COPY

AD-A221 385

AD

AD-E402 039

Technical Report ARPAD-TR-90001

THE FEASIBILITY OF DETECTING CORROSION IN ELECTRIC FUZES USING THE THERMAL TRANSIENT TECHNIQUE

Andre Shankle
Robert Maiello

April 1990

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

US ARMY
ARMAMENT MUNITIONS & CHEMICAL COMMAND
ARMAMENT RDE CENTER

Product Assurance Directorate
Picatinny Arsenal, New Jersey

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER Technical Report ARPAD-TR-90001	5. MONITORING ORGANIZATION REPORT NUMBER)
6a. NAME OF PERFORMING ORGANIZATION AMCCOM, PA&TD; 6b. OFFICE SYMBOL AMSMC-QAH-T (D)	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (CITY, STATE, AND ZIP CODE) Technology Office Picatinny Arsenal, NJ 07806-5000	7b. ADDRESS (CITY, STATE, AND ZIP CODE)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION ARDEC, IMD STINFO Br; 8b. OFFICE SYMBOL SMCAR-IMI-I	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (CITY, STATE, AND ZIP CODE) Picatinny Arsenal, NJ 07806-5000	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO.

11. TITLE (INCLUDE SECURITY CLASSIFICATION)
THE FEASIBILITY OF DETECTING CORROSION IN ELECTRIC FUZES USING THE THERMAL TRANSIENT TECHNIQUE

12. PERSONAL AUTHOR(S)
Andre Shankle, Robert Maiello

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (YEAR, MONTH, DAY)	15. PAGE COUNT
Final	FROM 9/89 TO 1/90	April 1990	70

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)
FIELD	GROUP	SUB-GROUP	Thermal transient Corrosion Electric fuze Non-destructive test Mines

19. ABSTRACT (CONTINUE ON REVERSE IF NECESSARY AND IDENTIFY BY BLOCK NUMBER)

The thermal transient test can be used to detect corrosion of the bridgewire in an electric fuze. The fuzes are used to set self-destruct times in mines but a corroded bridgewire may set a wrong self-destruct time thus causing injury to friendly troops.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL I. HAZNEDARI	22b. TELEPHONE (INCLUDE AREA CODE) AV 880-3316; 22c. OFFICE SYMBOL SMCAR-IMI-I

DD FORM 1473, 84 MAR

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

CONTENTS

FIGURES

INTRODUCTION

The object of this experiment was to determine if the thermal transient test can be used to detect corrosion on the bridgewire in an electric fuze or electroexplosive device (EED) (fig. 1). The fuzes are used to set self-destruct times in the following mines: M74, M75, BLU-92/B (fig. 2). When the mines are exposed to high humidity the bridgewire inside the fuze is susceptible to corrosion. An open (corroded) fuze may initiate the wrong self-destruct time which in turn will create a hazardous condition for friendly troops. Two examples of severe corrosion of the bridgewire in a fuze are shown in figures 3 and 4. These photographs were taken by a scanning electron microscope.

The current method for detecting corrosion in a fuze is measuring the cold resistance of the bridgewire. A high resistance reading indicates evidence of corrosion. It will be determined if the thermal transient test can be used as an alternative method.

THEORY

The thermal transient test is a nondestructive examination technique for inspection of the critical bridgewire interface. The test allows one to see inside the fuze nondestructively and determine if certain failure conditions or abnormalities are present.

Application of a current to a hot bridgewire type fuze causes the bridgewire temperature to increase due to dissipation of energy in the bridgewire. The temperature rise is accompanied by a corresponding increase in the resistance of the bridgewire material having a reasonable temperature coefficient of resistivity (TCR). By controlling the amplitude and duration of the current pulse the fuze will return to ambient temperature with no discernible permanent change at cessation of the pulse. The pulse magnitude is selected so that stress thermal characteristics become responsive. Pulse duration is chosen to produce interface thermal equilibrium. The rate at which the bridgewire changes, and the maximum value of the change, are determined by the interface characteristics. The signals generated by the changes are displayed on an oscilloscope for observation and analysis.

A fuze will generate a thermal response curve whose specific shape is controlled by the thermal capacity and thermal resistance inherent in the design of the fuze. A normal heating curve is always smooth and continuous. A typical electrothermal response of a fuze under test is illustrated in figure 5. The horizontal axis is a time base. The vertical axis represents the voltage developed across the bridgewire terminals.

Thermal response curves generated by the thermal transient test graphically describe the electrothermal character of the bridgewire interface under examination. The normal heating curve can be seriously degraded by interface faults; such as, corrosion, defective bridgewire welds, and other irregularities. A normal curve is shown in figure 6 and an abnormal curve due to corrosion is shown in figure 7. Defective mechanical fuzing of the bridgewire and posts, corrosion of the bridgewire and weld joints combine to generate a wide variety of erratic responses.

Thermal Transient Apparatus

Applying current to a bridgewire produces a rise in bridgewire temperature. The resistance of the bridgewire increases as does the voltage drop across it.

The apparatus used for measuring the thermal characteristics of electroexplosive devices (EED) was designed by Pasadena Scientific Industries (fig. 8).

The machine applies a balancing current to the device under test. Essentially a Wheatstone bridge is balanced. This is a low current pulse (10 mA was used for this experiment) to balance the Wheatstone bridge by obtaining a null or zero voltage on the oscilloscope. The variable resistor will match the resistance of the device under test.

A test current pulse can now be applied to the bridge and the voltage drop across the bridge can now be measured on the oscilloscope. This voltage drop will be the voltage drop across the device under test.

Using a storage oscilloscope one can capture the test pulse as a voltage drop. The test pulse for a normal fuze is the bridge is shown in figure 9. Observing higher frequencies, the test pulse can be seen as the bridgewire (in the fuze) heats up and its resistance changes (fig. 9). Sweeping for a still shorter time, one can observe the initial part of the pulse as the voltage drop increases across the fuze. (fig. 9).

A balancing current of 10 milliamperes was used. The pulse duration was 15 milliseconds. This pulse was repeated approximately once every second. A normal thermal curve for an electric fuze as the device under test is shown in figure 6. Note the short spike in the initial part of the curve. This is caused by the reactance of the machine bridge and other components as the test pulse is applied. The beginning of the trace was considered to be voltage = 0, time = 0.

Digital Storage Oscilloscope

The Nicolet Model 905 was used for the display and storage of the thermal measurements. The trigger output from the thermal transient apparatus was connected to channel B of the oscilloscope for amplification. Channel A was used for the voltage signal from the bridge. In the millisecond range the test pulse could be observed and in the microsecond range the thermal response could be observed.

Machine settings were:

Channel A: 100 mV full scale D.C. coupling

Channel B: 200 mV full scale D.C. coupling

Sweep: millisecond and microsecond range

Trigger: Channel B

Procedure

1. Perform thermal transient test on 25 electric fuzes. These should be brand new parts. This includes a measure of cold resistance with an ohmmeter.

2. Subject 15 of the 25 to an extreme environment of high humidity and high temperature.

3. Thermal transient measurement on all 25 fuzes.

4. Continue 24-hour periods of extreme conditions on the test group of 15 fuzes. Take thermal measurements of the entire set of 25 after each period.

5. Periods for this experiment were: 0 hours humidity exposure, 24, 48, 72, 96, 168, and 192 hours.

6. Compare thermal curves of fuzes subjected to humidity to the original thermal curves of 0 hours humidity exposure.

7. Correlate thermal measurements to the degree of corrosion of the fuzes. This includes inspection of the bridgewire and header cap assembly under an electron microscope.

The first part of each test was measure of the cold resistance of the fuze. This was done with an ohmmeter. The maximum current through the fuze from the meter was approximately 2 milliamperes. The resistance would increase if the ohmmeter was held on the fuze for too long. This presented some error, plus or minus 0.3 ohms at the most.

The fuze was then connected to the thermal transient machine input through two short clip connectors, approximately one inch in length. The resistance of the cables did not appear to affect the signal from the bridge and was therefore considered nominal.

The machine was balanced by obtaining a flat trace (zero voltage drop) on the oscilloscope. This was done with the 10 mA balancing current. The thermal test was conducted using the 25 mA pulse. The curves were stored on disk. Measurements taken were maximum voltage (amplitude), half the maximum voltage, and time to reach half the maximum voltage.

Fifteen fuzes wre subjected to a high humidity, high temperature environment. The environment was 100 percent humidity at a temperature of 150°F. After 24 hours in this humid environment the thermal test was repeated with the same settings (test current = 25 mA for 15 ms) on the thermal transient machine. The only different setting was the balance resistance which required adjustment for each fuze in order to balance out the cold resistance.

After a fuze was subjected to a humid environment, the time to reach half the maximum voltage was subtracted from the respective time from test 1 (the time to reach half the maximum voltage for that fuze with no humidity exposure). This difference (t2-t1 for example) represents the difference in rise time between two thermal tests for the test group (fuzes 1 through 15). The control group (fuzes 16 through 25) also had a difference in rise (t2-t1) but neither t2 nor t1 represents the fuze subjected to any humidity. These fuzes were in a dry place at room temperature for all tests. The difference in rise time for this group was then considered the variation in measurement due the thermal transient test set. Averaging the differences for the control group a machine error was obtained. This was then subtracted from the test group rise time differences (t2-t1-average control group difference). This quantity was then considered the difference in rise time between two thermal tests and is corrected for machine error. This was done for tests 2 through tests 7.

After all thermal tests were done the fuzes were examined under optical microscope to observe the header seal on the fuze. The head was then cut open and they were examined under a scanning electron microscope. This work resulted in exceptional pictures of the fuze bridgewire and weld joints of all 25 fuzes.

DISCUSSION

Voltage and time measurements were taken from each test. Data are tabulated in appendix A with the following explanations:

Ro is the cold resistance of the fuze as measured on an ohmmeter.

Vmax is the maximum amplitude the voltage across the fuze reached. When no Vmax is given in the table Vmax is simply the voltage V(t). All voltages are d.c. and in millivolts.

V(t) is the voltage at one point on the thermal curve and was usually taken at Vmax or near it.

t(1/2) is the time in microseconds at which the voltage drop is V(t) divided by two.

T2,T3...-T1 represents the rise time t(1/2) from test 1 (0 hours humidity exposure) subtracted from t(1/2) of another test.

T2,T3...-T1-avg. ctrl. diff. represents t(1/2) of test 1 subtracted from t(1/2) another test. Subtracted from this quantity is the average difference in rise times of the control group (fuzes 16 through 25).

Where data is missing in the tables the fuze was pulled out either to be examined under the electron microscope, or the fuze was blown, or the resistance had increased and it could not be tested by the thermal transient machine.

Also computed was the coefficient B from equation 2 (fig. 5) for each fuze from each of the seven tests. This is tabulated in appendix B.

The maximum voltage drop for all 25 fuzes on the first test is shown on graph 1 (app C). Note the large spread or variation between the fuzes. The amplitude of the voltage will vary between 33 mV to 92 mV depending on the fuze. Again, the current was the same for all the tests. The maximum voltage reached for the other six thermal tests is shown on graphs C-2 through C-7 (app C). Note that the voltages for the test group (fuzes 1 through 15 on the horizontal axis) and the voltages for the control group (fuzes 16 through 25) remain approximately the same from test to test. The graph is the same shape for each test. This indicates that the variance in voltage readings is due to the fuzes and not to the thermal test set.

The time to reach V(t)/2 or approximately half the maximum voltage for each test is shown on graphs C-8 thorugh C-14 (app C). Here again, the times are scattered from fuze to fuze but the graph takes the same shape for each test. Here, however, the rise times for the test group (fuzes 1 through 15) start to increase as the fuzes are exposed to more humidity. Note that in each test in the control group (fuzes 16 through 25) the rise time never goes above 500 microseconds. Comparing graphs C-8 and C-9 (app C), one can see that fuze 3 has increased from a rise time of 230 μS (0 hours humidity) to a rise time of 800 μS after just 24 hours of high humidity and high temperature exposure.

The difference in rise time after the test fuzes were in high humidity is shown in graph C-15 (app C). This graph and graphs C-16 through C-20 are corrected for machine error by subtracting out the average difference in the control group between the two tests from the test group rise times. These graphs show that on the average the test group (fuzes 1 through 15) showed a greater change in rise time than the control group (fuzes 16 through 25). Some fuzes in the test group did not show a significant change in rise time compared to test 1. Note also that some changes in rise time of the test group were equal to the variance in rise time of the control group.

The difference in rise time between tests 2 through 7 and test 1 should be zero (ideally) for the control group. The control group should not vary from test to test as the fuzes 16 through 25 were not subjected to any stress between test. The difference in rise time measurements here must then be a variation in test conditions or the machine error (or actual deterioration of the control fuzes). Subtracting the average of the rise time differences from all of the rise time differences was considered a correcting factor in test measurements. Both the difference in rise time and the corrected difference are shown in the tabulated data of appendix A.

The next part of the expreiment was to fit the curve to equation 2 (fig. 5) which was done by calculating the coefficient "B". This is inversely proportional to the rise time. These coefficients are tabulated in appendix B. The calculated coefficients with the coefficient for each test plotted with test 1 coefficients are summarized on graphs C-1 through C-6 (app C). For example, in graph 22 the square points represent test 3. Note the coefficients are lower in the test group of test 3 than test 1. The coefficients remain generally stable for the control group (fuzes 16 through 25).

The coefficients for six thermal tests are shown on bar graph B-6 (app B). Test 6 of 168 humidity exposures was omitted from the plot due to the plotting program. The leftmost bar represents the coefficient B from test 1; 0 hours humidity exposure. One can see the bar height decreses as the test increases for fuzes 1 through 15, the test group. The rightmost bar (test 7) is always lower than the leftmost (test 1). In general, the B coefficient decreased as the fuzes were subjected to more humidity.

Lastly, the fuzes were examined under optical and scanning electron microscope. The results showed minor to severe corrosion for all 25 fuzes. The test fuzes (1 through 15) had severe corrosion, but the control group also showed corrosion that was considered severe. Typical corrosion is shown in figures 3 and 4.

CONCLUSION

The purpose of this experiment was to determine if the thermal transient technique is a feasible way to detect corrosion of a fuze bridgewire. Referring to graph C-15 (app C) one can see a difference between the rise time of a fuze after exposure to a humid environment (fuzes 1 through 15) and the rise time of a fuze that was not exposed to humid conditions. The results of test 2, 24 hours humidity exposure in appendix C show an average rise time of 332 microseconds for the control group while the average rise time for the test group was 400 microseconds. Clearly there was a difference between the test group and control group measured on the thermal transient apparatus. There was, however, a large standard deviation in all measurements (large scatter of readings). This could be explained by assuming faulty seals on the fuzes, thereby compromising fuze integrity. The consistency of these readings ruled out that machine error and the variance was taken to be from the fuzes themselves. Referring to graph C-15 (app C) again, one can see that the difference in rise time from test 1 for the test group can be the same order of magnitude as the control group. Within a test the variance in measurements can account for the two groups showing the same rise time difference from test 1.

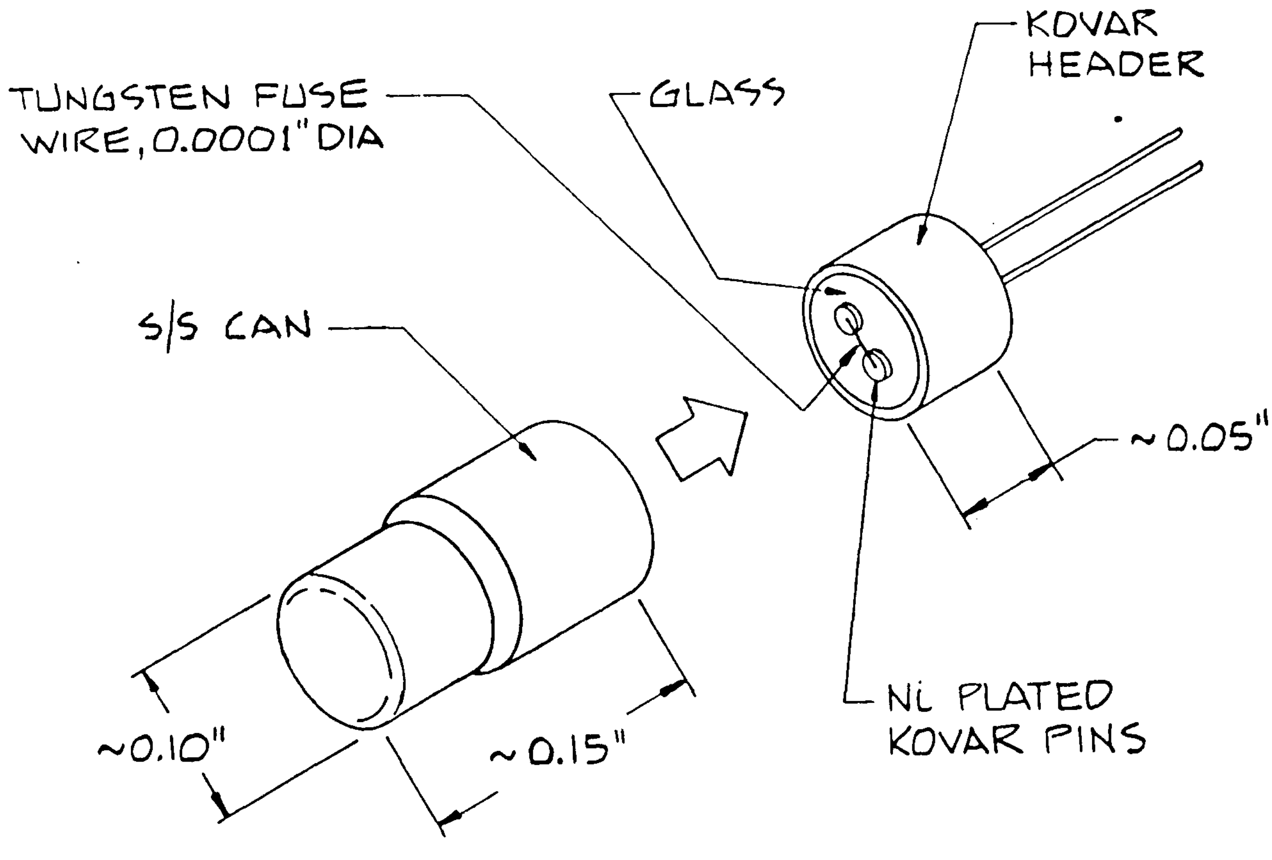
Again, the machine error was considered the average difference of a control group from test 1 because there should not have been a difference for this group. Referring to graphs C-15 through C-20 (app C) one can see that the control group's rise time difference from test 1 varies from test to test. The difference, however, was generally stable. For example, control fuze 20 has a difference from test 1 of +62, +23, +44, +26, +29, and +22 µS for test 2 through 7, respectively. This is a plus or minus 20 µS change from test to test. The change is most probably experimental error in each thermal test. This error could include balancing conditions of each test, contact of wire clips and fuze leads (oxidation of the leads also), and temperature changes in the lab which would affect the heat dissipation at the fuze bridgewire.

Another example of a corroded bridgewire is shown in figure 10 (fuze 9 from the test group after 192 hours of humidity exposure). The bridgewire of fuze 18 from the control group is shown in figure 11. Note corrosion along the wire and how the wire is bent out of the weld to the fuze lead (lower left corner). There were similar defects in all 25 fuzes from the results of the electron microscope evaluation. The control group fuzes showed minor to severe corrosion as did the test group. This can account for the large variance in measurements between fuzes as each fuze possessed a unique degree of corrosion or weld defect. While the corrosion on test group fuzes was expected, lifted bridgewire at the weld was not.

On the average though, the thermal rise time increased for the test group as humidity exposure increased (app C graphs C-15 through C-20). Fuzes 1 through 15, on the average, can be seen to increase as the test increases. While some differences from the test group are the same order of magnitude as the control group, there was generally more of a change in rise time in the test group then the control group.

