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Study to Develop Improved Fire Resistant Aircraft Passenger Seat Materials

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16. Abstract

The Phase III study of the NASA "Improved Fire Resistant Aircraft Seat Materials" involved fire tests of improved materials in multilayered combinations representative of cushion configurations. Tests were conducted to determine their thermal, smoke, and fire resistance characteristics. Additionally, a "Design Guideline" for Fire Resistant Passenger Seats was written outlining general seat design considerations. Finally, a three-abreast "Tourist Class" passenger seat assembly fabricated from the most advanced fire-resistant materials was delivered to the Ames Research Center.

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PREFACE

This report is submitted under Contract NAS2-9337. The report covers the period 4 December 1979 through 30 September 1980.

The program was performed at Douglas Aircraft Company, McDonnell Douglas Corporation, Long Beach, California. Mr. Fred E. Duskin was Principal Investigator and Program Director at Douglas Aircraft Company and was assisted by the Materials and Producibility Engineering Section.

All data is submitted unpublished, in confidence, to NASA-Ames.

ABSTRACT

The Phase III study of the NASA "Improved Fire Resistant Aircraft Seat Materials" involved fire tests of improved materials in multi-layered combinations representative of cushion configurations. Tests were conducted to determine their thermal, smoke, and fire resistance characteristics. Additionally, a "Design Guideline" for Fire Resistant Passenger Seats was written outlining general seat design considerations. Finally, a three abreast "Tourist Class" passenger seat assembly fabricated from the most advanced fire-resistant materials was delivered to the Ames Research Center.

CONTENTS

Section		Page
1	INTRODUCTION	1
2	SYMBOLS AND ABBREVIATIONS	2
3	TESTING OF MATERIALS	3
	3.1 Follow-on Screening Tests	3
	3.2 Flotation Materials	3
	3.3 Multilayer Tests	3
4	MATERIALS DATA EVALUATION	29
	4.1 Data Evaluation	29
	4.1.1 Individual Materials Specification	29
	4.1.2 Multilayer Material Specimens	29
	4.1.3 Summary	30
	4.2 Material Guideline	30
5	ECONOMIC ANALYSIS	35
	5.1 Material Costs and Weights	35
6	DESIGN GUIDELINE -- FIRE RESISTANT SEATS	40
7	RECOMMENDATION	48
8	PASSENGER SEAT ASSEMBLY	49
APPENDIX A -- MATERIAL TEST PROCEDURES		50
APPENDIX B - MATERIAL TEST RESULTS		55

LIST OF ILLUSTRATIONS

Figure		Page
1	TGA Curve of Sedellia 100% Wool (117)	7
2	TGA Curve of Cotton Muslin 44/40 Cnt (228)	7
3	TGA Curve of Vonar 3/Polyscrim (229)	8
4	TGA Curve of Urethane Flex Foam CS2850 (322)	8
5	TGA Curve Polyimide Foam 17-20-1 (323)	9
6	TGA Curve Polyether Urethane (324)	9
7	TGA Curve of Ensolite Type M (412)	10
8	TGA Curve of Ensolite Type ALS (413)	10
9	TGA Curve of Airex S32.5 (414)	11
10	Heat Release Rate Testing Results	16
11	ML Construction	18
11A	ML Construction	21
12	Multilayer Specimen Heat Release Rate	25
13	Individual Material Heat Release Rate at 3.5 w/cm^2	27
14	Cost/100 Cushion Sets (Bottom and Back)	38
15	Weight Estimate/100 Cushion Sets (Bottom and Back)	39
16	Structural Frame	41
17	Recline Mechanism	42
18	Decorative Shroud	44
19	Food Trays	45
20	Structural Fire Barrier	47
A-1	Typical Multiple Layer Test Specimen	54

LIST OF TABLES

Table		Page
1	Data Summary Chart	5
2	Individual Materials	12
3	Data Summary Chart	14
4	Results Animal Toxicity Tests	15
5	Seat Design Test Configurations 3-7-80	17
6	Heat Release Tests Multilayer Specimens	23
7	Seat Material Guidelines	31
8	Material Economics	36
9	Final Seat Design Test Configuration 5-19-80	37
B-1	List of Materials Screened	56
B-2	Animal Toxicity Test Results	58

SECTION 1

INTRODUCTION

The purpose of this program is to develop an improved fire resistant aircraft seat. The program is divided into four phases. Phase I established a data base with emphasis on thermal characteristics of a wide range of individual seat material candidates. Phase II was concerned with the thermal response of multilayer seat material constructions. Additionally, a preliminary seat specification was written and a source fire was developed. This report covers work accomplished during Phase III which involved continued testing of multilayer seat material constructions, outlining general seat design considerations in a "Design Guideline" for Fire Resistant Passenger Seats, and fabricating a three abreast "Tourist Class" passenger seat assembly from the most advanced fire-resistant materials available. The following Phase IV of this program will encompass the fabrication and full scale burn testing of various seat cushion configurations. Results will be compared to determine the degree of fire resistance achieved by the improved materials and seat designs.

The following report covers all work accomplished in Phase III.

SECTION 2

SYMBOLS AND ABBREVIATIONS

av	average
BTU	British thermal unit
^oC	degrees Celsius (centrigrade)
cc	cubic centimeter
cm	centimeter
cm^2	square centimeter
DAC	Douglas Aircraft Company
dm^2	decimeter square
^oF	degrees Fahrenheit
FAA	Federal Aviation Agency
FAR	Federal Aviation Requirements
ft	feet
g/cc	grams per cubic centimeter
g/m^2	grams per square meter
hr	hour
in	inch
kg	kilogram
kg/cm^2	kilogram per square centimeter
kg/m^2	kilogram per square meter
kw	kilowatt
lb	pound
lb/ft^2	pounds per square foot
lb/ft^3	pounds per cubic foot
m	meter
mm	millimeter
min	minutes
ml	multilayer (specimen)
NASA	National Aeronautics and Space Administration
NASA-Ames	National Aeronautics and Space Administration, Ames Research Center
N	Newton
PBI	Polybenzamidazole
psi	pounds per square inch
sec	second
TC	thermocouple
TGA	thermal gravimetric analysis
W	watt

SECTION 3

TESTING OF MATERIALS

Phase III material tests were intended to extend the data base established in Phases I and II. Multilayer tests were extended to incorporate new material. The test methods were basically consistent with those employed in the Phase I and Phase II programs.

3.1 FOLLOW-ON SCREENING TESTS

New materials were screened in accordance with methods described in Appendix A. Results of screening tests on materials included in the Phase III program are summarized in Table 1. The results of TGA testing are shown in Figures 1 through 9. Results of heat release rate tests are shown for individual materials, in Table 2. A list of materials incorporated in Phase III testing and other test data can be found in Appendix B.

3.2 FLOTATION MATERIALS

An early decision was required for selection of a flotation foam recommended by NASA for incorporation in the multilayer test specimens. This decision was necessary to permit early fabrication of test specimens for Phase III and early material procurement for the Phase IV program. Three closed cell polyvinyl chloride foams were considered, and the results of screening tests are reported in Tables 3 and 4. Heat release rate testing results at 3.5 w/cm^2 are reported in Figure 10.

The Airex S 32.5 (414) foam manufactured by Lonza, Inc. was selected.

This selection was made based on several considerations as follows:

1. This foam was significantly lower in weight.
2. The foam met burn requirements.
3. The high smoke number generated was equal to the other vinyls.
4. The material was in the same general range of heat release rate.
5. The material showed no unusual toxicity.
6. The material would be protected by a fire blocking layer and reinforcing layer.

3.3 MULTILAYER TESTS

Multilayer test configurations were negotiated with NASA. The final material combinations are shown in Table 5. These specimens were run at 3.5 w/cm^2 heat flux level [approximate black body temperature of 616°C(1140°F)]. It was felt that higher fluxes would not permit identification of individual differences as they would compress the time for events during testing. The 3.5 w/cm^2 radiant heat flux was still considered to be significantly higher than any small ignition source in terms of thermal threat level. Halfway through the program the baseline urethane foam CS 2850 (322) became unavailable, and the multilayer tests had to be repeated substituting a new baseline urethane foam 2043 FA(324) from North Carolina Foam Industries.

The individual multilayer specimen configurations are shown in Figures 11 and 11A. The new baseline incorporating specimens are identified as the "A" modification.

The results of heat release rate testing are reported for multilayer spcimens in Table 6. The results are charted in Figure 12 for ease of comparison. The results may be compared with individual heat release rate testing charted in Figure 13.

TEXTILES & (Thermoplastic)

TABLE 1

DATA SUMMARY CHART

Test & Test Method	Units	ST7427-112 (104)	20787 Kermel Wool Blend (101)	* 100% Wool Sedellia Blue (117)	* FR Cotton Muslin 44/40 (228)	400-11 Durette Batt (216)	Nomex III (221)			
Weight Thickness	gm/m^2	457 gm/m^2	290 gm/m^2	407 gm/m^2 12.7 oz/yd^2	158 gm/m^2	362 gm/m^2	254 gm/m^2			
Burn Test DMS 1511 Burn Time Burn Length Drip	sec. in.	1 1 2.3 2.6 ND ND	0 0 4.5 5.0 ND ND	1.3 3.3 3.0 2.7 ND ND	0 0 2.8 2.5 ND ND	0 0 .6 .7 ND ND	0 0 2.3 2.6 ND ND			
NBS Smoke DMS 1500 Nonflaming Flaming	 90 sec 4 min 90 sec. 4 min	28 73 64 127	21 38 21 37	17 34 52 105	0 0 0 0	0 1 6 11	5 14 0 2			
Colorfastness Method 5660 Method 5651(B)	Light Crocking	20SFH 40SFH exc exc	20SFH 40SFH exc good	20SFH 40SFH fnt slgt exc exc	-	-	-			
LOI ASTM D 2863	warp % fill %	33 31	30 50	33	48 -	38*	29			
TGA Temp at 50% wt. loss	°C	430	540	425	305	525	570			
Ignition Pill Test	ASTMD 2859	No burn char in area of pill	No burn char in area of pill	0.6in Dia x 0.3 in deep Vonar 3/PS						

* Phase III data

TABLE 1 (CONTINUED)

DATA SUMMARY CHART

FOAM & (Solid Elastomer)

Test & Test Method	Units	CS2850 * Urethane Foam Reeves Bro (322)	LS200 Neoprene (317)	Ensolite * Type M (412)	Ensolite * Type ALS (413)	FG215 Glass Block (300)	Polyimide 1720-1 Foam 1.5 pcf (323)	* Vonar 3/PS Polyester Scrim (229)	* Airex S32.5 (414)	* 2043 FA Urethane Foam N.C. Ind. (324)
Density Weight	lbs/ft^3 oz/yd^2	3.2	8.0	4.1	5.5	1.9 - 3.7	1.5	 26.7	3.27	1.9 10.9
Burn Test DMS 1511 Burn Time Burn Length Drip	sec. in	0 4.6 0	0 1.4 ND	5 4.7 ND	0 2.4 ND	0 2.5 ND	10 2.7 ND	0 2.4 ND	5 5.5 ND	0 0 6.0 5.3 0 0
NBS Smoke DMS 1500 Nonflaming Flaming	 90 sec. 4 min. 90 sec. 4 min.	36 63 52 119	27 71 51 122	- - 223 247	- - 121 222	5 8 4 6	0 5 6 16	49 90 0 91 148	 >700 >700	39 87 47 71 flash.
Pill Test Ignition ASTM D 2859		10sec 2 in dia 0.5 in deep	Char in 0.7 inch diameter				0 sec. 1.12 dia .22 in deep		1 in dia x .4 in depth burn	1.8 in dia .91 in depth
LOI	%	23				33	36.5	30-40scrim 50-60foam	25	235
TGA Temp. at 50% wt. loss	°C	380	475	440	440	max loss 24% @ 500°C	570	565	270	290
CORROSION DPS 8.86		-	-	-	-	-	-	very slgt corrosion	-	-

* Phase III data

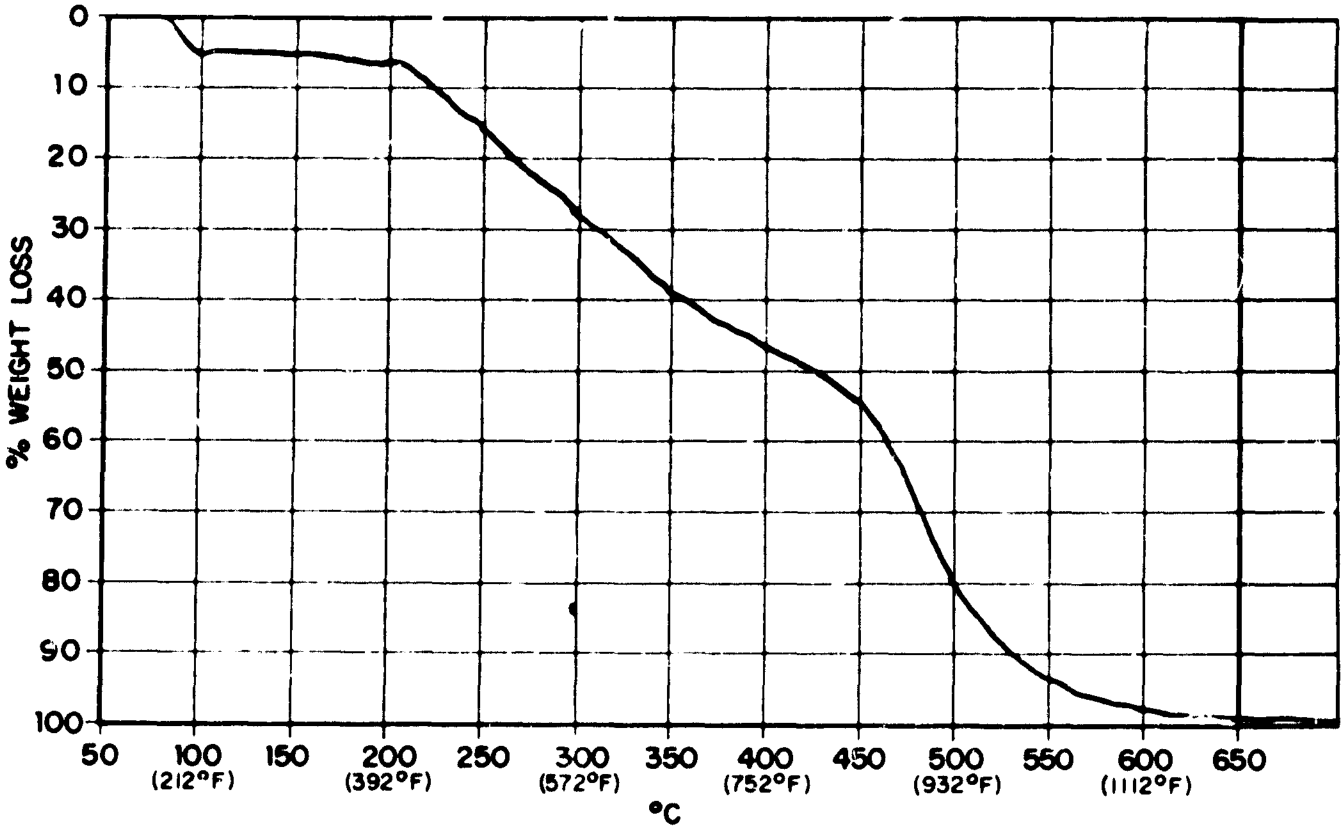


FIGURE 1. TGA CURVE OF SEDELLIA 100 PERCENT WOOL (117)

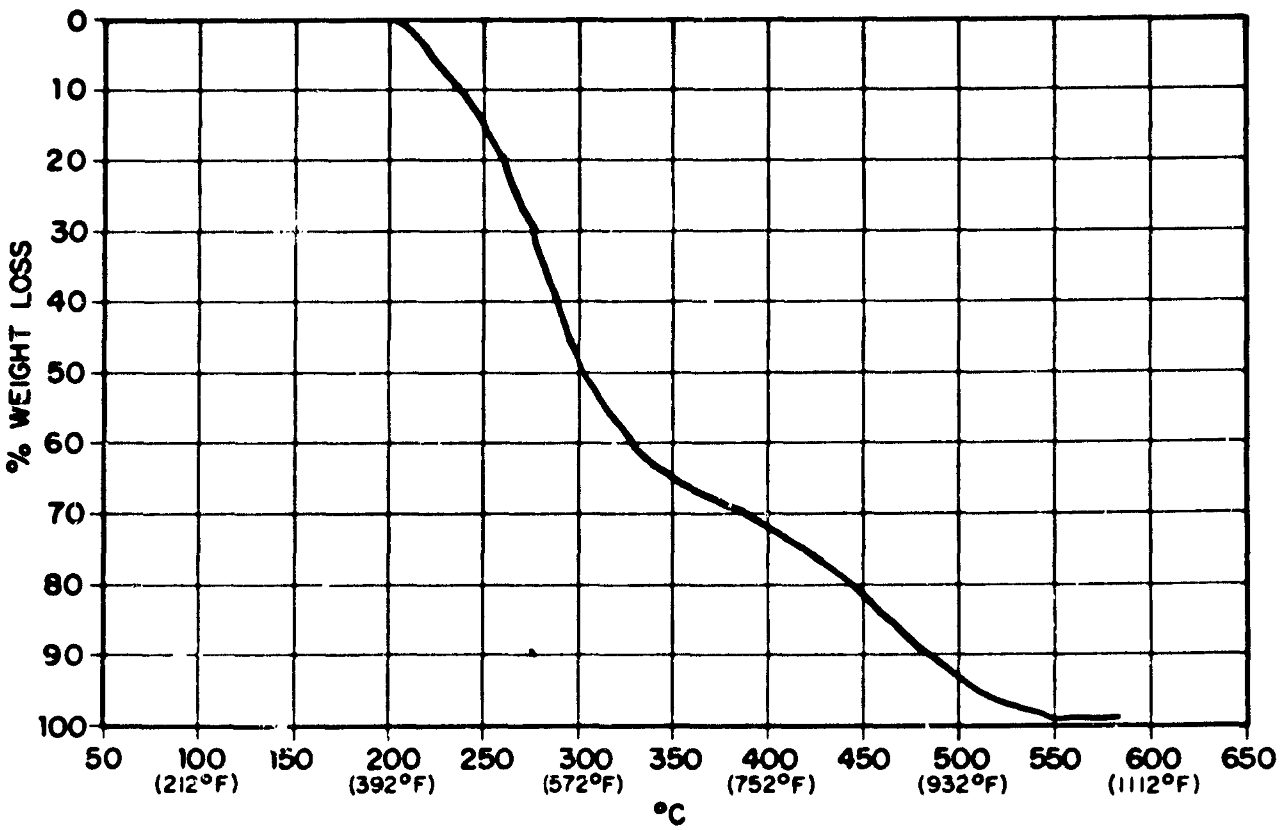


FIGURE 2. TGA CURVE OF COTTON MUSLIN 44/40 CNT (228)

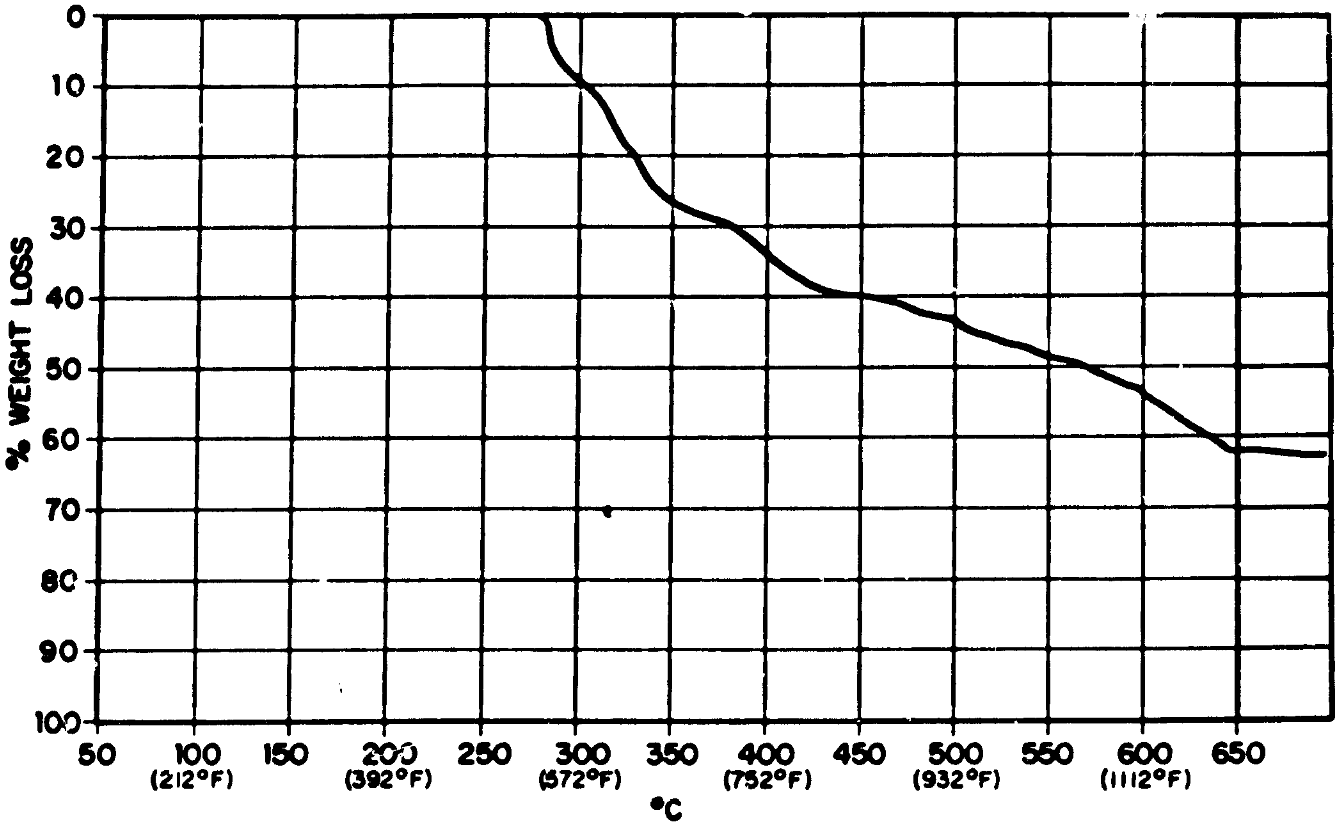


FIGURE 3. TGA CURVE OF VONAR 3/POLYSCRIM (229)

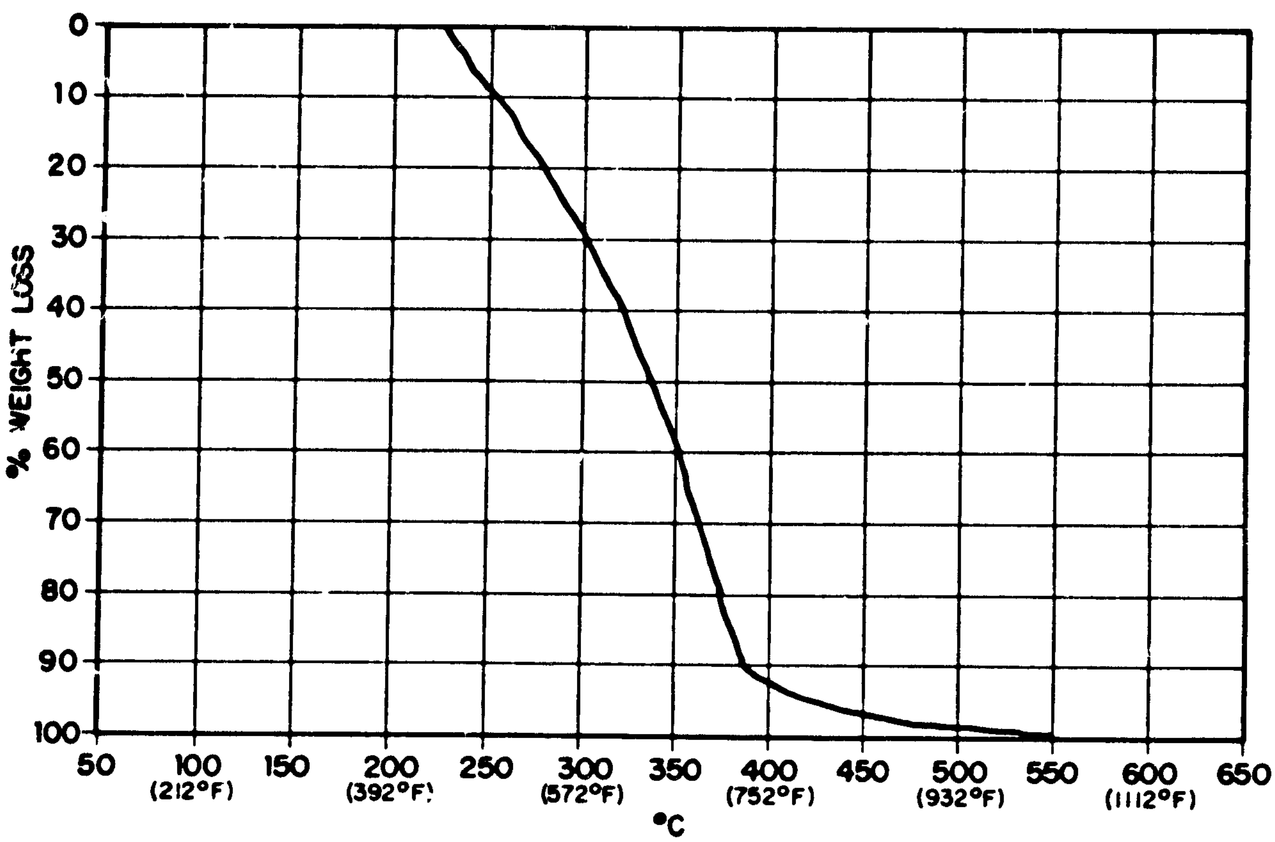


FIGURE 4. TGA CURVE OF URETHANE FLEX FOAM C S2850 (322)

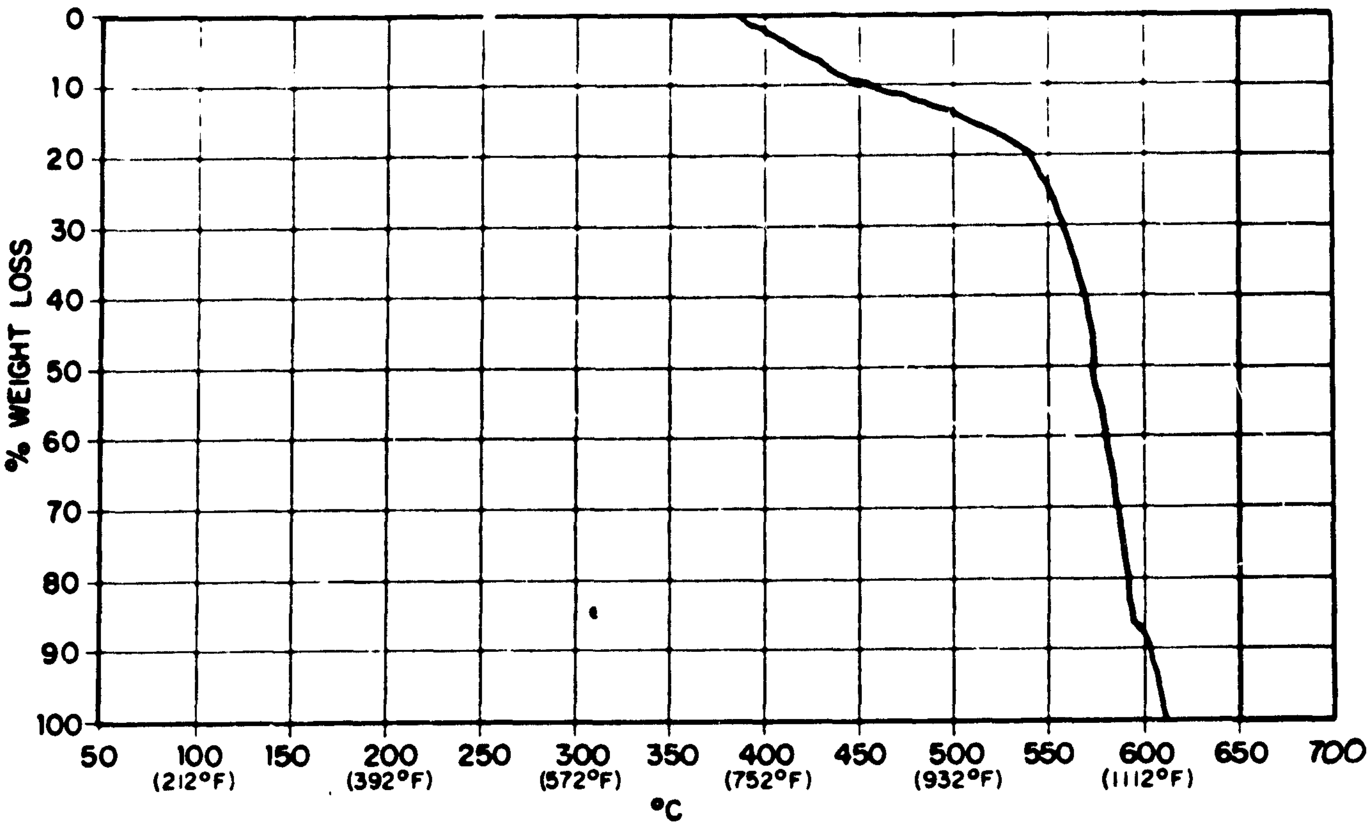


FIGURE 5. TGA CURVE POLYIMIDE FOAM 17-20-1 (323)

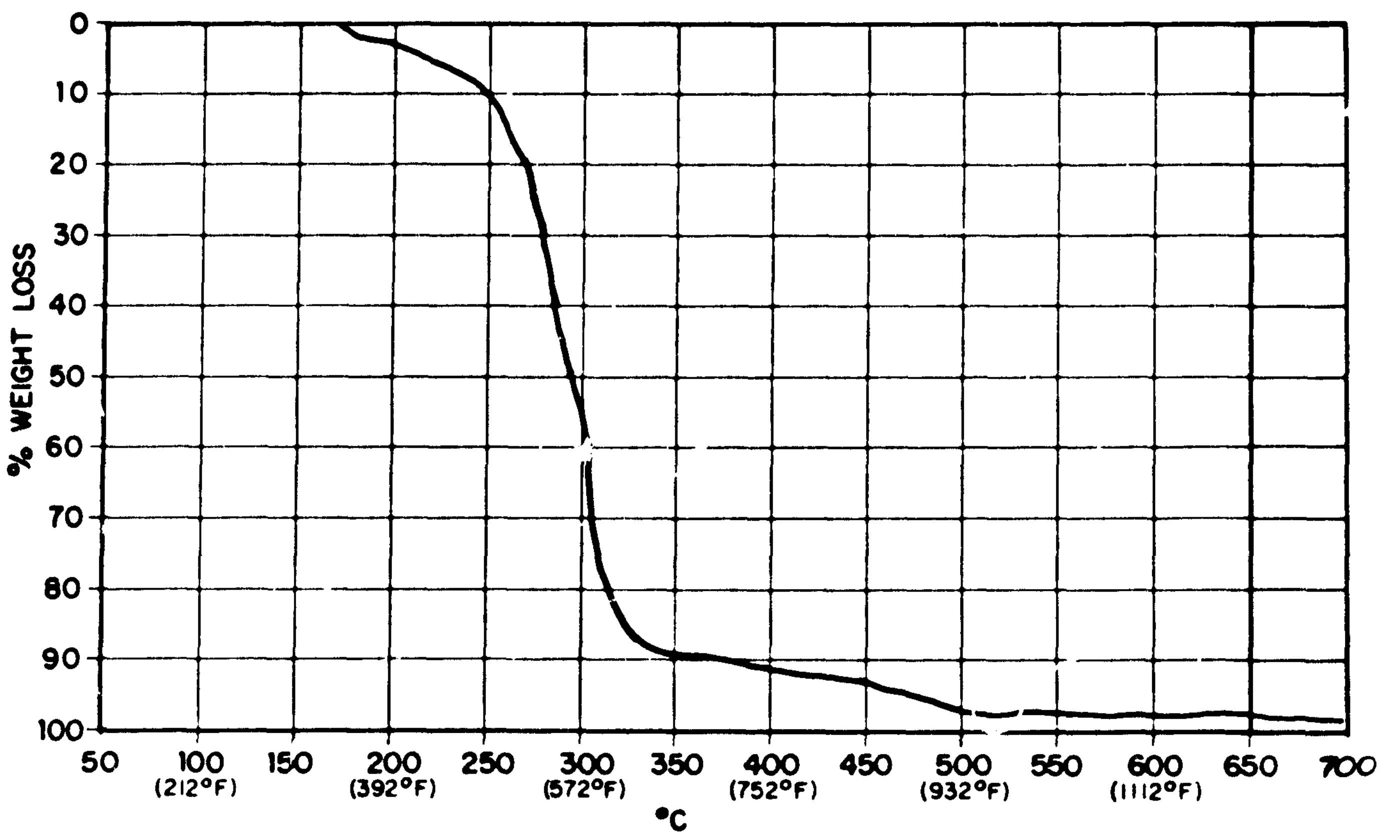


FIGURE 6. TGA CURVE POLYETHER URETHANE (324)

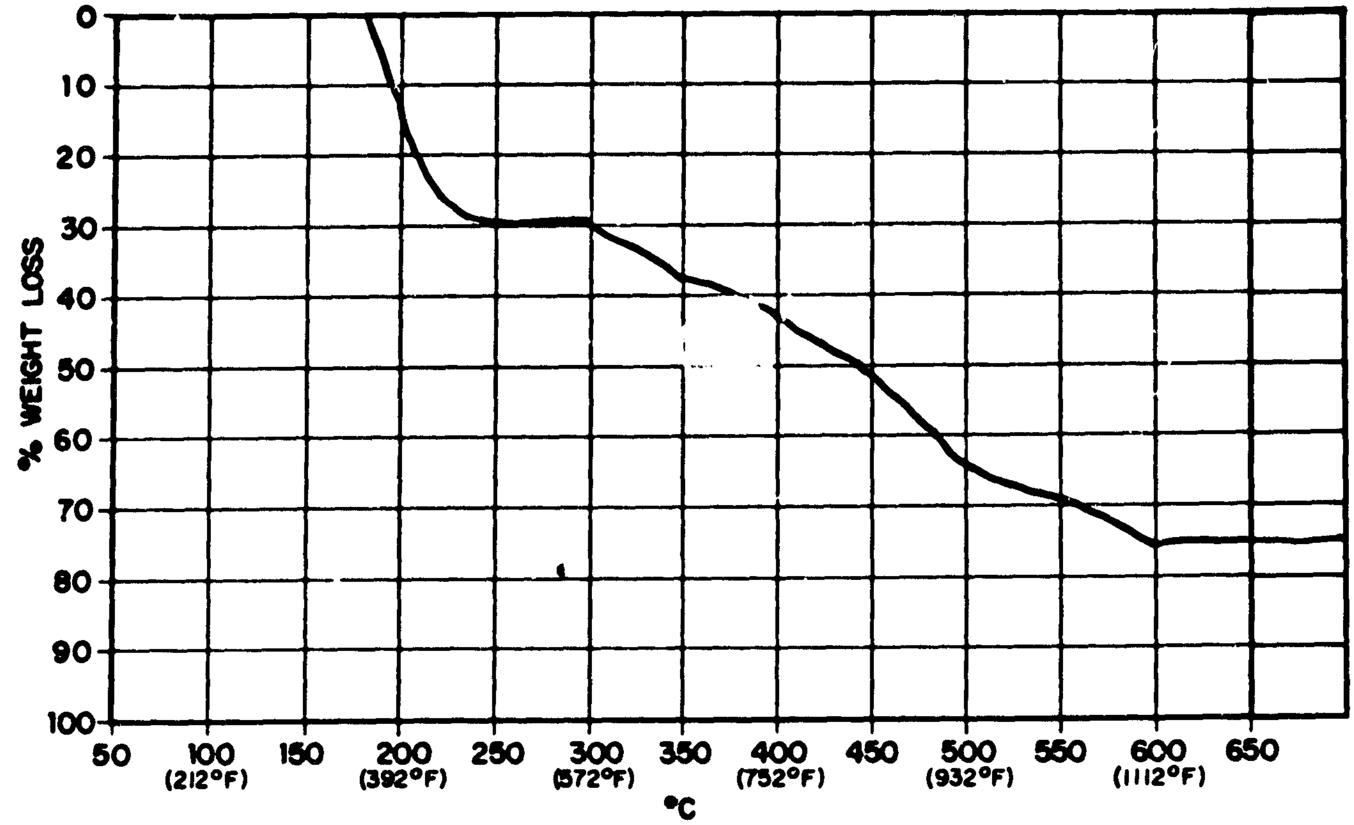


FIGURE 7. TGA CURVE OF ENSOLITE TYPE M (412)

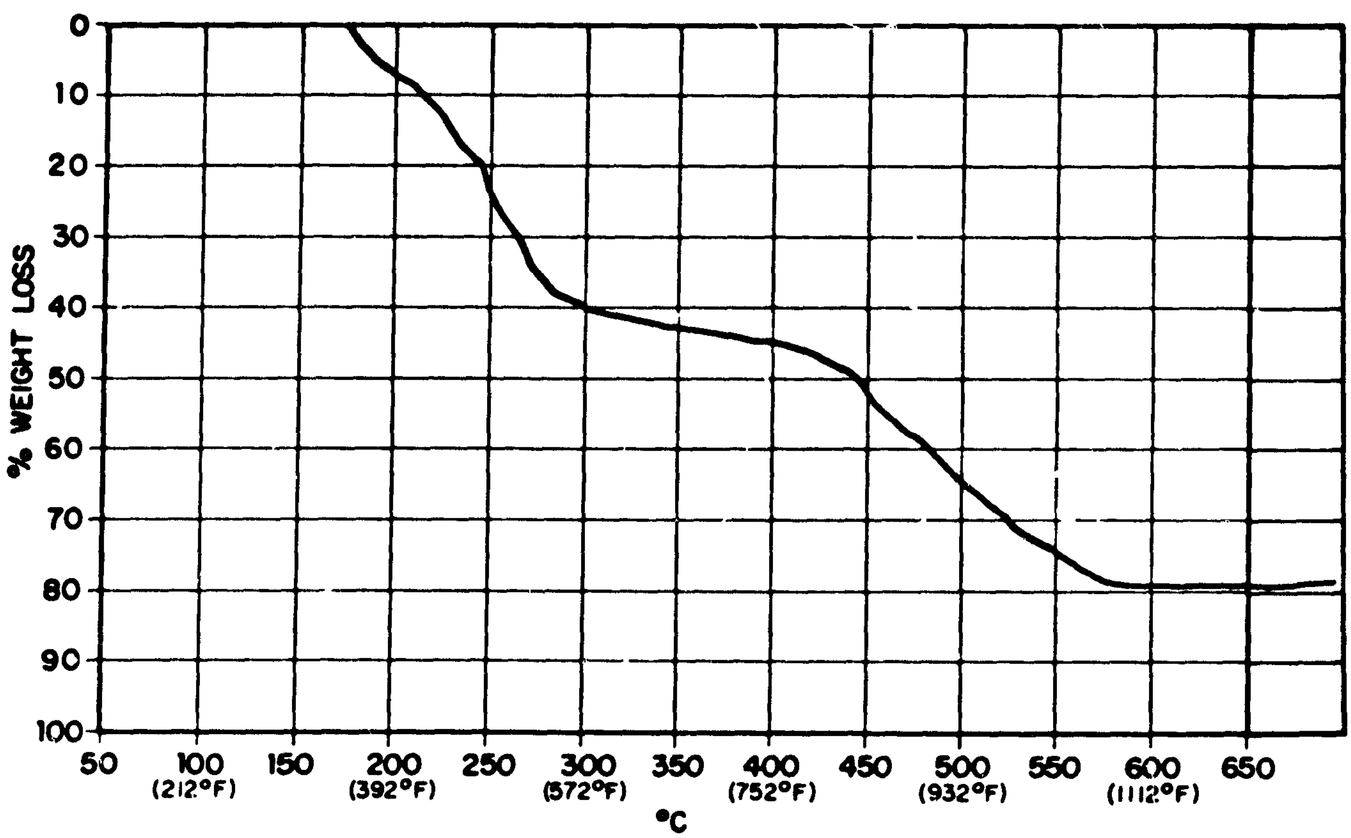


FIGURE 8. TGA CURVE OF ENSOLITE TYPE ALS (413)

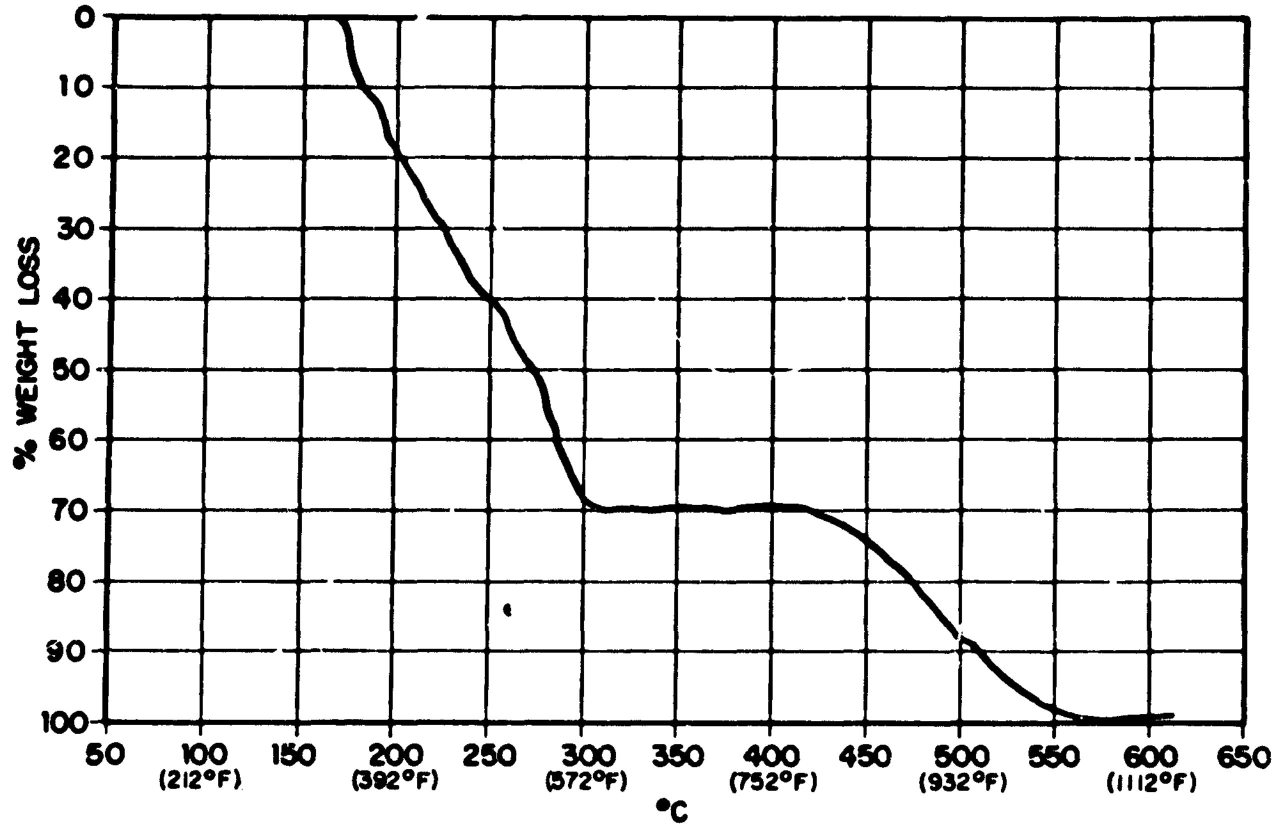


FIGURE 9. TGA CURVE OF AIREX S 32.5 (414)

TABLE 2

INDIVIDUAL MATERIALS

SAMPLE IDENTIFICATION	HEAT FLUX W/cm²	TIME TO IGNITION sec.	FLAME TRAVEL RATE mm/sec	HEAT RELEASE KW - MIN./m²: MAX. KW/m² at sec.	HEAT RELEASE TIME INTERVAL - MINUTES: 1.5	3.0	5.0	10.0	SMOKE RELEASE SSU/m²: MAX SSU/m² at sec.	SMOKE RELEASE TIME INTERVAL - MINUTES: 1.5	3.0	5.0	10.0
20787	2.5		2.7		36	42.1	49.4	65.2					
Kermel Wool	3.5		10		32.6	41.0	43.6	-					
Blend (101)	5.0		ND		50.3	72.9	102.3	-					
ST4727-112	2.5		3		91.8	115.4	132.5	162.8					
Sun Eclipse Blue (104)	3.5		>6		88.8	115.6	130.9	158.9					
Wool/Nylon	5.0		6.7		85.6	112.0	132.0	160.0					
Sedellia Blue 3177	2.5	<3	7.6		41	48	53	66	1.3 @ 39sec	1	1	3	6
100% Wool	3.5	<3	12.7		52	63	72	96	40 @ 20sec	3	4	5	7
(117)	5.0	Flashed	>30		60	78	96	132	9.7 @ 20sec	7	11	12	16
Durette Batt	2.5		None		7.3	16.7	28.0	71.7					
400-11	3.5		None		1.6	6.3	13.7	36.9					
(216)	5.0		None		8.8	28.4	47.4	-					
Vonar 3/PS	2.5	None	None		-2	-1	6	36	2.8 @280sec	1	3	5	9
(229)	3.5	80	2.5		-2	8	16	40	3.8 @113sec	2	5	6	8
	5.0	<3	1.3		13	34	55	106	15.8@67.5sec	8	16	23	26
Nomex III	2.5	None	-		-3	-3	-3	-2	7 @ 16 sec	8	18	28	71
(221)	3.5	5	~8		3	3	6	22	2.5 @ 20sec	1	3	4	7
	5.0	4	~5		22	35	54	96	12.8@ 8 sec	3	4	5	10
Cotton Muslin	2.5	-	-		5	10	17	24	No measur-	-	-	-	-
44/40 cnt	3.5	<5	6.9		7	11	21	45	able smoke	-	-	-	-
(228)	5.0	<2	>30		13	21	33	66		-	-	-	-
LS200	2.5	None	None		-3	-1	5	50	1.3 @ 12sec	1	2	3	6
Neoprene	3.5	None	None		4	13	26	80	1.7 @ 12sec	1	2	2	6
(317)	5.0	<2	12.7		46	94	129	223	28 @ 11 sec	12	20	22	25
CS2850	2.5	<2	>10		105	129	147	182	25 @ 10 sec	10	11	12	15
Urethane	3.5	<2	>15		107	132	153	198	4.2 @10 sec	17	18	19	22
(322)	5.0	<2	>20		104	135	162	218	65 @ 6 sec	18	19	20	22
FG215					6.0	11.8	23.2	35.1					
Glass Block					3.2	8.1	13.6	24.6					
(300)					-	-	-	-					

TABLE 2 (CONTINUED)

