THE UNIVERSITY OF MICHIGAN

Department of Mechanical Engineering

Cavitation and Multiphase Flow Laboratory

Report No: UMICH 320711-2-1

(I) VIBRATORY CAVITATION DAMAGE AT STANDARD CONDITIONS

(II) COMPUTER OUTPUT ANALYSIS

Submitted by :

Mohammed AKBI
Undergraduate Research Student

To :

Professor F. G. HAMMITT
as a Report for M. E. 490
(Directed Undergraduate Research)

Supported by Aerojet Liquid Rocket Company and Internal University of Michigan (Work Study and SEP) Funds.

April 6, 1978

TABLE OF CONTENTS

PART (I)

PART (II)

PART(I)

I ABSTRACT

In vibratory cavitation, the forces causing the cavities to form and collapse are due to a continuous series of high amplitude, high-frequency pressure pulsations in the liquid. The compression-decompression phenomena causes the cavities to occur.

There are two important data to record for each material tested: Incubation Period (IP) and Mean Depth of Penetration Rate (MDPR). They are related in the following equation (where n and C are constants):

$$(IP)^n = C/MDPR_{max} \qquad (1)$$

A computer program was used to give us the best-fit line and the best-fit values of n and C for each material.

II ACKNOWLEDGEMENT

Aside from the author, many tests were run by Charles Muller and the computer program and plots were done by Robert J. NIEDZIELSKI*

III WORK ITEMS PERFORMED

Three different materials were tested under standard conditions (1.0 mils, 80°F, 1 Bar in sea water) to find a correlation between them. Also Al 1100-0 and Ti 6Al-4V specimens sent by Aerojet were tested under the same conditions in order to have a basis for comparison.

Table III summarizes the work performed in the first part of our tests and Table I summarizes tests done using Aerojet specimens only. Table II gives an average value for the Incubation Period and the MDPR for each material. Further discussion on this matter will be done in part V of this report.

* R.J. Niedzielski Jr., "Computer Analysis Programs, computer graphics", Report NO. UMICH 14571-15-I, April 1978

IV NEW REDUCED DATA

So far two important data were found using some measurement and calculations:

1. The Incubation Period: Intercept of the abcissa of a curve of cumulative weight loss vs. test duration with the tangent drawn from the first maximum slope.

2. MDPR: Mean depth of penetration rate based on total surface area (diameter 5/8")

The new reduced data that are now introduced are namely:

1. The "0.1 mil" incubation period. This corresponds to the time at which there is a substantial MDPR (small and finite). For our case we used 0.1 mil as a point where time is recorded. This was introduced because of its simplicity and practicality (it lends itself to easy comparison).

2. Incubation Scale Factor k ($= \frac{\tau}{IP}$) where τ is the time at which we have maximum cavitation (or inflection point) and IP is incubation period. Values of k for different materials are tabulated (Table III). This new parameter k was introduced because it helps predict when maximum erosion rate is going to occur so that it can be avoided.

V RESULTS AND CONCLUSION

1. Al 1100-0

Three Al 1100-0 specimens sent by Aerojet were run at standard conditions. University of Michigan specimens behave about the same way as Aerojet specimens do. The IP for Aerojet specimens was lower (about 20%) than that of the U of M ones; however the averaged values of IP for both U of M's and Aerojet's were very close (6.33 min and 6.85 min). The MDPR data for Aerojet's show a behavior almost identical to U of M's ; each MDPR vs. Test duration curve has two characteristic peaks. The $MDPR_{max}$ (averaged values) as given in Table II, show 6.7 mils/hr for U of M and 5.9 mils/hr for Aerojet- a difference of 12%.

2. Ti 6Al-4V

Two Ti specimens, supplied by Aerojet, were run at standard conditions. Their results were very close to our previous tests using U of M Ti specimens.

The average value for IP was 128.5 min for Aerojet's and 133 min for U of M's. The $MDPR_{max}$ was 102.4 mils/1000 hours and 112 mils/1000 hours for Aerojet's and U of M's respectively.

Altogether, U of M test specimens and Aerojet cannot be discriminated because there is no systematic difference between the materials. The small difference in IP and $MDPR_{max}$ values are due to experimental errors only.

3. Incubation Scale Factor (k)

K varies between 1.5 for small mechanical intensities to 2.5 for higher ones. K seems to be independent of the material tested but there is a slight increase of k as the intensity increases.

Both U of M test specimens and Aerojet's present similar k's. So the predictability for maximum erosion rate occurrence is the same for U of M's and Aerojet's.

Further analysis of the problem of cavitation damage of Ti 6Al-4V, Al 1100-0, and SS 17-4 is done using the profocorder results and computer program results and plots.

VI APPENDIX

TABLE I *

MATERIAL	Incubation–Period (min)	0.1 mil IP	M. D. P. R. max (mils/1000 hrs.)
Al 1100-0 16-A	7.2	2.9	6186
Al 1100-0 17-A	6.5	3.2	5640
Ti 6AL-4V 16-A	130	160	111.34
Ti 6AL-4V 17-A	95	150	87.9
Ti 6AL-4V 18-A	95	140	108

* Aerojet Specimens
Standard conditions in Sea water

TABLE II. (comparison between Aerojet and U of M specimens)

DATA / MATERIAL	Incubation Period (min)	M. D. P. R. max (mils /1000 hrs)
Al 1100-0	6.33 / 6.85	6668 / 5913
Ti 6AL-4V	133 / 128.5	112 / 102.4

Note: U of M / Aerojet — AVERAGED VALUES

TABLE - III

U of M SPECIMENS

MATERIAL	CONDITIONS T = 80°F P = 1.0 atm. SEA WATER	INC. PERIOD (Tang. Intercept) (min)	INFLECTION POINT (τ) (min.)	INC. SCALE FACTOR (k) = τ/I.P.
- AL 1100 - 0				
# 8	1.0 mil	7.5	13.5	2.12
# 9	1.0 mil	7.5	12.5	1.80
# 10	1.2 mil	4.0	8.5	1.66
- S.S. 17-4C				
# 1	1.0 mil	70	150	2.14
# 2	1.0 mil	75	160	2.13
# 4	1.5 mil	50	75	1.5
- S.S. 17-4 W				
# 5	0.66 mil	105	135	1.29
# 2	0.55 mil	110	195	1.77
# 8	1.0 mil	63	105	1.67
- Ti 6AL-4V				
# 4	0.55 mil	420	630	1.50
# 10	0.60 mil	480	648	1.35
# 8	0.63 mil	210	252	1.20
# 5	1.0 mil	75	185	2.46
# 11	1.0 mil	105	165	1.57
# 14	1.0 mil	90	156	1.73

Aerojet SPECIMENS (Ti#17-A NOT INCLUDED BECAUSE INFLECTION POINT DID NOT OCCUR)

- AL 1100 - 0				
# 16-A	1.0 mil	7.2	14.5	2.01
# 17-A	1.0 mil	6.5	11.5	1.76
- Ti 6AL-4V				
# 16-A	1.0 mil	130	204	1.57
# 18-A	1.0 mil	95	160	1.68

