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A FLAMMABILITY STUDY OF THIN PLASTIC FILM MATERIALS

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ABSTRACT

The Materials Science Laboratory at the Kennedy Space Center presently conducts flammability tests on thin plastic film materials by using a small needle rake method. In this study, flammability data from twenty-two thin plastic film materials were obtained and cross-checked by using three different testing methods: (a) the presently used small needle rake, (b) the newly developed large needle rake, and (c) the previously used frame.

In order to better discern the melting-burning phenomenon of thin plastic film materials, five additional specific experiments were performed. These experiments determined (1) the heat sink effect of each testing method, (2) the effect of the burn angle on the burn length or melting/shrinkage length, (3) the temperature profile above the ignition source, (4) the melting point and the fire point of each material, and (5) the melting/burning profile of each material via infrared (IR) imaging.

The experimentations gave the following results: Comparison of the three flammability test methods revealed inconsistent pass/fail results in four of the twenty-two samples. The heat sink effect experimentation depicts that the frame method acted like a large heat sink. Increasing the burn angles affected both the burn length and the melting/shrinkage length. The temperature profile above the ignition source revealed that convection currents affect the air temperature gradient. Melting point data, fire point data and infrared imaging discerned whether the material was burning or shrinking (i.e., melting).

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I. Introduction

1.1 Background Information

A fire near the Orbiters, payloads, ordnance materials, hypergols or practically any place at KSC could potentially cause catastrophic results. Fires have the capability to destroy millions of dollars worth of equipment and endanger hundreds of lives. Therefore, careful flammability testing must be performed to eliminate fire hazardous materials.

Thin plastic film materials are used widely at KSC for an extensive variety of needs. Some of these needs are (1) the packaging of small items such as transistors, (2) the crating of large items such as satellites, (3) the draping of items up to the size of a spacecraft, and (4) the shielding of workers and equipment from debris.

Thin plastic film materials used at KSC must pass flammability tests conducted in the Materials Science Laboratory. The flammability tests measure and describe the properties of materials in response to heat and flame under ambient conditions. The results from these tests are used to classify materials proposed for use in spacecraft and associated equipment as Group I and Group II. Group I materials can be used without restrictions. Group II materials do not pass Group I criteria and must be subjected to additional flammability testing. Group II materials are restricted from use in spacecraft and associated equipment.

1.2 NASA's Upward Propagation Test (NHB 8060.1B Test 1)

Specifications for NASA's upward propagation test can be found in the NASA publication NHB 8060.1B Test 1, "Flammability, Odor, and Offgassing Requirements and Test Procedures for Materials and Environments that Support Combustion" (reprint May 1988). The publication requires that thin plastic film samples be cut into 2.5 by 12 inch rectangles and placed on a framed or needle rake sample holder. The sample's bottom edge must be located at least three inches from the base of a hood. Ignition of the sample is accomplished by employing a regulated energy source. The ignition source consists of a length of No. 20 gauge bare nickle-chromium wire sufficient to wind a minimum of three turns around a standard clean weld "B" igniter (hexamethylenetetramine based). See Figure 1. The nominal diameter of this igniter is 0.125" with a length of one inch. The flame temperature is 2000°F ± 200°F and burns for a duration of 25 ± 5 seconds. The upper edge of the igniter surface is placed 0.25 inches from the bottom edge of the sample. See Figure 2 for a picture of a burning sample.

The acceptance criteria states that the material shall be considered noncombustible, or self-extinguishing, if less than six inches of the sample is consumed and the time of burning does not exceed 10 minutes. There must be no sparking, sputtering or dripping of flaming particles from the test sample. A minimum of three samples must be tested. A failure of any one of the three samples constitutes failure of the material.

The thin plastic film materials are burned in a non-oxygen enriched atmosphere, i.e., air (79% N_2 and 21% O_2) at 14.7 psia in a hood.

In regard to sample preparation, samples are cut from the same batches of materials for all tests in order to reduce variability.

II. Procedures

2.1 Test Materials

Twenty-two thin plastic film materials were tested. Table 1 lists each thin plastic film material with the following information: generic type, thickness, type of sample holder, burn length, burn time, propagation rate, dripping of flaming particles, self-extinguishing, and pass or fail.

2.2 Description of Sample Holders

Frame Sample Holder: This sample holder consists of a vertically mounted steel clamped frame that overlaps 1/4 inch on each side of a sample along the full 12 inch minimum length of the sample, leaving a 2 inch wide by 12 inch long exposed center section (see Figure 3).

Small Needle Rake Sample Holder: This sample holder is made of steel with needles spaced 3 inches apart lengthwise. A 2 1/2 by 12 inch sample is impaled onto the needle rake. It is also mounted vertically (see Figure 4).

Large Needle Rake Holder: This sample holder is identical to the small needle rake holder except it is larger. It impales a 12 by 12 inch sample onto its needle rake (see Figure 5).

Specifications for NASA's upward propagation test (NHB 8060.1B Test 1) allows one to use either the frame or small needle rake in testing thin plastic film materials. The large needle rake was devised by the author of this paper and is not yet approved by NASA.

2.3 Tests Performed

The Materials Science Laboratory at KSC presently conducts flammability tests on thin plastic film materials by using a small needle rate method. In this study, data from twenty-two thin plastic film materials was obtained and cross-checked by using three different methods: (1) the presently used small needle rake, (2) the newly developed large needle rake, and (3) the previously used frame. Documentation of data from these three tests was recorded on video tapes.

In order to better discern the melting-burning phenomenon of thin plastic film materials, five additional tests were performed. These experiments (1) determined the heat sink effect of each method, (2) determined the effect of the burn angle on the burn length or the shrinkage length, (3) determined the temperature profile above the ignition source, (4) determined the melting point and the fire point for each thin plastic film material, and (5) employed infrared imaging to determine the melting/burning profile of the thin plastic film materials in question.

III. Results

3.1 Comparison of The Three Different Flammability Methods

Table 2 gives a comparison of the three different flammability test methods (frame, small needle rake, and large needle rake) for twenty-two thin plastic film materials. Eleven of the twenty-two materials were consistent in passing all three test methods while seven were consistent in failing all three test methods. There were inconsistencies in pass/fail results among three test methods for four of the materials (FRAS Sheet MG-3 mils, Staticure FR, RCAS 2400 and 3M 2100). All four of these materials passed the frame test but failed the small needle rake test. Only 3M 2100 failed the large needle rake test method.

3.2 Heat Sink Effect

In order to investigate the heat sink effect of the frame, the small needle rake, and the large needle rake, thermocouples were placed in the air 1/16 inch from the bottom inside corner of the frame and 1/16 inch above the bottom needle of the small and the large needle rakes. Thermocouples were also placed on all three sample holders at three inches and six inches above the base. Figures 6, 7 and 8 reveal the placement of the thermocouples.

Fixture comparisons at the base (Figure 9), three inches above the base (Figure 10), and six inches above the base (Figure 11) depict that the temperatures are much lower in air near the frame holder than for the small needle rake. Since the frame and the needle rake holders are the same size, this means that the frame is absorbing much more heat than the small needle rake, i.e., the frame is a much better heat sink. Temperatures are low near the large needle rake holder because of the distance from the flame.

3.3 Burn Length or Shrinkage Length as a Function of Burn Angle

Four materials (An 120, Halar, Herculite 80 and Polyethylene) were burned at various angles (0, 5, 10, 15, 20, 25, 30 degrees. See Figure 12 for the burn angle orientation). For materials like polyethylene that burned 12 inches, i.e., entirely consumed, the burn angle had no effect upon burn length (Figure 13). For materials like AN 120 and Halar, the consumed length was due to burn and shrinkage. Figures 14 and 15 reveal that angles of 20 degrees or larger eliminates the shrinkage. For materials that consistently burn a definite length without any shrinkage, like Herculite 80, Figure 16 depicts that the burn length is almost inversely proportioned to burn angle.

3.4 Temperature Profile Above the Ignition Source

Figure 17 shows the small needle rake holder with thermocouples placed at the base and at one inch intervals up to seven inches. Figure 18, The Vertical Flame Temperature Profile, reveals the peak temperatures from the base of the frame to seven inches above the frame at one inch intervals. The peak temperatures from four to seven inches above the base ranges from 250° to 500°F, a temperature exceeding the melting point for each thin plastic film material tested. It is understandable that a seven inch consumed length for a material like AN 120 is due to melt and/or shrinkage rather than burn since AN 120 has a melting point of 374°F.

3.5 Melting Point and Fire Points

The melting point is the temperature at which the material disappears as if it were dissolving. Shrinkage is the contraction or curling up of the material. The fire point is the lowest temperature at which the mixture of vapors from the surface of the material and the test atmosphere continue to burn after ignition. In most thin plastic film materials, shrinkage will occur before melting and melting will occur before burning.

The Microchemical Analysis Branch of the Materials Science Laboratory determined the melting points (peak apex), onsets and joules per gram for the thin plastic film materials (Table 3). The Materials Testing Branch provided auto-ignition testing graphs via the interactive DSC V3.0 program. See Figures 19 and 20 for auto-ignition graphs of polyethylene and FRAS sheet MG, respectively.

3.6 Infrared Imaging

Figures 21 and 22 show the progression of a melting front of FRAS sheet MG via photos of infrared imaging. Analysis of the IR spectrum reveals that the temperature of the melting front is a blue color, which on the scale at the bottom of the photo equals 225°F (107°C), the melting point of FRAS sheet MG. This example is one of many IR examples depicting thin plastic film materials melting instead of burning. IR documentation for all twenty-two thin plastic film materials was recorded on video tape.

IV. Conclusions and Recommendations

Section 3.1 shows that inconsistent results can be obtained using the three different methods of testing. Four out of twenty-two materials exhibited inconsistencies among the three methods. This research project attempts to discover the reasons for these discrepancies.

Section 3.2 reveals that the frame holder serves as a large heat sink, absorbing and dissipating heat required for material combustion. Materials that burn completely, such as polyethylene, are often extinguished when the flame comes near the edge of the frame holder. The small needle rake method, although an insignificant heat source, also has a flaw in that melted material often accumulates on the tips of the needle rakes, bursts into flame and sometimes drip as flaming particles from the tips. Many thin plastic film materials will not burn at their manufactured thickness but will burn when increased to a thicker dimension. The large needle rake holder is also an insignificant heat source. It eliminates the accumulation of melted material around the tips because the horizontal burn is not wide enough to reach the tips.

I recommend that consideration be given to using a needle rake holder larger than the one that is presently being used at KSC. A needle rake that holds a 6 inch by 12 inch sample will be a good compromise between the small needle rake holder and the large needle rake holder used in these experiments.

The experimentations described in Section 3.3 makes it clear that the burn angle should be zero degrees. These experiments show that varying the burn angle is successful in eliminating the melt length on some of the materials. This is good because it is advantageous to eliminate the shrinkage length. But, varying the burn angle also affects the burn length (which we do not desire to eliminate or interfere with). Materials that ignite and burn completely are not affected by the burn angle. I recommend a zero degree burn angle as presently deployed.