INDIVIDUAL MATERIALS

SAMPLE IDENTIFICATION	HEAT FLUX W/cm²	TIME TO IGNITION sec.	FLAME TRAVEL RATE mm/sec	HEAT RELEASE KW - MIN./m²					SMOKE RELEASE SSU/m²				
				MAX. KW/m² at sec.	TIME INTERVAL - MINUTES				MAX. SSU/m² at sec.	TIME INTERVAL - MINUTES			
					1.5	3.0	5.0	10.0		1.5	3.0	5.0	10.0
Ensolite M (412)	2.5	<2	19		86	118	132	151	161@11.3sec	145	147	149	153
	3.5	flashes 2	>30		101	136	163	217	270@11.3sec	183	184	185	187
	5.0	flashes 2	>30		107	145	182	250	353@ 6.5sec	173	174	175	178
Ensolite ALS (413)	2.5	<2	7.6		42	108	135	184	84@125 sec	39	60	62	65
	3.5	<2	>15		55	123	155	204	118@ 6.3sec	80	116	118	120
	5.0	<2	>30		67	126	164	236	208@ 6.3sec	149	185	186	190
Airex S32.5 (414)	2.5	<3	>11		81	102	113	131	189@27.5sec	118	121	122	125
	3.5	<2	>30		74	89	98	114	308@238sec	168	170	172	177
	5.0	<2	>30		72	91	107	146	35@20 sec	166	167	168	171
Polyimide Foam 1.5#/ft³ (323)	2.5	None	None		1	5	12	34	7@ 72 sec	3	3	7	10
	3.5	<2	6.4		10	20	38	75	1.3@ 15 sec	5	5	5	6
	5.0	<2	>25		23	43	74	126	8.9@7.5 sec	3	4	5	14
2043 FA Urethane Foam Baseline (324)	2.5	flashes <2	Melts ~30		68	118	144	188					
	3.5	flashes <1	Melts ~76		85	114	135	179					
	5.0	flashes <1	Melts >76		89	112	131	159					

NOTE: DATA IN THIS TABLE HAVE SAME BASIS AS PHASES I AND II REPORTS

TABLE 3

DATA SUMMARY CHART

Test & Test Method	Units	Ensolite M (412)	Ensolite ALS (413)	Airex S32.5 (414)	S2850 Urethane Foam (322)
Density Weight	lbs/ft^3 oz/yd^2	3.5 - 5.0 24.5	4.5 - 8.5 32.9	3.27	
Burn Test DMS 1511 Burn Time Burn Length Drip	 sec. in	 5 4.7 ND	 0 2.4 ND	 5 5 5 ND	 0 4.6 ND
NBS Smoke DMS 1500 Nonflaming Flaming	 90 sec. 4 min. 90 sec. 4 min.	 223 247	 121 247	 >700 >700	 36 63 52 119
Pill Test Ignition ASTM D 2859				1 inch dia x .4 depth	10sec 2 inch dia x .5 depth
LOI	%			25	23
TGA Temp. at 50% wt. loss	°C	440	440	270	380

TABLE 4

RESULTS ANIMAL TOXICITY TESTS

MATERIAL NO. & NAME	MATERIAL WEIGHT GRAMS	ANIMAL WEIGHT GRAMS	NORMALIZE DATA PER GM MATL 25 GM MOUSE		APPARENT MATERIAL PYROLYZED MG
			Ti	Td	
Ensolite M					
2/1	0.2481	27.7	1.27	-	143
2/2	0.2537	26.4	.96	2.16	152
2/3	0.2576	24.2	1.18	2.54	145
2/4	0.2768	24.2	1.37	9.89	164
AV			1.2 ± 0.17	4.9 ± 4	
Ensolite ALS					
1/1	0.9802	26.6	1.43	3.68	598
1/2	0.2790	27.0	1.05	7.88	159
1/3	0.2752	23.8	1.16	>9.64	154
1/4	0.2742	26.2	1.20	6.22	153
AV			1.2 ± 0.16	6.9 ± 2.5	
Airex Foam					
3/4	0.5292	25.3	2.74	3.88	473
3/5	0.5395	25.1	2.24	2.55	505
3/6	0.5051	25.0	2.86	5.68	458
AV			2.6 ± 0.33	4.0 ± 1.6	

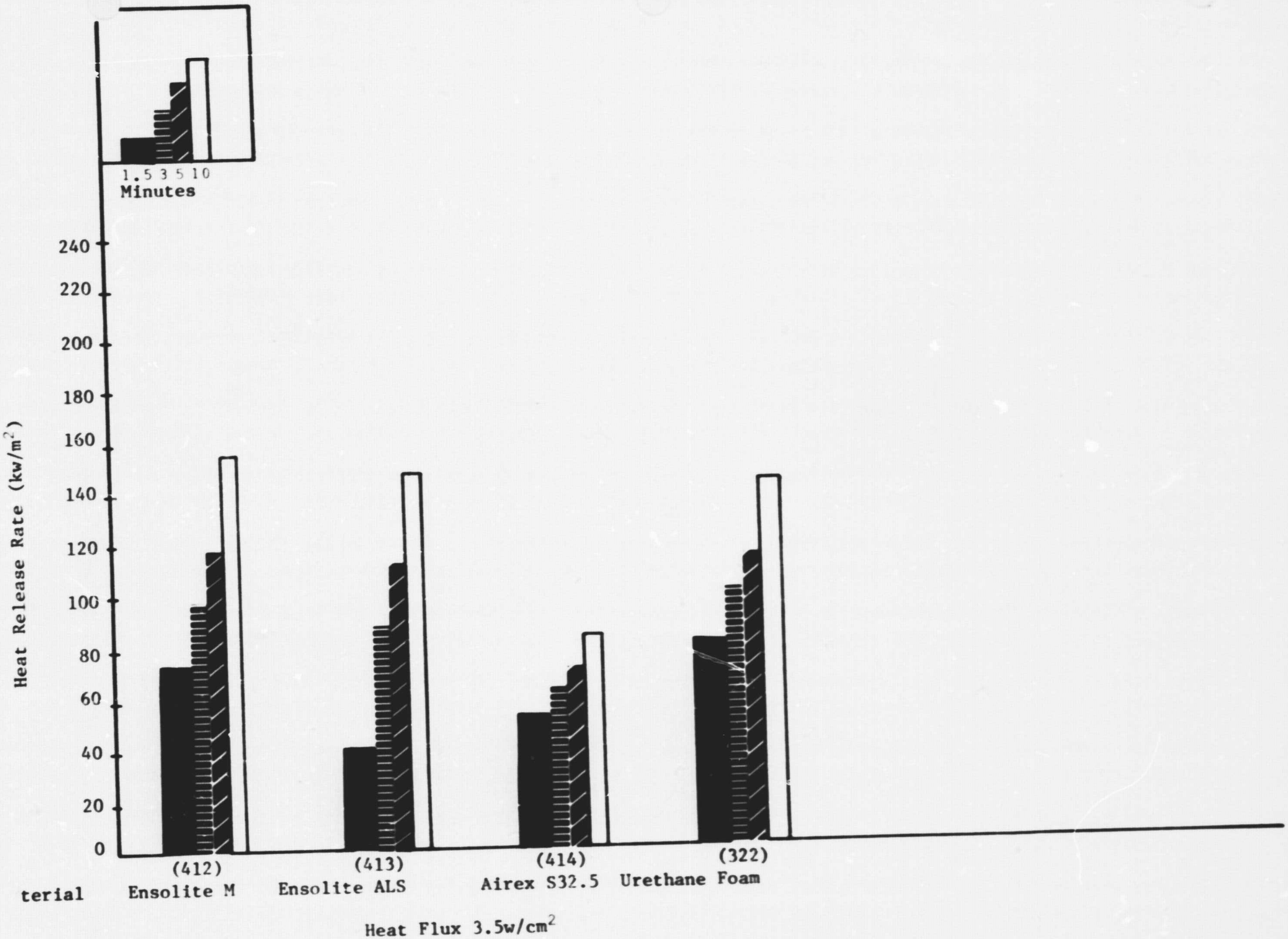


FIGURE 10. HEAT RELEASE RATE TESTING RESULTS

TABLE 5

SEAT DESIGN TEST CONFIGURATIONS

TEST NUMBER	UPHOLSTERY	FIRE BLOCKING & SLIP COVER	CUSHION REINFORCEMENT (ADHESIVE R2332 N/F)	CUSHION	REMARKS
1	ST4727-112 Sun Eclipse Wool/Nylon (104)	None	Cotton Muslin 44/40 Cnt (228)	CS2850 Urethane (322)	Baseline
2	ST4727-112 Sun Eclipse Wool/Nylon (104)	400-11 Durette Batt (216)	Nomex III (221)	CS2850 Urethane (322)	Fire Barrier
3	ST4727-112 Sun Eclipse Wool/Nylon (104)	Vonar 3/PS (229)	Cotton Muslin 44/40 Cont (228)	CS2850 Urethane (322)	Fire Barrier
4	20787 Kermel/Wool Blend (101)	Nomex III (221) 1/2" LS-200 Neoprene (317)	None	CS2850 Urethane Foam with Airex Foam 32.5 (414)	Fire Barrier and Flotation
5	20787 Kermel/Wool Blend (101)	Nomex III (221) 1/2" LS-200 Neoprene (317)	None	CS2850 Urethane (322)	Fire Barrier
6	20787 Kermel/Wool Blend (101)	None	Nomex III (221)	1/2" LS-200/Polyimide Foam 1" (323)	Lightweight Combined Cushion
7	Sedellia Blue 3177 100% Wool (117)	None	Cotton Muslin 44/40 Cnt (228)	Polyimide Foam (323) 1" t	Fire Retardant Cushion
8	Sedellia Blue 3177 100% Wool (117)	None	Cotton Muslin 44/40 Cnt (228)	Polyimide Foam with Airex Foam 32.5(414)	Fire Retardant Cushion with Flotation
9	Sedellia Blue 3177	Vonar 3/PS (229)	Nomex III (221)	FG 215 Glass Batt (309)	Fire Retardant Cushion with Fire Blocking

1)

ST4727-112 Sun Eclipse Blue (104)

Cotton Muslin 44/40 Cnt (228)

Cement

S2850 Urethane Foam (1 inch t) (322)
11 x 11 Area

BASE LINE

NOTE: No cuts material folded at corners

2)

ST4727-112 Sun Eclipse Blue (104)

400-11 Durette Batt (216)

Nomex III Fabric (221)

Cement

S2850 Urethane Foam (1 inch t) (322)
11 x 11 Area

NOTE: No cuts material folded at corners

3)

ST4727-112 Sun Eclipse Blue (104)

Vonar 3/PS (229)

Cotton Muslin 44/40 Cnt (228)

Cement

S2850 Urethane Foam (1 inch t) (322)

NOTE: No cuts material folded at corners

4)

20787 Kermel/Wool Blend (101)

Nomex III Fabric (221)

Cement

LS200 Neoprene Foam (317) 1/2 inch t

Cement

S2850 Urethane Foam (1/2 inch t) (322)

Airex S32.5 (1/2 inch t) (414)

NOTE: Cut at corners except Kermel decorative but all material over cushion edges

FIGURE 11. ML CONSTRUCTION

5)

20787 Kermel Wool Blend (101)

Nomex III Fabric (221)

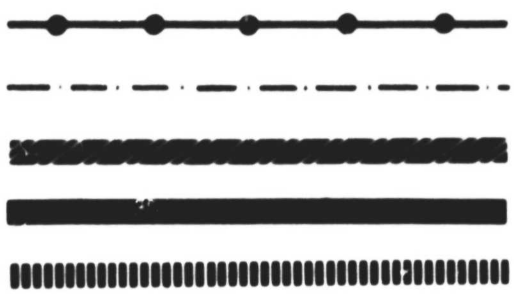
LS200 Neoprene Foam (317) 1/2 inch t

Cement

S2850 Urethane Foam 1 inch t (322)

NOTE: LS200 cut at corner & cemented
Nomex III folded only

6)



20787 Kermel Wool Blend (101)

Nomex III Fabric (221)

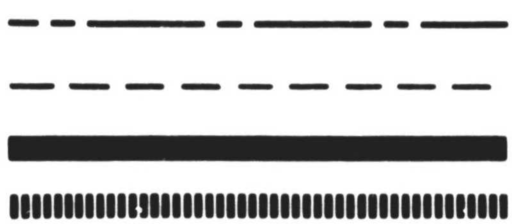
LS200 Neoprene Foam (317) 1/2 inch t

Cement

Polyimide Foam (323) 1 inch t

NOTE: LS200 cut at corner & cemented
Nomex III folded only

7)



Sedellia Blue 3177 (117)

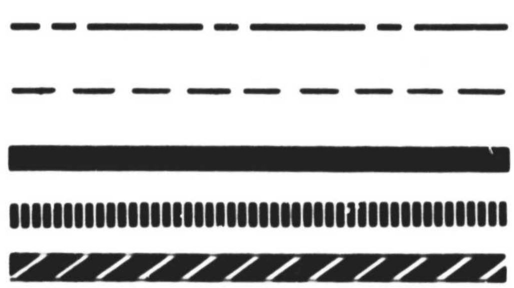
Cotton Muslin 44/40 Cnt (228)

Cement

Polyimide Foam (323) 1 inch t

NOTE: No cuts material folded only

8)



Sedellia Blue 3177 (117)

Cotton Muslin 44/40 Cnt (228)

Cement

Polyimide Foam (323) 1/2 inch

Airex S32.5 (1/2 inch t) Foam

NOTE: Dam of Polyimide around edge of
Airex

FIGURE 11. ML CONSTRUCTION (CONTINUED)

9)

Sedellia Blue 3177 (117)

Vonar 3/PS (229)

Nomex III Fabric (221)

Cement

FG215 Glass Batt Cushion (300) 1 inch t

NOTE: No cuts material folded at corners

FIGURE 11. ML CONSTRUCTION (CONTINUED)

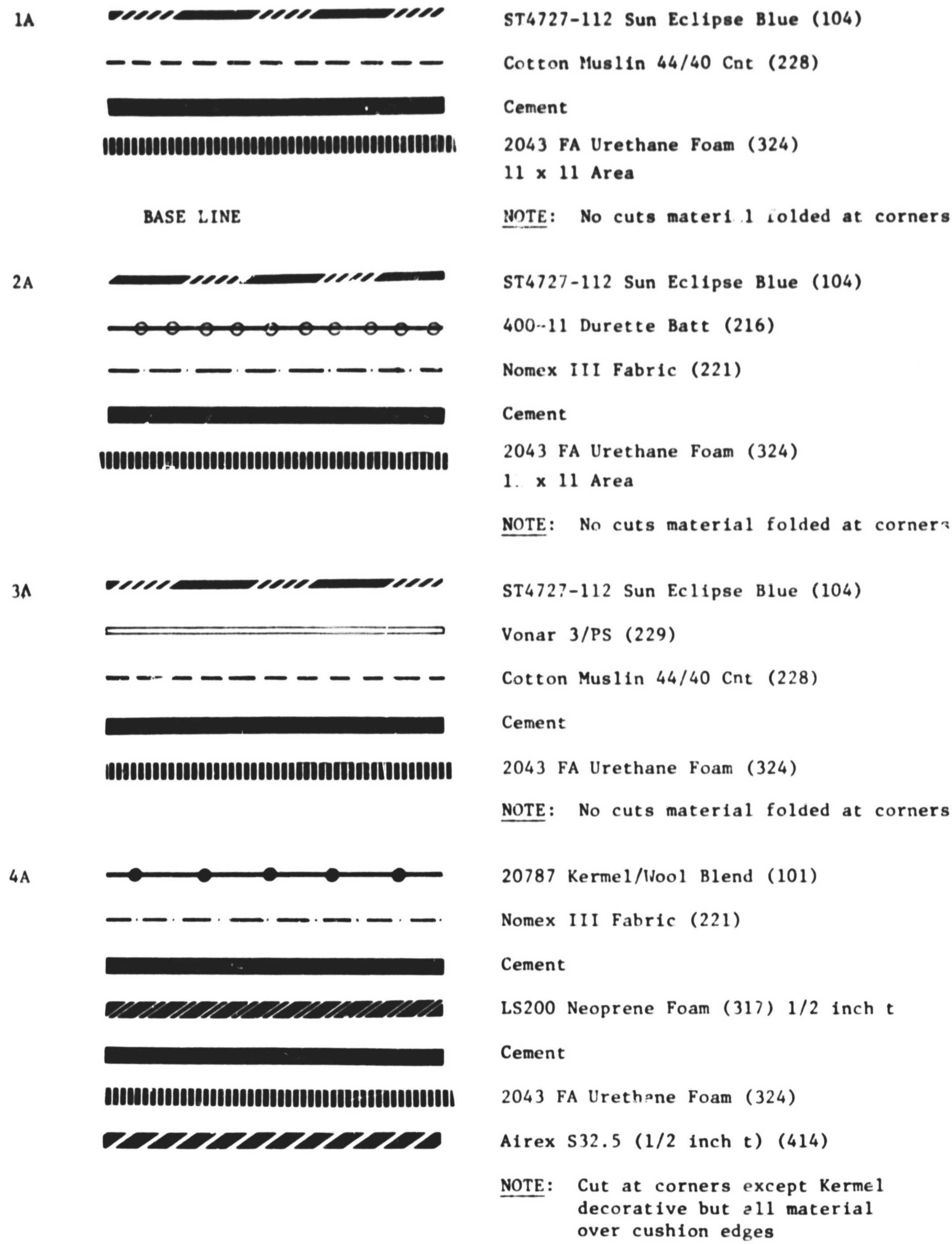
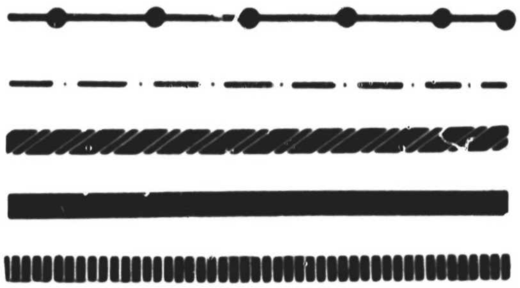


FIGURE 11A. ML CONSTRUCTION

5A



20787 Kermel Wool Blend (101)

Nomex III Fabric (221)

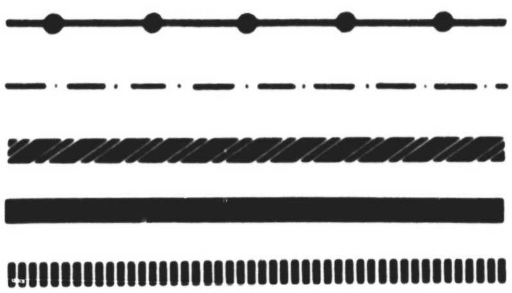
LS200 Neoprene Foam (317) 1/2 inch t

Cement

2043 FA Urethane Foam (324)

<u>NOTE</u>: LS200 cut at corner & cemented
Nomex III folded only

6A



20787 Kermel Wool Blend (101)

Nom. III Fabric (221)

LS200 Neoprene Foam (317) 1/2 inch t

Cement

Polyimide Foam (323) 1 inch t

<u>NOTE</u>: LS200 cut at corner & cemented
Nomex III folded only

7A

Sedellia Blue 3177 (117)

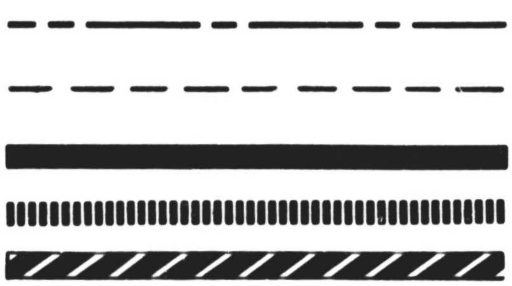
Cotton Muslin 44/40 Cnt (228)

Cement

Polyimide Foam (323) 1 inch t

<u>NOTE</u>: No cuts material folded only

8A



Sedellia Blue 3177 (117)

Cotton Muslin 44/40 Cnt (228)

Cement

Polyimide Foam (323) 1/2 inch

Airex S32.5 (1/2 inch t) Foam

<u>NOTE</u>: Dam of Polyimide around edge of
Airex

FIGURE 11A. ML CONSTRUCTION (CONTINUED)

TABLE 6

HEAT RELEASE TESTS MULTILAYER SPECIMENS

SAMPLE IDENTIFICATION	HEAT FLUX W/cm²	TIME TO IGNITION sec.	FLAME TRAVEL RATE mm/sec.	HEAT RELEASE KW - MIN./m²					SMOKE RELEASE SSU/m²				
				MAX. KW/m² at sec.	TIME INTERVAL - MINUTES				MAX. SSU/m² at sec.	TIME INTERVAL - MINUTES			
					1.5	3.0	5.0	10.0		1.5	3.0	5.0	10.0
ML-1A Wt = 114.9gram (run 14280) (Baseline)	3.5	9	9.8	121 @ 93	108	223	297	396	56 @ 27	33	43	43	46
ML-2A (run 14180) WT = 152.7 g	3.5	6	12.7	105 @ 180	63	153	296	467	37 @ 180	6	31	43	44
ML-3A (run 14080) Wt = 200.7g	3.5	6	8.5	106 @ 186	50	108	266	430	80 @ 185	16	61	122	125
ML-4A (run 11980) Wt = 282.1 g	3.5	9	9.8	64 @ 443	13	16	22	156	177 @ 443	2	4	6	215
ML-5A (run 14380) Wt = 225.0 g	3.5	2	25.4	116 @ 234	24	44	216	426	203 @ 234	1	6	192	193
ML - 1 (run 8080) Wt = 142.5 g	3.5	9	12.7	129 @ 95	103	241	403	586	63 @ 95	43	83	104	110
ML - 2 (run 8180) Wt = 182.4 g	3.5	8	12.7	124 @ 180	61	136	365	651	83 @ 160	6	43	116	128
ML-3 (run 8580) Wt = 216.8 g	3.5	6	11.5	122 @ 200	49	85	278	546	75 @ 197	15	28	109	126
ML-5 (run 8480) Wt = 289.3 g	3.5	6	7.1	100 @ 420	17	22	47	423	98 @ 420	1	1	11	198
ML-6 (run 7880) Wt = 260.3 g	3.5	6	7.5	32.8 @ 300	16	22	44	174	12 @ 315	1	3	8	21

TABLE 6 (CONTINUED)

HEAT RELEASE TESTS MULTILAYER SPECIMENS

SAMPLE IDENTIFICATION	HEAT FLUX W/cm²	TIME TO IGNITION sec.	FLAME TRAVEL RATE mm/sec.	HEAT RELEASE KW - MIN./m²					SMOKE RELEASE SSU/m²				
				MAX. KW/m² at sec.	TIME INTERVAL - MINUTES				MAX. SSU/m² at sec.	TIME INTERVAL - MINUTES			
					1.5	3.0	5.0	10.0		1.5	3.0	5.0	10.0
ML-7 (run 8080) Wt = 92.7 g	3.5	6	12.7	86 @ 21	80	141	190	287	21 @ 20	9	11	12	14
ML-8 (run 14480) Wt = 348.2 g	3.5	6	18.1	94 @ 120	81	197	273	399	132 @ 120	27	132	133	134
ML-9 (run 8380) Wt = 219.3 g	3.5	5	11.5	76.9 @ 245	55	75	186	368	63 @ 235	12	13	82	90

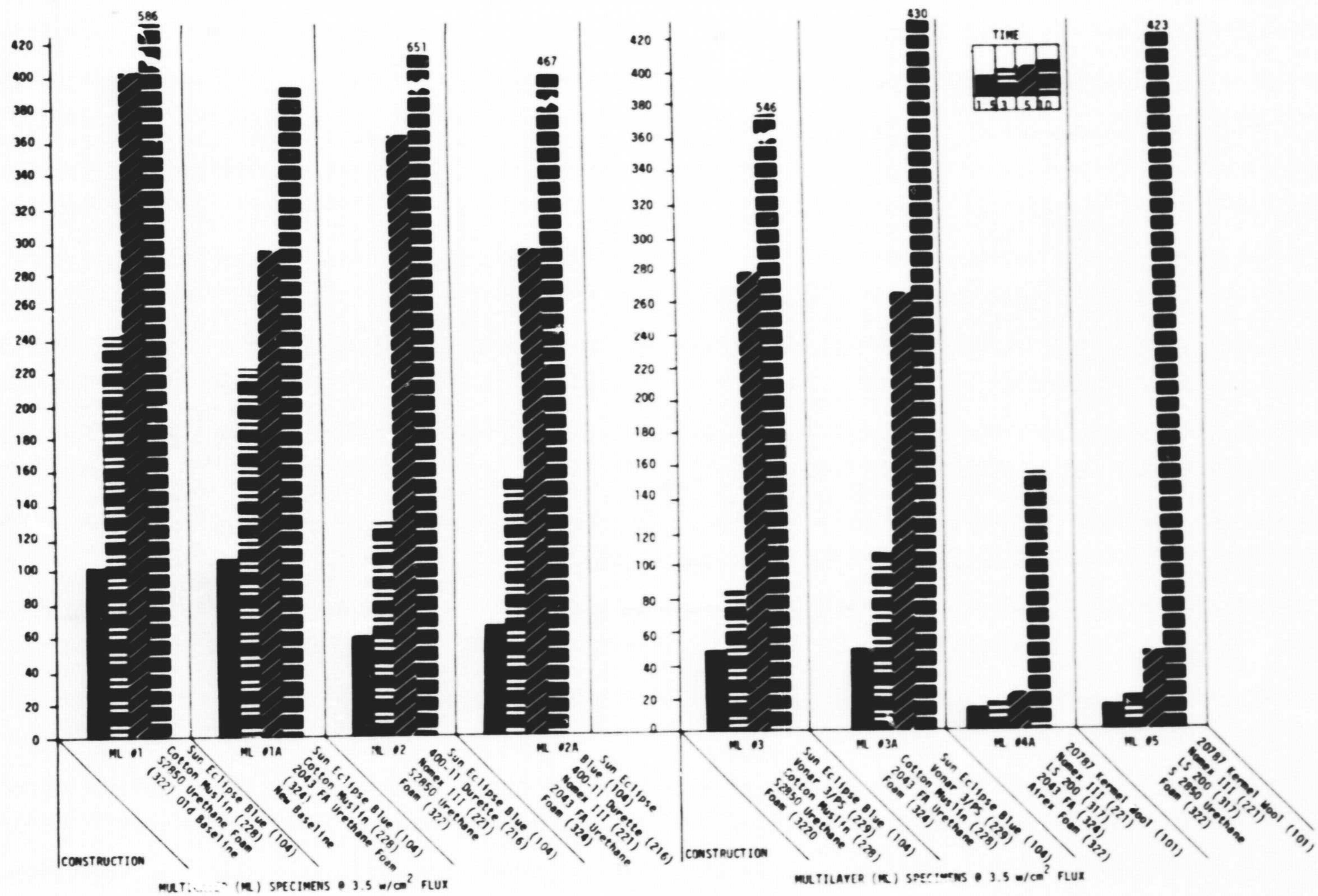


FIGURE 12. MULTILAYER SPECIMEN HEAT RELEASE RATE

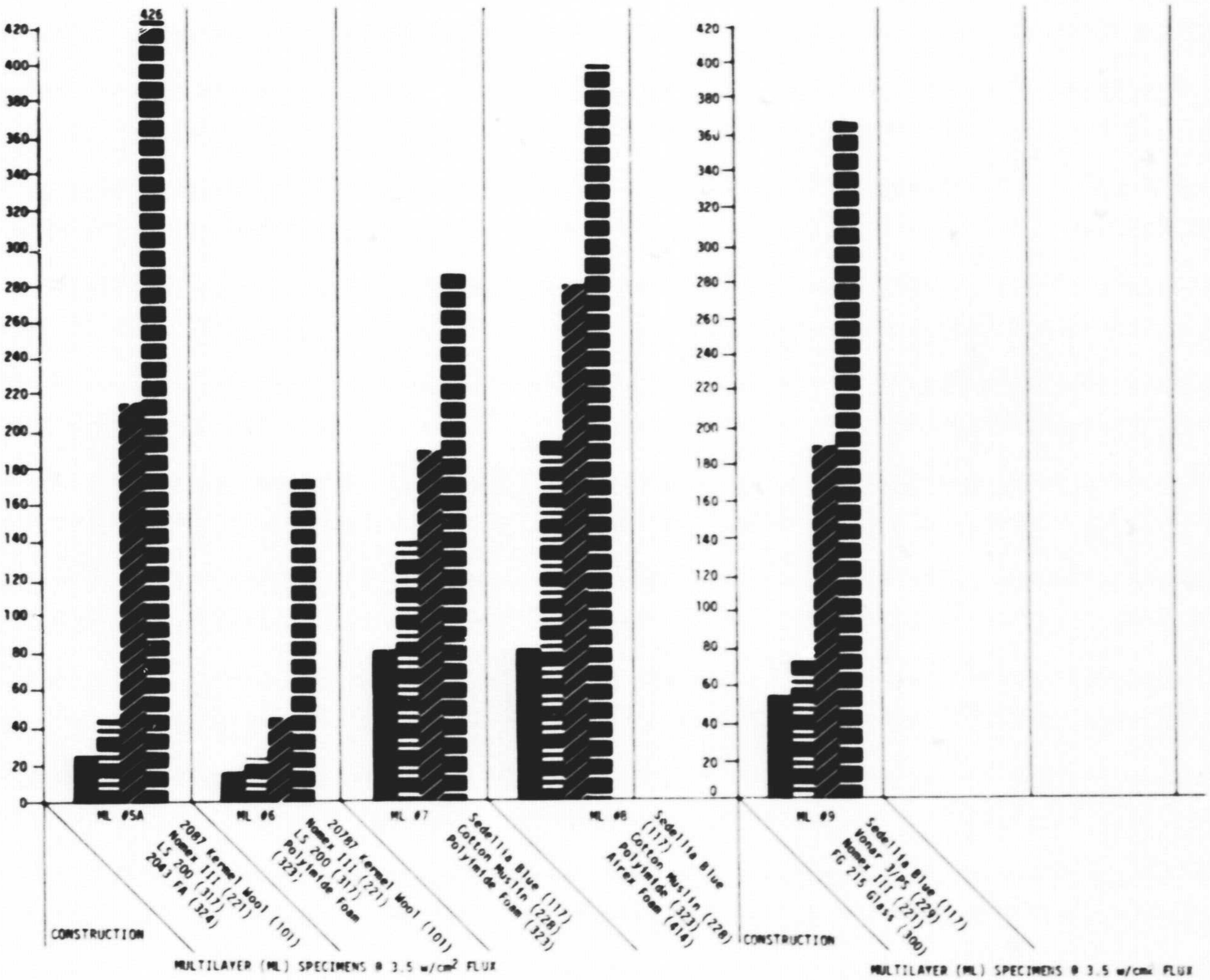


FIGURE 12. MULTILAYER SPECIMEN HEAT RELEASE RATE (CONTINUED)

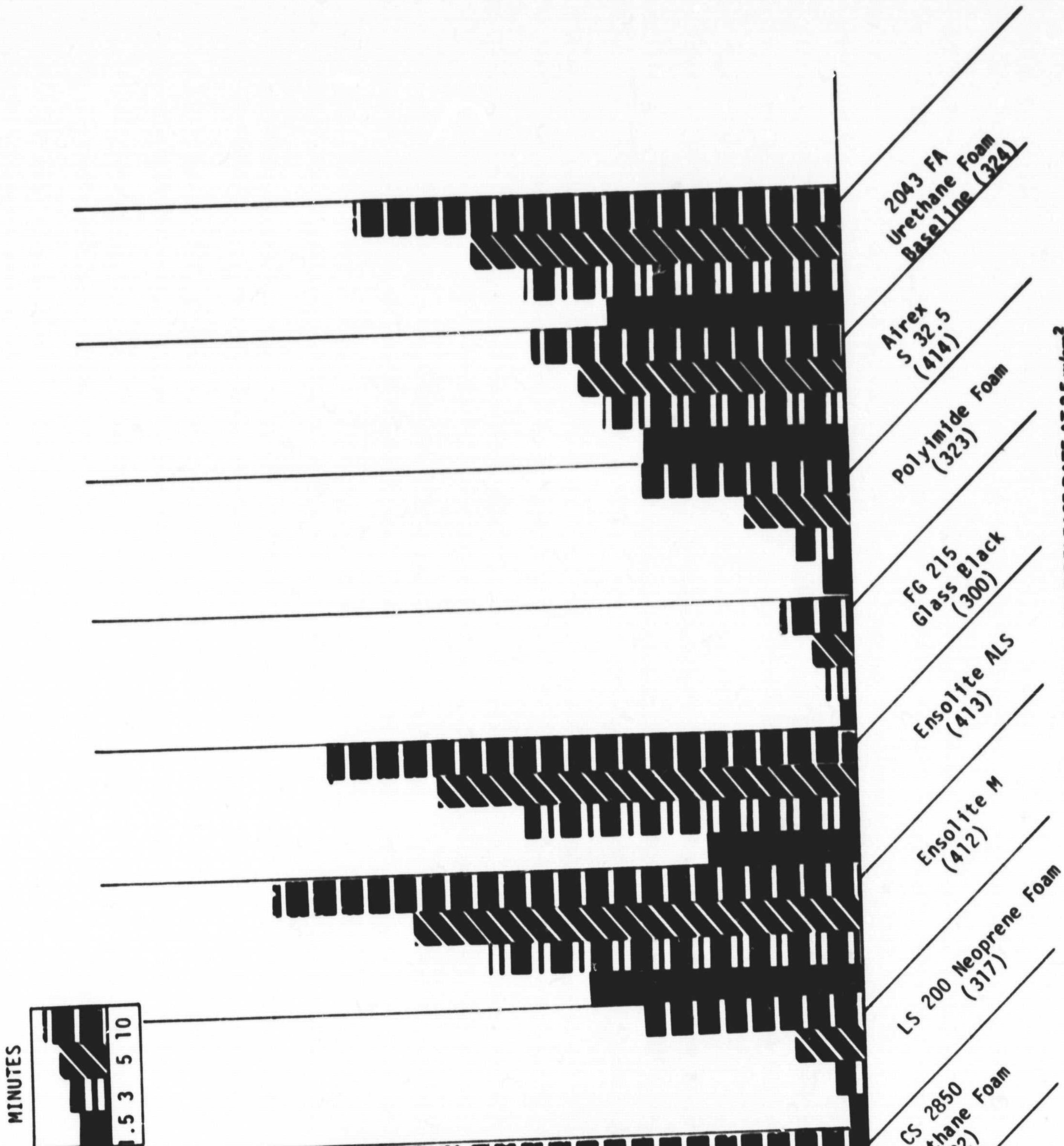


FIGURE 13. INDIVIDUAL MATERIAL HEAT RELEASE RATE AT 3.5 w/cm^2

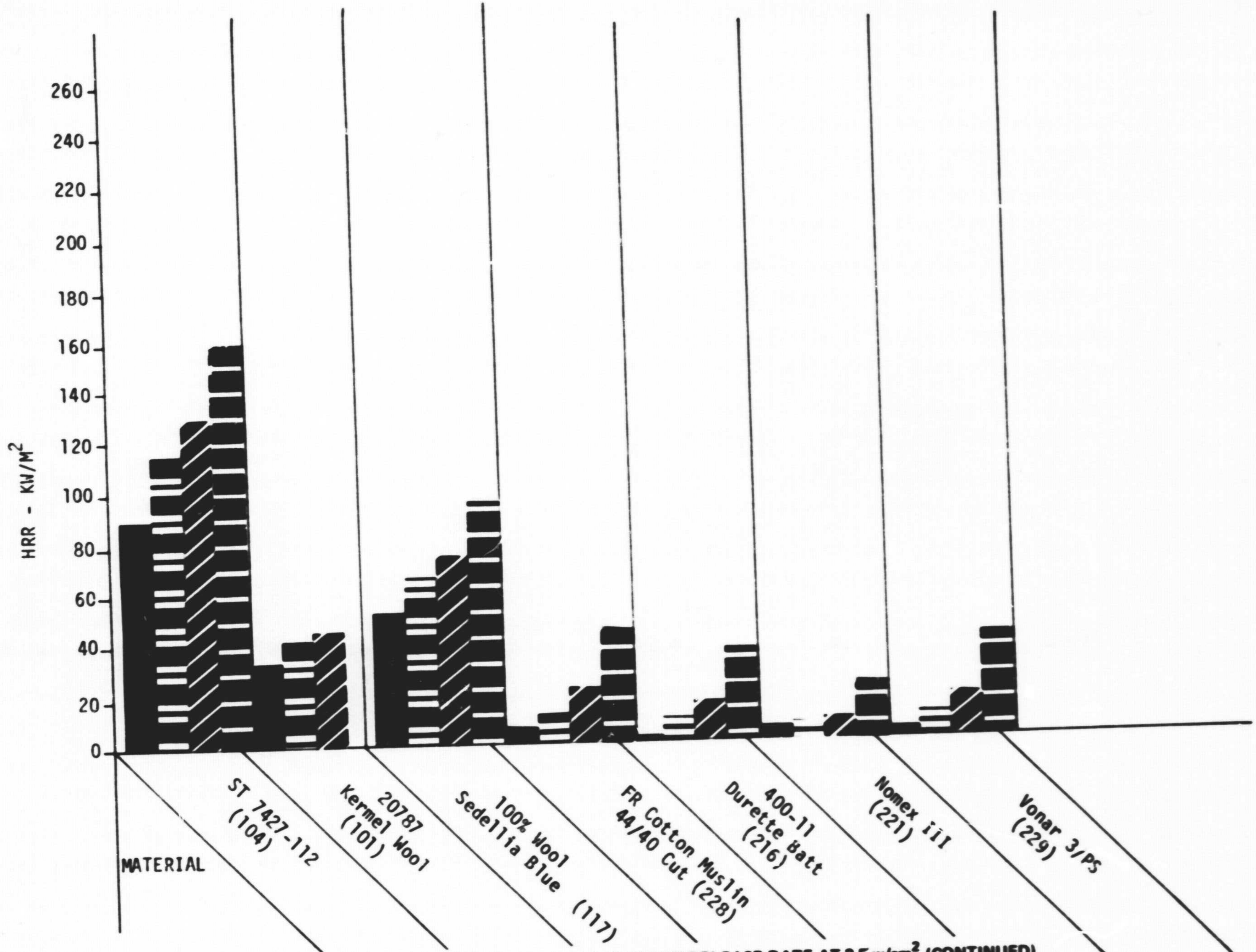


FIGURE 13. INDIVIDUAL MATERIAL HEAT RELEASE RATE AT 3.5 w/cm² (CONTINUED)

SECTION 4

MATERIALS DATA EVALUATION

4.1 DATA EVALUATION

4.1.1 Individual Material Specimens

The Phase II program results showed in Kermel wool (101) to have slightly improved performance when compared to the wool nylon blend (104). The Phase III program results showed the Kermel wool (101) to have slightly improved performance when compared to 100 percent wool Sedellia blue (117) as well. The smoke generation of the Kermal wool was significantly less than the 100 percent wool. TGA temperature at 50 percent weight loss was 540°C for the Kermel wool blend as compared to 425°C for the 100 percent wool.

Of the two slip sheet materials, the Nomex III (221) and FR cotton muslin (228) performance was in the same general range although the TGA temperature at 50 percent weight loss was 570°C for the Nomex III compared to 305°C for the cotton muslin.

The LS200 Neoprene foam (317), the Vonar 3/PS (229) and 400-11 Durette Batt (216) performance, when considered as a fire blocking material, were in the same general range for heat release and other properties except for smoke. The Durette material was significantly lower in smoke generation.

The advanced cushion materials LS200 (317), GF215 (300) and polyimide foam (323), when compared to either of the baseline foams (322,324), show significant improvement in heat release rate properties. They are improved in terms of the rate at which heat is released, which represents a fire spread potential, and in terms of total heat released. Overall, both of the baseline foams performed within a comparable range. The LS200 may serve as fire blocking or cushion material, but its relatively high density will present design challenges when used as cushioning material.

The flotation foams Ensolite M (412), Ensolite ALS (413), and Airex S32.5 (414) performance was in the same general range as the baseline urethanes, both in the rate of heat released and total heat released. The flotation foams do not show improved characteristics and represent a general area requiring thermal resistivity improvement.

4.1.2 Multilayer Material Specimens (Figure 12)

The first five minutes of test basically represent the response of the upper layers for the multilayer specimens other than baseline, where only thermally thin materials of limited resistivity are involved. The reproducibility of testing is shown by comparing upper layers of similar construction during the first five minutes; for example, No's 2 and 2A, No's 3 and 3A, and No's 4A and 5. Poorer reproducibility was obtained for No's 5A and 6. Early release of volatiles from the foam could account for the difference at five minutes.

One of the most significant results is the indication that a fire blocking layer contributes significantly to the reduction in the rate of heat released and to the total heat released even when the cushion material is a baseline urethane foam. This can be seen in comparing No.'s 4A with 6, the latter incorporating an advanced cushion material. This can also be seen when comparing No.'s 5 with 1, which is the baseline with the same foam cushion. While the Vonar 3/PS seems to be less effective in the specific constructions tested compared to LS200, it also improves the urethane performance as can be seen by comparing No.'s 3A with 1A and 3 and 1. It should be noted that the 3/16 inch Vonar was compared with a 1/2 inch LS200.

The protection of the flotation foam by the fire blocking layer can be seen in comparing No.'s 4A and 8.

4.1.3 Summary

The results of the Phase III materials test program may be summarized as follows:

A. The material data base has been expanded.

B. The reproducibility of multilayer tests was very good.

C. The advanced materials continued to perform significantly better under thermal threat than the baseline materials.

D. Baseline material performance is significantly improved by incorporation of a fire blocking layer.

E. Additional work is needed to develop flotation material with improved fire resistivity.

F. The flotation material performance may be improved by use of a fire blocking layer.

4.2 MATERIAL GUIDELINES

Material guidelines have been prepared based on the poorest performance of an advanced material together with allowance for lot-to-lot variation. This latter basis is somewhat arbitrary and would require an expanded test program to become more accurate. The guidelines are only valid in terms of the test methodology specified. Any test variation would require new guideline numbers to be established. The guidelines basically assume that a material meeting the guidelines indicated would perform in a similar manner to the advanced materials tested in the program when exposed to a similar thermal threat. The guidelines would not ncecessarily pertain to other thermal threats. The guidelines are outlined in Table 7.

TABLE 7

SEAT MATERIAL GUIDELINES

FUNCTIONAL LAYER	TEST	TEST METHOD	GUIDELINES VALUE
Decorative Fabrics	Colorfastness	FTMS 191 Method 5660	Minimum good after 20 SFH and 40 SFH
	Color Availability	-	Wide range including pastels
	Burn Resistance	DMS 1511	Burn time avg. 5.0 sec max. Burn length avg. 15.24 cm max. Drip ND
	Smoke	DMS 1500	NF 90 sec 4 min 40 100 max F 90 sec 4 min 100 150 max
	Toxicity	Per method reported in NASA CR-152056	No unusual toxicity
	Abrasion	Wyzenbeck method FTMS 191 method 5304.1 tested against Nomex III S/470 20,000 cycles	20% max - Loss instrength
Slipsheet or Topper	Burn Resistance	DMS 1511	Burn time avg. 0 sec Burn length avg. 7.6 cm max. Drip ND
	Smoke	DMS 1500	NF 90 sec 4 min 10 25 F 90 sec 4 min 10 20
	Toxicity	Per method reported in NASA CR-152056	No unusual toxicity
	Abrasion	Wyzenbeck method per FTMS 191 method 5304.1 tested against ST4727-122 sun eclipse blue 20,000 cycles	10% max - Loss in strength
Fire Blocking	Burn Resistance	DMS 1511	Burn time avg. 0 sec Burn length avg. 7.6 cm max. Drip ND
	Smoke	DMS 1500	NF 90 sec 4 min 55 100 F 90 sec 4 min 100 155
	Toxicity	Per method reported in NASA CR-152056	No unusual toxicity

TABLE 7 (CONTINUED)
SEAT MATERIAL GUIDELINES

FUNCTIONAL LAYER	TEST	TEST METHOD	GUIDELINE VALUE
Fire Blocking (Cont'd)	Abrasion	Wyzenbeck method per FTMS 191 Method 5304.1 Tested against 10,000 cycles	50% Max - Loss in strength
	Heat Release Rate	Per method reported in NASA CR-152056	@ 3.5w/cm^2 Max @ 1.5 min = 6 kw/m^2 3.0 min = 18 kw/m^2 5.0 min = 35 kw/m^2
	TGA	@ 20°C per minute in air	Max Wt. Loss % 80% Temp @ 50% Wt loss 560°C
Cushion Reinforcement	Burn Resistance	DMS 1511	Burn time avg. 0 sec max. Burn length Avg. 8.9 cm max. Drip ND
	Smoke	DMS 1500	NF 90 sec 4 min 10 15 max F 90 sec 4 min 5 7 max
	Toxicity	Per method reported in NASA CR-152056	No unusual toxicity
	Tear	FTMS 191 Method 5132	8.0 kg min
Cushion	Burn Resistance	DMS 1511 + Modified DMS 1511 for metling material	Burn time avg. 6 sec max. Burn length avg. 15.2 cm max. Drip ND
	Smoke	DMS 1500	NF 90 sec 4 min 35 80 max F 90 sec 4 min max. 55 132
	Toxicity	Per method reported in NASA CR-152056	No unusual toxicity
	Heat Release Rate	Per method reported in NASA CR-152056	@ 3.5 w/cm^2 Max @ 1.5 min = 18 kw/m^2 3.0 min = 28 kw/m^2 5.0 min = 48 kw/m^2

TABLE 7 (CONTINUED)

SEAT MATERIAL GUIDELINES

FUNCTIONAL LAYER	TEST	TEST METHOD	GUIDELINE VALUE
Cushion (Cont'd)	TGA	@ 20 C per minute in air	Max Wt Loss % = 75 Temp @ 50% = 470°C
	Indentation and Deflection	ASTM D240G Method A	@ 25% 18.2 kg min
	Compression Set	ASTM D 1055 Method 19.1	Increase @ 50% Defl = 10% max
	*Density	ASTM D1564	.14 gm/cc (1 lbs/ft^3) max.
Cushion Flotation Core	Burn Resistance	DMS 1511	Burn time avg. 6 sec max. Burn length avg. 15.2 cm max. Drip ND
	Heat Release Rate	Per method reported in NASA CR-152056	@ 3.5 w/cm^2 Max @ 1.5 min = 115 kw/m^2 3.0 min = 148 kw/m^2 5.0 min = 180 kw/m^2 10.0 min = 225 kw/m^2
Thermoplastic Shrouds	Burn resistance .043 thickness	DMS 1511	Burn time avg. 0 sec max Burn length avg. 4.0 cm Drip ND
	Smoke	DMS 1500	NF 90 sec 4 min 4 sec 25 max F 90 sec 4 min 75 200 max
	Toxicity	Per method reported in NASA CR-152056	No unusual toxicity
	TGA	@ 20°C per minute in air	Max wt Loss T 98 Temp @ 50% Wt Loss 505°C min
Thermoset Seat Bottom	Burn Resistance	DMS 1510	Burn time avg. 1 sec max, Burn length avg. 5 cm max. Drip ND

*See discussion

TABLE 7 (CONTINUED)

SEAT MATERIAL GUIDELINES

FUNCTIONAL LAYER	TEST	TEST METHOD	GUIDELINE VALUE
Thermoset Seat Bottom (Cont'd)	Smoke	DMS 1500	NF 90 sec 4 min 25 50 max F 90 sec 4 min 25 50 max
	TGA		% wt Loss Max
Hardware Components	Burn Resistance	DMS 1510	Burn time avg. 15 sec max Burn length avg. 15.2 cm max Drip ND

SECTION 5

ECONOMIC ANALYSIS

The cost impact of manufacturing aircraft passenger seat cushions from fire resistant materials/constructions cannot be reasonably determined until a production order of a particular design is produced. It may be safe to assume that the manufacturing costs would increase in comparison to present construction practices. Additional labor would be required to produce the multilayered constructions and new cutting die templates would be needed for cutting the multilayers.

Finally, major manufacturing problems are not anticipated for fire resistant material substitutions.

5.1 MATERIAL COSTS AND WEIGHTS

The cost and weights of individual seating materials are presented in Table 8. Using these values, a cost and weight estimate for material usage was performed on each of the Seat Design Test Configurations listed in Table 9.

The cost results are presented in Figure 14. Figure 14 shows all configurations costing more than the baseline seat (No. 1). A cost for polyimide foam was not available.