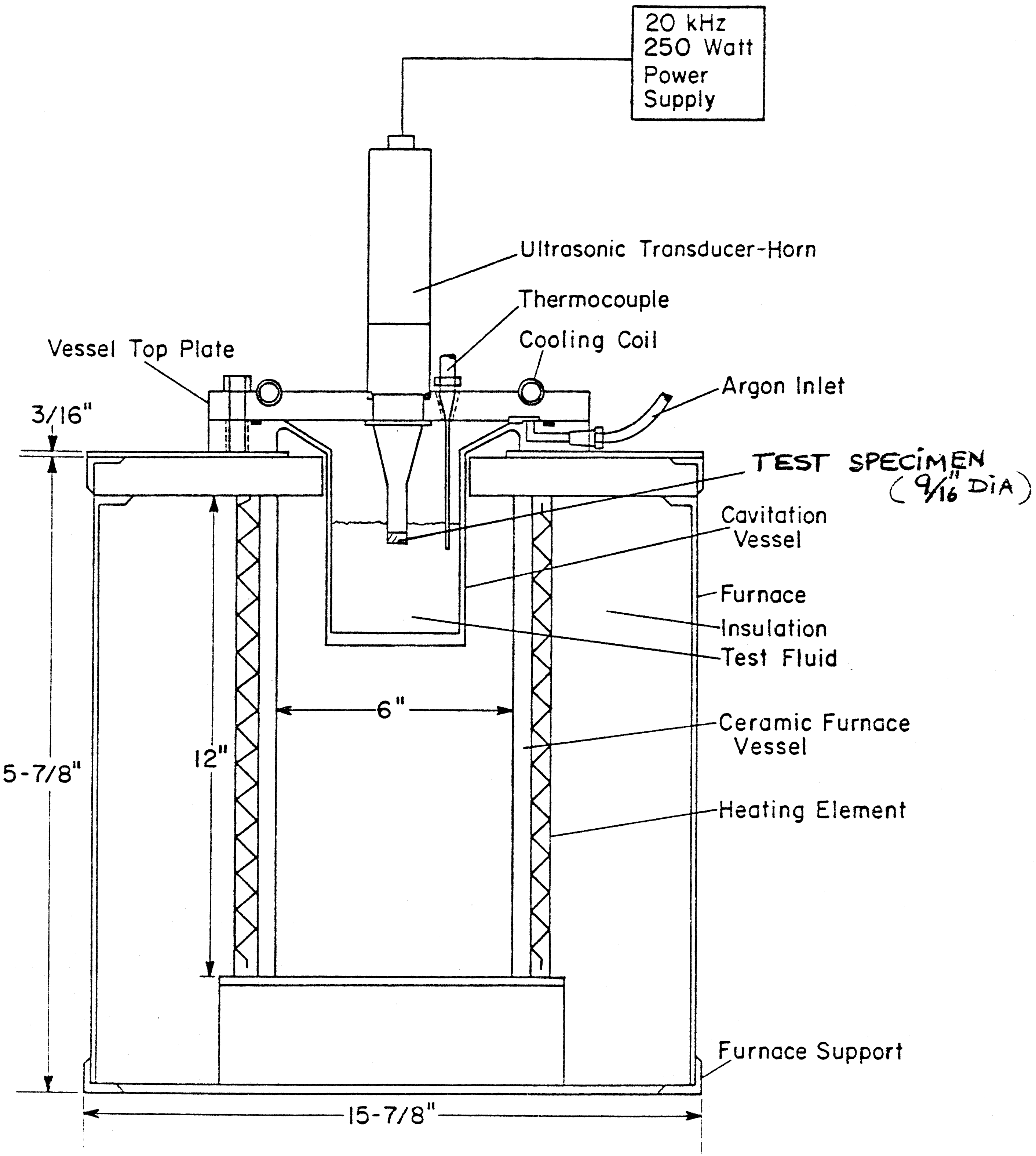


Fig. 1 Vibratory Facility Cavitation Erosion Study In sea water

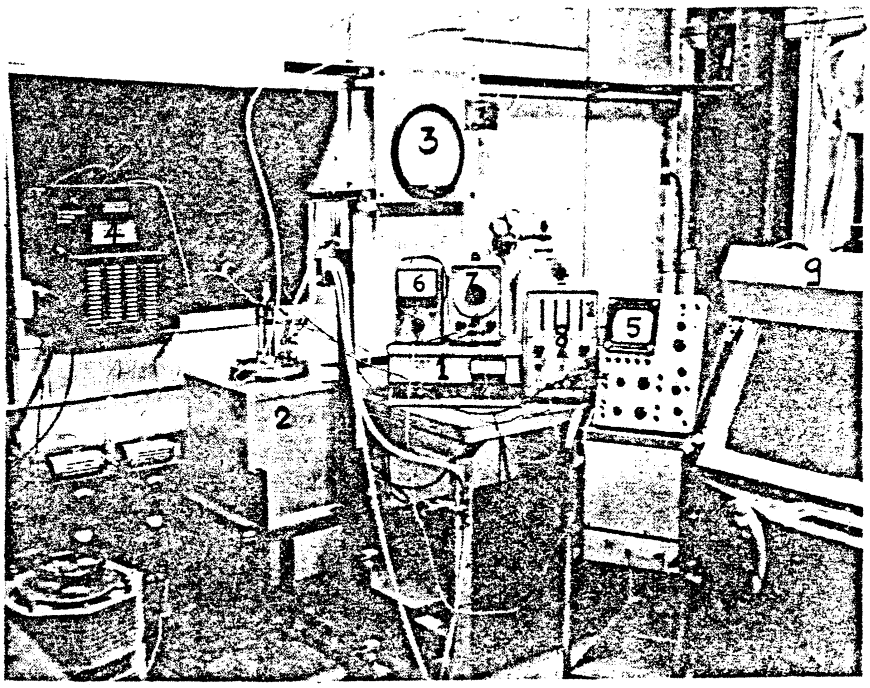
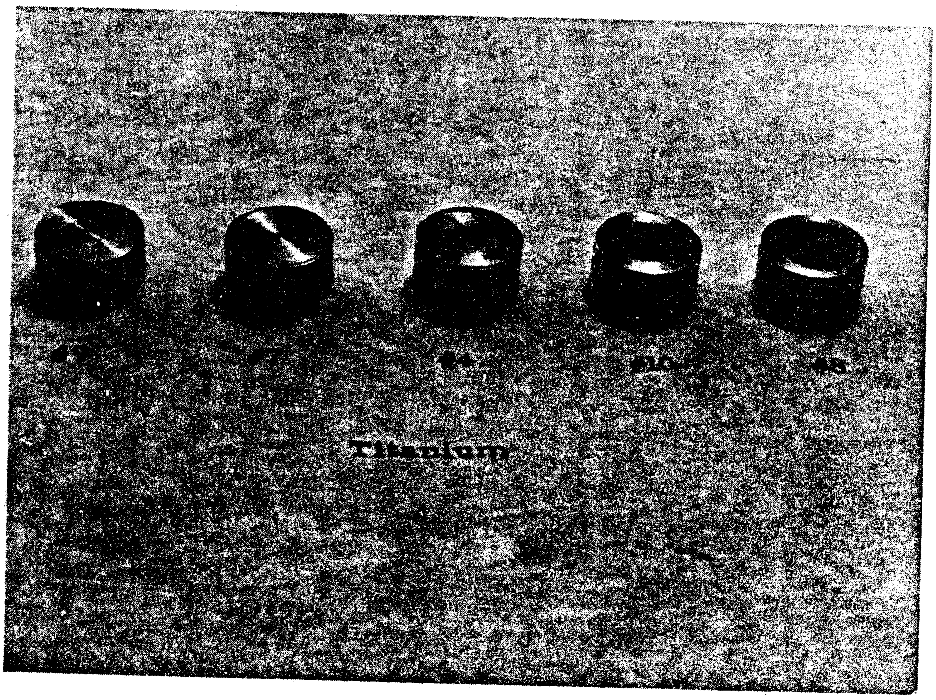


Figure 2. Photograph of the High-Temperature Ultrasonic Cavitation Facility

1. Amplifier
2. Vibratory Horn
3. Pressure gage
4. Heating element
5.6.7.8. Calibration Apparatus
9. Heat Treatement cage



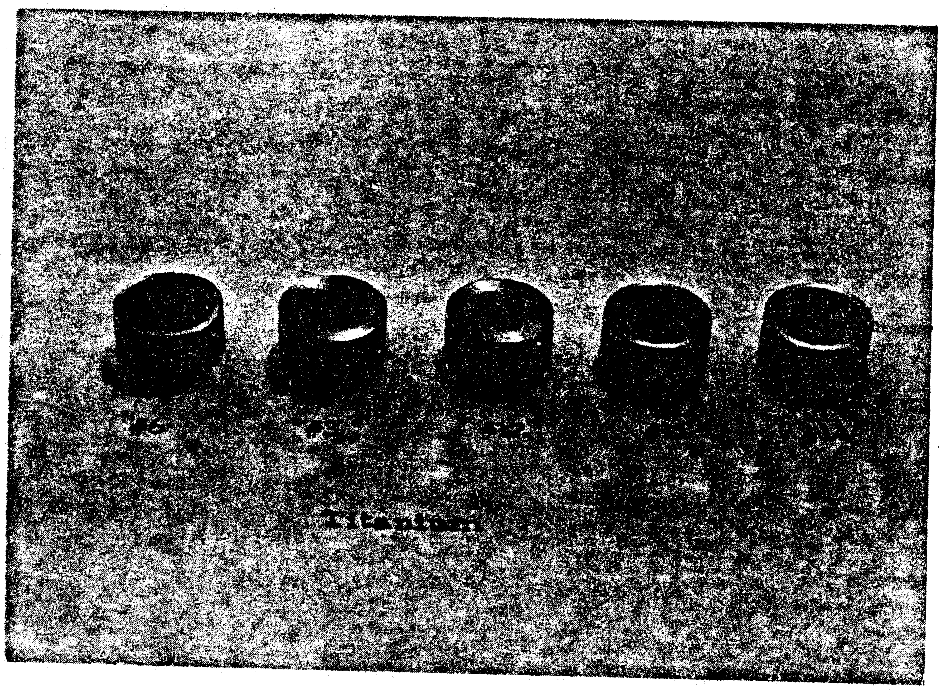
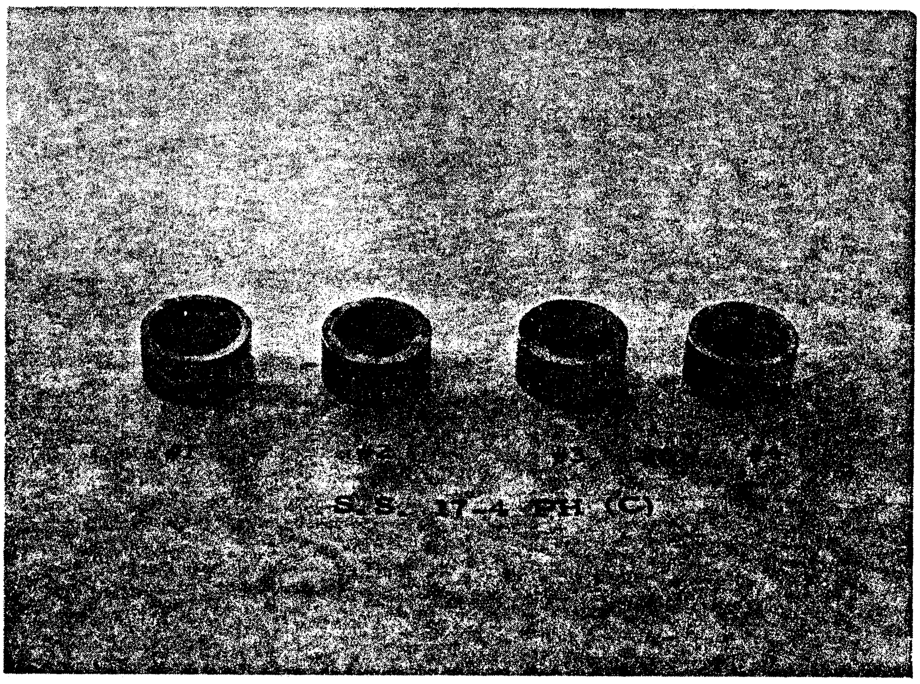


Fig 3.



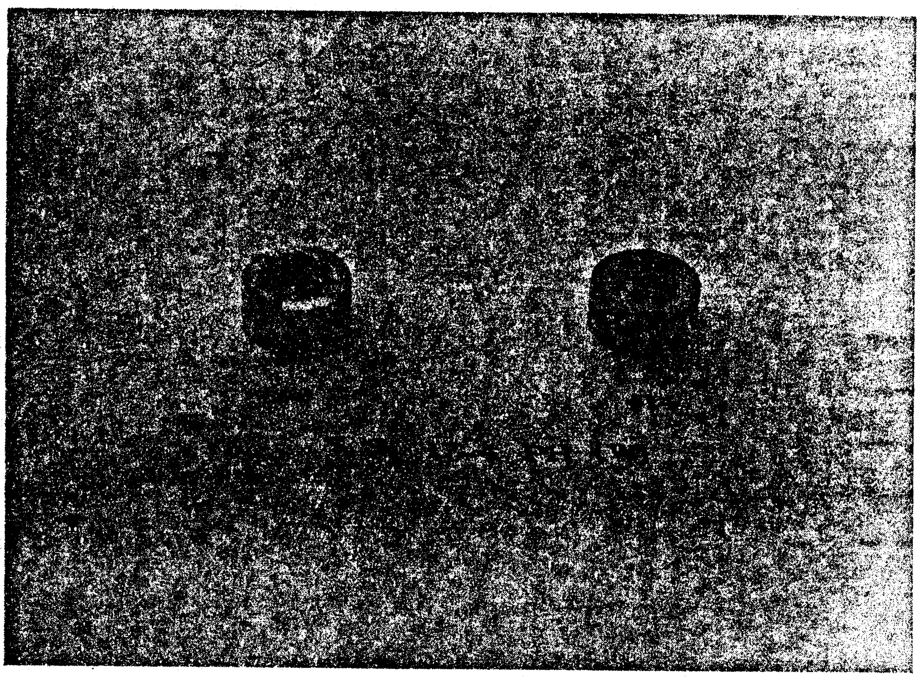
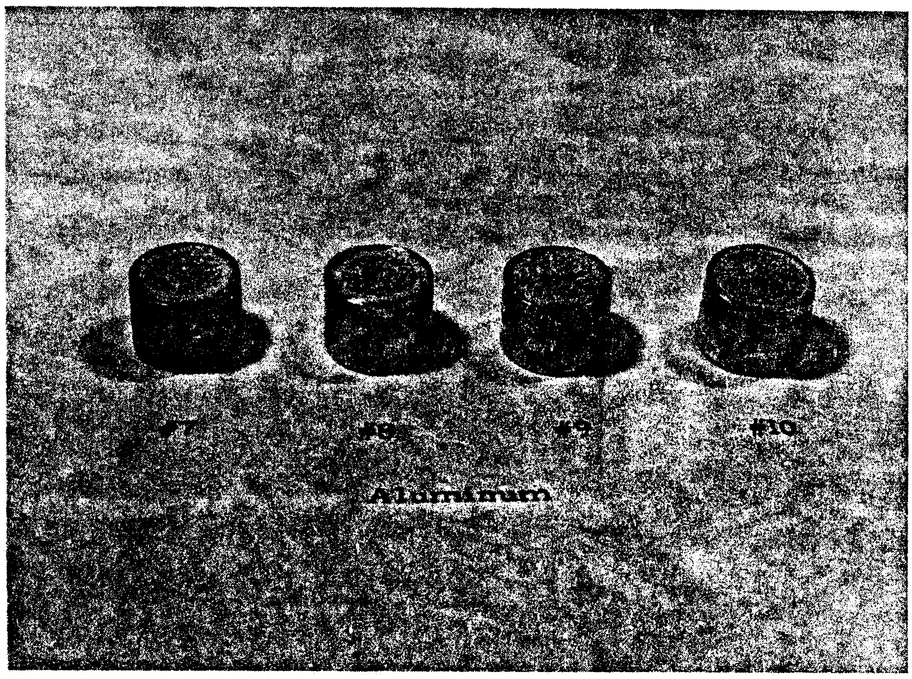


Fig 4.