Section 3.4, The Temperature Profile Above the Ignition Source, reveals that the air temperature seven inches above the bottom of the sample is sufficient to melt some of the materials. After examining the melting point temperatures for the twenty-two materials in Section 3.5, it is understandable why the melt lengths of materials like AN 110, AN 120 and FRAS sheet MG exceed six inches. Infrared imaging of the burning thin plastic film materials, as described in Section 3.6, answers a very important question: "Is the material burning or melting?" Infrared imaging of materials such as AN 110, AN 120, FRAS sheet MG, Proguard, Llumaloy and Staticure reveal that all have melt lengths exceeding six inches in at least one of the three test methods. The tester should not fail these materials because consumption exceeded six inches. If there is a question of whether a six inch or greater consumed length is due to burn or melt, I recommend using infrared imaging analysis.

Flammability investigations have revealed that most thin plastic film materials are either clear-cut failures or clear-cut passes no matter which of the three test methods are used. However, there are a few marginal materials which are not clear-cut pass or fail. These marginal materials require a closer examination and I recommend for these materials a minimum of six (preferably ten) samples be tested. Testing three samples, as specified in NASA publication NHB 8060.1B Test 1, may not be sufficient in marginal materials.

It is important and essential that the flammability test method eliminates subjectivity and ambiguity on the part of the test operator. The test operator must place special scrutiny on marginal materials.

A more realistic and practical flammability classification for thin plastic film materials in regard to burn/melt (shrinkage) length is suggested by the following criteria:

CLASS	CRITERIA OF ACCEPTABILITY	WHERE IT CAN BE USED
A	No damage to the sample exceeding 6 inches (burning, melting, or shrinkage), burn time may not exceed 10 minutes and no sparking, sputtering or dripping of flaming particles.	Anywhere in a spacecraft or in ground support equipment (GSE) areas.

CLASS	CRITERIA OF ACCEPTABILITY	WHERE IT CAN BE USED
B	No damage to the sample exceeding 9 inches (burning, melting, shrinkage), burn time may not exceed 10 minutes and no sparking, sputtering or dripping of flaming particles.	Anywhere outside of a 5 foot perimeter around the spacecraft.
C	Any materials not meeting the criteria of acceptability defined in Class A and B.	Nowhere.

V. References

1. Comparison of Results of the European Space Agency Oxygen Index Test and The NASA Upward Propagation Test, Document No. TR-581-001, NASA, Johnson Space Center, White Sands Test Facility, 1989.

2. Flammability, Odor and Offgassing for Materials in Environments that Support Combustion, Document No. NHB 8060.1B, Office of Space Transportation Systems, 1988.

3. Physical and Chemical Test Results of Plastic Films, Document No. MTB-402-85, NASA, Kennedy Space Center, Materials Testing Branch, 1986.

4. Physical and Chemical Test Results of Plastic Films (addition of materials #60 through #96), Document No. MTB-402-85, Addendum 1-88, NASA, Kennedy Space Center, Materials Testing Branch, 1988.

5. Unpublished Paper, Recommendations for Test 1 (Upward Flame Propagation).

TABLE 1 - FLAMMABILITY RESULTS FOR THIN PLASTIC FILM MATERIALS

MATERIAL NAME	GENERIC NAME	THICKNESS (MILS)	METHOD	BURN LENGTH (INCHES)	BURN TIME (SEC)	PROPAGATION RATE (IN/S)	DRIPPING FLAMING PARTICLES	SELF EXTINGUISH.	PASS OR FAIL
ACLAR 33 C	PCTFE	3	FRAME	3.0	10	18.0	NO	YES	PASS
			SM. NEEDLE	2.6	4	39.0	NO	YES	PASS
			LG. NEEDLE	4.0	8	30.0	NO	YES	PASS
WRIGHTLON 7400	NYLON	2	FRAME	4.8	8	36.0	NO	YES	PASS
			SM. NEEDLE	2.8	3	56.0	NO	YES	PASS
			LG. NEEDLE	3.1	6	31.0	NO	YES	PASS
HERCULITE 80	PVC/DACRON	19	FRAME	5.7	17	10.6	NO	YES	PASS
			SM. NEEDLE	3.0	20	6.3	NO	YES	PASS
			LG. NEEDLE	3.5	22	9.5	NO	YES	PASS
HALAR	ECTFE	2	FRAME	4.7	12	21.7	NO	YES	PASS
			SM. NEEDLE	5.0	10	25.0	NO	YES	PASS
			LG. NEEDLE	4.5	16	27.0	NO	YES	PASS
PROGUARD	ANTISTATIC NYLON	2	FRAME	3.7	7	31.7	NO	YES	PASS
			SM. NEEDLE	4.0	14	17.1	NO	YES	PASS
			LG. NEEDLE	6.0	16	22.5	NO	YES	PASS
AN-35	METALIZED PVF	13	FRAME	4.2	15	16.8	NO	YES	PASS
			SM. NEEDLE	4.3	14	18.4	NO	YES	PASS
			LG. NEEDLE	4.7	16	17.6	NO	YES	PASS
AN-110	PVF/POLYESTER	3	FRAME	8.0*	16	30.0	NO	YES	PASS
			SM. NEEDLE	6.0*	7	51.4	NO	YES	PASS
			LG. NEEDLE	6.5*	11	35.5	NO	YES	PASS
AN-120	PVF/POLYESTER	6	FRAME	6.1*	17	21.5	NO	YES	PASS
			SM. NEEDLE	6.3*	9	42.0	NO	YES	PASS
			LG. NEEDLE	6.3*	14	27.0	NO	YES	PASS

TABLE 1 (CONTINUED)

MATERIAL NAME	GENERIC NAME	THICKNESS (MILS)	METHOD	BURN LENGTH (INCHES)	BURN TIME (SEC)	PROPAGATION RATE (IN/S)	DRIPPING FLAMING PARTICLES	SELF EXTINGUISH.	PASS OR FAIL
LLUMALOY (35%)	METALIZED POLYESTER	1	FRAME	7.0*	4	105.0	NO	YES	PASS
			SM. NEEDLE	4.2	4	63.0	NO	YES	PASS
			LG. NEEDLE	5.3	6	53.0	NO	YES	PASS
LLUMALOY (50%)	METALIZED POLYESTER	1	FRAME	6.8*	4	102.0	NO	YES	PASS
			SM. NEEDLE	5.3	7	45.4	NO	YES	PASS
			LG. NEEDLE	5.0	6	50.0	NO	YES	PASS
FRAS sheet MG (2 mils)	POLYETHYLENE	2	FRAME	4.0	14	17.1	NO	YES	PASS
			SM. NEEDLE	7.5*	13	34.7	NO	YES	PASS
			LG. NEEDLE	6.3*	12	31.5	NO	YES	PASS
FRAS sheet MG (3 mils)	POLYETHYLENE	3	FRAME	6.1*	12	30.5	NO	YES	PASS
			SM. NEEDLE	5.4	11	29.4	YES	YES	FAIL
			LG. NEEDLE	6.0*	13	27.7	NO	YES	PASS
STATICURE FR	NYLON/STATICURE COATING	2	FRAME	6.3*	10	37.8	NO	YES	PASS
			SM. NEEDLE	4.2	8	31.5	YES	YES	FAIL
			LG. NEEDLE	4.5	14	19.3	NO	YES	PASS
RCAS 2400	POLYAMIDE NYLON	2	FRAME	4.5	12	22.5	NO	YES	PASS
			SM. NEEDLE	3.8	10	22.8	YES	YES	FAIL
			LG. NEEDLE	3.2	7	27.4	NO	YES	PASS
3M-2100	POLYESTER/NICKEL	3	FRAME	5.3	14	22.7	NO	YES	PASS
			SM. NEEDLE	6.2	40	9.3	YES	YES	FAIL
			LG. NEEDLE	12.0	153	4.7	YES	YES	FAIL
AS-6000	NYLON	2	FRAME	7.3	16	27.4	YES	YES	FAIL
			SM. NEEDLE	6.0	17	21.2	YES	YES	FAIL
			LG. NEEDLE	7.0	36	11.7	YES	YES	FAIL

TABLE 1 (CONTINUED)

MATERIAL NAME	GENERIC NAME	THICKNESS (MILS)	METHOD	BURN LENGTH (INCHES)	BURN TIME (SEC)	PROPAGATION RATE (IN/S)	DRIPPING FLAMING PARTICLES	SELF EXTINGUISH.	PASS OR FAIL
BAYSTAT (antistatic grid	NYLON/POLYETHYLENE/ CARBON	3	FRAME	6.3	20	18.9	YES	YES	FAIL
			SM. NEEDLE	12.0	30	24.0	YES	YES	FAIL
			LG. NEEDLE	5.0	20	15.0	YES	YES	FAIL
RCAS 1200	POLYETHYLENE	6	FRAME	7.0	15	28.0	YES	YES	FAIL
			SM. NEEDLE	12.0	47	15.3	YES	NO	FAIL
			LG. NEEDLE	12.0	98	7.3	YES	NO	FAIL
PVC	POLYVINYL CHLORIDE	4	FRAME	10.0	15	40.0	YES	YES	FAIL
			SM. NEEDLE	12.0	21	34.2	YES	NO	FAIL
			LG. NEEDLE	12.0	15	48.0	YES	YES	FAIL
POLYETHYLENE	POLYETHYLENE	4	FRAME	5.8	13	26.8	YES	YES	FAIL
			SM. NEEDLE	12.0	42	17.1	YES	NO	FAIL
			LG. NEEDLE	12.0	92	7.8	YES	NO	FAIL
ST-600	PE/PVA/CARBON	4	FRAME	12	25	28.8	YES	NO	FAIL
			SM. NEEDLE	12	22	32.7	YES	NO	FAIL
			LG. NEEDLE	12	27	26.7	YES	NO	FAIL
VELOSTAT	POLYOLEFIN (BLACK)	9	FRAME	12.0	60	12.0	YES	NO	FAIL
			SM. NEEDLE	12.0	45	16.0	YES	NO	FAIL
			LG. NEEDLE	12.0	112	6.4	YES	NO	FAIL

* Material passed because a portion of the length is attributable to shrinkage

TABLE 2

COMPARISON OF THE THREE FLAMMABILITY TEST METHODS

MATERIAL NAME	GENERIC TYPE	METHOD		
		FRAME	SMALL NEEDLE RAKE	LARGE NEEDLE RAKE
ACLAR 33 C	PCTFE	PASS	PASS	PASS
WRIGHTLON 7400	NYLON	PASS	PASS	PASS
HERCULITE 80	PVC/DACRON	PASS	PASS	PASS
HALAR	ECTFE	PASS	PASS	PASS
PROGUARD	ANTISTATIC NYLON	PASS	PASS	PASS*
AN-35	METALIZED PVF	PASS	PASS	PASS
AN-110	PVF/POLYESTER	PASS*	PASS*	PASS*
AN-120	PVF/POLYESTER	PASS*	PASS*	PASS*
LLUMALOY (35%)	METALIZED POLYESTER	PASS*	PASS	PASS
LLUMALOY (50%)	METALIZED POLYESTER	PASS*	PASS	PASS
FRAS sheet MG (2 mils)	POLYETHYLENE	PASS	PASS*	PASS*
FRAS sheet MB (3 mils)	POLYETHYLENE	PASS*	FAIL (4 OF 10)	PASS*
STATICURE FR	NYLON/STATICURE COATING	PASS*	FAIL (2 OF 10)	PASS*
RCAS 2400	POLYAMIDE NYLON	PASS	FAIL (3 OF 10)	PASS
3M-2100	POLYESTER/NICKEL	PASS	FAIL	FAIL
AS-6000	NYLON	FAIL	FAIL	FAIL
BAYSTAT (antistatic grid)	NYLON/POLYETHYLENE/CARBON	FAIL	FAIL	FAIL
RCAS 1200	POLYETHYLENE	FAIL	FAIL	FAIL
PVC	POLYVINYL CHLORIDE	FAIL	FAIL	FAIL
POLYETHYLENE	POLYETHYLENE	FAIL	FAIL	FAIL
ST-600	PE/PVA/CARBON	FAIL	FAIL	FAIL
VELOSTAT	POLYOLEFIN (BLACK)	FAIL	FAIL	FAIL

* Passed the test even though the shrinkage carried the consumed length beyond six inches.