The results of the electron microscope inspection showed that all of the fuzes possessed some degree of corrosion as given. The results of the thermal measurements and humidity exposure represent the thermal transient apparatus detecting an even greater degree of corrosion while showing a large variance between measurements from each fuze.

THE TUNGSTEN FUSE



After wire attachment and inspection, the S/S can is crimped over end of header and header to can interface sealed with a potting material.

Figure 1. Electric fuze

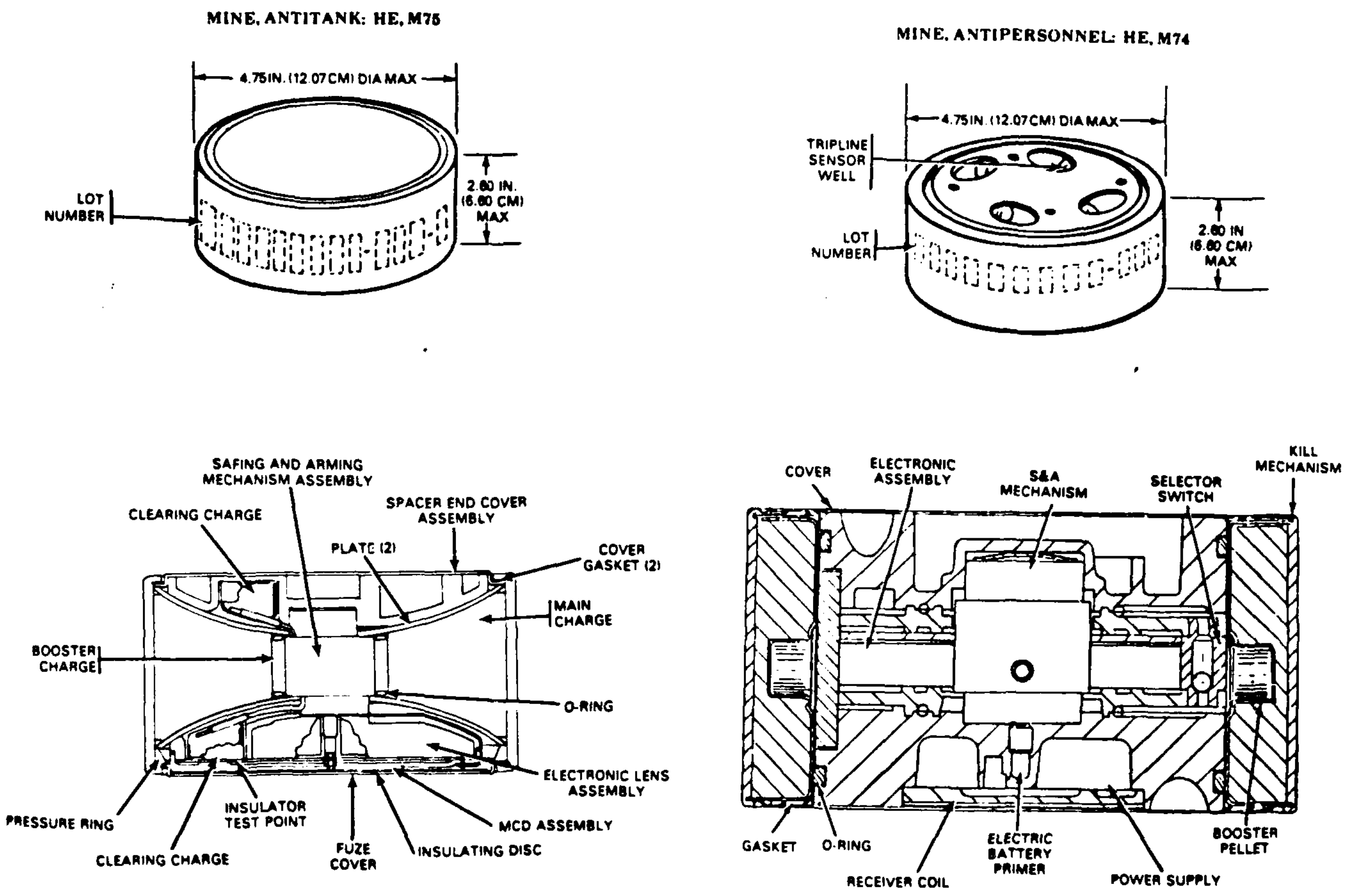


Figure 2. Two mines which use the electric fuze

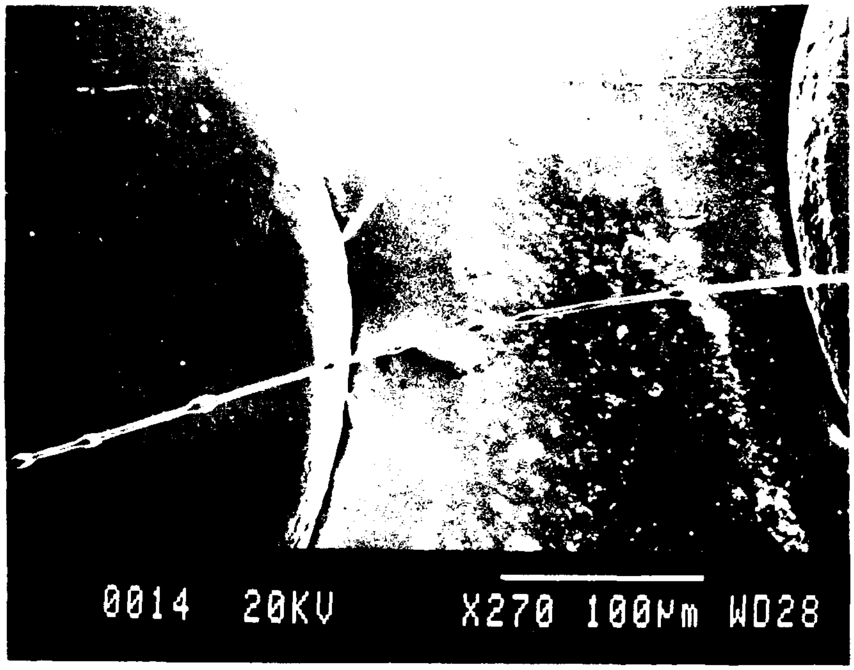


Figure 3. Severe corrosion along the bridgewire

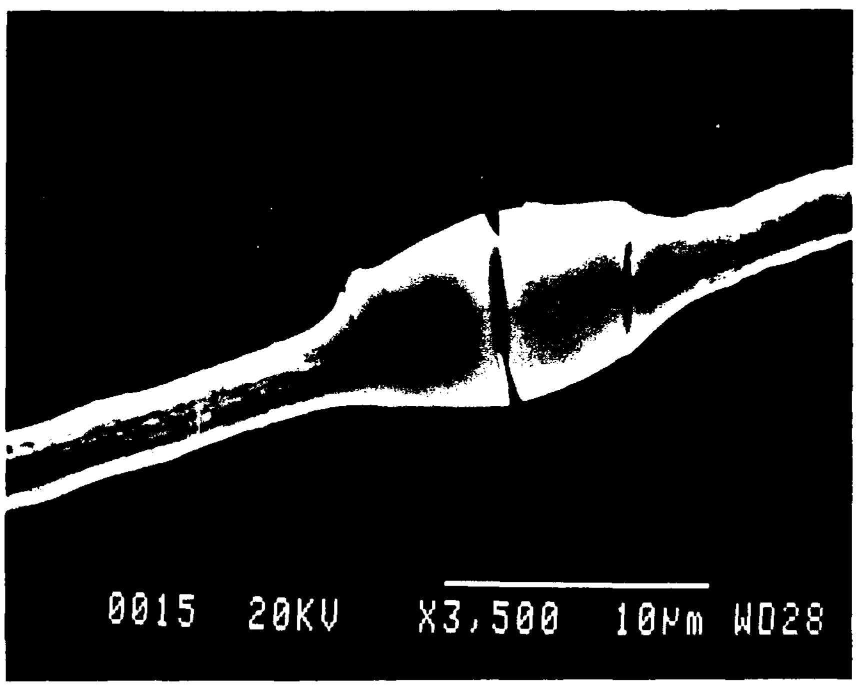
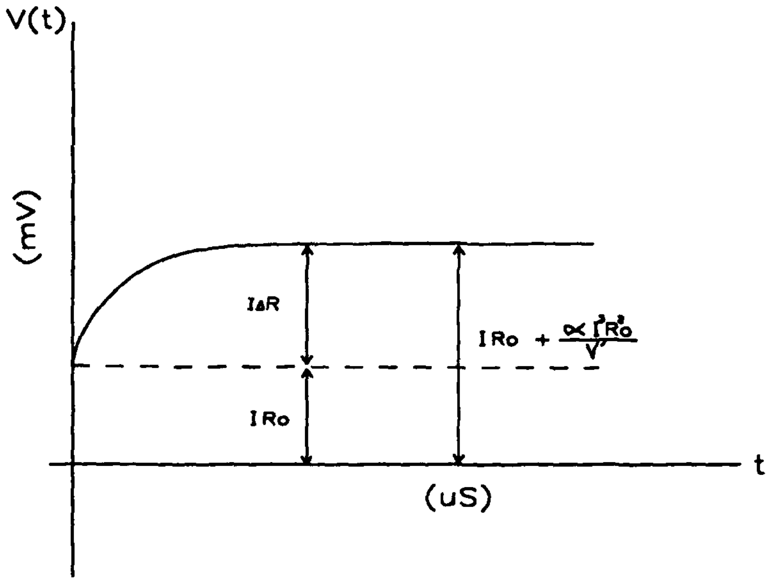


Figure 4. Close-up of corroded bridgewire



$$V(t) = I\,Ro\left[\,1 + \frac{\alpha I^2 Ro}{V'}\left(1 - e^{-\frac{V' t}{C_p}}\right)\right] \qquad (1)$$

$$V' = V - \alpha I^2 Ro \quad \text{and} \quad \tau = \frac{C_p}{V} = \text{time constant}$$

Where:

V = Thermal Conductance

I = Test Current

Ro = Cold Resistance

α = Temperature Coeff. of Resistivity

C_p = Thermal Capacitance

Equation 1 can be rewritten:

$$V'(t) = Vmax\left(1 - e^{-Bt}\right) \qquad (2)$$

Where: $V'(t) = V(t) - I\,Ro$

$$B = \frac{V'}{C_p}$$

$$Vmax = \frac{\alpha I^3 Ro^2}{V'}$$

Solving (2) for B:

$$B = \frac{-1}{t} * Ln\left(1 - \frac{V'(t)}{Vmax}\right)$$

Figure 5. Voltage drop across fuze

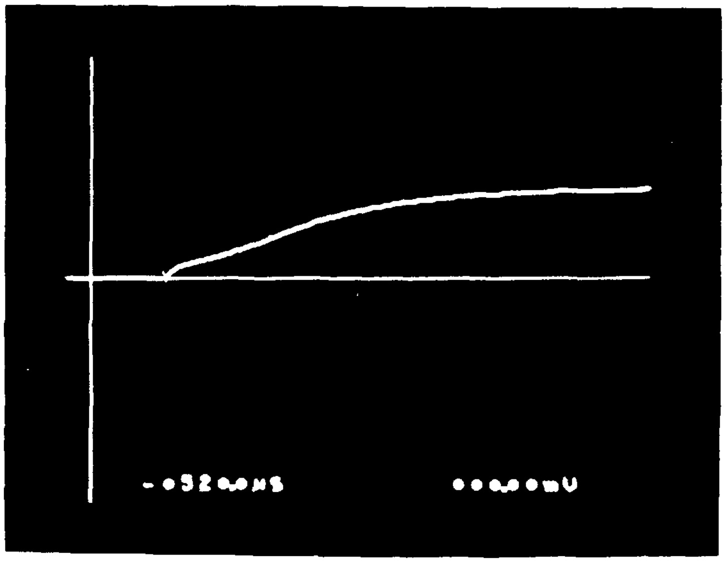


Figure 6. A normal heating curve

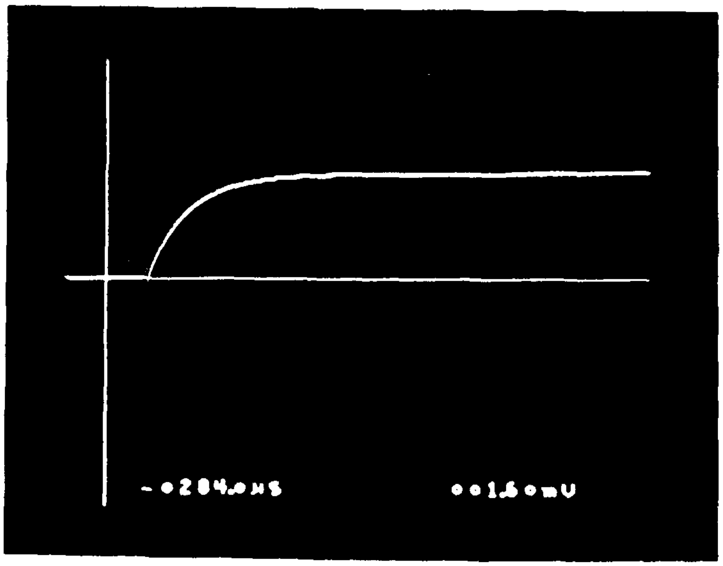
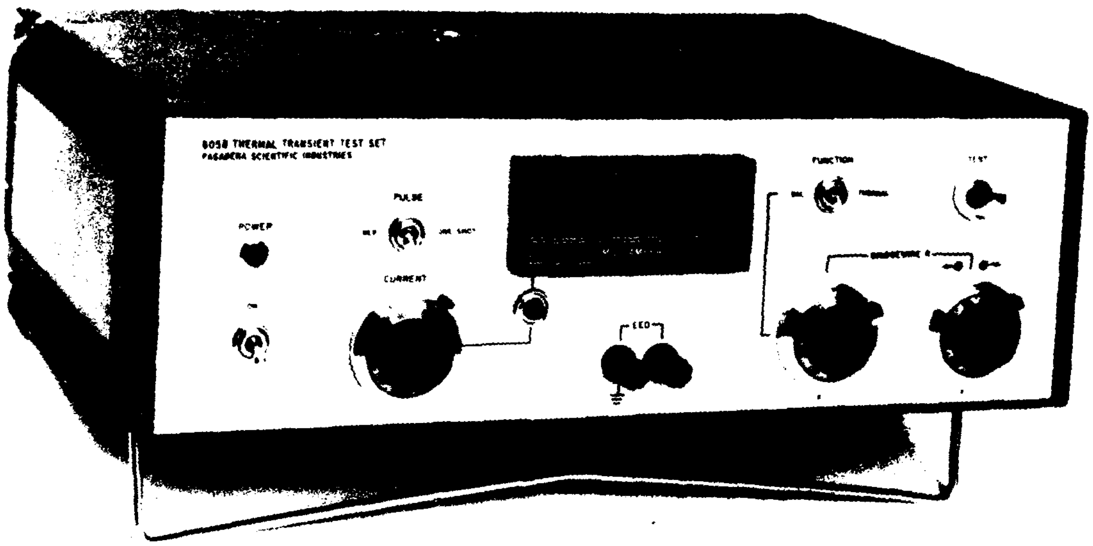
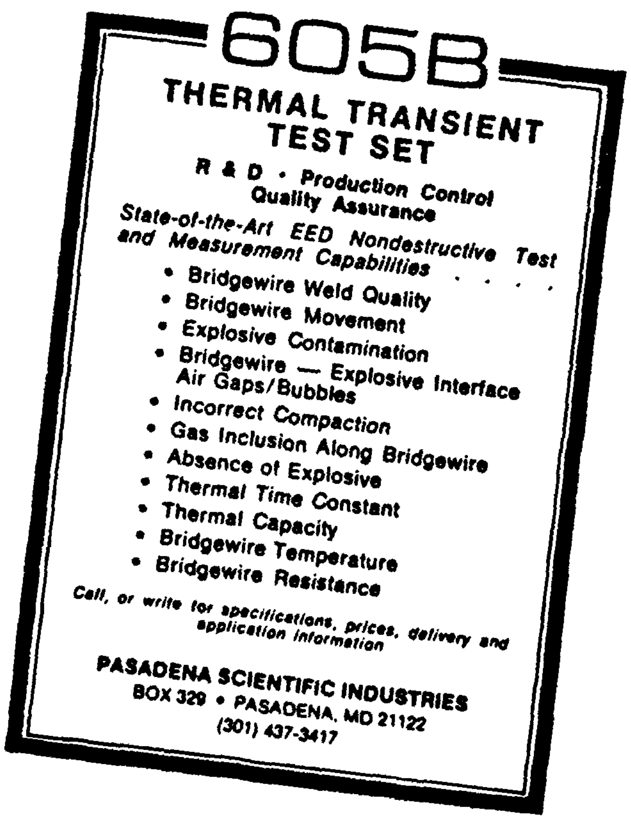
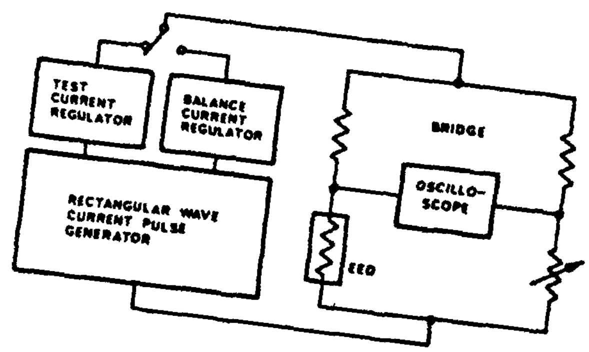


Figure 7. An abnormal heating curve







Circuit configuration

Figure 8. Thermal transient test equipment

THERMAL TRANSIENT TEST SET - MODEL 605B

SPECIFICATIONS

* BRIDGEWIRE RESISTANCE RANGE: 0.10 to 10.50 ohms.

* TEST CURRENT: 10 to 2,000 milliamperes (adjustable by 10-turn front panel control).

* BRIDGE BALANCE CURRENT: 10 milliamperes (internally adjustable from 5 to 15 milliamperes).

TEST CURRENT INDICATOR: 3½ digit panel meter (0 to 1999 milliamperes).

BRIDGEWIRE RESISTANCE READOUT: Two 10-turn dials.

CURRENT PULSE MODES: Repetitive or one-shot (selectable by front panel switch).

CURRENT PULSE DURATION: 10 to 70 milliseconds (adjustable by internal control).

CURRENT PULSE REPETITION RATE: 2.5 to 9.0 pulses per second (adjustable by internal control).

BRIDGE BALANCE STATUS INDICATOR: Two (2) light emitting diodes (LED's).

INPUT POWER: 105 - 125V, 50-60Hz, 75 watts (max).

TEMPERATURE: Operating: $0^{\circ}C$ to $+50^{\circ}C$
Storage : $-40^{\circ}C$ to $+70^{\circ}C$

COOLING: Convection.

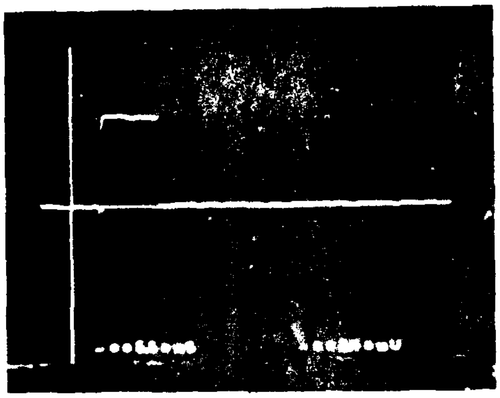
DIMENSIONS: 16.88"W x 5.25"H x 12.70"D (bench mount).
19.00"W x 5.25"H x 12.70"D (rack mount).

