WVT-TR-76014

AD

THE EFFECTS OF TEMPERATURE ON TIME TO PROPELLANT COOK-OFF

US ARMY ARMAMENT COMMAND

BENET WEAPONS LABORATORY
WATERVLIET ARSENAL
WATERVLIET, N.Y. 12189

April 1976

TECHNICAL REPORT

AMCMS No. 553G. 12. 42621

Pron No. 71-X-00609

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XM123E1 Z-8 Propelling Charge
Thermal Effects
Cook-off
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Propelling Charge
Cannon Tube

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Thermal Effects Test IV provided data to be used in determining time-temperature relationships for cook-off of XM123E1 Zone 8 Propelling Charges in the 155mm XM199 Cannon. This was accomplished by preheating an XM181 Cannon stub tube as uniformly as possible to selected temperatures in the nominal range 375 - 500°F. XM123E1 Zone 8 Propelling Charges, having been conditioned to 145°F, were then inserted into the chamber of the stub tube. In all, nineteen charges were loaded, and cook-off occurred in all cases. Tube temperatures at

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20. various points near the bore were monitored by thermocouples, and time to ignition was noted. From this data, a statistical curve was generated which depicts time to cook off as a function of maximum chamber temperature for the XM123E1 Propelling Charge and XM181 Cannon. Due to similarities between the XM181 and XM199 Cannon tubes, the results are equally applicable to the XM123E1 Zone 8 Propelling Charge in the XM199 Cannon.

WVT-TR-76014

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Background

The XM123E1 Propelling Charge is a separate-loading, cloth bag charge which is loaded into the chamber at the rear of the gun tube. To begin a normal firing sequence, a separately loaded primer is mechanically fired; this produces a flame which follows a path through the cannon's breech mechanism to the chamber of the tube. The charge s (rear) base igniter pad is kindled which, in turn, lights the center core igniter. The latter is positioned at the longitudinal axis of the charge and runs its entire length. The core igniter burns rapidly and helps assure that the propellant aggregate burns from back to front (axially) and from inside out (radially). In general, this burning is rather predictable and, though very rapid, is not considered to be explosive in nature.

If a propelling charge is inserted into a hot tube and allowed to remain there for a period of time, an event known as "cook-off" may occur. Cook-off may be defined as an unintended ignition of the propelling charge (not due to primer ignition) which is a direct consequence of the hot tube heating and eventually igniting the loaded charge. Necessarily, then, the propellant aggregate burns from the outside in (radially) and may begin at any point (axially) depending on random factors such as tube hot-spots and tube-charge contact. In this case, propellant oxidation is rather unpredictable, spanning the range from spasmodic burning to explosion.

Naturally, cook-off is regarded as a highly undesirable event. Should it occur with the breech still open, the crew is highly vulnerable to flame and blast, both of which may be considerable. If the breech is closed, cook-off may result in both crew injury (should personnel be standing in the path of recoiling parts) and unpredictable projectile range/accuracy characteristics. Thus, from a safety point of view, the benefits of determining the temperatures at which cook-off may occur (and corresponding times to cook off) are fairly obvious.

The time required for propelling charge cook-off has been previously observed to be a function of tube temperature, the function itself being generalized in form as follows:

$$t(T) = X \cdot (T - T_o)^{-Y}, \quad (T \geq T_o)$$

where $t(T)$ = time to cook off (function of T)

T = maximum chamber temperature of tube at cook-off.

T_o = a constant } determined from analysis of

X,Y = positive functions } test data, if desired.

It can be seen that the time required for the propelling charge to remain in the hot tube before cook-off occurs is inversely proportional to the tube temperature. Further, if the tube temperature approaches the constant T_o, the anticipated time to cook off goes to infinity; that is, there exists a temperature, T_o, at (and below) which cook-off will not occur regardless of how long the charge is allowed to remain in the hot tube.

The general form of the cook-off equation above should remain the same regardless of the tube and propelling charge used; the value of T_o and the functions X and Y, however, vary from system to system.

Purpose

The purpose of this test is to determine cook-off time-temperature relationships for XM123E1 Zone 8 Propelling Charges (conditioned to 145°F) loaded into an XM199 Cannon. Due to similarities between the XM181 and XM199 Cannon tubes, results will be identical if we test XM123E1 Propelling Charges in an XM181 Cannon. A further purpose of this test is to determine, if possible, the value of T_o, the temperature at and below which cook-off will probably not occur (regardless of how long the charge is allowed to remain in the hot tube) for the above thermally equivalent systems.

Method

An XM181 Cannon tube (viz. Fig. 1-2) was machined to stub tube length, and radial holes were drilled to a distance of .062 inches from the bore at seven axial locations (viz. Fig. 3 for details). Thermocouples were inserted into these holes to monitor temperatures at the bore. The tube was assembled to an XM181 Breech Mechanism Assembly (viz. Fig. 4) and mounted onto a Universal Test Stand (WTV-F11989). To prevent the creation of an appreciable heat sink, wooden yokes were employed to support the tube on the test stand.

Calrod strip heaters were placed around the tube's circumference followed by a layer of fiberglass insulation. With the current turned on, the tube was thus heated from the outside in. The test director controlled heat input in attempting to bring the tube uniformly to a predetermined temperature level.

The XM123E1 Zone 8 Propelling Charges were conditioned for 24 hours at 145°F. At the appropriate time, each charge was placed in the heated stub tube in its normal loaded position. No projectiles or other obstructions were placed in the bore in front of the charge due to safety considerations. The breechblock was then immediately closed and tube temperatures were recorded every ten seconds until slightly after cook-off. In each case, the time to charge cook-off was noted (moment of insertion is t = 0).

For shot number 1-C (viz. Table I), the charge was loaded "as received"; the resulting cook-off was explosive in nature, and the entire test stand recoiled several inches. From both safety and structural points of view a repetition of this event was deemed highly undesirable. To prevent a recurrence, the remaining rounds were tested only after removal of the base igniter and the core igniter bags. The igniter tube, in all cases except 5-C, was reinserted to help support the charge, an asset during loading. This modification would not affect the time to cook off since primary ignition occurs at the outside diameter of the charge; rather, the main effect would be an alteration of the nature of the overall propellant oxidation. All remaining charges cooked off without exploding and tended instead to burn (spasmodically but intensely) for relatively long periods of time before finally auto-ejecting from the tube and burning on the ground. No further recoil was observed.

Data

Test conditions, along with nominal insertion temperatures and times to cook off, can be found in Table I.

Graphic displays of the actual bore temperatures as a function of time can be found in the Appendix. Thermocouples are numbered as in Fig. 3, and time t = 0 is the time of charge insertion.

A recapitulation of all nineteen cases can be found in Fig.5. This graph depicts the number 3 thermocouple reading (at the time of cook-off) plotted vs. time to cook off.

Discussion of Data

Raw data in the Appendix discloses that thermocouple number 3 was invariably located at the hottest portion of the chamber in actual contact with the inserted charge. Therefore, Fig. 5 represents the foundation of the cook-off time-temperature relationship previously specified as the primary objective of this test. These data were divided into two sets, namely the first nine and the last twelve points. A least squares analysis was performed on both sets individually, and the 99% two-sided prediction interval was calculated. The results of these analyses are given in Fig. 6. Further calculations were made testing the hypothesis that the least squares line for the second set of data points has zero slope; however, the 99% confidence interval for slope proved to be [-.1046, -.0268]. Thus it cannot be determined from this analysis that the curve has zero slope since the interval does not include the value "zero".

As expected, the raw data conforms to the shape predicted (generally) by the cook-off function. With increasing temperature, a decrease in time to cook off can be noted; this is especially evident for values of temperature greater than 395°F. Conversely, as time to cook off increases, the curve begins to asymptote to the single temperature value previously designated as T_o. However, since the "zero slope" hypothesis mentioned above has been rejected, we are unable to assign a conclusive value to T_o. Thus, it is apparent that another cook-off criterion should be developed.

One such criterion would be to select representative times and, from Fig. 6, determine the minimum temperature required to cause cook-off. For example, cook-off will probably not occur before 300 seconds (5 minutes) has elapsed if the bore temperature is less than or equal to 370°F. Also, it is apparent that within 570 seconds (9.5 minutes), the danger of cook-off is probably not present if the bore temperature is less than or equal to 350°F. Statements such as these can be said to be true in at least 99 cases out of 100.

Conclusions

1. The cook-off time-temperature relationships for XM123E1 Zone 8 Propelling Charges (conditioned to 145°F) placed in a hot XM199 Cannon are given by Fig. 6.

2. Cook-off is expected to occur 99 times out of 100 for time-temperature points between the solid (prediction interval) lines.

3. Conversely, cook-off is expected to occur less than one time in 100 for time-temperature points below the lower solid (prediction interval) line.

4. If the tube temperature is less than or equal to 370°F, cook-off is not expected to occur sooner than 5 minutes from the time of charge insertion.

5. If the tube temperature is less than or equal to 350°F, cook off is not expected to occur sooner than 9.5 minutes from the time of charge insertion.