TABLE 3

MELTING POINTS AND FIRE POINTS
FOR THIN PLASTIC FILM MATERIALS

	Melting Points			Fire Point
Sample	Peak Apex (C)	Onset (C)	Joules/gram	(C)
3M2100	106.9	95.7	52.0	Above 600
PVC	Decomposes w/o melting			
RCAS 1200	108.8	95.7	79.7	Above 600
Velostat	96.4	77.6	36.2	Above 600
Baystat	106.8	93.5	53.9	Above 600
AN 120	190.5	167.3	26.6	Above 600
Polyethylene	108.0	96.6	77.9	300
AN 110	191.1	177.9	6.3	Above 600
RCAS 2400	214.0	200.9	49.7	Above 600
FRAS Sheet MG	107.1	97.1	71.8	Above 600
Staticure	214.5	204.7	60.0	Above 600
AN 35	251.7	247.1	18.9	Above 600
Aclar 33C	202.0	194.6	12.6	Above 600
Wrightlon 7400	210.9	198.3	29.5	Above 600
Llumaloy (35%)	247.7	238.3	37.2	Above 600
Llumaloy (50%)	247.3	240.2	37.4	Above 600
Herculate 80	244.2	231.1	8.2	Above 600
AS 6000	214.6	206.2	46.6	Above 600
Proguard	212.7	196.5	37.9	Above 600

