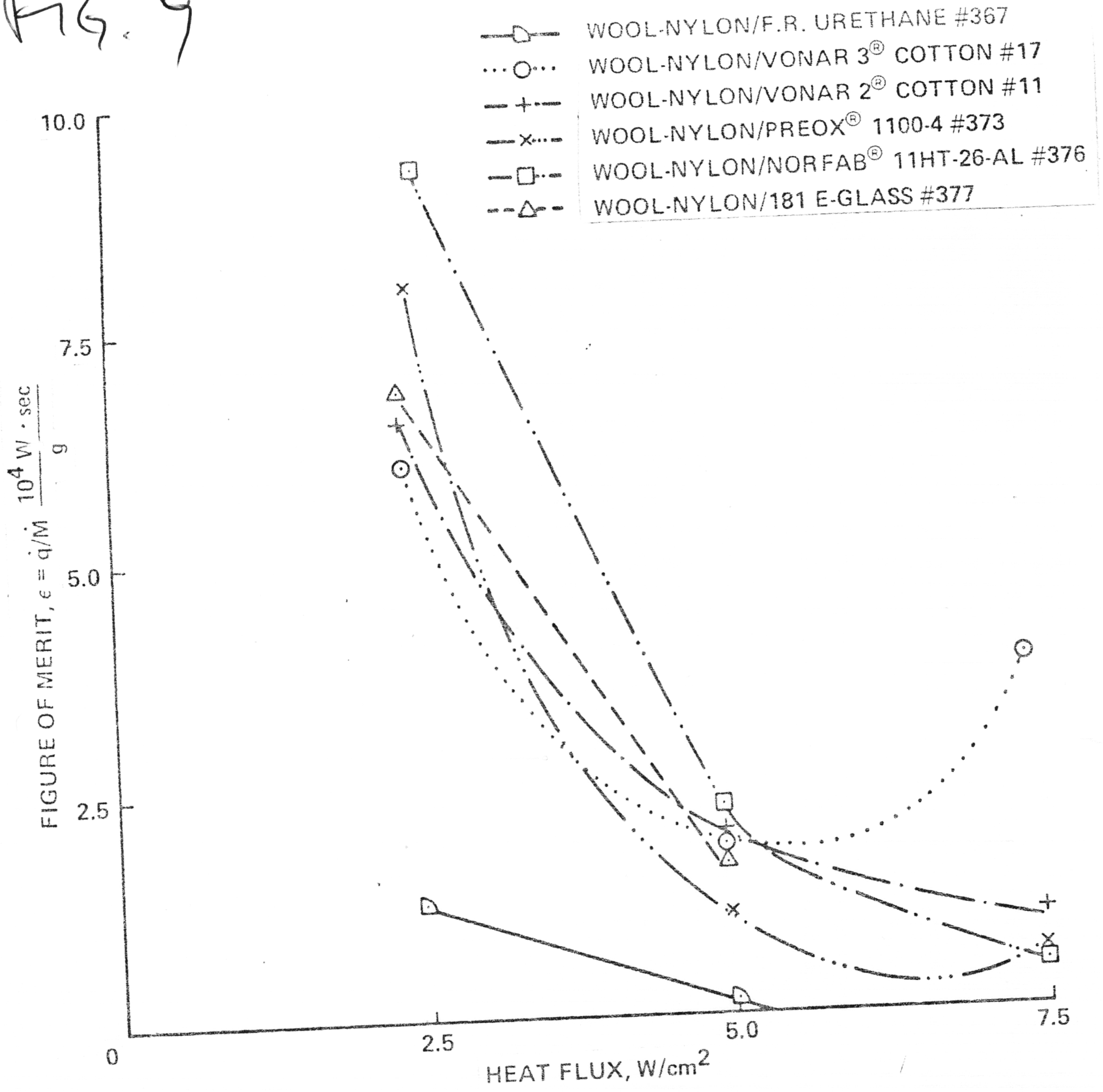


FIG. 9



WOOL-NYLON/F.R. URETHANE #367
WOOL-NYLON/VONAR 3® COTTON #17
WOOL-NYLON/VONAR 2® COTTON #11
WOOL-NYLON/PREOX® 1100-4 #373
WOOL-NYLON/NORFAB® 11HT-26-AL #376
WOOL-NYLON/181 E-GLASS #377
10.0
7.5
5.0
2.5
0
2.5
5.0
7.5
FIGURE OF MERIT, ε = q/Ṁ $\frac{10^4 W \cdot sec}{g}$
HEAT FLUX, W/cm²

FIG. 10

FIGURE OF MERIT COMPARISON OF HEAT BLOCKING LAYERS
N.F. URETHANE AS A FUNCTION OF HEAT FLUX AT 2 min