The weight results are presented in Figure 15. Figure 15 shows that the seat configuration using the polyimide foam cushion (No. 7) would produce a weight savings in comparison to the baseline seat. All other cushion configurations would result in a weight increase.

With the cost values of polyimide foam unavailable for comparison, the cushion configuration using a fire blocking layer of Vonar 3/PS protecting a urethane foam cushion appears the most appealing candidate when considering cost in cushion design.

TABLE 8

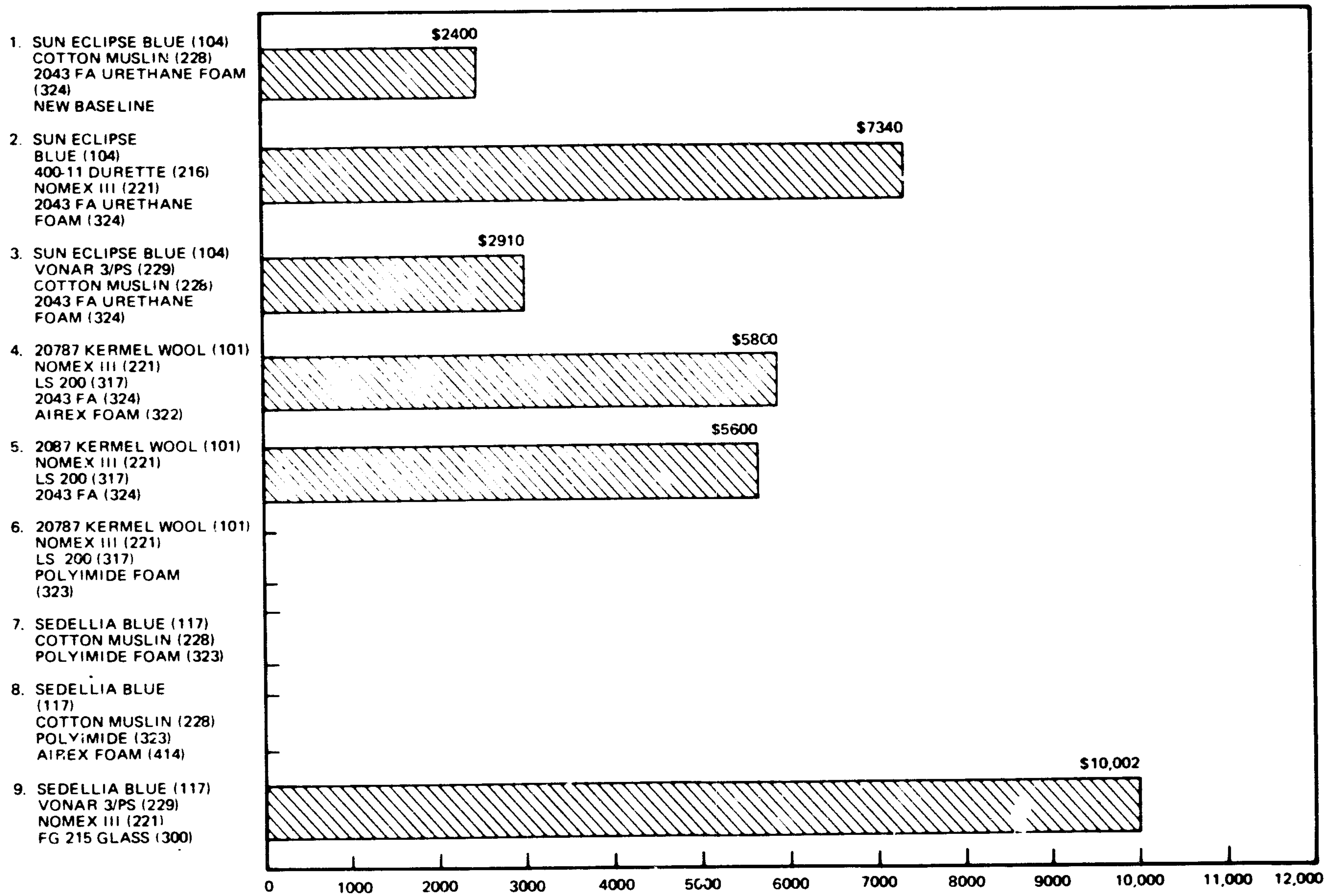
MATERIAL ECONOMICS

MATERIAL	WEIGHT	PRICE 1980 $
ST4727-112 SUN ECLIPSE WOOL/NYLON (104)	456 g/m^2 (0.84 LB/YD^2)	14.14/m^2 (17.95/LIN YD)
20787 KERMEL/WOOL BLEND (101)	293 g/m^2 (0.54 LB/YD^2)	24.8/m^2 (20.78/YD^2)
SEDELLIA BLUE 3117 100 PERCENT WOOL (117)	408 g/m^2 (0.75 LB/YD^2)	15.76/m^2 (20.00/LIN YD)
COTTON MUSLIN 44/40 Count (228)	158 g/m^2 (0.29 LB/YD^2)	0.59/m^2 (0.75/LIN YD)
400-11 DURRETTE BATT (216)	364 g/m^2 (0.67 LB/YD^2)	14.97/m^2 (19.00/L[illegible])
VONAR 3/PS (229)	831 g/m^2 (1.53 LB/YD^2)	3.81/m^2 (3.19/YD^2)
NOMEX ITT (221)	255 g/m^2 (0.47 LB/YD^2)	9.64/m^2 (12.23/LIN YD)
2043 FA URETHANE (324)	32 kg/m^3 (2.0 LB/FT^3)	169.48/m^3 (4.80/FT^3)
AIREX S32.5 (414)	52 kg/m^3 (3.27 LB/FT^3)	402.53/m^3 (11.40/FT^3)
LS 200 NEOPRENE (317)	128 kg/m^3 (8.0 LB/FT^3)	635.58/m^3 (18.00/FT^3)
POLYIMIDE (323)	24 kg/m^3 (1.5 LB/FT^3)	
FG 215 GLASS BLOCK (300)	44.94 kg/m^3 (2.8 LB/FT^3)	1758.44/m^3 (49.80/FT^3)

TABLE 9

FINAL SEAT DESIGN TEST CONFIGURATION

TEST NUMBER	UPHOLSTERY	FIRE BLOCKING	CUSHION REINFORCEMENT (ADHESIVE R2382 N/F)	CUSHION	REMARKS
1	ST4727-112 Sun Eclipse Wool/Nylon (104)	None	Cotton Muslin 44/40 Cnt (228)	2043FA Urethane (324)	Baseline
2	ST4727-112 Sun Eclipse Wool/Nylon (104)	400-11 Durette Batt (216)	Nomex III (221)	2043FA Urethane (324)	Fire Barrier
3	ST4727-112 Sun Eclipse Wool/Nylon (104)	Vonar 3/PS (229)	Cotton Muslin 44/40 Cnt (228)	2043FA Urethane (324)	Fire Barrier
4	20787 Kermel/Wool Blend (101)	Nomex III (221) 1/2" LS-200 Neoprene (317)	None	2043FA Urethane Foam with Airex (414) Core	Fire Barrier and Flotation
5	20787 Kermel/Wool Blend (101)	Nomex III (221) 1/2" LS-200 Neoprene (317)	None	2043FA Urethane (324)	Fire Barrier
6	20787 Kermel/Wool Blend (101)	None	Nomex III (221)	1/2" LS-200/ Polyimide Foam	Lightweight Combined Cushion
7	Sedellia Blue 3177 100% Wool (117)	None	Cotton Muslin 44/40 Cnt (228)	Polyimide Foam (323)	Fire Retardent Cushion
8	Sedellia Blue 3177 100% Wool (117)	None	Cotton Muslin 44/40 Cnt (228)	Polyimide Foam Airex (414) Core	Fire Retardent Cushion with Flotation



NOTE: COST DOES NOT INCLUDE MATERIAL SCRAPPAGE

FIGURE 14. COST/100 CUSHION SETS (BOTTOM AND BACK)

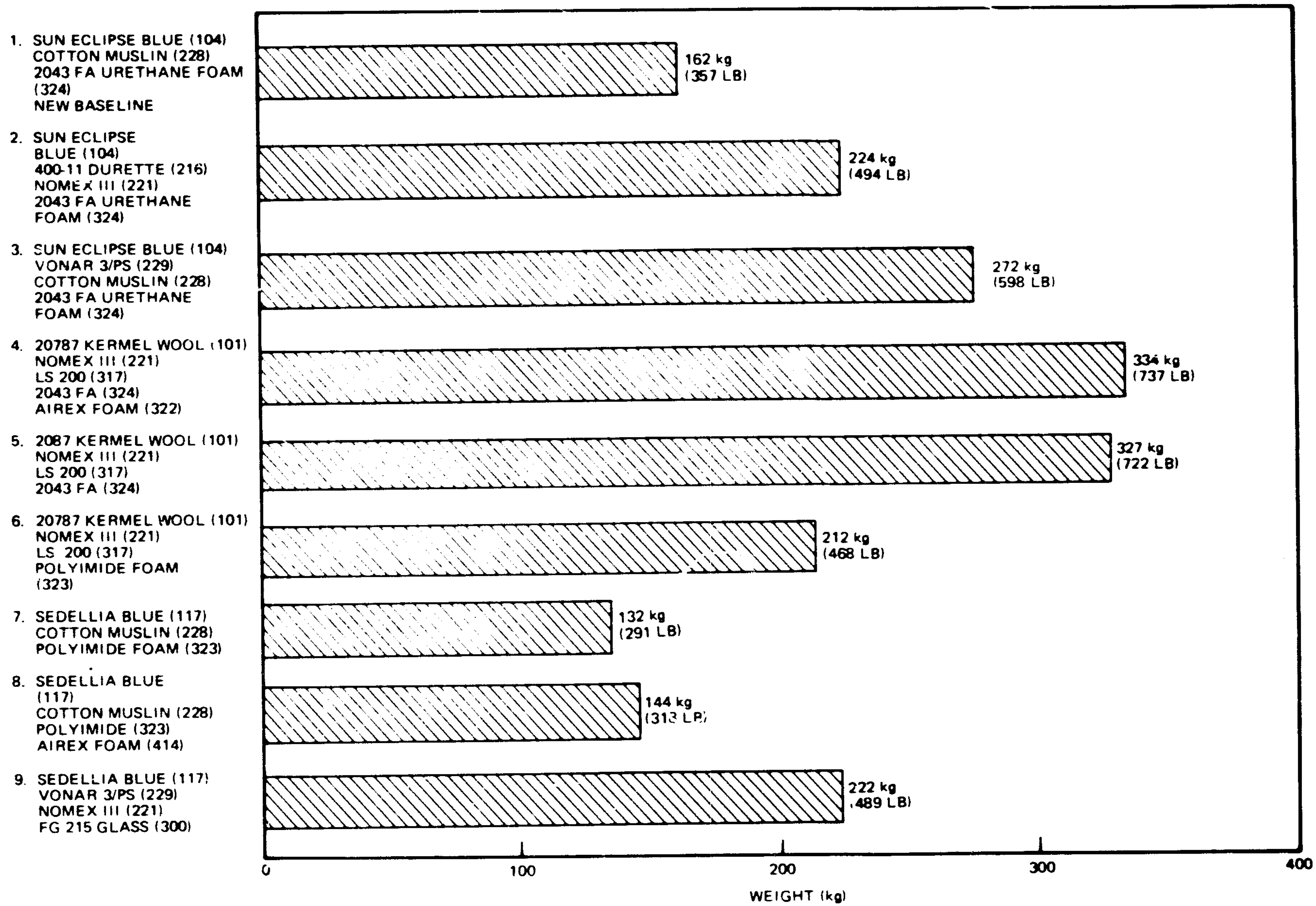


FIGURE 15. WEIGHT ESTIMATE/100 CUSHION SETS (BOTTOM AND BACK)

SECTION 6

DESIGN GUIDELINE – FIRE RESISTANT SEATS

The following information is provided as a guideline that may be consulted for material and design considerations for improvement of aircraft passenger seat fire resistance.

Those seat components explored are listed below:

- o Structural Frame
- o Recline Mechanism
- o Decorative Shrouds
- o Armrests
- o Food Trays
- o Structural Fire Barriers
- o Literature Pocket
- o Seat Cushions

6.1 STRUCTURAL FRAME (Figure 16)

In studying the structural framework of different passenger seats, it has shown that very little may be done to improve its fire resistance. However, later in this guide, it will be noted that some of the materials used in the cushion construction could greatly increase the weight of the aircraft. It would, therefore, be advantageous to explore seat structure that would be lightweight without sacrificing structural strength in order to compensate for the additional cushion weights. Determining structural designs is beyond the scope of this program and will not be discussed further.

6.2 RECLINE MECHANISMS (Figure 17)

The major concern in a recline mechanism design is to prevent a seat back from inadvertently reclining during a fire.

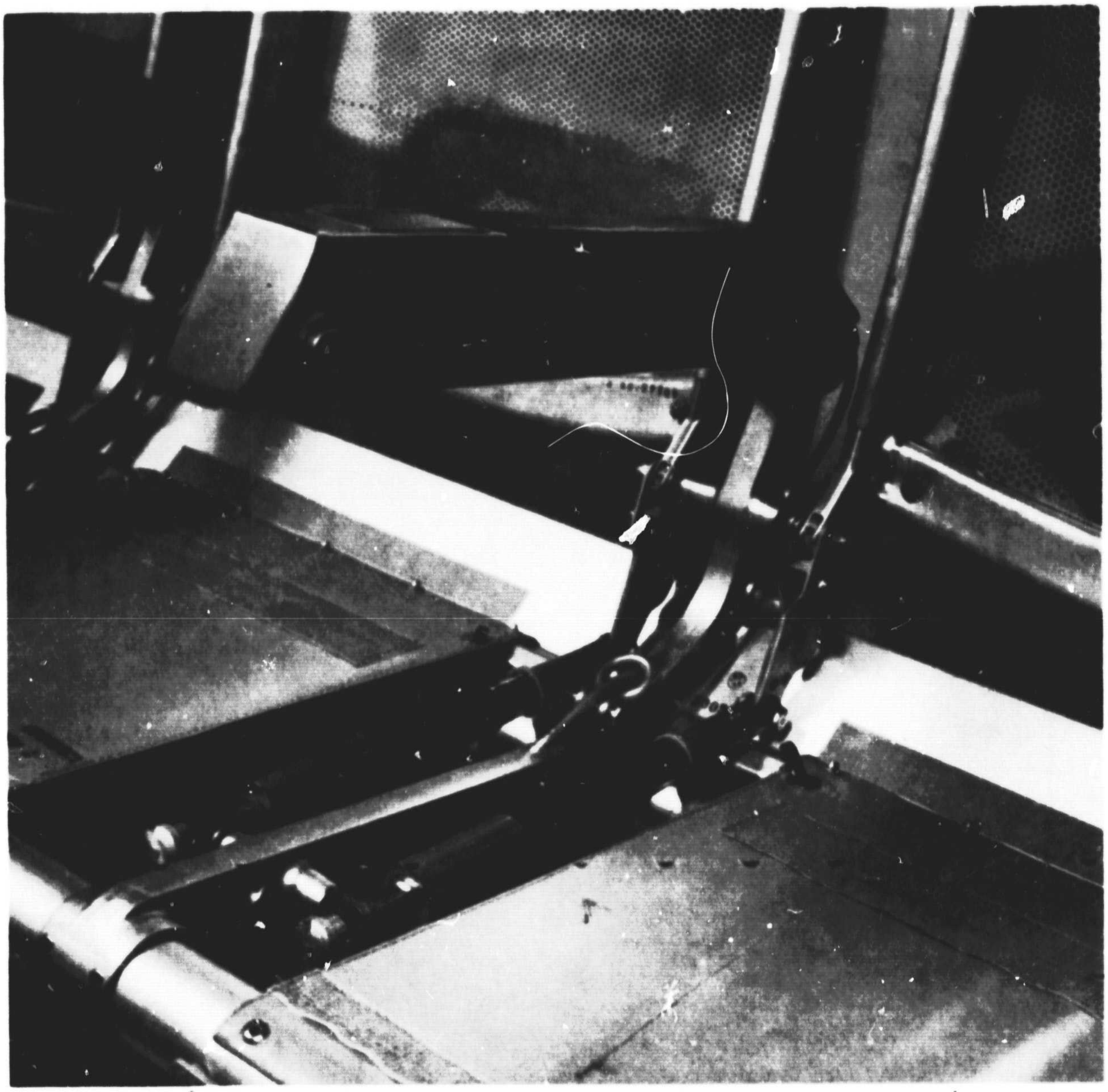
There are three areas where the recline mechanism may become nonfunctional due to heat from fire. These areas are attachments to the seat frame and seat back, cylinder casing, and internal seals.

Causes for these failures may be improperly installed attachments, attachment melting, cylinder melting, and O seal distortion due to expansion of the hydraulic fluid.

The recline mechanisms frame and seat attachments are normally metal. Their physical failure would be due to an extremely hot fire in which very little of the seat would survive. The same may be said for the cylinder casing which is also metal.

Failure of the O ring would result in hydraulic fluid being lost. This fluid is not of substantial volume and its possible ignition should not prove a threat to the seat.

FIGURE 16. STRUCTURAL FRAME



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STRUCTURAL ATTACHMENTS

- REQUIRES INTENSE IRE OR IMPROPER INSTALLATION FOR FAILURE

RECLINE MECHANISM

- SPRING RESTORES SEAT TO UPRIGHT POSITION SHOULD HYDRAULIC FLUID BE LOST

FIGURE 17. RECLINE MECHANISM

The loss of the mechanism fluid will not result in the seat reclining. The design of the mechanism is such that the spring provides for restoring the seat to its upright position regardless of the absence of hydraulic fluid.

The above discussion was in regards to a hydraulic system. A mechanical system would eliminate the O seal failure, otherwise it will have the same virtues as the hydraulic system.

An improperly installed mechanism appears the most likely of the failures to take place. In this particular instance, it would require a recline stop to regulate maximum seat back travel.

6.3 DECORATIVE SHROUDS (Figure 18)

A shroud by definition is that which covers, conceals, or protects. In regards to the aircraft seat, this means covering a sometimes less than aesthetic frame structure, concealing passenger controls, and protecting the passenger from potentially hazardous surfaces. Ruling factors in materials used for shrouds are formability and weight. If the frame structure itself could provide aesthetics, protection, and concealment, the shroud would be eliminated or reduced in mass as a potential fuel for a fire. The alternative is to use that material which best meets all needs yet will not produce a fire threat. Materials used in present shroud construction include ABS and PVC. ABS and PVC are easily formed to detailed shapes with thin, weight efficient cross sections. However, ABS and PVC have poor burn characteristics and produce large quantities of smoke when they thermally decompose. A possible alternative is the usage of a low-smoking polycarbonate or other material which will meet or exceed those values suggested in Table 1 and listed under Decorative Shroud.

6.4 ARMREST

The armrest provides comfort for the arm and acts as a divider. A study of armrests has revealed that their cushioning effect ranges from firm to very hard. Armrests on aircraft seats include polyurethane foams with a nylon skin or an extruded PVC/nylon material. Alternatives may be a self-skinning foam with LS200 neoprene burn properties or a polycarbonate extrusion. Recommended burn characteristics for armrest materials are located in Table 1.

6.5 FOOD TRAYS (Figure 19)

The food tray has three possible failure points which may appear during seat burn. These are attachments of tray structure to the seat, the tray stowage latch, and the tray materials themselves. Like the recline mechanism, the tray/seat attachments are of a metal nature and their failure would be due to an extremely intense fire. The tray stowage latch and tray materials are normally non-metallic and in the case of the tray, provide a large surface area. Failure of the stowage latch would allow the tray to lower and produce additional potential surface area to become exposed to the fire.

The food tray is an important item in that reducing its tendency to burn not only eliminates fuel to an existing fire, but due to its surface area in its stowed position, it would provide a fire barrier to seats exposed to that fire. For these reasons, careful considerations should be made in the design

LO-06220

DECORATIVE SHROUD

- AREA REDUCTION OR ELIMINATION
- FIRE RETARDANT MATERIAL SUBSTITUTION

FIGURE 18. DECORATIVE SHROUD

FOOD TRAY LATCH

- MATERIAL SUBSTITUTION TO PREVENT FAILURE FROM HEAT OF FIRE

FOOD TRAY

- EXPOSES LARGE SURFACE AREA TO FIRE WHEN LOWERED DUE TO LATCH FAILURE

FIGURE 19. FOOD TRAYS

of the stowage latch with materials for both the latch and tray. Materials commonly found in food tray constructions includes thermoformed ABS. Due to its basically clean shape, a food tray might not require as highly formable material as ABX. Alternative materials may be metal, low smoke polycarbonate, or other materials that meet or exceed the guidelines of Table 1.

6.6 STRUCTURAL FIRE BARRIER (Figure 20)

In this section the main concern is protection to the bottom of the seat cushion from heat. Not wanting to touch on the integrity of the cushion support structural design, it is merely suggested that if a material can provide the structural physical properties required for that seat and yet protect the cushion from possible heat damage, the seat as a whole would benefit. An alternative would be a fire barrier attached to the bottom of the supportive structure. An aluminum seat bottom is offered by some seat manufacturers as an option to the cloth fabric. An alternative to the aluminum and its weight might be a fiberglass cloth with phenolic resin, while PBI and Nomex may be considered candidate materials for existing cloth fabric seat bottom designs. Suggested burn properties for a fire barrier are found in Table 1.

6.7 LITERATURE POCKET

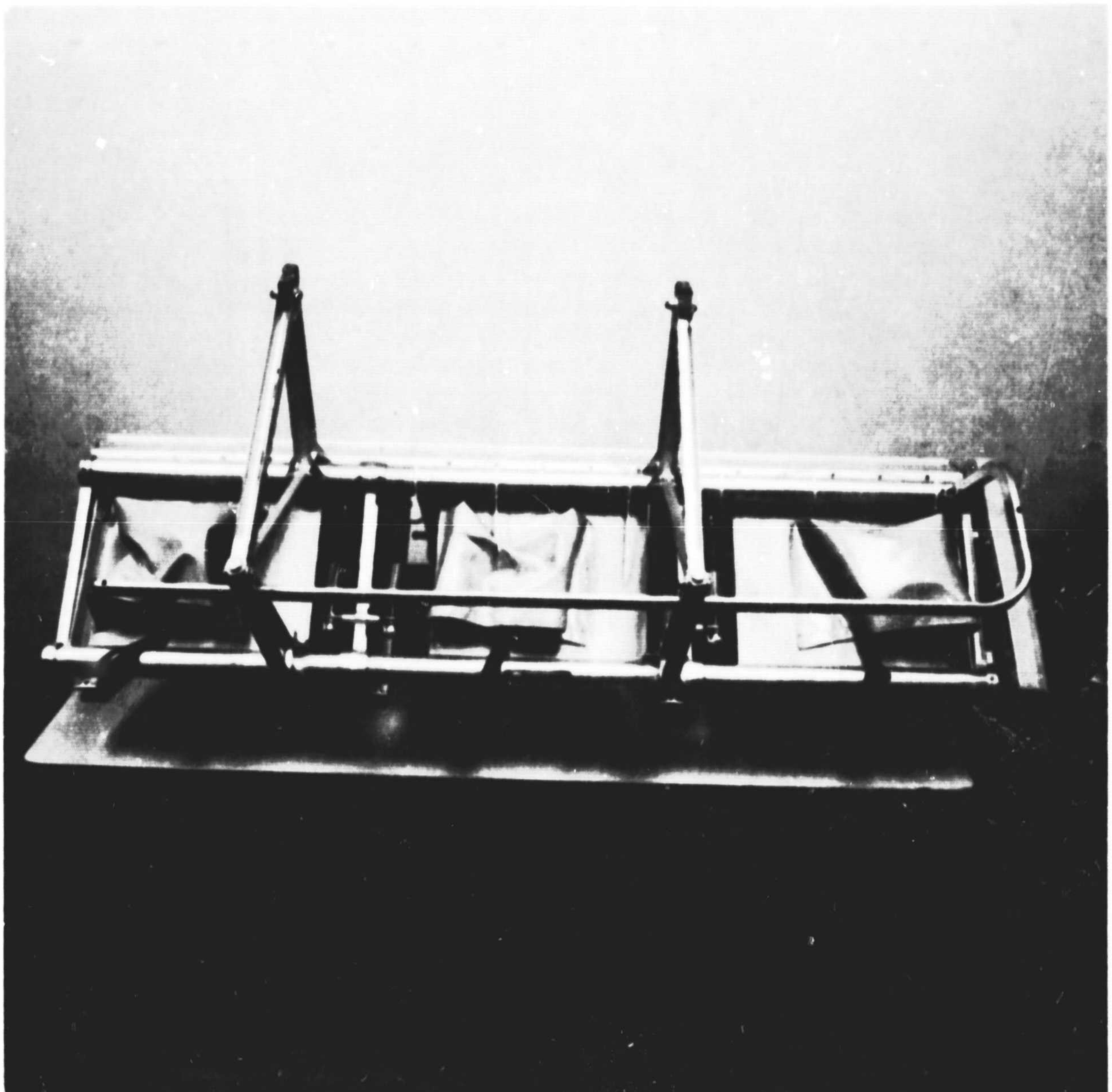
The literature pocket's principal function is to provide a convenient location for the Emergency Information Card, the airline magazine, and the air sickness containers. Unfortunately, they are also a convenient compartment for stowage of a passenger's flammable carry-on paper products including facial tissues, newsprint, and worst of all, cigarette by-products. All of these items are of concern because they will provide fuel to an existing fire as well as produce a fire themselves.

Literature pocket design considerations might involve providing visibility of a potential fire hazard as well as visibility of a smoldering fire. In conjunction with the design, materials could be chosen which would contain a fire within the pocket or protect the pocket's contents from an existing fire. Fire containment/resistance might include a fire resistant pocket lining material,fire resistant decorative upholstery materials, and an air-tight seal for the pocket opening.

6.8 SEAT CUSHIONS

Seat cushions provide a large volume source of fuel for starting or supplying a fire. A basic passenger seat consists of a cushioning layer, slip cover, and a decorative upholstery material. The cushioning layer provides the majority of the seat cushion volume and depending on their usage may contain a flotation layer as well as a cushioning layer.

Studies have been and are still being made on the best way to protect or replace the cushioning layer. These include fire resistant upholstery materials, fire blocking layers, and total replacement of the cushioning layer with foams more resistant to thermal decomposition. At the time of this writing, fire blocking materials available were a higher density than the materials they were to replace, causing significant weight impacts on the aircraft. It must be determined to what degree a fire-hardened cushion must retain physical properties that now exist. It is beyond the scope of this guide to determine optimum fire blocking layers thicknesses or material properties needed to meet passenger comforts.



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SEAT BOTTOM FIRE BARRIER

- FIRE BARRIER ATTACHED TO SUPPORTIVE STRUCTURE
- MATERIAL SUBSTITUTION TO PROVIDE STRUCTURAL CUSHION SUPPORT AND FIRE PROTECTION TO CUSHION

FIGURE 20. STRUCTURAL FIRE BARRIER

SECTION 7

RECOMMENDATIONS

This completes the laboratory screening and multi-layer testing of materials for the NASA Fire Resistant Seat Program in preparation for full scale cushion burn testing. Laboratory tests have shown positive results when fire blocking layers were used. However, their optimum application in cushion design was beyond the scope of this program.

It is therefore recommended that additional programs be funded which will continue the study of fire blocking materials and to determine their optimum usage.

SECTION 8

PASSENGER SEAT ASSEMBLY

A 3-abreast "tourist class" passenger seat assembly was constructed using improved fire resistant seat materials. Materials used in this seat are described in Table 9 as Test No. 6. The bottom cushion consisted of a 1/2 inch LS200 neoprene layer on the top and front sides of a polyimide foam block. The LS200/Polyimide cushion was completely covered on all sides by a layer of Nomex III. 20787 Kermel/Wool blend upholstery material was attached per Fairchild Burns manufacturing practices. The back cushion and headrest were identical to the bottom cushion with the exception of a 1/4 inch layer of LS200 neoprene on the front (passenger) side instead of a 1/2 inch layer. The cushions were fitted to a Fairchild Burns Airest 2000 seat assembly.

This design is considered the most advanced in relation to fire-resistant seat cushion materials. This design is not presently used in aircraft production seats and employs materials with fire retardent properties. This passenger seat assembly was shipped to Ames Research Center, Moffett Field, California 94035, Receiving Department 221-5, M/F NAS 2-9337.

APPENDIX A

MATERIAL TEST PROCEDURES

MATERIAL TEST PROCEDURES

SCREENING TESTS

All materials were first screened to current FAA burn requirements. Screening tests consisted of a series of selected small scale laboratory tests. The combination of these screening tests represented a significantly higher fire resistance performance standard than laboratory test standards currently imposed on aircraft seat materials.

The modified burn test was the only nonstandard test that was conducted. The modification took into account that the standard burn test permits melting material to be removed from the direct flame by the very mechanism of melting and in affect reducing exposure time to the flame for those materials.

SCREENING TEST METHODS

FABRIC		FOAM	
PROPERTY	TEST METHOD	PROPERTY	TEST METHOD
Screening:			
Weight	*Method 5041	Density	ASTM 1564 Suffix W
Burn	**FAR 25.853(b)	Burn	**FAR 25.853(b)
	**FAR 25.853(a)		**FAR 25.853(b) Mod.
NBS Smoke	***Tech Note 708	NBS Smoke	***Tech Note 708
		Ignition	ASTM D2859
		LOI	ASTM D2863-70
		TGA	At 20°C per minute in air
LOI	ASTM D2863-70		
TGA	At 20°C per minute in air		

*Federal Test Method Standard No. 191, Textile Test Methods

**Federal Aviation Regulations Part 25 Airworthiness Standards: Transport Category Airplanes

***NBS Technical Note No. 708; Test Method for Measuring the Smoke Generation Characteristics of Solid Materials

RELATIVE TOXICITY TESTS

Swiss-Webster strain albino mice weighing approximately 25 grams were exposed to pyrolysis/combustion products generated within a 5.3 liter volume rectangular glass chamber sealed at the top with a plexiglass lid. An exercise wheel and drive mechanism, electrical power leads for the microcombustion tube used for pyrolysis/combustion of the sample, and a radiation shield were mounted on the lid.

With the subject placed inside the exercise wheel and a 0.5-gram sample loaded into the microcombustion tube (connected to a power lead), aluminum foil radiation shield in place, assembly integral with the lid was inserted in the chamber and clamped in sealed position. A magnetically-driven fan stirrer was placed in the chamber to provide rapid mixing of the pyrolysis/combustion products evolved from the test specimen during a run.

Final preparation for conducting a test consisted of connecting a variable speed electric motor to drive the exercise wheel and the Variac transformer controlled power leads to the pyrolysis/combustion tube feed through leads on the lid. The test parameters used in these tests were:

Exercise wheel rotation speed – 6 RPM

Input power – 20 VAC, 5.3 amperes

Sample beating rate – 300^{o}C/minute

Heating period – 200 seconds

Biological endpoints – time to incapacitation, Ti
time to death, Td

Total test time (per run) – 30 minutes

THERMOGRAVIMETRIC ANALYSIS

The candidate materials were tested for weight loss by standard procedures using a DuPont Instrument Company Thermal Analyzer. Approximately 5 to 15 mg samples were introduced into the sample cup and heated at a rate of 20^{o}C per minute in a low flow of dry air (75 ml/min). Rates of weight loss versus temperature (time) were recorded by potentiometric recorder until no further weight loss was detected (usually in 30 to 35 minutes).

HEAT AND SMOKE RELEASE RATE AND THERMAL PENETRATION TESTS

The candidate multilayer seat cushion specimens were tested in the Ohio State University version of the heat release rate calorimeter (HRR). This calorimeter was used to evaluate the heat and smoke released from 25 x 25 cm multilayer specimens laid up in the sample holder as shown in Figure A-1 when exposed to a radiant flux of 3.5 w/cm^{2}. Quantitative measures of heat released in terms of kilowatt (kw) or BTU/minute were calculated per square meter (m^2) of original surface areas exposed as a function of time.

The Douglas (modified) HRR chamber and auxiliary pen recorder and gas monitoring instrumentation is employed to evaluate the fire response of nonmetallic materials. The principal value of testing the seat materials in the HRR calorimeter was to provide an insight into the dynamic response of each material in a fire environment, and the potential contribution of each material in the cushion to the propagation of fire. These characteristics are applicable to the identification and selection of the best materials for seat construction in each use category as discussed in the report.

A special modified, lightweight, stainless steel sample holder and refractory backing board of low thermal capacitance was used for all tests to reduce heat absorption by the holder immediately following injection of the mounted sample into the HRR chamber. As indicated in Figure A-1 up to 3 chromel alumel thermocouples were included in the multilayer test specimens to measure the thermal penetration rates of heat into the layup at three locations (two on baseline specimens). Samples were stored in a laboratory atmosphere varying from 38-45 percent relative humidity.

The electrically powered Glowbar^R radiant panel heating source was adjusted to the required thermal flux using a Hycal Radiometer-Calorimeter and allowed to equilibrate to a constant level with air flowing through the chamber. In most tests baseline recorded temperature variations (noise) differentially recorded between the air input temperature and the exit stack of the HRR were observed to hold within ± 0.5 division of chart (equivalent to approximately 1 Kw/m^2 heat release).

The recorded curves of heat (temperature) were read out and calculated against calibrations obtained at the same airflow setting as the test materials using natural gas of known heat content.

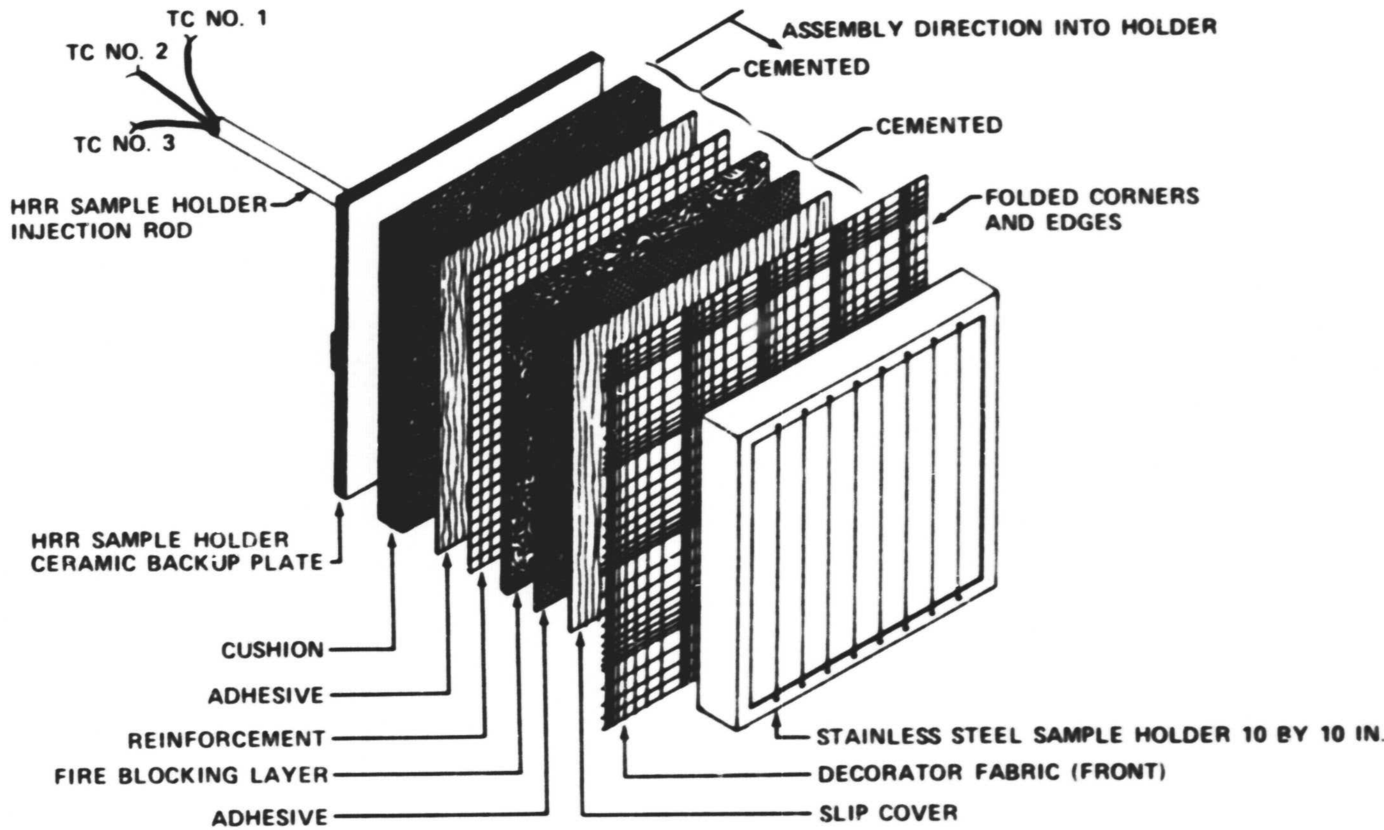


FIGURE A-1. TYPICAL MULTIPLE LAYER TEST SPECIMEN

APPENDIX B

MATERIAL TEST RESULTS

TABLE B-1

LIST OF MATERIALS SCREENED

MATERIAL NUMBER	PRODUCT NUMBER	MATERIAL DESCRIPTION	TRADE NAME	SUPPLIER
101	20787	Kermel/Wool Blend Decorative Fabric	Kermel/Wood	H. Lelievre Paris, France
104	ST4227-112	90% Wool/10% Nylon Blend Sun Eclipse Blue, Decorative Fabric		Collins & Aikman Charlotte, NC & Albemarle, SC
117	3177	100% Wool, Sedellia Blue Decorative Fabric		Collins & Aikman Charlotte, NC
216	400-11	Durette Needle Punch Felt (Chlorinated Aramid) 10.4 oz/yd^2	Durette	Fire Safe Products St. Louis, MO
221	S/470	Nomex Duck Fabric (Natural) 7.5 oz/yd^2	Nomex III	Southern Mills Senoia, Georgia
228	44/40 Cnt	Cotton Muslin 44/40 Cnt		Hanes Converting P. O. Box 457 Conover, NC 28613
229	3/PS	Vonar 3/PS Interliner with Polyester Scrim	Vonar	Allen Industries, Inc. Richmond, VA
300	FG215	Glass Fiber Clock Cushion (Edge Grain)		Expanded Rubber & Plastics Gardena, CA
317	LS200	Neoprene Foam 8 #/Ft^3	Toyad	Toyad Corp. Latrobe, PA 15650
322	S2850	Urethane Foam (Baseline)		Reeves Brothers Charlotte, NC 28213

TABLE B-1 (CONTINUED)

LIST OF MATERIALS SCREENED

MATERIAL NUMBER	PRODUCT NUMBER	MATERIAL DESCRIPTION	TRADE NAME	SUPPLIER
323	1720-1 1.5 #/Ft^3	Polyimide Foam, Flexible 1.5 p.c.f.		Solar Turbine & International San Diego, CA
324	2043 FA 2 #/Ft^3	Urethane Foam		North Carolina Foam Ind. Mount Airy, NC 27030
412	M	Closed Cell PVC Foam	Ensolite	Uniroyal Mishawaka, IN 46544
413	ALS	Closed Cell PVC Foam	Ensolite	Uniroyal Mishawaka, IN 46544
414	S32.50	Closed Cell PVC Foam 3 lbs/Ft^3	Airex	Lonza, Inc. Fair Lawn, NJ 07410

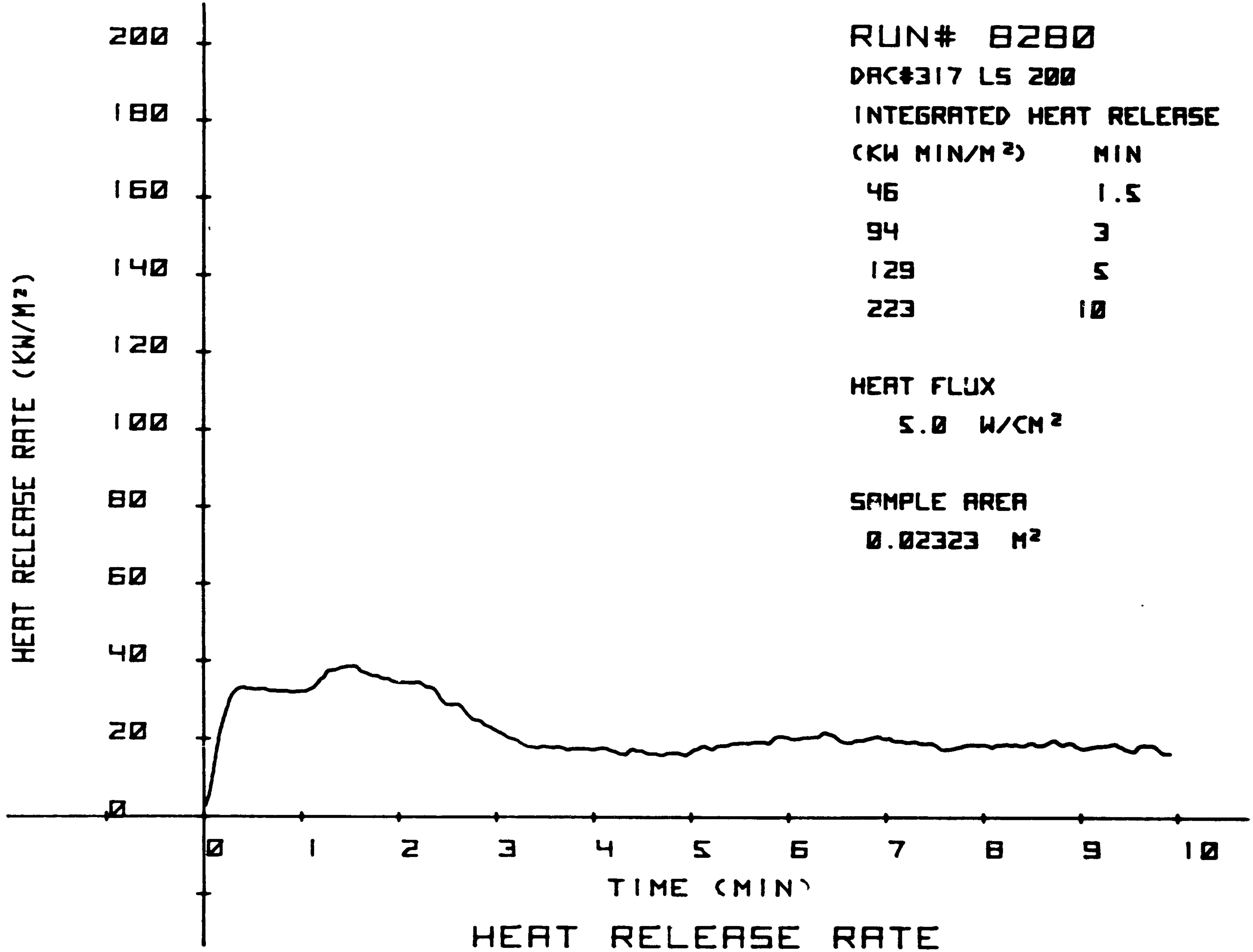
TABLE B-2

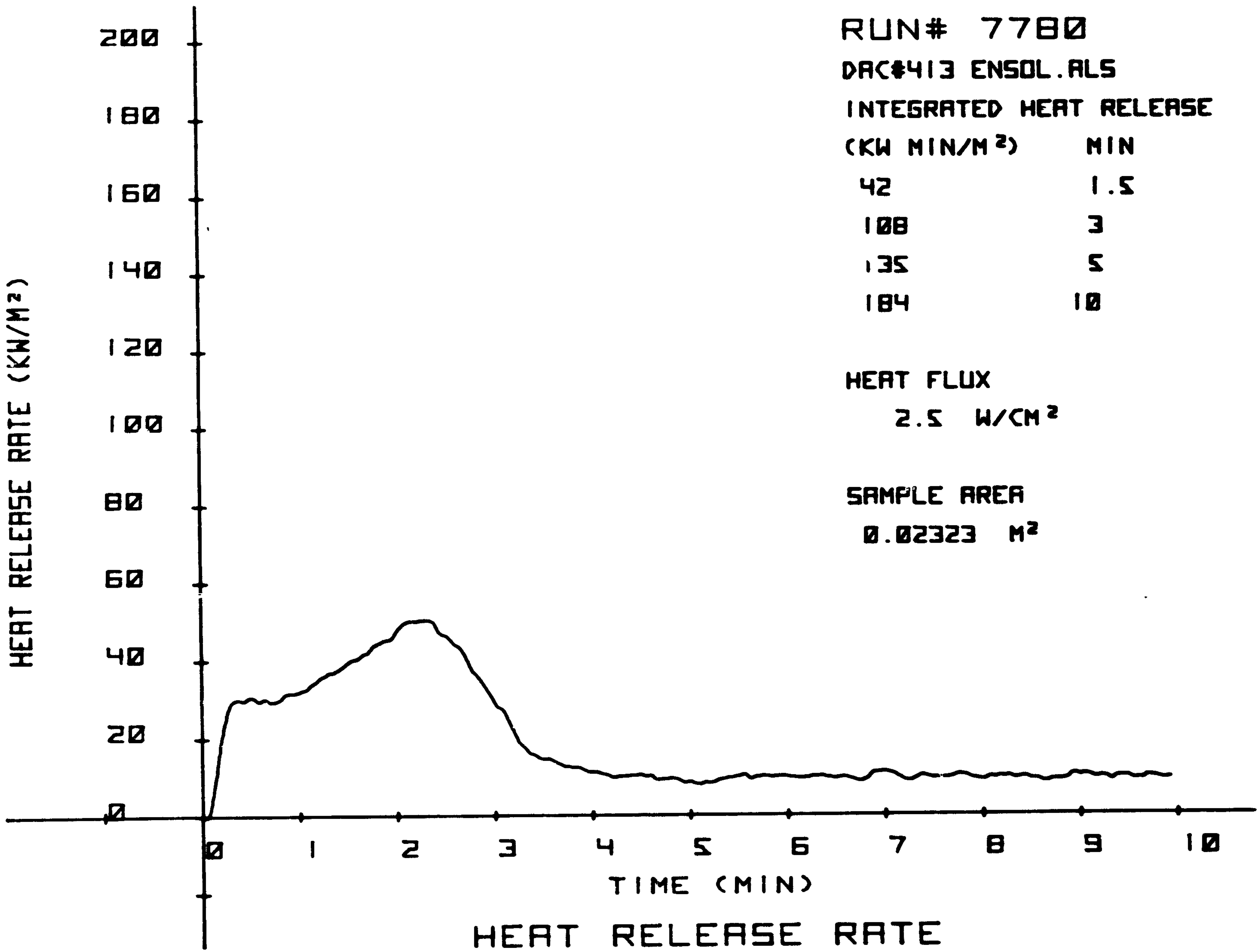
ANIMAL TOXICITY TEST RESULTS

MATERIAL NO. & NAME		MATERIAL WEIGHT GRAMS	ANIMAL WEIGHT GRAMS	OBSERVED Ti MIN.	OBSERVED Td MIN.	NORMALIZE DATA PER GM MATL 25 GM MOUSE Ti	NORMALIZE DATA PER GM MATL 25 GM MOUSE Td	APPARENT MATERIAL PYROLYZED MG	APPARENT PYROLYZED MATL. CONC. IN CHAMBER MG/ℓ	NOTES
Ensolite M	2/1	0.2481	27.7	5.65	-	1.27	-	143	27	Char Yield = 41%
	2/2	0.2537	26.4	4.00	9.00	.96	2.16	152	29	Yc = 41%
(412)	2/3	0.2576	24.2	4.43	9.53	1.18	2.54	145	27	Yc = 44%
	2/4	0.2768	24.2	4.80	34.58	1.37	9.89	164	31	Yc = 41%
	AV					$\overline{X}$ = 1.2 ± 0.17	4.9 ± 4			Max. Chamber Temp. 87-90°F
Ensolite ALS	1/1	0.9802	26.6	1.55	4.0	1.43	3.68	598	113	Yc = 39%
	1/2	0.2790	27.0	4.07	30.5	1.05	7.88	159	28	Yc = 43%
(413)	1/3	0.2752	23.8	4.00	>33.3	1.16	>9.64	154	29	Yc = 44%
	1/4	0.2742	26.2	4.58	23.75	1.20	6.22	153	29	Yc = 44%
						$\overline{X}$ = 1.2 ± 0.16	6.9 ± 2.5			Max. Chamber Temp. 87-90°F
Airex Foam	3/4	0.5292	25.3	5.23	7.42	2.74	3.88	473	89	Yc = 11%
	3/5	0.5395	25.1	4.17	4.75	2.24	2.55	505	95	Yc = 6.4%
(414)	3/6	0.5051	25.0	5.67	11.25	2.86	5.68	458	86	Yc = 9.4%
						$\overline{X}$ = 2.6 ± 0.33	4.0 ± 1.[illegible]			Max. Chamber Temp. 88-92°F
Polyimide Foam	4/1	0.5254	27.8	3	4.47	1.42	2.11	[illegible]	42	Yc = 57.8%
	4/2	0.2455	31.1	4.92	11.63	0.97	2.30	1[illegible].6	19	Yc = 59%
(323)	4/3	0.2656	29.7	4.2	11.25	0.94	2.52	110.6	21	Yc = 58.4%
										Max. Chamber Temp. 84-87°F
Vonar III/PS	5/1	0.5205	26.6	No	No	No	No	267.8	50.5	Yc = 48.6%
(229)	5/2	1.4991	28.8	No	No	No	No	745.4	140.6	Yc = 50.3%
										Max. Chamber Temp. 90°F
Cotton Muslin	6/1	0.5192	29.0	6.17	13.4	2.76	6.00	348	65.8	Yc = 33%
	6/2	0.5245	27.3	5.53	14.95	2.66	7.19	351	66.3	Yc = 33%
(228)	6/3	0.5276	32.4	6.25	17.70	2.55	7.21	353	67	Yc = 33%
						$\overline{X}$ = 2.7 ± 0.10	6.8 ± 0.7			Max. Chamber Temp. 85-88°F