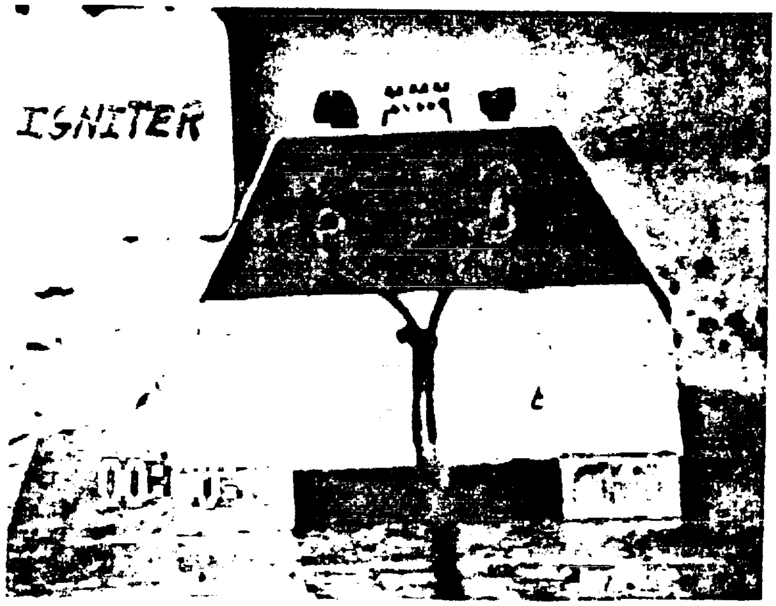


FIGURE 1. IGNITER SOURCE

FIGURE 2. BURNING SAMPLE

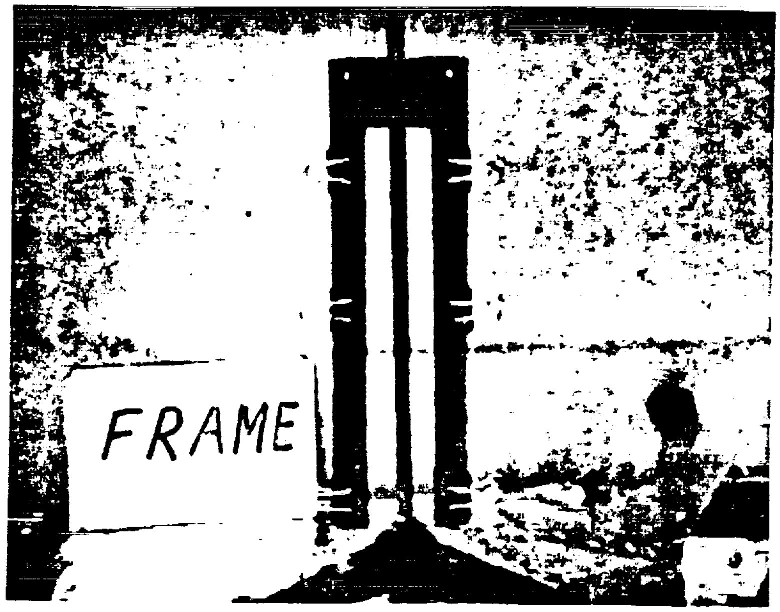


FIGURE 3. FRAME SAMPLE HOLDER

FIGURE 4. SMALL NEEDLE RAKE SAMPLE HOLDER

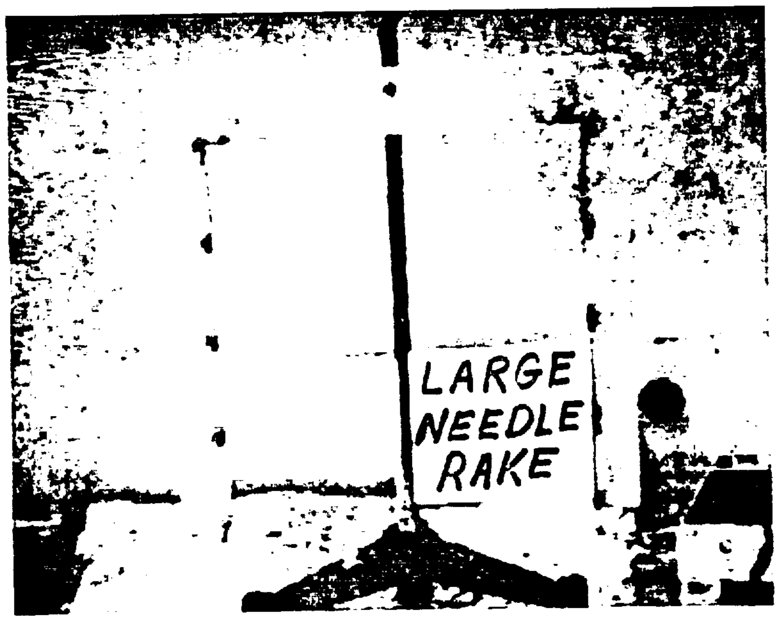


FIGURE 5. LARGE NEEDLE RAKE SAMPLE HOLDER

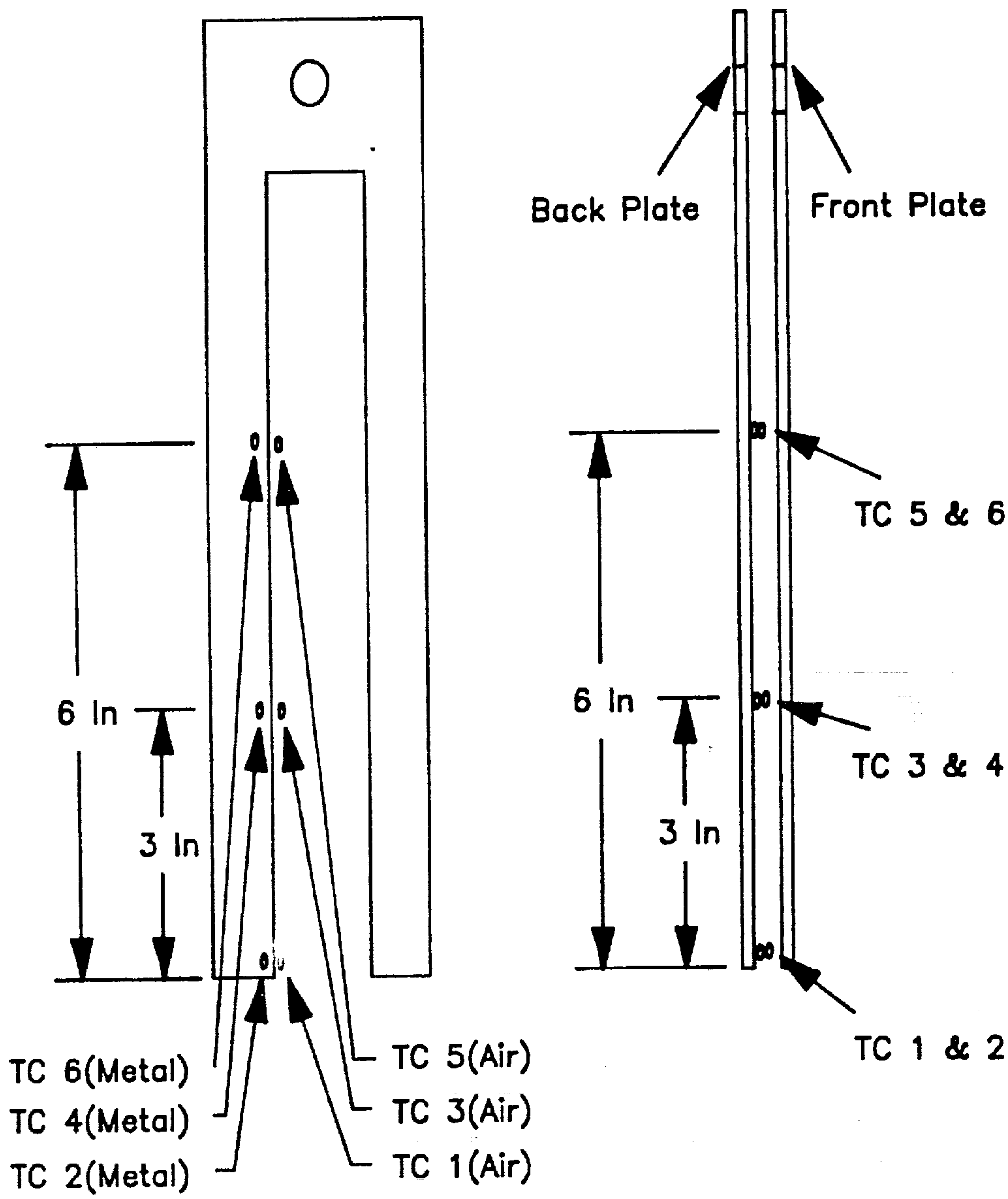


Figure 6. Frame Thermocouple Locations

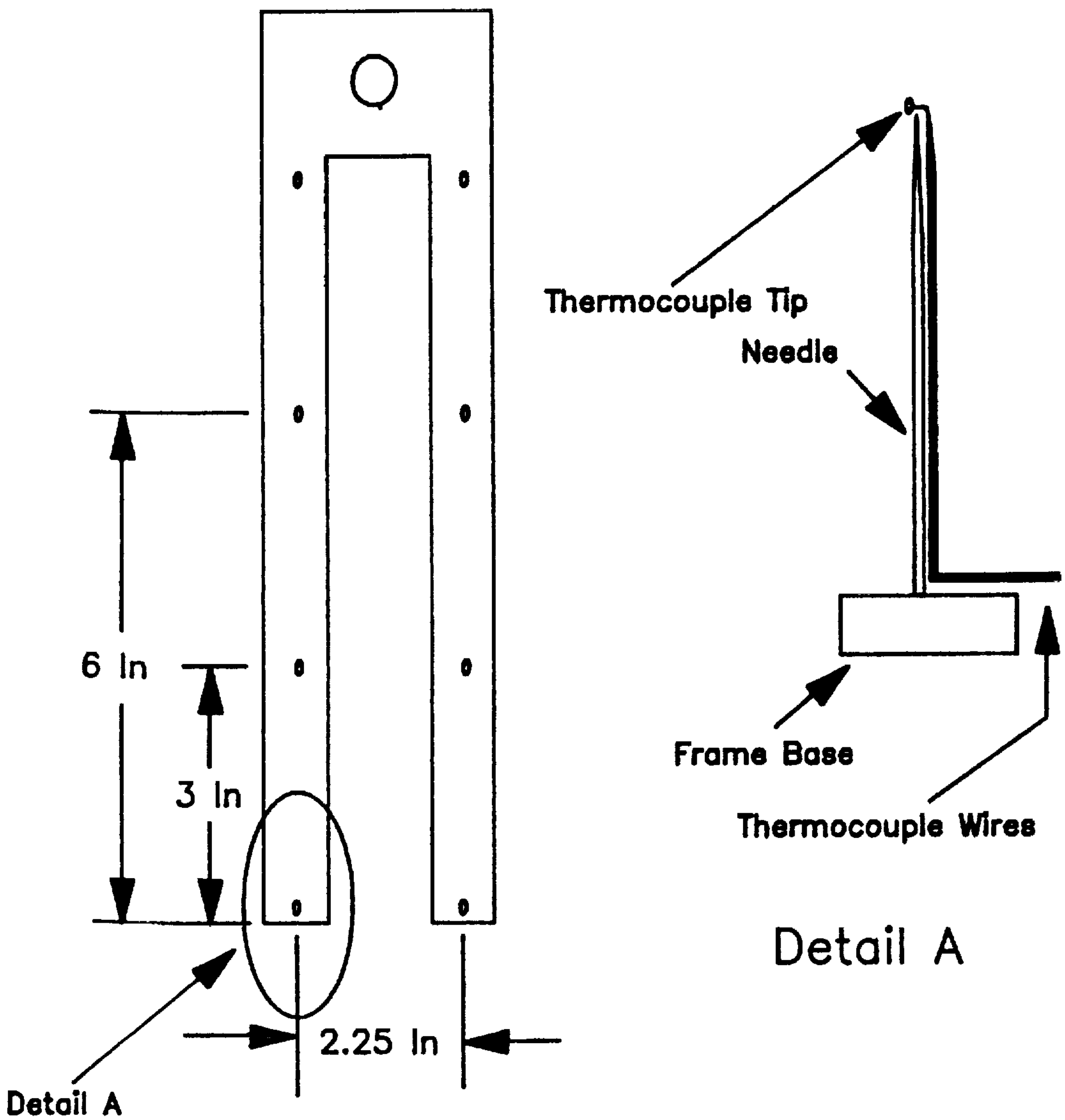