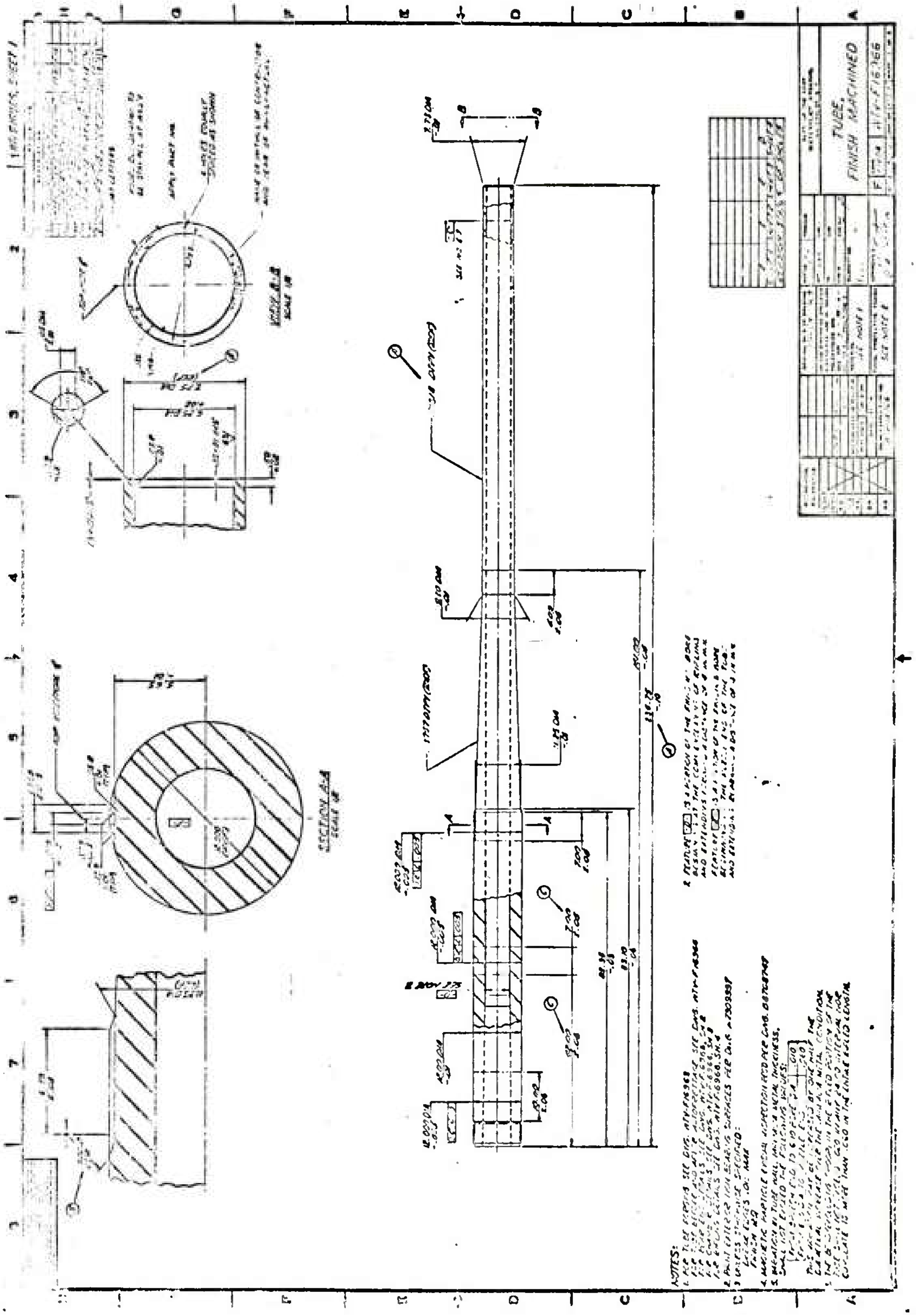


Fig. 1 XM181 Tube, Finish Machined

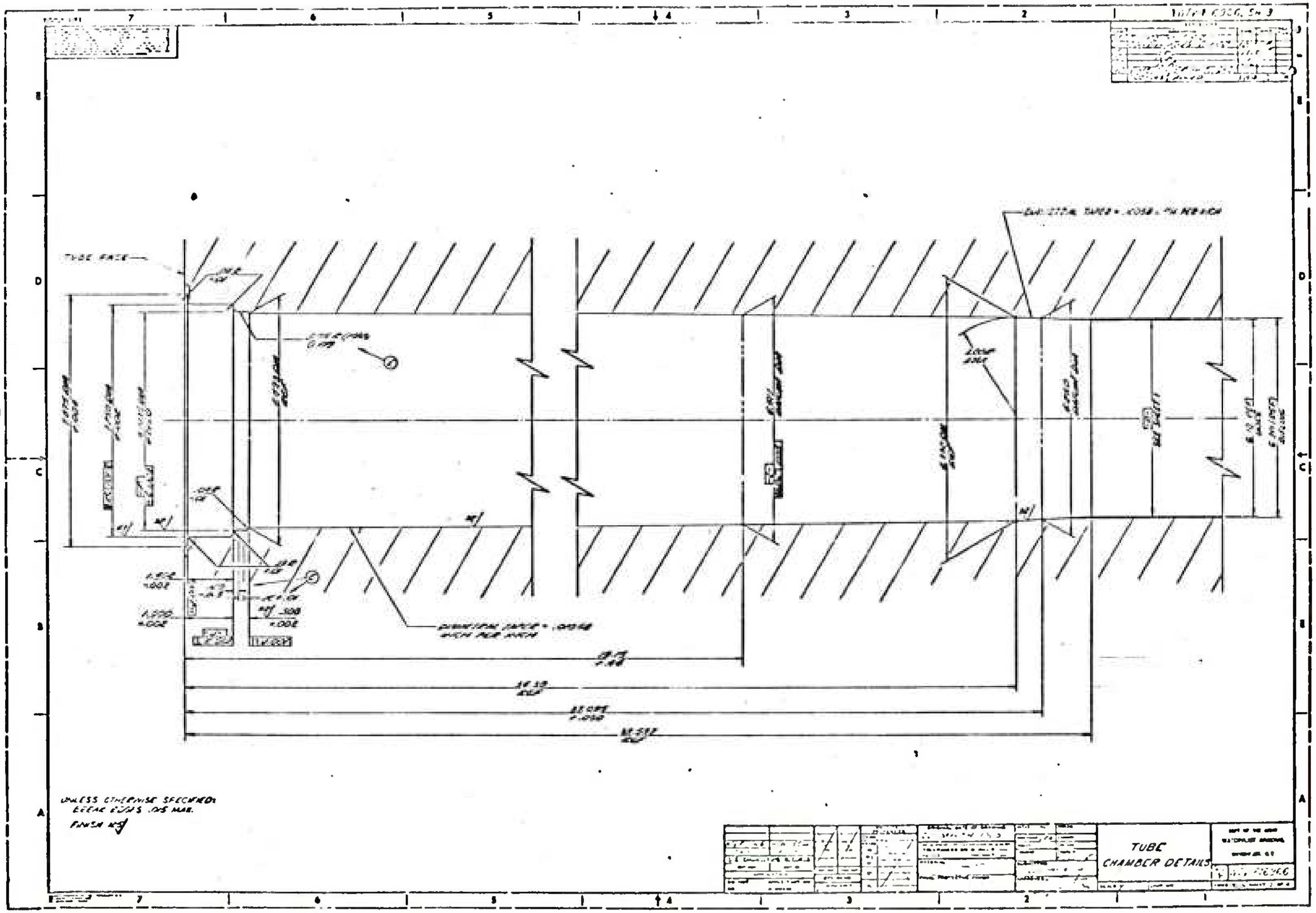


Fig. 2 XM181 Tube, Chamber Details

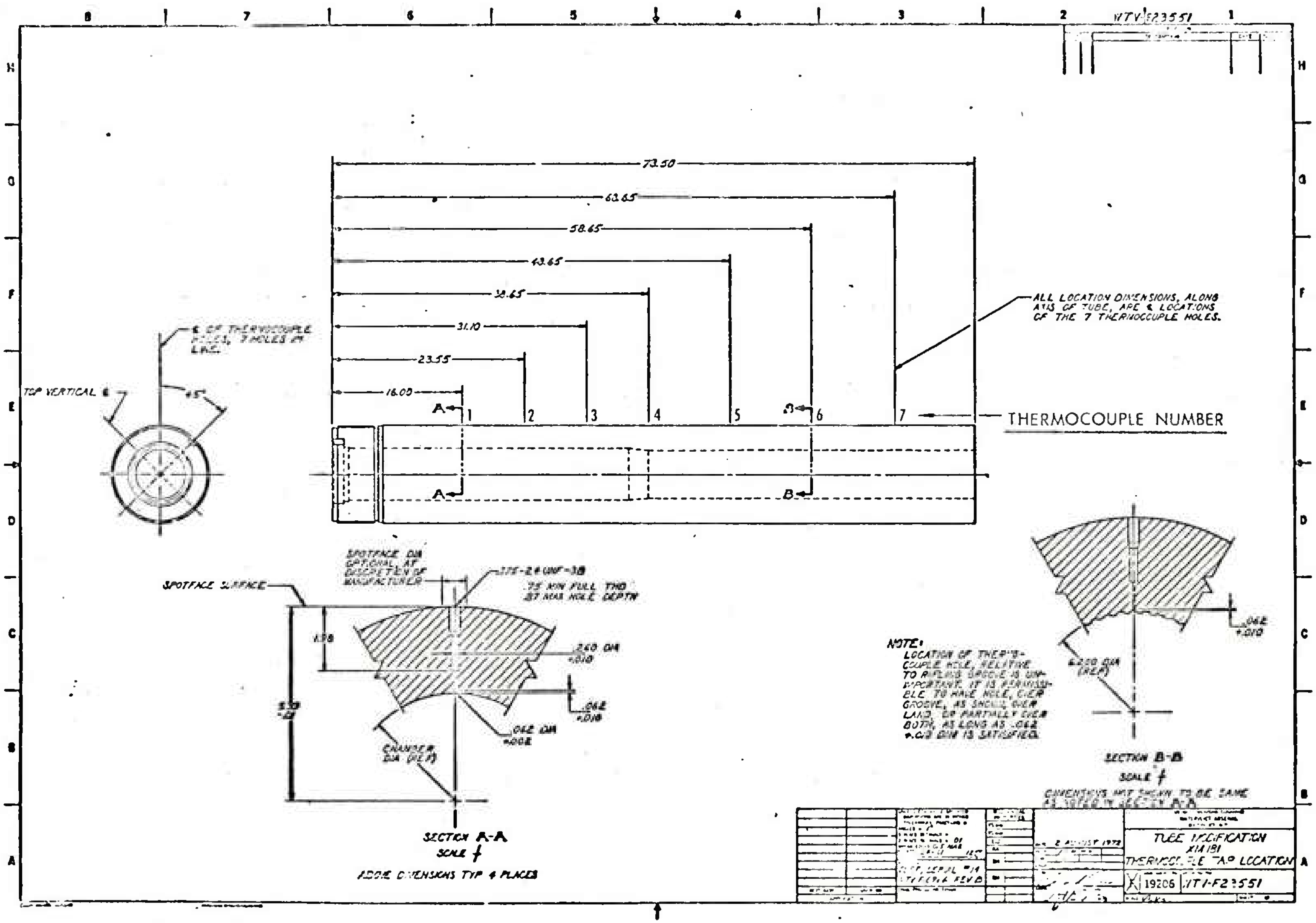


Fig. 3 Stub Tube; Thermocouple Numbers and Locations

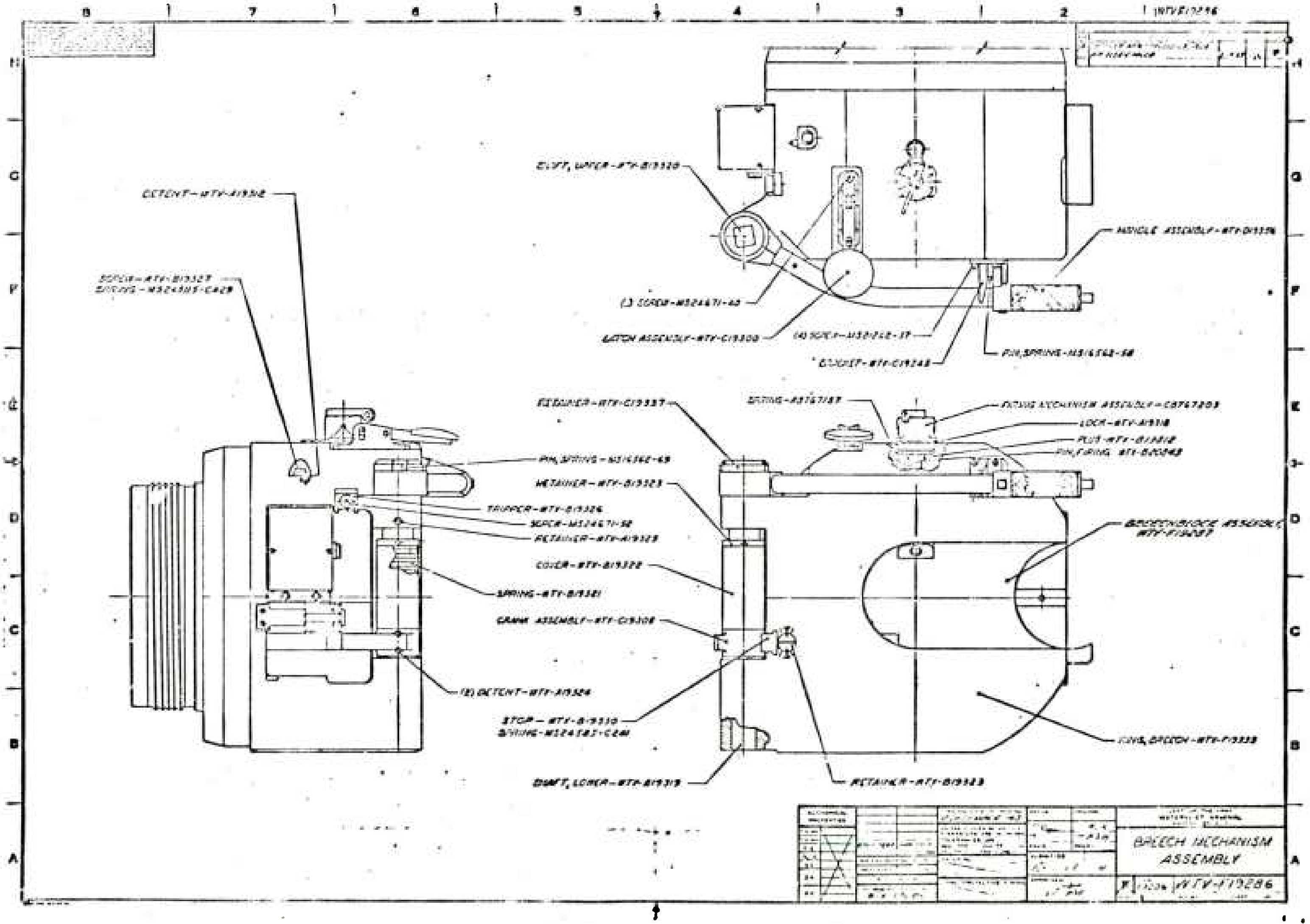


Fig.4 XM181 Breech Mechanism Assembly

WTV
THERMAL TEST
CONTRACT #DAAF07-73-C-0045
Table 1 Test Log

DATE: 9-20-72

Shot No.	Prop. Chg.	Lot No.	Amb. Temp. °F	R.H. %	Wind Direction & Velocity	Sky Conditions	Chg. Temp. °F	Ins. Temp. #4 Therm.	Time Chg. Ins.	Sec's To Smoke	Sec's To Ign. Of Chg.		
1-C	XM123E1	RAD-E-1-72	62	41	W@10MPH	Clear	145°	400°	11:25AM	None	166.7		Possible junction was not operating
													10-6-72
2-C	XM123E1	RAD-E-1-72	66	66	SSE@ 10MPH	Partly Cloudy	145°	400° F	9:59AM		146.6		Center ign. core bags & ign. pad removed.
3-C	XM123E1	"	67	55	SW@ 10MPH	Partly Cloudy	145°	400° F	11:18AM		202.2		Center ign. core bags & ign. pad removed.
4-C	XM123E1	"	68	50	Calm	Sunny Scat.Cld	145°	450°	1:35PM		73.6		Center ign. core bags & ign. pad removed.
5-C	XM123E1	"	69	45	N@5MPH	Partly Cloudy	145°	450°	2:50PM		43.2		Base of charge in approx. 7" past breech end of tube (wooden dowel in center of charge.
													10-9-72
6-C	XM123E1	"	48	46	NW @ 8-10MPH	Cloudy	145°	450° F	11:05PM	15 Sec	27.7		Center ign. core bags & ign. pad removed.
7-C	XM123E1	"	50	35	NW @ 15 MPH	Cloudy	145°	-500° F	1:18PM	None	38.3		Center ign. core bags & ign. pad removed.
8-C	XM123E1	"	50	32	WNW@ 18MPH	Partly Cloudy	145°	500° F	3:00PM	None	22.8		Center ign. core bags & ign. pad removed.
													10-10-72
9-C	XM123E1	"	46	29	Calm	Sunny	145°	375° F	10:05AM	215Sec.	575.0		Center ign. core bags & ign. pad removed.
10-C	XM123E1	"	47	32	E@ 0-20 MPH	Sunny	145°	375° F	11:55AM	78Secs.	540.4		Center ign. core bags & ign. pad removed.
11-C	XM123E1	"	49	27	NW @ 4 MPH	Sunny	145°	375°	2:09PM	50 Secs	567.0		Center ign. core bags & ign. pad removed.
12-C	XM123E1	"	49	26	NW @2 MPH	Sunny	145°	390°F	3:43PM	46Sec.	425.2		Center ign. core bags & ign. pad removed.

WTV

THERMAL TEST

CONTRACT #DAAF07-73-C-0045

Table 1 Test Log (Cont.)