WEIGHT: 22.5 lbs (approx) net;
36.0 lbs (approx) shipping

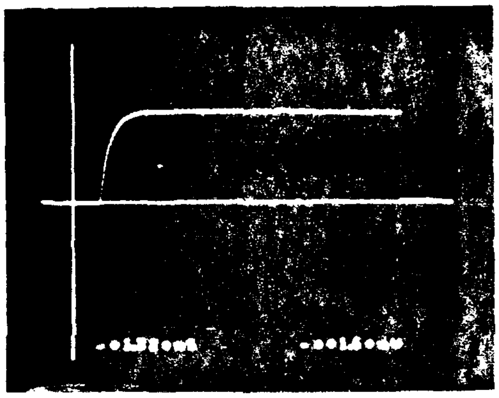
ACCESSORIES SUPPLIED: AC power cord; coaxial cable assemblies; Reference Bridgewire RB101; cabinet tilt stand; Installation and Operating Manuals.

* NOTE: The 605B has a single-ended output and is designed for use with a user-supplied oscilloscope with 1mv/cm vertical deflection sensitivity.

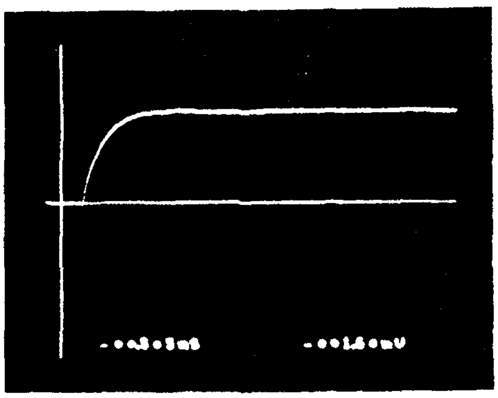
Figure 8. Continued



20 µS sweep



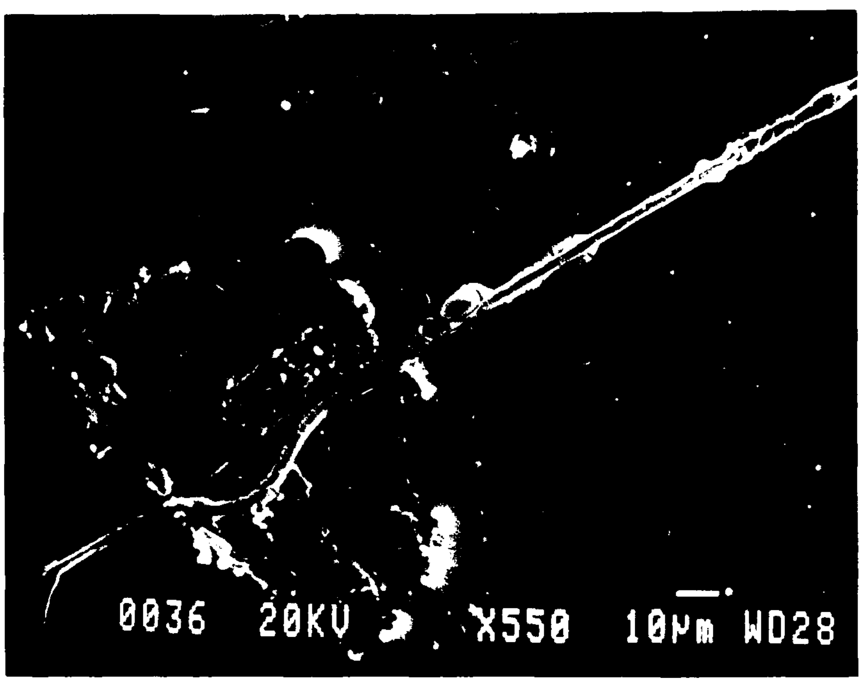
10 µS sweep



2 µS sweep

Figure 9. Test pulse

Figure 10. Fuze 9 test group



Fuze 11. Fuze 18 control group

Appendix A

Tabulated Thermal Data

		Test 1	0 Hours Humidity		
Fuss#	Ro	Vmax	V(t)	V(t)/2	t 1/2
1	9.5	78.4	77.6	38.8	337
2	8		32.8	16.4	263
3	9.5		49.6	24.8	230
4	8.7		63.2	31.6	347
5	9.5	91.2	90.4	45.2	359
6	9.9		49.6	24.8	198
7	10	52.8	52	26	192
8	9.1		42.4	21.2	181
9	9.6		89.6	44.8	418
10	8.4		56.8	28.4	371
11	9.4		88.8	44.4	413
12	9.4		64.8	32.4	315
13	9.3	43.2	41.6	20.8	146
14	8.3		61.6	30.8	341
15	9.5	40.8	40	20	186
16	9.5	46.4	44.8	22.4	210
17	9.3	80	78.4	39.2	414
18	9.2	48	47.2	23.6	275
19	8.6		66.4	33.2	383
20	9	78.4	76.8	38.4	374
21	9.1		56.8	28.4	277
22	8.9		44	22	235
23	9.1	32.8	32	16	168
24	9.2	85.6	84	42	327
25	9.3	89.6	84.8	42.4	374

TEST 2-- 24 HOURS Humidity

fuss #	r0	V max	V(t)	V(t)/2	t1/2	track	avg
1	9.7	85.6	84.8	42.4	376	1	
2	8.1		32.8	16.4	300	2	
3	9.8	40	39.2	19.6	799	3	
4	8.8	64.8	63.2	31.6	512	4	
5	9.8	99.2	97.6	48.8	486	5	
6	9.9		51.2	25.6	246	6	
7	10.1		50.4	25.2	257	7	
8	9.3		46.4	23.2	206	8	
9	9.7	99.2	96.8	48.4	503	1	
10	8.5	63.2	62.4	31.2	450	2	
11	9.7	96.8	94.4	47.2	544	3	
12	9.9	65.6	64	32	432	4	
13	9.5	44.6	40.8	20.4	217	5	
14	8.8	63.2	62.4	31.2	538	6	avg.Samp.
15	9.9		53.6	26.8	141	7	400.4666
16	9.5		49.6	24.8	218	8	
17	9.7	87.2	86.4	43.2	426	1	
18	9.5		47.2	23.6	305	2	
19	9.1		70.4	35.2	428	3	
20	9	80.8	80	40	436	4	
21	9.2		55.2	27.6	257	5	
22	9.2		44.8	22.4	202	6	
23				0		7	
24	9.4		88.8	44.4	343		avg.Ctr.
25	9.6		96	48	374	8	332.1111

	Test 2	Diff. from Test 1	
t2-t1=t		Fuss #	t-avg.
39		1	25.667
37		2	23.667
569		3	555.667
165		4	151.667
127		5	113.667
48		6	34.667
65		7	51.667
25		8	11.667
85		9	71.667
79		10	65.667
131		11	117.667
117		12	103.667
71		13	57.667
197		14	183.667
-45		15	-58.333
8		16	8
12		17	12
30		18	30
45		19	45
62		20	62
-20		21	-20
-33	avg.Dff.	22	-33
	13.33333	23	0
16	std.Ctrl	24	16
0	28.13064	25	0

TEST 3-- 48 Hours Humidity

fuss#	Ro	Vmax	V(t)	V(t)/2	t(1/2)	Avg t(1/2
1	10.1	88	87.2	43.6	467	
2	8.3		33.6	16.8	422	
3						
4	10.6	92.8	87.2	43.6	577	
5	10.2		105.6	52.8	462	
6	10.5		44	22	236	
7	10.7		40.8	20.4	221	
8	9.6		48	24	208	
9	9.9	100	98.4	49.2	467	
10	8.8	66.4	64	32	463	
11	11.2	118.4	113.6	56.8	551	
12	10.1	68	67.2	33.6	436	
13	10.1	41.6	40	20	192	
14	10.1	88	80.8	40.4	623	avg Samp
15	10.1	41.6	40.8	20.4	187	393.7142
16	9.5		53.6	26.8	193	
17	9.4	88	87.2	43.6	407	
18	9.3		51.1	25.55	252	
19	8.8		70.4	35.2	370	
20	9.2		84	42	397	
21	9.3	56.8	56	28	248	
22	9.1	45.6	44.8	22.4	222	
23						
24	9.4		88	44	362	avg Ctrl
25	9.6	96.8	94.4	47.2	398	316.5555

	Test 3 Diff. from Test 1		
Fuse#	t3-t1=t	avg diff.	t-avg.dif.
1	130		132.222
2	159		161.222
3			
4	230		232.222
5	103		105.222
6	38		40.222
7	29		31.222
8	27		29.222
9	49		51.222
10	92		94.222
11	138		140.222
12	121		123.222
13	46		48.222
14	282		284.222
15	1		3.222
16	-17		-17
17	-7		-7
18	-23		-23
19	-13		-13
20	23	ctr dif	23
21	-29	-2.22222	-29
22	-13	std.	-13
23		21.93818	
24	35	std(n-1)	35
25	24	23.269	24

TEST 4-- 72 Hours Humidity

fuss#	r0	Vmax	V(t)	v(t)/2	t(1/2)	avg
1	10.4	88.8	88	44	392	
2	8.6	34.4	32.8	16.4	289	
3						
4	11.7		unbalance	0		
5	10.3	107	104	52	469	
6	11	44	43.2	21.6	269	
7	11.2		38.4	19.2	314	
8	10		40	20	225	
9	10.4	96	94.4	47.2	588	
10	9	67.2	65.6	32.8	508	
11				0		
12	10.2	68.8	68	34	455	
13	10.3		41.6	20.8	193	
14	15.9		unbalance	0		avg.Samp
15	10		42.4	21.2	219	356.4545
16	9.4	51.2	50.4	25.2	185	
17	9.3	88.8	87.2	43.6	403	
18	9.2		51.2	25.6	248	
19	8.6	72	70.4	35.2	408	
20	9.4	87	86.4	43.2	418	
21	9.3	55.2	54.4	27.2	236	
22	9.3		43.2	21.6	196	
23						
24	9.6	82.4	81.6	40.8	334	avg.Ctrl.
25	9.9		92	46	395	313.6666

	Test 4 Diff. from Test 1		
fuss #	t4-t1=t	Avg. Diff	t-Avg. Ctrl
1	55		60.111
2	26		31.111
3			
4			
5	110		115.111
6	71		76.111
7	122		127.111
8	44		49.111
9	170		175.111
10	137		142.111
11			
12	140		145.111
13	47		52.111
14			
15	33		38.111
16	-25		-25
17	-11		-11
18	-27		-27
19	25		25
20	44		44
21	-41		-41
22	-39	Avg Ctrl	-39
23		-5.11111	
24	7		7
25	21		21

TEST 5 96 Hours Humidity

fuss#	Ro	Vmax	V(t)	V(t)/2	t(1/2)	Avg t1/2
1	10.4	92.8	91.2	45.6	424	
2	8.6	28.8	28	14	735	
3	Cut-up			0		
4	13.2			0		
5	10.3	112	107.2	53.6	641	
6	10.6		44.8	22.4	240	
7	11		40	20	246	
8	9.8		42.4	21.2	223	
9	10.3	107.2	105.6	52.8	482	
10	9.2	66.4	60.8	30.4	948	
11	Cut-up			0		
12	10.3	67.2	65.6	32.8	482	
13	10.3	42.4	41.6	20.8	350	
14	Blown			0		avg t1/2
15	10.3	43.2	41.6	20.8	218	453.5454
16	9.3		49.6	24.8	196	
17	9.2		84	42	403	
18	9	48	47.2	23.6	235	
19	8.5		69.6	34.8	381	
20	8.1		83.2	41.6	400	
21	9.3		55.2	27.6	239	
22	9.1		44	22	213	avg ctrl.
23	Cut-up			0		312.8888
24	9.7		86.4	43.2	340	std.ctrl.
25	9.6	92.8	92	46	409	85.30135

Test 5 Diff. from Test 1

fuss #	t5-51=t	avg diff.	t-avg.dif.
1	87		92.88
2	472		477.88
3			
4			
5	282		287.88
6	42		47.88
7	54		59.88
8	42		47.88
9	64		69.88
10	577		582.88
11			
12	167		172.88
13	204		209.88
14		avg samp.	
15	32	183.9090	37.88
16	-14		-14
17	-11		-11
18	-40		-40
19	-2		-2
20	26		26
21	-38		-38
22	-22	avg ctrl.	-22
23		-5.88888	
24	13	std ctrl.	13
25	35	24.95972	35

TEST 6 168 Hour Humidity

fuss#	Ro	Vmax	V(t)	V(t)/2	t(1/2)	Avg t1/2
1	blown					
2	9.1		26.4	13.2	587	
3				0		
4	17.3			0		
5	10.9		96	48	91	
6	10.7		39.2	19.6	461	
7	11		36	18	221	
8	9.9		42.4	21.2	423	
9	10.3		89.6	44.8	636	
10	9.8		49.6	24.8	1222	
11				0		
12	10.6		18.4	9.2	339	
13	10.2		39.2	19.6	687	
14	blown			0		avg t1/2
15	10		43.2	21.6	210	487.7
16	9.5	52.8	52	26	183	
17	9.4		88.8	44.4	395	
18	9.3		51.2	25.6	254	
19	8.7	73.6	72.8	36.4	401	
20	9.2		85.6	42.8	403	
21	9.3		56.8	28.4	225	
22	9.2	44.8	44	22	219	avg ctrl.
23				0		314.1111
24	9.5		87.2	43.6	345	std.ctrl.
25	9.6		94.4	47.2	402	87.21804

Test 6 Diff. from Test 1

fuss #	t6-t1=t	avg diff.	t-avg.dif.
1			
2	324		328.67
3			
4			
5	-268		-263.33
6	263		267.67
7	29		33.67
8	242		246.67
9	218		222.67
10	851		855.67
11			
12	24		28.67
13	541		545.67
14		avg samp.	
15	24	224.8	28.67
16	-27		-27
17	-19		-19
18	-21		-21
19	18		18
20	29		29
21	-52		-52
22	-16	avg ctrl.	-16
23		-4.66666	
24	18	std ctrl.	18
25	28	27.01439	28

TEST 7 192 Hours Humidity

fuss#	Ro	Vmax	V(t)	V(t)/2	t(1/2)	Avg t1/2
1	blown			0		
2	8.9	28.8	27.2	13.6	390	
3	Cut-up			0		
4	Blown			0		
5	10.9	120	113.6	56.8	637	
6	10.9		44.8	22.4	266	
7	11		39.2	19.6	227	
8	9.9	43.2	41.6	20.8	244	
9	10.4	107.2	104	52	493	
10	10.1	75.2	65.6	32.8	914	
11	Cut-up			0		
12	Blown			0		
13	10.7		40.8	20.4	209	
14	blown			0		avg t1/2
15	10.4		44	22	261	404.5555
16	9.2	50.4	49.6	24.8	180	
17	9.1		84	42	323	
18	9		50.4	25.2	243	
19	8.4		68	34	341	
20	8.9		79.2	39.6	396	
21	8.7		53.6	26.8	239	
22	8.9		40.8	20.4	235	avg ctrl.
23				0		300.7777
24	9.2	85.6	84.8	42.4	350	std.ctrl.
25	9.3		91.2	45.6	400	74.17363

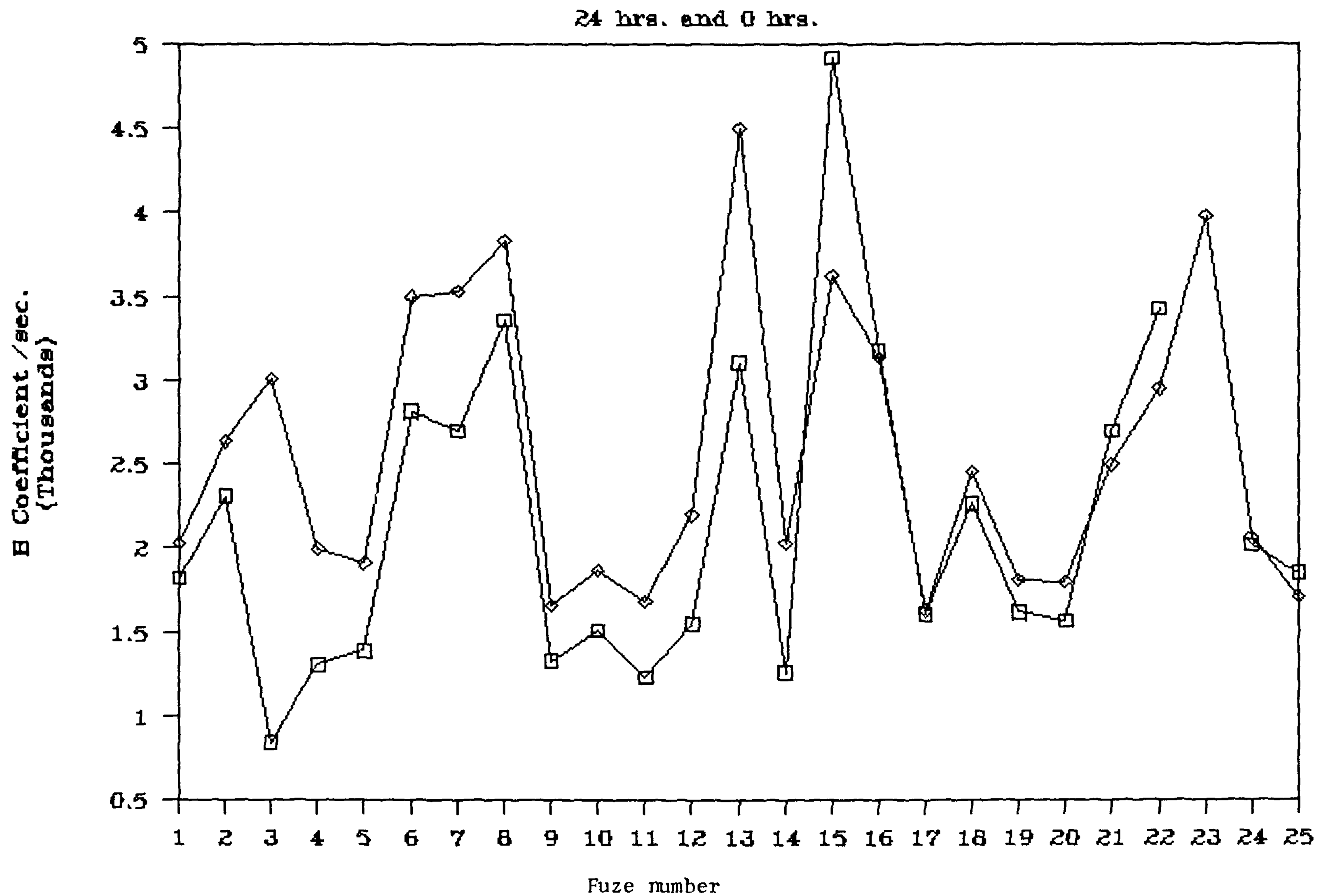
Test 7 Diff. from Test 1

fuss #	t7-t1	avg diff.	t7-t1-avg.ctrl.	
1				
2	127		145	
3				
4				
5	278		296	
6	68		86	
7	35		53	
8	63		81	
9	75		93	
10	543		561	
11				
12				
13	63		81	
14		avg samp.		avg. diff
15	75	147.4444	93	165.4444
16	-30		-30	
17	-91		-91	
18	-32		-32	
19	-42		-42	
20	22		22	
21	-38		-38	
22	0	avg ctrl.	0	
23		-18		
24	23	std ctrl.	23	
25	26	36.79673	26	