Figure 7. Small Needle Rake
Thermocouple Locations

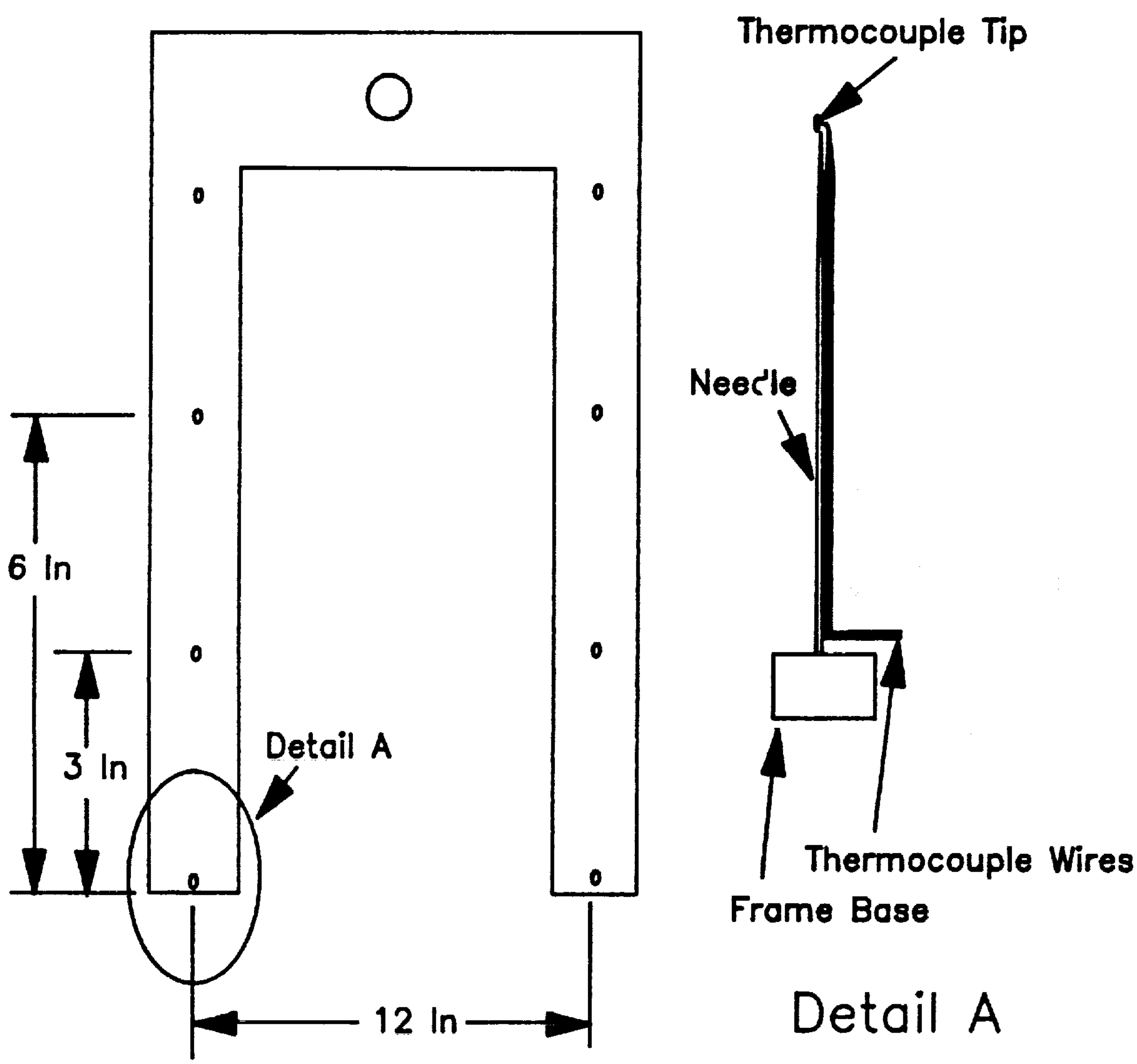


Figure 8. Large Needle Rake Thermocouple Locations

Figure 9
Fixture Comparison At Flame Base
No Sample Present In Fixture

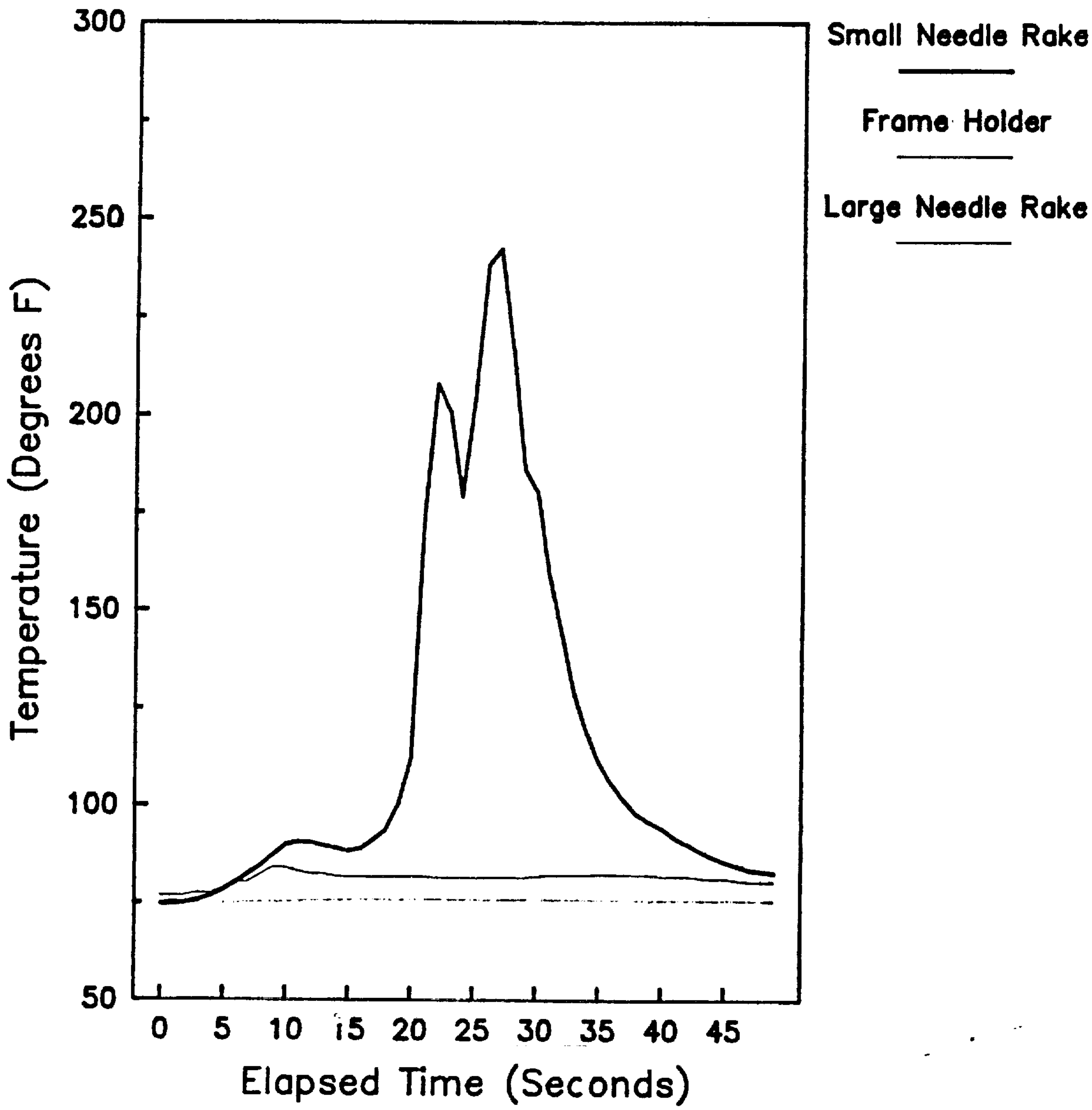


Figure 10
Fixture Comparison At 3" From Flame Base
No Sample Present In Fixture

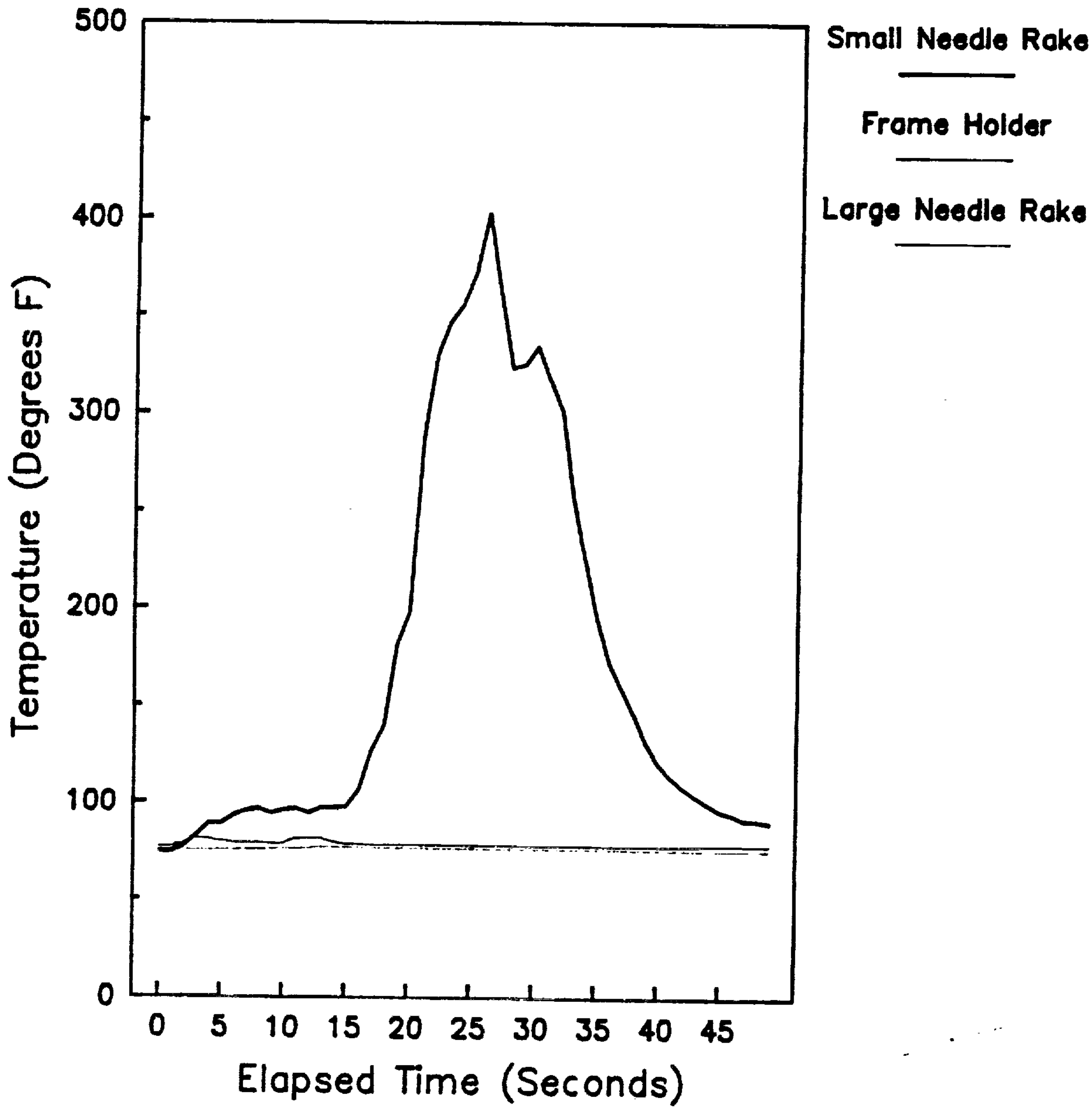
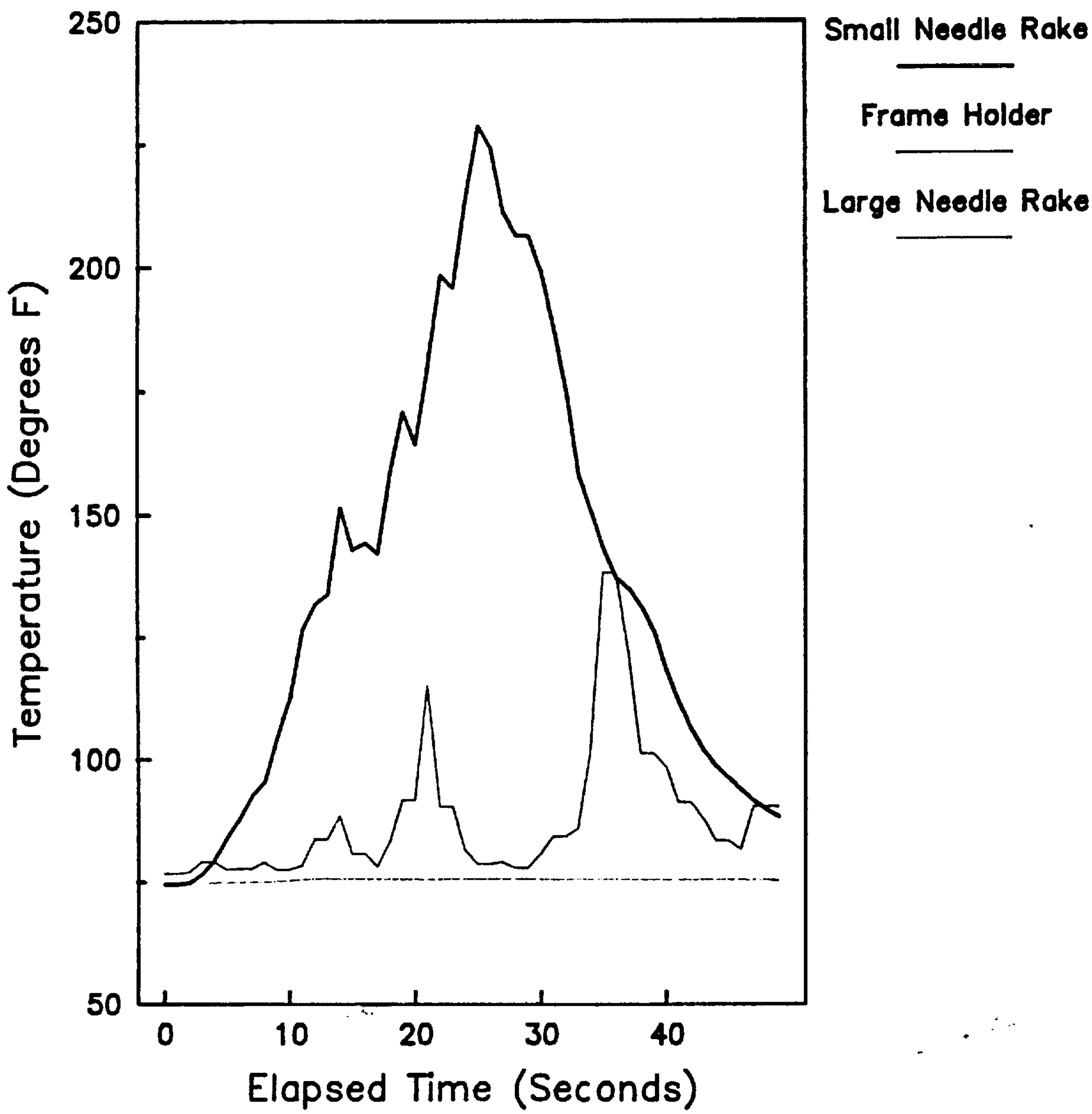