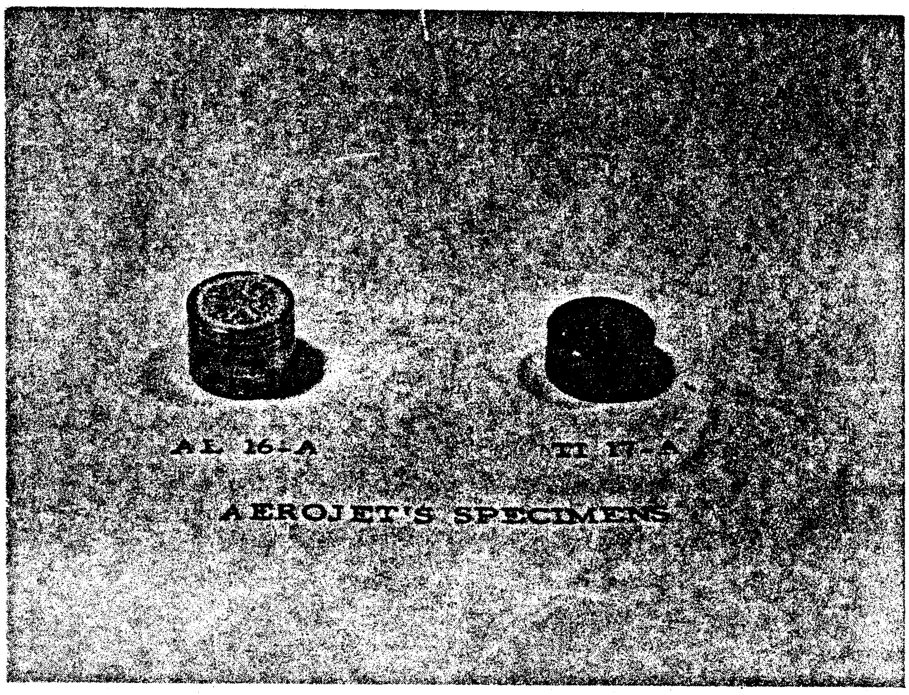


Fig 5.

D A T A

A N D

C U R V E S

OF CUM. WEIGHT LOSS VS. EXPOSURE TIME
AND MDPR VS. EXPOSURE TIME

MATERIAL DAMAGE SHEET

HORN: Titanium

AMPLITUDE: 1.0 mils (set 5)

WATER: Sea Water

TEMPERATURE: 80F

PRESSURE: 1 atm

TORQUE:

PRE-RUN:

MATERIAL: Al 1100

NUMBER: 16 - A

APPROX. DATE: 12/02/77

DENSITY: 0.09751 lbm/in³

AREA: 0.248 in²

M. D. P. FACTOR:

$c = \left(\frac{1}{\rho A}\right) = .09098$

COMMENTS:

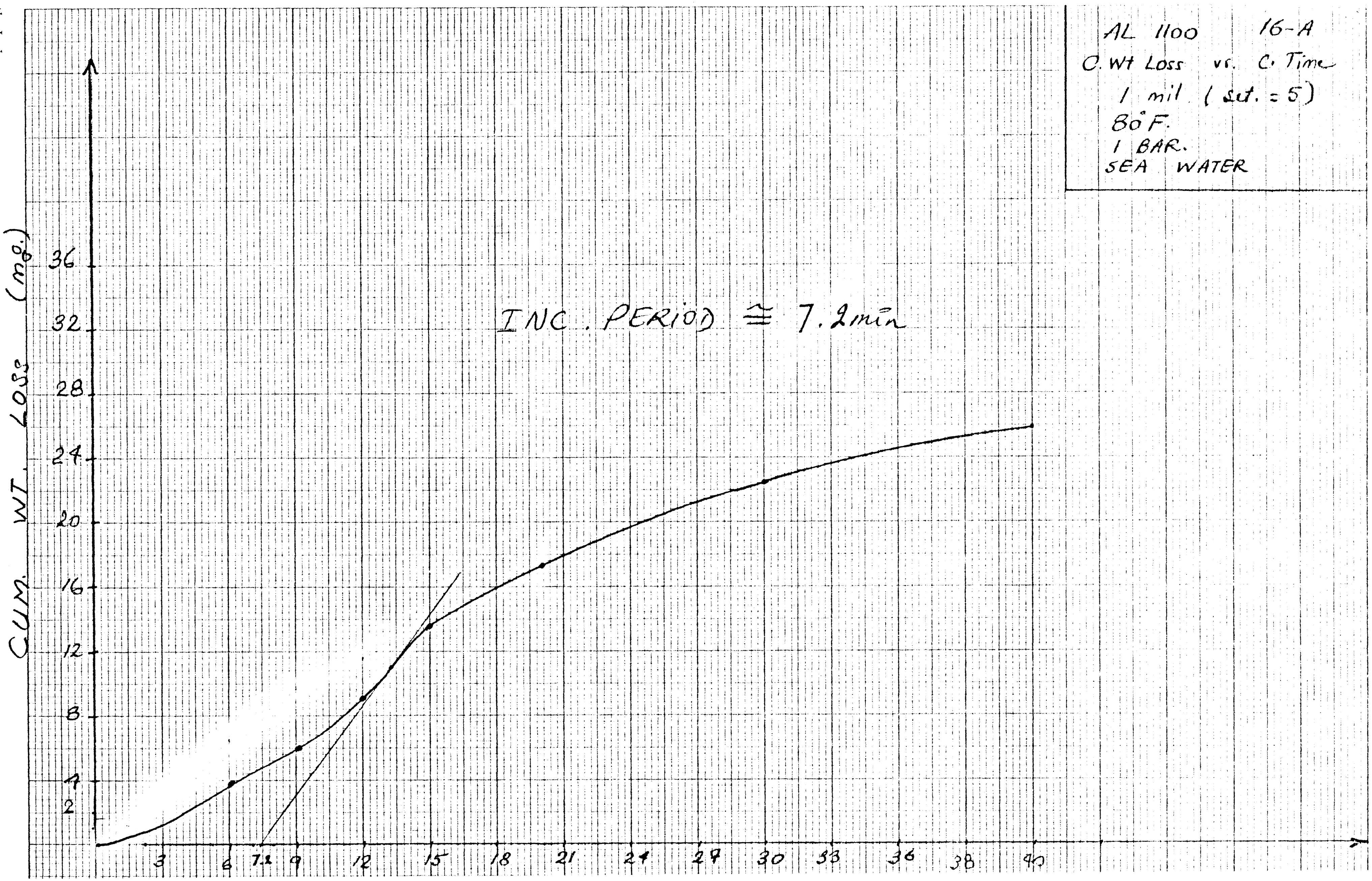
$$MDPR = \frac{0.09098\,(WL)\,(60)}{\Delta t \,\text{min}}$$

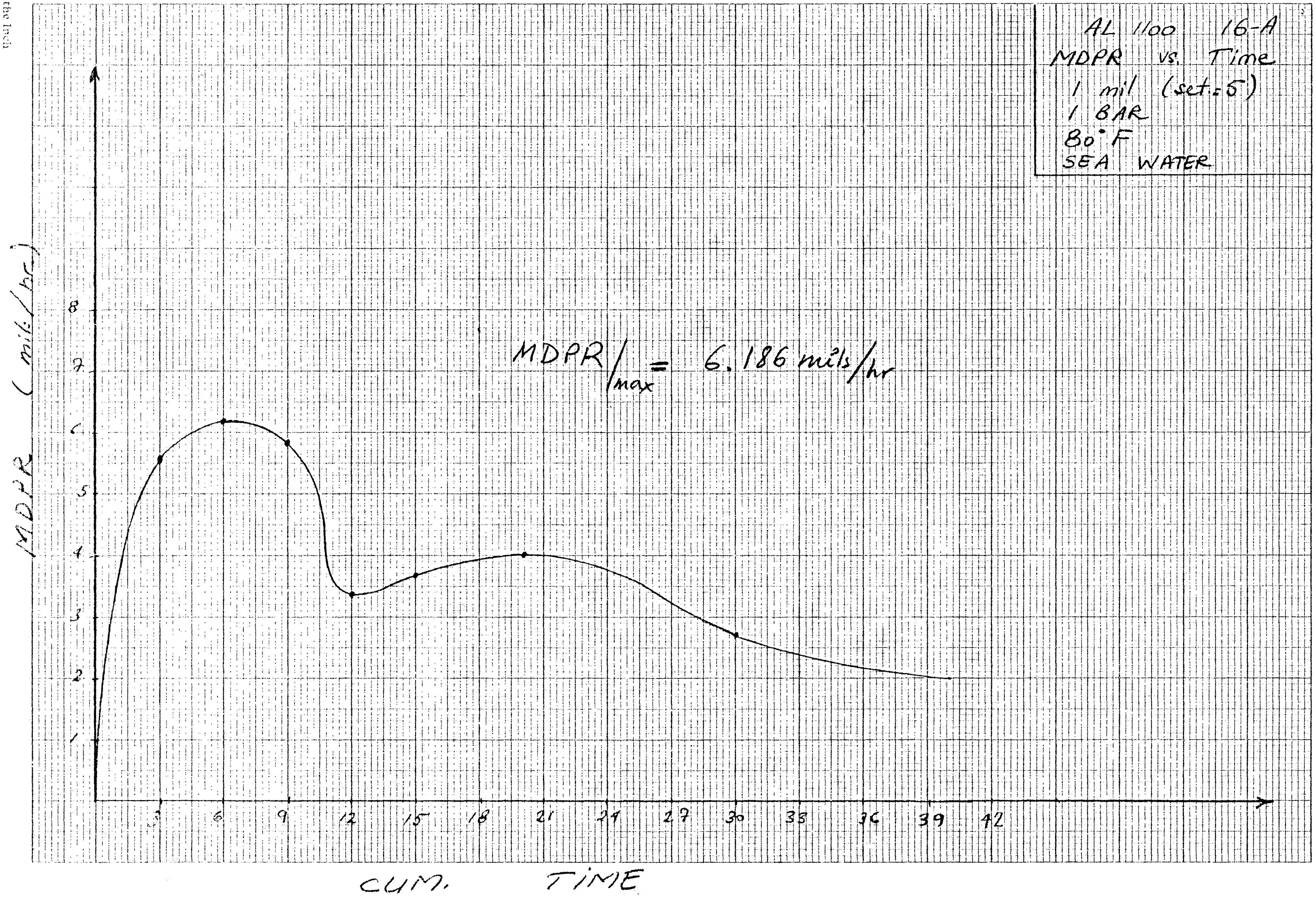
Incubation Period = 7.2 min

$MDPR/_{max}$ = 6.186 mils/hr

DATA

TIME INTERVAL (min)	CUMULATIVE TIME (min)	WEIGHT LOSS (mg)	CUM. WT. LOSS (mg)	M. D. P.	M. D. P. R. (mils/hr)
3	3	3.05	3.05	0.2775	5.55
3	6	3.40	6.45	0.3093	6.186
3	9	3.2	9.65	0.2911	5.822
3	12	1.85	11.50	0.1683	3.366
3	15	2.05	13.55	0.1865	3.73
5	20	3.70	17.25	0.3366	4.039
10	30	5.05	22.3	0.4594	2.756
10	40	3.65	25.95	0.332077	1.992
10	50				