DATE: 10-11-72

Shot No.	Prop. Chg.	Lot No.	Amb. Temp. °F	R.H. %	Wind Direction & Velocity	Sky Conditions	Chg. Temp. °F	Ins. Temp. #4 Therm.	Time Chg. Ins.	Sec's To Smoke	Sec's To Ign. Of Chg.		
13-C	XM123E1	RAD-E-1-72	47	47	SW @4 MPH	Sunny	145°	390° F	10:14AM	30Sec.	527.0		Center ign. core bags & ign. pad removed.
14-C	XM123E1	"	53	37	SW @8 MPH	Sunny	145°	390° F	11:54AM	26Sec.	423.4		Center ign. core bags & ign. pad removed.
15-C	XM123E1	"	55	36	SW@10 MPH	Sunny	145°	420° F	1:50PM	20Sec.	121.6		Center ign. core bags & ign. pad removed.
16-C	XM123E1	"	56	35	SW@8 MPH	Partly Cloudy	145°	420° F	3:23PM	15Sec.	126.0		Center ign. core bags & ign. pad removed.
													10-12-72
17-C	XM123E1	"	52	69	SW@4-6 MPH	Cloudy	145°	395° F	9:32AM	86Sec.	460.9		Center ign. core bags & ign. pad removed.
18-C	XM123E1	"	52	79	Calm	Cloudy & rain	145°	395° F	11:20AM	None	236.2		Center ign. core bags & ign. pad removed.
19-C	XM123E1	"	52	80	Calm	Cloudy	145°	395° F	1:25PM	50Sec.	524.0		Center ign. core bags & ign. pad removed.

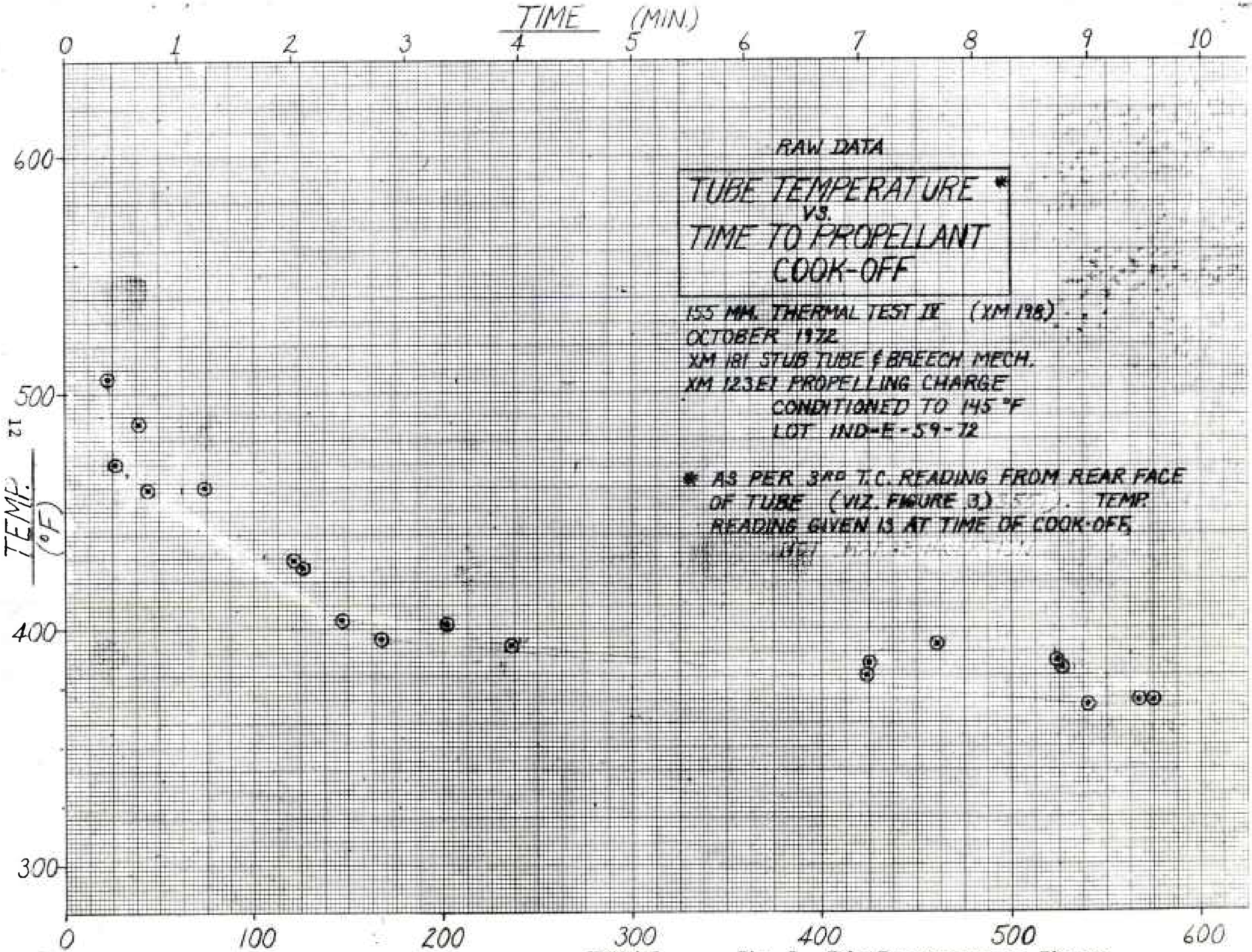


Fig. 5 Tube Temperature vs. Time to Propellant Cook-off (Raw Data)

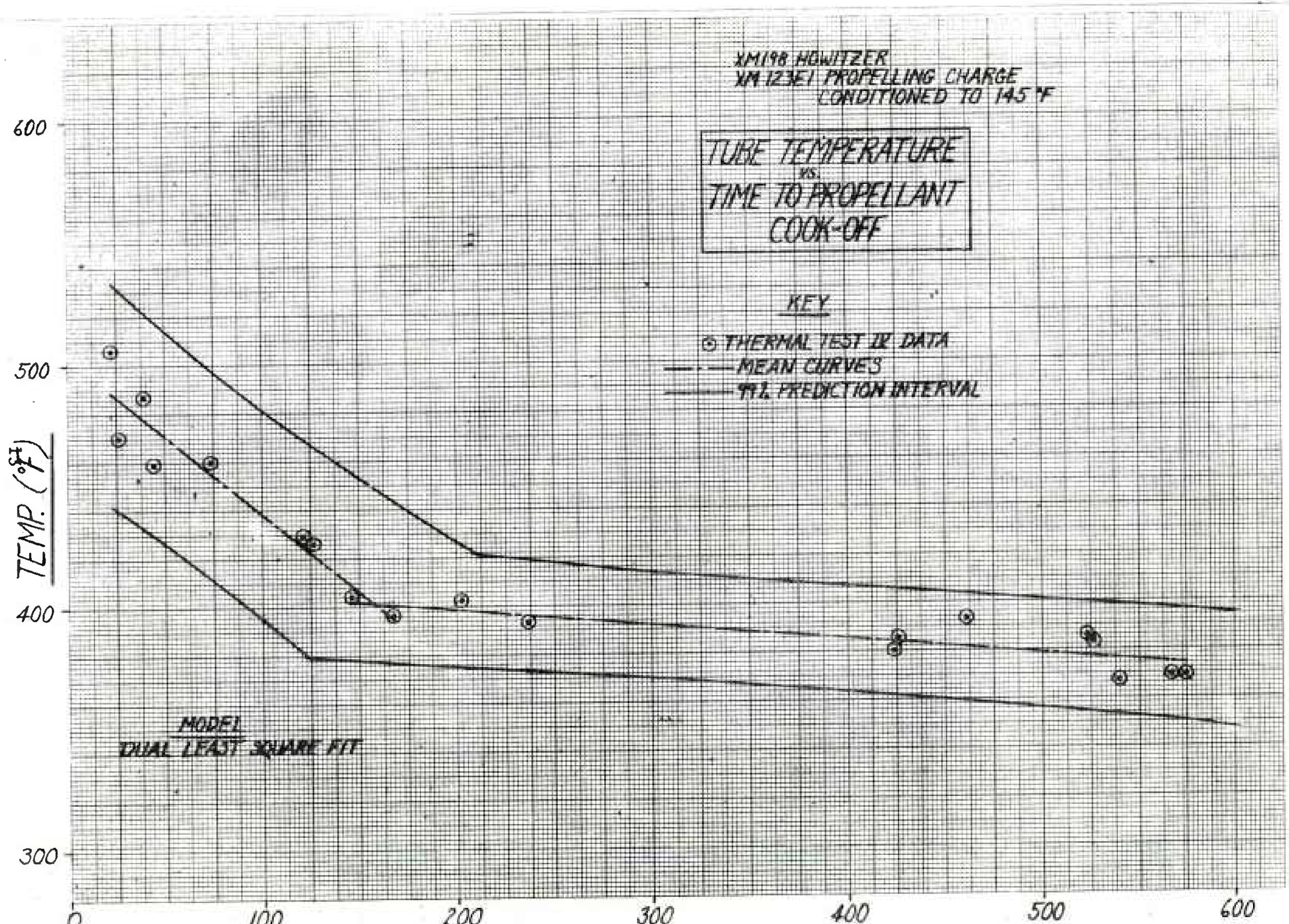
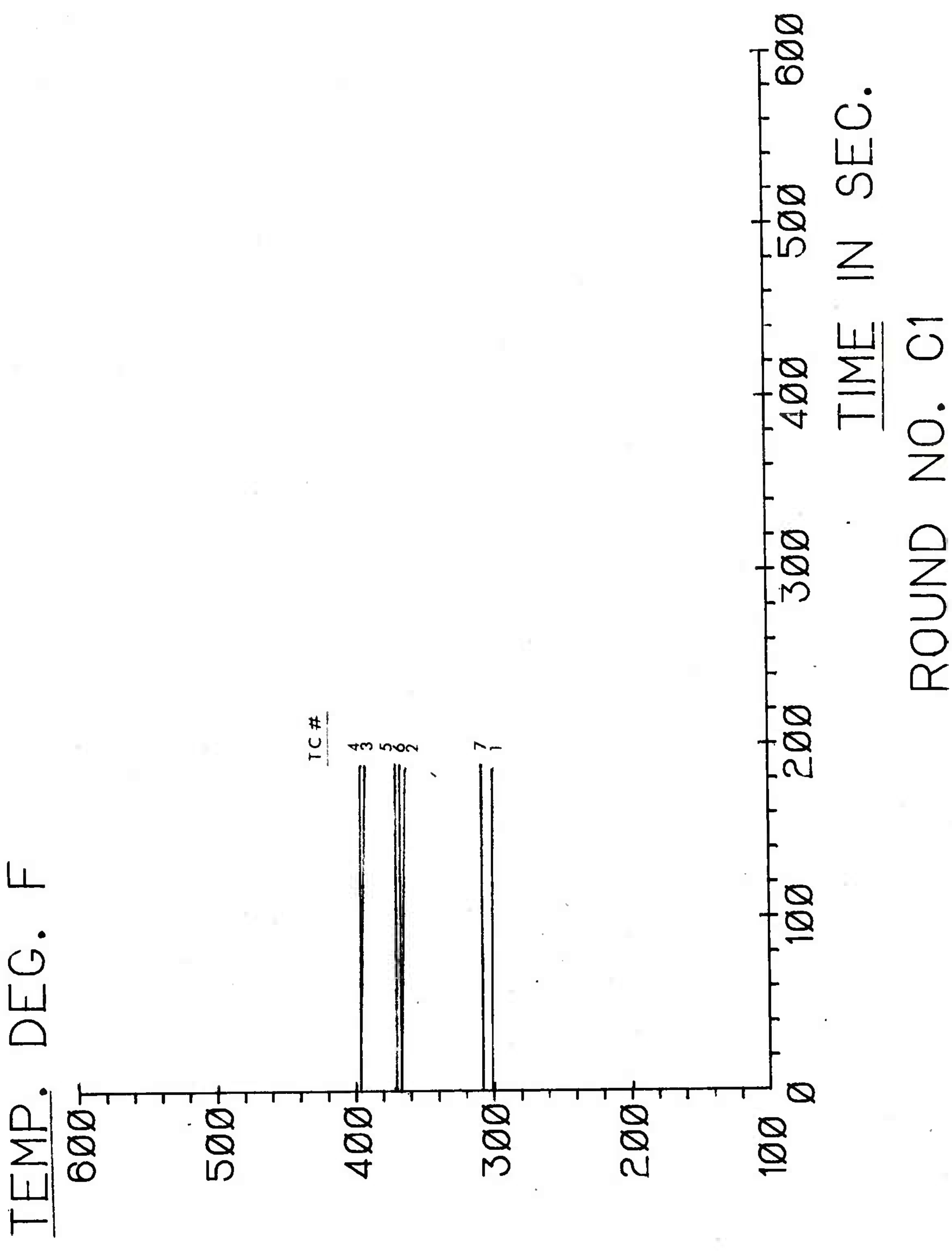


Fig. 6 Tube Temperature vs. Time to Propellant Cook-off (Statistical Data)