Figure 11

Fixture Comparison At 6" From Flame Base
No Sample Present In Fixture



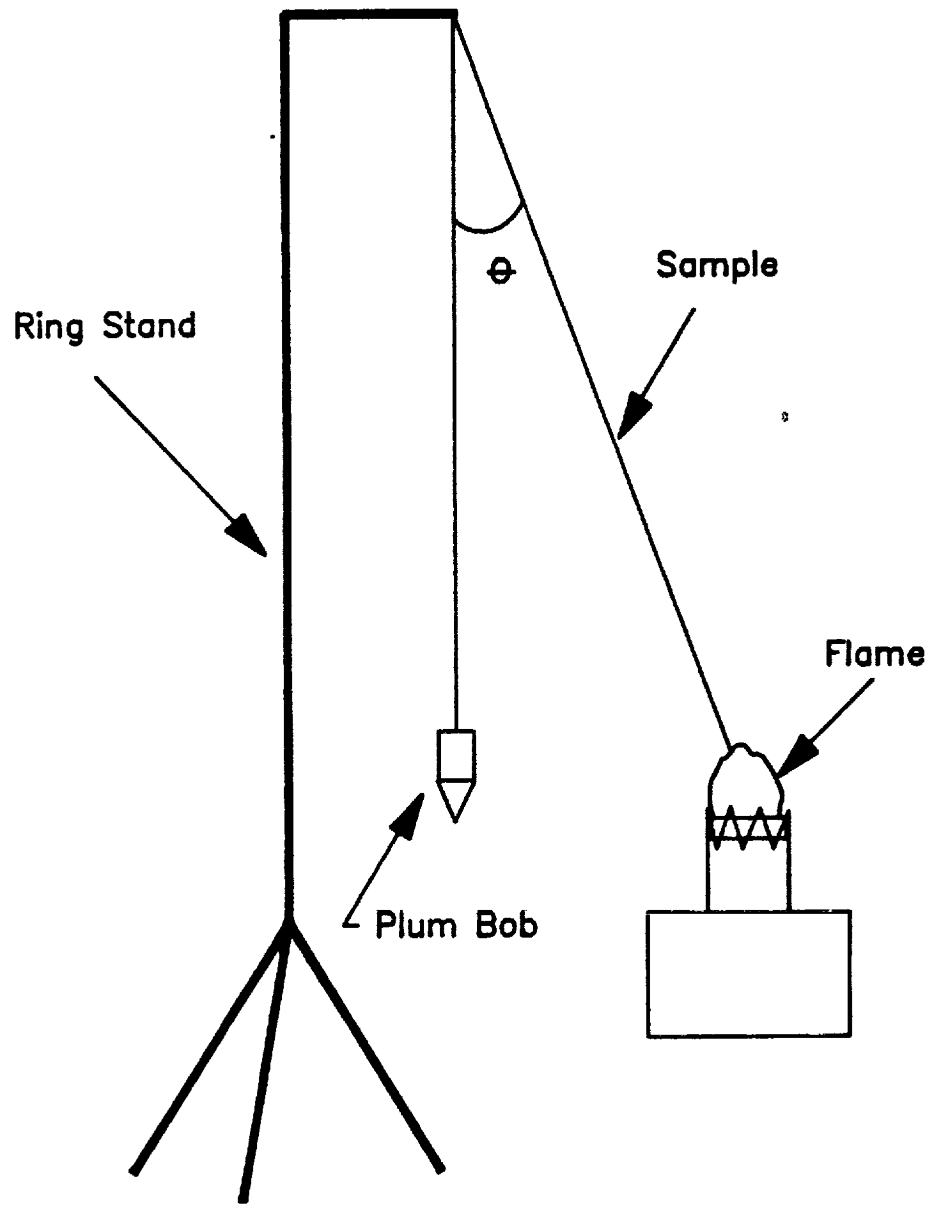


Figure 12. Burn Angle Orientation

θ = Burn Angle

Figure 13
Burn Length Of Polyethylene
As A Function Of Angle

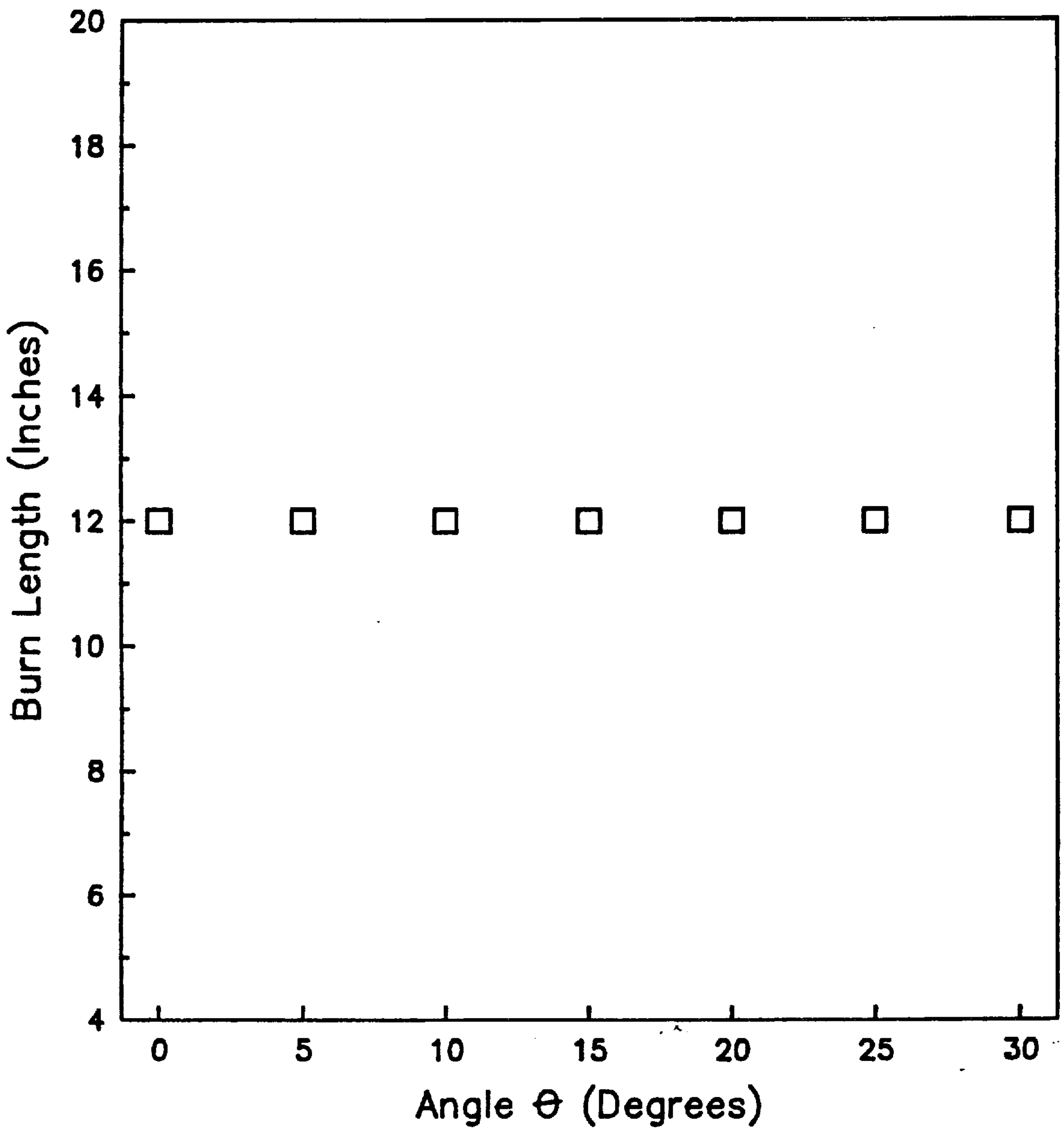


Figure 14

Shrinkage Of AN 120
As A Function Of Angle

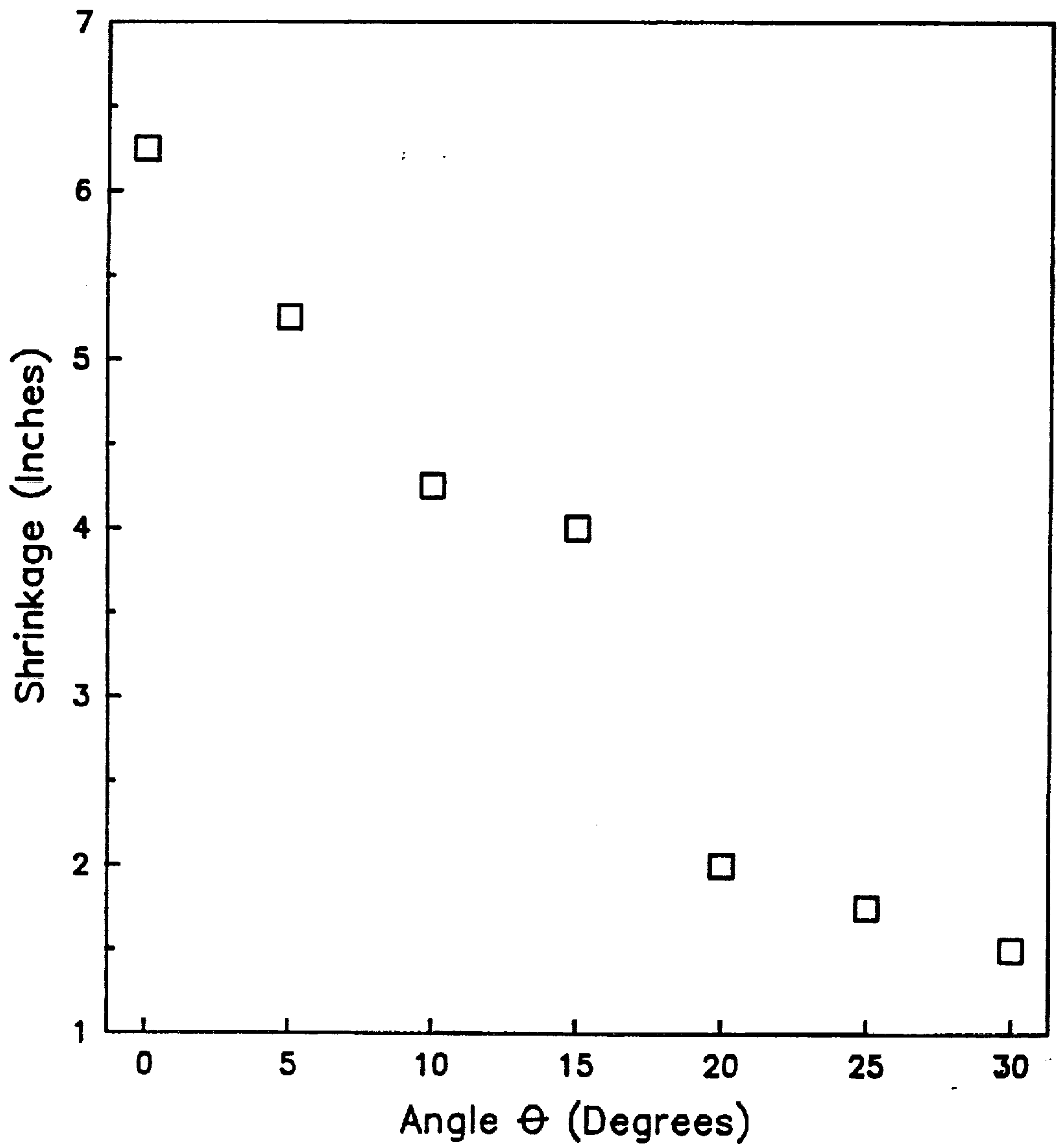


Figure 15
Shrinkage Of Halar As A Function Of Angle