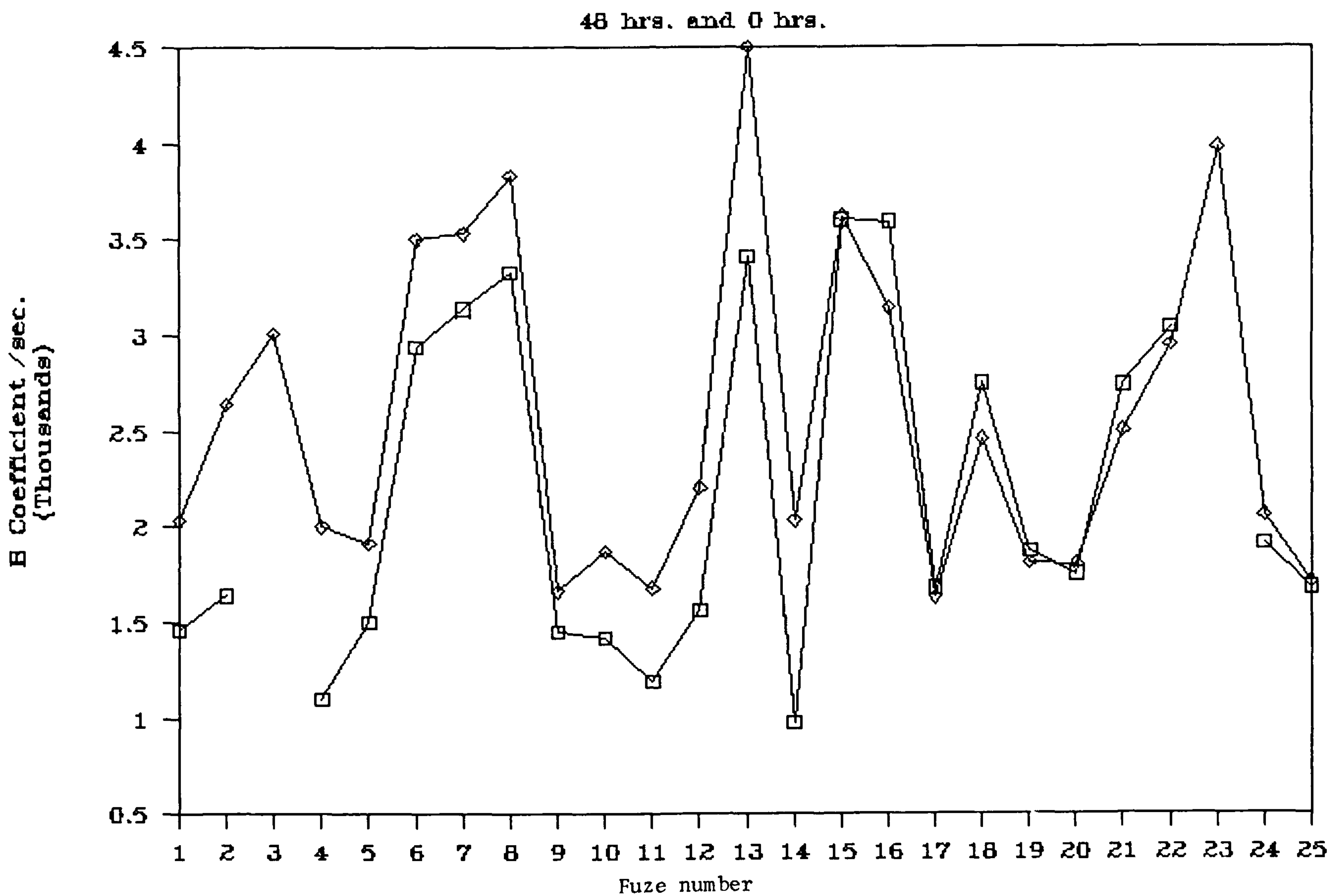
Appendix B

Coefficients and Graphs

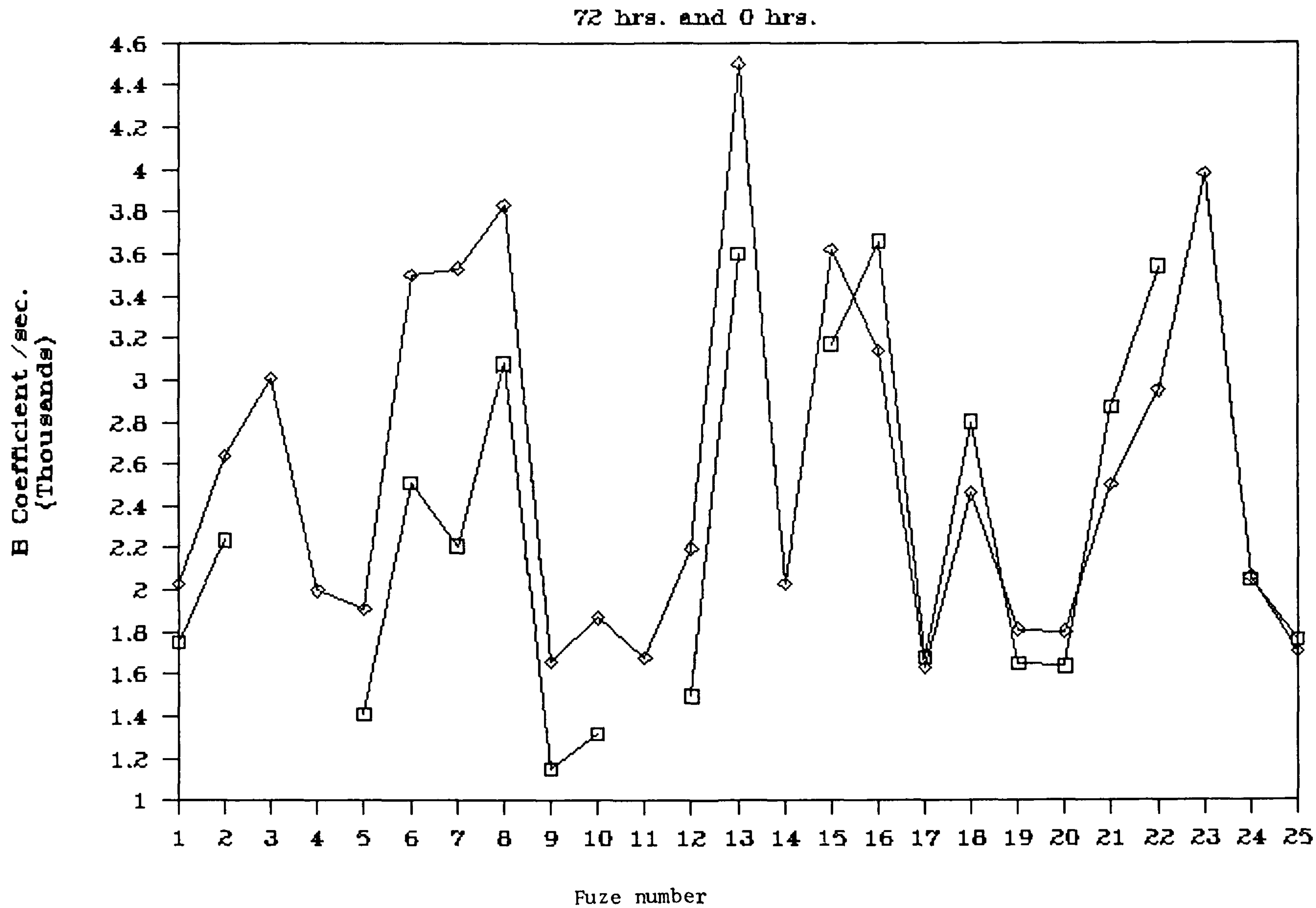
	Coefficient		B		(/sec)		
fuse#	192 hrs	168 hrs	96 hrs	72 hrs	48 hrs	24 hrs	0 hrs.
1			1590	1750	1460	1820	2030
2	1640	1180	906	2240	1640	2310	2640
3						843	3010
4					1100	1310	2000
5	1000	7630	1020	1410	1500	1390	1910
6	2600	1500	2890	2510	2940	2820	3500
7	3050	3140	2820	2210	3140	2700	3530
8	2690	1640	3110	3080	3330	3360	3830
9	1350	1090	1410	1150	1450	1330	1660
10	627	567	646	1320	1420	1510	1870
11					1190	1230	1680
12		2044	1390	1500	1560	1550	2200
13	3320	1000	1927	3600	3410	3110	4500
14					974	1260	2030
15	2660	3300	3010	3170	3600	4920	3620
16	3760	3790	3540	3660	3590	3180	3140
17	2150	1755	1720	1680	1680	1610	1630
18	2850	2730	2880	2800	2750	2270	2460
19	2030	1730	1850	1650	1870	1620	1810
20	1750	1720	1730	1640	1750	1570	1800
21	2900	3080	2900	2870	2740	2700	2500
22	2950	3170	3250	3540	3040	3430	2950
23							3980
24	1950	2010	2040	2050	1910	2020	2060
25	1730	1720	1670	1760	1680	1850	1710



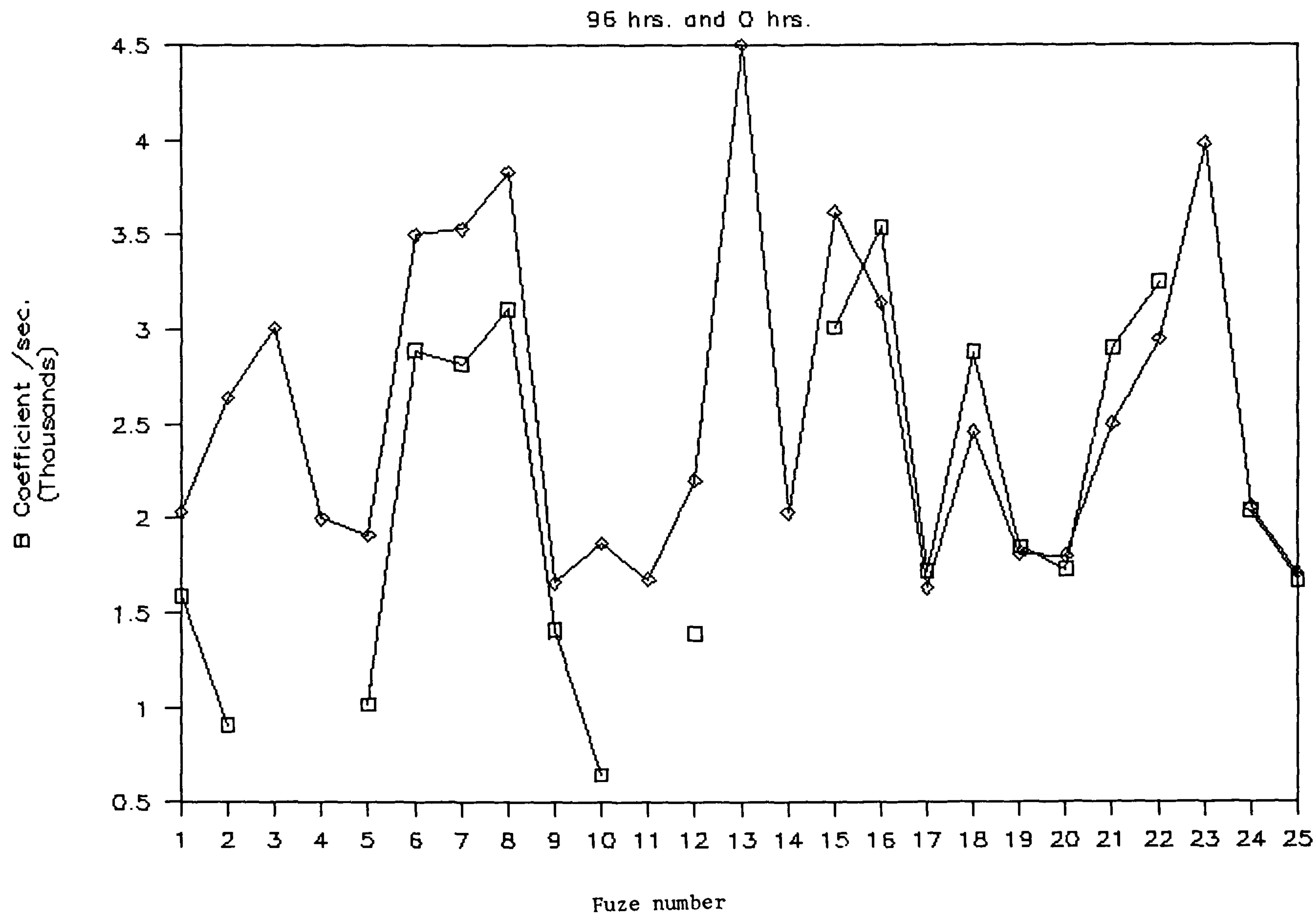
Graph B-1. Coefficient versus fuzes 1 through 25



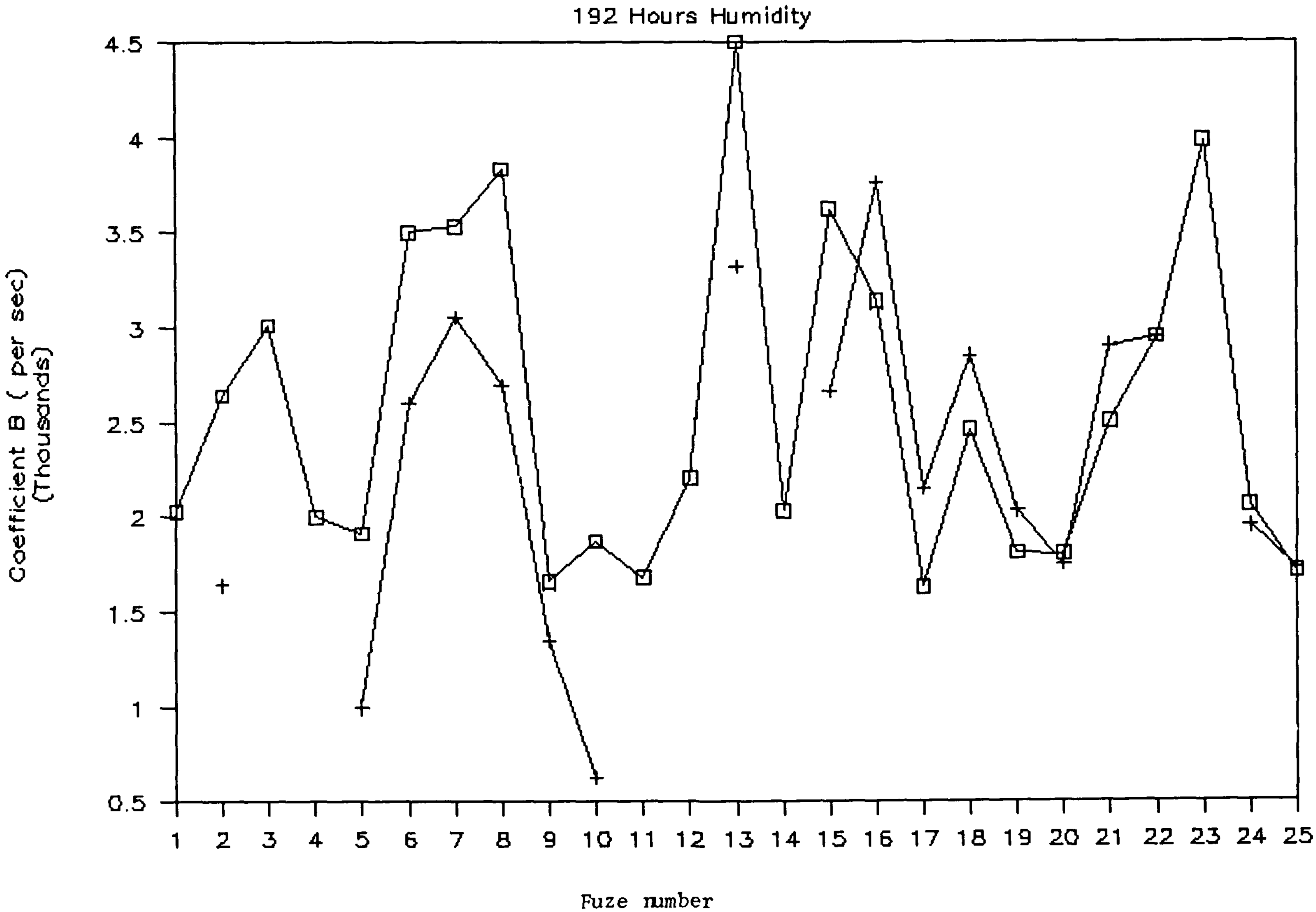
Graph B-2. Coefficient versus fuzes 1 thorugh 25



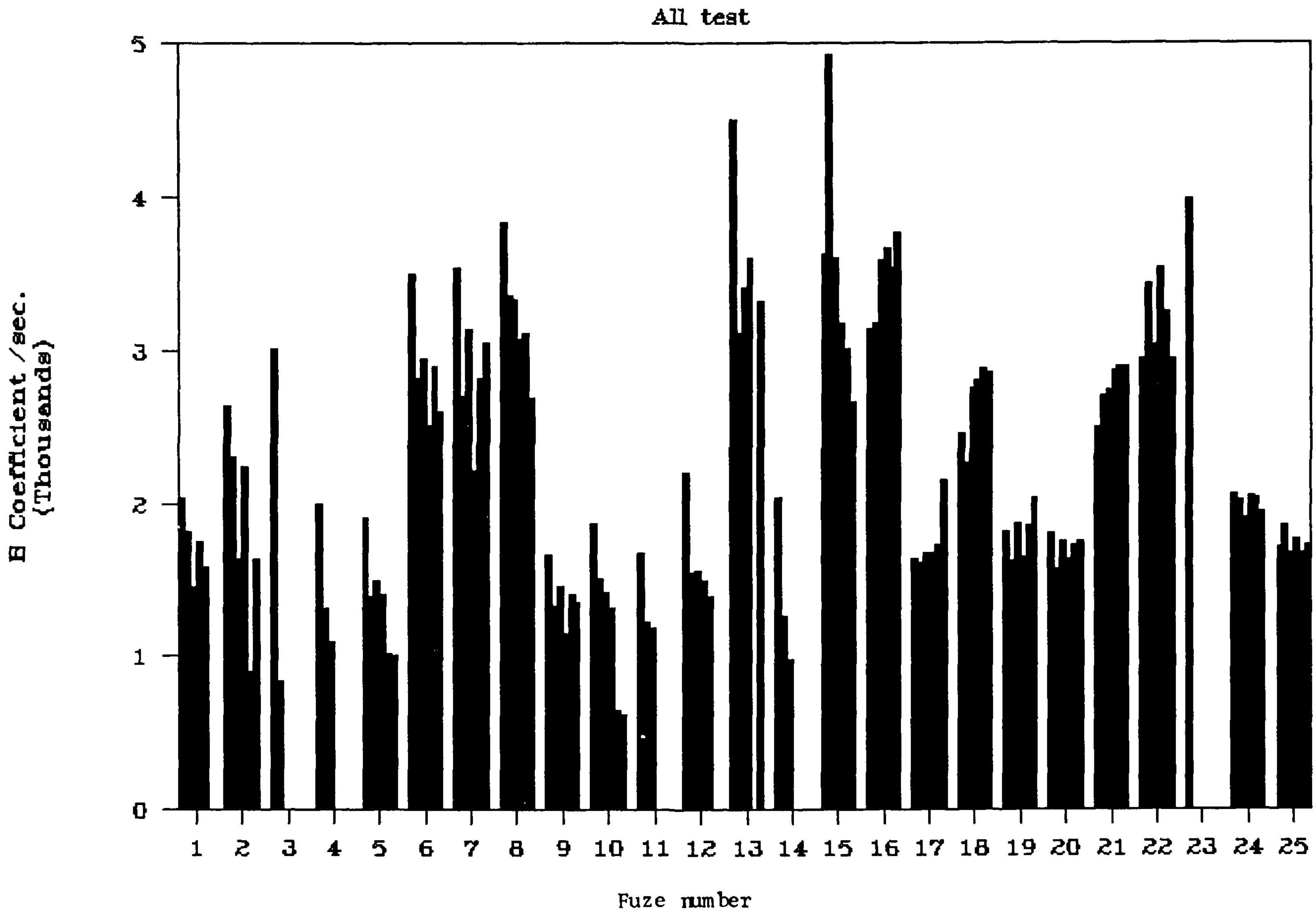
Graph B-3. Coefficient versus fuzes 1 through 25