APPENDIX

The following is a graphic presentation of stub tube temperatures as monitored by thermocouples 1-7; see page 8 for thermocouple locations and numbering system. For details of test conditions for each round, see also pages 10-11.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5
6
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1
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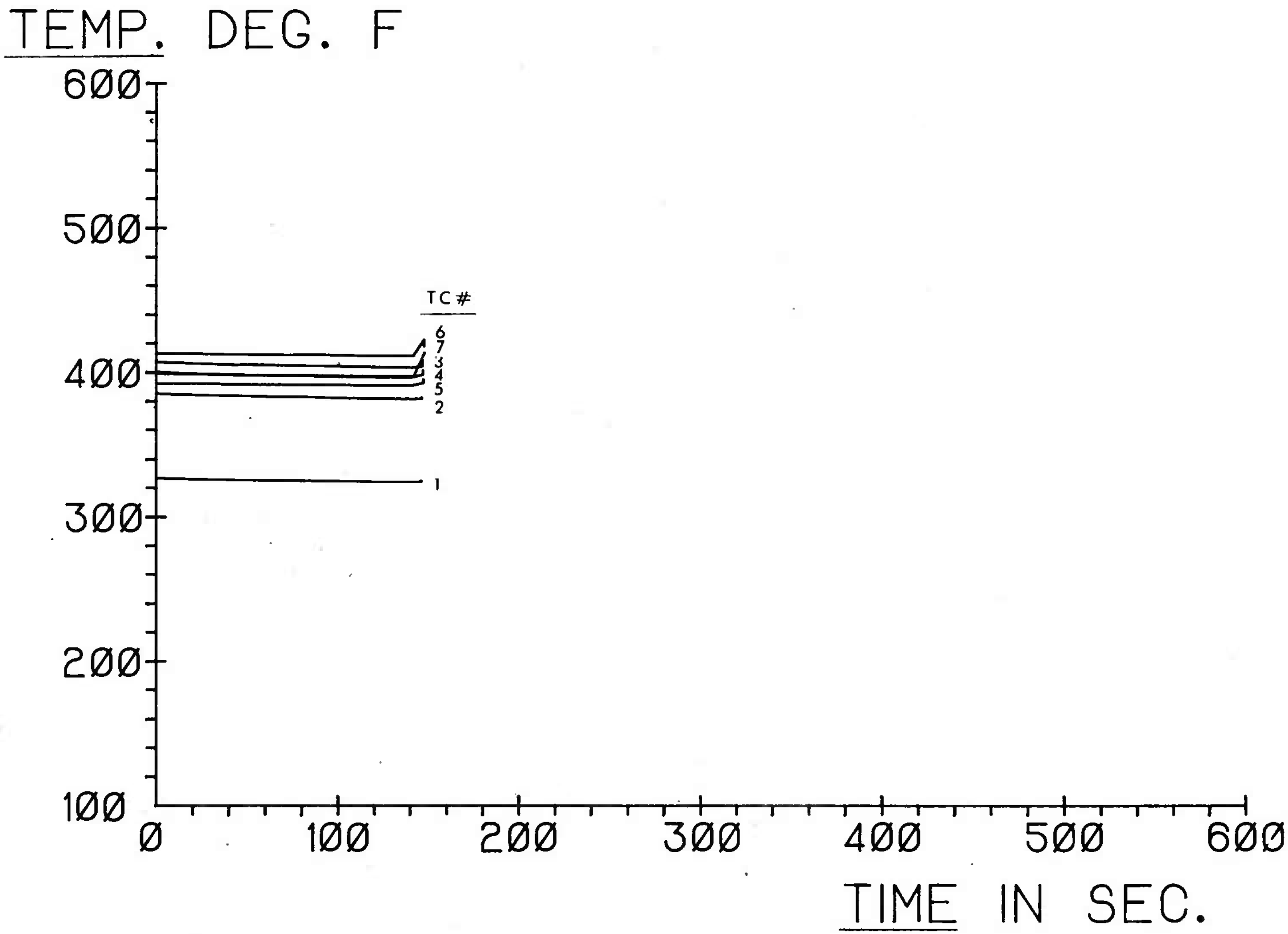
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TIME IN SEC.

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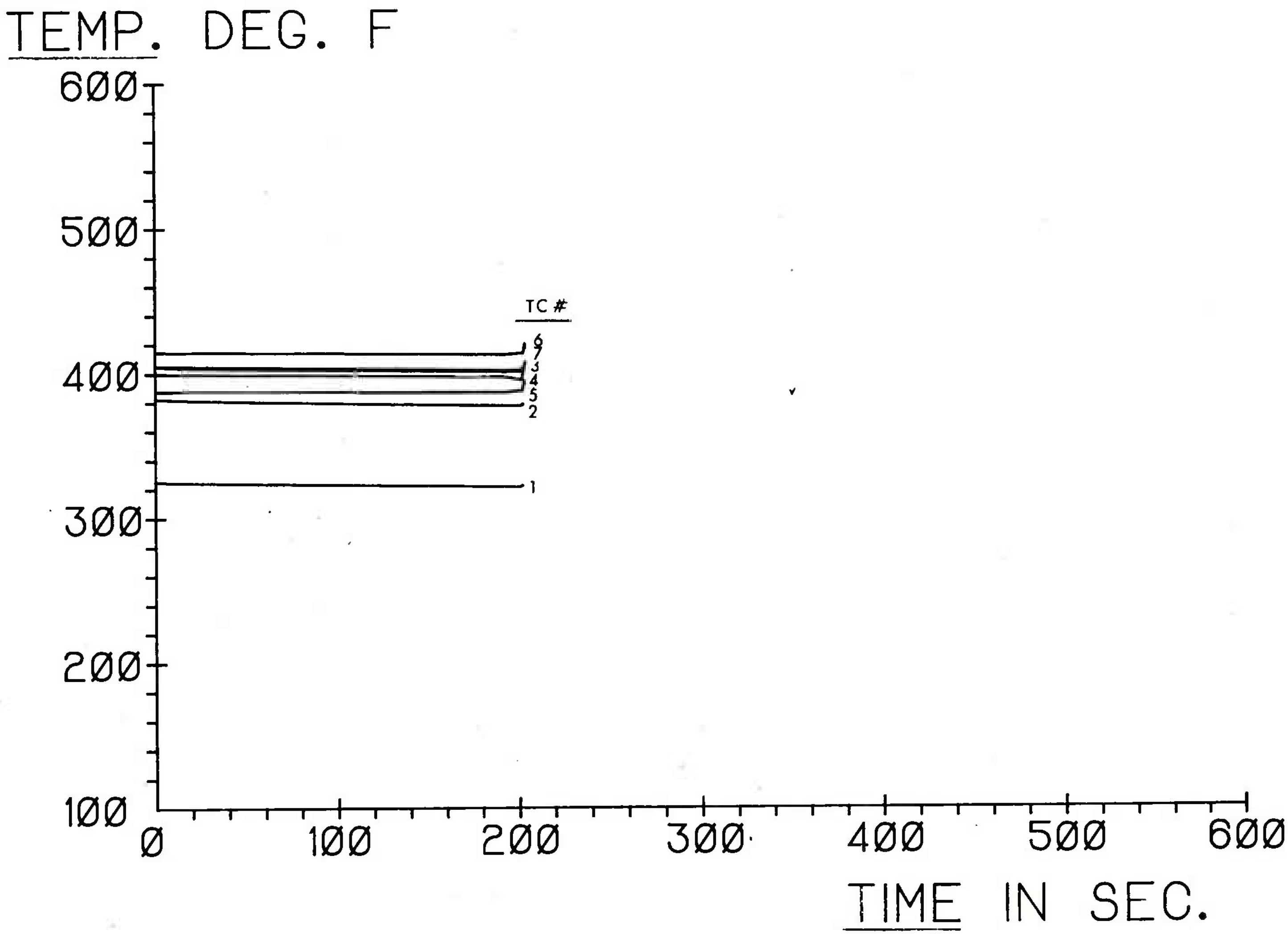
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TIME IN SEC.

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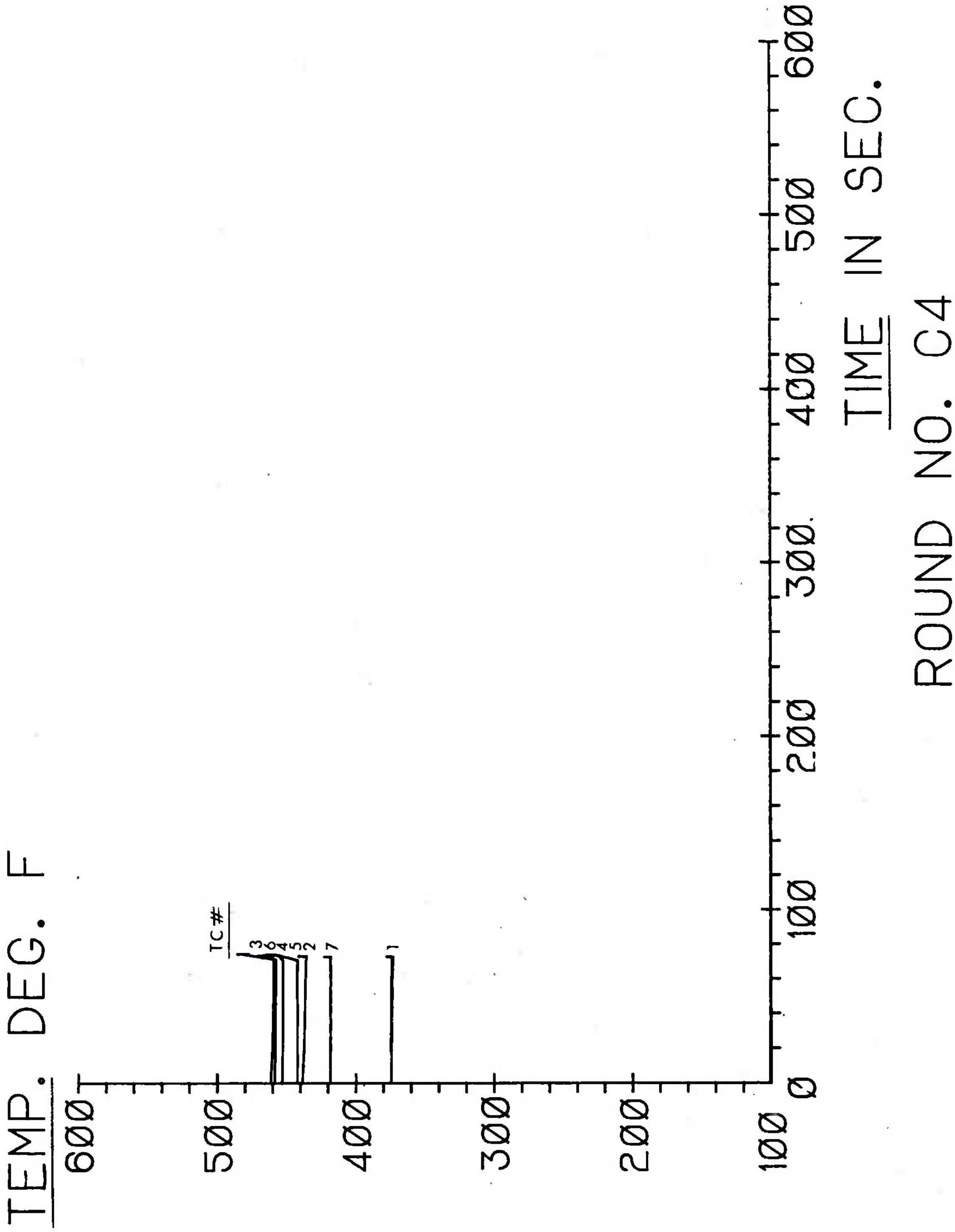
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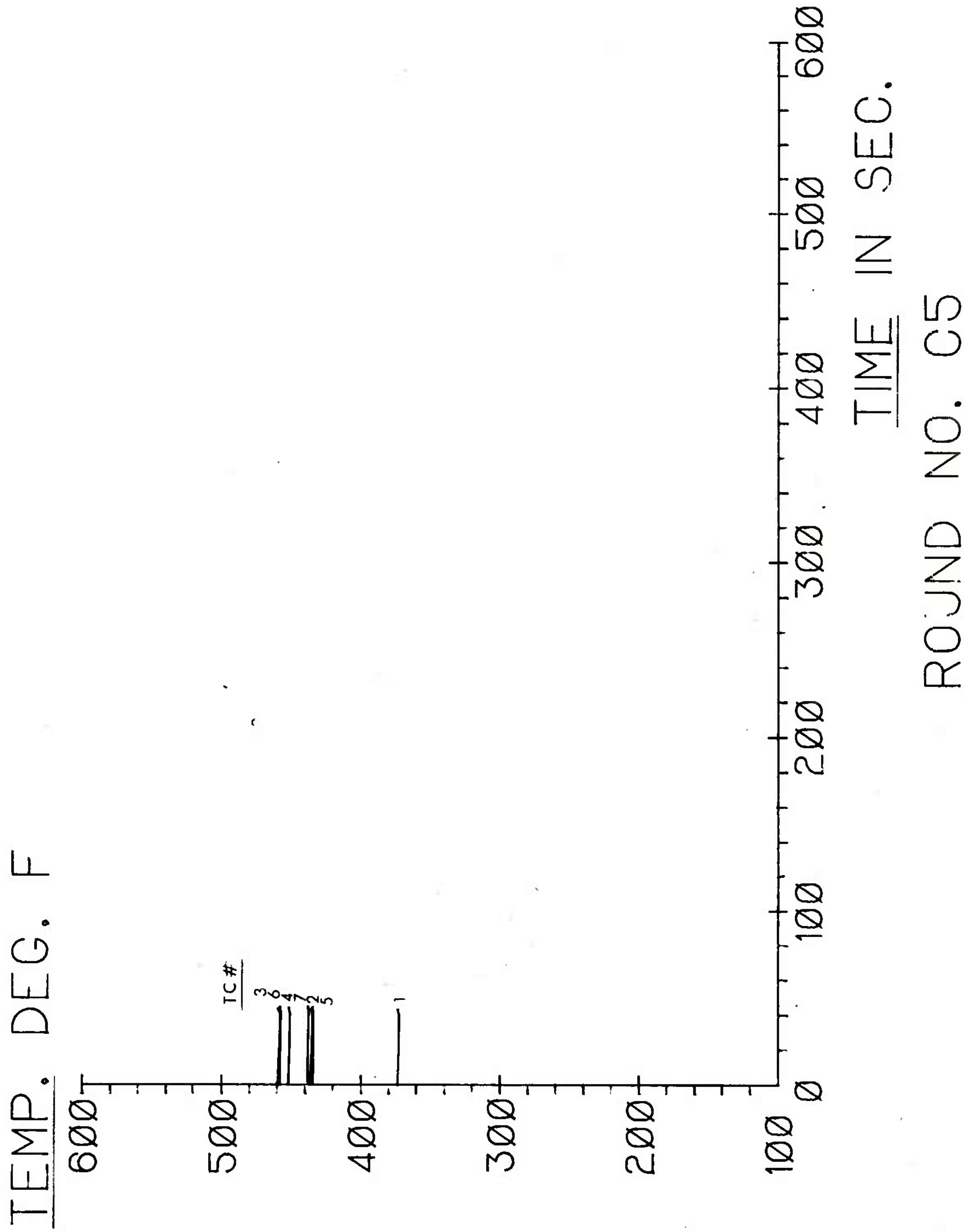