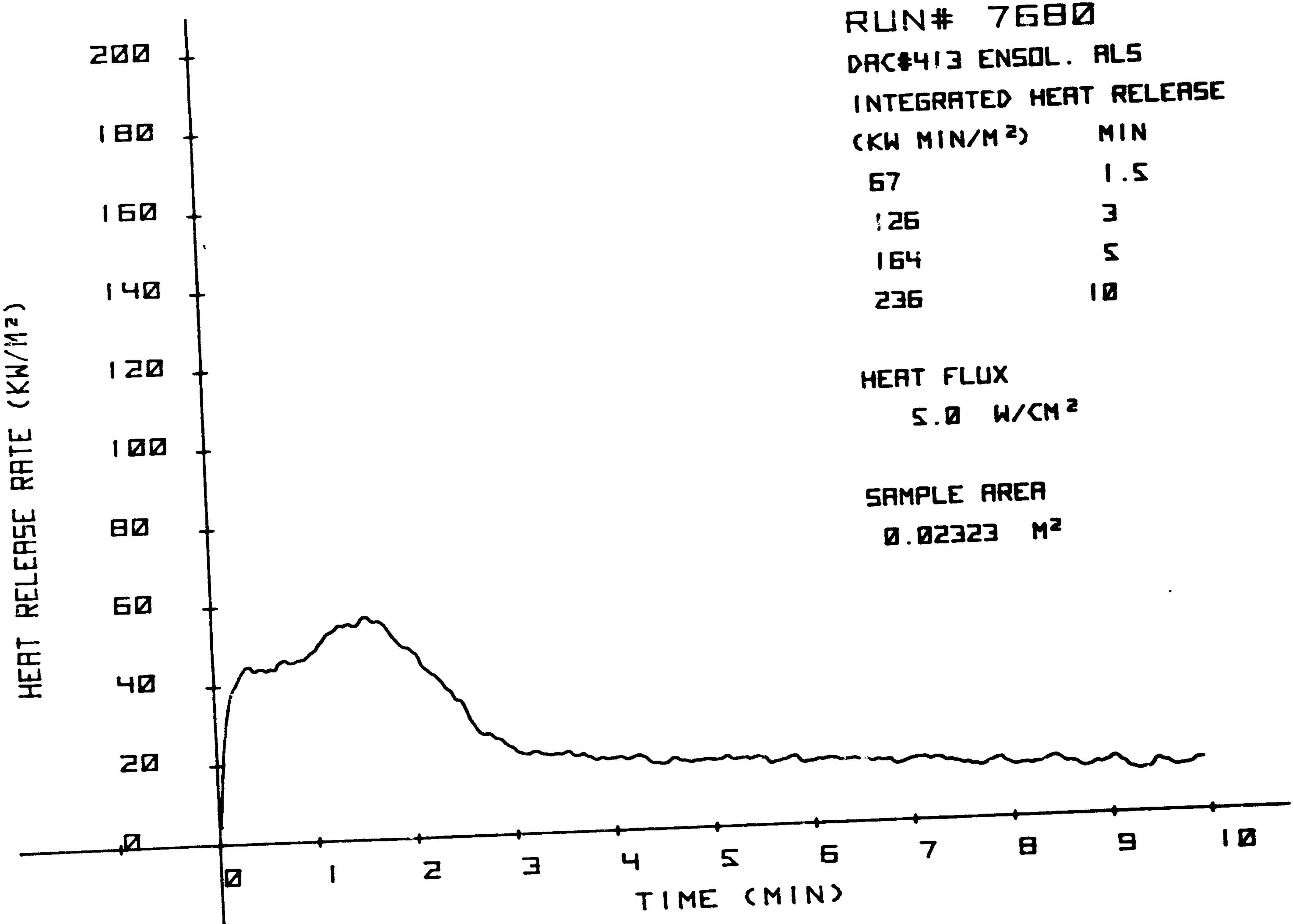
TABLE B-2 (CONTINUED)
ANIMAL TOXICITY TEST RESULTS

MATERIAL NO. & NAME	MATERIAL WEIGHT GRAMS	ANIMAL WEIGHT GRAMS	OBSERVED		NORMALIZE DATA PER GM MATL 25 GM MOUSE		APPARENT MATERIAL PYROLYZED MG	APPARENT PYROLYZED MATL. CONC. IN CHAMBER MG/ℓ	NOTES
			Ti MIN.	Td MIN.	Ti	Td			
Nomex 3 7/1 7/2 (221) 7/3	0.5252 0.3137 0.3084	28.3 29.3 27.5	3.33 4.67 3.82	6.13 16.5 6	1.55 1.25 1.07	2.85 4.42 1.68	249.6 155.1 150.5	47.1 29.3 28.4	Yc = 53% Yc = 51% Yc = 51% Max. Chamber Temp. 80-88°F
					$\overline{X}$ = 1.29 ± 0.24	2.9 ± 1.4			
Sedallia Blue 8/1 8/2 (117) 8/3	0.5218 0.1549 0.1559	29.2 27.8 29.2	2.18 4.53 3.57	3.43 10.83 9.67	0.98 0.63 0.48	1.53 1.51 1.29	385.6 123.8 113.2	72.75 23.36 21.36	Yc = 26% Yc = 20% Yc = 27% Max. Chamber Temp. 82-86°F
					0.7 ± 0.25	1.44 ± 0.13			
9-1 2043 FA Baseline PU Foam (324)	0.4893	224.5 182. 42.5	375sec	420sec	1.799 min	2.015 min	14.9715 14.5615 0.4100 CY 16.21%	77.36	Temp. 76°F - Very dense smoke, hardly see the mice at 110 sec smoke kept coming out at 200 sec Max. Temp. 86°F
9-2 2043 FA Baseline PU Foam (324)	0.4737	216.5 182. 34.5	283sec	440sec	1.620 min	2.517 min	14.9818 14.5646 0.4172 CY 11.93%	78.71	Start Temp. 80°F Max. Temp. 87°F
9-3 2043 FA Baseline PU Foam (324)	0.4900	219.5 182. 37.5	458sec	688sec	2.494	3.746	14.9562 14.5700 .3862 CY 21.18%	72.87	Start Temp. 76°F Max. Temp. 88°F


RUN# 8280
DAC#317 LS 200
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
46 1.5
94 3
129 5
223 10
HEAT FLUX
5.0 W/CM²
SAMPLE AREA
0.02323 M²
HEAT RELEASE RATE (KW/M²)
0
20
40
60
80
100
120
140
160
180
200
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE



HEAT RELEASE RATE



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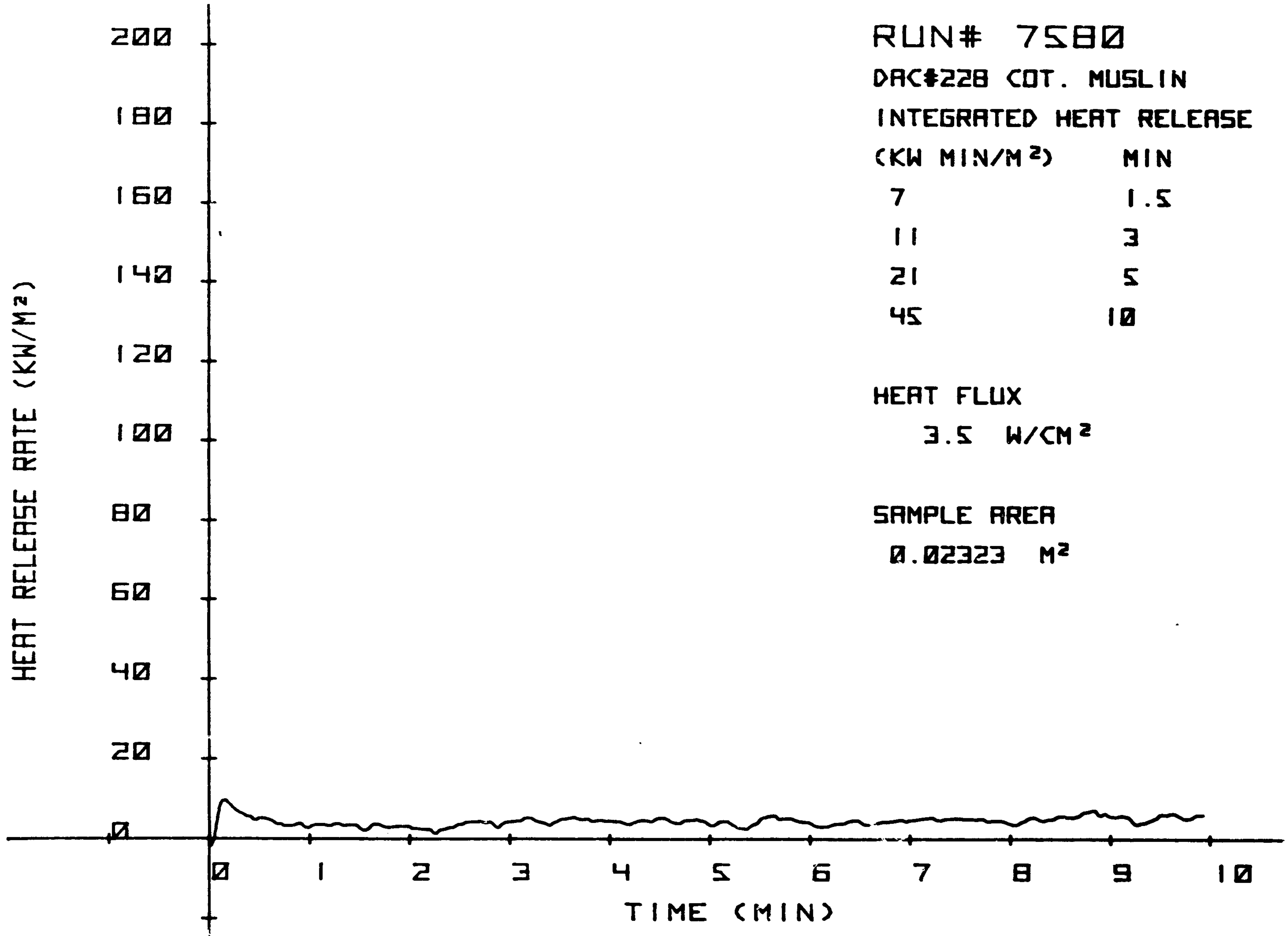
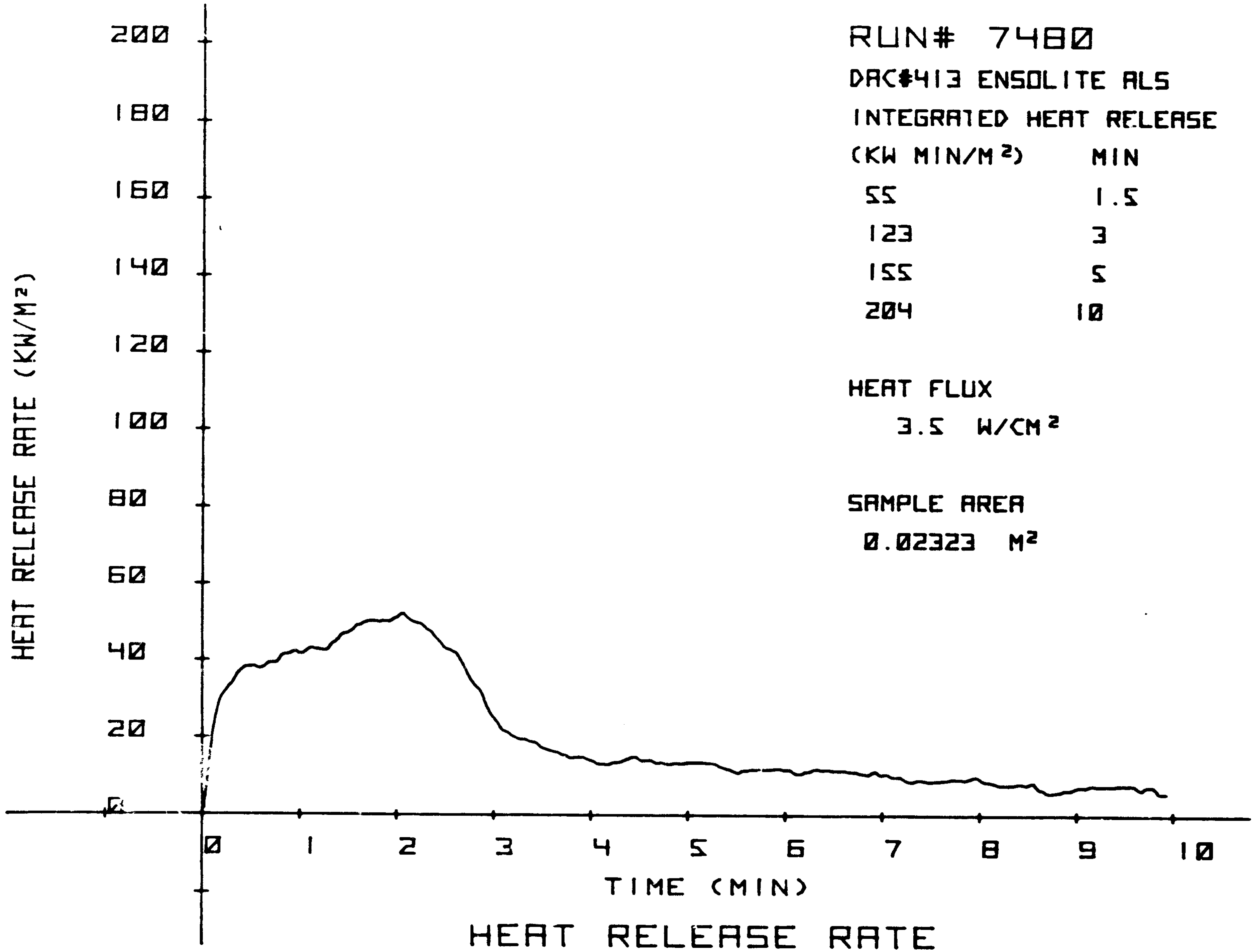
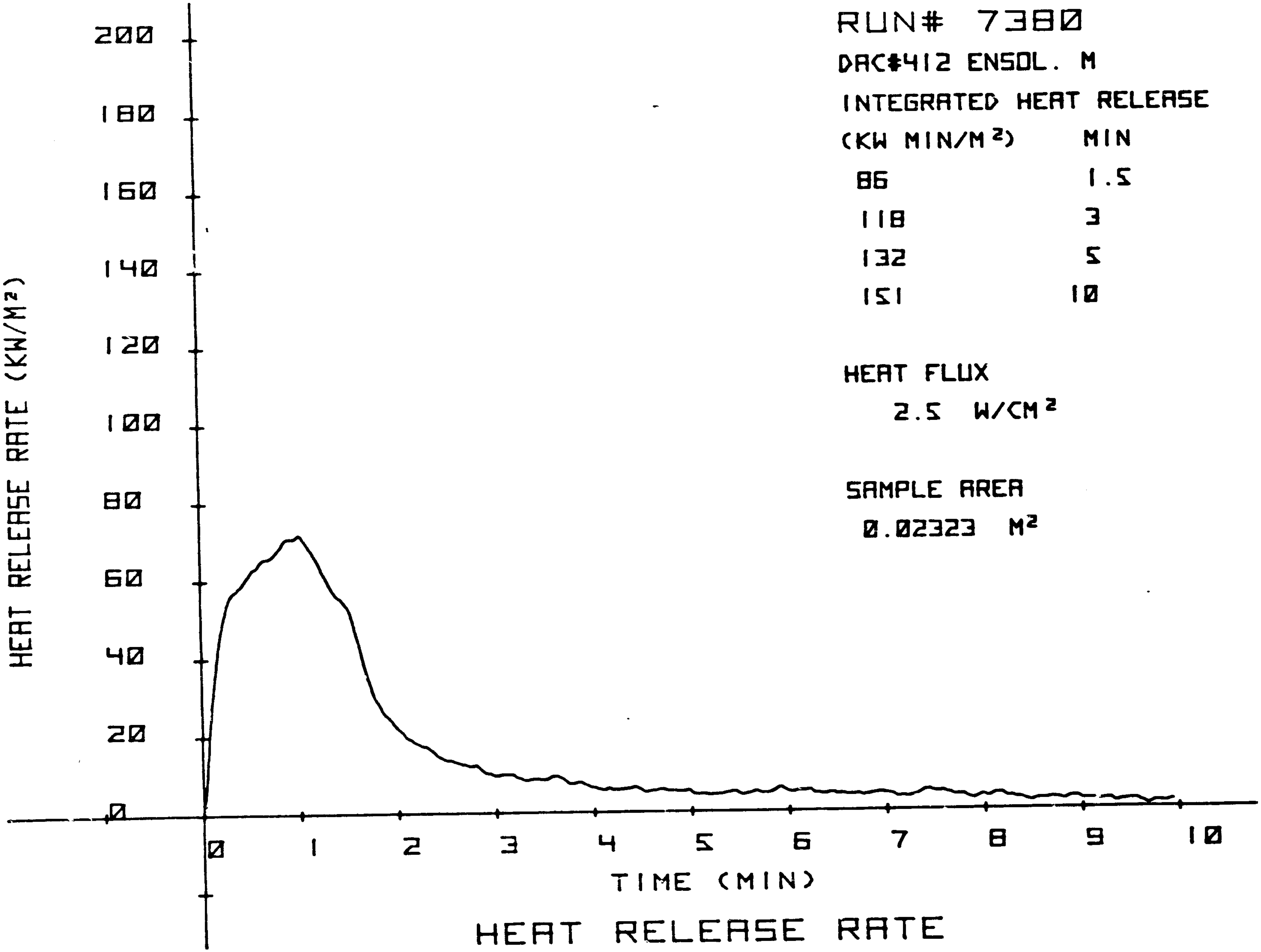


HEAT RELEASE RATE


RUN# 7480
DAC#413 ENSOLITE ALS
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
55 1.5
123 3
155 5
204 10
HEAT FLUX
3.5 W/CM²
SAMPLE AREA
0.02323 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE



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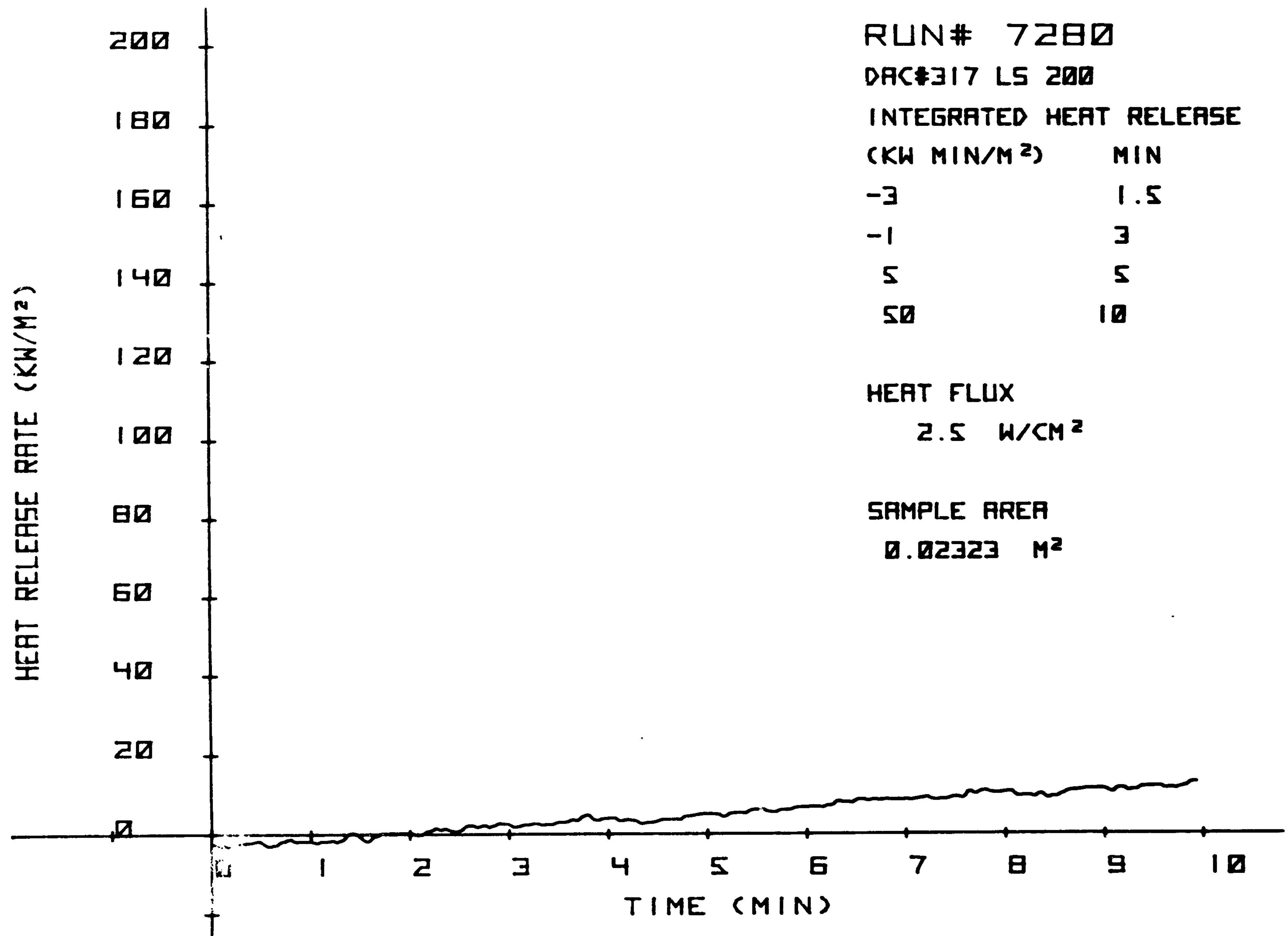

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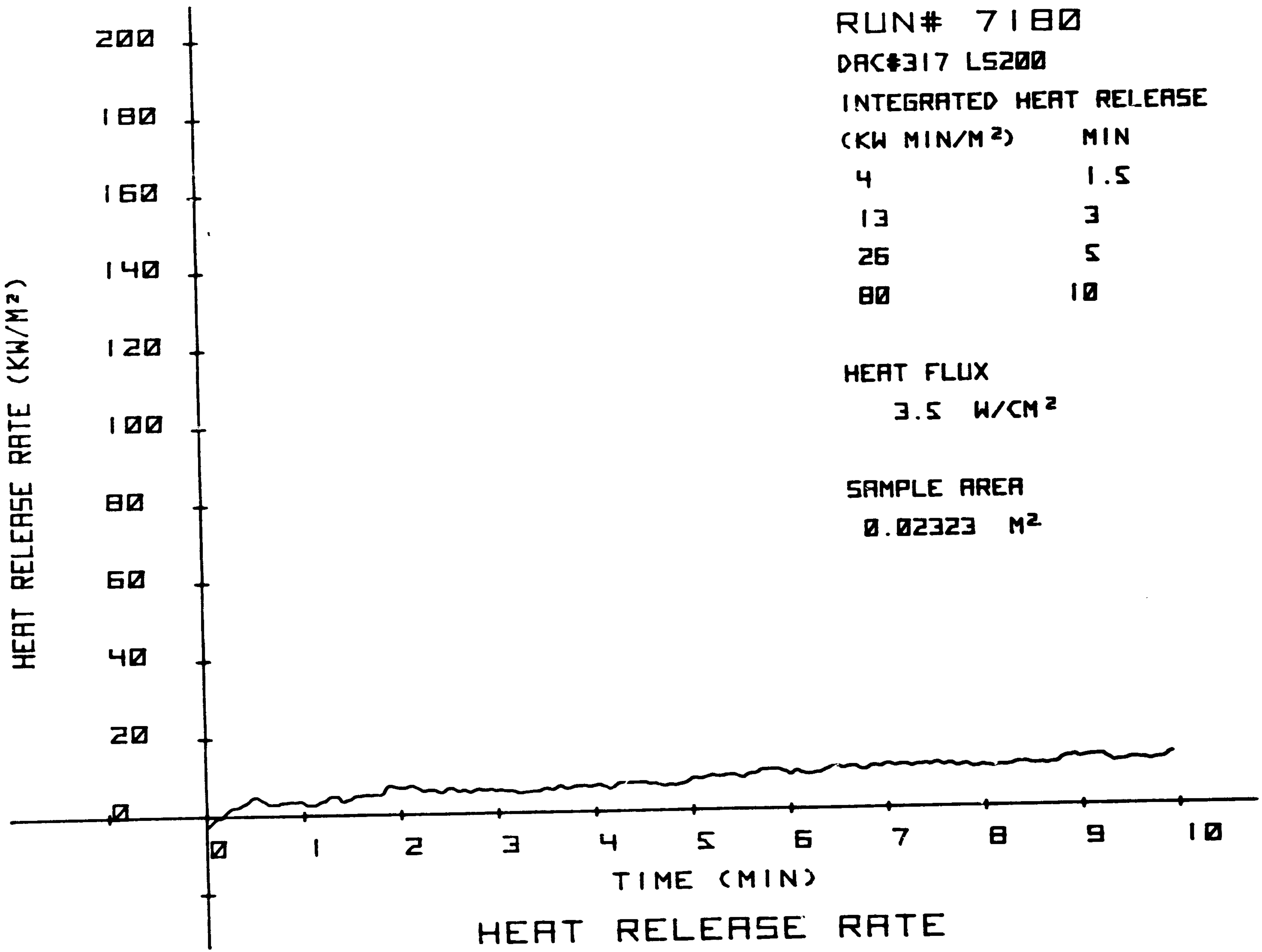

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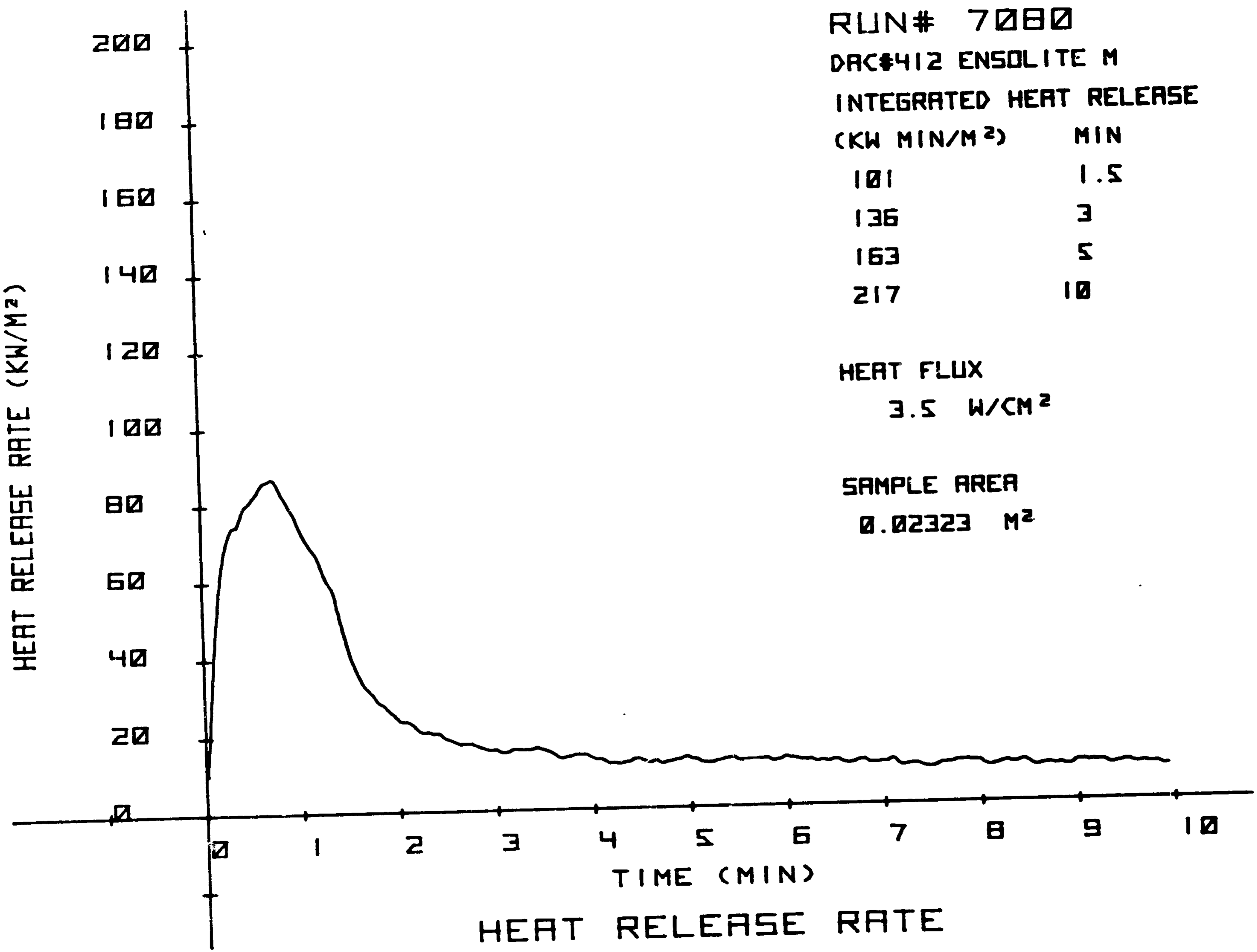

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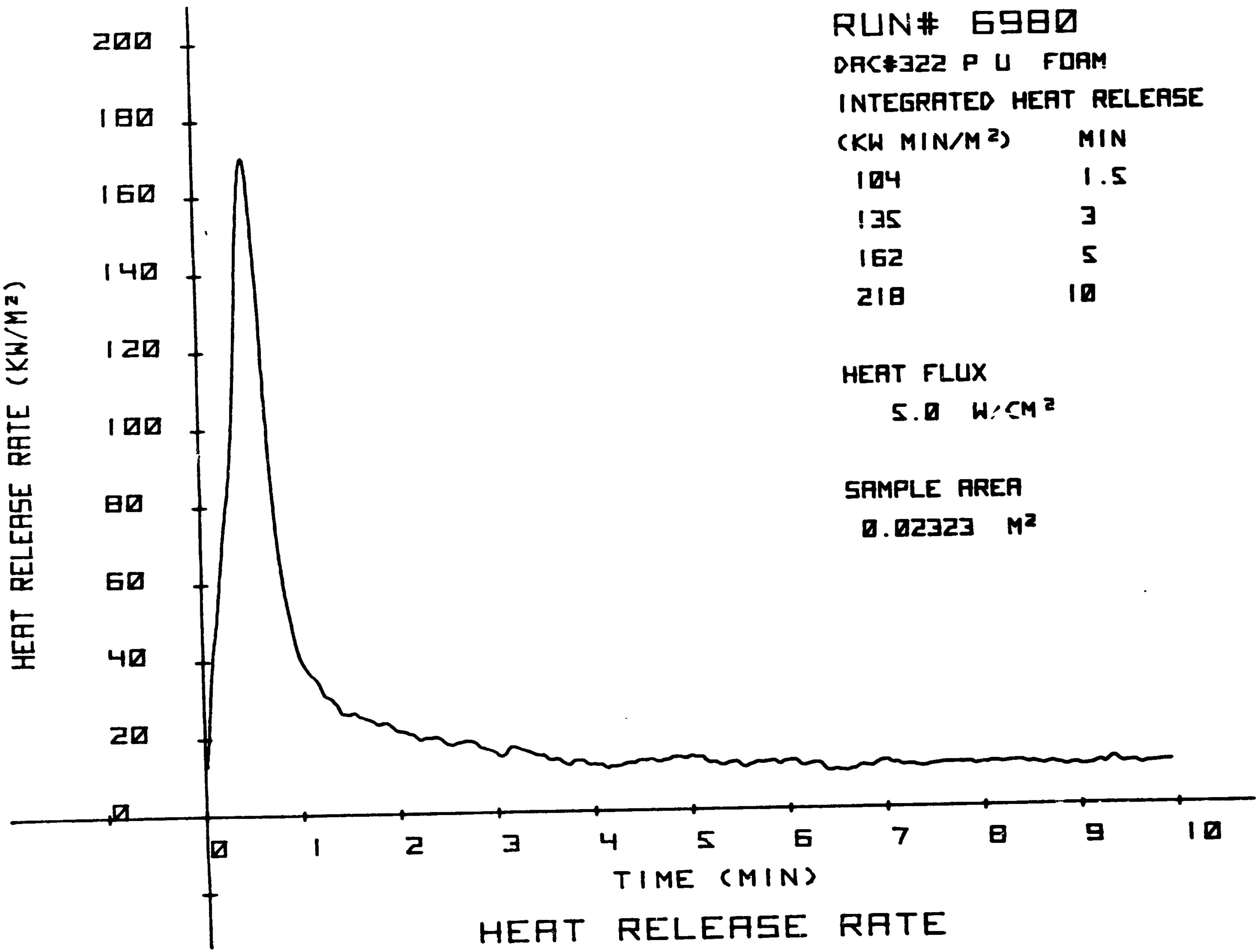

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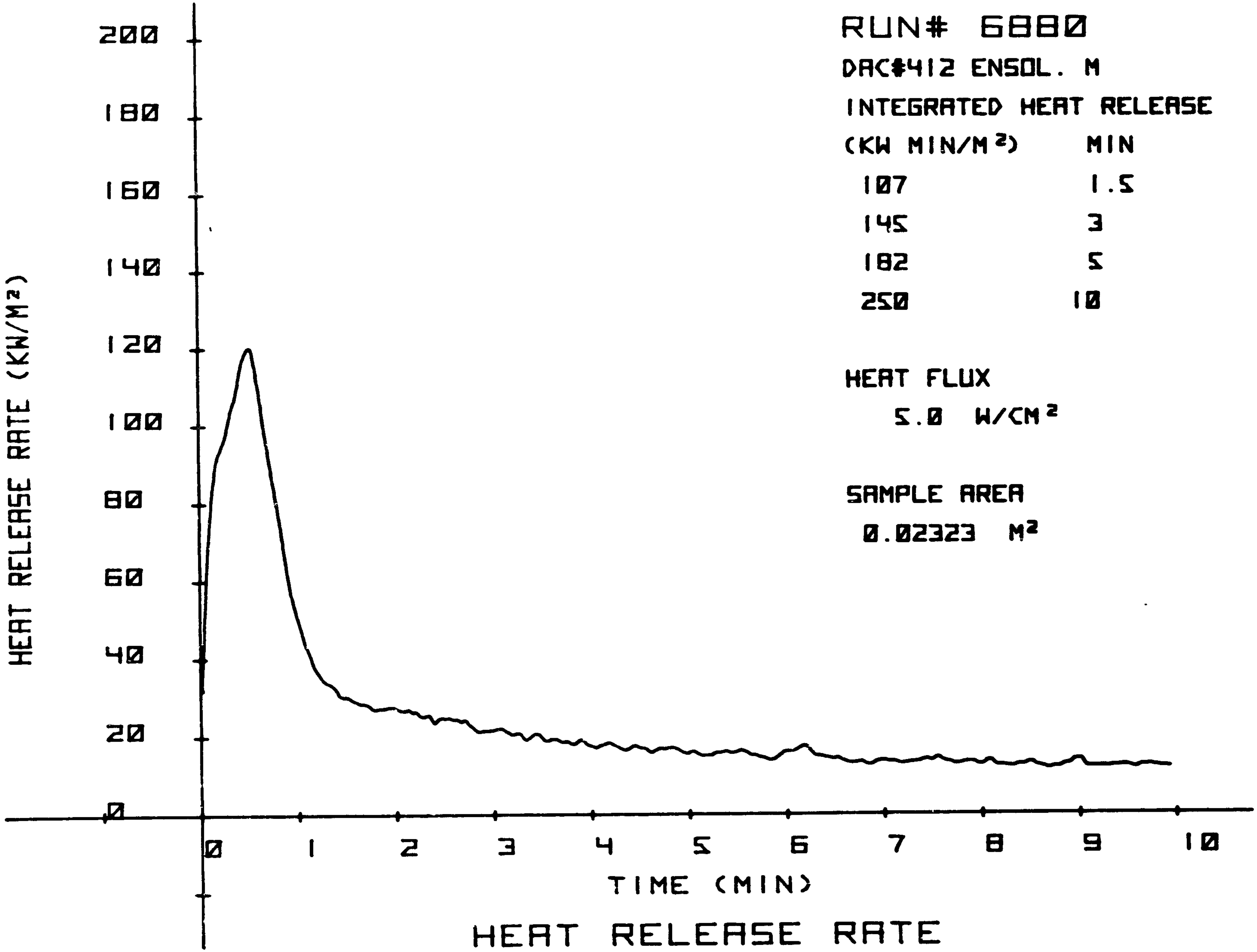
DAC#322 P U FOAM
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
104 1.5
135 3
162 5
218 10
HEAT FLUX
5.0 W/CM²
SAMPLE AREA
0.02323 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE



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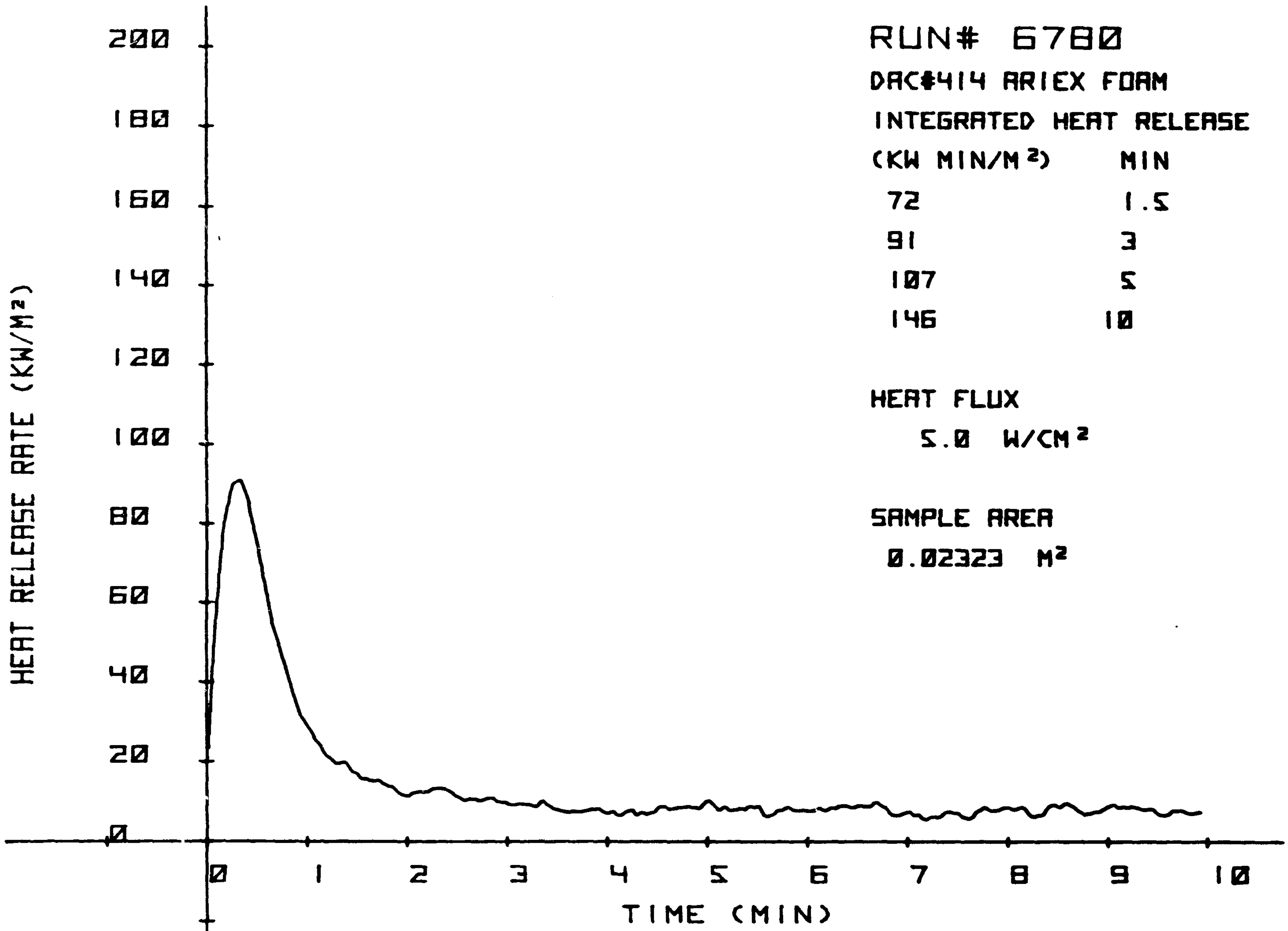