Graph B-4. Coefficient versus fuzes 1 through 25



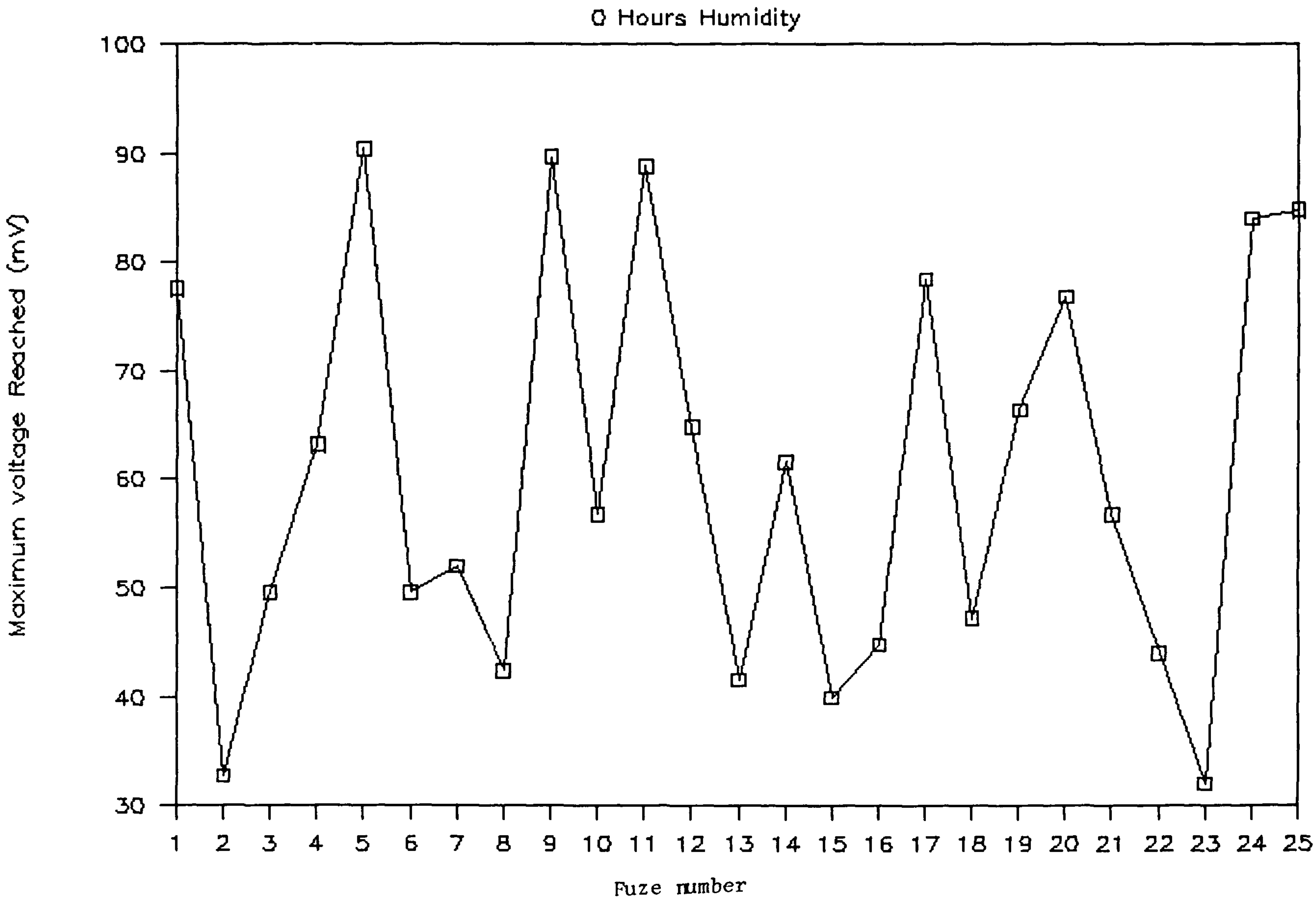
Graph B-5. Coefficient test 1 and test 7



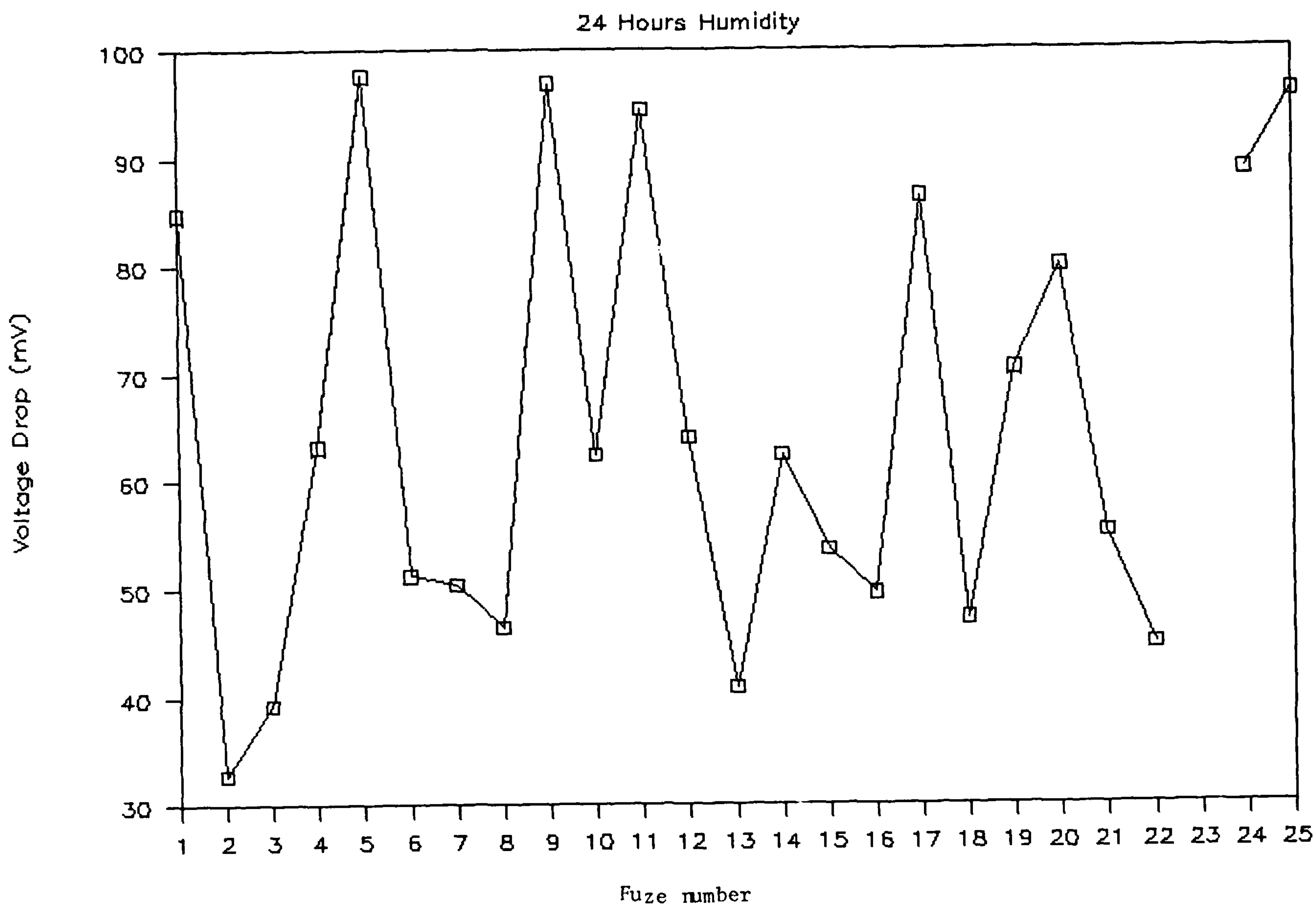
Graph B-6. Coefficient versus fuzes 1 through 25

Appendix C

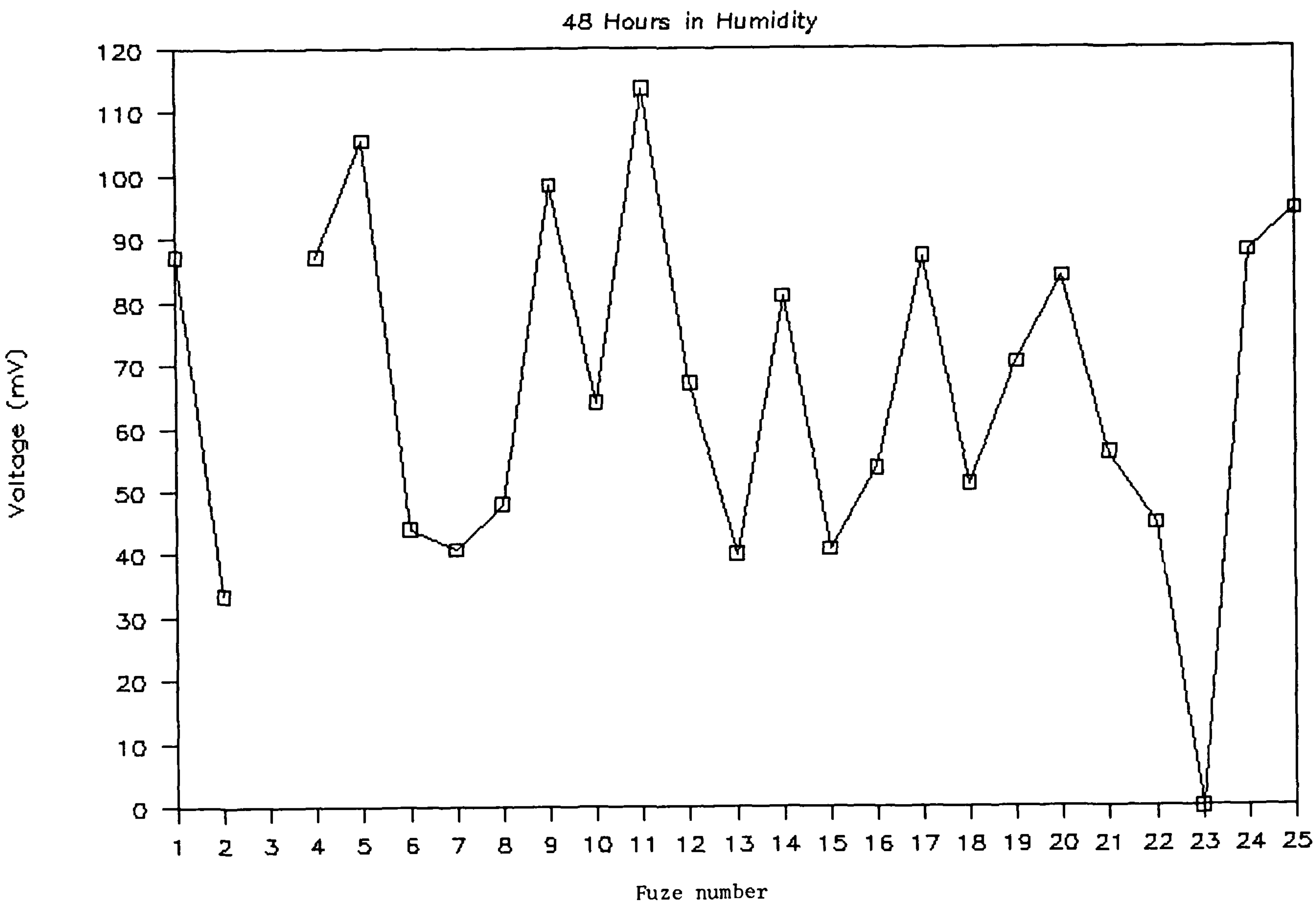
Graphical Data



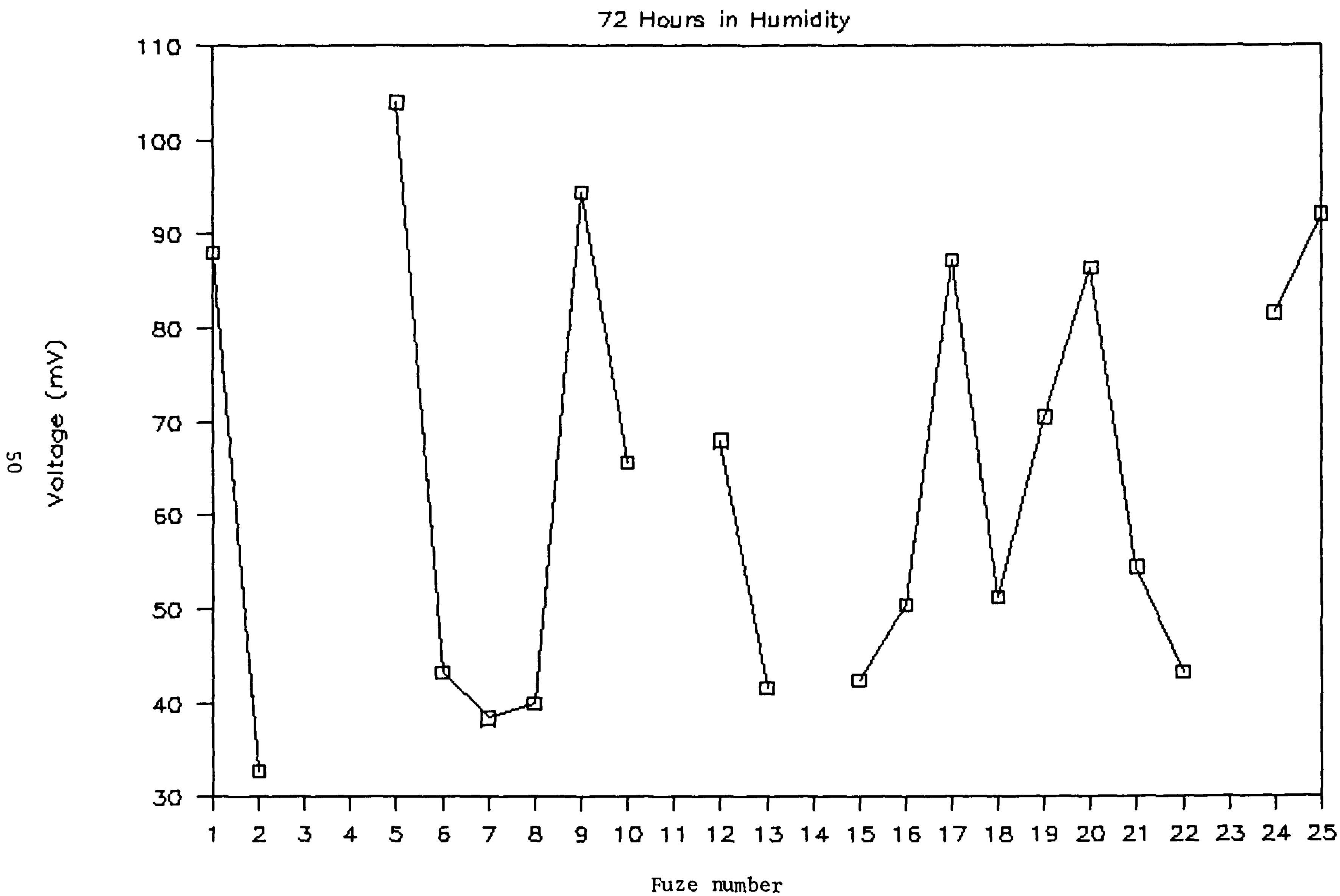
Graph C-1. Maximum voltage drop versus fuzes 1 through 25



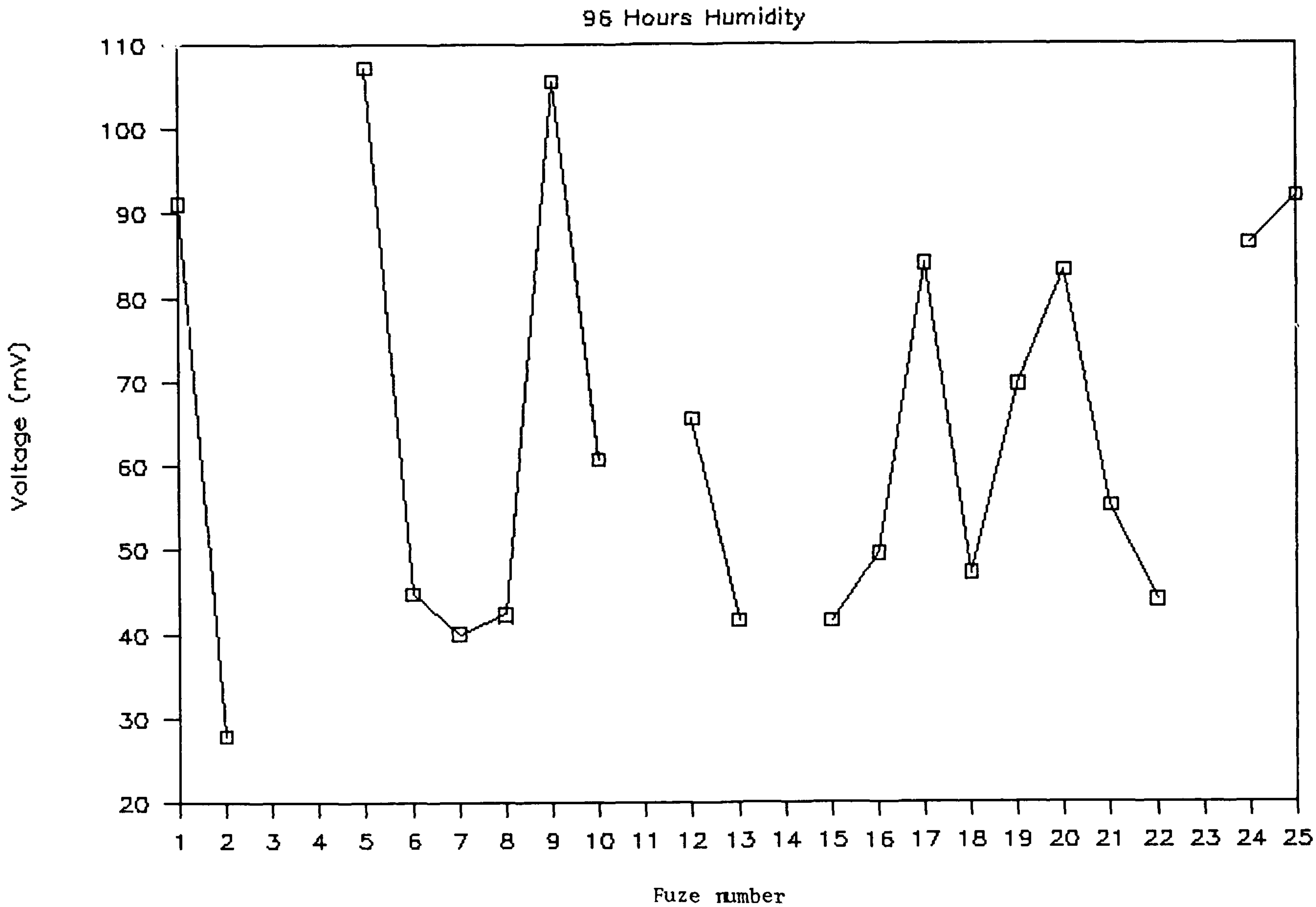
Graph C-2. Maximum voltage drop versus fuzes 1 through 25