TEMP. DEG. F
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400
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200
100
TC #
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4
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2
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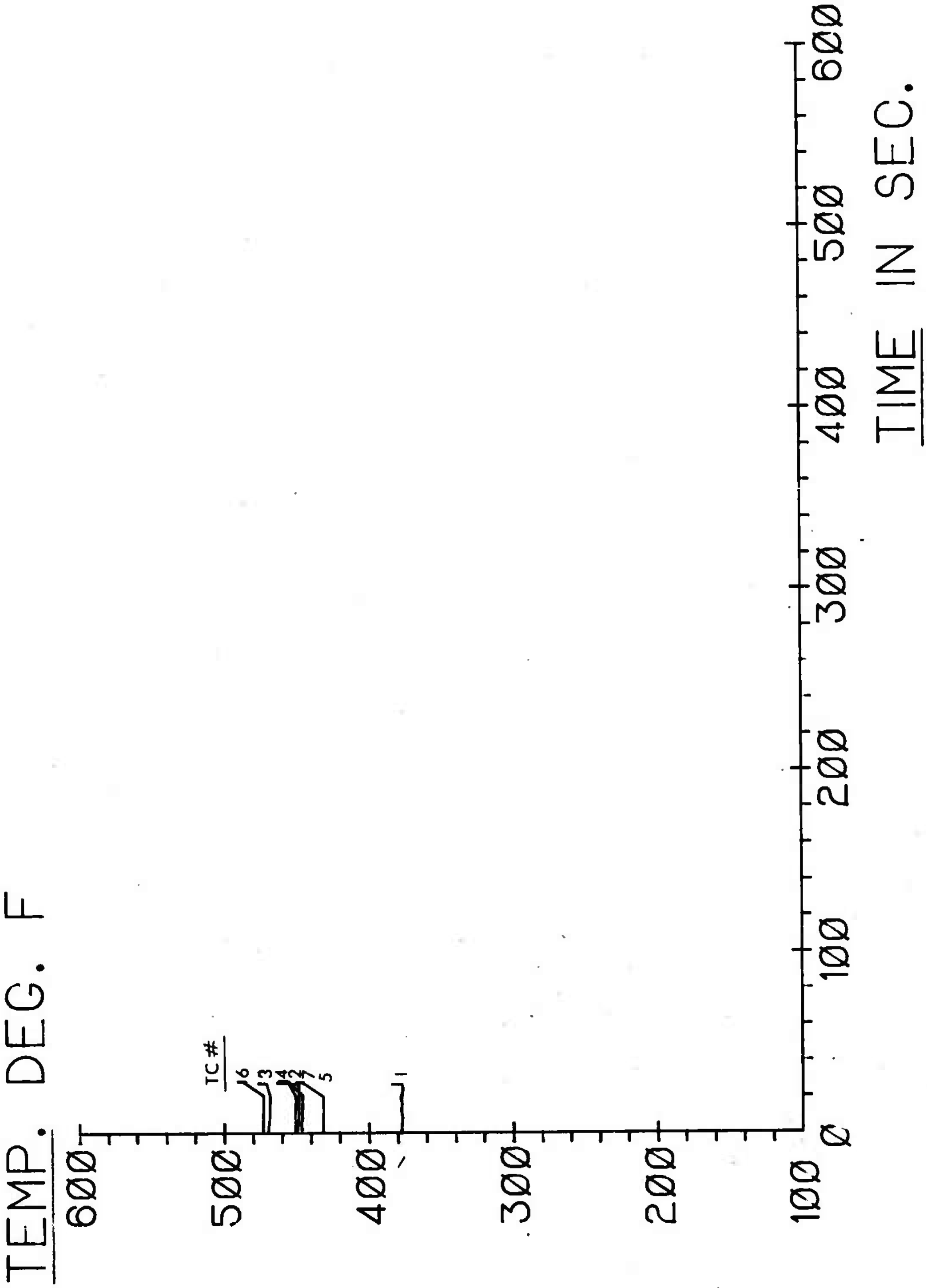
300
400
500
600
TIME IN SEC.
ROUND NO. C5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100
TC #
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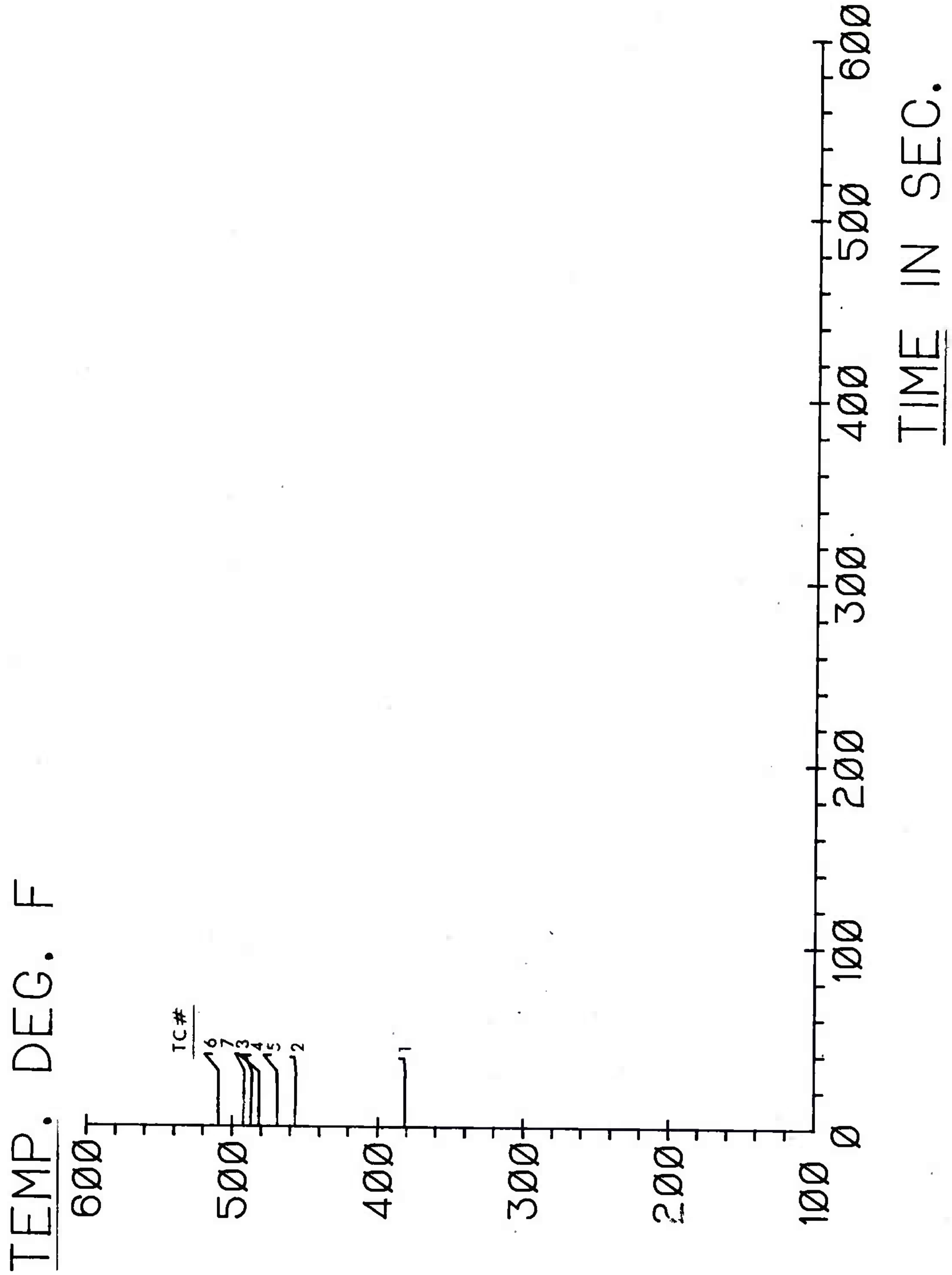
100
200
300
400
500
600
TIME IN SEC.

ROUND NO. C6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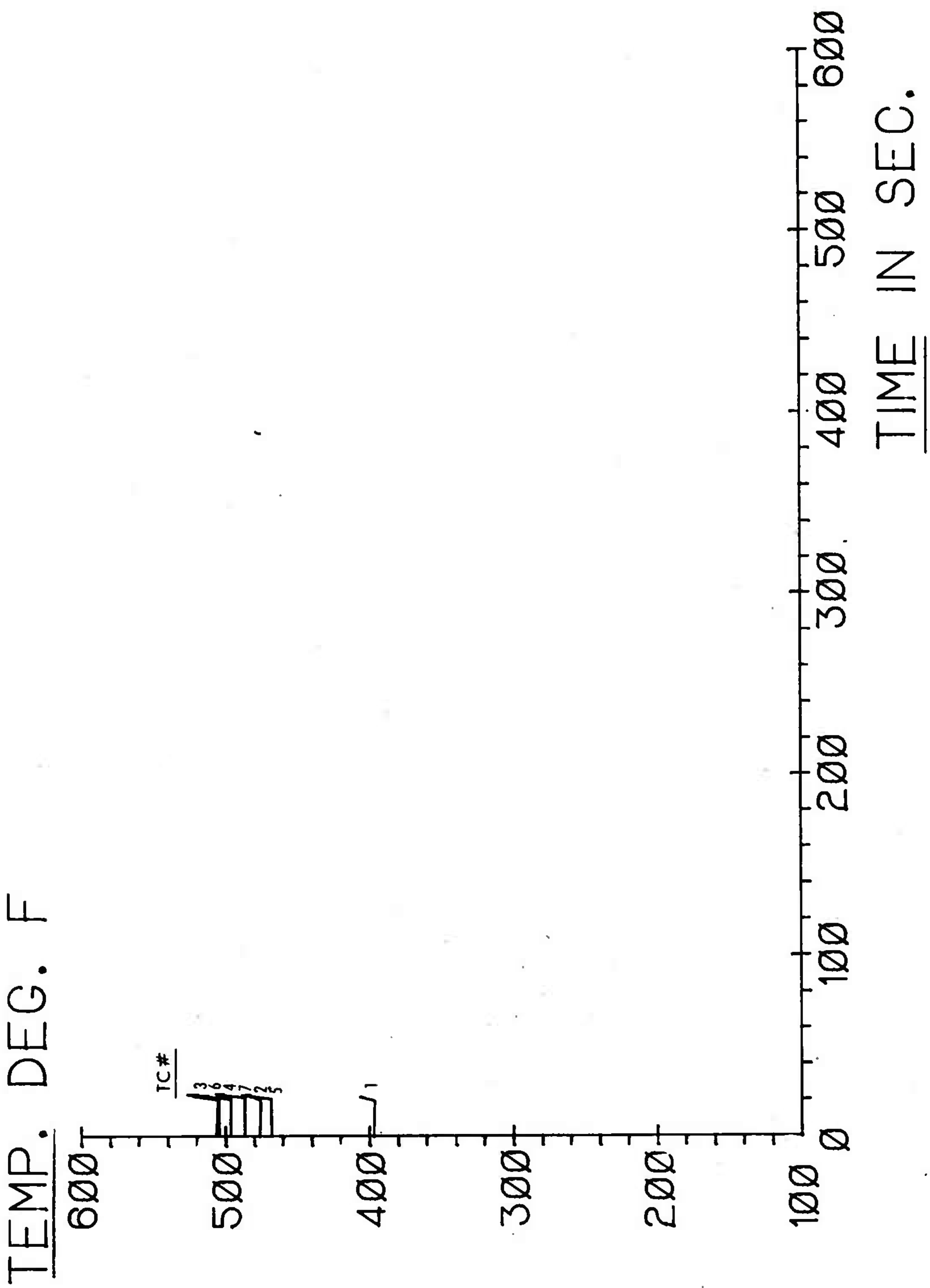
TIME IN SEC.