AL 1100 16-A
C. Wt Loss vs. C. Time
1 mil (Sct. = 5)
80°F.
1 BAR.
SEA WATER
CUM. WT. LOSS (mg.)
2
4
8
12
16
20
24
28
32
36
INC. PERIOD ≅ 7.2min
3
6
7.2
9
12
15
18
21
24
27
30
33
36
38
40



AL 1100 16-A
MDPR vs. Time
1 mil (set: 5)
1 BAR
80°F
SEA WATER
MDPR/max = 6.186 mils/hr
MDPR (mils/hr)
8
7
6
5
4
3
2
1
3
6
9
12
15
18
21
24
27
30
33
36
39
42
CUM. TIME

MATERIAL DAMAGE SHEET

HORN: Titanium

AMPLITUDE: 1.0 mils (at 5)

WATER: Sea Water

TEMPERATURE: 80F

PRESSURE: 1 atm

TORQUE:

PRE-RUN:

MATERIAL: Al 1100-0

NUMBER: 17-A

APPROX. DATE: 12/02/77

DENSITY: 0.09751 lbm/in³

AREA: 0.248 in²

M. D. P. FACTOR:

$c = \left(\frac{1}{\rho A}\right) = .09098$

COMMENTS:

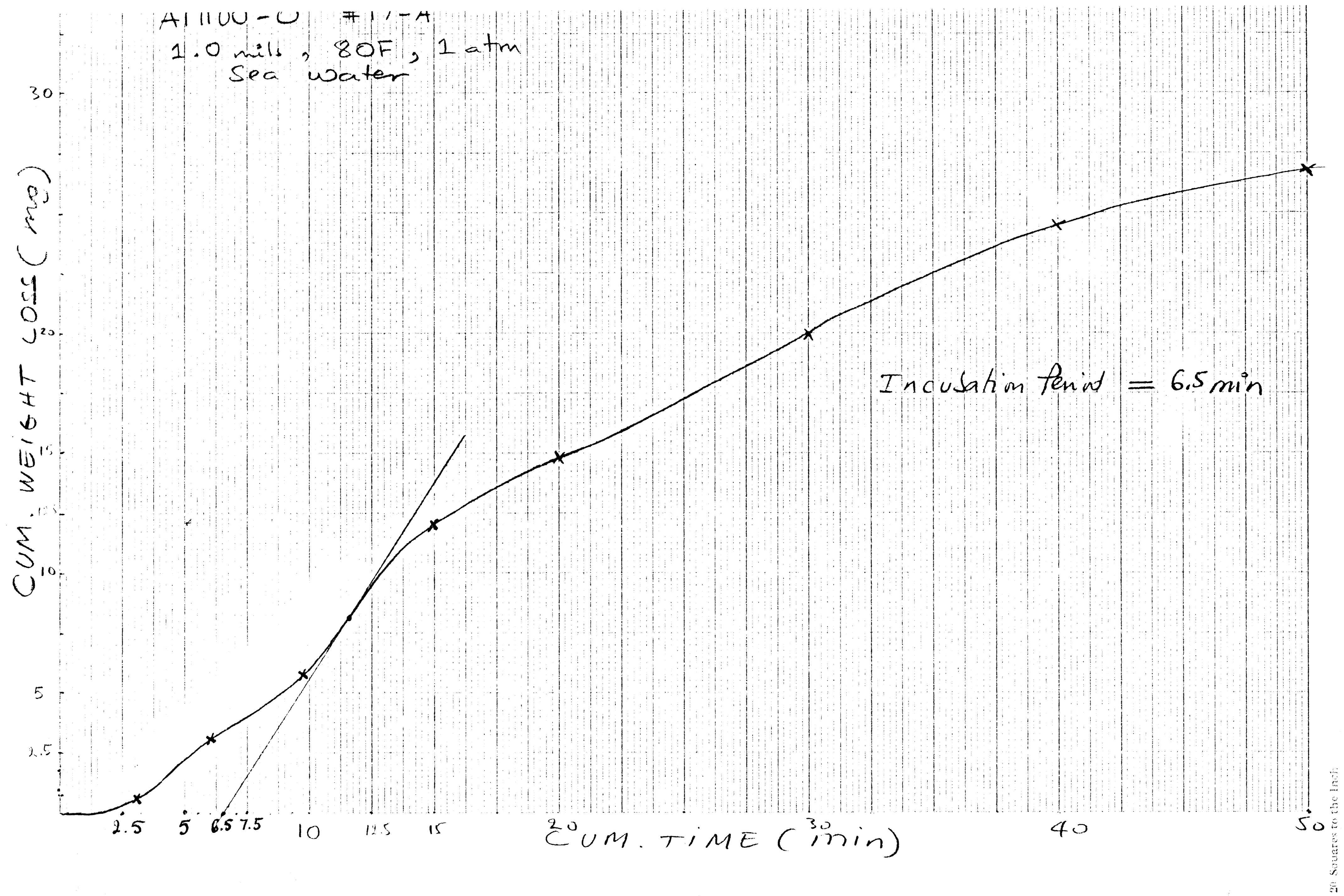
$$MDPR = \frac{0.09098\,(WL)(60)}{\Delta t_{min}}$$

Incubation Period = 6.5 min

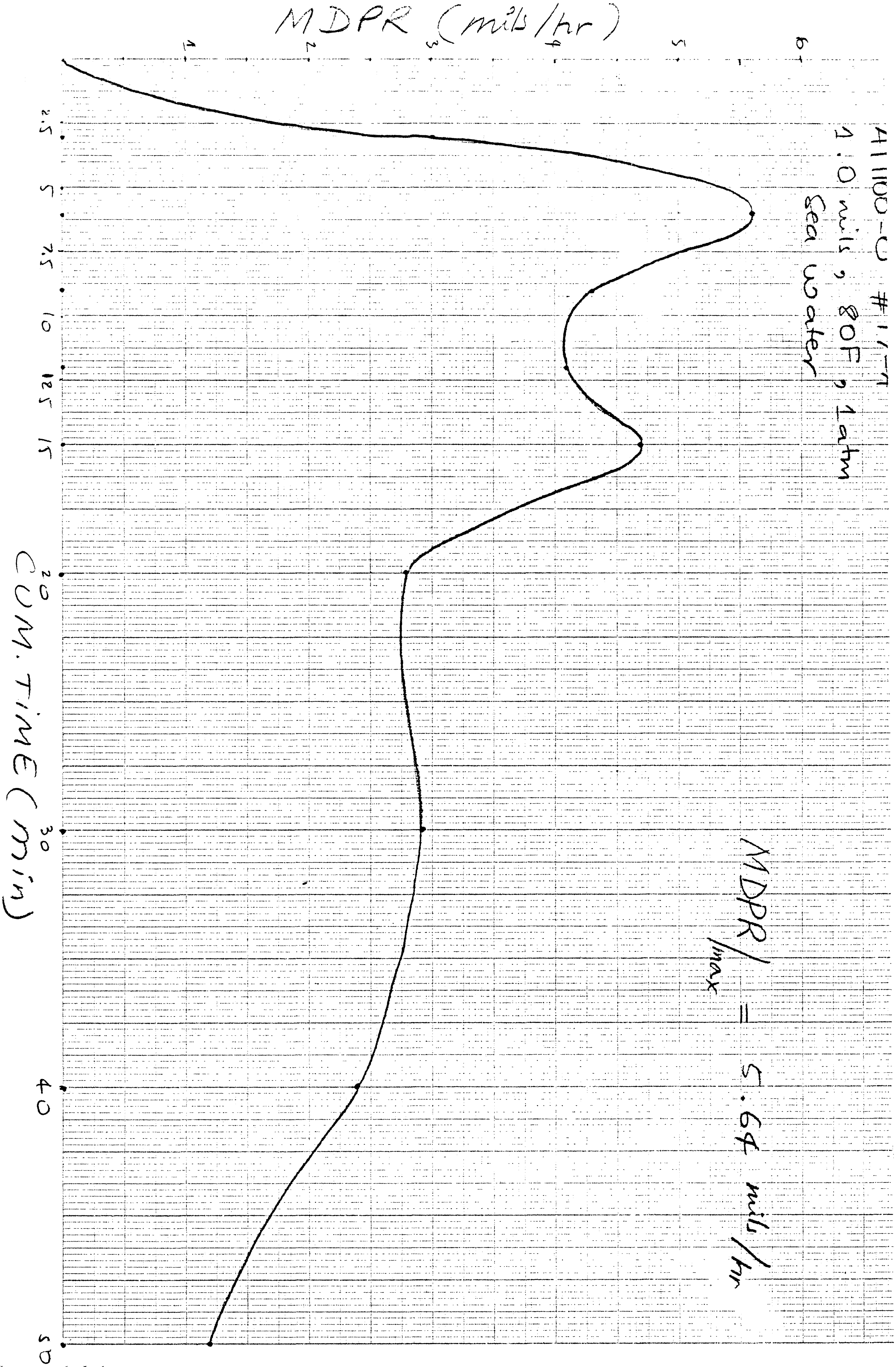
$MDPR|_{max}$ = 5.64 mils/hr

DATA

TIME INTERVAL (min)	CUMULATIVE TIME (min)	WEIGHT LOSS (mg)	CUM. WT. LOSS (mg)	M. D. P.	M. D. P. R. (mils/hr)
3	3	1.7	1.7		3.093
3	6	3.1	4.8		5.64
3	9	2.4	7.2		4.36
3	12	2.3	9.5		4.18
3	15	2.6	12.1		4.73
5	20	2.5	14.6		2.73
10	30	5.3	19.9		2.89
10	40	4.4	24.3		2.40
10	50	2.1	26.4		1.146



1.0 mils, 80F, 1 atm
Sea water
CUM. WEIGHT LOSS (mg)
30
5
10
15
20
2.5
5
6.5
7.5
10
12.5
15
20
30
40
50
CUM. TIME (min)
Incubation Period = 6.5 min
20 Squares to the Inch



20 Squares to the Inch

MATERIAL DAMAGE SHEET

HORN: Ti

MATERIAL: Ti 6AL-4V

AMPLITUDE: 1.0 mils (7.55 setting)

NUMBER: 16-A

WATER: Sea water

APPROX. DATE: 1-13-78

TEMPERATURE: 80°F

DENSITY: 4.43 g/cm^3

PRESSURE: 1 atm

AREA: 0.235 in^2

TORQUE:

M. D. P. FACTOR:

PRE-RUN:

$C = (\rho A)^{-1} = 0.0586$

COMMENTS:

$MDP = (C)(WL)$

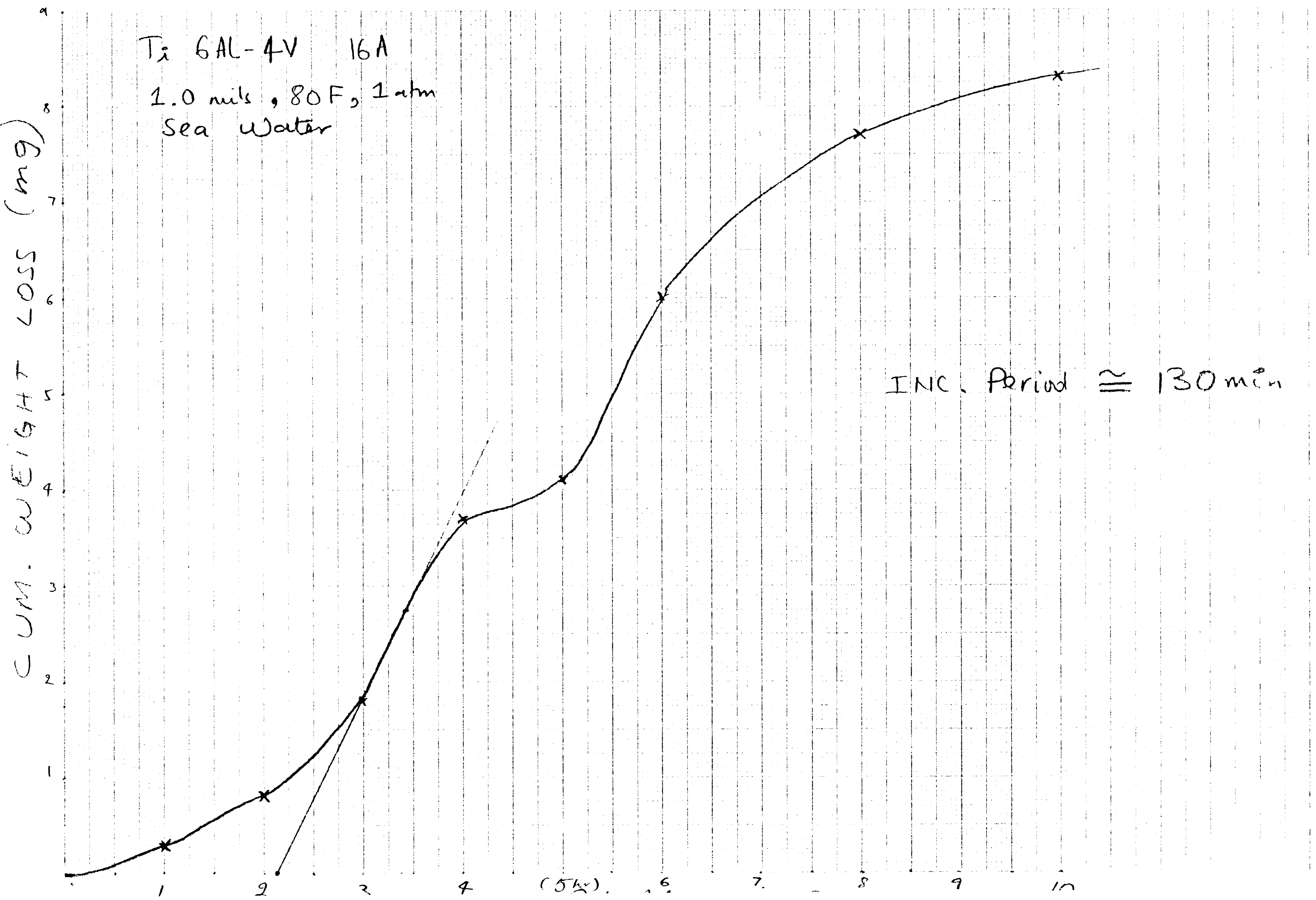
$$MDPR = \frac{MDP}{\Delta t} = \frac{C(WL)}{\Delta t} = \frac{(0.0586)WL}{\Delta t}$$

Incubation Period ≅ 130 min

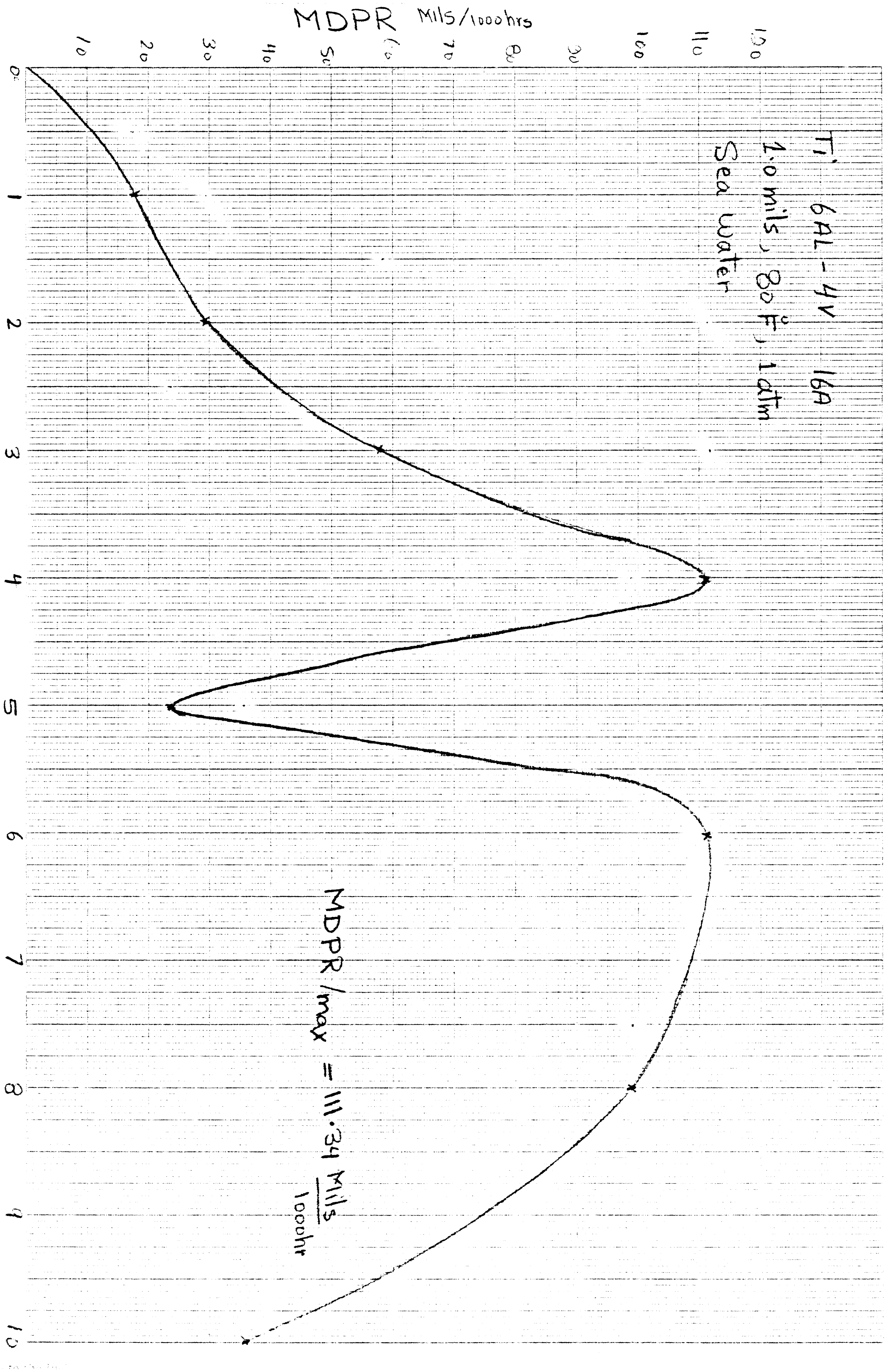
$MDPR/_{max} = 111.34$ mils/1000hrs

DATA

TIME INTERVAL hr	CUMULATIVE TIME (hr)	WEIGHT LOSS mg	CUM. WT. LOSS mg	M. D. P.	M. D. P. R. mils/1000hrs
1	1	0.3	.3		17.53
1	2	0.5	.8		29.3
1	3	1.0	1.8		58.6
1	4	1.9	3.7		111.34
1	5	0.4	4.1		23.44
1	6	1.9	6.0		111.34
2	8	1.7	7.7		99.62
2	10	0.6	8.3		35.16



Ti 6AL-4V 16A
1.0 mils, 80F, 1 atm
Sea Water
CUM. WEIGHT LOSS (mg)
INC. Period ≅ 130 min
1
2
3
4
5
6
7
8
9
(5 hr)



MDPR Mils/1000hrs
10
20
30
40
50
60
70
80
90
100
110
120
0
1
2
3
4
5
6
7
8
9
10
Ti 6AL-4V 16A
1.0 mils, 80°F, 1 atm
Sea Water
MDPR/max = 111.34 Mils/1000hr

MATERIAL DAMAGE SHEET

HORN: Ti

AMPLITUDE: 1.0 mils (25 setting)

WATER: Sea water

TEMPERATURE: 80°F

PRESSURE: 1 atm

TORQUE:

PRE-RUN:

MATERIAL: Ti

NUMBER: 17-A

APPROX. DATE: 12/02/77

DENSITY: 4.43 g/cm³

AREA: 0.235 in²

M. D. P. FACTOR: c = 0.0586 ($= \frac{1}{\rho A}$)

COMMENTS:

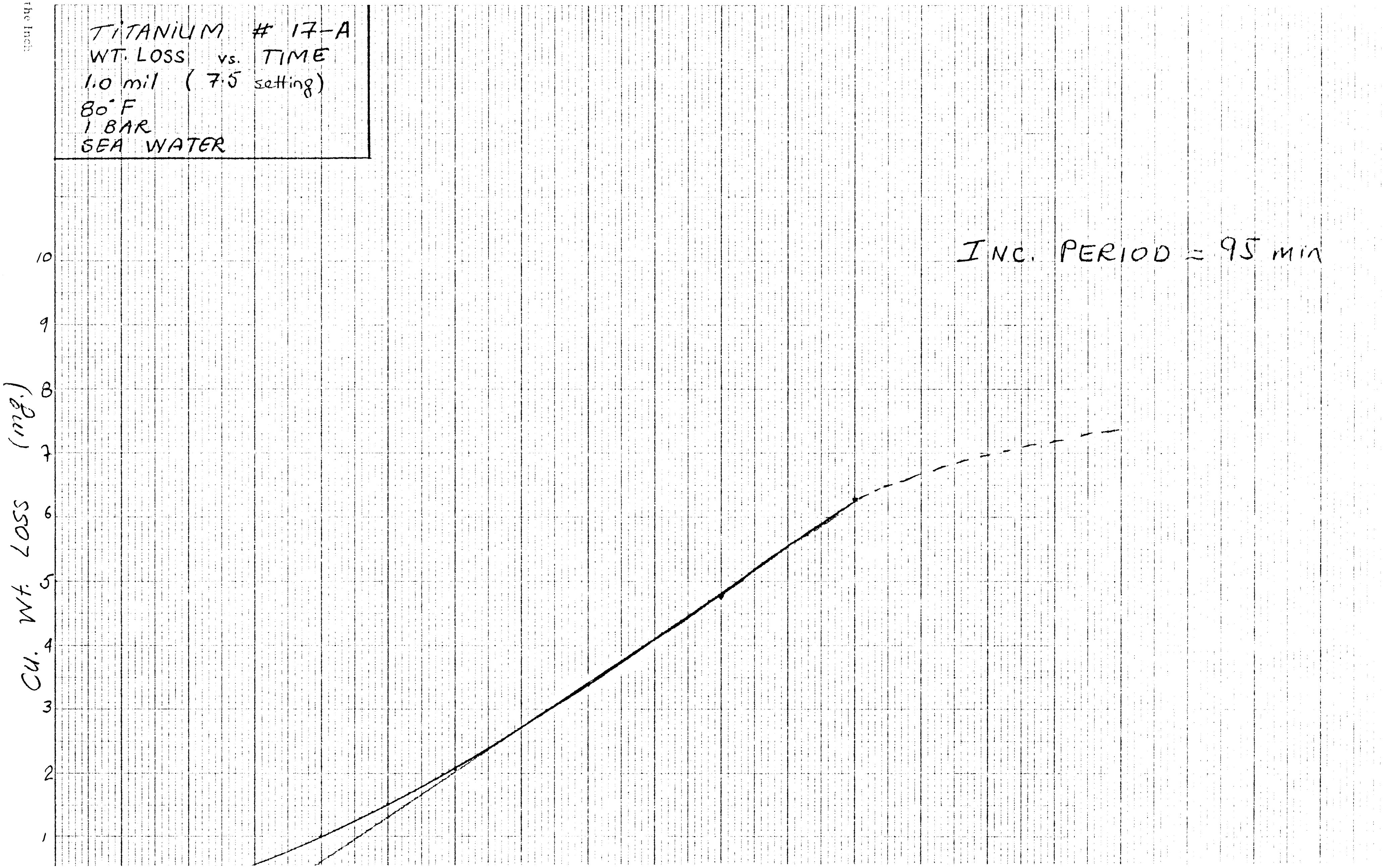
$$MDPR = \frac{(WL)\,c}{\Delta t}$$

Incubation Period = 95 min.