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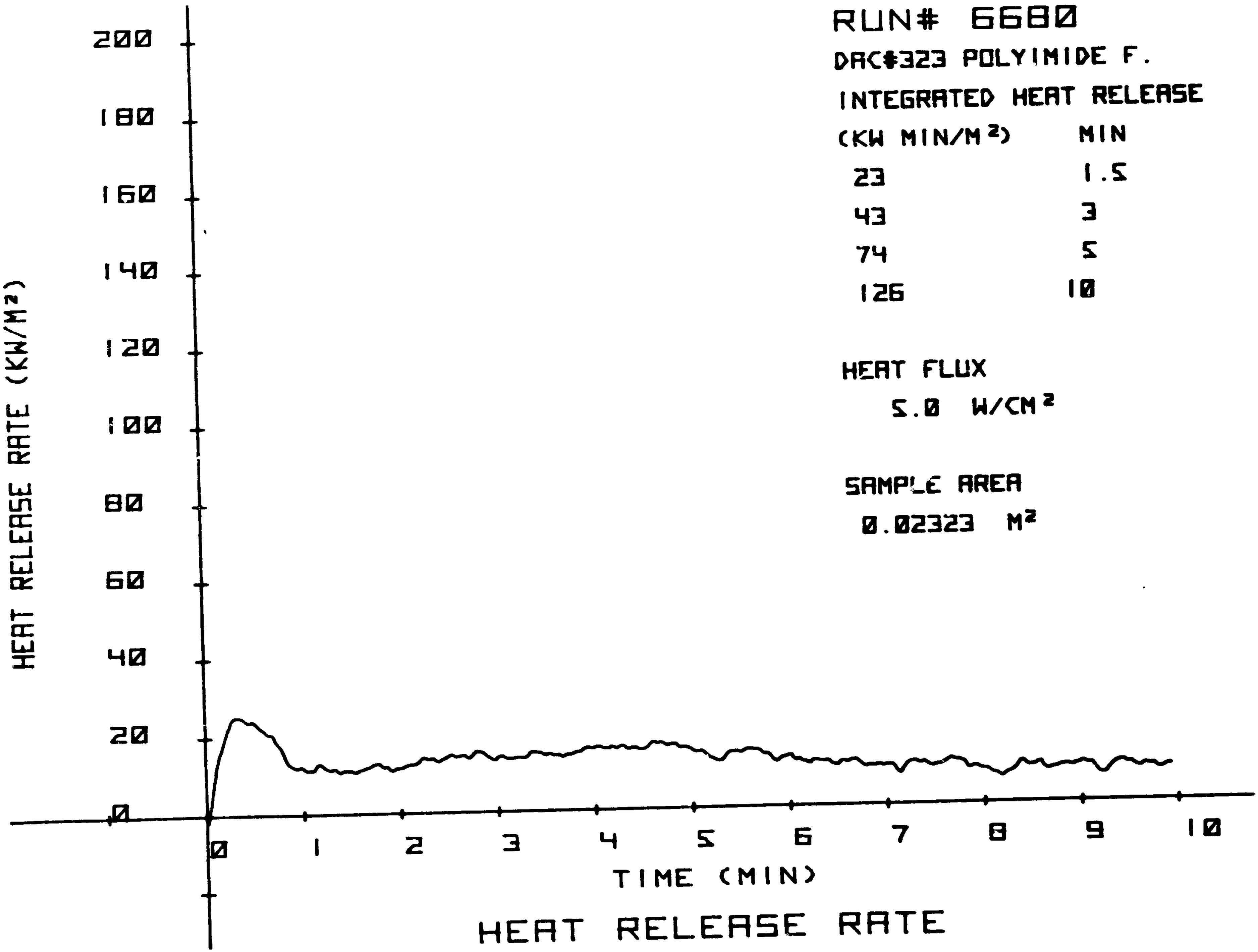
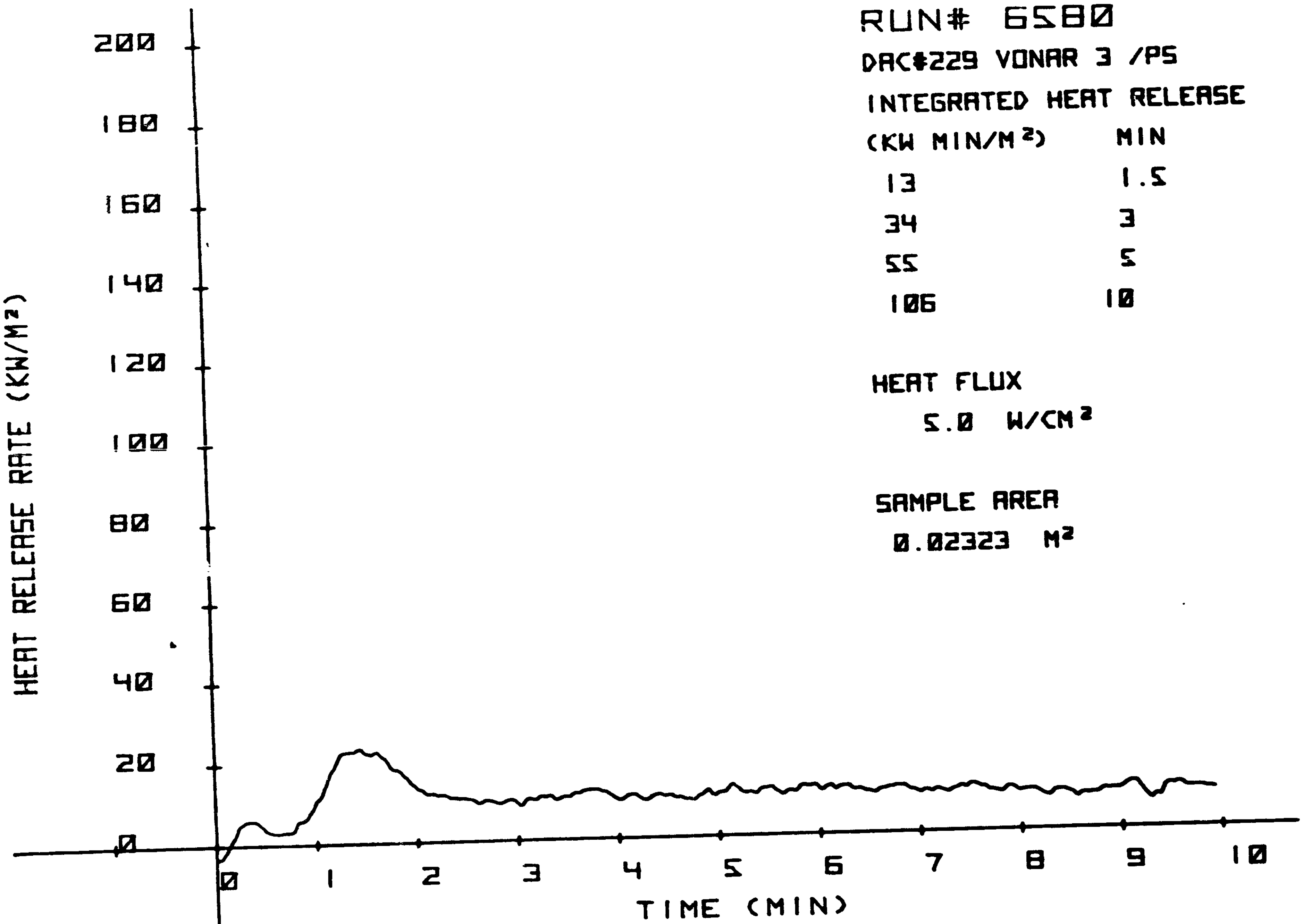
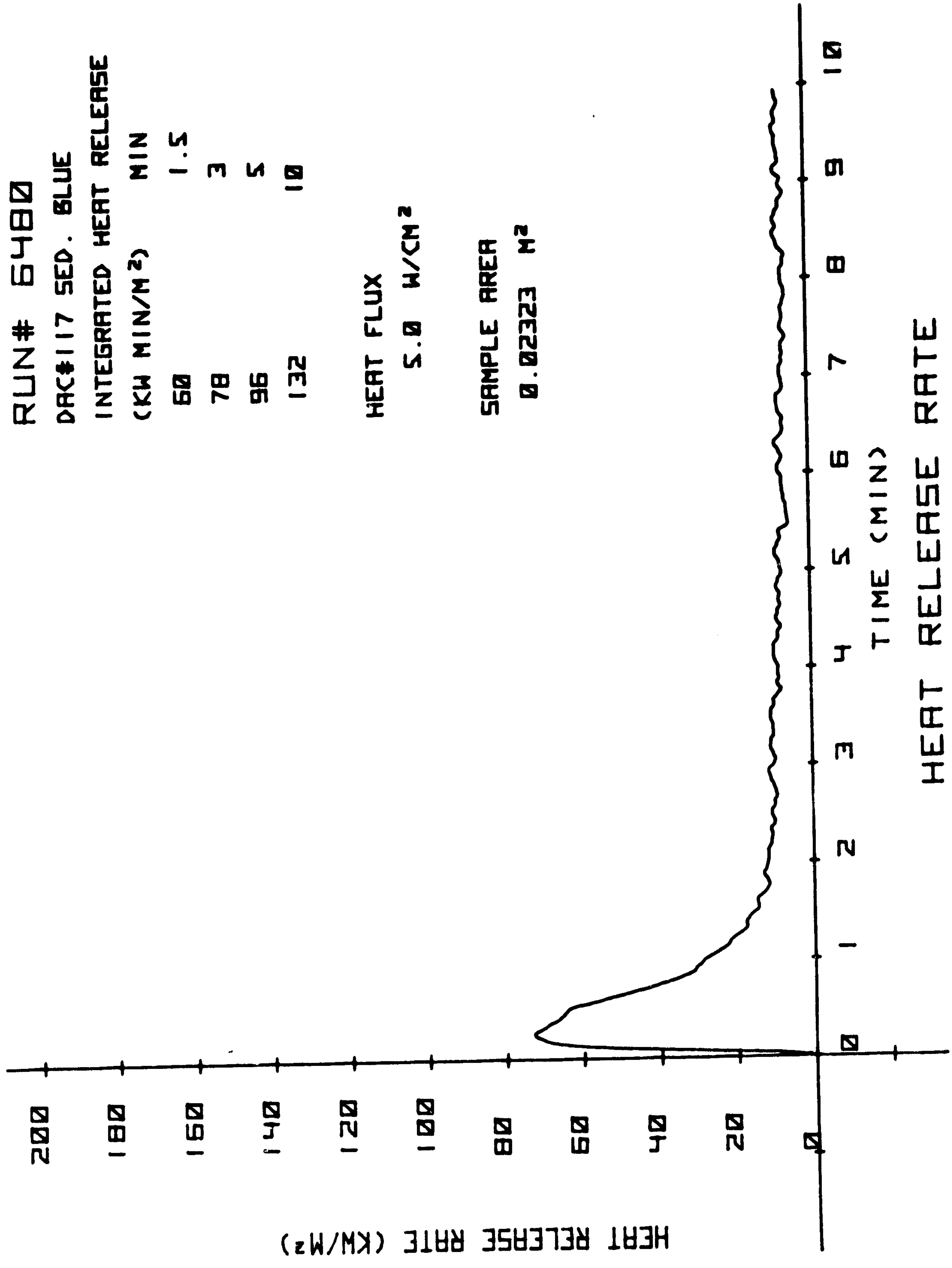


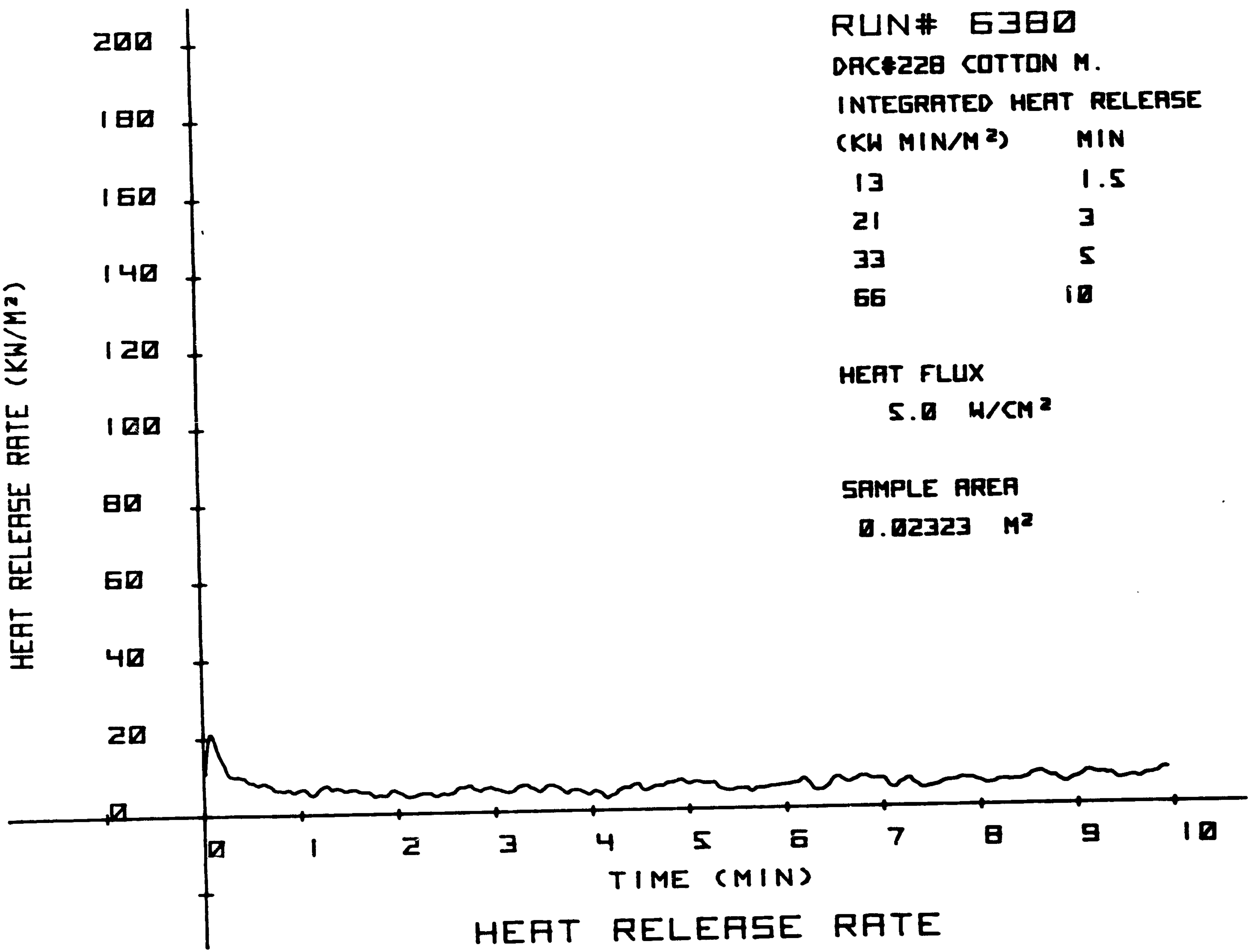
HEAT RELEASE RATE



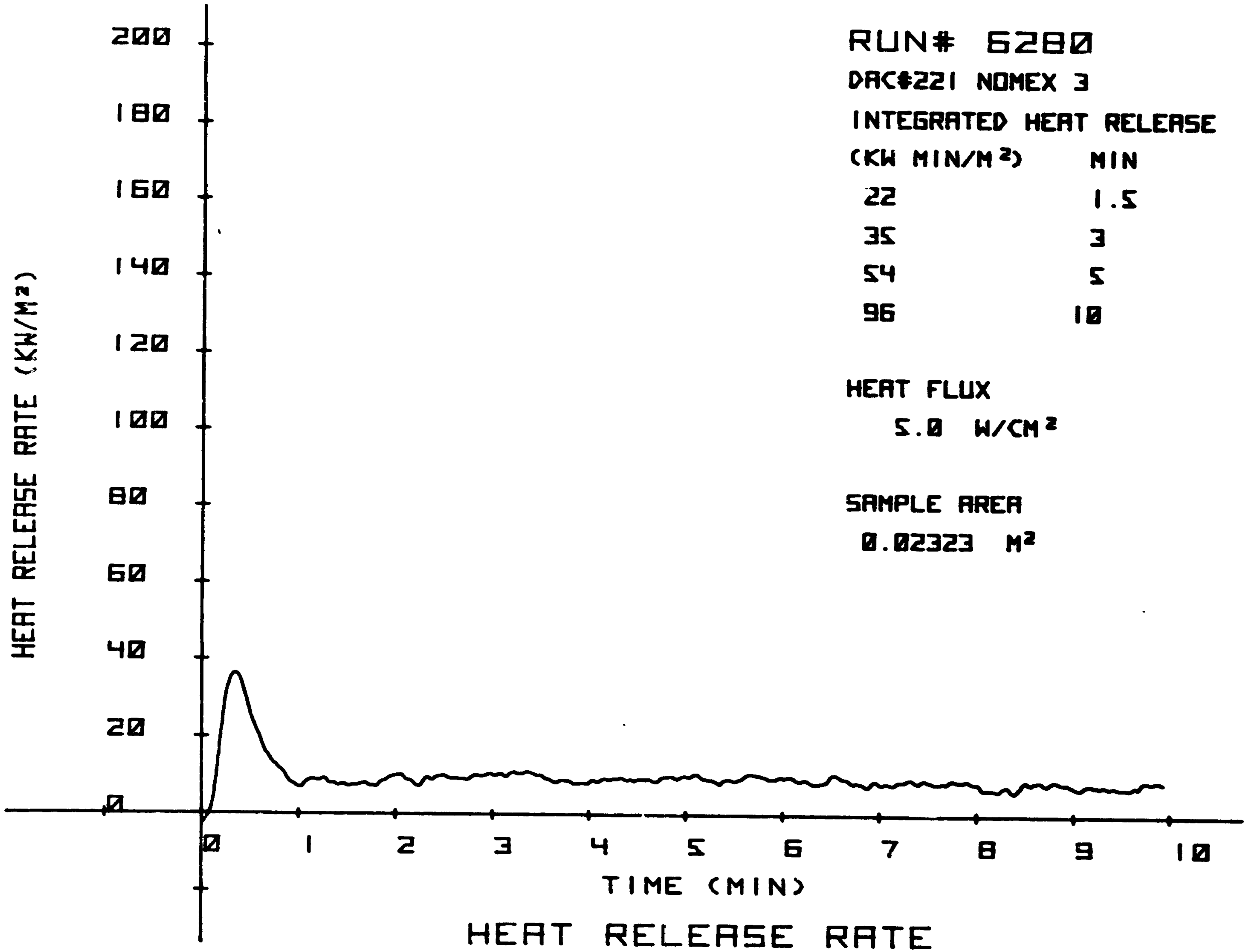
HEAT RELEASE RATE



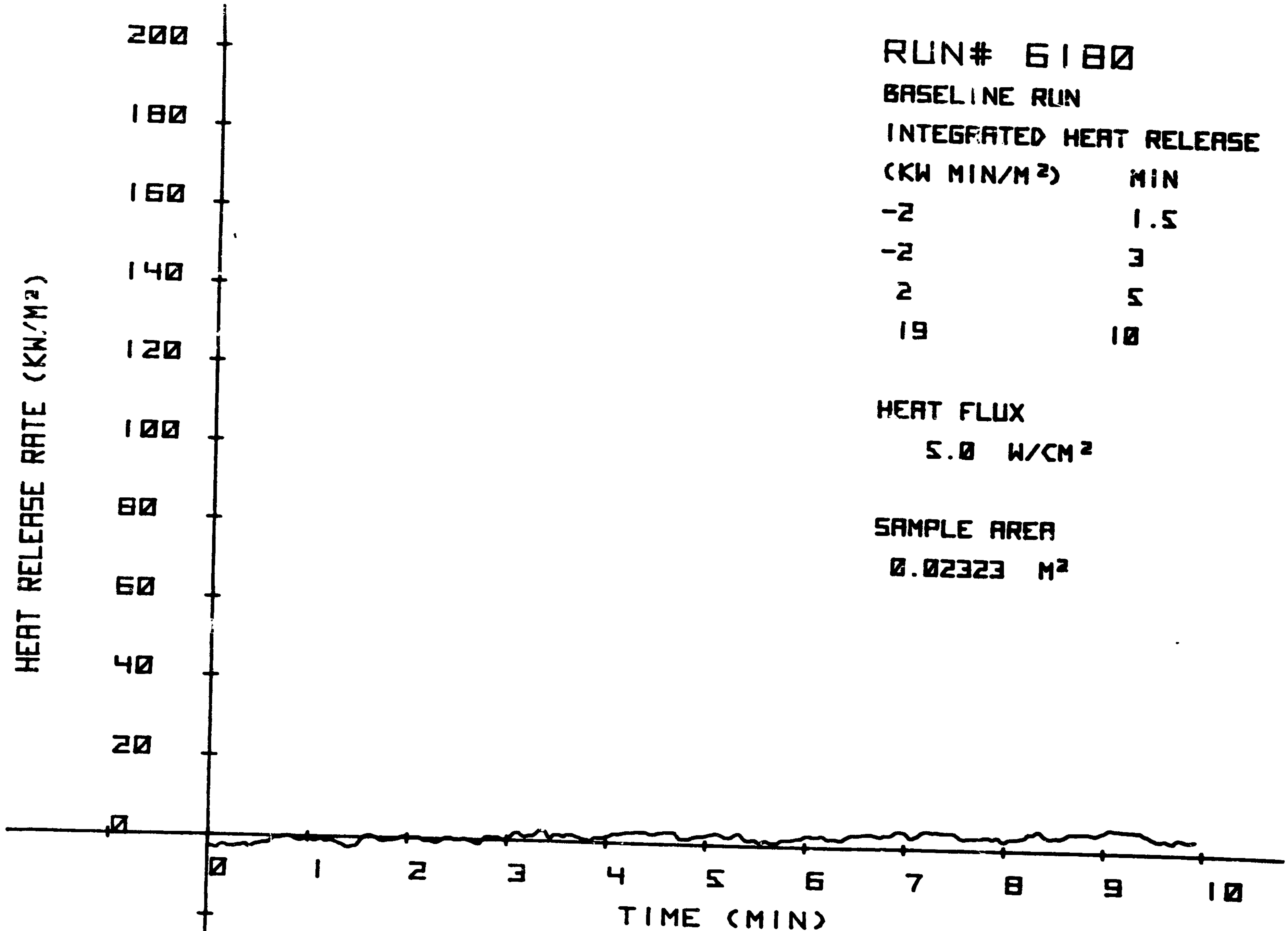
RUN# 6480
DAC#117 SED. BLUE
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
60 1.5
78 3
96 5
132 10
HEAT FLUX
5.0 W/CM²
SAMPLE AREA
0.02323 M²
HEAT RELEASE RATE (KW/M²)
0 20 40 60 80 100 120 140 160 180 200
TIME (MIN)
0 1 2 3 4 5 6 7 8 9 10
HEAT RELEASE RATE



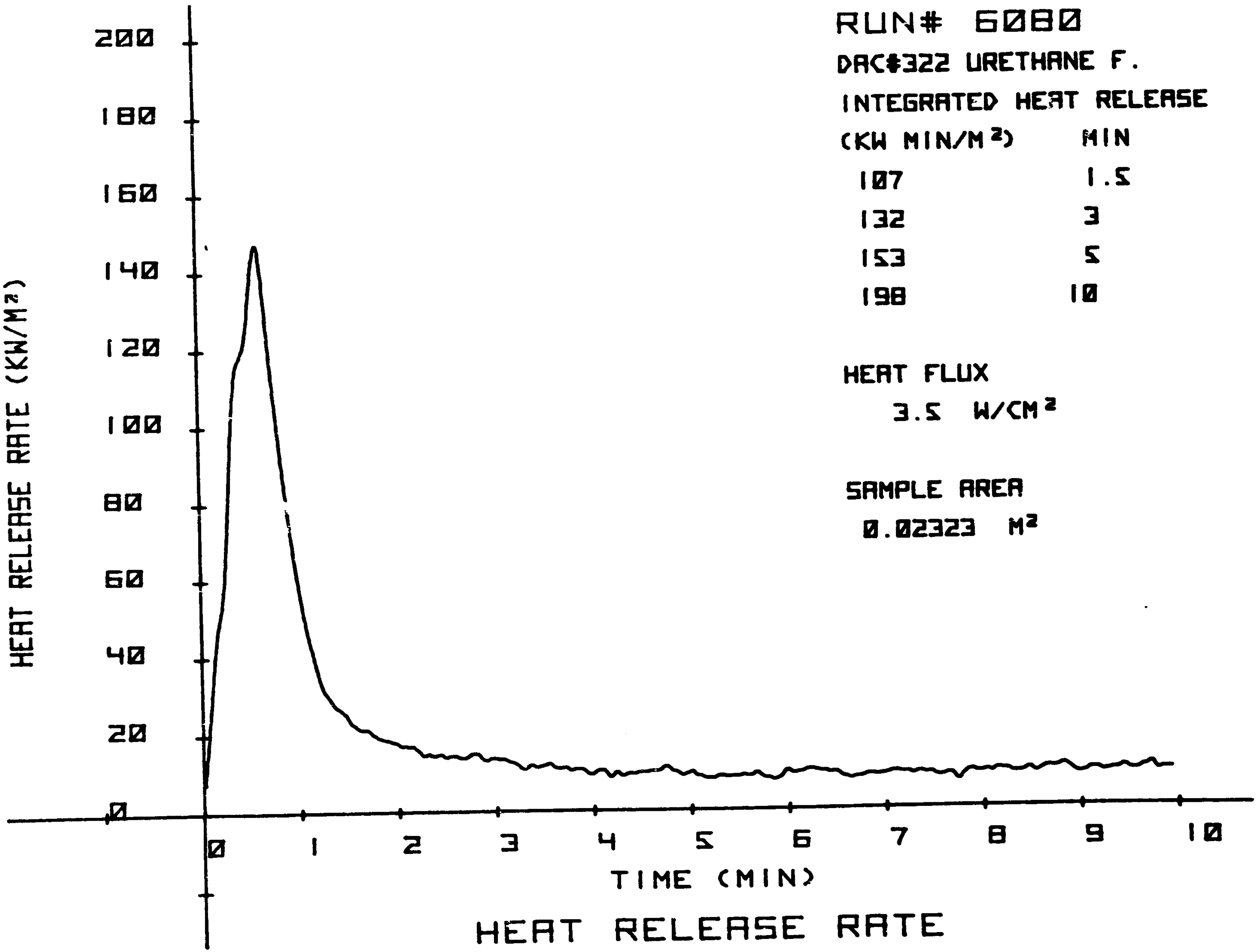
HEAT RELEASE RATE

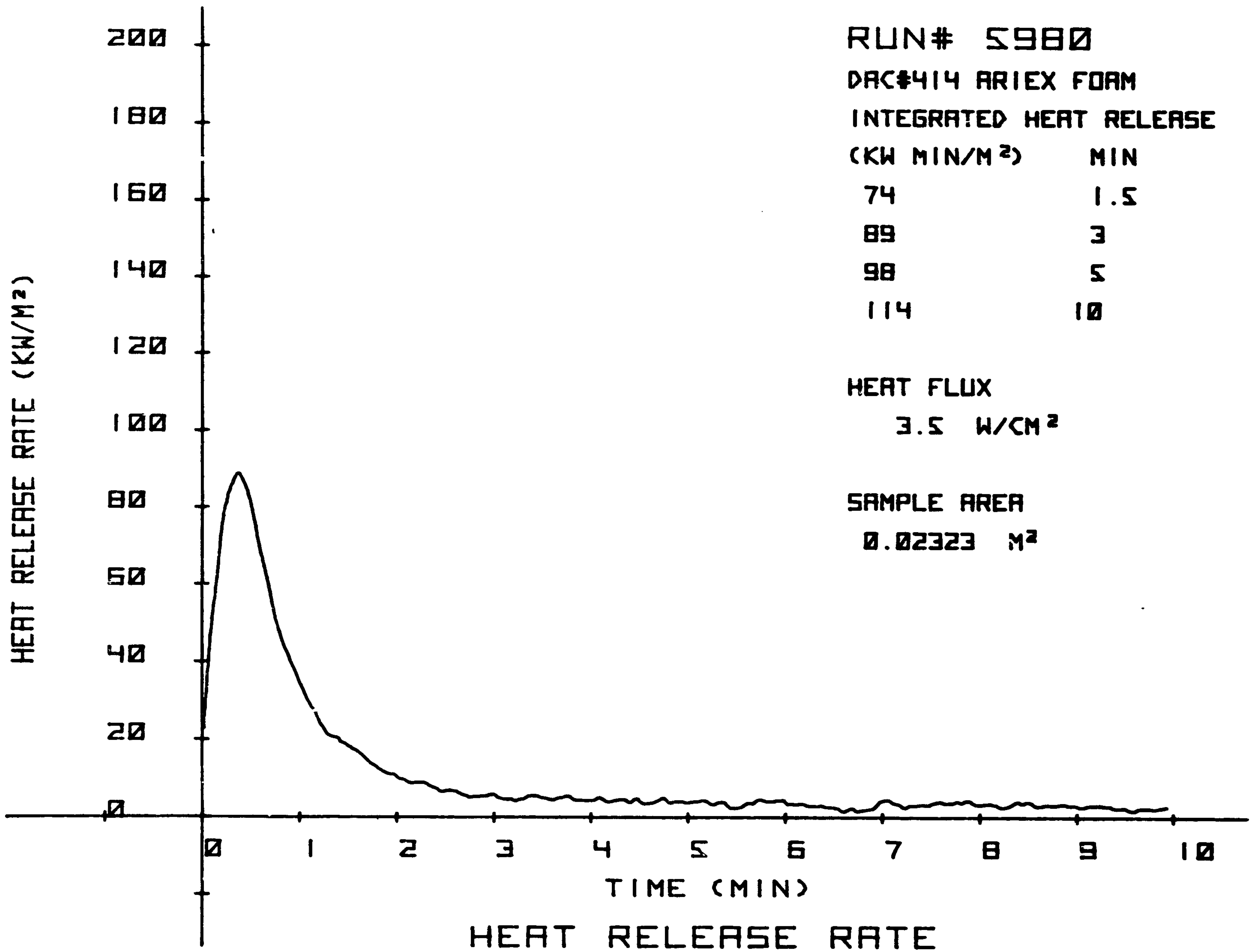


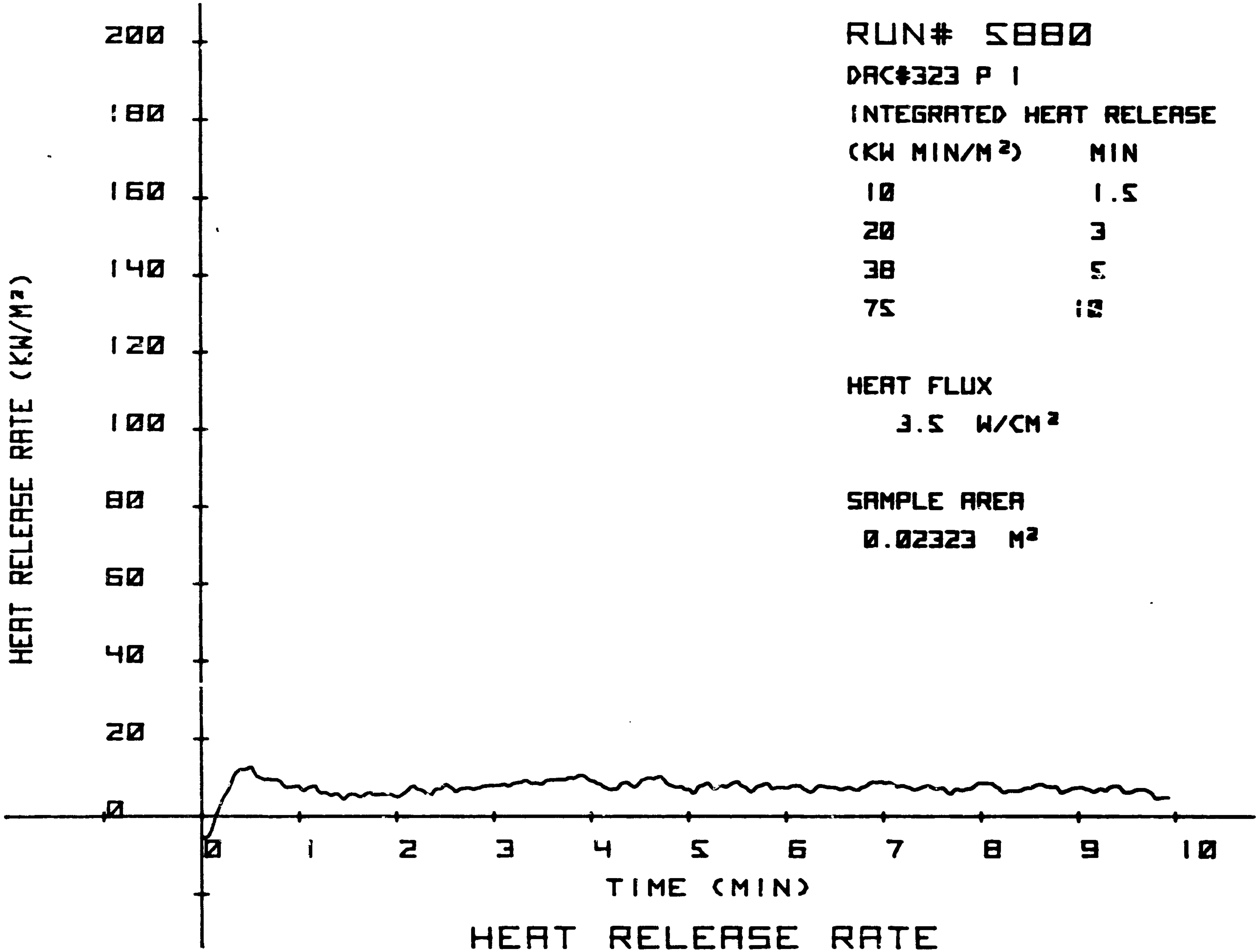
HEAT RELEASE RATE



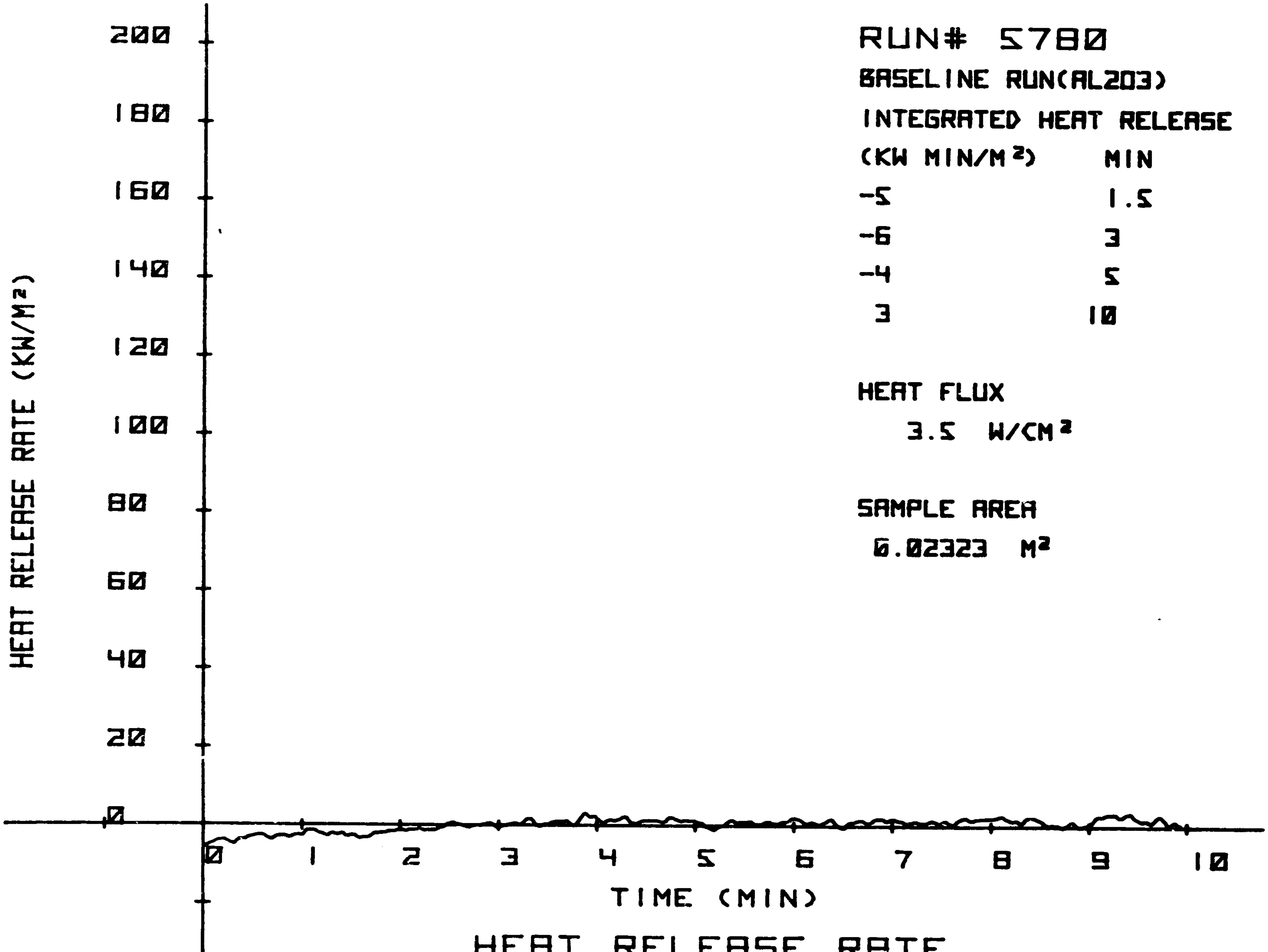
HEAT RELEASE RATE


RUN# 6080
DAC#322 URETHANE F.
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
107 1.5
132 3
153 5
198 10
HEAT FLUX
3.5 W/CM²
SAMPLE AREA
0.02323 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE

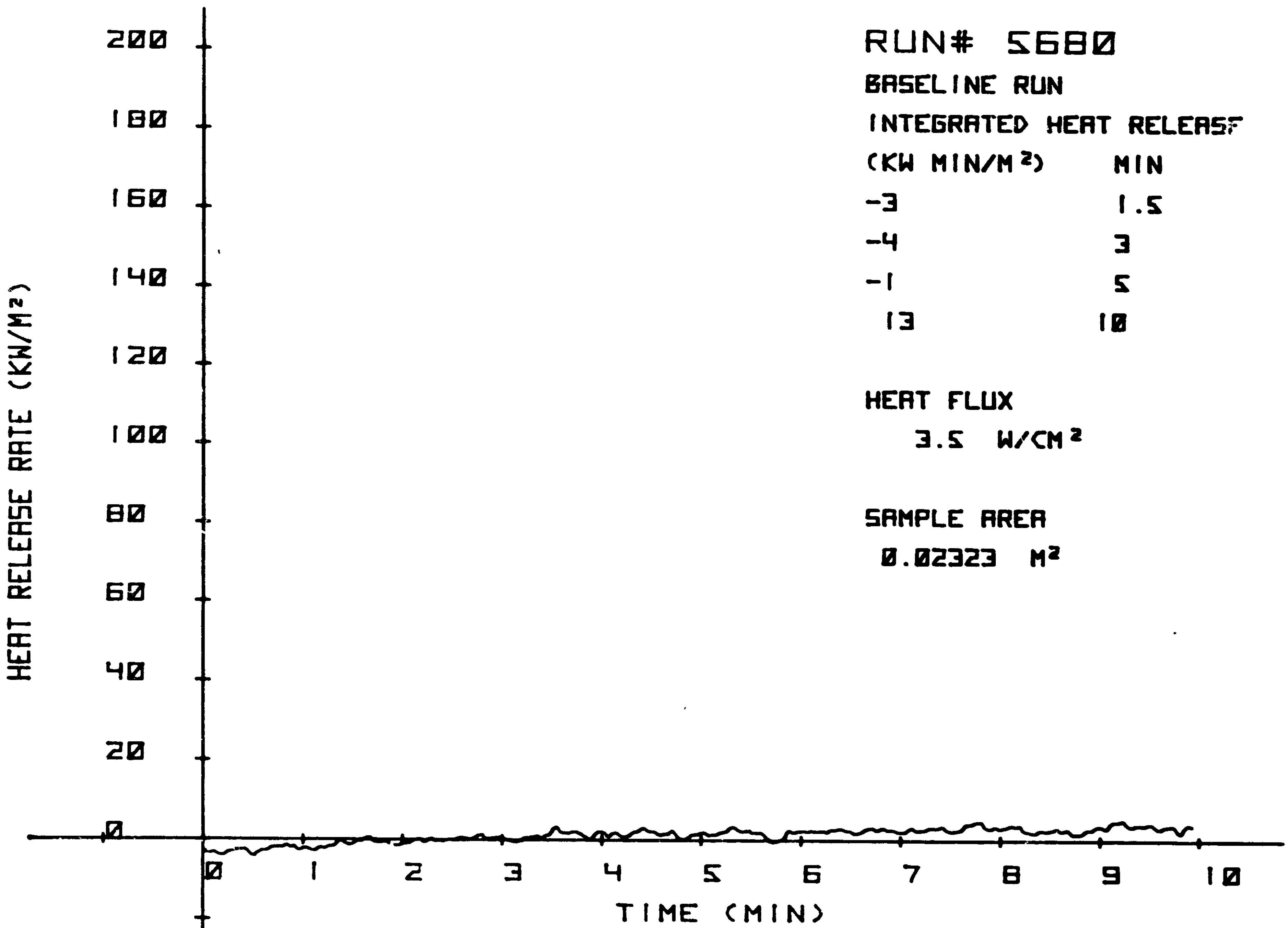

RUN# 5980
DAC#414 ARIEX FOAM
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
74 1.5
89 3
98 5
114 10
HEAT FLUX
3.5 W/CM²
SAMPLE AREA
0.02323 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE



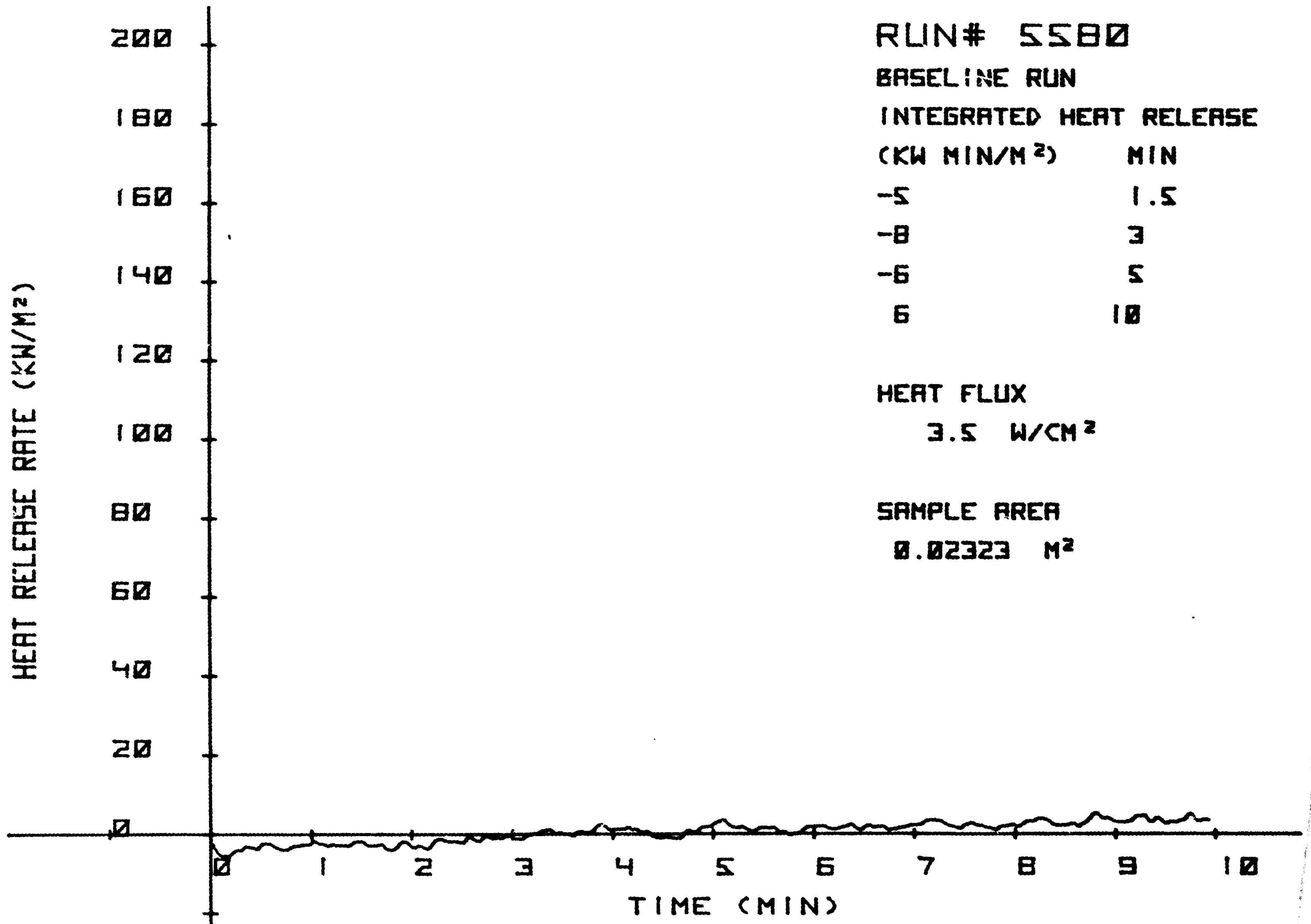
HEAT RELEASE RATE



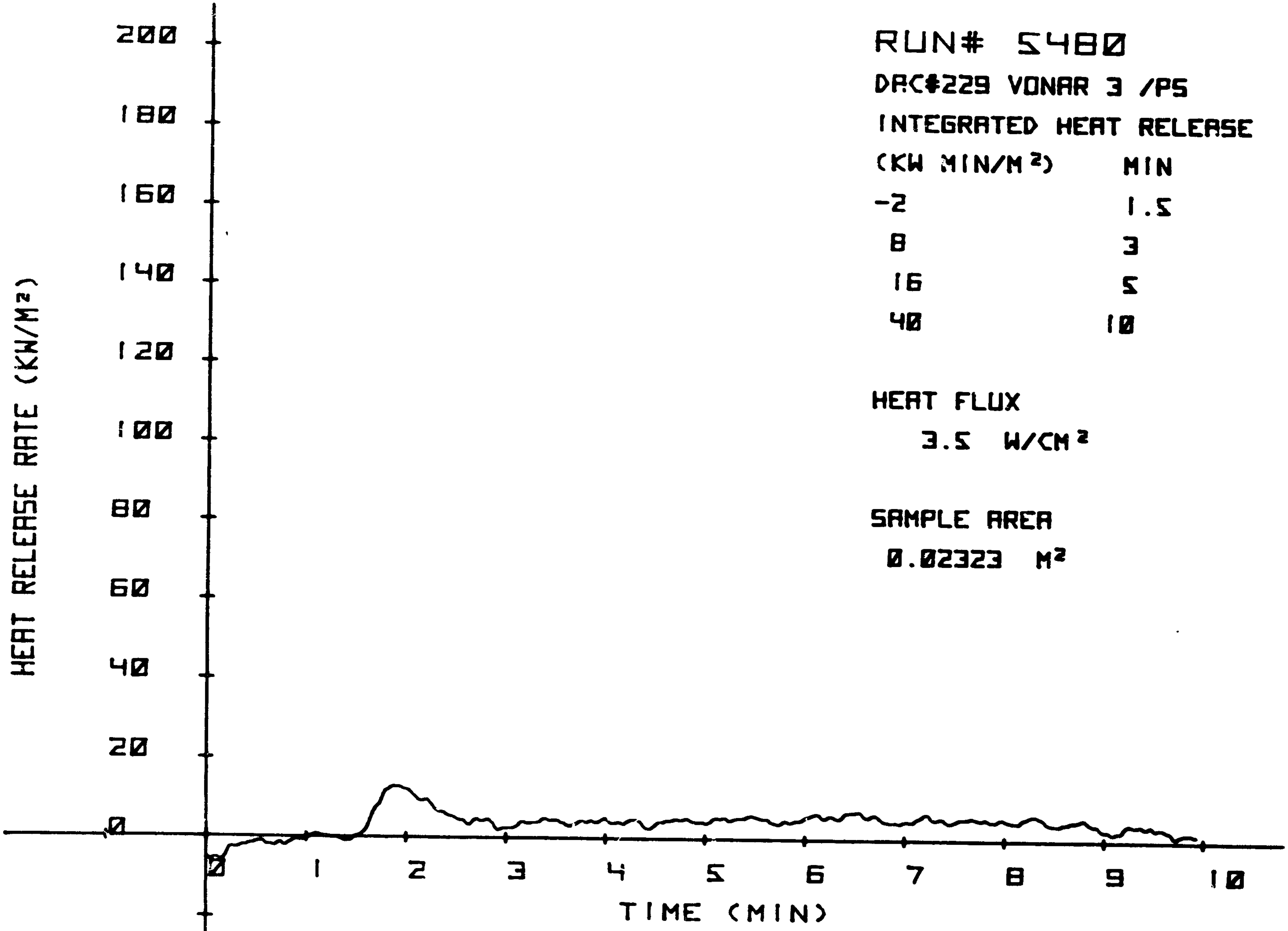
HEAT RELEASE RATE



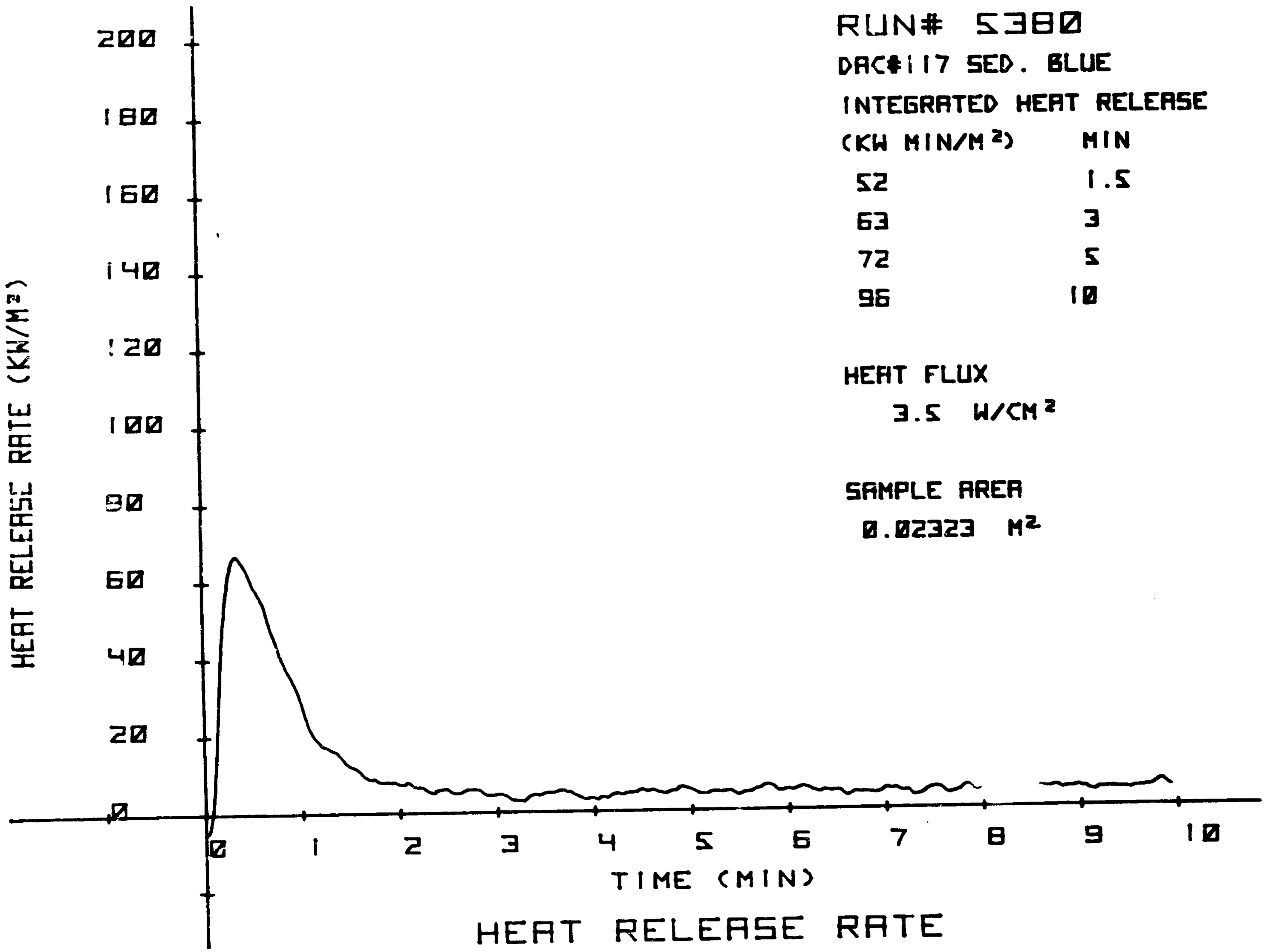
HEAT RELEASE RATE



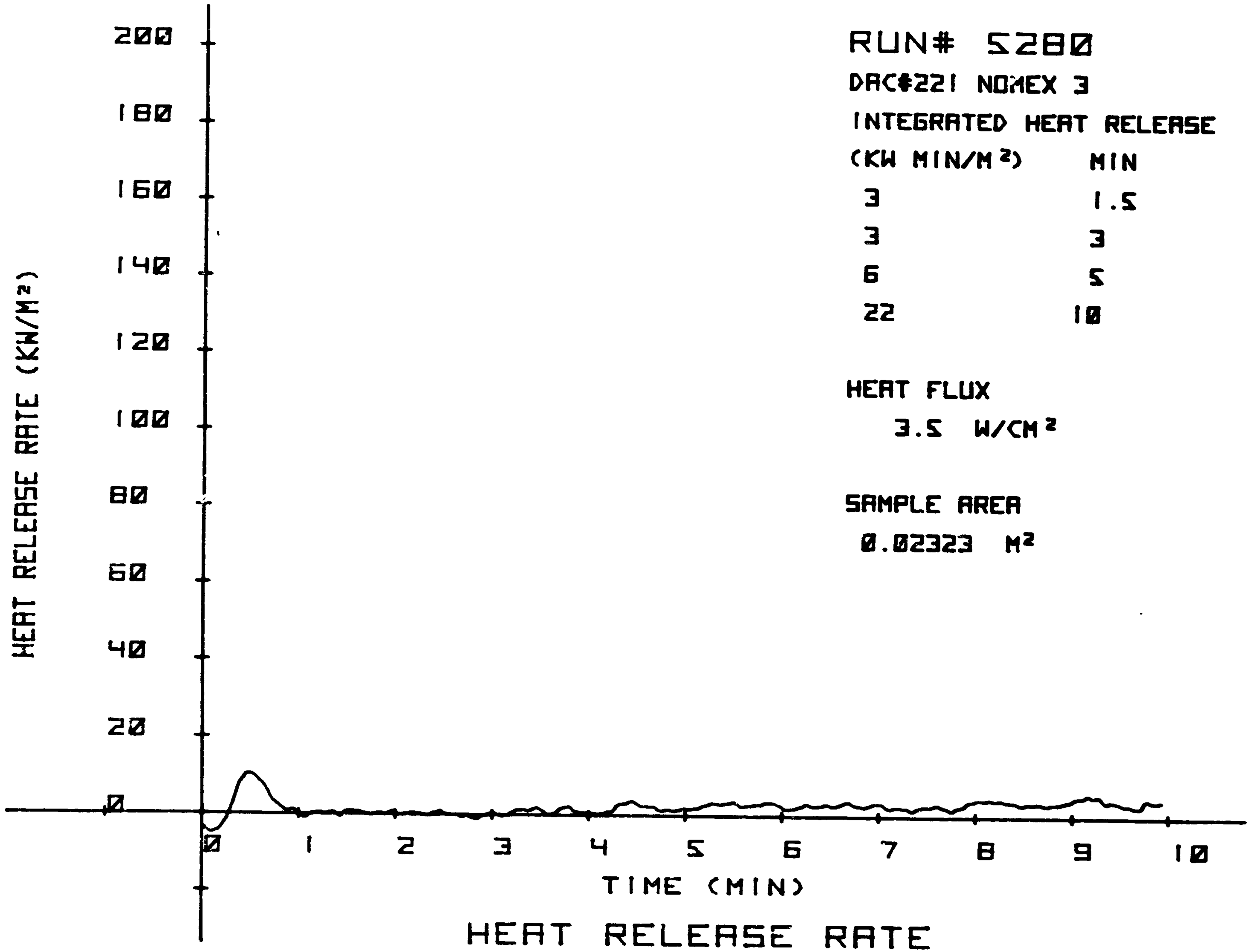
HEAT RELEASE RATE

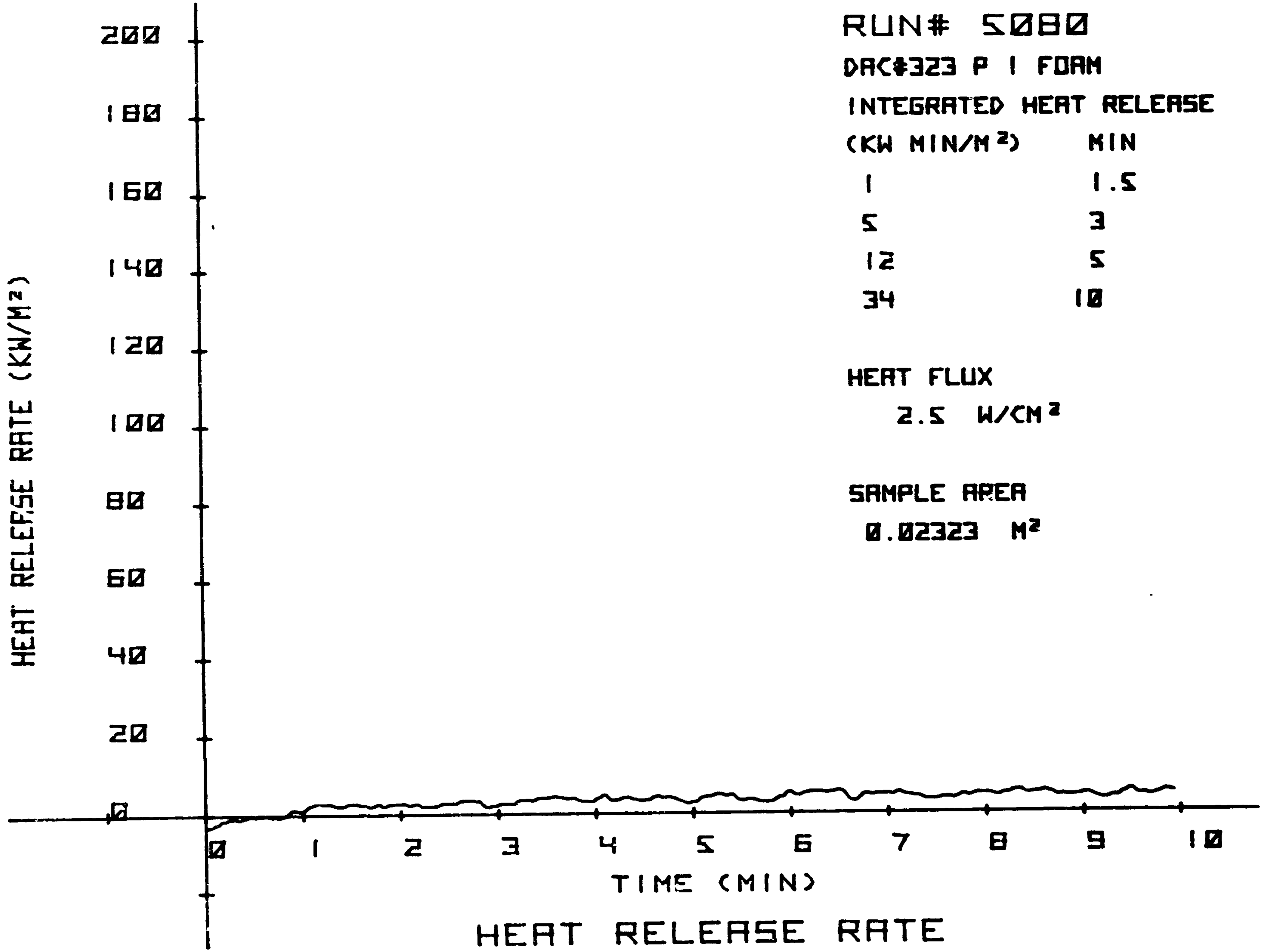


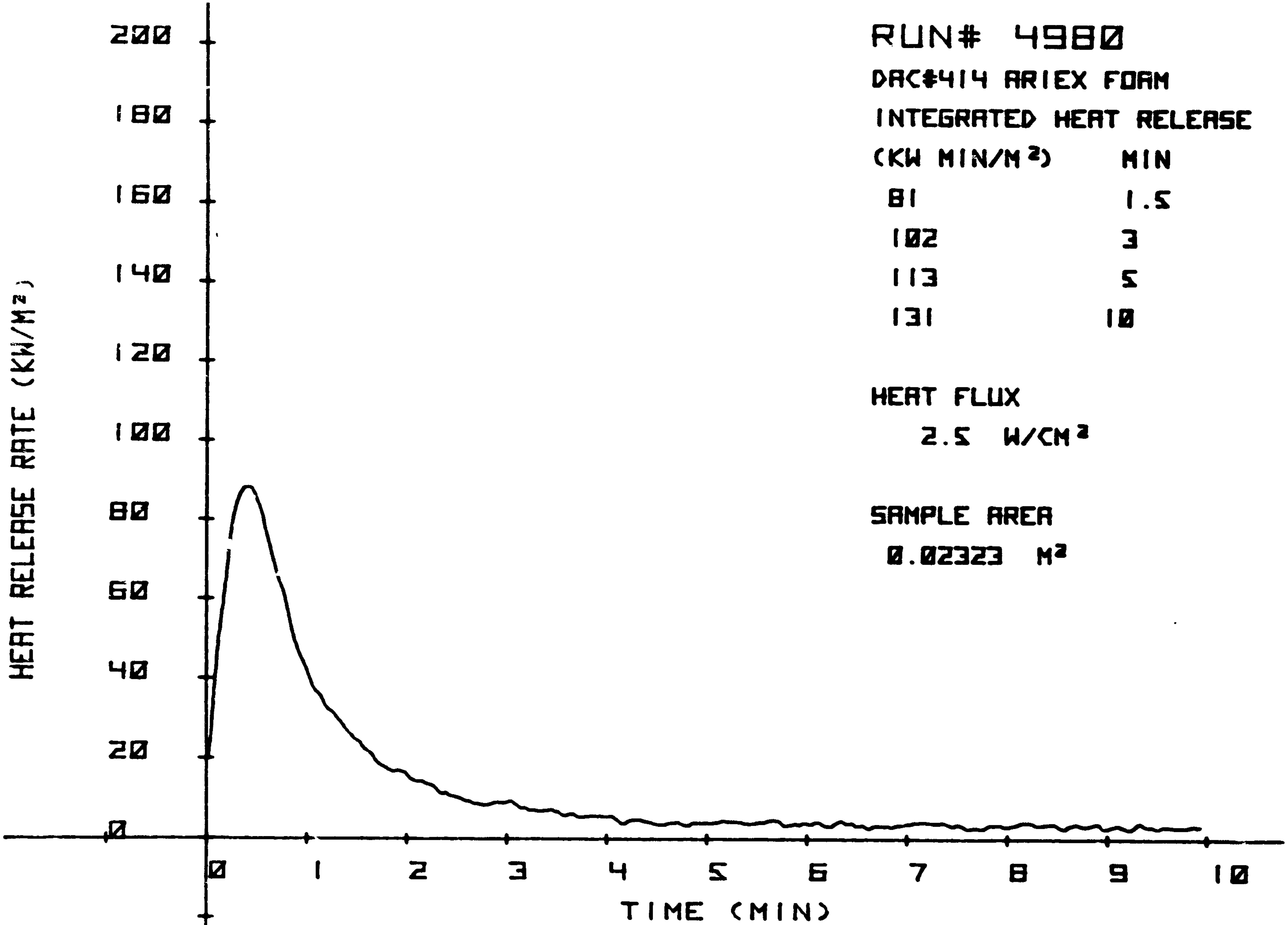
HEAT RELEASE RATE



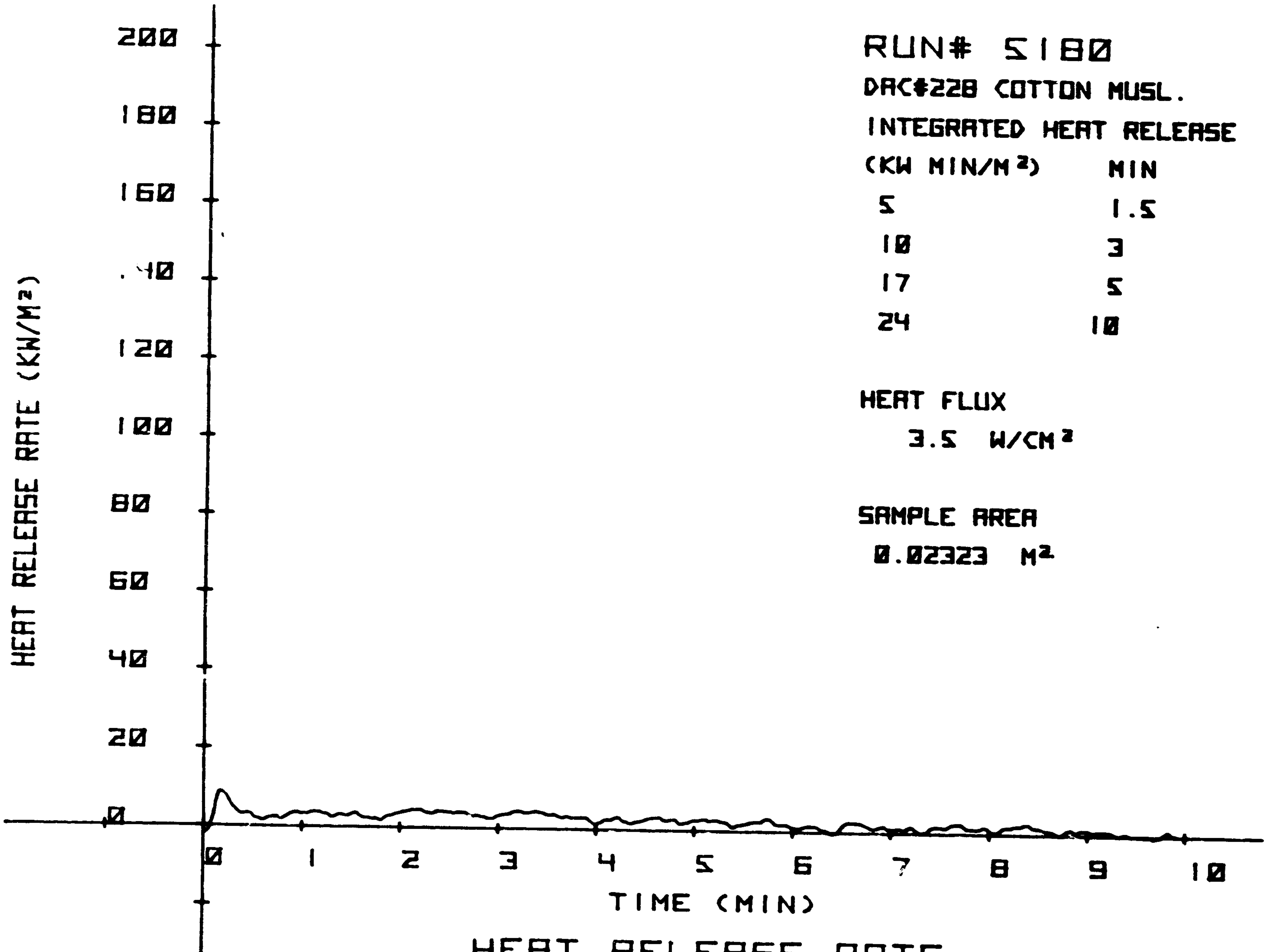
HEAT RELEASE RATE


RUN# 5280
DAC#221 NOMEX 3
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
3 1.5
3 3
6 5
22 10
HEAT FLUX
3.5 W/CM²
SAMPLE AREA
0.02323 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE

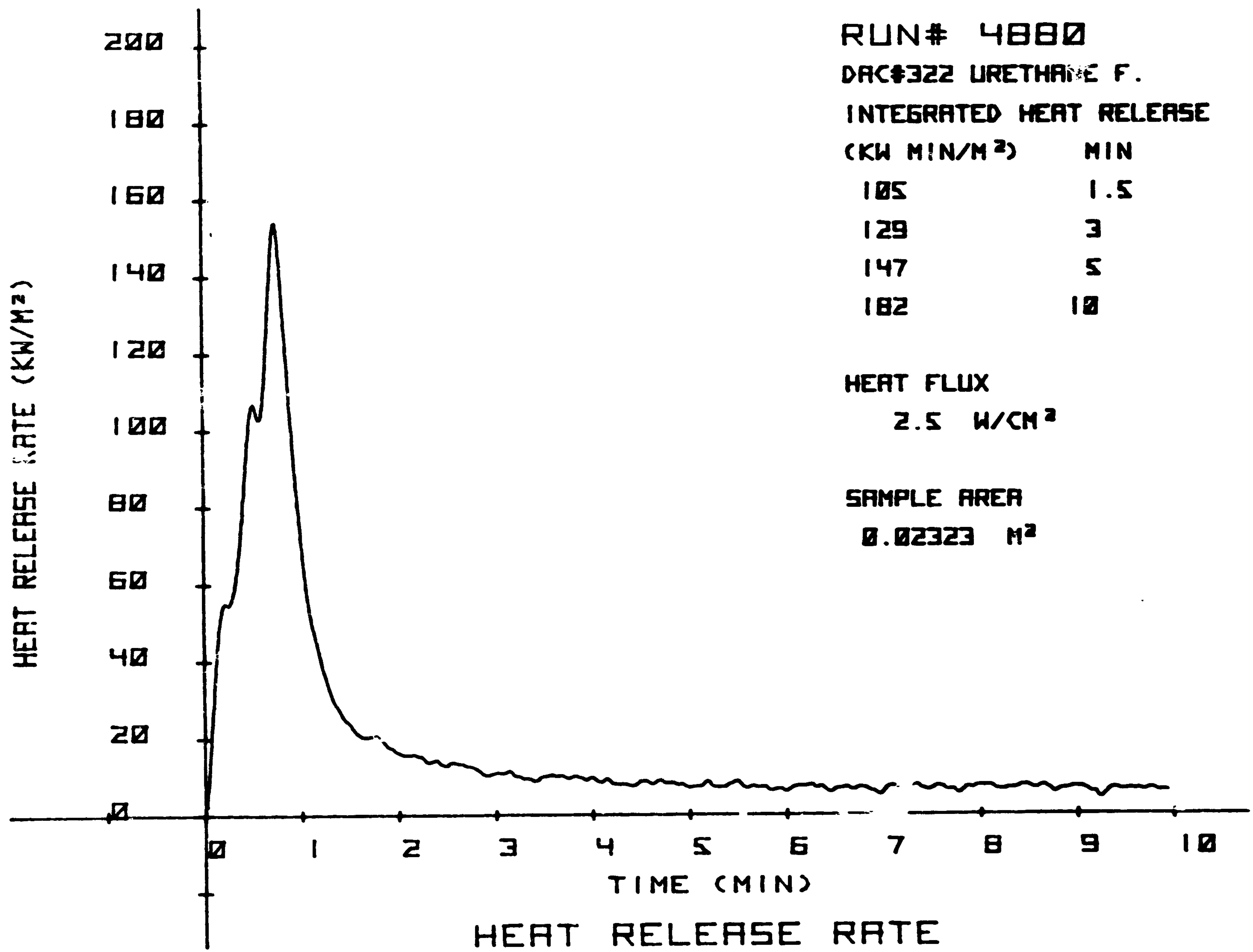

RUN# 5080
DAC#323 P I FOAM
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
1 1.5
5 3
12 5
34 10
HEAT FLUX
2.5 W/CM²
SAMPLE AREA
0.02323 M²
200
180
160
140
120
100
80
60
40
20
0
HEAT RELEASE RATE (KW/M²)
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE

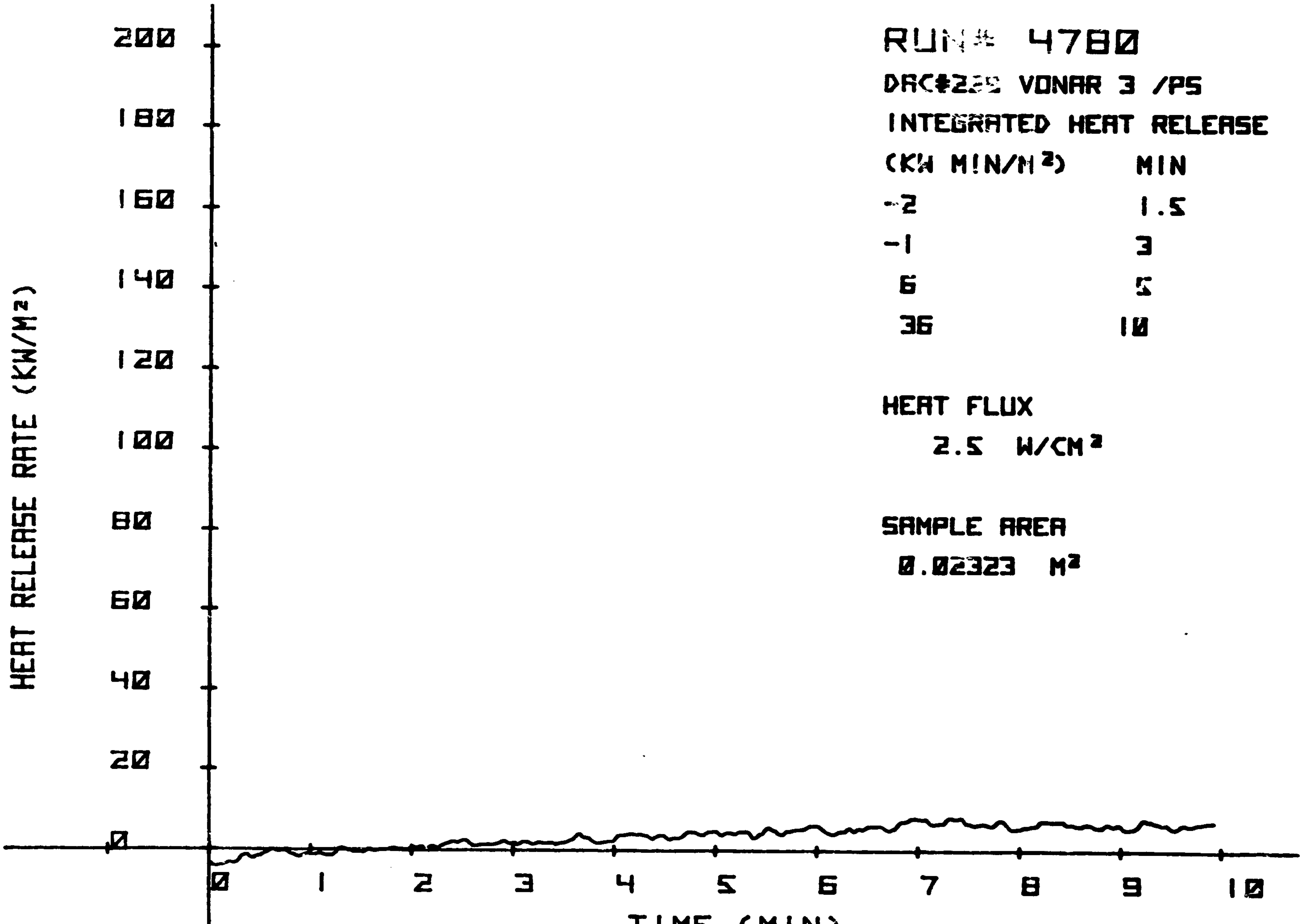


HEAT RELEASE RATE



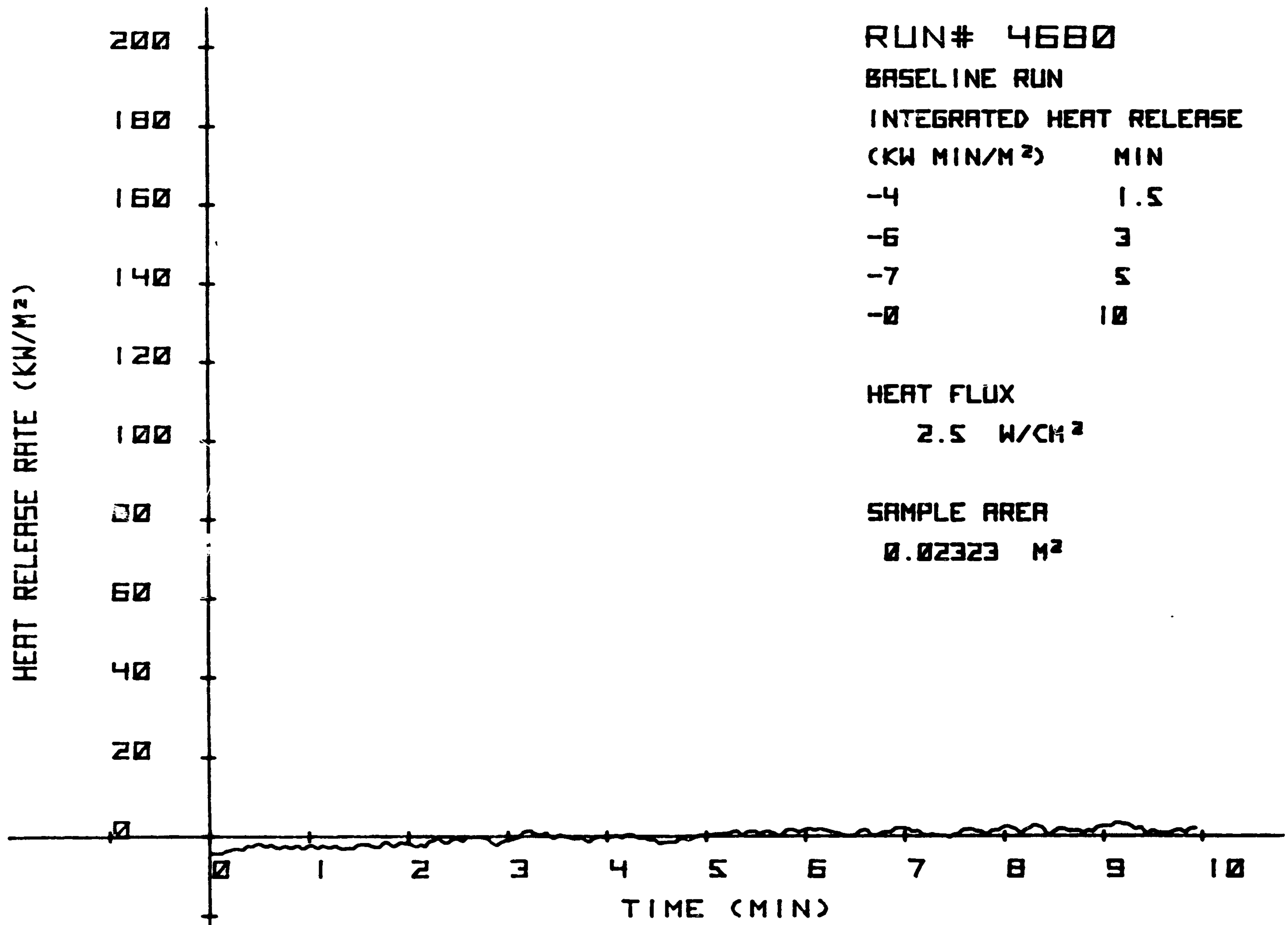
HEAT RELEASE RATE


RUN# 4880
DAC#322 URETHANE F.
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
105 1.5
129 3
147 5
182 10
HEAT FLUX
2.5 W/CM²
SAMPLE AREA
0.02323 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
TIME (MIN)
HEAT RELEASE RATE

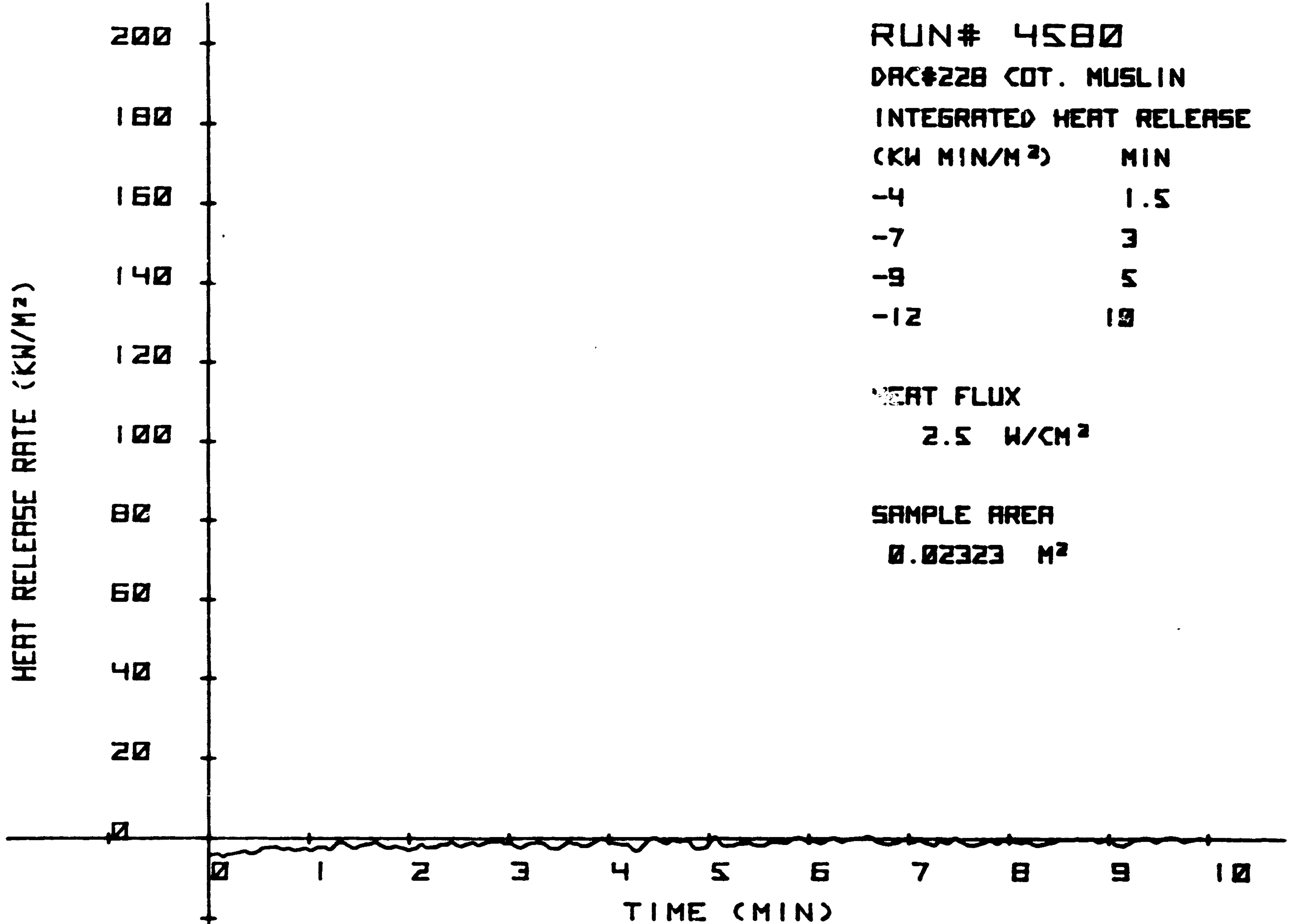


HEAT RELEASE RATE

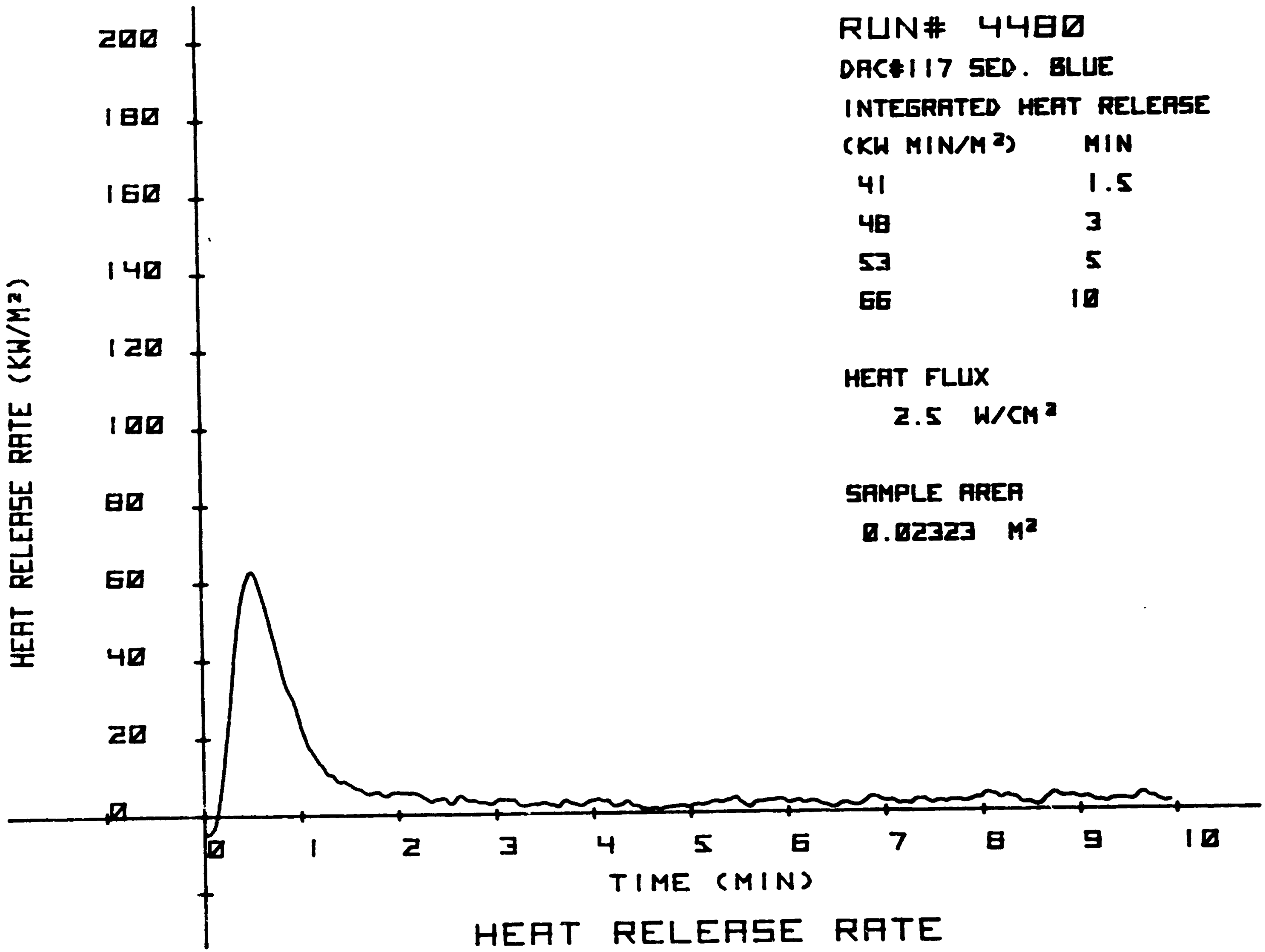
C-2

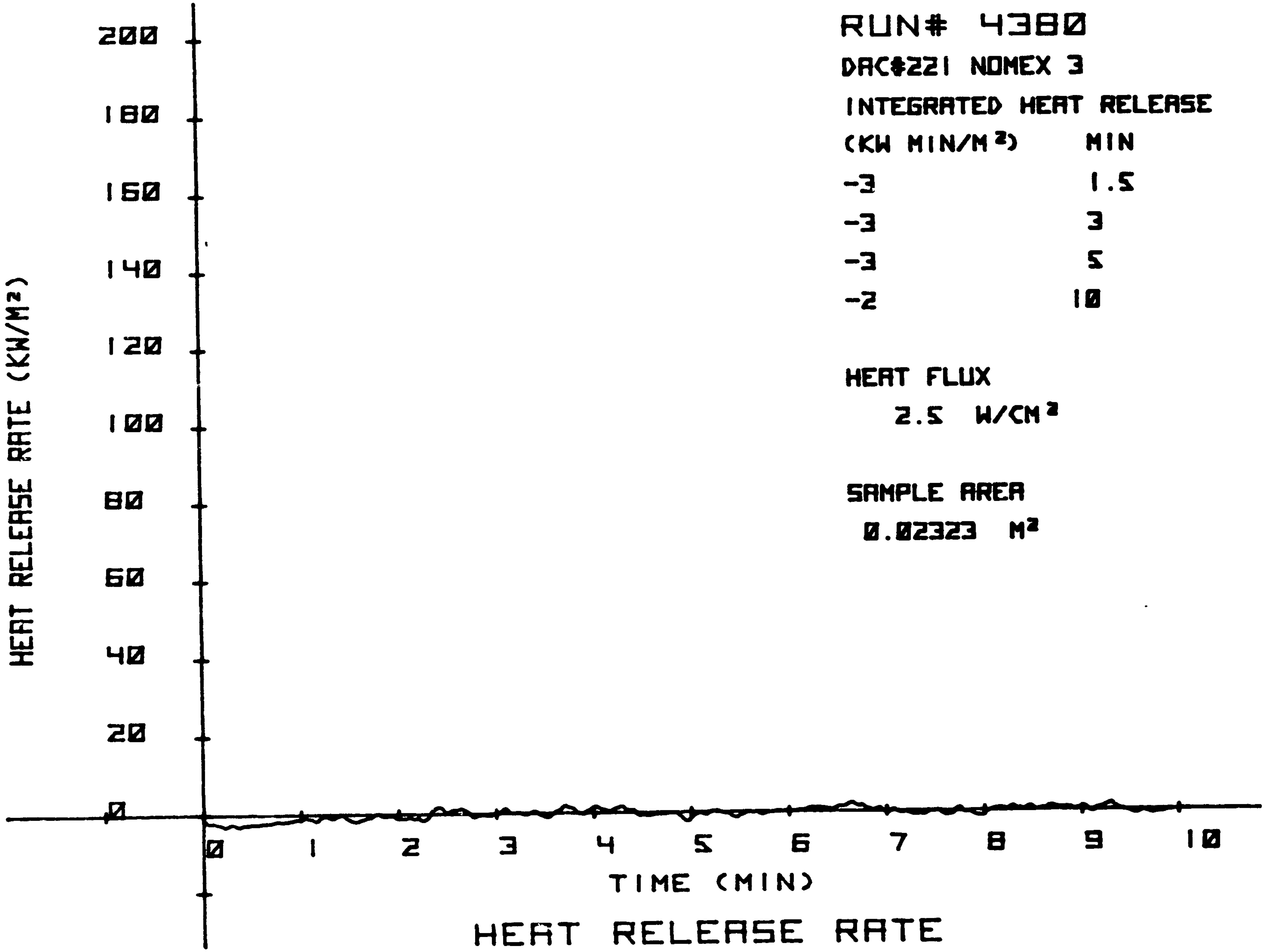


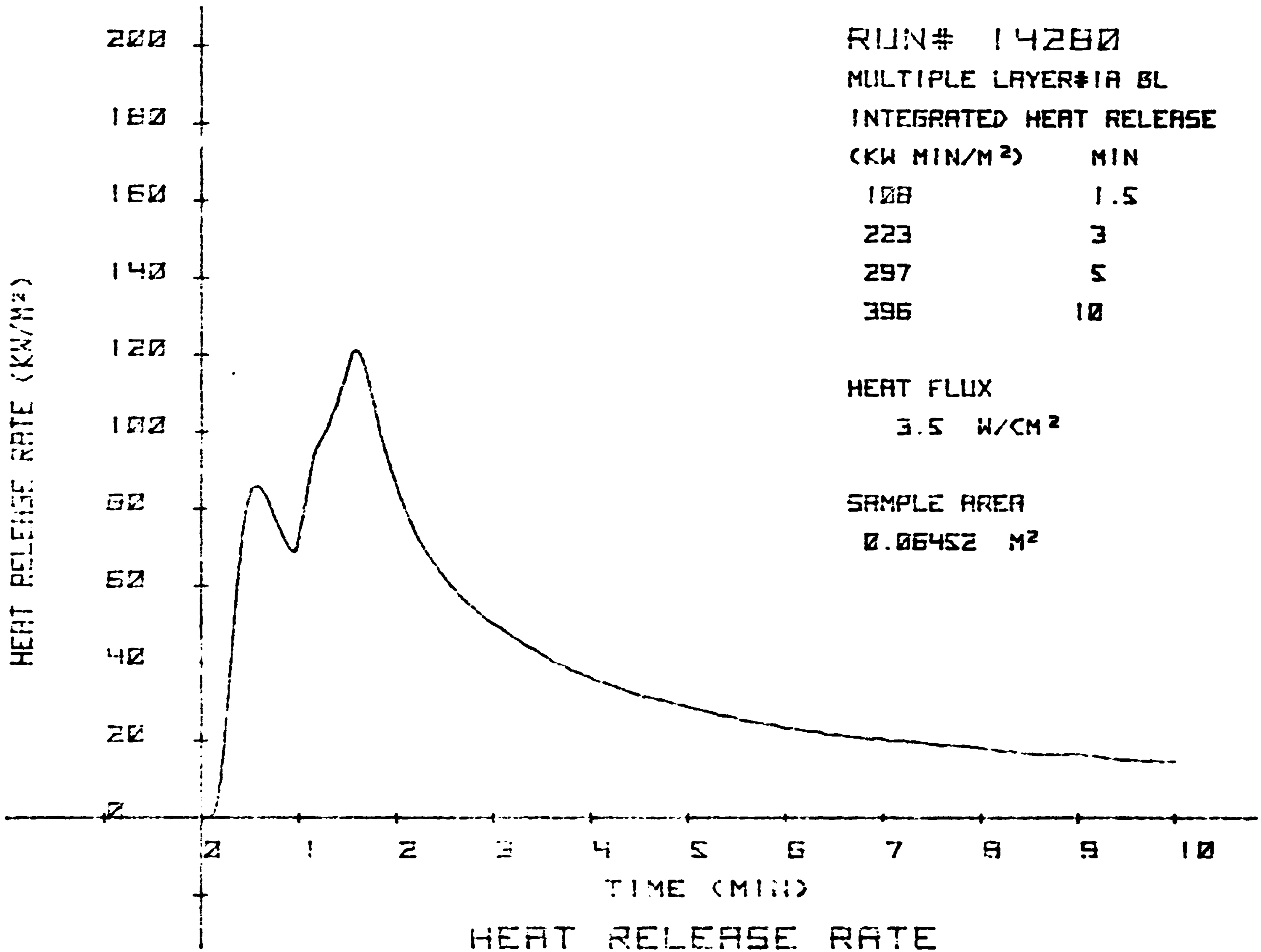
HEAT RELEASE RATE



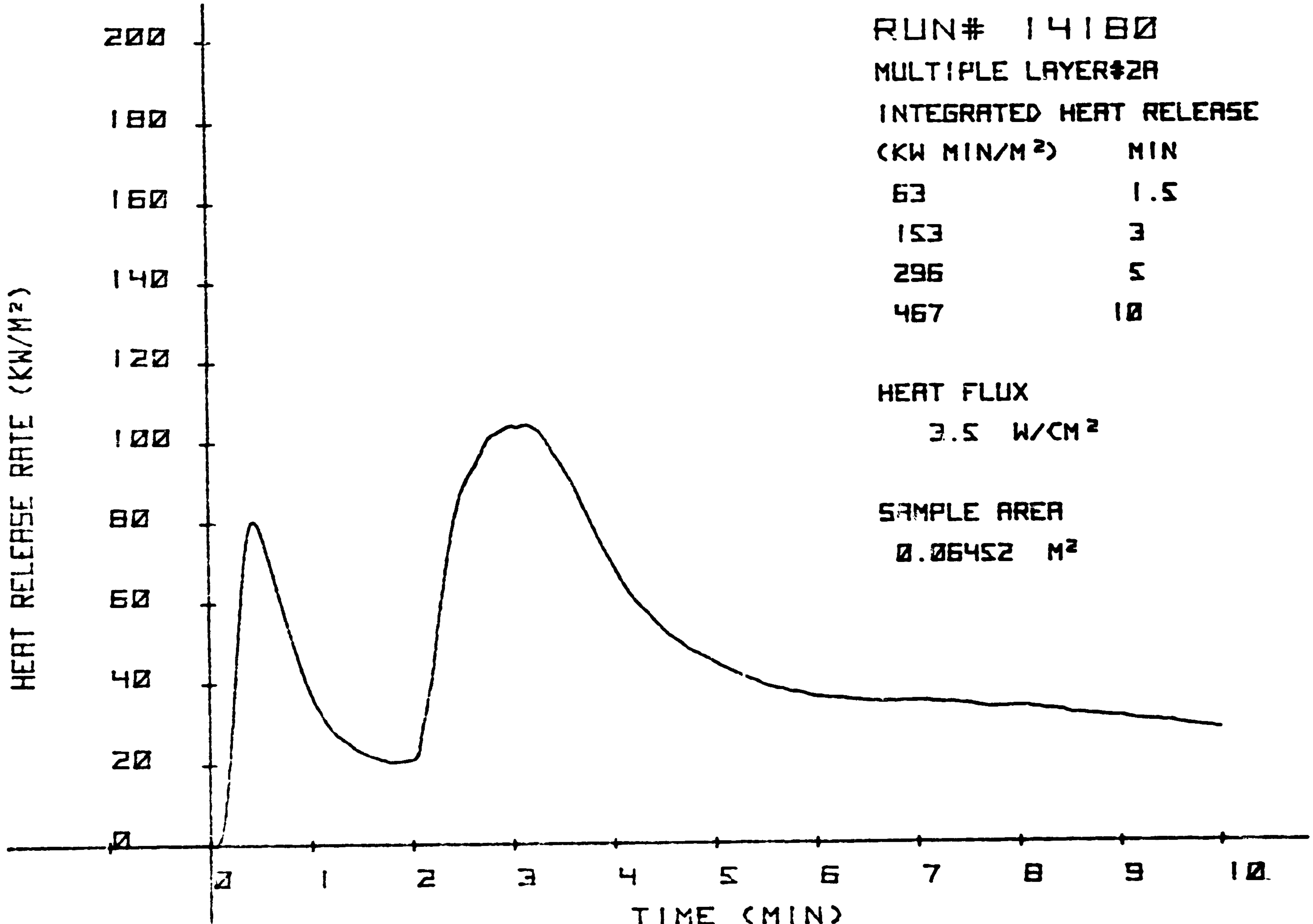
HEAT RELEASE RATE


RUN# 4480
DAC#117 SED. BLUE
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
41 1.5
48 3
53 5
66 10
HEAT FLUX
2.5 W/CM²
SAMPLE AREA
0.02323 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE

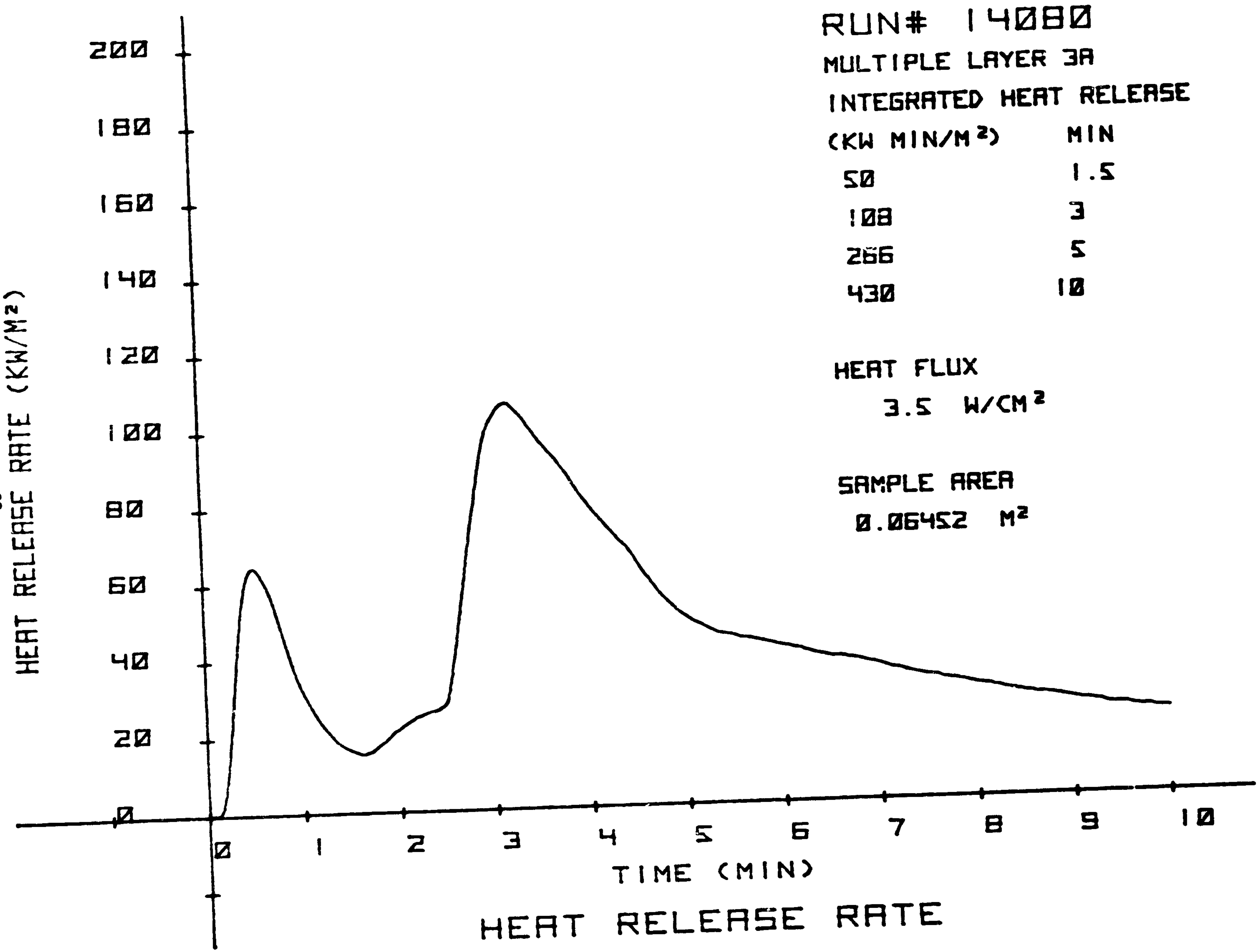

RUN# 4380
DAC#221 NOMEX 3
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
-3 1.5
-3 3
-3 5
-2 10
HEAT FLUX
2.5 W/CM²
SAMPLE AREA
0.02323 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE

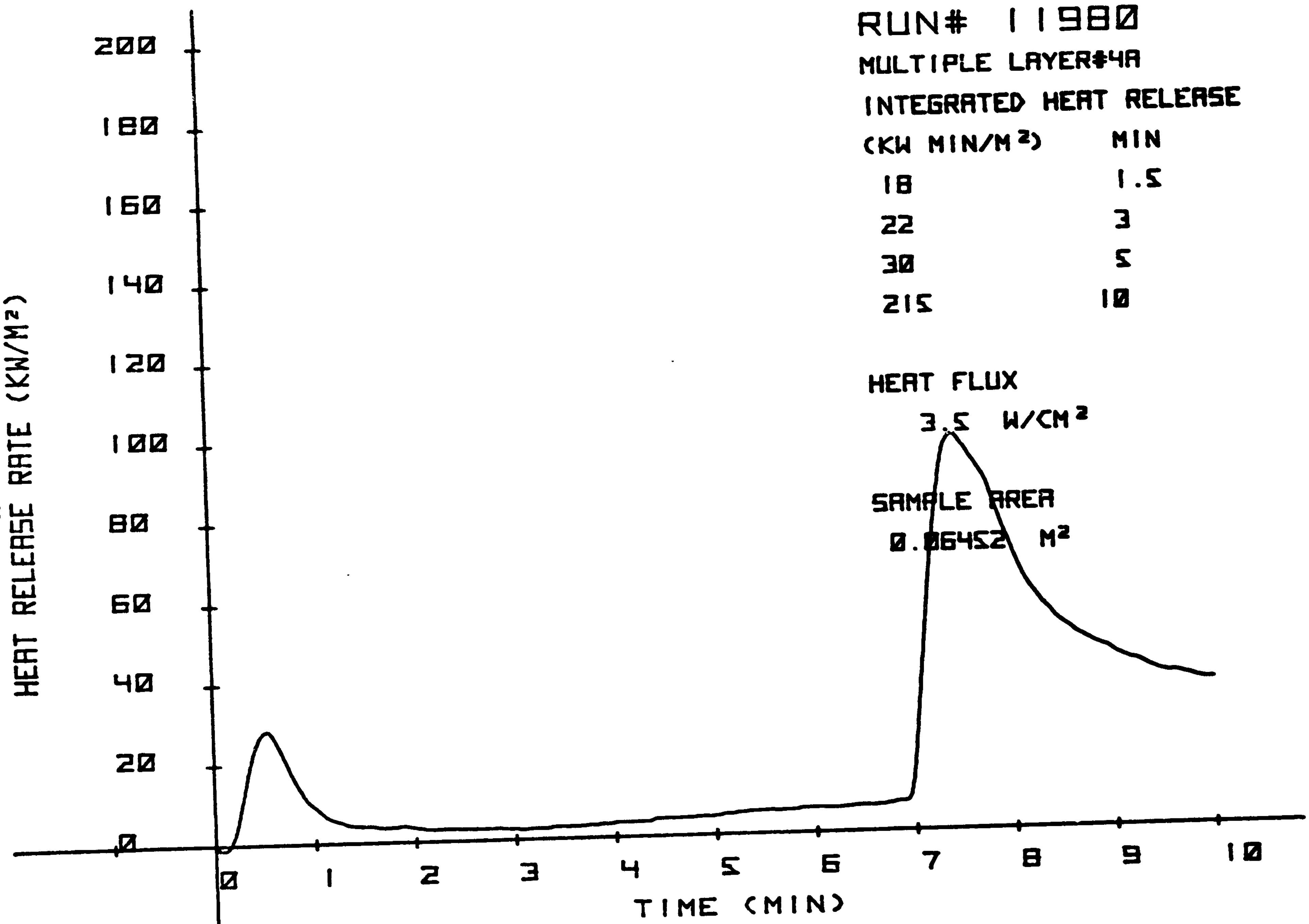


RUN# 14280
MULTIPLE LAYER#1A BL
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
108 1.5
223 3
297 5
396 10
HEAT FLUX
3.5 W/CM²
SAMPLE AREA
0.06452 M²
200
180
160
140
120
100
80
60
40
20
0
HEAT RELEASE RATE (KW/M²)
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE

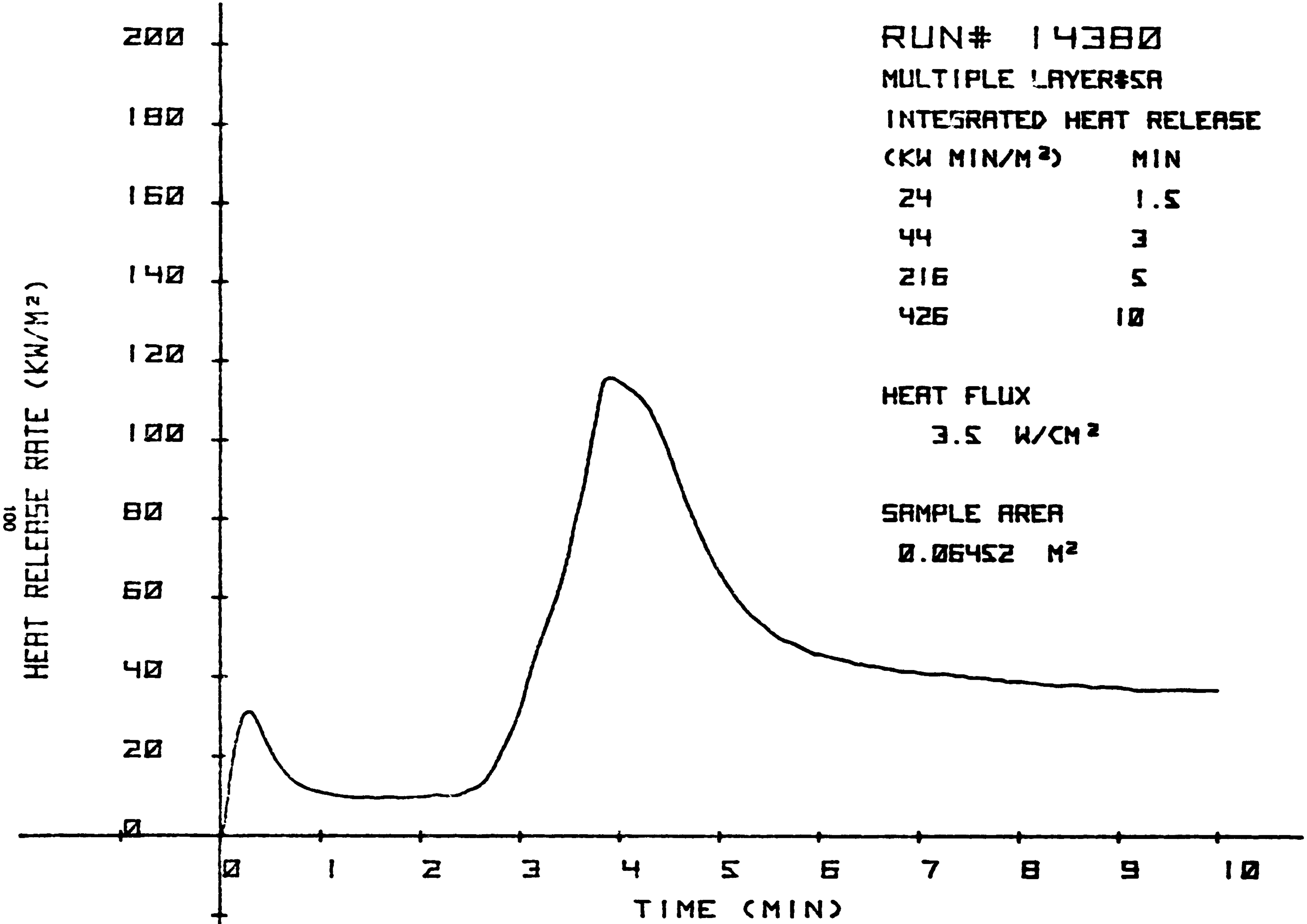


HEAT RELEASE RATE

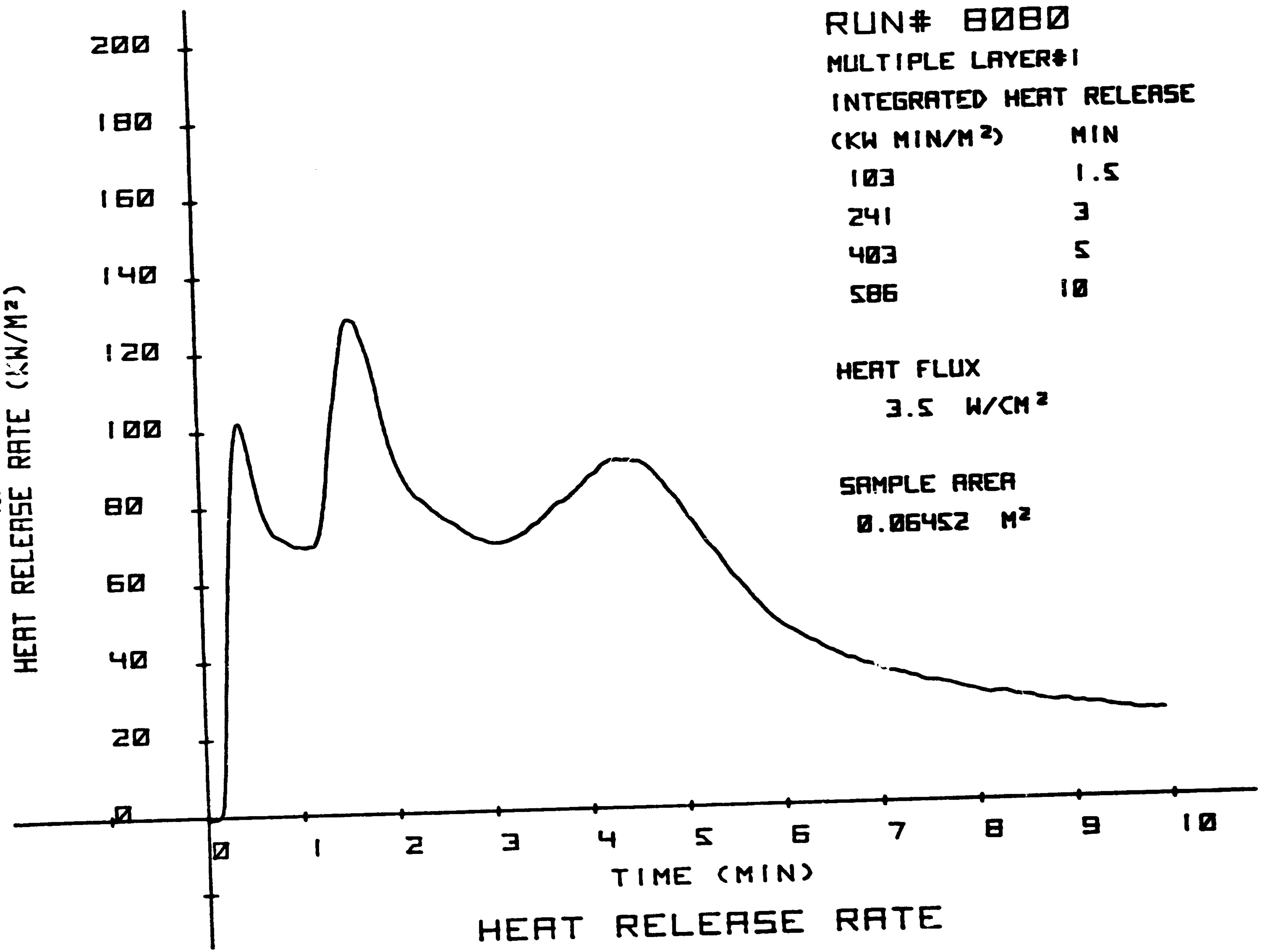

RUN# 14080
MULTIPLE LAYER 3A
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
50 1.5
108 3
266 5
430 10
HEAT FLUX
3.5 W/CM²
SAMPLE AREA
0.06452 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE

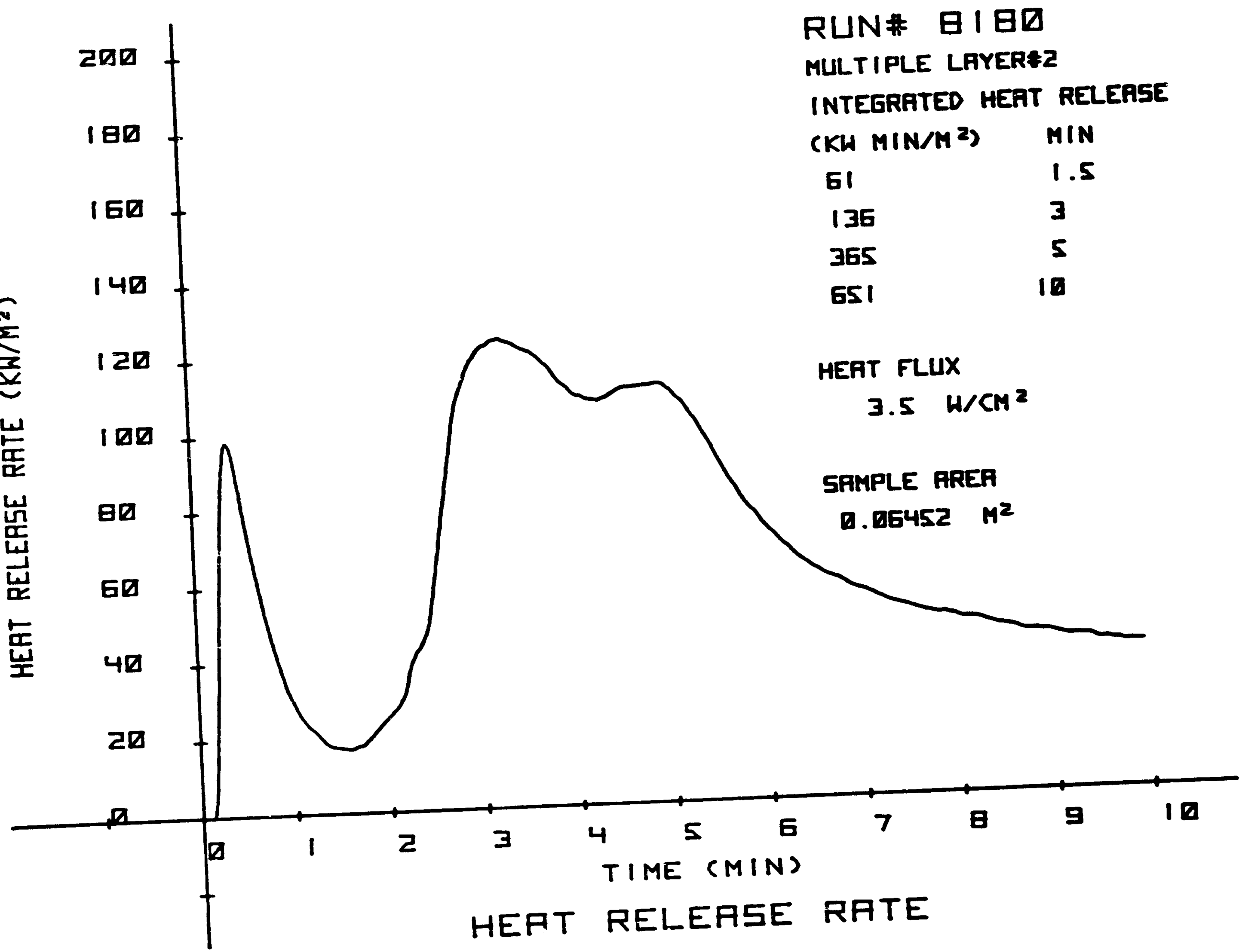


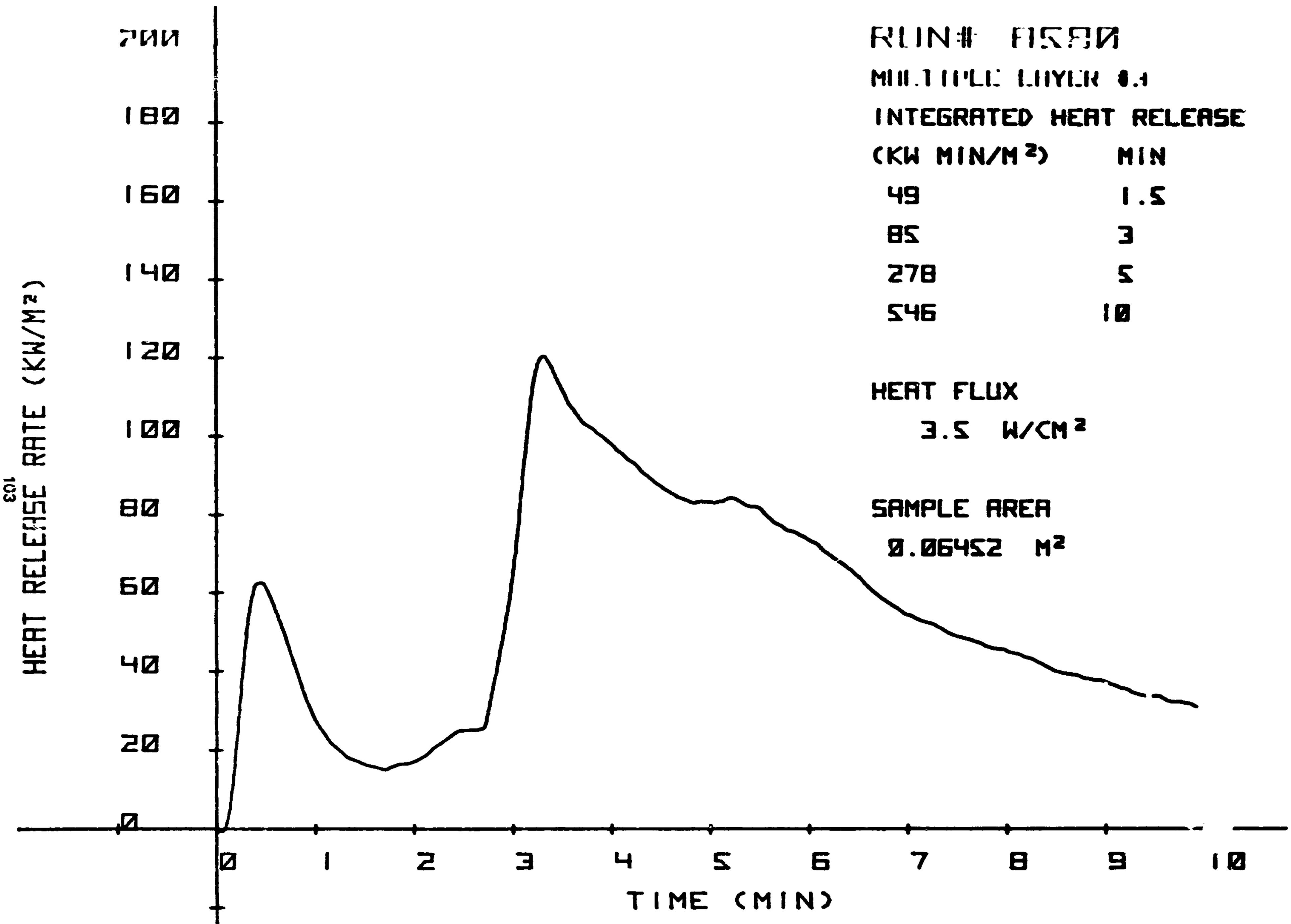
HEAT RELEASE RATE



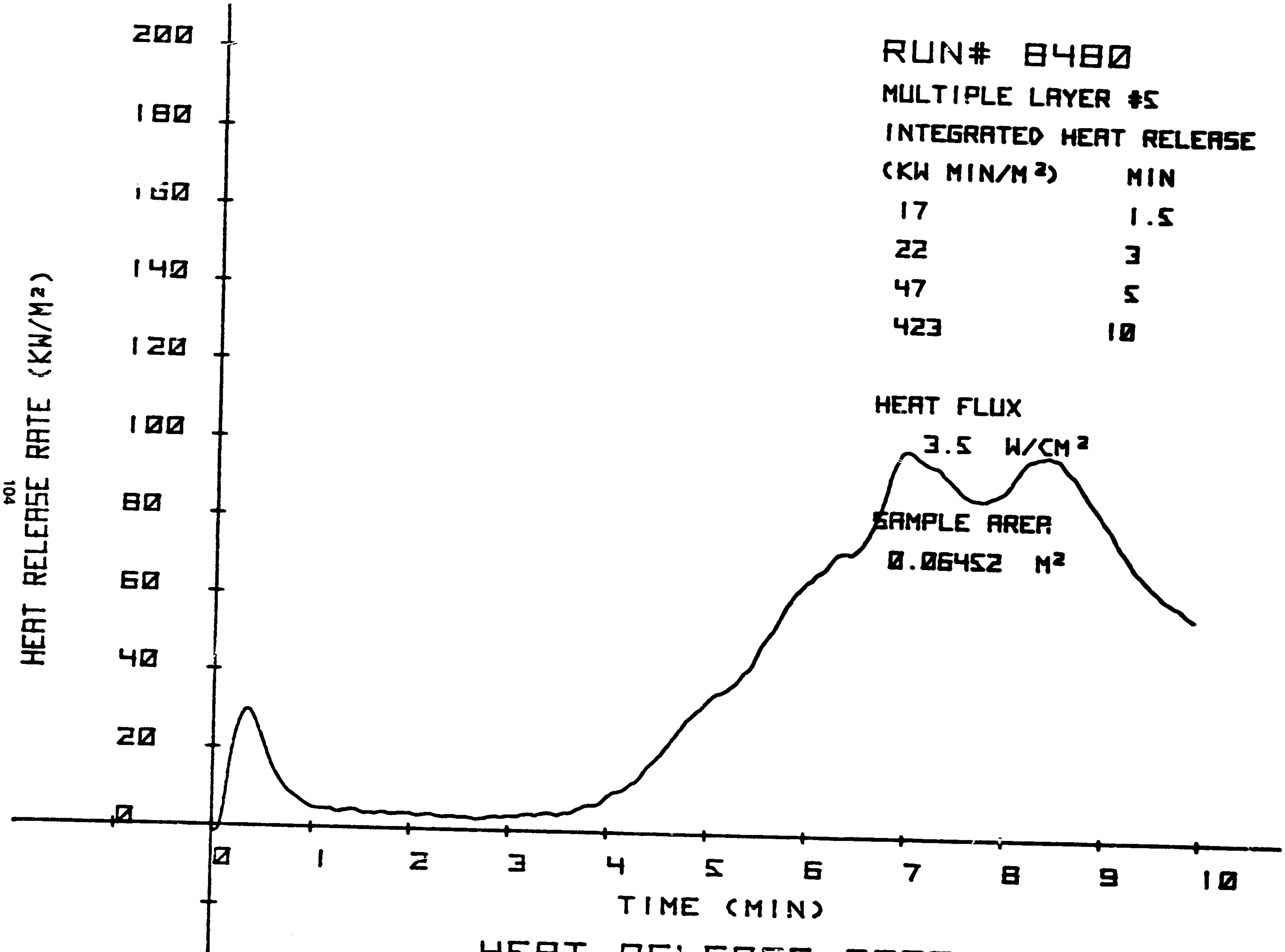
HEAT RELEASE RATE


RUN# 8080
MULTIPLE LAYER#1
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
103 1.5
241 3
403 5
586 10
HEAT FLUX
3.5 W/CM²
SAMPLE AREA
0.06452 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE

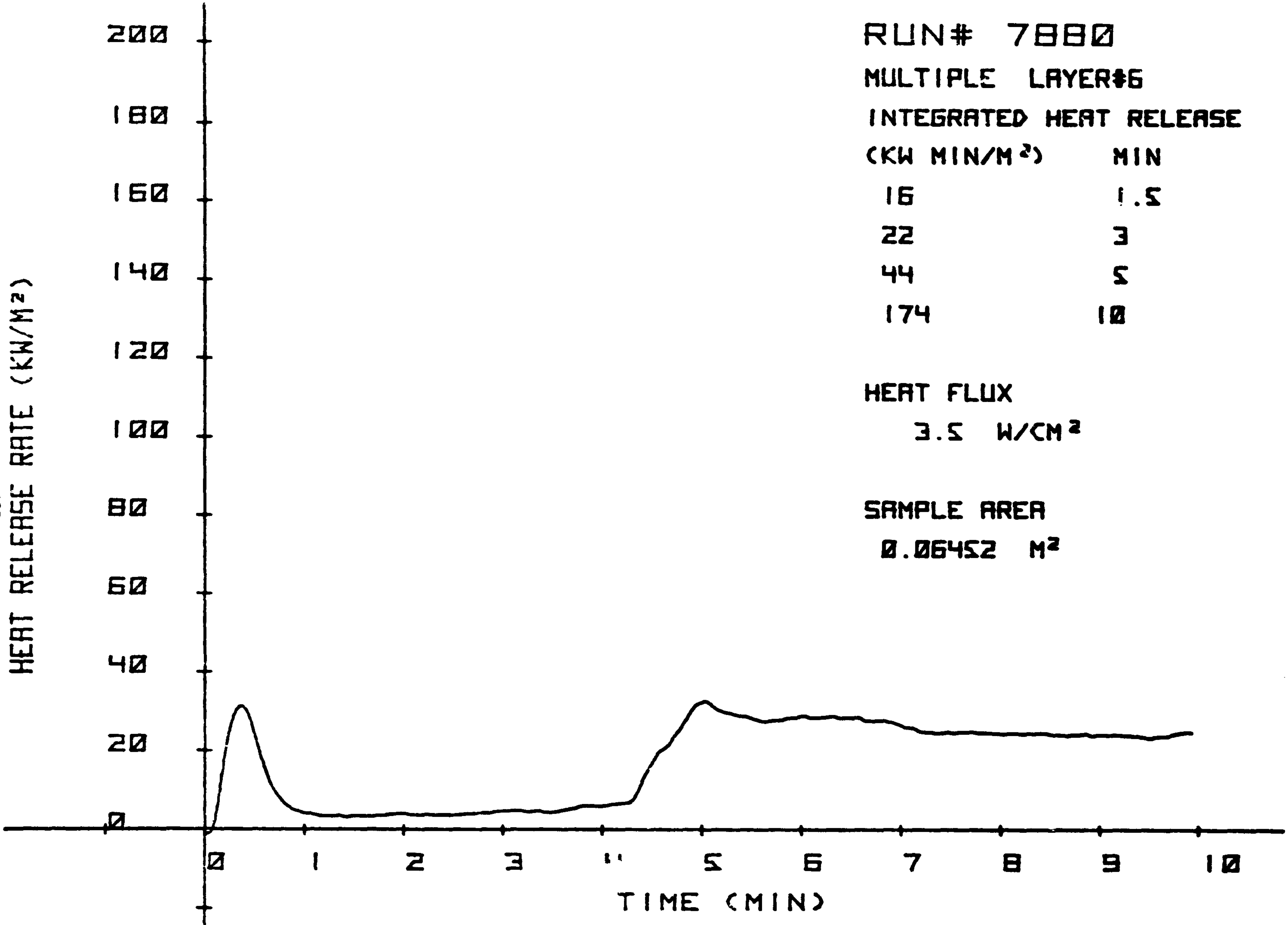

RUN# 8180
MULTIPLE LAYER#2
INTEGRATED HEAT RELEASE
(KW MIN/M²) MIN
61 1.5
136 3
365 5
651 10
HEAT FLUX
3.5 W/CM²
SAMPLE AREA
0.06452 M²
HEAT RELEASE RATE (KW/M²)
200
180
160
140
120
100
80
60
40
20
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
HEAT RELEASE RATE