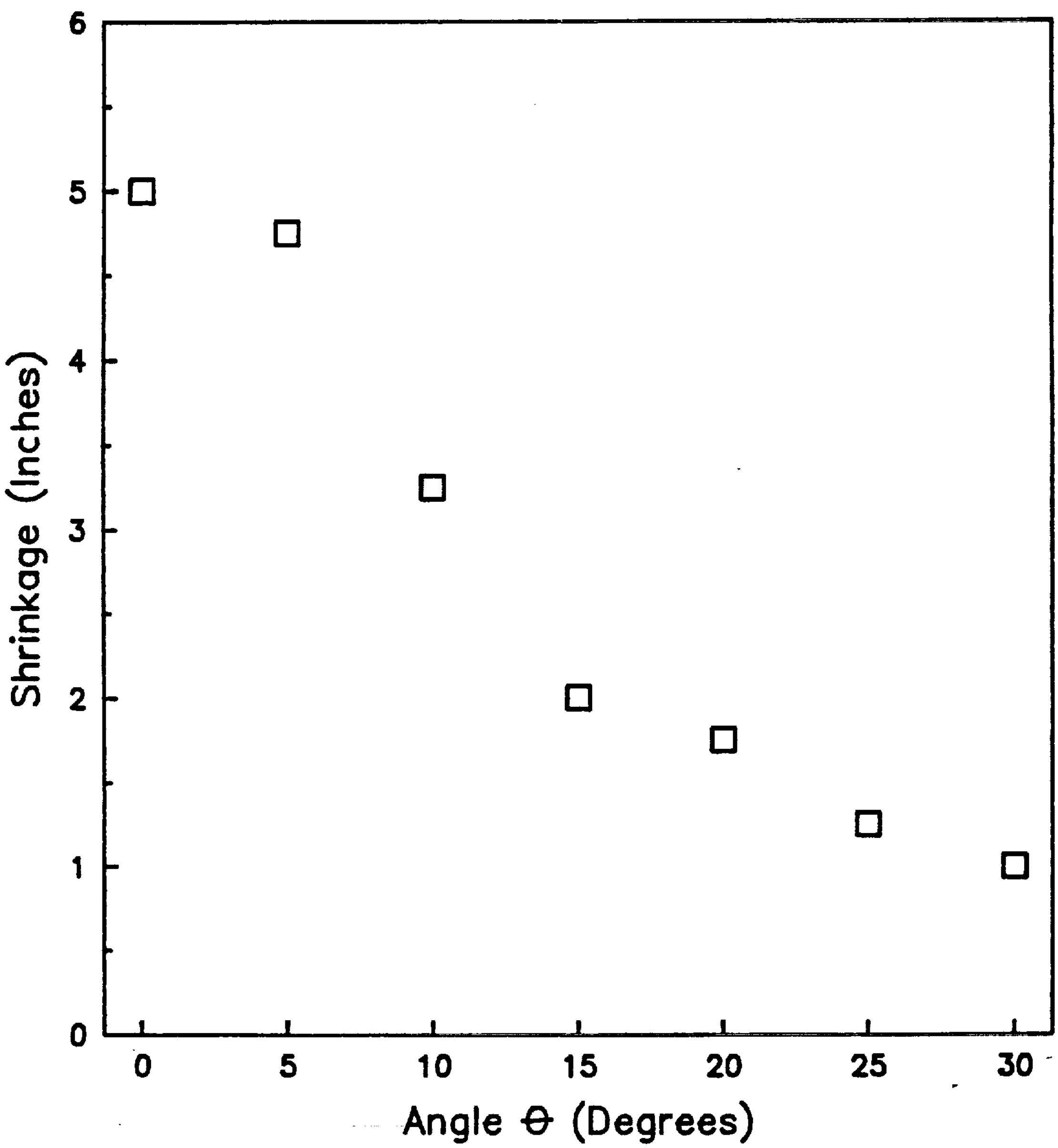
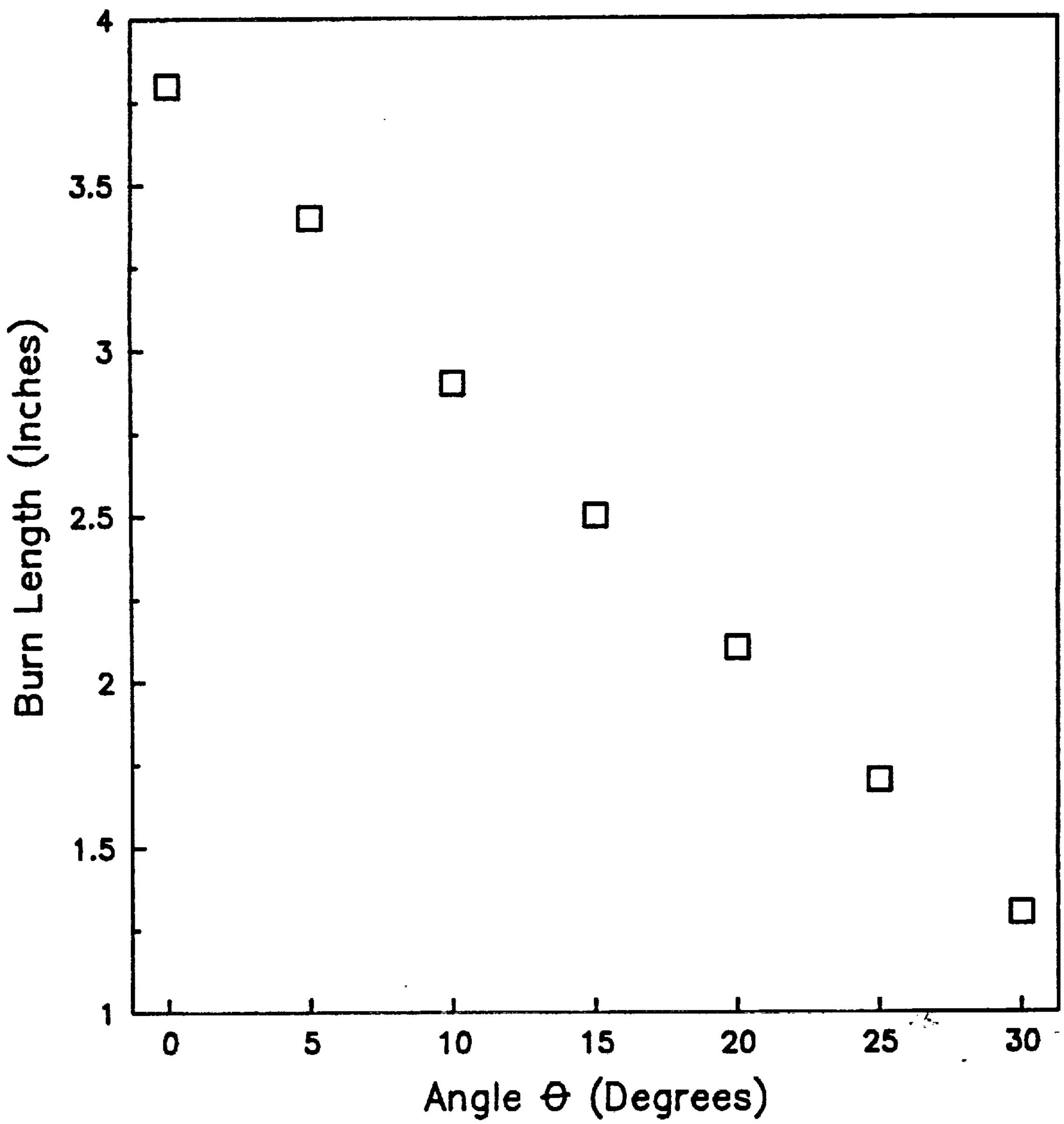


Figure 16
Burn Length Of Herculite 80
As A Function Of Angle



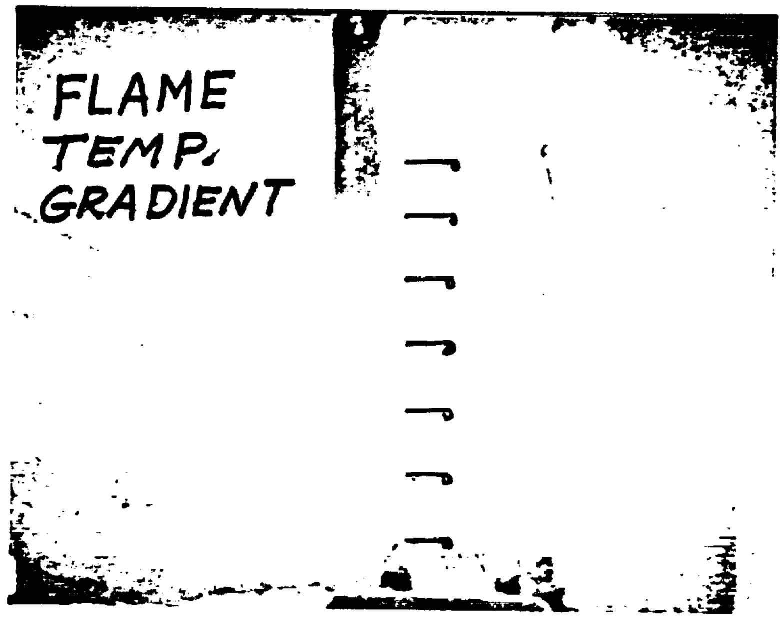
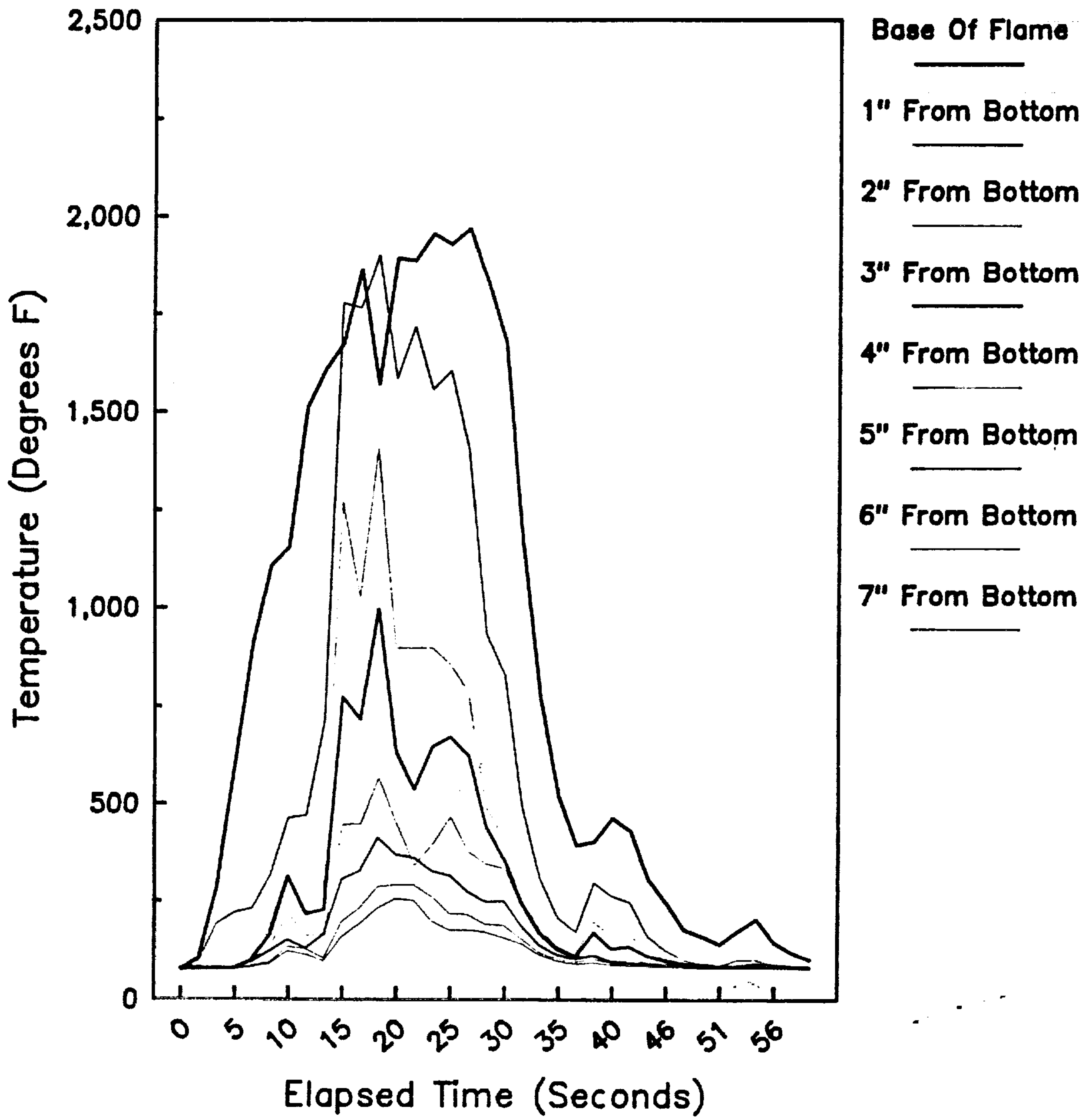


FIGURE 17. THERMOCOUPLE PLACEMENT FOR TEMPERATURE PROFILE ABOVE IGNITION SOURCE

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 18
Vertical Flame Temperature Profile