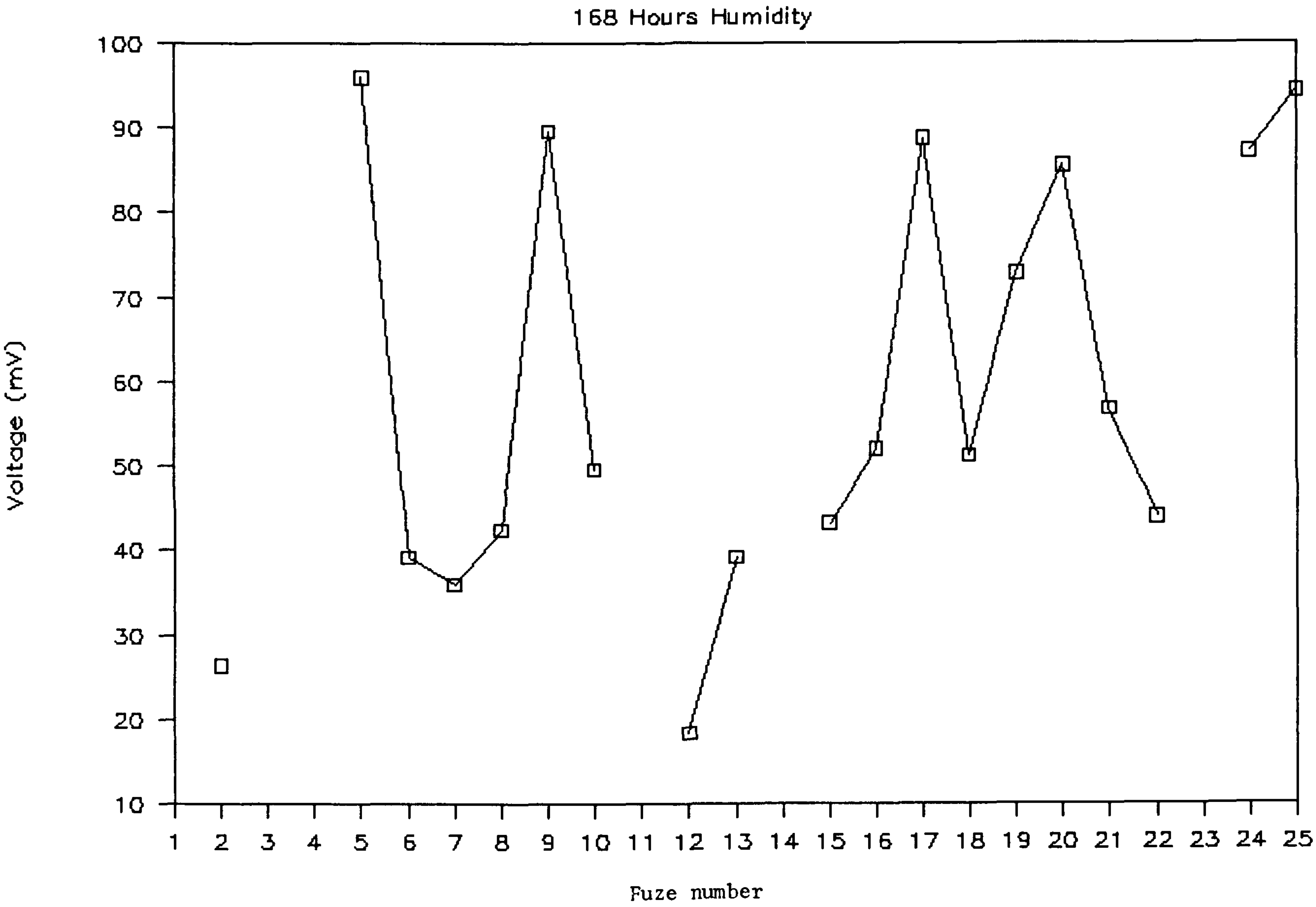
Graph C-3. Maximum voltage drop versus fuzes 1 through 25



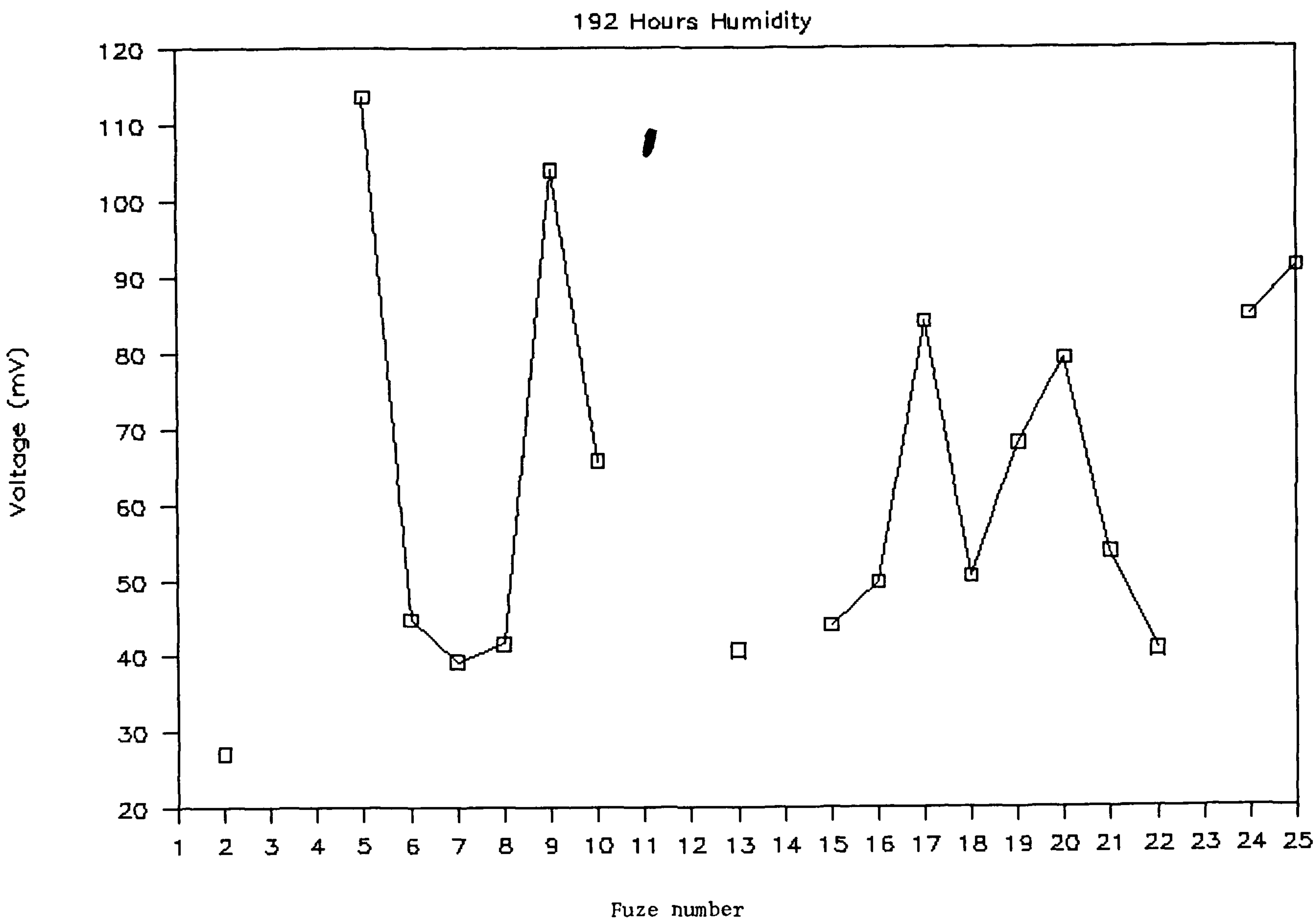
Graph C-4. Maximum voltage drop versus fuzes 1 through 25



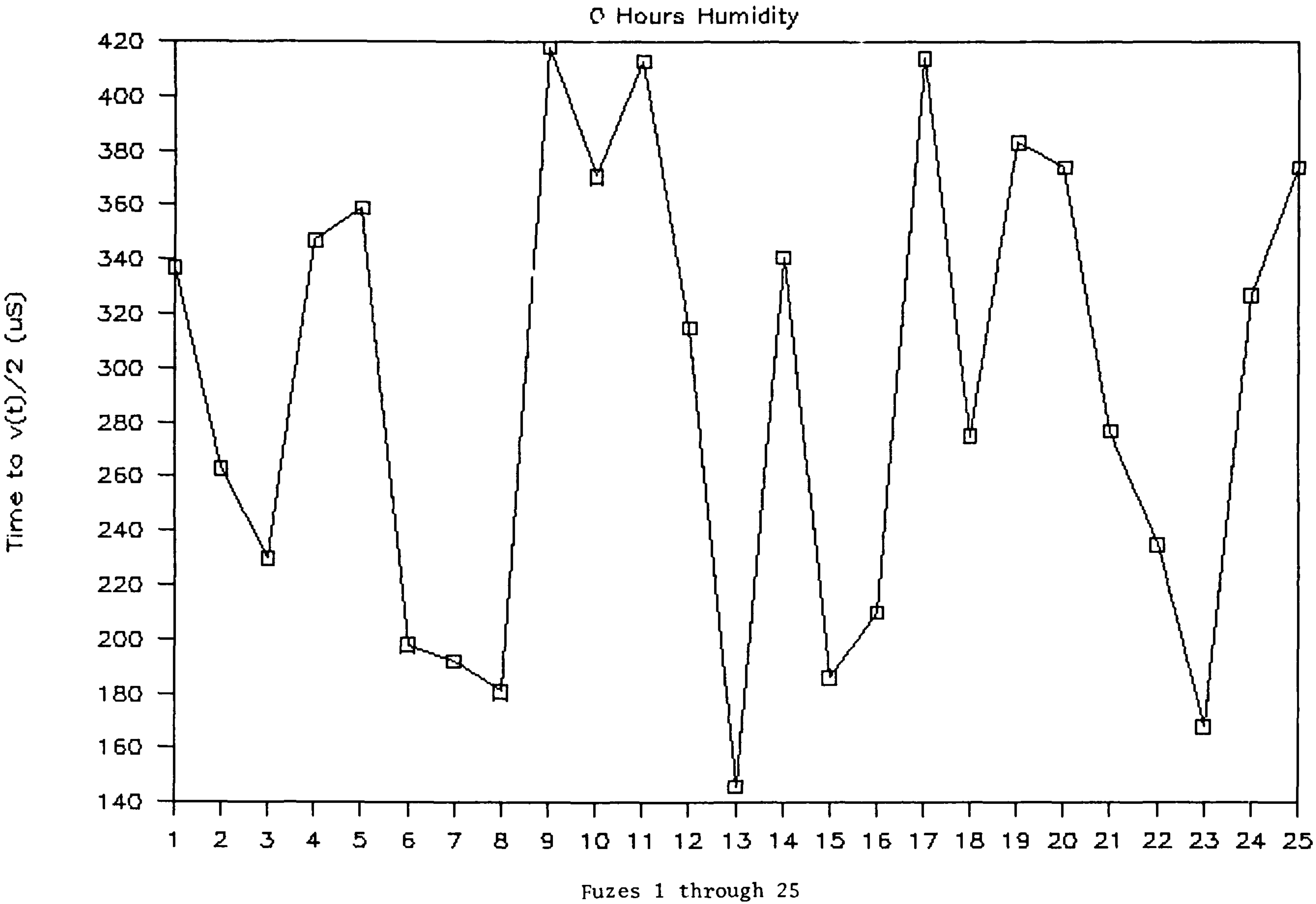
Graph C-5. Maximum voltage drop versus fuzes 1 through 25



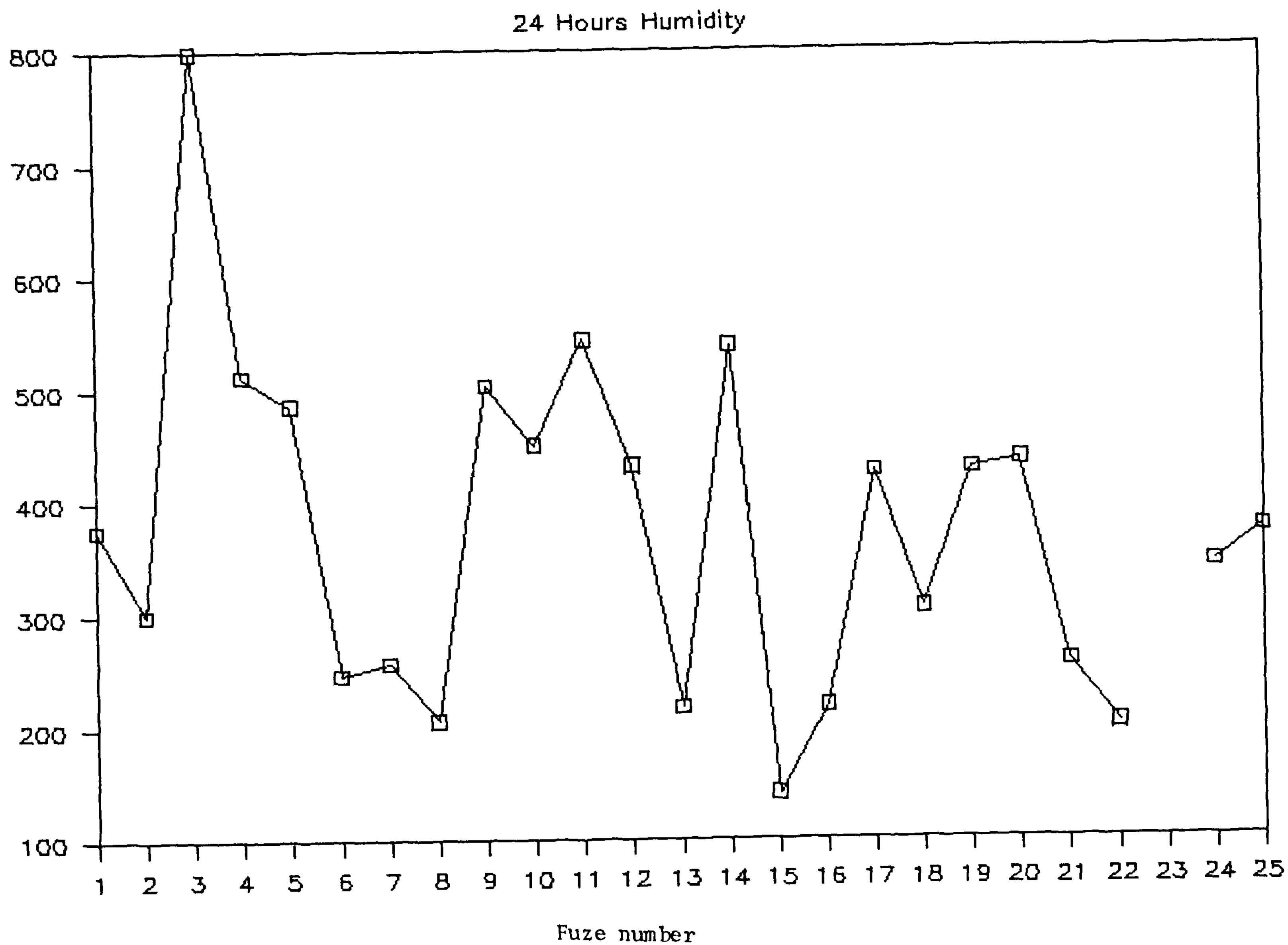
Graph C-6. Maximum voltage drop versus fuzes 1 through 25



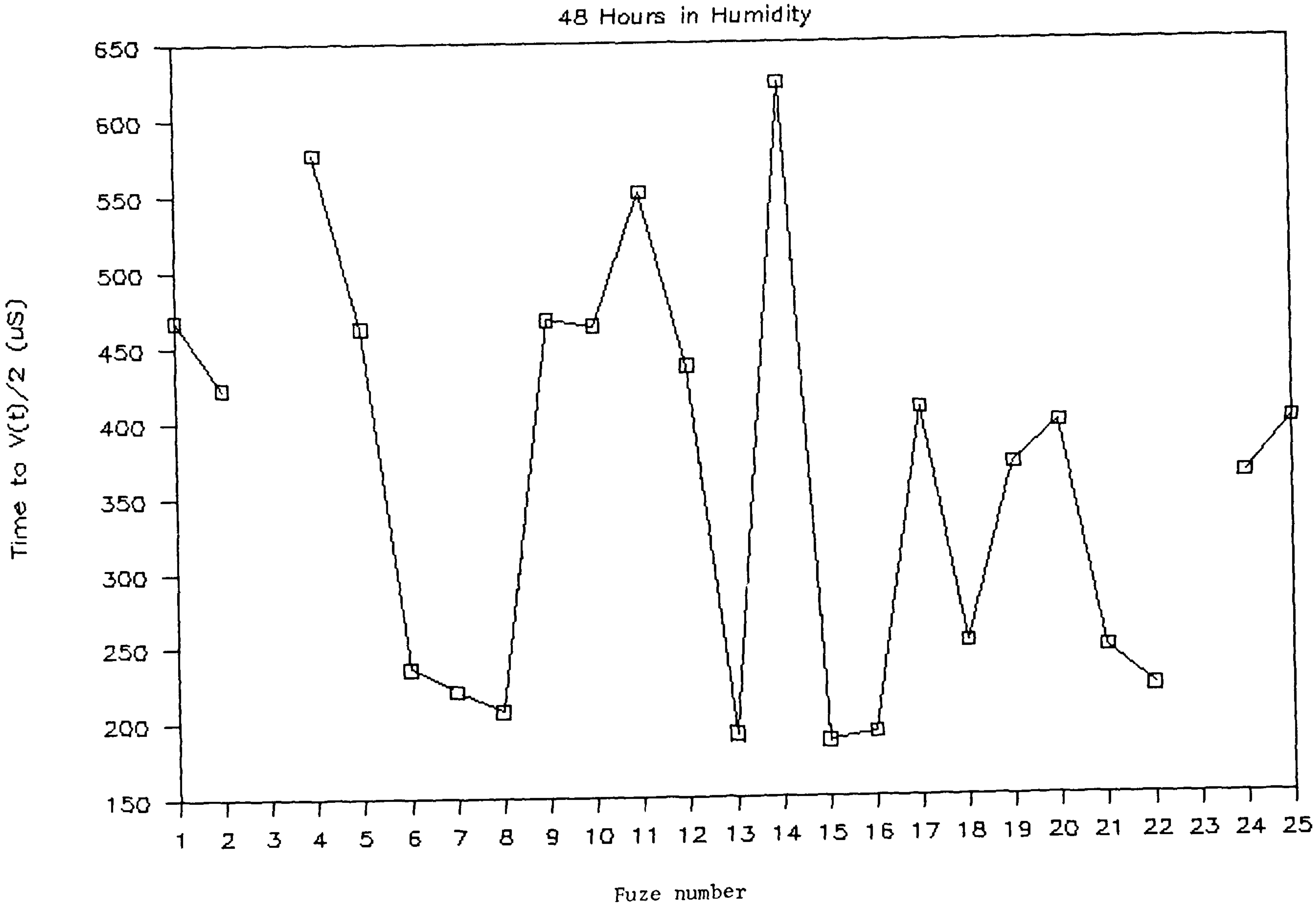
Graph C-7. Maximum voltage drop versus fuzes 1 through 25