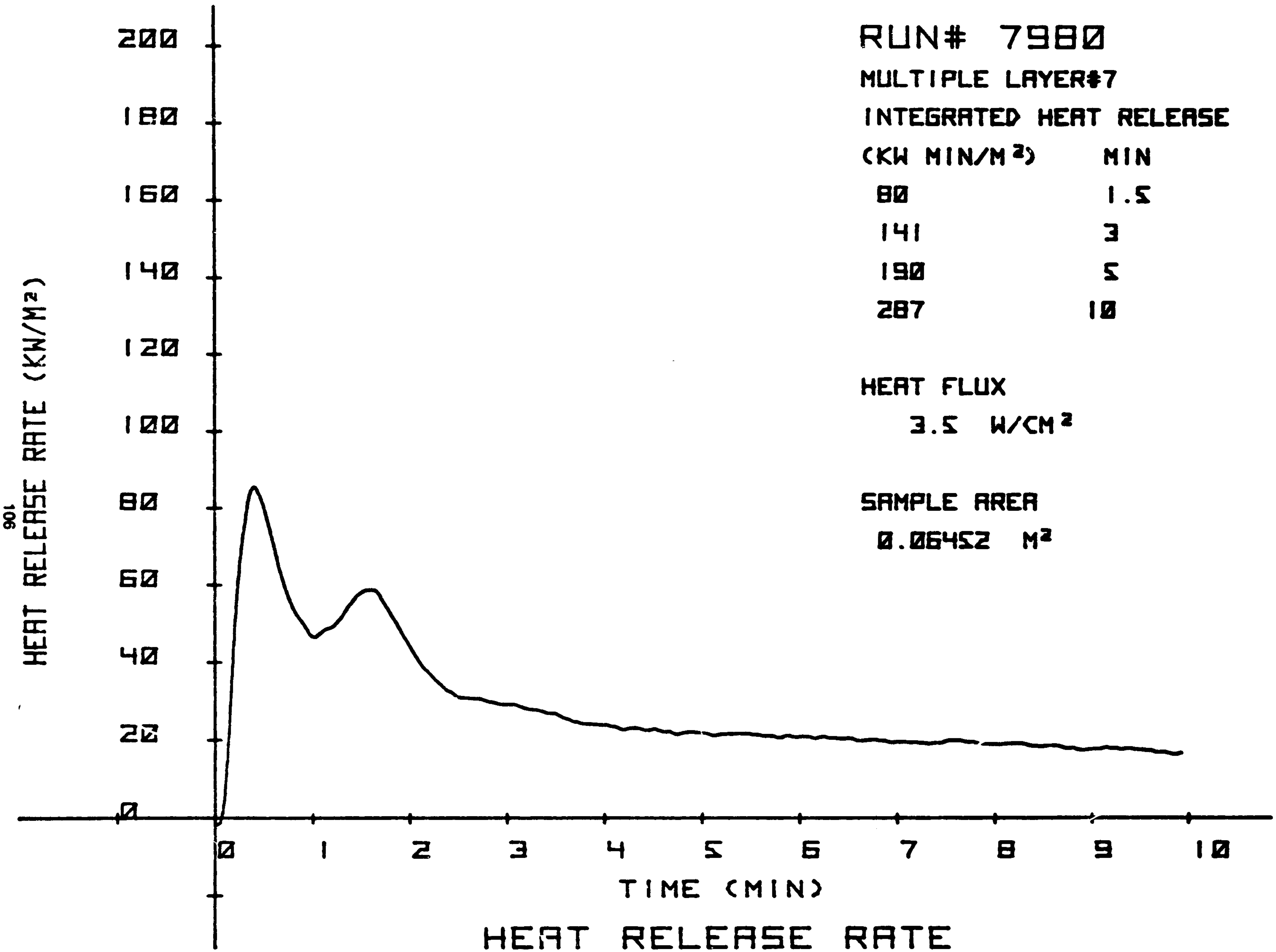
HEAT RELEASE RATE



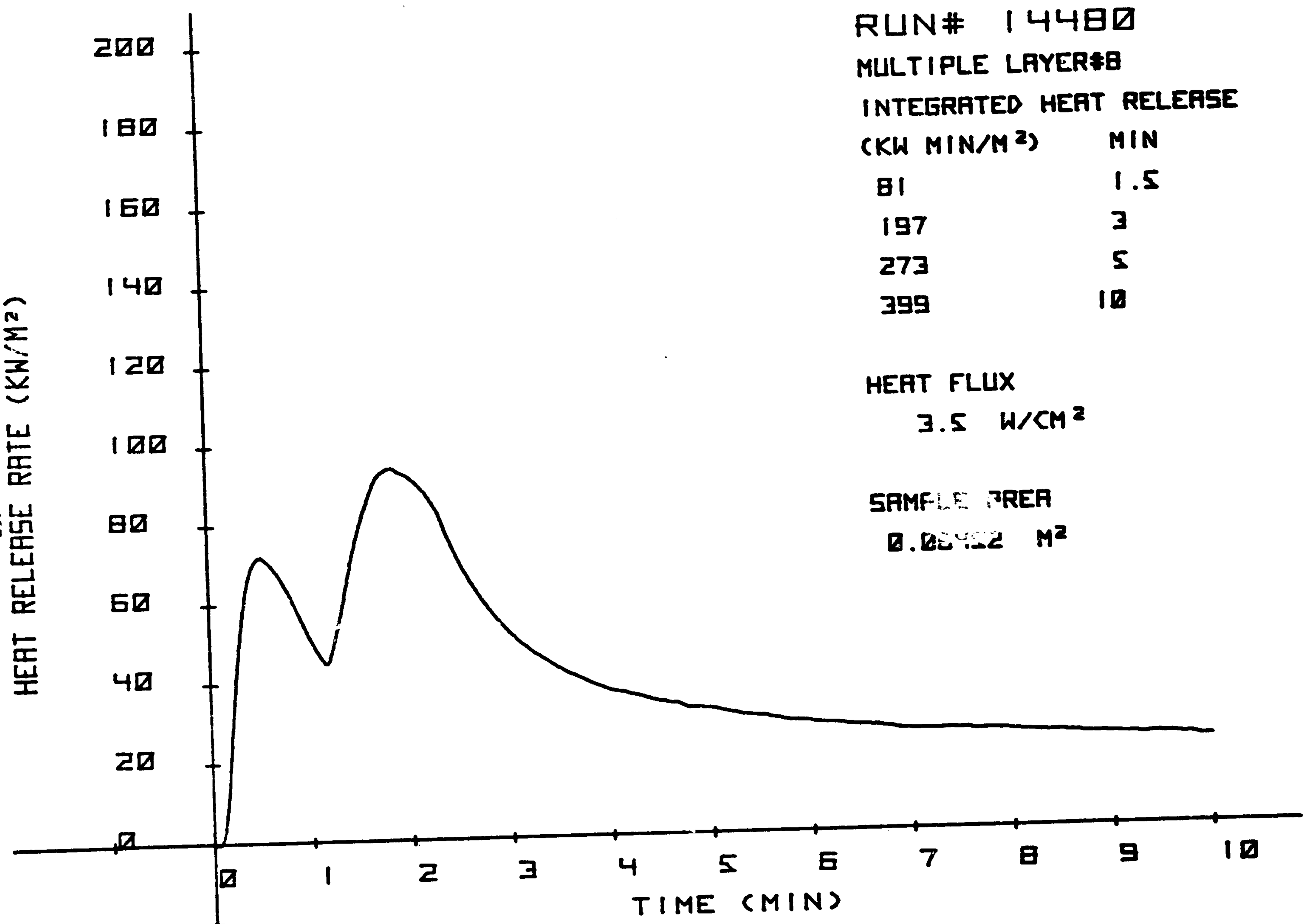
HEAT RELEASE RATE



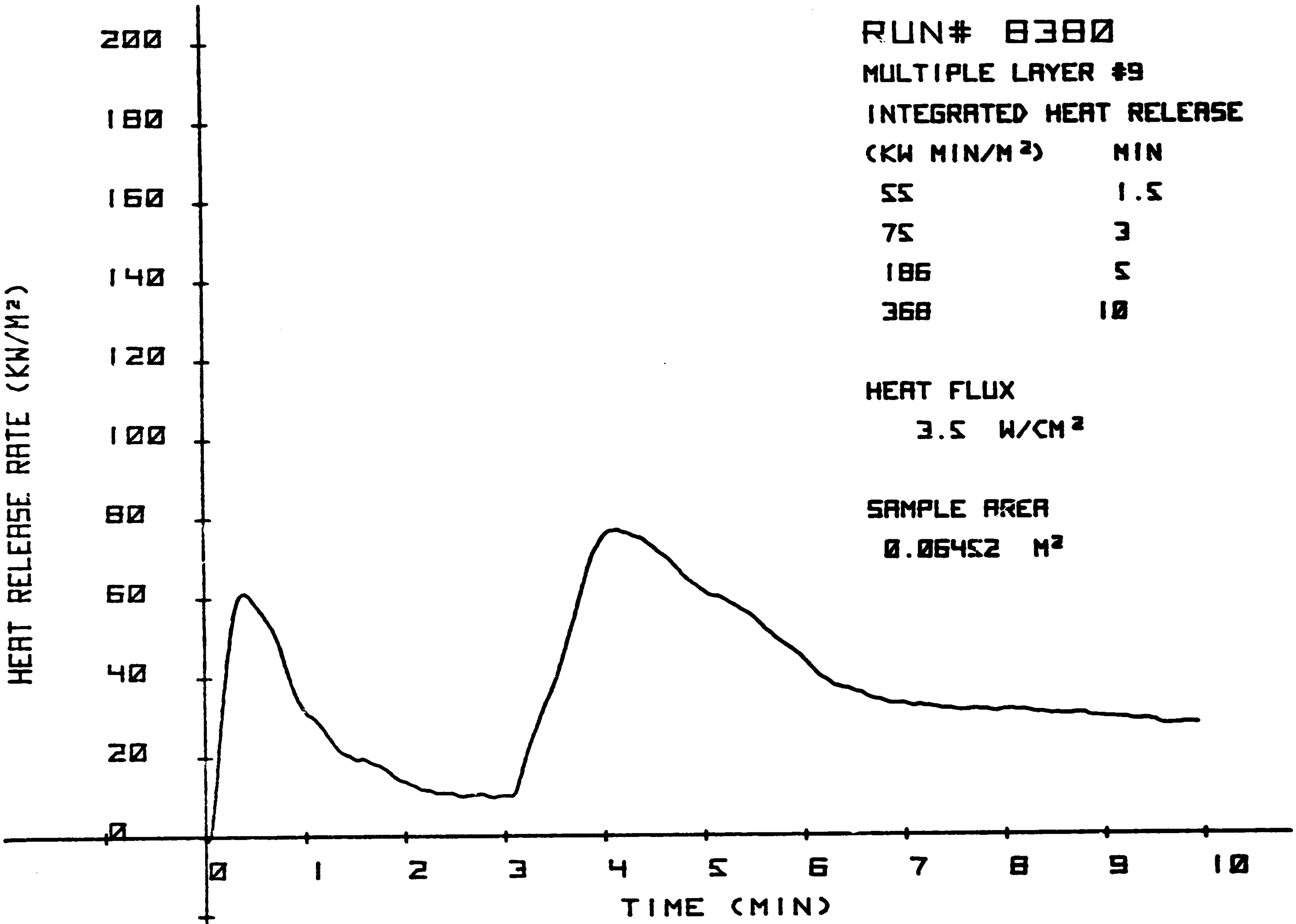
HEAT RELEASE RATE



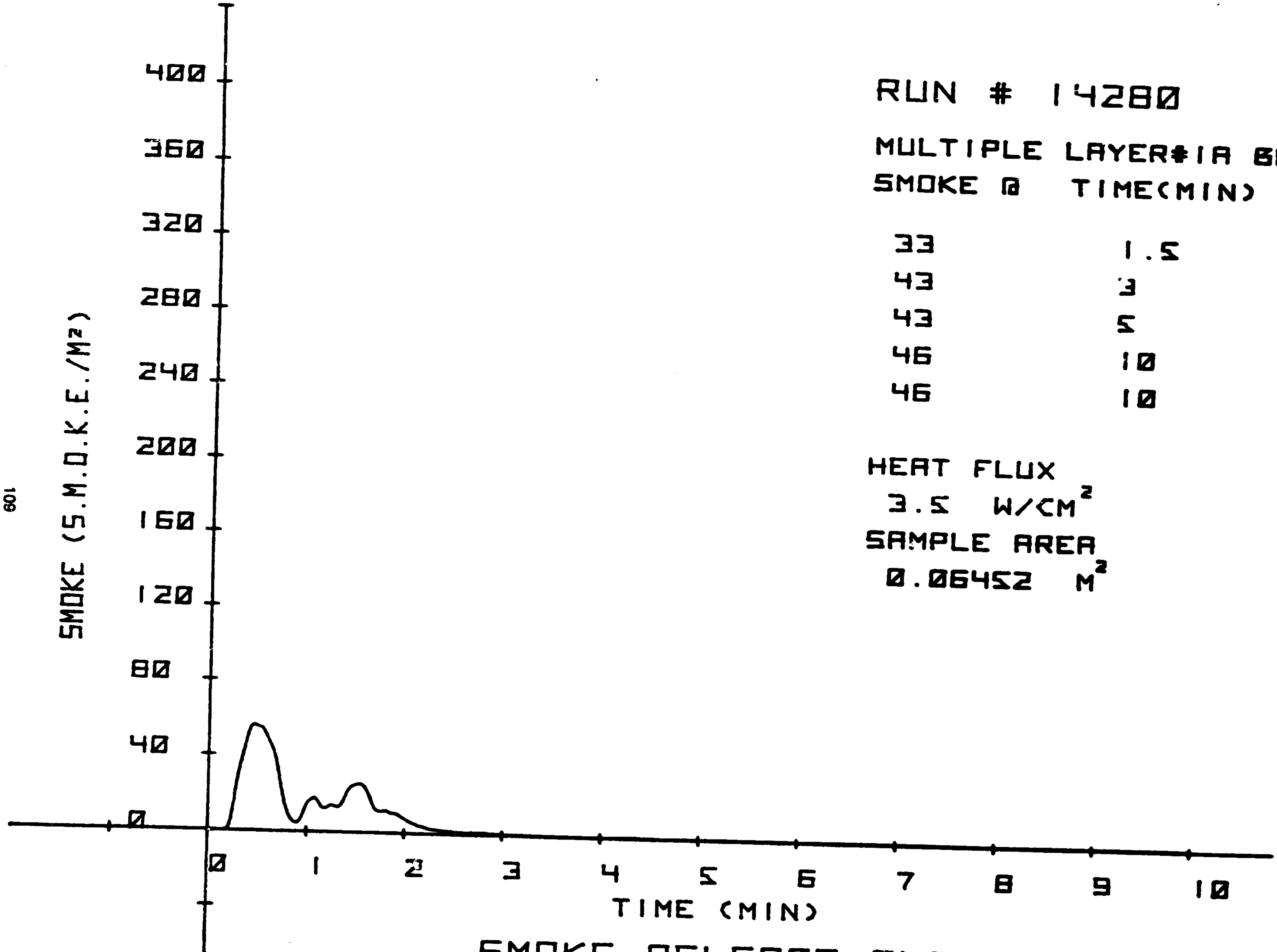
HEAT RELEASE RATE



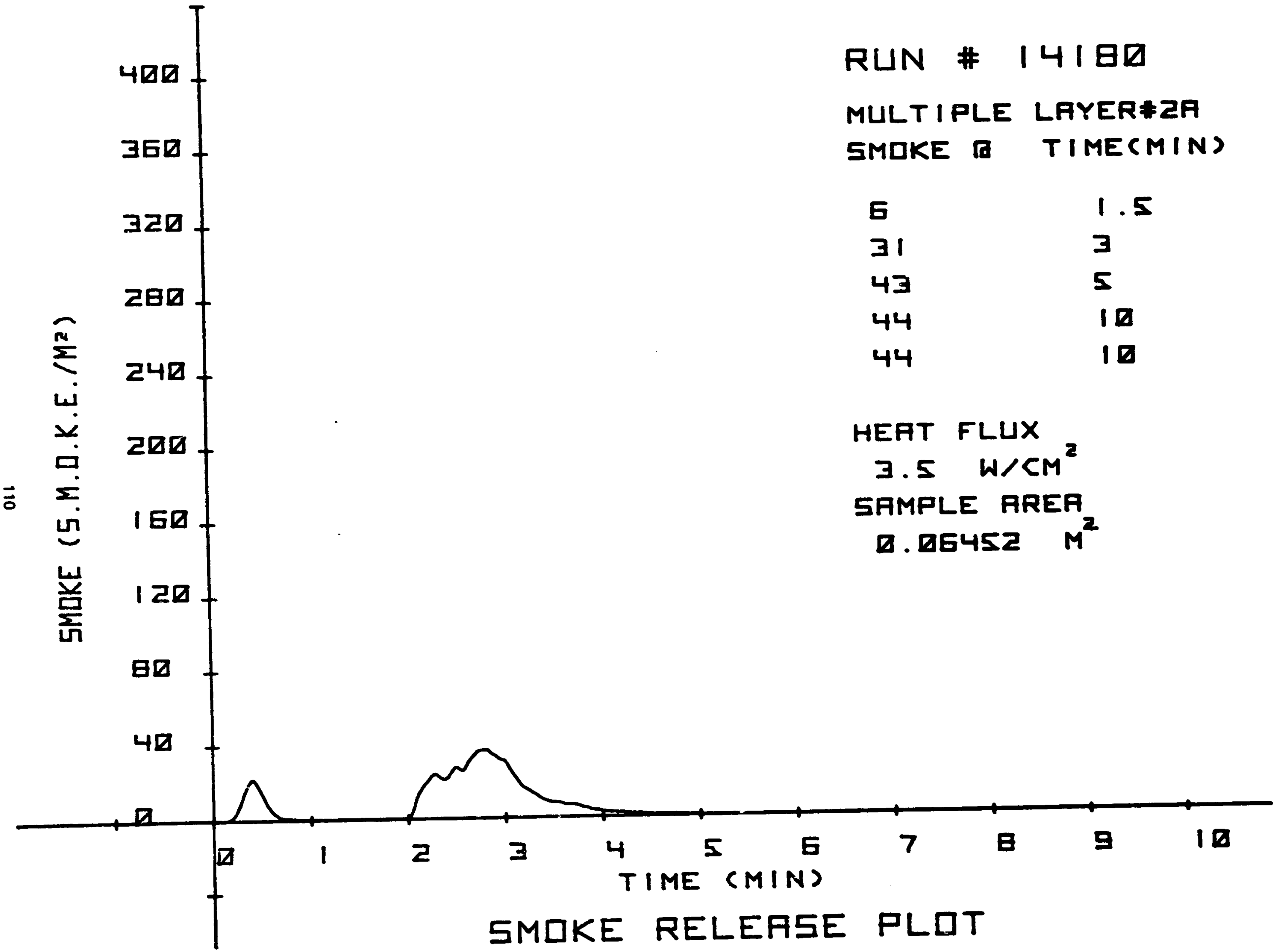
HEAT RELEASE RATE



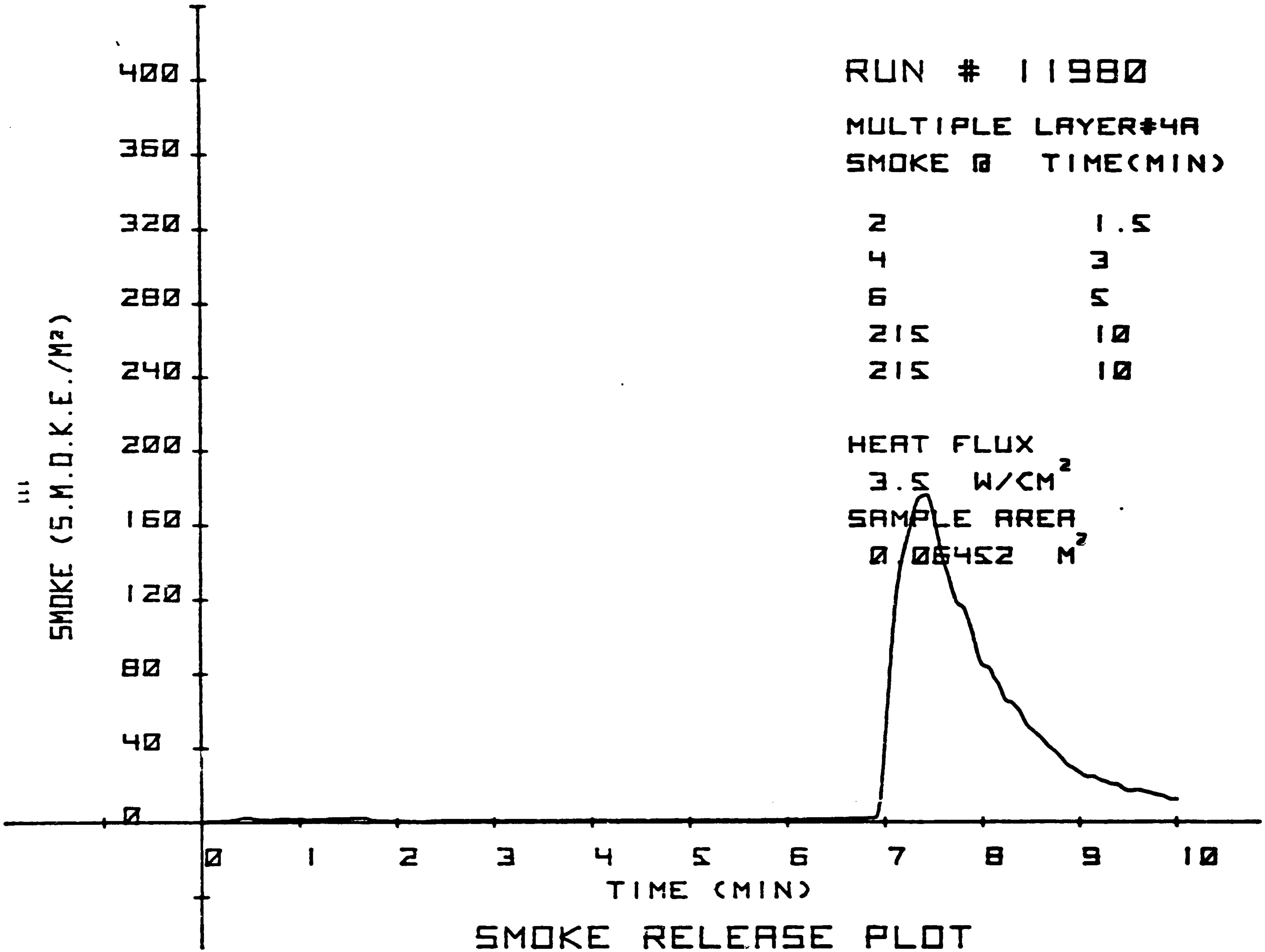
HEAT RELEASE RATE



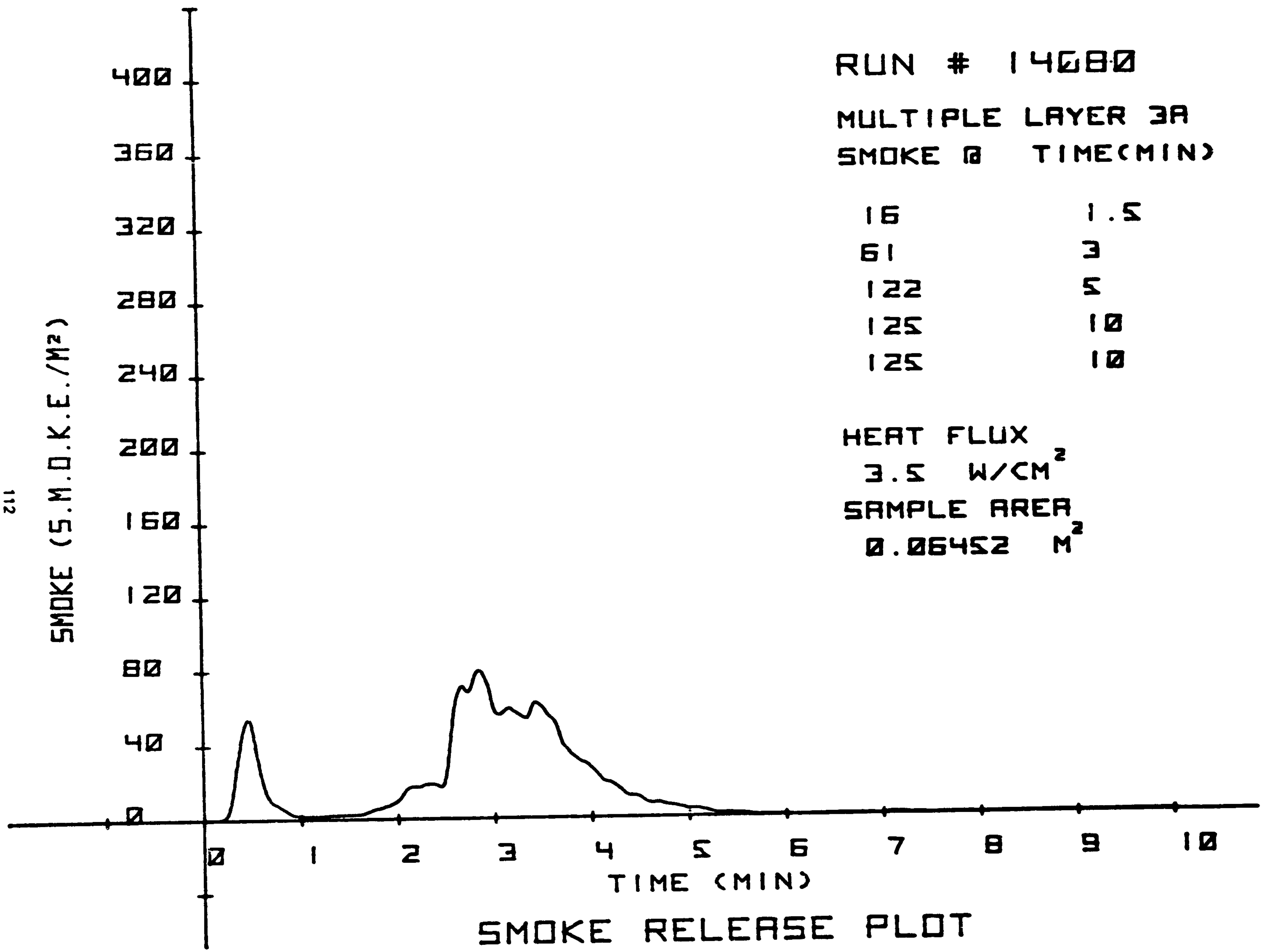
SMOKE RELEASE PLOT



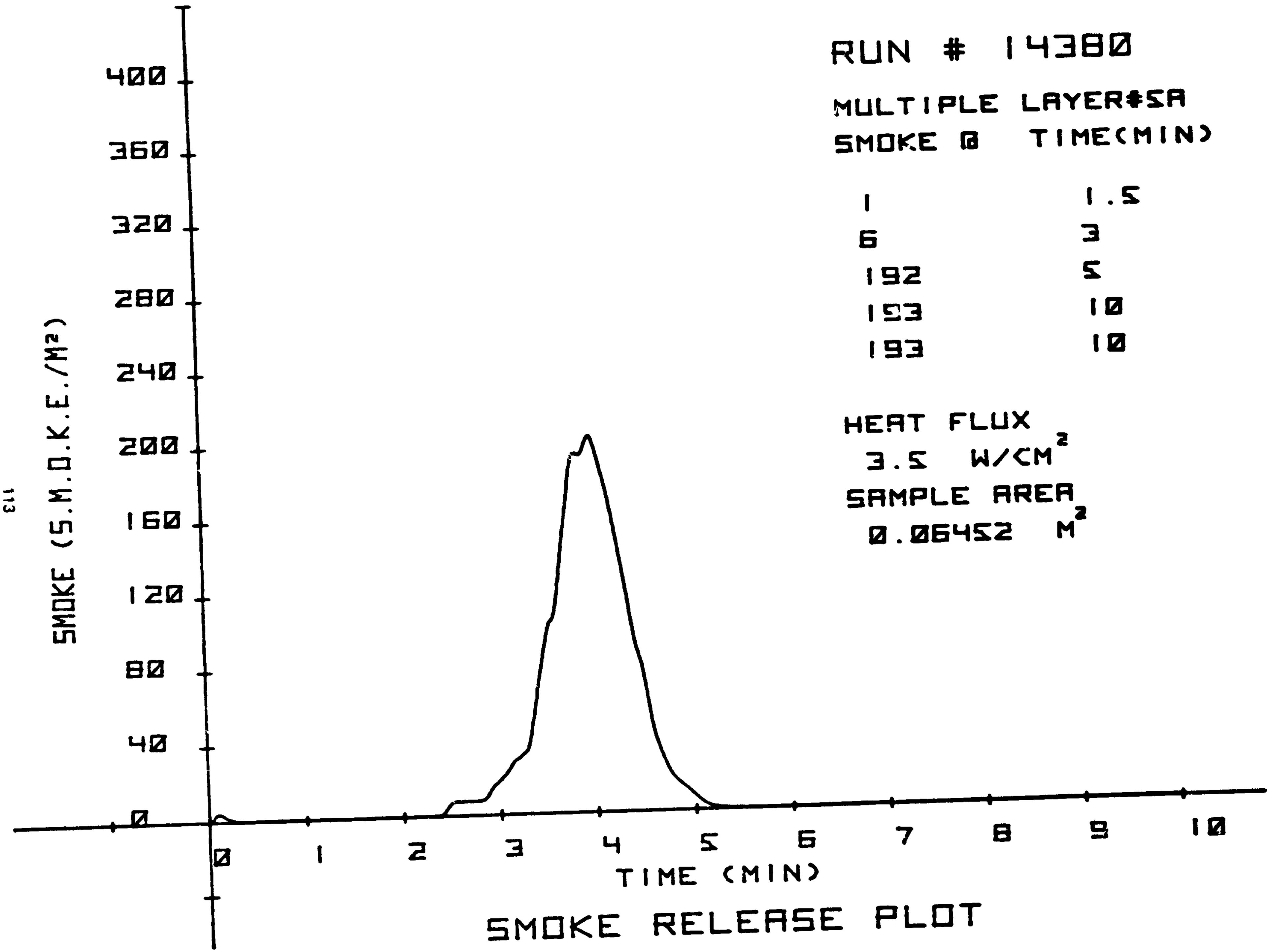
SMOKE RELEASE PLOT



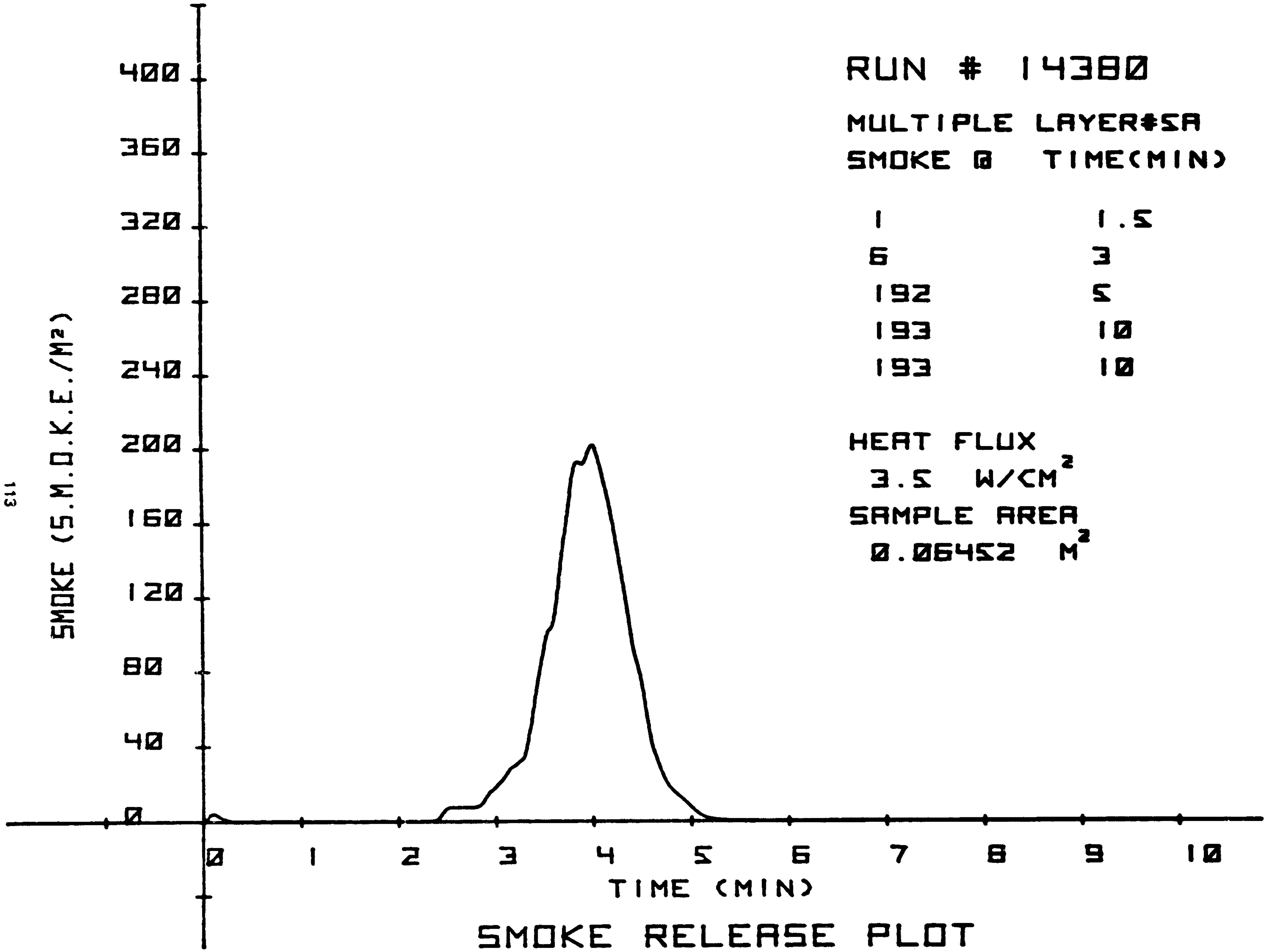
SMOKE RELEASE PLOT



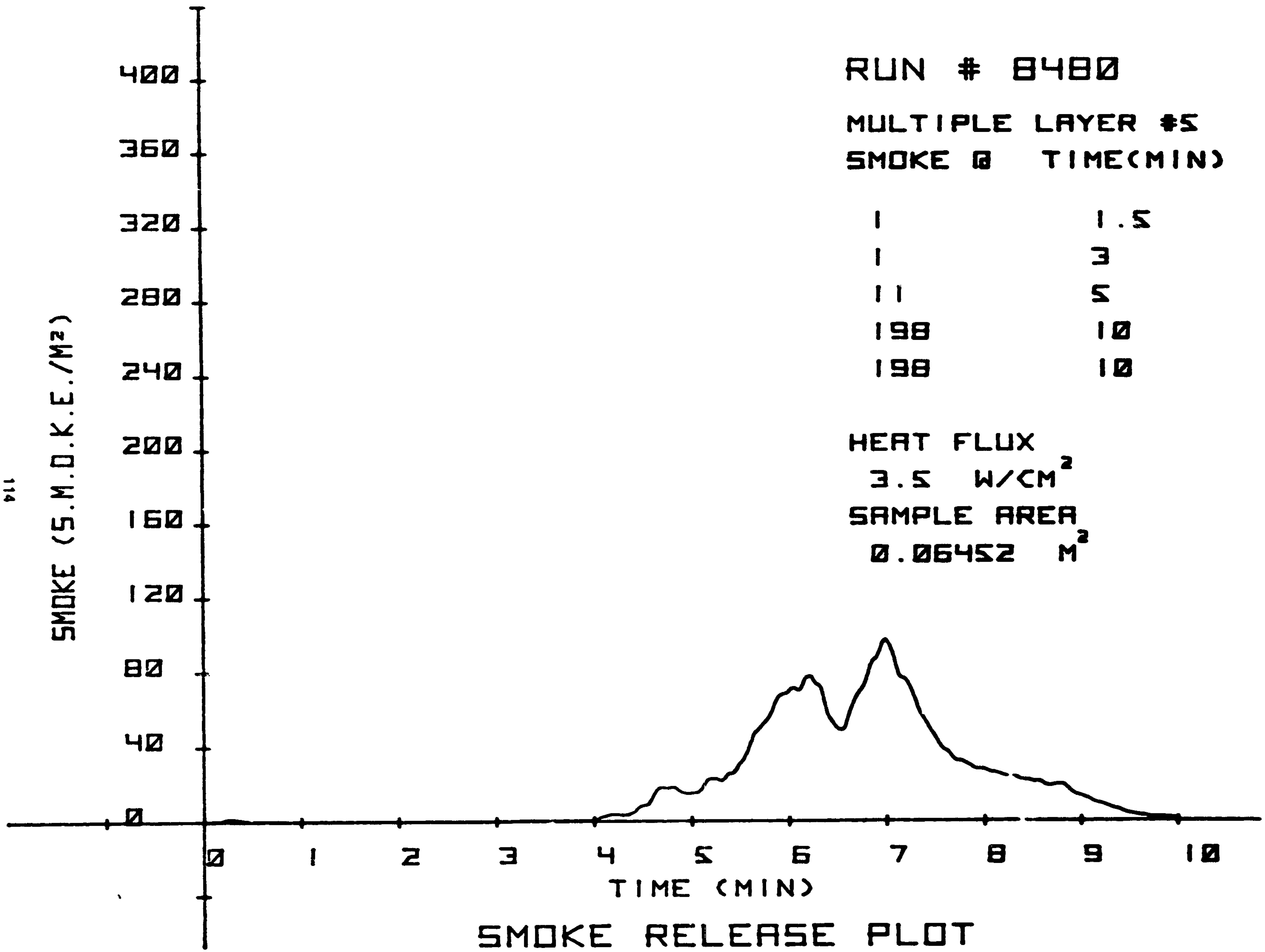
SMOKE RELEASE PLOT



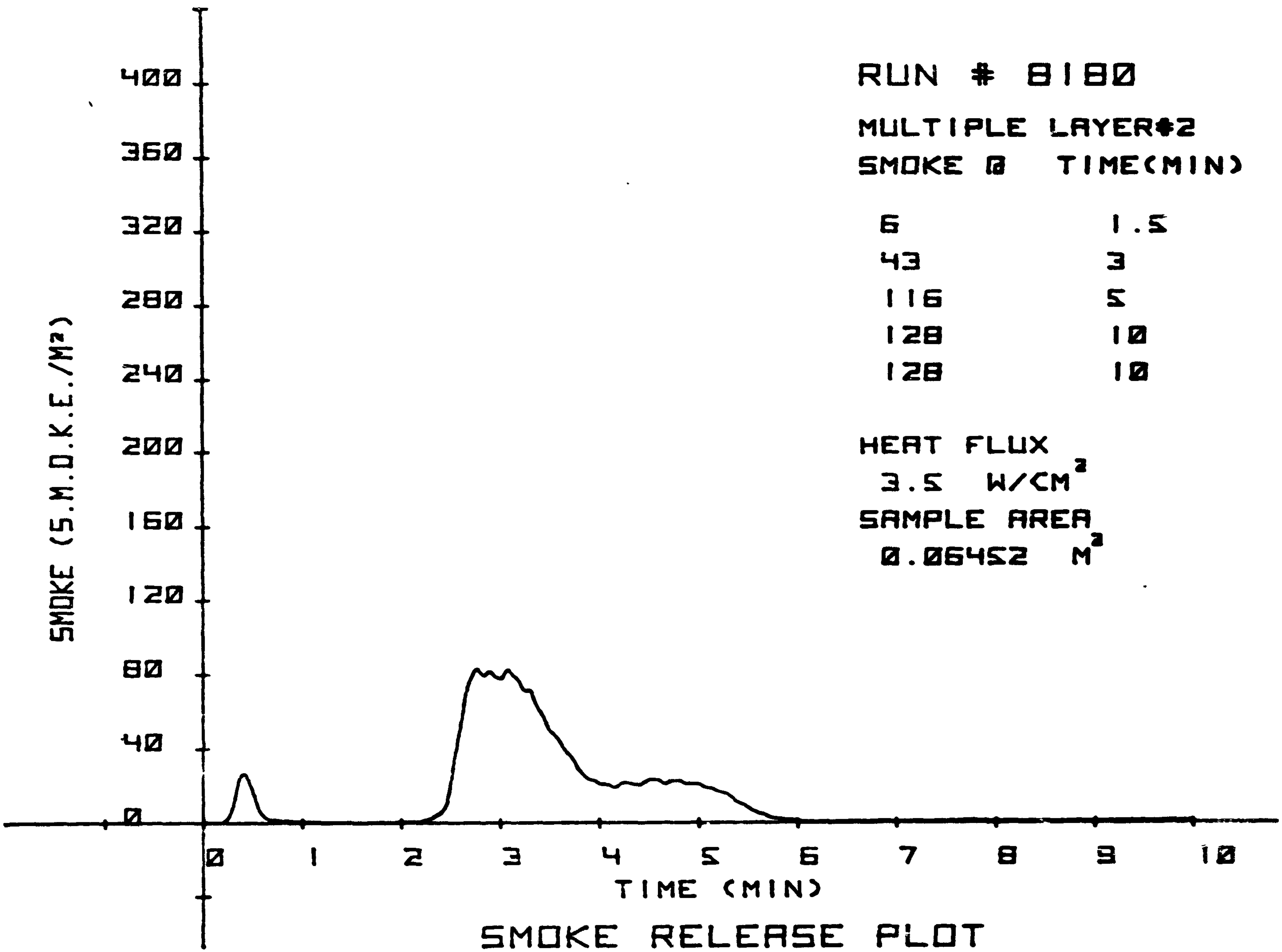
SMOKE RELEASE PLOT



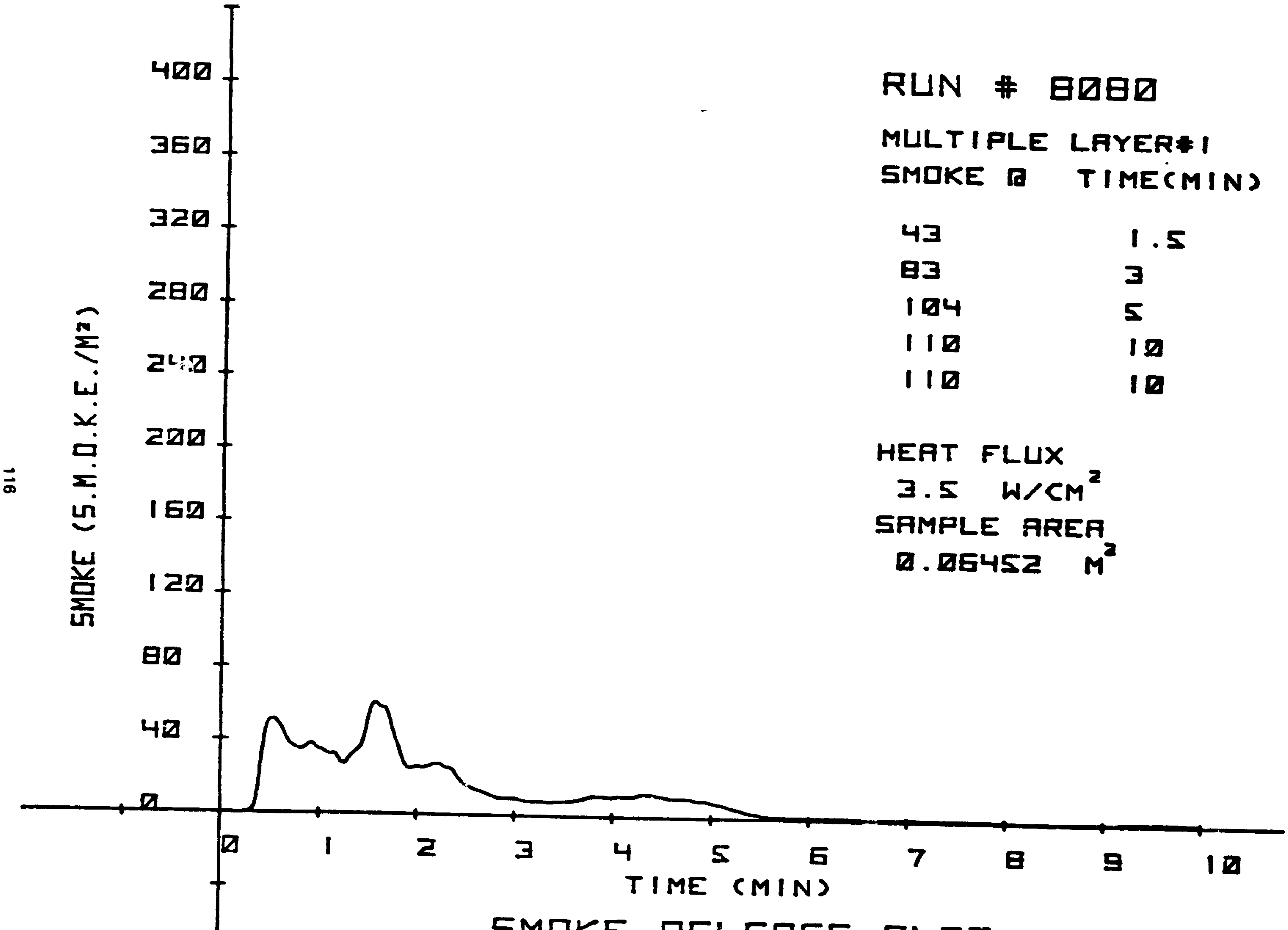
SMOKE RELEASE PLOT



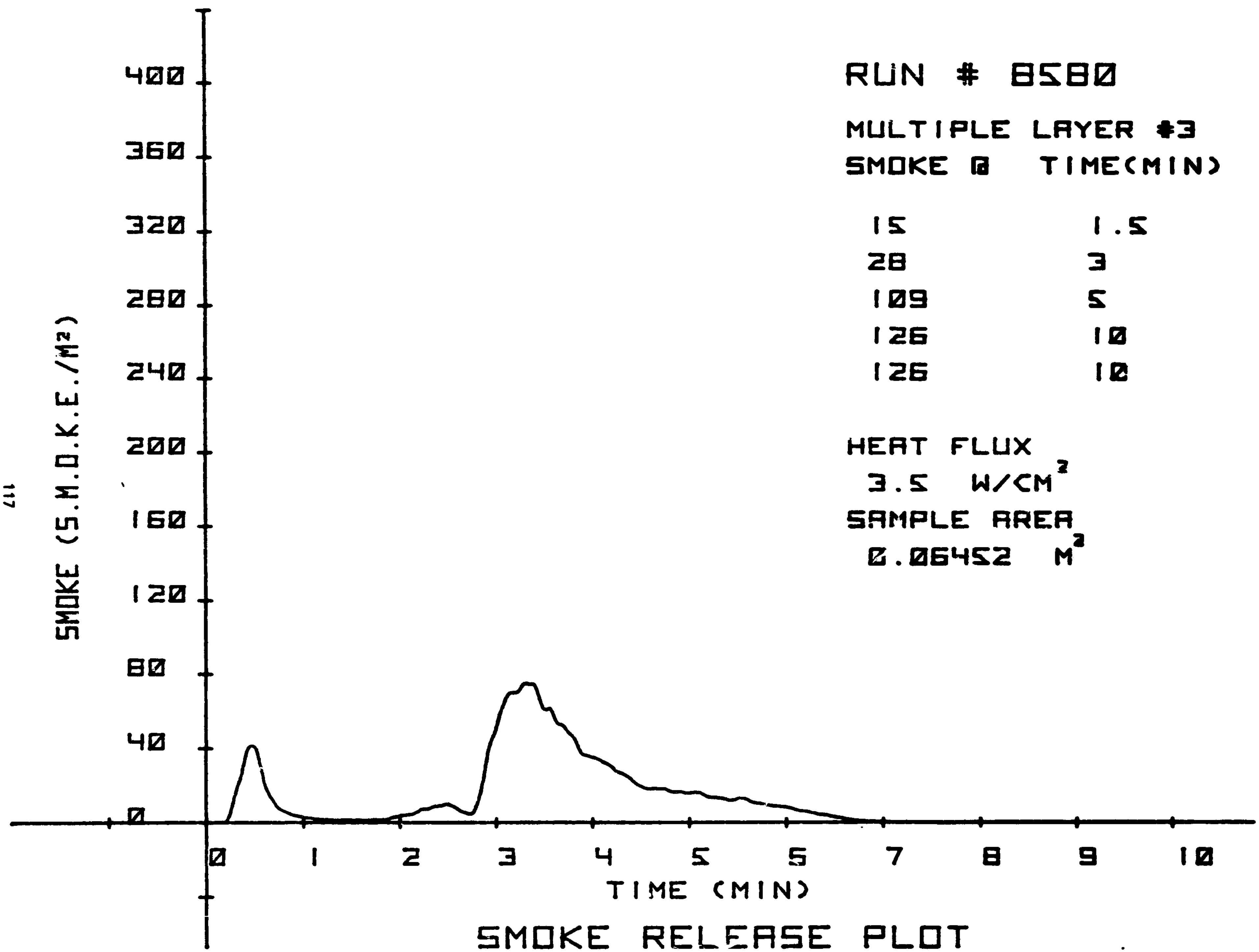
SMOKE RELEASE PLOT



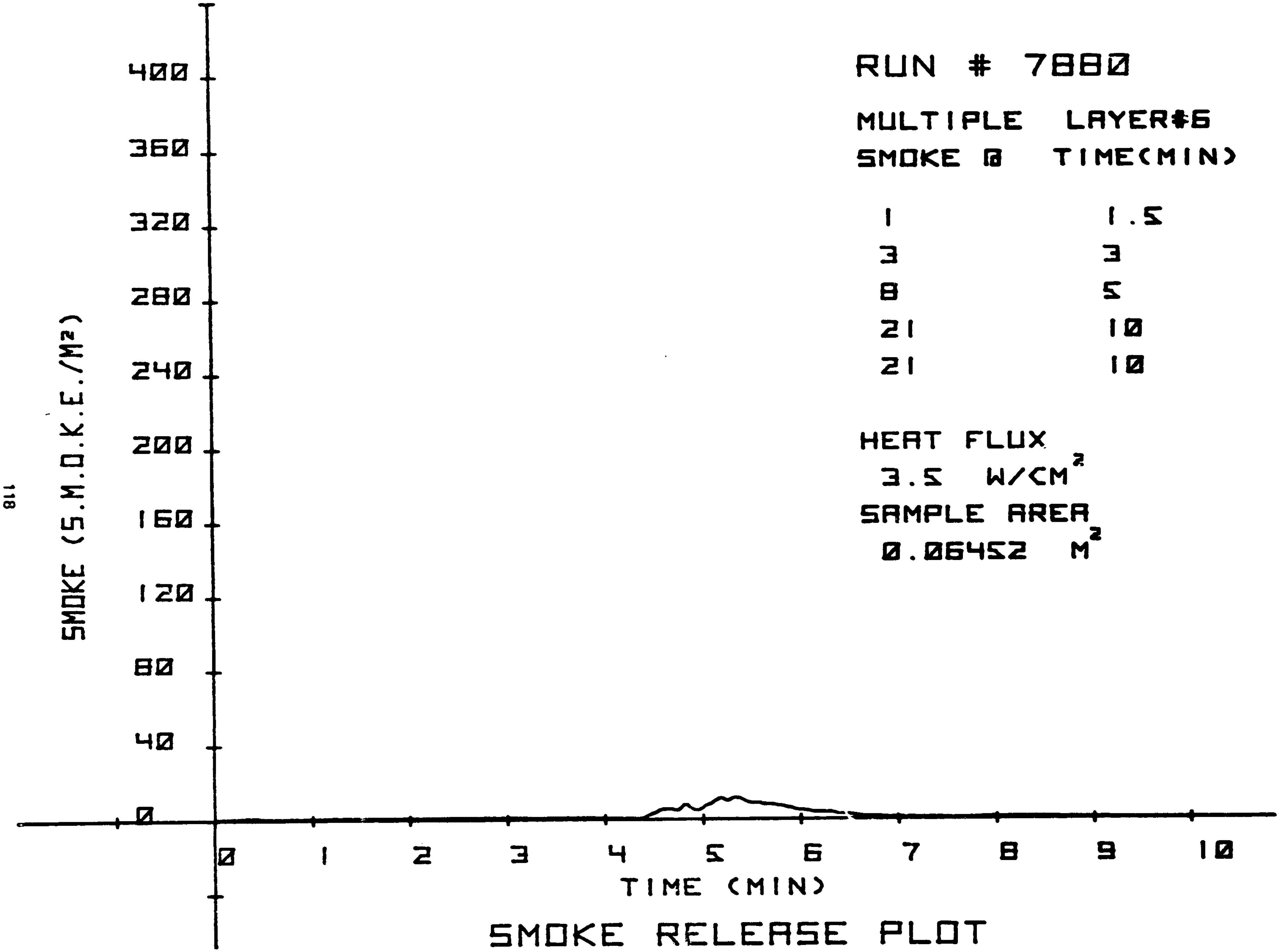
SMOKE RELEASE PLOT



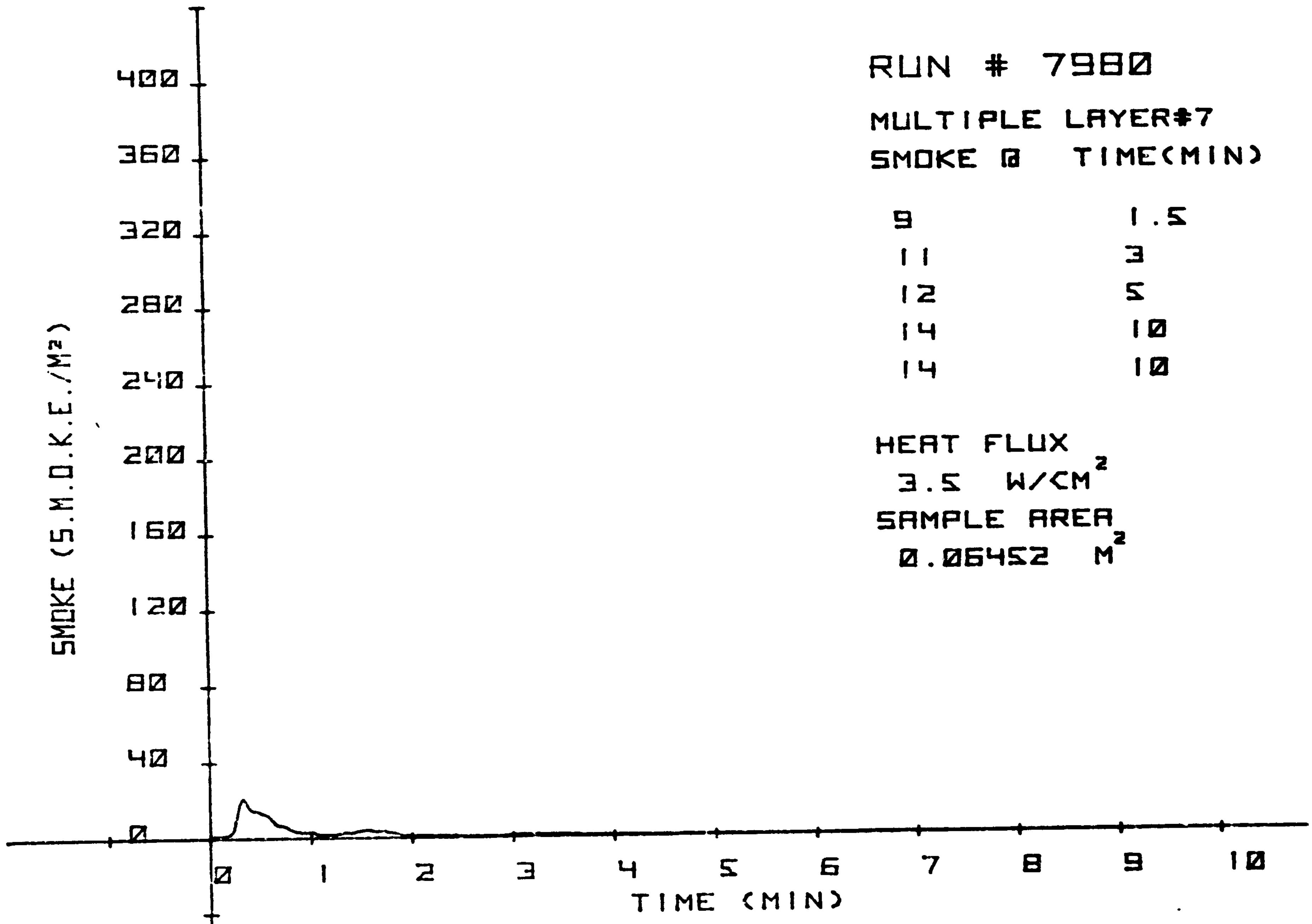
SMOKE RELEASE PLOT



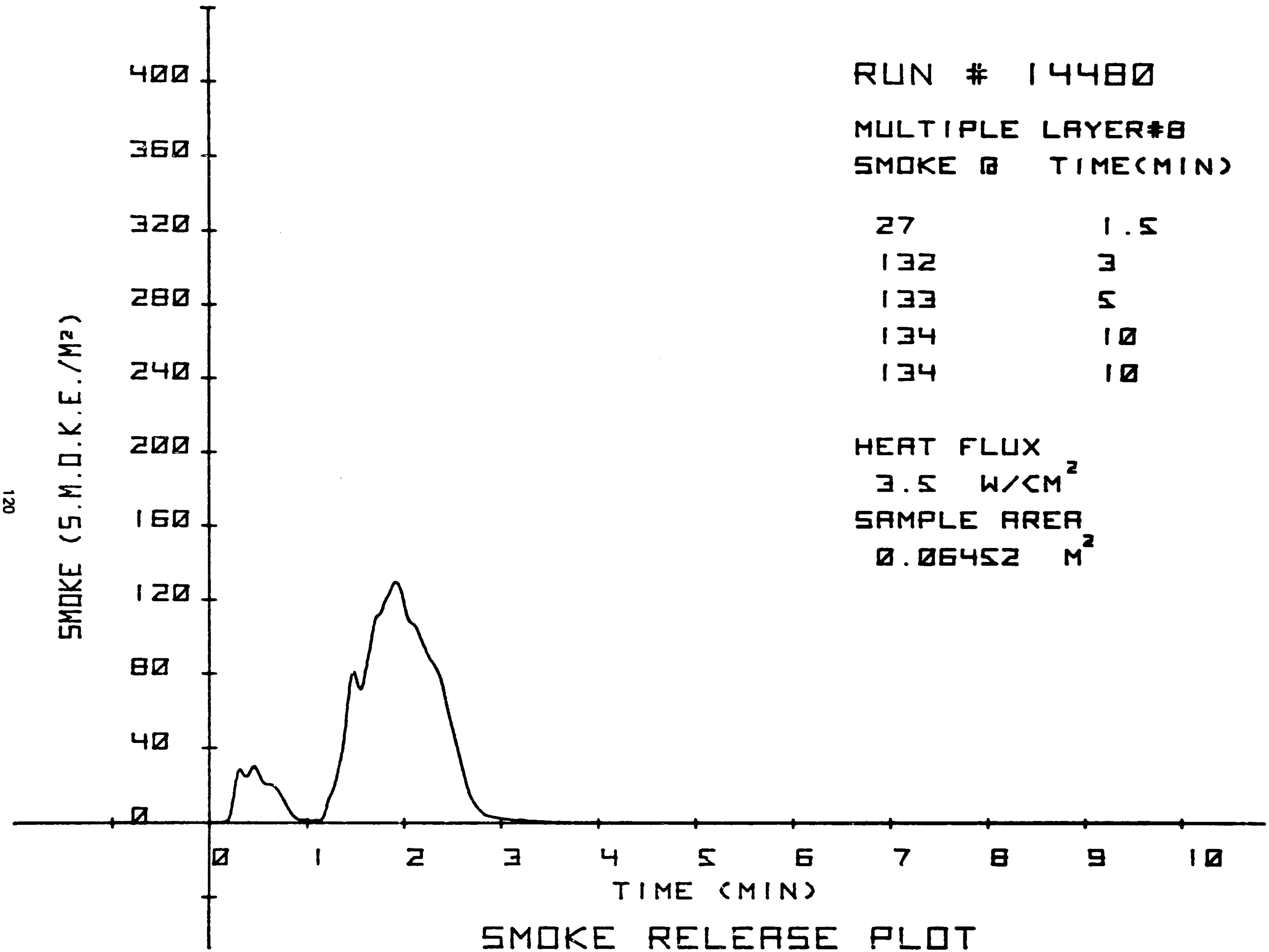
SMOKE RELEASE PLOT



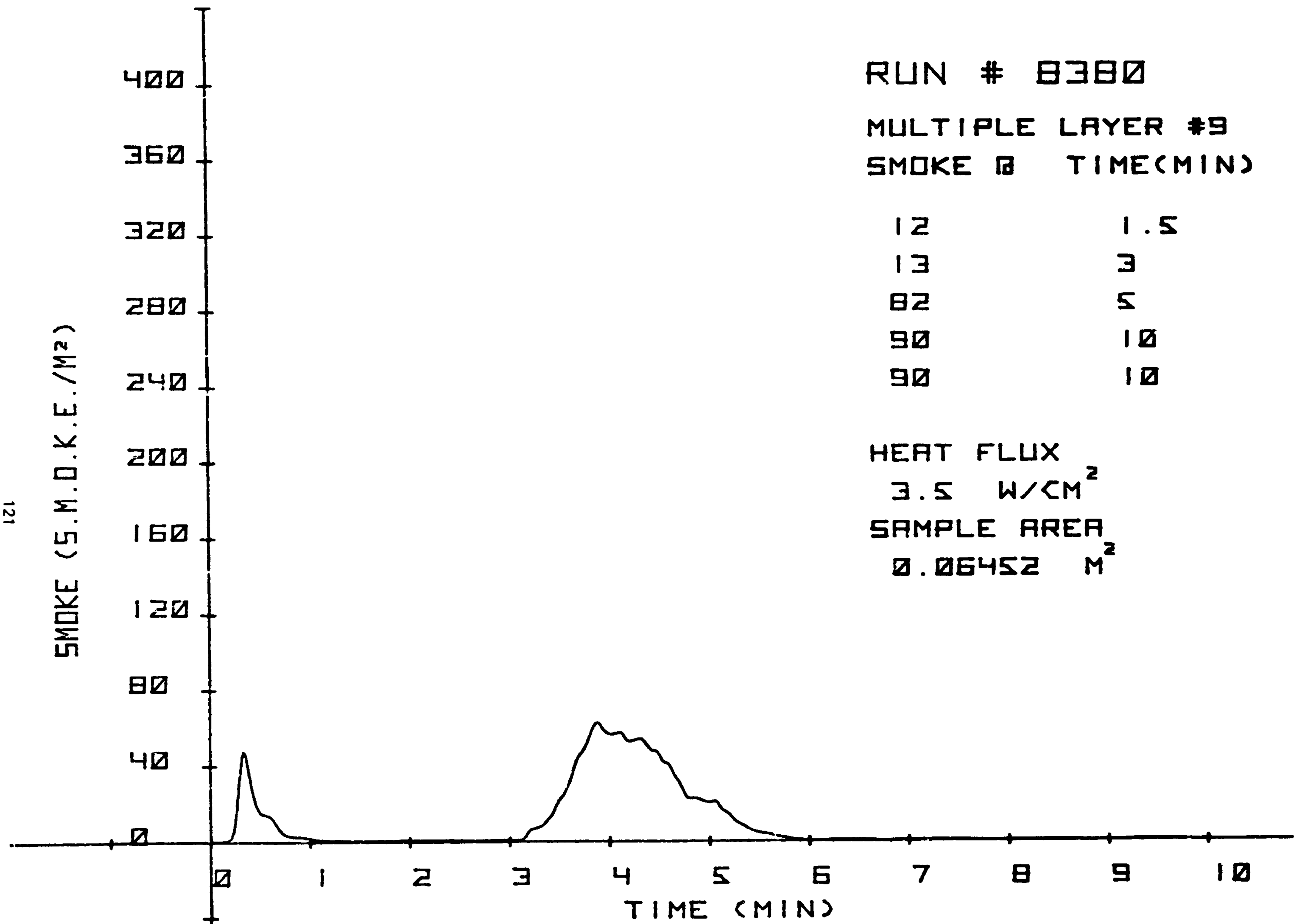
RUN # 7880
MULTIPLE LAYER#6
SMOKE @ TIME(MIN)
1 1.5
3 3
8 5
21 10
21 10
HEAT FLUX
3.5 W/CM²
SAMPLE AREA
0.06452 M²
SMOKE (S.M.O.K.E./M²)
400
360
320
280
240
200
160
120
80
40
0
0 1 2 3 4 5 6 7 8 9 10
TIME (MIN)
SMOKE RELEASE PLOT



SMOKE RELEASE PLOT



SMOKE RELEASE PLOT



SMOKE RELEASE PLOT