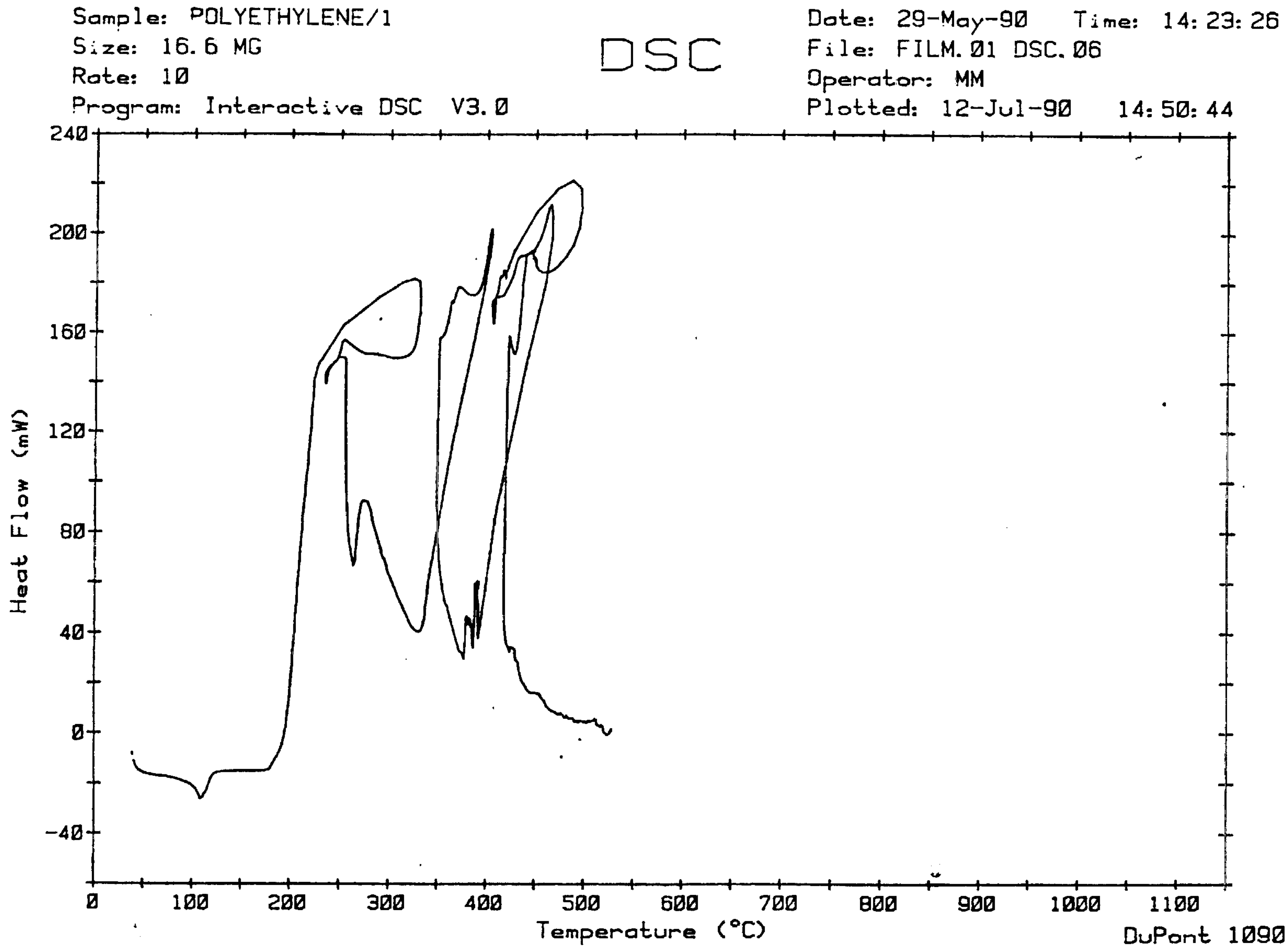


FIGURE 19. AUTO-IGNITION GRAPH FOR POLYETHYLENE

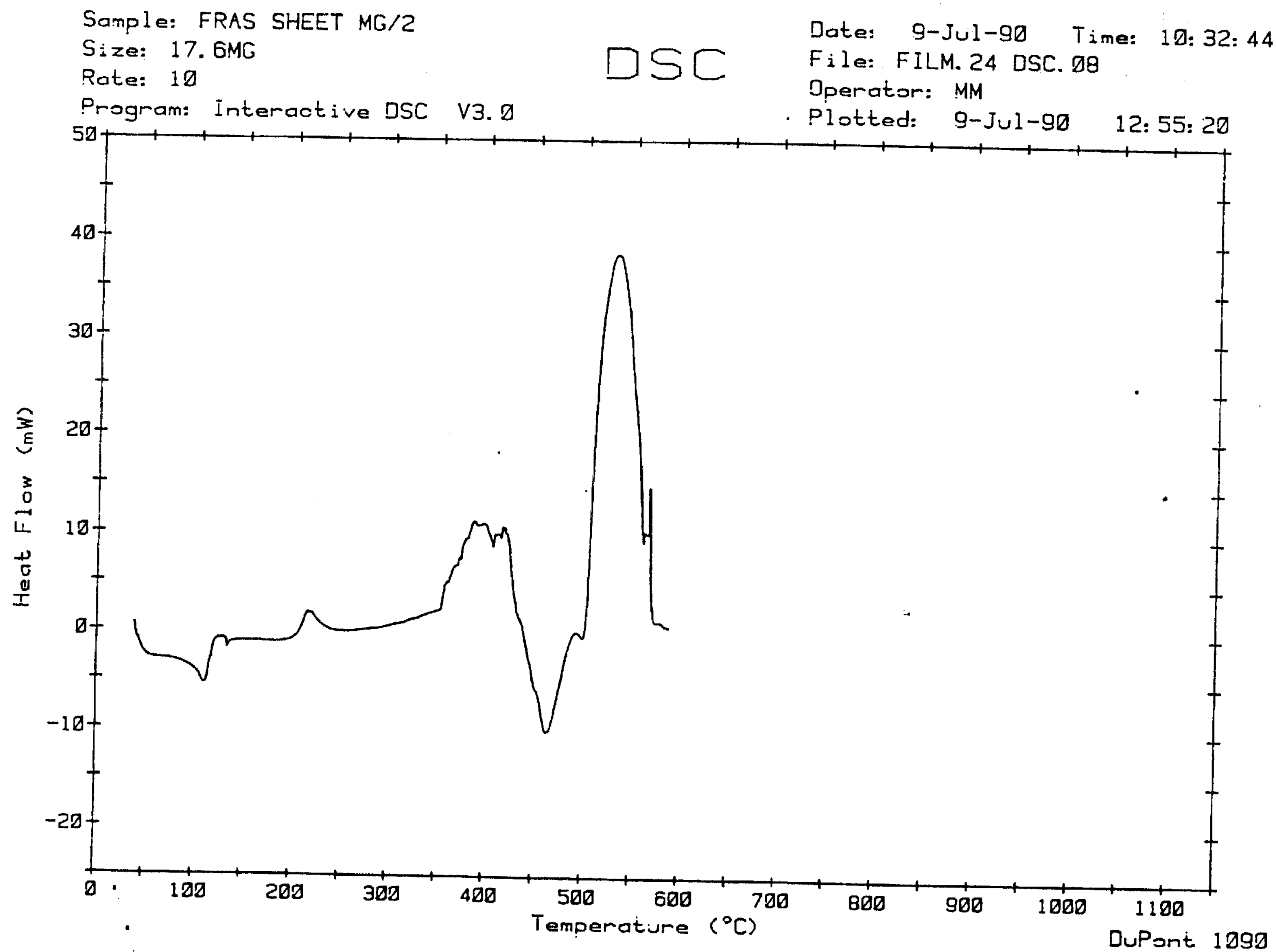


FIGURE 20. AUTO-IGNITION GRAPH FOR FRAS SHEET MG

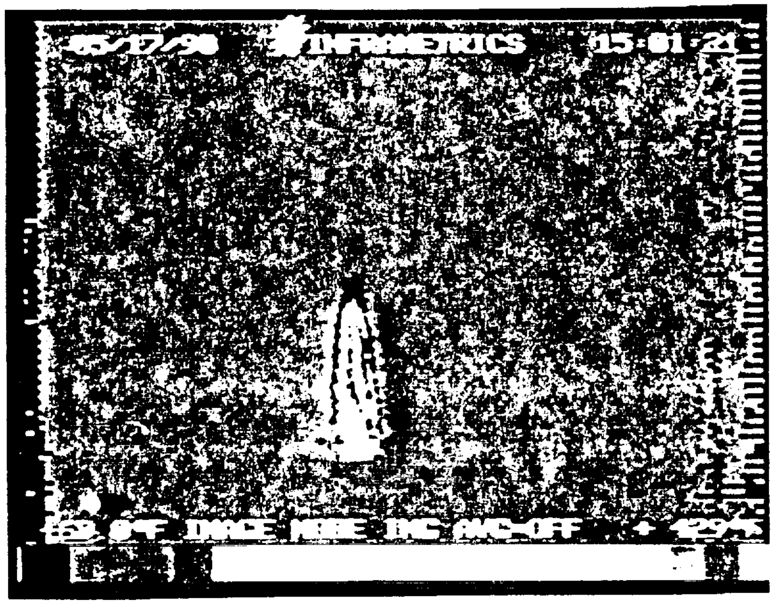


FIGURE 21. INFRARED IMAGING AT TIME X

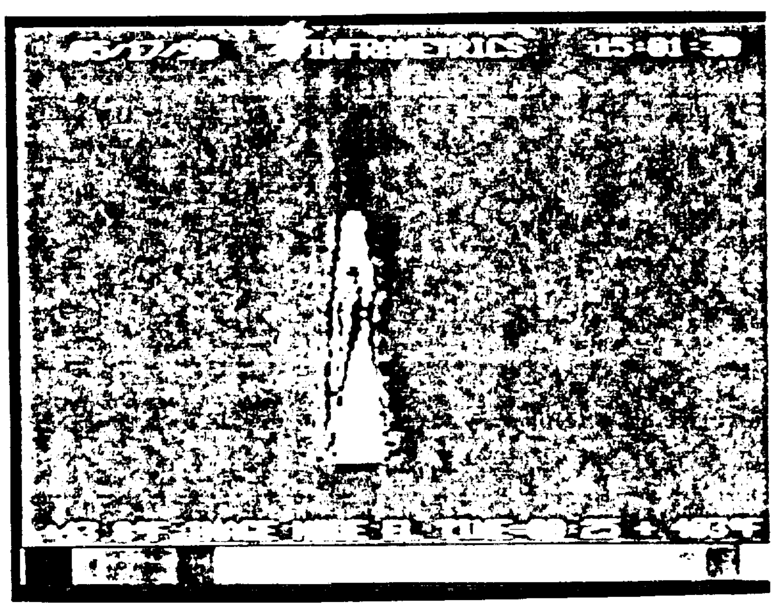


FIGURE 22. INFRARED IMAGING AT TIME X + 2 SECONDS