$$MDPR|_{max} = 87.9\ \frac{mils}{1000\,hr}$$

DATA

TIME INTERVAL (hr)	CUMULATIVE TIME (hr)	WEIGHT LOSS (mg)	CUM. WT. LOSS (mg)	M. D. P.	M. D. P. R. (mils/1000hrs)
1	1	.2	.2	.01172	11.72
1	2	.8	1.0	.04688	46.88
1	3	1.05	2.05	.06153	61.53
1	4	1.35	3.40	.07911	79.11
1	5	1.35	4.75	.07911	79.11
1	6	1.50	6.25	.0879	87.9 ← MAX MDPR!
2	8				
2	10				
2	12				



TITANIUM # 17-A
WT. LOSS vs. TIME
1.0 mil (7.5 setting)
80° F
1 BAR
SEA WATER
INC. PERIOD = 95 min
CU. Wt. LOSS (mg.)
1
2
3
4
5
6
7
8
9
10

MATERIAL DAMAGE SHEET

[FO]RN:	Ti	MATERIAL:	Ti
[AM]PLITUDE:	1.0 mils (7.5 kHz)	NUMBER:	18 - A
[W]ATER:	Sea water	APPROX. DATE:	12/02/77
[TE]MPERATURE:	80 F	DENSITY:	4.43 g/cm^3
[PR]ESSURE:	1 atm	AREA:	0.235 in^2
[TO]RQUE:		M. D. P. FACTOR:	
[RE]-RUN:			$c = 0.0586 \left(= \frac{1}{\rho A}\right)$

[CO]MMENTS:

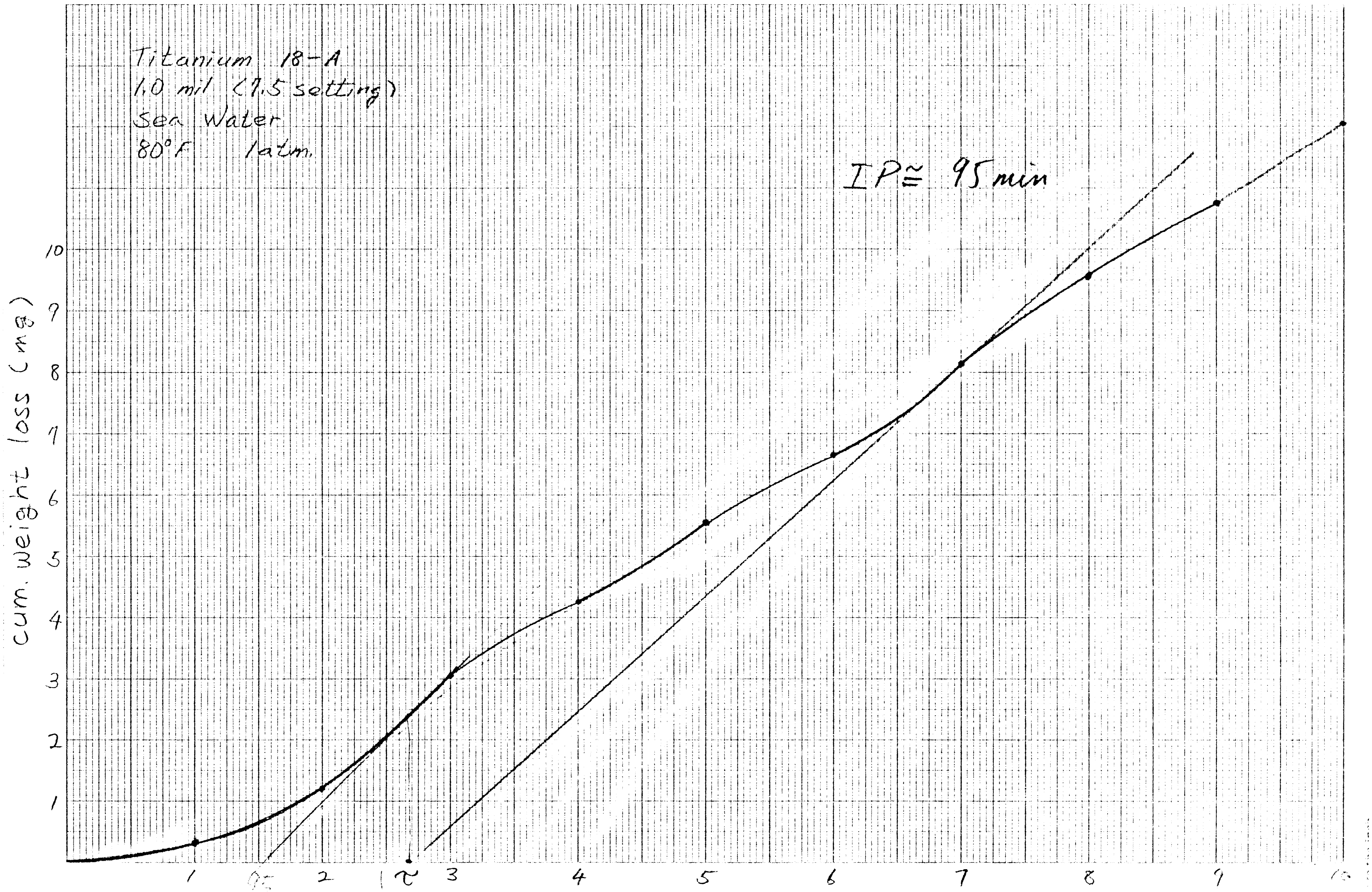
$$MDPR = \frac{(WL)\, c}{\Delta t}$$

Incubation Period = 95 min

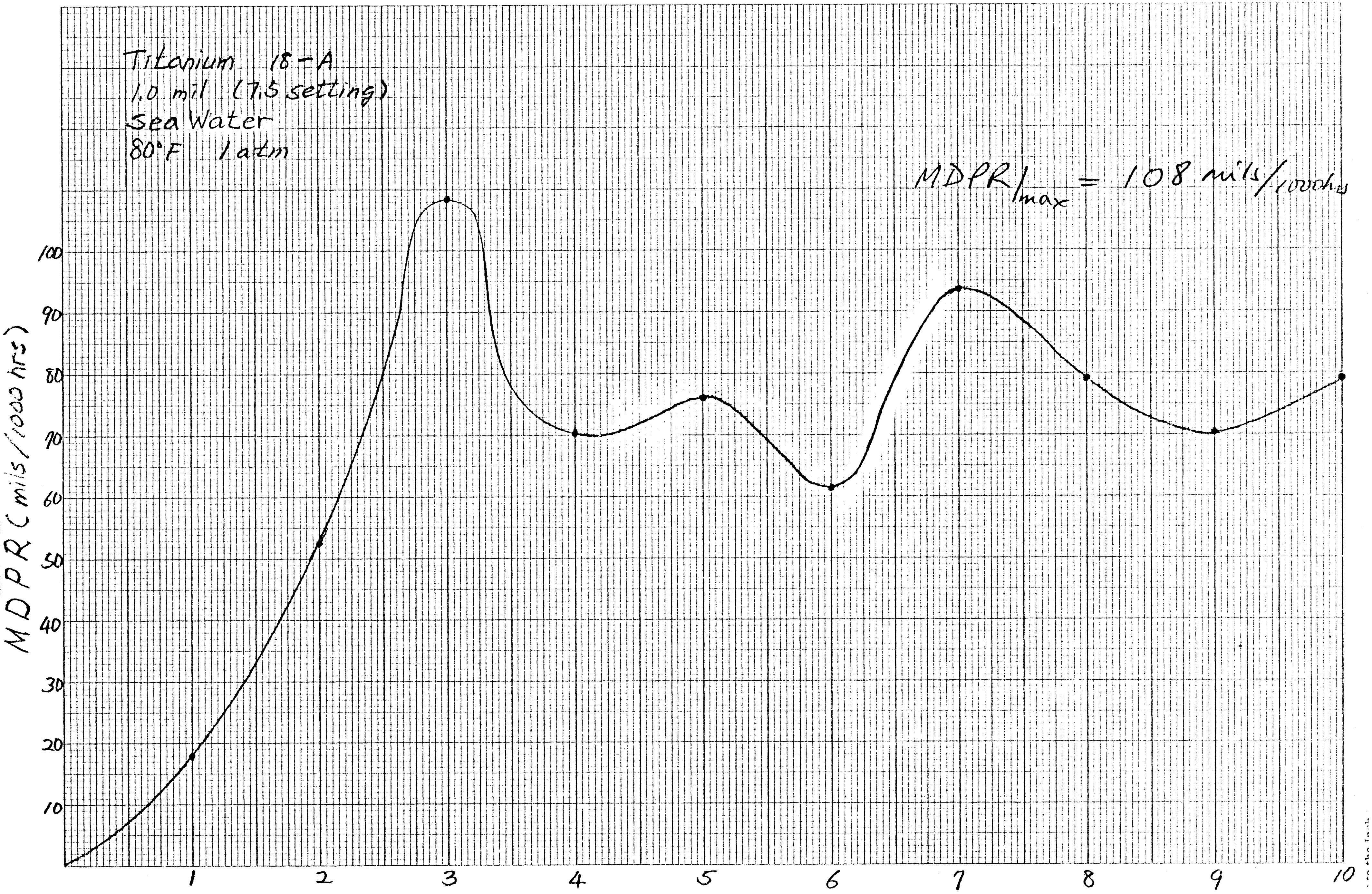
$MDPR|_{max}$ = 108 mils/1000 hrs

DATA

[TI]ME [IN]TERVAL ([h]r)	CUMULATIVE TIME (hr)	WEIGHT LOSS (mg)	CUM. WT. LOSS (mg)	M. D. P.	M. D. P. R. (mils/1000 hrs)
1	1	.3	.3		17.58
1	2	.9	1.2		52.74
1	3	1.85	3.05		108.41
1	4	1.2	4.25		70.32
1	5	1.3	5.55		76.18
1	6	1.05	6.6		61.53
1	7	1.6	8.2		93.76
1	8	1.35	9.55		79.11
1	9	1.2	10.75		70.32
1	10	1.35	12.05		79.11



Titanium 18-A
1.0 mil (7.5 setting)
Sea Water
80°F 1atm.
IP ≅ 95 min
cum. weight loss (mg)
1
2
3
4
5
6
7
8
9
10
τ


Titanium 18-A
1.0 mil (7.5 setting)
Sea Water
80°F 1 atm
MDPR|max = 108 mils/1000hrs
MDPR (mils/1000 hrs)
10
20
30
40
50
60
70
80
90
100
1
2
3
4
5
6
7
8
9
10

PART(II)

I INTRODUCTION

The two most important parameters that we measure in our tests for each material are the Incubation Period(IP) and the Mean Depth of Penetration rate(MDPR). The IP is found from the cumulative weight loss vs. exposure time curves. Then we find MDPR (volume loss per exposed area) using the material densities.