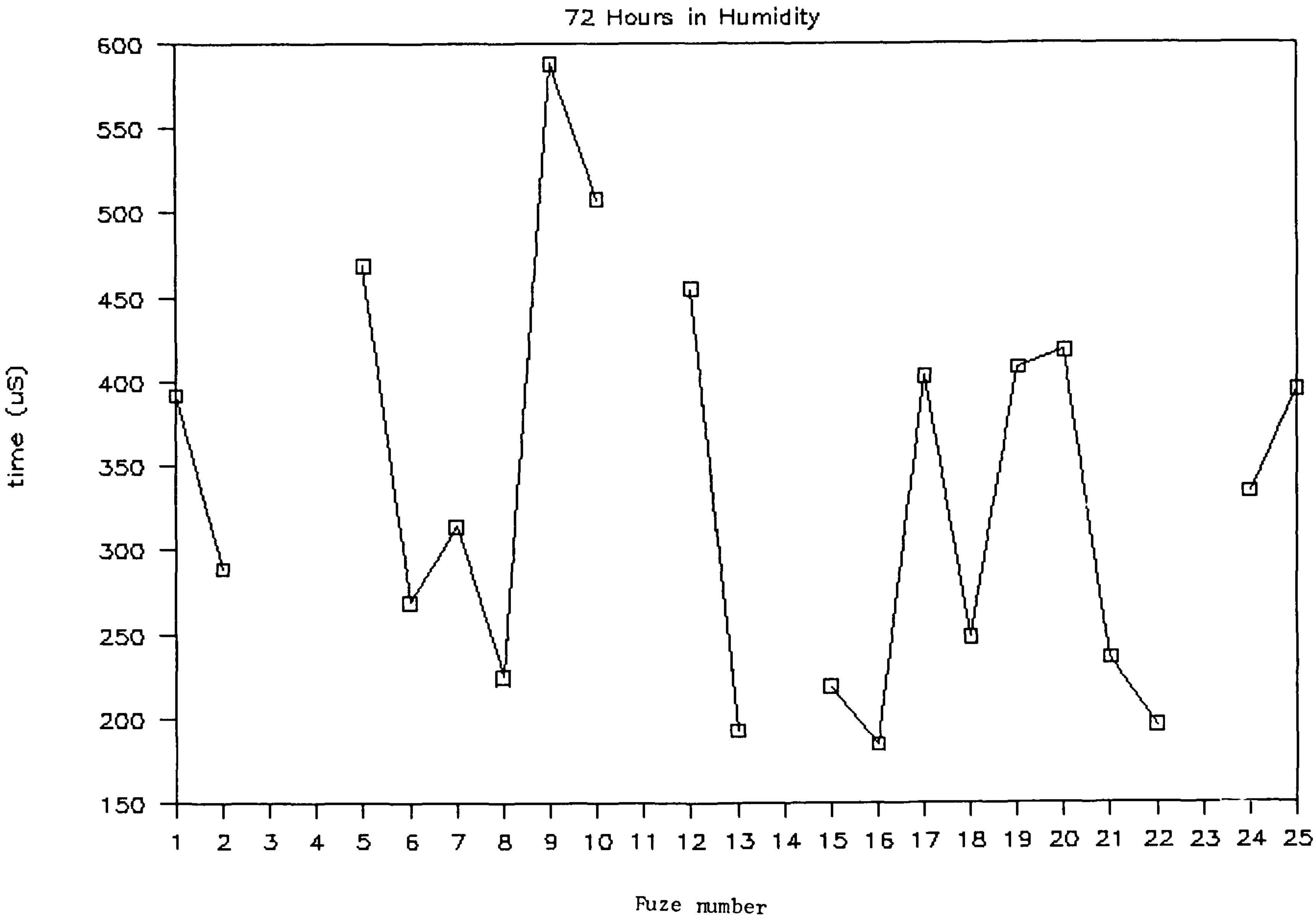
Graph C-8. Time to reach 1/2 Vmax



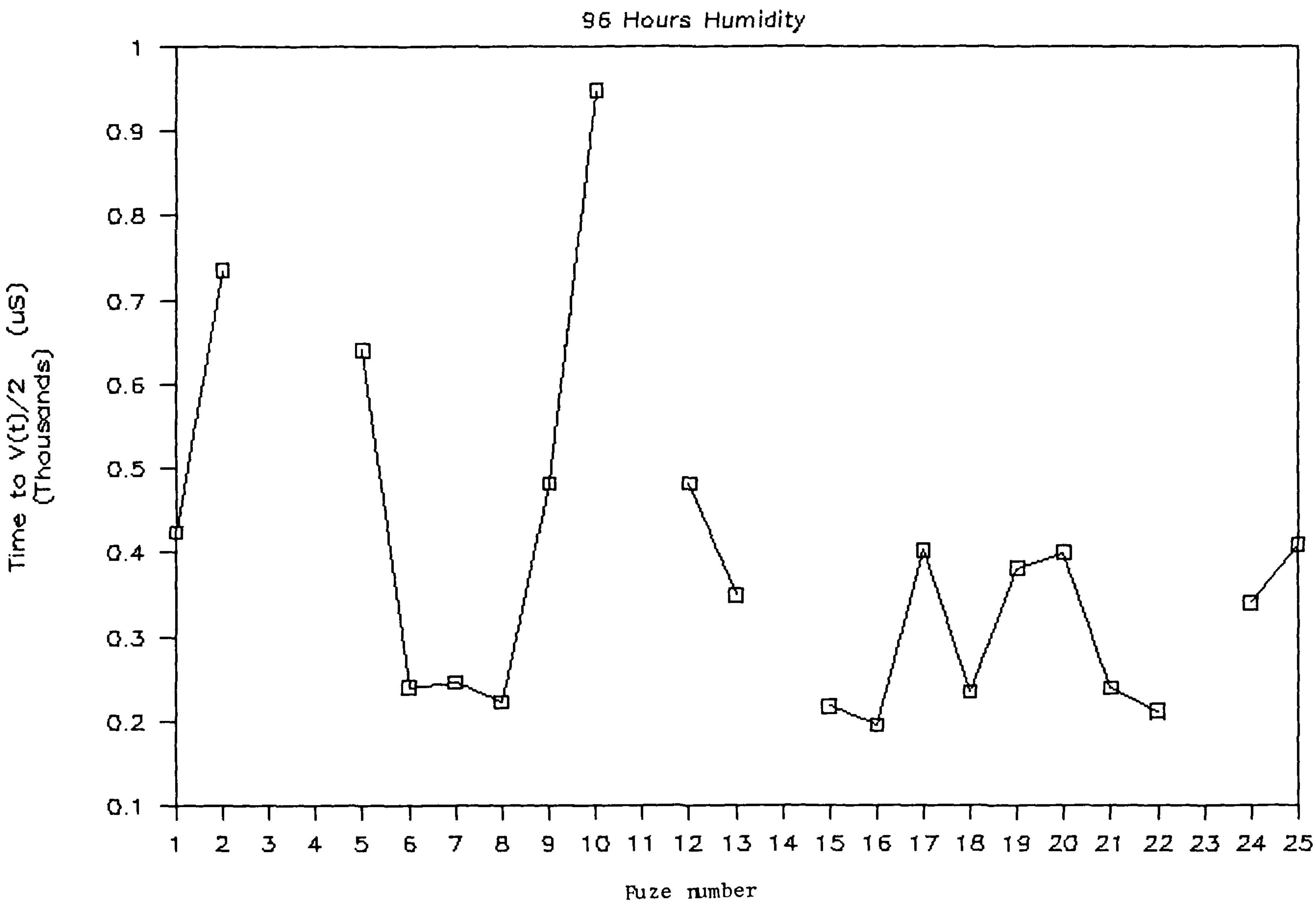
Graph C-9. Time to V(t)/2 versus fuzes 1 through 25



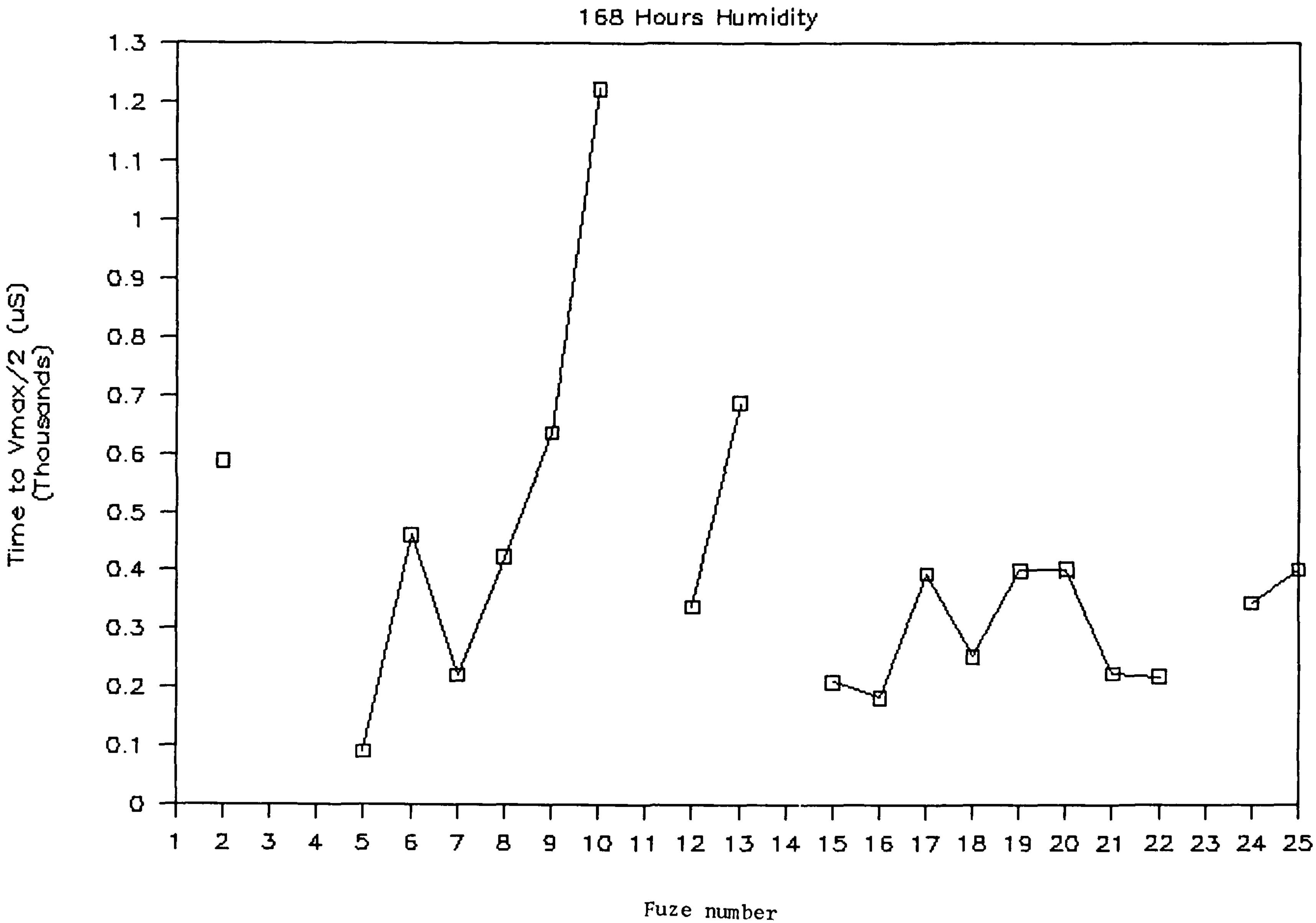
Graph C-10. Time to V(t)/2 versus fuzes 1 through 25



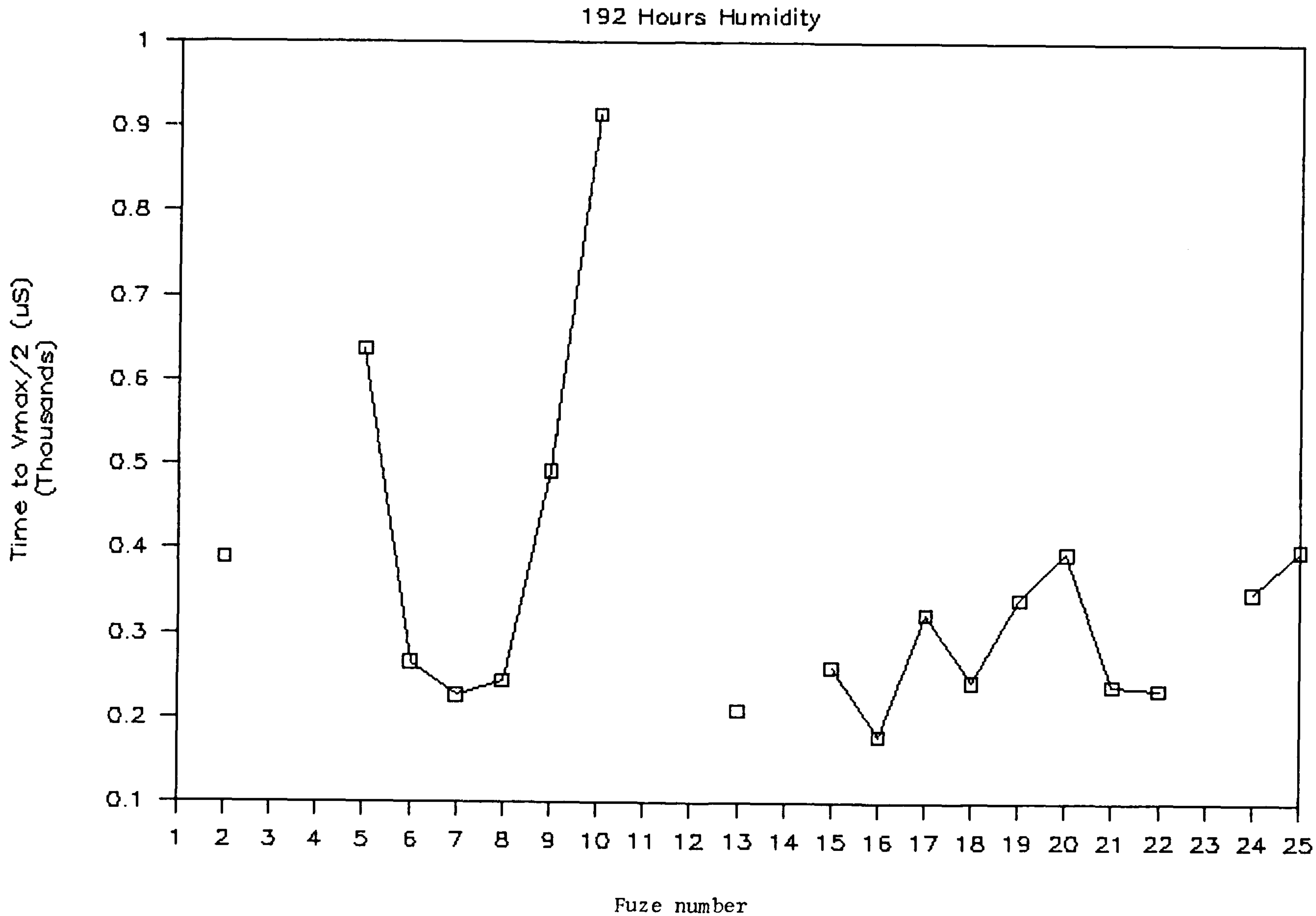
Graph C-11. Time to V(t)/2 versus fuzes 1 through 25



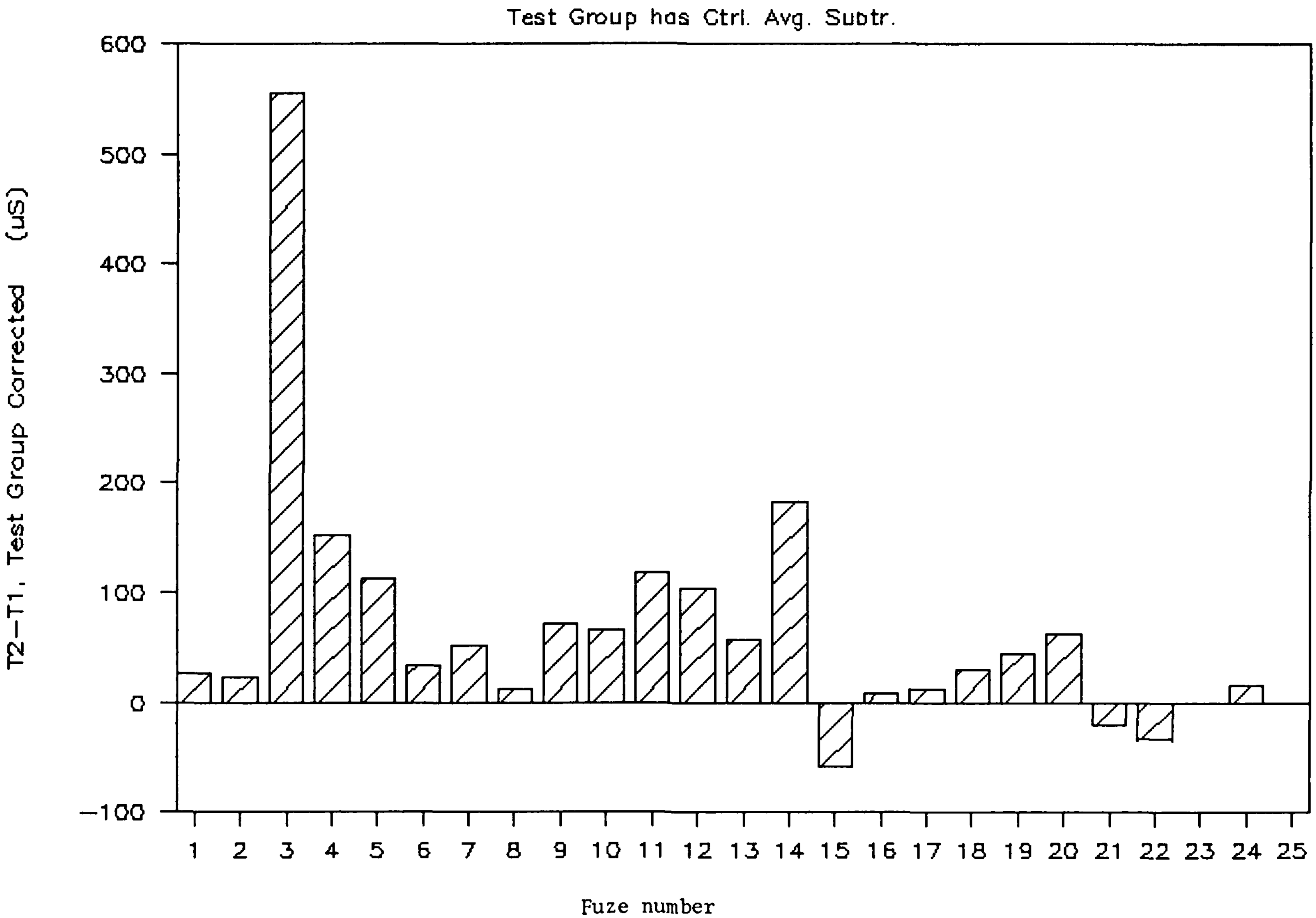
Graph C-12. Time to V(t)/2 versus fuzes 1 through 25