ROUND NO. C7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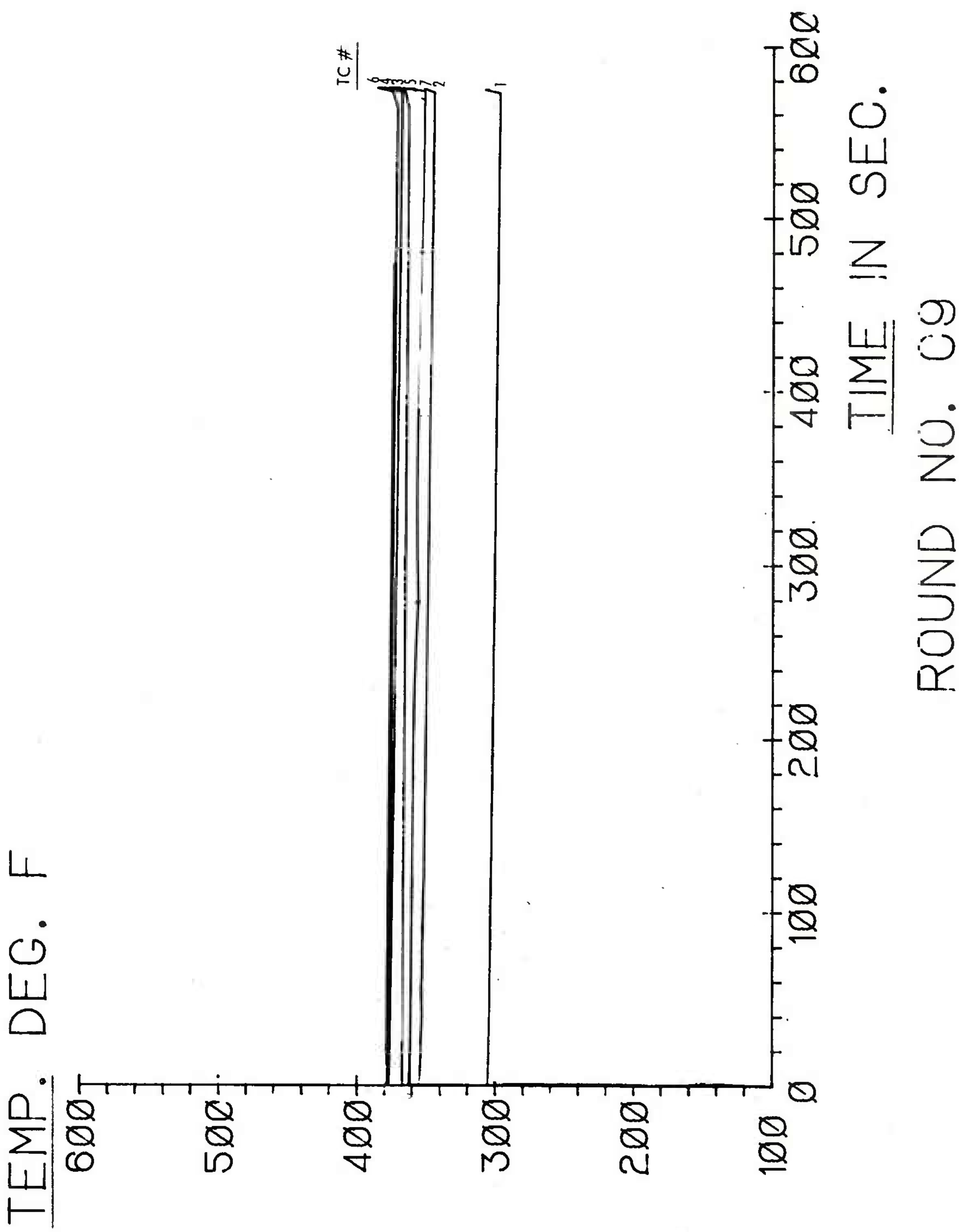
TIME IN SEC.

ROUND NO. C8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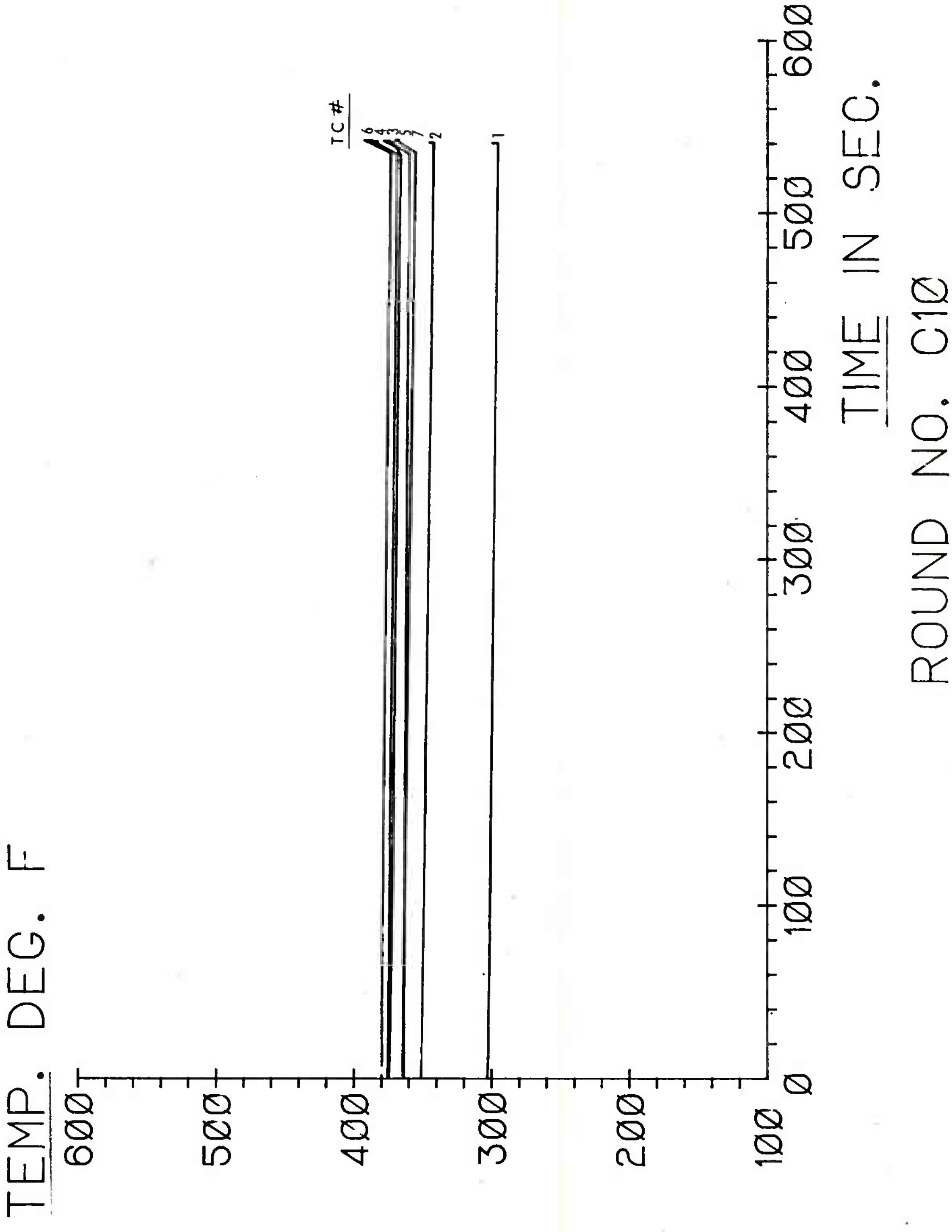