A relationship between IP and $MDPR_{max}$ was found from experimental data and it seems that the two quantities are related to the following equation:

$$\left(\frac{IP_1}{IP_2}\right)^n = \frac{MDPRmax2}{MDPR_{max1}} = k$$

This equation can be simplified into:

$$(IP)^n = C/(MDPR_{max}) \qquad (1)$$

Various attempts were made to draw the IP vs. $MDPR_{max}$ curves manually but were inaccurate and therefore a computer program was written to calculate the best-line fit as well as n and C.

II ANALYTICAL PROCEDURE

If we take the logarithm base 10 of both sides of(1) and simplify:

$$n \log IP = \log C + \log 1/MDPR_{max}$$

Or, by rearranging the equation;

$$\log 1/MDPR_{max} = n \log IP - \log C \qquad (2)$$

If we want to draw the curve $\log(1/MDPR_{max})$ vs log IP then (2) has the equation of a standard line: y=mx+b where m is the slope and b corresponds to the log of the proportional constant. In order to find m and C, the following equations were used

$$m = \frac{\sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i \Big/ n}{\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2 \Big/ n}$$

$$C = 10^{\left[\left(\left|\sum_{i=1}^{n} y_i\right| + m\left(\sum_{i=1}^{n} x_i\right)\right)/n\right]}$$

These two numbers are the ones that are most important in the MDPR and incubation period analysis. In addition to a proportional constant for the best-fit line, a constant can be found for each pair of data points using the calculated slope according to the original equation

$$C = (x_i^m)(y_i) \quad \text{or} \quad C = (\text{Incubation Period})^m \, (\text{MDPR})$$

By finding the proportional constant for each pair of data points, an analysis can be made of all the proportional constants obtained for a set. The average proportional constant is calculated by

$$\bar{C} = \frac{1}{N} \sum_{i=1}^{n} C_i$$

The proportional constant mean deviation is found by

$$MD = \frac{1}{N} \sum_{i=1}^{n} \left| C_i - \bar{C} \right|$$

The proportional constant standard deviation is defined by

$$SD = \sqrt{\frac{(\bar{C} - C_i)^2}{(N - 1)}}$$

The proportional constant root mean square is calculated by

$$RMS = \sqrt{\left(\frac{1}{N}\right) \sum_{i=1}^{n} C_i^2}$$

III. Results and Computer Output

The computer output enabled us to get the values of n (exponent) and c (constant y-intercept) for each material tested. Then best-fit lines of $(\frac{1}{MDPR})^*$ vs. IP (Tan intercept and $(\frac{1}{MDPR})$ vs. IP (0.1 mil) were plotted for each material.

In previous experiments, values of n were computed manually and found to be close to unit (1) which means that the MDPR is inversely proportional to the first degree of IP (see relation (1)).

This calculated result was confirmed using the computer program. The exponent n varies between 0.901 and 1.32 for the material tested, thus the best-fit lines make approximately a 45° angle with the horizontal axis. The small deviations are due to experimental errors only. Note that n is independent of the material tested. The constant C varies over a broad range of values (i.e. 12920 to 64429). Since the C's indicate only the position of the lines (y - intercept) and not their behavior, they do not influence our results.

In summary the plots made by the machine verify relation (1) better than manual plots.

IV APPENDIX

1) MDPR and INCUBATION DATA ANALYSIS

For AL1100 0

SS17 4 (CAST , WROUGHT)

TITANIUM 6AL 4V

2) PLOTS OF (1/MDPR) VS. INCUBATION PERIODS

For AL1100 0

SS17 4 (CAST, WROUGHT)

TITANIUM 6AL 4V

1) MDPR and INCUBATION DATA ANALYSIS

MDPR AND INCUBATION DATA ANALYSIS

ALUMINUM 1100-0
TANGENT INTERCEPT

INCUBATION DATA		MDPR DATA		PROPORTIONAL
INCBT	LOG(INCBTN)	MDPR	LOG(MDPR)	CONSTANT
7.500	0.875061	7096.000	-3.851013	53096.555
7.500	0.875061	7018.000	-3.846213	52512.914
4.000	0.602060	12450.000	-4.095170	49720.508
7.200	0.857333	6186.000	-3.791409	44438.012
6.500	0.812913	5640.000	-3.751279	36580.969

E OF LINE(EXPONENT,N) = 0.9988479

PROPORTIONALITY CONSTANT = 40835.262

TISTICAL ANALYSIS OF PROPORTIONAL CONSTANT

HMATIC MEAN = 47269.773

DEVIATION = 5408.242

DARD DEVIATION = 6886.898

MEAN SQUARE = 47669.434

MUM PROPORTIONAL CONSTANT = 53096.555

MUM PROPORTIONAL CONSTANT = 36580.969

* *

HDPE AND INCUBATION DATA ANALYSIS

ALUMINUM 1100-0
0.1 MIL

INCUBATION DATA		HDPE DATA		PROPORTIONAL
INCBT	LOG(INCBTN)	HDPE	LOG(HDPE)	CONSTANT
2.500	0.397940	7096.000	-3.851013	15330.414
3.500	0.544068	7018.000	-3.846213	20118.727
1.500	0.176091	12450.000	-4.095170	17506.766
2.900	0.462398	6186.000	-3.791409	15140.453
3.200	0.505150	5640.000	-3.751279	14995.082

PE OF LINE(EXPONENT,N) = 0.8406805

PROPORTIONALITY CONSTANT = 16507.699

ATISTICAL ANALYSIS OF PROPORTIONAL CONSTANT

HMATIC MEAN = 16618.273

DEVIATION = 1755.563

DARD DEVIATION = 7232.516

MEAN SQUARE = 16735.336

IMUM PROPORTIONAL CONSTANT = 20118.727

IMUM PROPORTIONAL CONSTANT = 14995.082

* *

MDPR AND INCUBATION DATA ANALYSIS

STAINLESS STEEL 17-4 PH
TANGENT INTERCEPT

INCUBATION DATA		MDPR DATA		PROPORTIONAL
INCBT	LOG(INCBTN)	MDPR	LOG(MDPR)	CONSTANT
0.000	1.845098	138.600	-2.141763	13622.625
5.000	1.875061	125.400	-2.098297	13278.594
0.000	1.698970	214.500	-2.331428	14659.637
5.000	2.021189	174.000	-2.240549	26497.543
0.000	2.041392	100.000	-2.000000	16013.043
3.000	1.799340	198.000	-2.296665	17368.023
0.000	2.079181	138.600	-2.141763	24380.613
5.000	0.698970	1800.000	-3.255273	10234.844
0.000	2.146128	9.900	-0.995635	2056.893

E OF LINE(EXPONENT,N) = 1.0798874

PROPORTIONALITY CONSTANT = 12919.656

TISTICAL ANALYSIS OF PROPORTIONAL CONSTANT

HMATIC MEAN = 15345.734

DEVIATION = 5083.594

DARD DEVIATION = 8875.461

MEAN SQUARE = 16800.738

MUM PROPORTIONAL CONSTANT = 26497.543

MUM PROPORTIONAL CONSTANT = 2056.893

*

MDPR AND INCUBATION DATA ANALYSIS

STAINLESS STEEL 17-4 PH
0.1 MIL

INCUBATION DATA		MDPR DATA		PROPORTIONAL
INCBT	LOG(INCBTN)	MDPR	LOG(MDPR)	CONSTANT
0.000	2.041392	138.000	-2.141763	47762.148
0.000	2.079181	125.400	-2.098297	48148.973
0.000	1.903090	214.500	-2.331428	49756.117
5.000	2.243038	174.000	-2.240549	106783.063
5.000	2.161368	100.000	-2.000000	48578.320
0.000	2.146128	198.000	-2.296665	92080.000
0.000	2.079181	138.000	-2.141763	53217.289
0.000	1.301029	1800.000	-3.255273	74536.500

E OF LINE(EXPONENT,N) = 1.2429361

PROPORTIONALITY CONSTANT = 61944.711

TISTICAL ANALYSIS OF PROPORTIONAL CONSTANT

HMATIC MEAN = 65107.781

DEVIATION = 19519.016

DARD DEVIATION = 25134.406

MEAN SQUARE = 68651.438

MUM PROPORTIONAL CONSTANT = 106783.063

MUM PROPORTIONAL CONSTANT = 47762.148

* *

MDPR AND INCUBATION DATA ANALYSIS

STAINLESS STEEL 17-4 PH (CAST)
TANGENT INTERCEPT

INCUBATION DATA		MDPR DATA		PROPORTIONAL
INCBT	LOG(INCBTN)	MDPR	LOG(MDPR)	CONSTANT
70.000	1.845098	138.600	-2.141763	37039.293
75.000	1.875061	125.400	-2.098297	36695.109
50.000	1.698970	214.500	-2.331428	36823.164

PE OF LINE(EXPONENT,N) = 1.3153229

T PROPORTIONALITY CONSTANT = 36852.121

ATISTICAL ANALYSIS OF PROPORTIONAL CONSTANT

THMATIC MEAN = 36852.500

N DEVIATION = 124.507

NDARD DEVIATION = 47022.473

T MEAN SQUARE = 36852.793

IMUM PROPORTIONAL CONSTANT = 37039.293

IMUM PROPORTIONAL CONSTANT = 36695.109

* *

MDPR AND INCUBATION DATA ANALYSIS

STAINLESS STEEL 17-4 PH (CAST)
0.1 MIL

INCUBATION DATA		MDPR DATA		PROPORTIONAL
INCBT	LOG(INCBTN)	MDPR	LOG(MDPR)	CONSTANT
0.000	2.041392	138.600	-2.141763	42483.945
0.000	2.079181	125.400	-2.098297	42735.250
0.000	2.079181	138.600	-2.141763	47233.703
0.000	1.903090	214.500	-2.331428	44610.113

E OF LINE(EXPONENT,N) = 1.2180223

PROPORTIONALITY CONSTANT = 44225.285

TISTICAL ANALYSIS OF PROPORTIONAL CONSTANT

HMATIC MEAN = 44265.734

DEVIATION = 1656.155

DARD DEVIATION = 38456.297

MEAN SQUARE = 44306.516

MUM PROPORTIONAL CONSTANT = 47233.703

MUM PROPORTIONAL CONSTANT = 42483.945

* *

MDPR AND INCUBATION DATA ANALYSIS

STAINLESS STEEL 17-4 PH (WROUGHT)
TANGENT INTERCEPT

INCUBATION DATA		MDPR DATA		PROPORTIONAL
INCBT	LOG(INCBTN)	MDPR	LOG(MDPR)	CONSTANT
5.000	0.698970	1800.000	-3.255273	11394.602
5.000	2.021189	174.000	-2.240549	36141.766
0.000	2.041392	100.000	-2.000000	21909.121
3.000	1.799340	198.000	-2.296665	22395.902
0.000	2.146128	9.900	-0.995635	2859.884

E OF LINE(EXPONENT,N) = 1.1465826

PROPORTIONALITY CONSTANT = 14265.379

TISTICAL ANALYSIS OF PROPORTIONAL CONSTANT

HMATIC MEAN = 19040.234

DEVIATION = 9530.410

DARD DEVIATION = 35610.625

MEAN SQUARE = 22129.047

MUM PROPORTIONAL CONSTANT = 36141.766

MUM PROPORTIONAL CONSTANT = 2859.884

* *

MDPR AND INCUBATION DATA ANALYSIS

STAINLESS STEEL 17-4 PH (WROUGHT)
0.1 MIL

INCUBATION DATA		MDPR DATA		PROPORTIONAL
INCBT	LOG(INCBTN)	MDPR	LOG(MDPR)	CONSTANT
20.000	1.301029	1800.000	-3.255273	66092.313
75.000	2.243038	174.000	-2.240549	86790.938
45.000	2.161368	100.000	-2.000000	39782.590
0.000	2.146128	198.000	-2.296665	75514.000