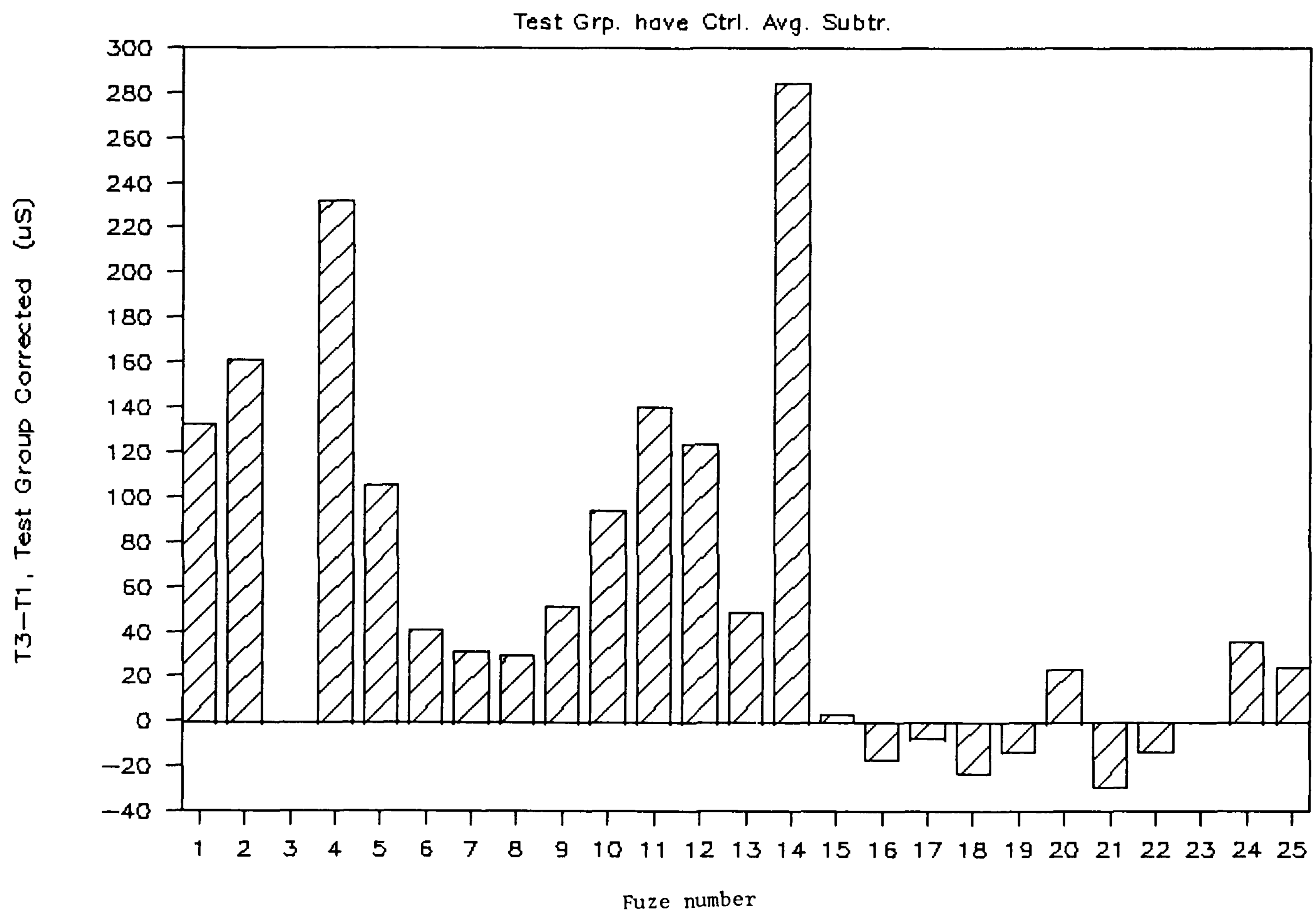
Graph C-13. Time to 1/2 Vmax versus fuzes 1 through 25



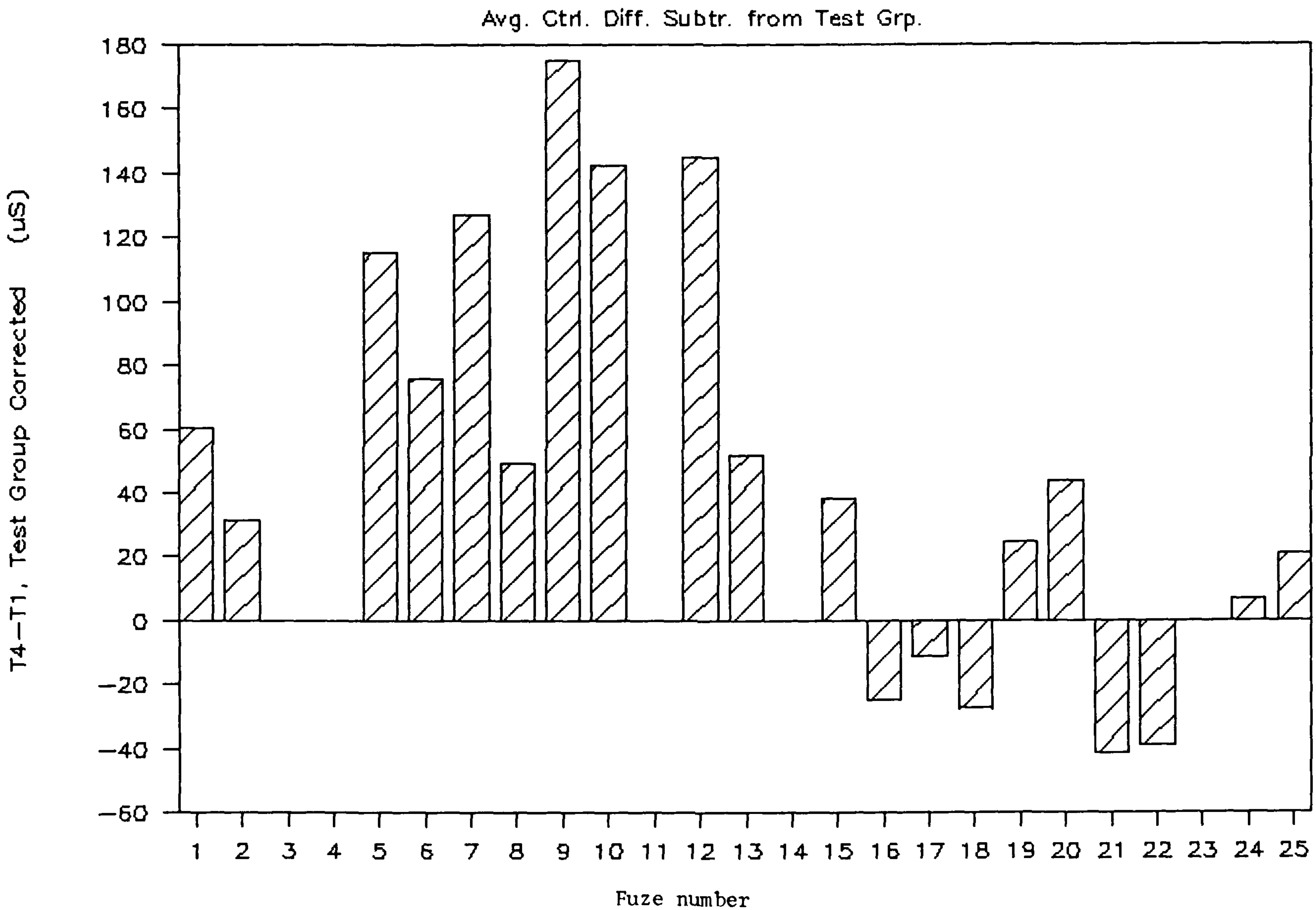
Graph C-14. Time to 1/2 Vmax versus fuzes 1 through 25



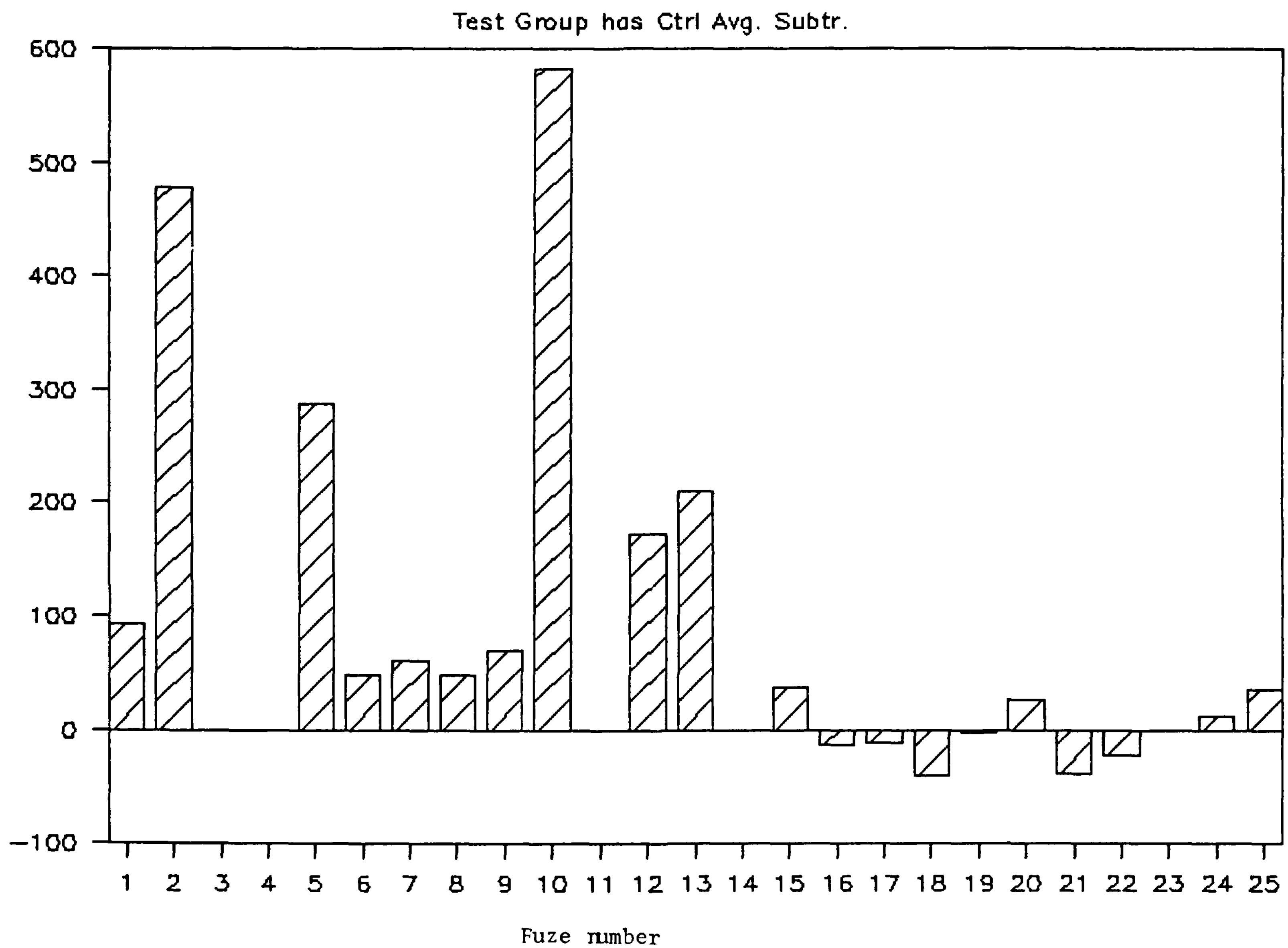
Graph C-15. T2 - T1 versus fuzes 1 through 25



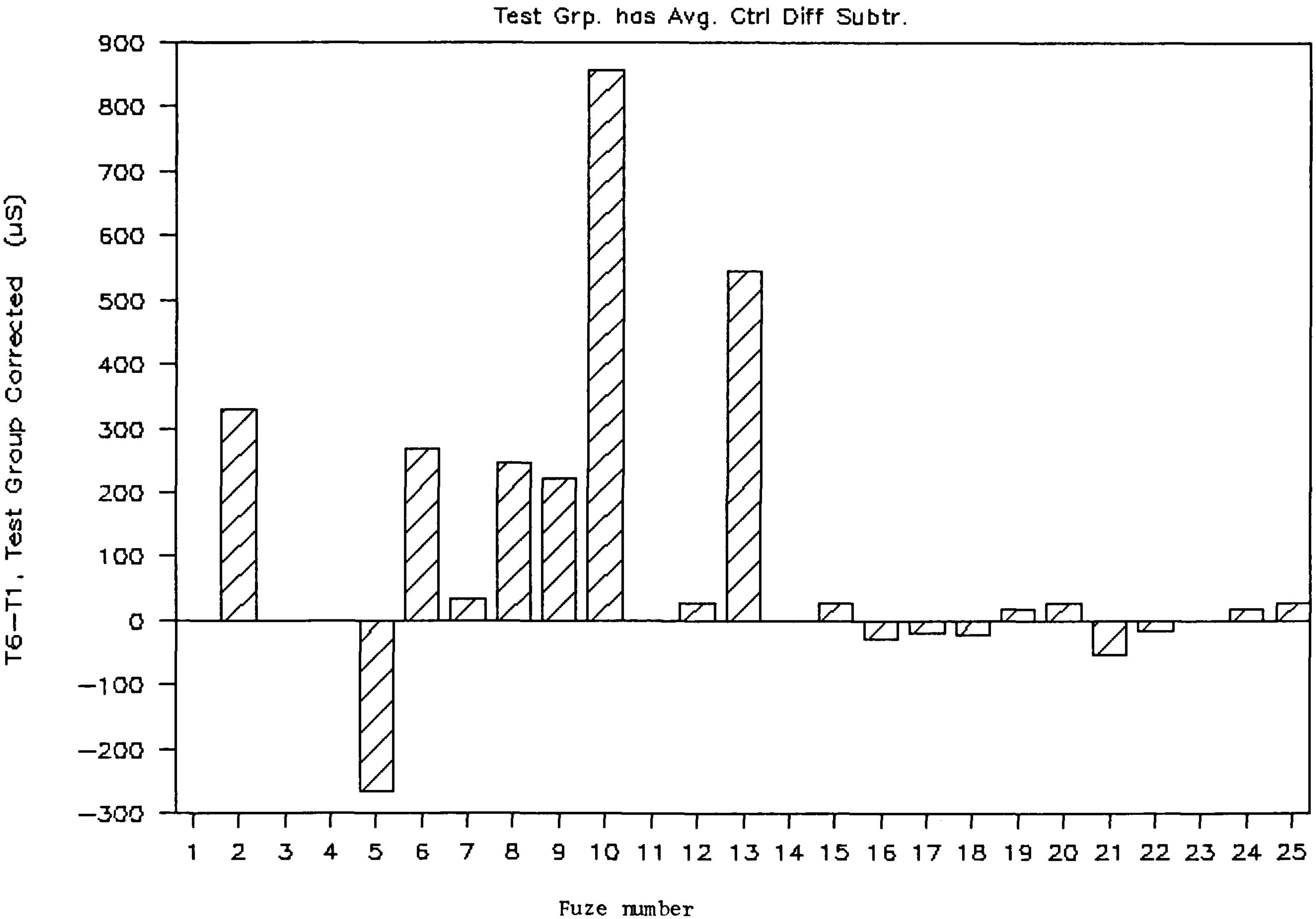
Graph C-16. T3 - T1 versus fuzes 1 through 25



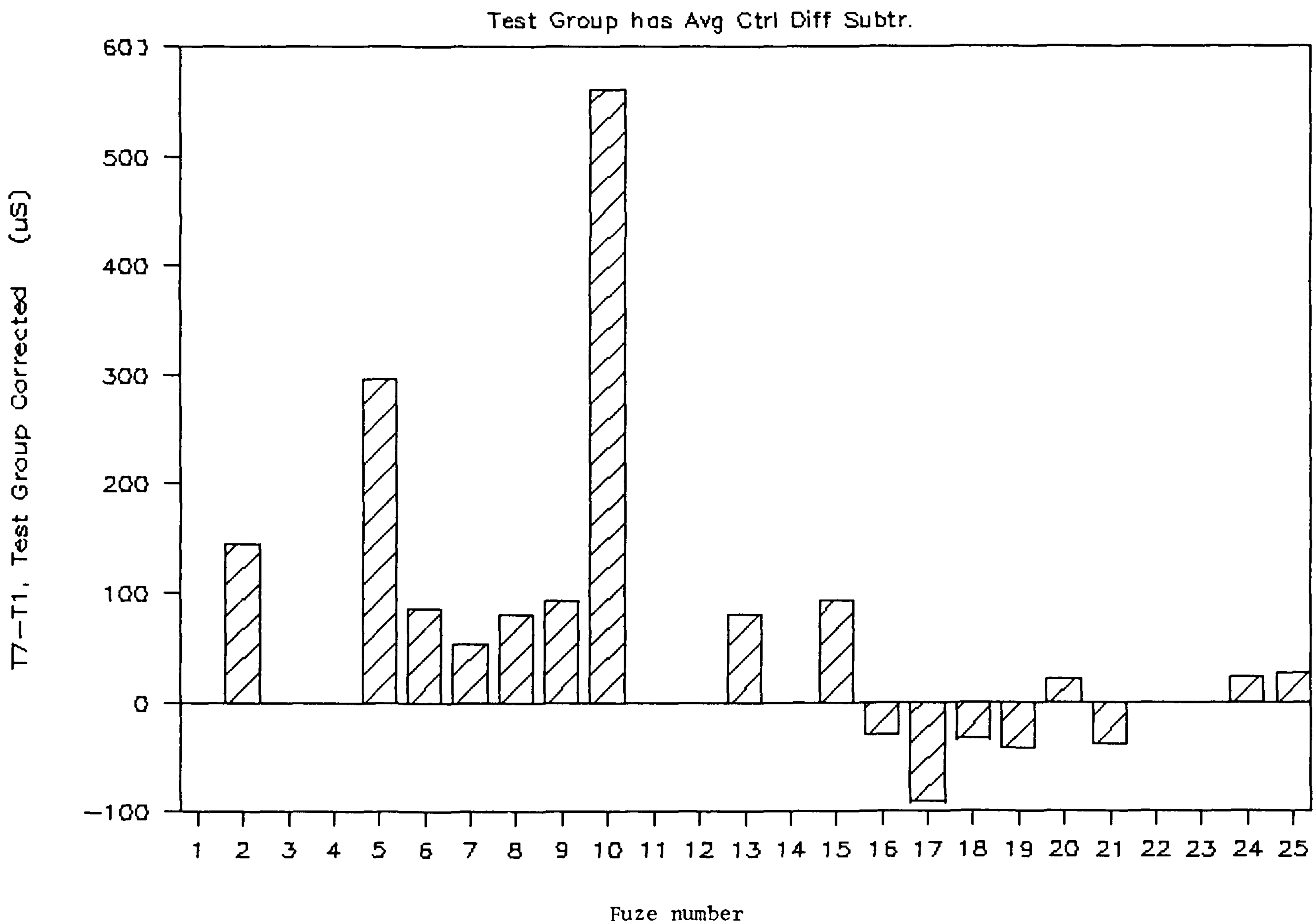
Graph C-17. T4 - T1 versus fuzes 1 through 25



Graph C-18. T5 - T1 versus fuzes 1 through 25



Graph C-19. T6 - T1 versus fuzes 1 through 25



Graph C-20. T7 - T1 versus fuzes 1 through 25

DISTRIBUTION LIST

Commander
Armament Research, Development and Engineering Center
U.S. Army Armament, Munitions, and Chemical Command
ATTN: SMCAR-IMI-I (5)
SMCAR-FSP-E, P. Houser
SMCAR-CCH-P
Picatinny Arsenal, NJ 07806-5000

Commander
U.S. Army Armament, Munitions and Chemical Command
ATTN: AMSMC-GCL (D)
AMSMC-QAH (D), G. Pap
AMSMC-QAH-T (D), A. Shankle
R. Maiello
AMSMC-QAN-R (D), R. Kuper
AMSMC-QAN-I (D), E. Persau
AMSMC-QAT-M (D)
Picatinny Arsenal, NJ 07806-5000

Administrator
Defense Technical Information Center
ATTN: Accessions Division (12)
Cameron Station
Alexandria, VA 22304-6145

Director
U.S. Army Materiel Systems Analysis Activity
ATTN: AMXSY-MP
Aberdeen Proving Ground, MD 21005-5066

Commander
Chemical Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCCR-MSI
Aberdeen Proving Ground, MD 21010-5423

Commander
Chemical Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCCR-RSP-A
Aberdeen Proving Ground, MD 21010-5423

Director
Ballistic Research Laboratory
ATTN: AMXBR-OD-ST
Aberdeen Proving Ground, MD 21005-5066

Chief
Benet Weapons Laboratory, CCAC
Armament Research, Development and Engineering Center
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCAR-CCB-TL
Watervliet, NY 12189-5000

Commander
U.S. Army Armament, Munitions and Chemical Command
ATTN: SMCAR-ESP-L
Rock Island, IL 61299-6000

Director
U.S. Army TRADOC Systems Analysis Activity
ATTN: ATAA-SL
White Sands Missile Range, NM 88002

Director
Industrial Base Engineering Activity
ATTN: AMXIB-MT
Rock Island, IL 61299-5000