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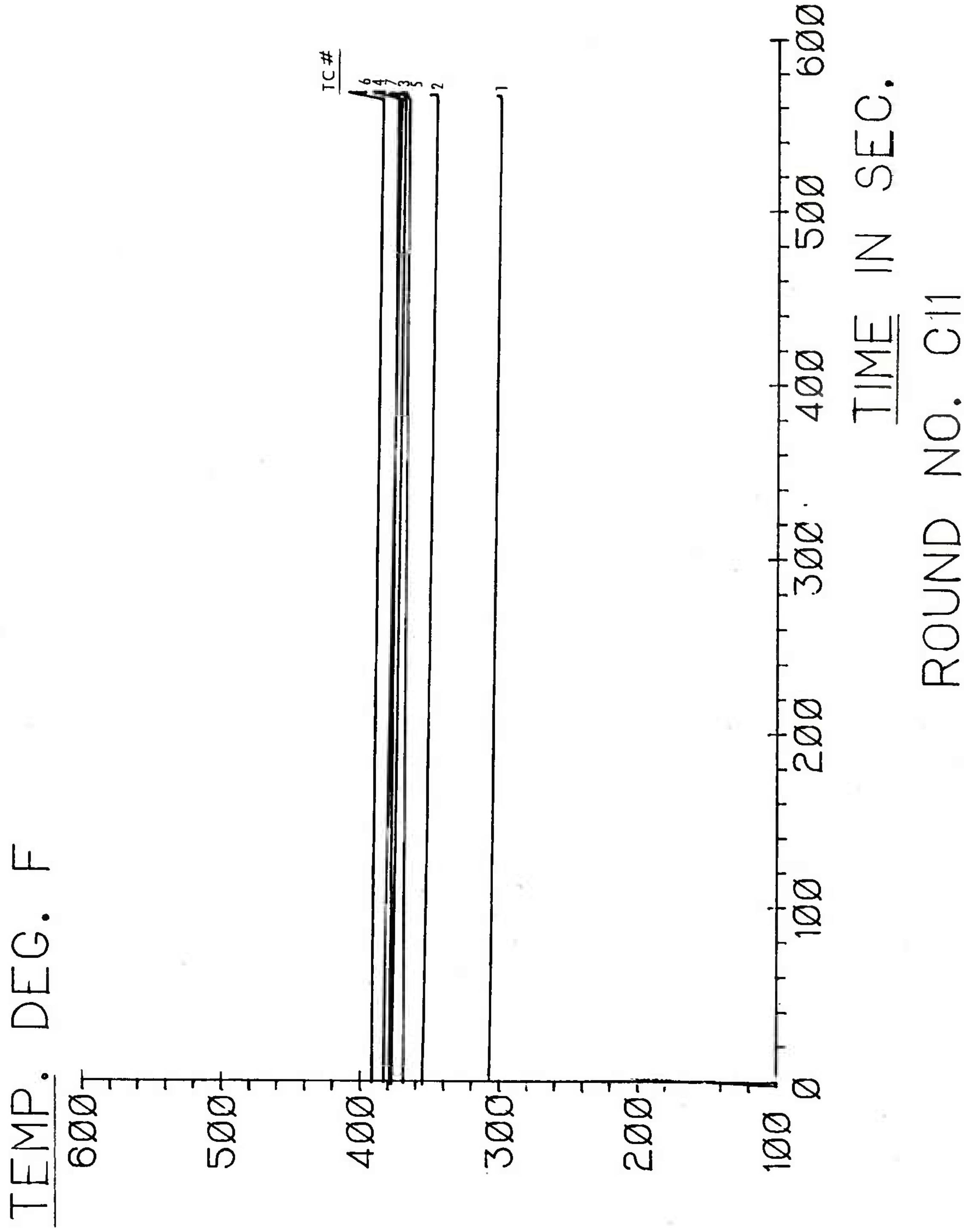
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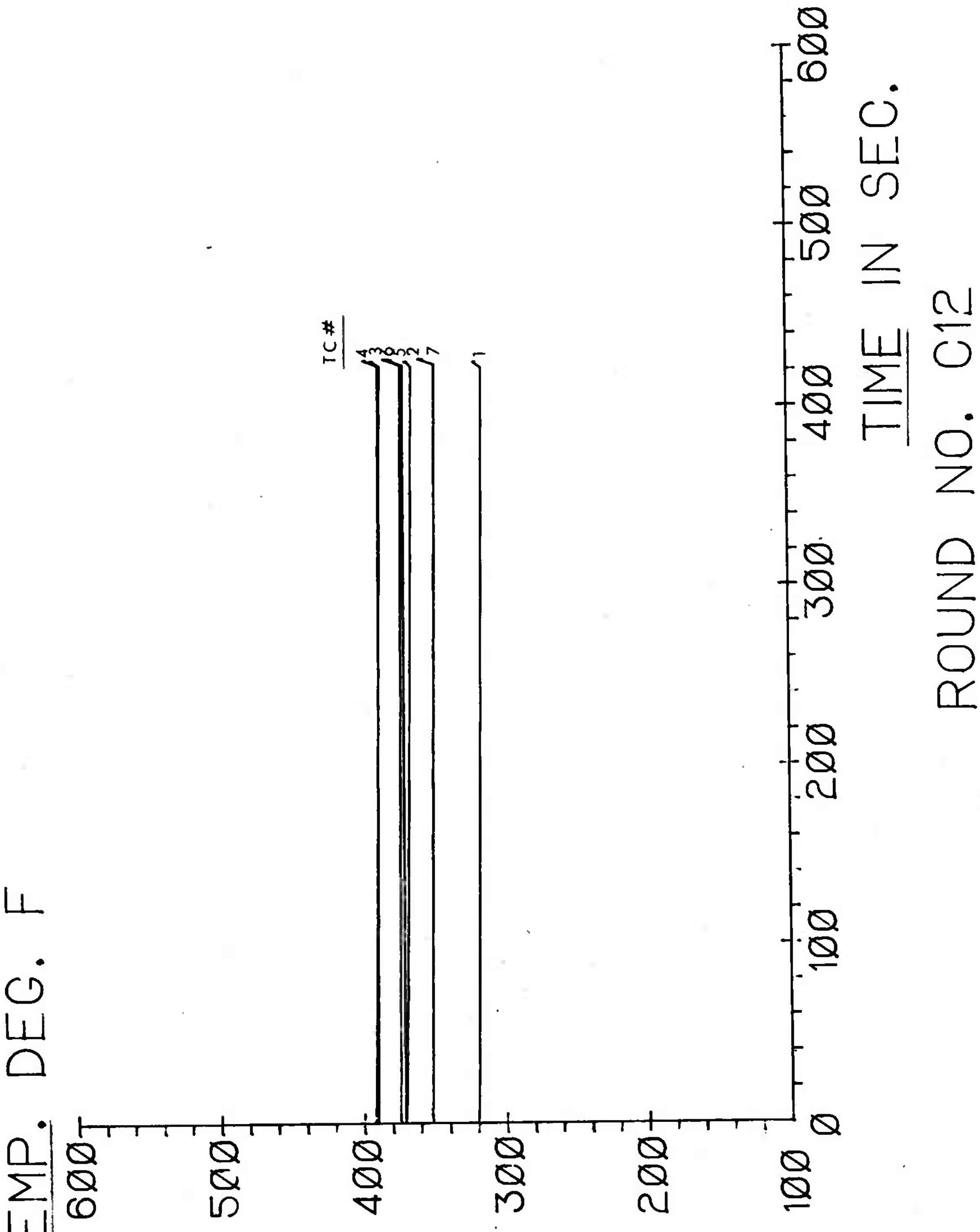
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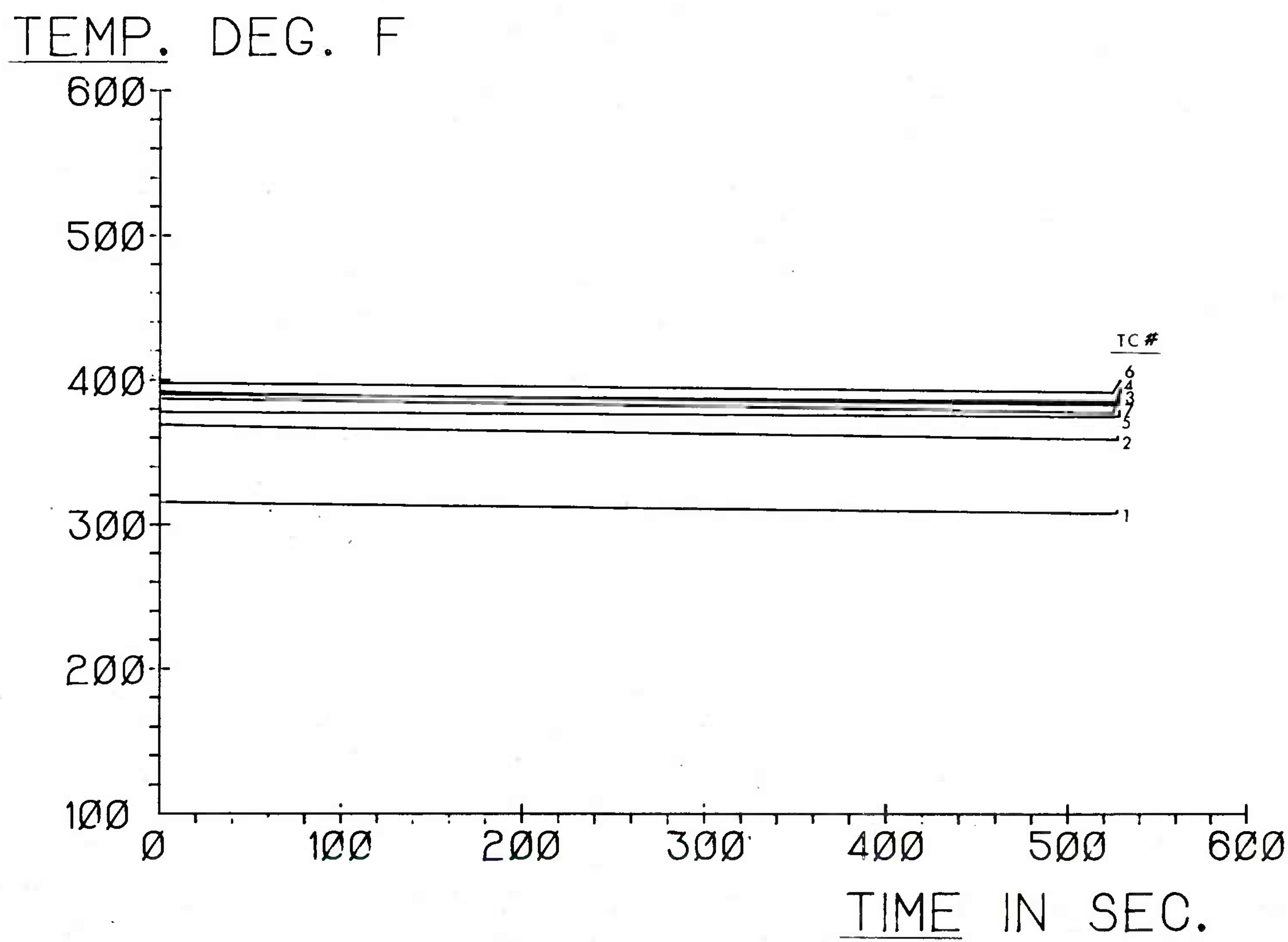
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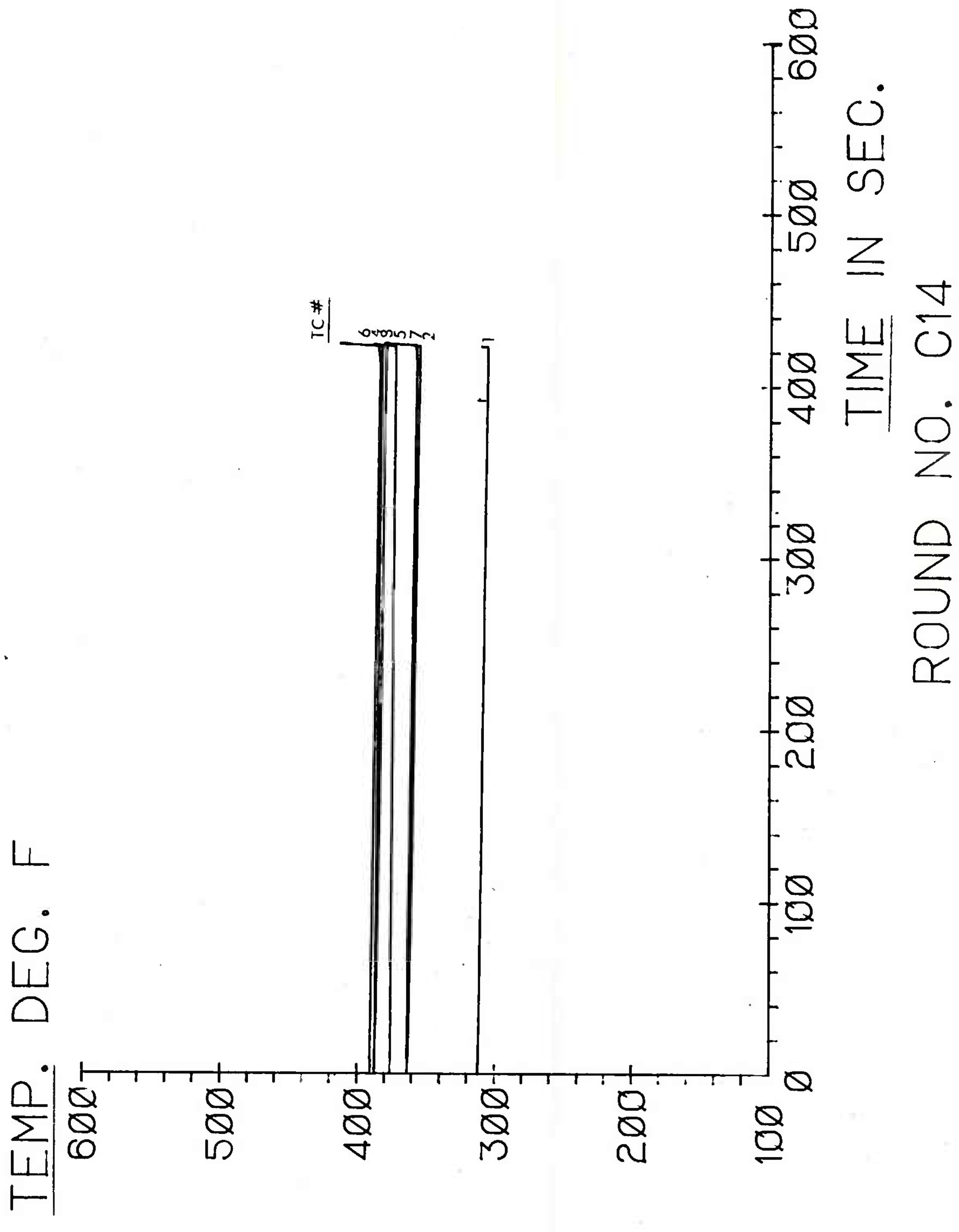
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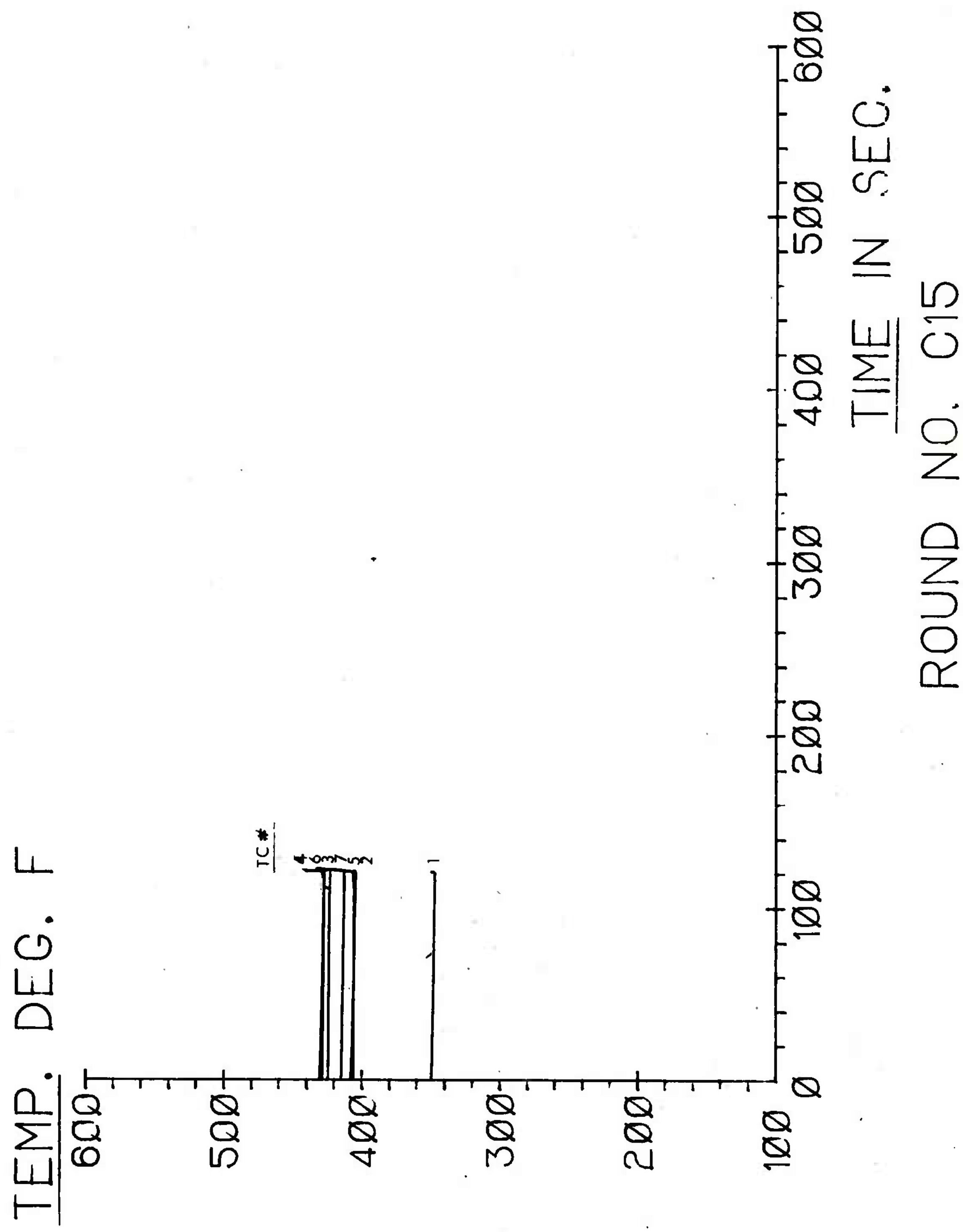
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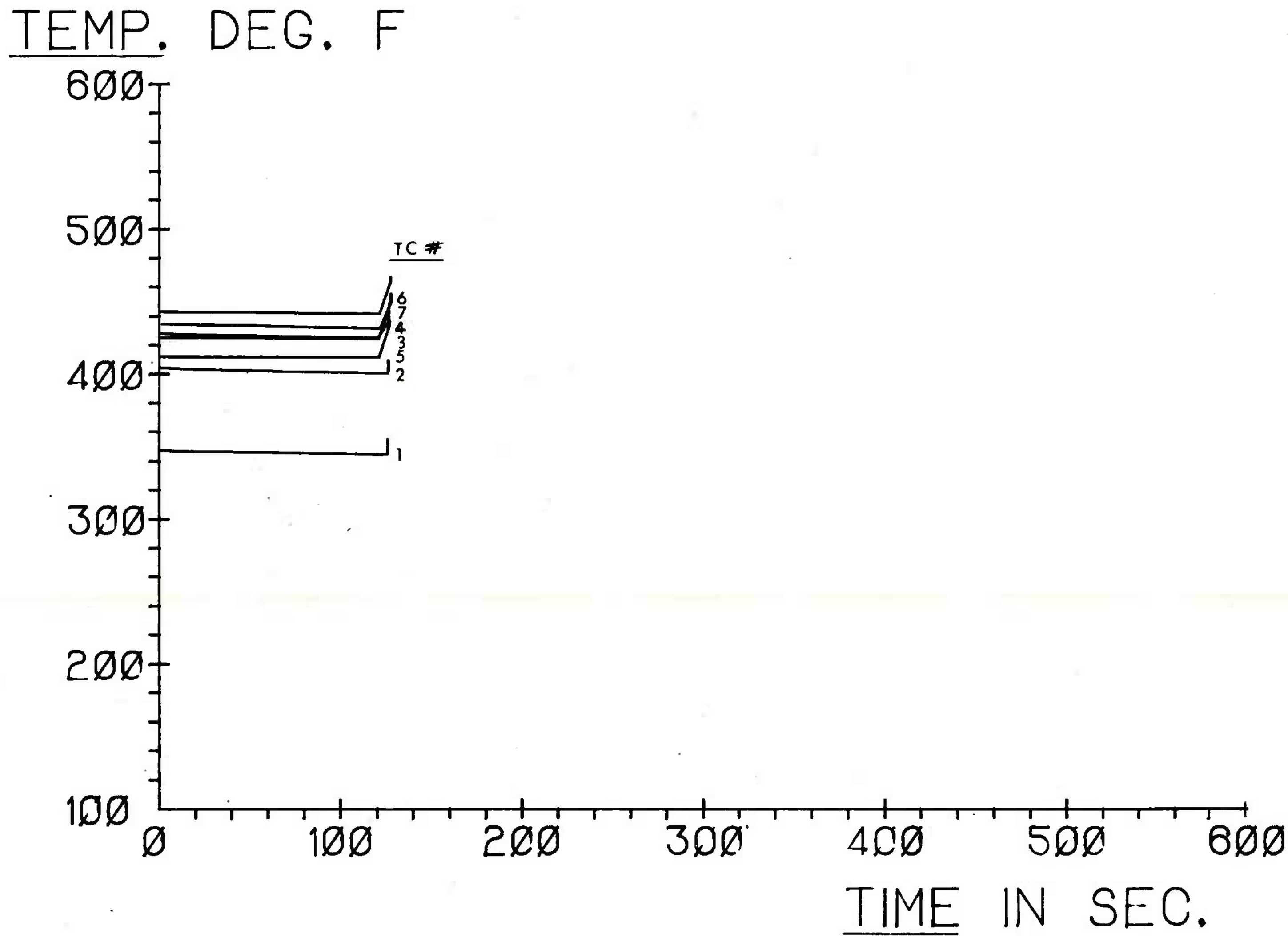
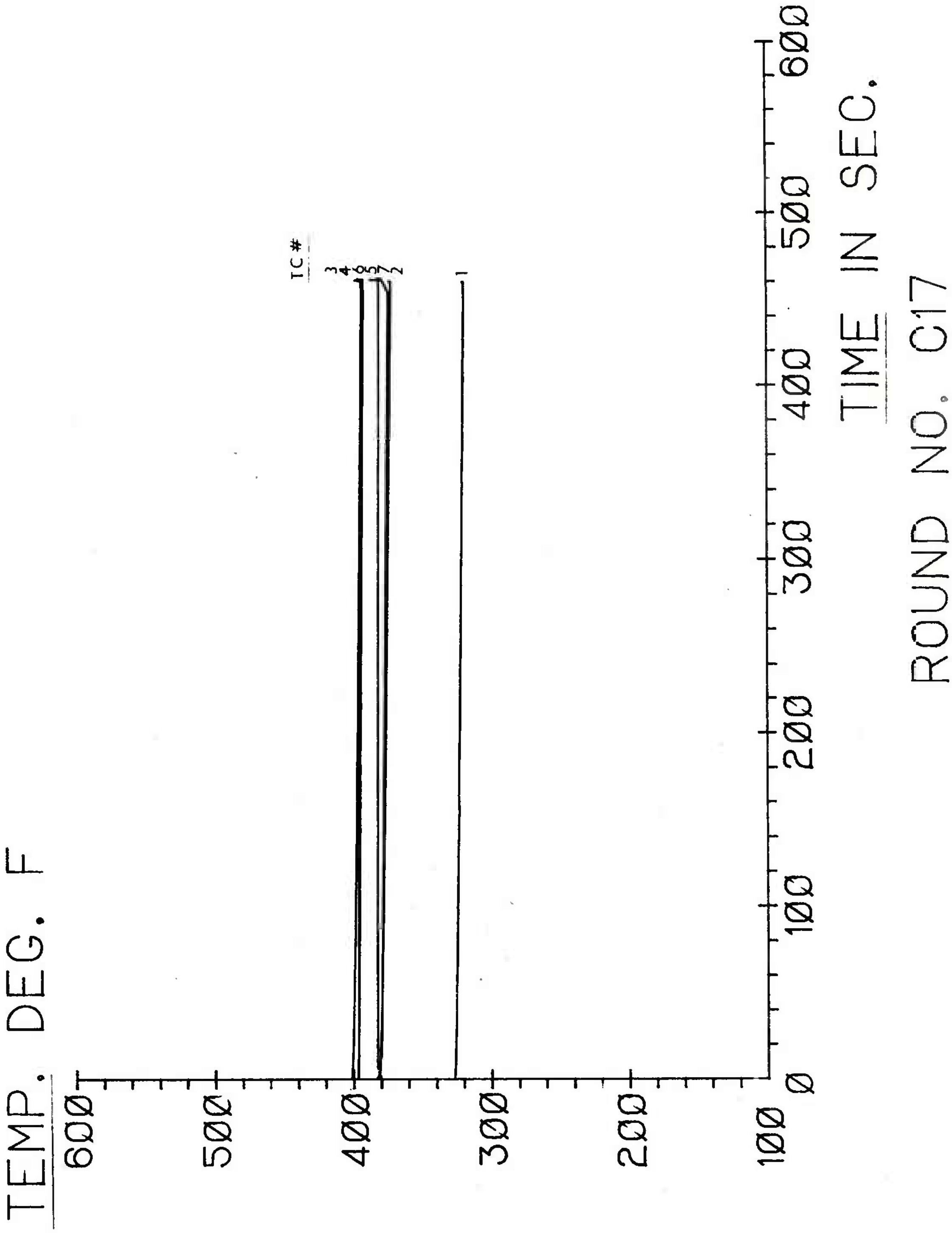
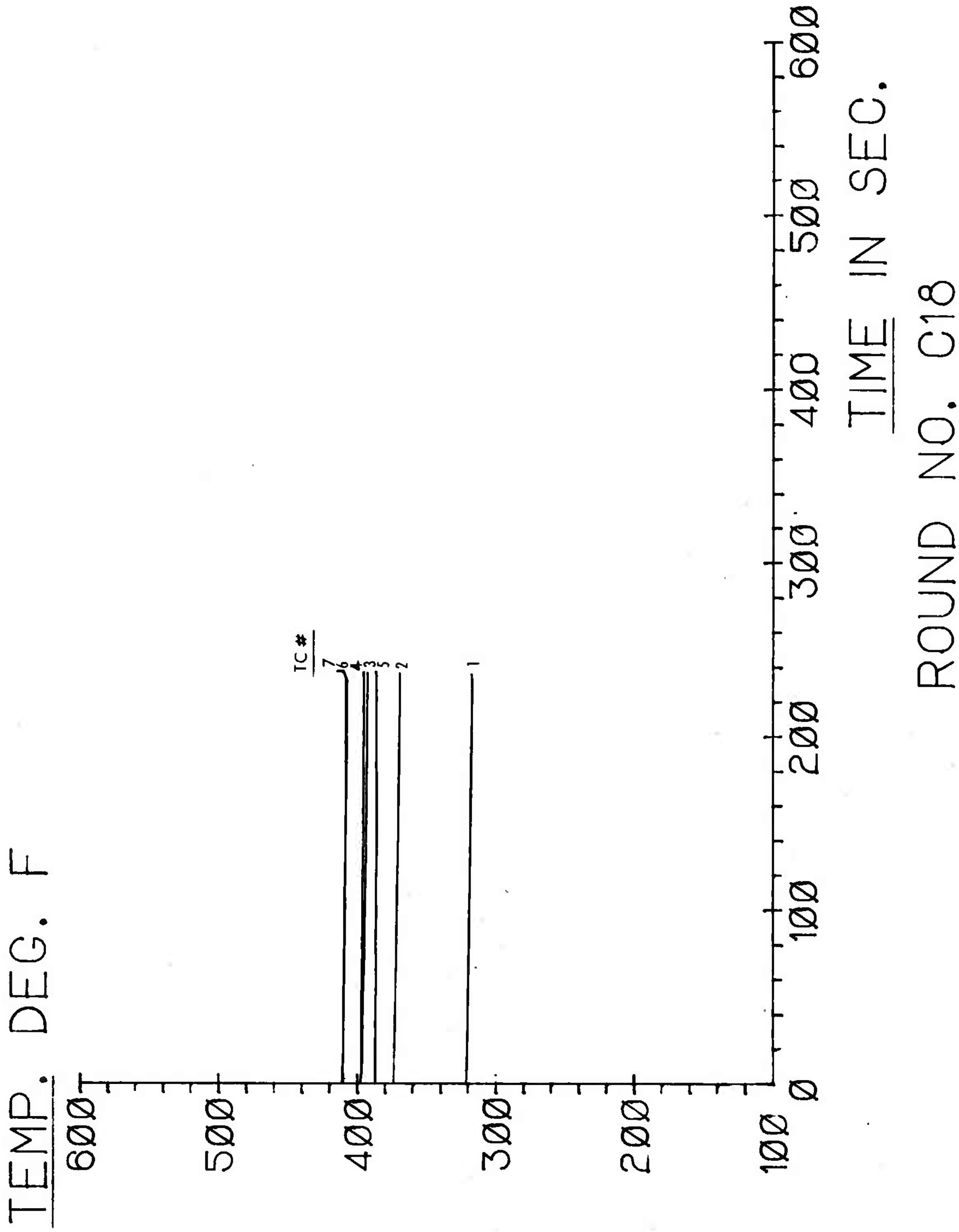
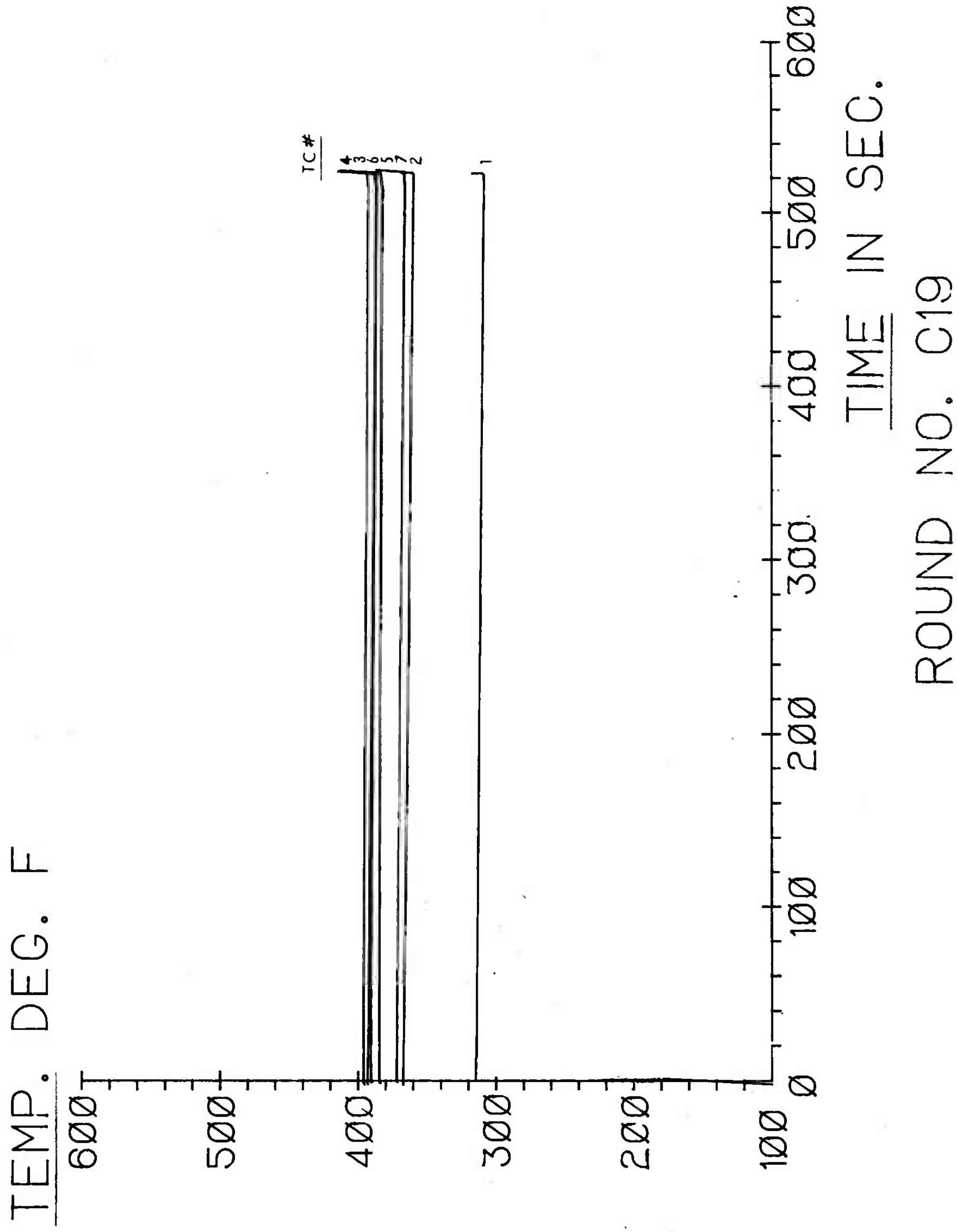
6ØØ
5ØØ
4ØØ
3ØØ
2ØØ
1ØØ
TC #
4
6
3
7
5
2
1
Ø
1ØØ
2ØØ
3ØØ
4ØØ
5ØØ
6ØØ
TIME IN SEC.
ROUND NO. C15


TEMP. DEG. F
600
500
400
300
200
100
TC #
6
7
4
3
5
2
1
0
100
200
300
400
500
600
TIME IN SEC.

ROUND NO. C16


TEMP. DEG. F
6ØØ
5ØØ
4ØØ
3ØØ
2ØØ
1ØØ
Ø
1ØØ
2ØØ
3ØØ
4ØØ
5ØØ
6ØØ
TIME IN SEC.
ROUND NO. C17
TC #
3
4
6
5
7
2
1


TEMP. DEG. F
6ØØ
5ØØ
4ØØ
3ØØ
2ØØ
1ØØ
TC #
7
6
4
3
5
2
1
Ø
1ØØ
2ØØ
3ØØ
4ØØ
5ØØ
6ØØ
TIME IN SEC.
ROUND NO. C18


TEMP. DEG. F
600
500
400
300
200
100
TIME IN SEC.
0
100
200
300
400
500
600
TC #
4
3
6
5
7
2
1
ROUND NO. C19