E OF LINE(EXPONENT,N) = 1.2027998

PROPORTIONALITY CONSTANT = 64429.512

TISTICAL ANALYSIS OF PROPORTIONAL CONSTANT

HMATIC MEAN = 67044.938

DEVIATION = 14107.508

DARD DEVIATION = 45746.512

MEAN SQUARE = 69256.500

MUM PROPORTIONAL CONSTANT = 86790.938

MUM PROPORTIONAL CONSTANT = 39782.590

* *

MDPR AND INCUBATION DATA ANALYSIS

TITANIUM 6AL-4V
TANGENT INTERCEPT

INCUBATION DATA		MDPR DATA		PROPORTIONAL
INCBT	LOG(INCBTN)	MDPR	LOG(MDPR)	CONSTANT
0.000	2.623249	7.810	-0.892651	2000.418
0.000	2.113943	111.340	-2.046651	9716.602
5.000	1.977723	87.000	-1.943939	5751.559
5.000	1.977723	108.000	-2.033423	7066.762
0.000	2.322219	42.200	-1.625312	5720.039
0.000	1.954242	79.110	-1.898231	4925.715
5.000	1.875061	127.000	-2.103804	6688.723
5.000	2.021189	158.200	-2.199206	11347.750
0.000	1.954242	82.040	-1.914025	5108.148
0.000	3.477121	3.900	-0.591065	6074.285
0.000	3.322219	3.910	-0.592177	4389.223
0.000	2.681241	5.860	-0.767898	1696.724
3.000	0.477121	1000.000	-3.000000	2741.931
0.000	1.954242	41.000	-1.612783	2552.830

E OF LINE(EXPONENT,N) = 0.9181247

PROPORTIONALITY CONSTANT = 4721.000

TISTICAL ANALYSIS OF PROPORTIONAL CONSTANT

HMATIC MEAN = 5412.895

DEVIATION = 2067.908

DARD DEVIATION = 22151.750

MEAN SQUARE = 6042.074

MUM PROPORTIONAL CONSTANT = 11347.750

MUM PROPORTIONAL CONSTANT = 1696.724

* *

MDPR AND INCUBATION DATA ANALYSIS

TITANIUM 6AL-4V
0.1 MIL

INCUBATION DATA		MDPR DATA		PROPORTIONAL
INCBT	LOG(INCBTN)	MDPR	LOG(MDPR)	CONSTANT
0.000	2.954243	7.810	-0.892651	12944.508
5.000	2.454844	42.200	-1.625312	19976.523
0.000	2.000000	79.110	-1.898231	11960.902
0.000	2.146128	127.000	-2.103804	27706.539
0.000	2.146128	158.200	-2.199206	34513.184
0.000	2.176091	82.040	-1.914025	19295.539
0.000	3.255273	3.900	-0.591065	13757.875
0.000	2.954243	5.860	-0.767898	9712.523
8.000	0.903090	1000.000	-3.000000	9641.770
0.000	2.518514	41.000	-1.612783	22770.664
0.000	2.204120	111.340	-2.046651	28094.852
0.000	2.176091	87.900	-1.943989	20673.793
5.000	1.977723	108.000	-2.033423	15441.172

E OF LINE(EXPONENT,N) = 1.0897665

PROPORTIONALITY CONSTANT = 17552.609

TISTICAL ANALYSIS OF PROPORTIONAL CONSTANT

HMATIC MEAN = 18960.730

DEVIATION = 6200.879

DARD DEVIATION = 24318.191

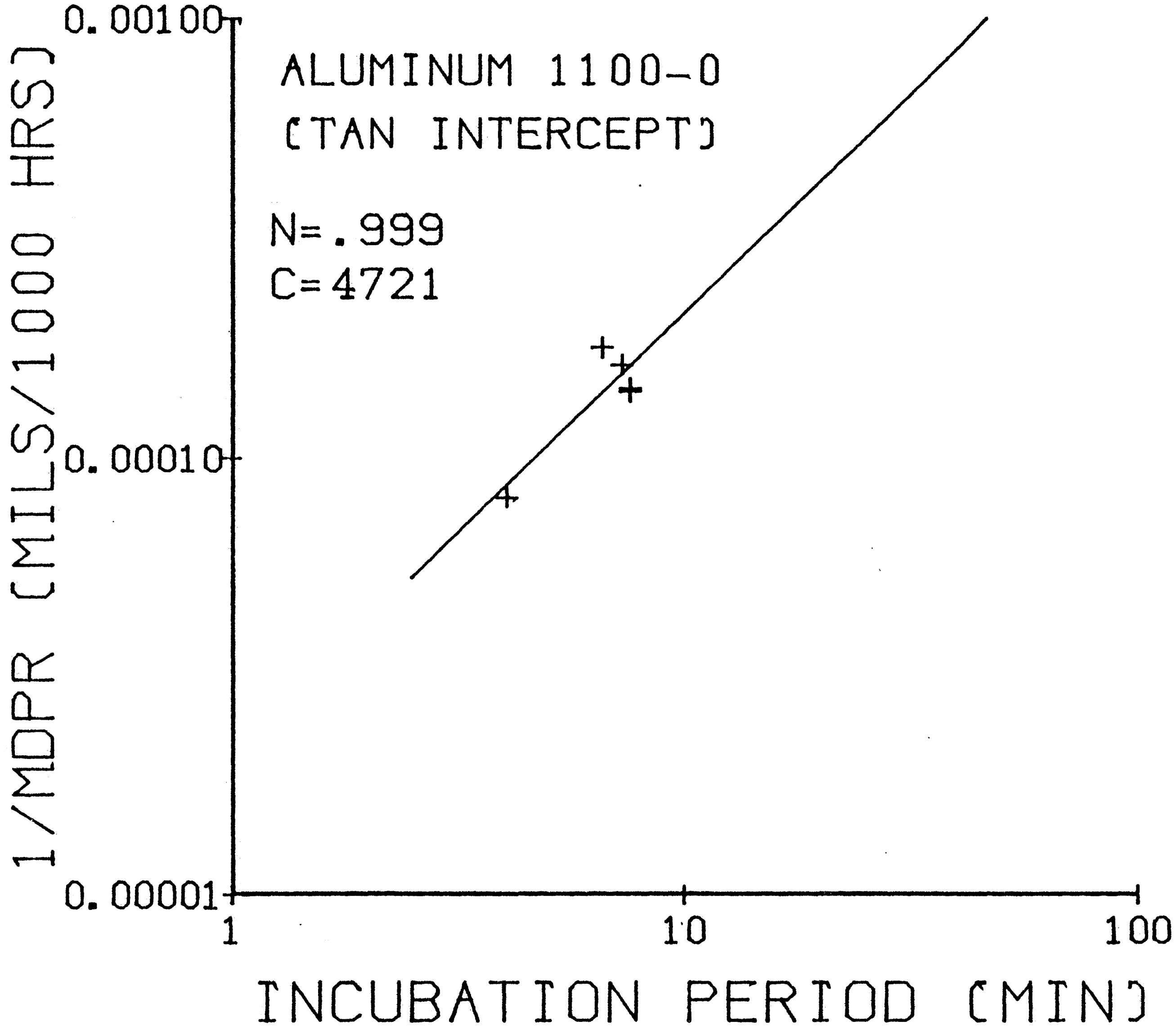
MEAN SQUARE = 20364.078

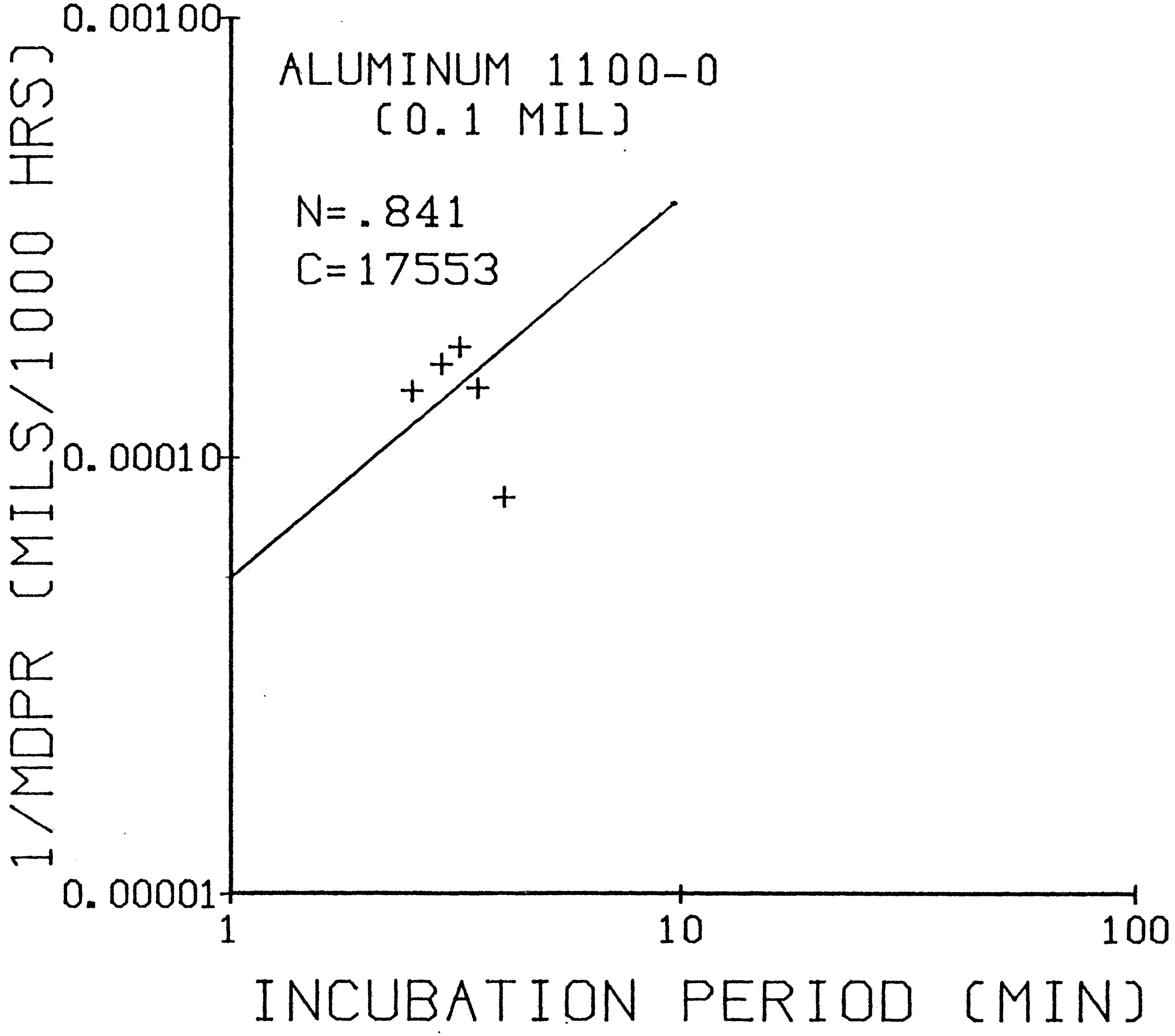
MUM PROPORTIONAL CONSTANT = 34513.184

MUM PROPORTIONAL CONSTANT = 9641.770

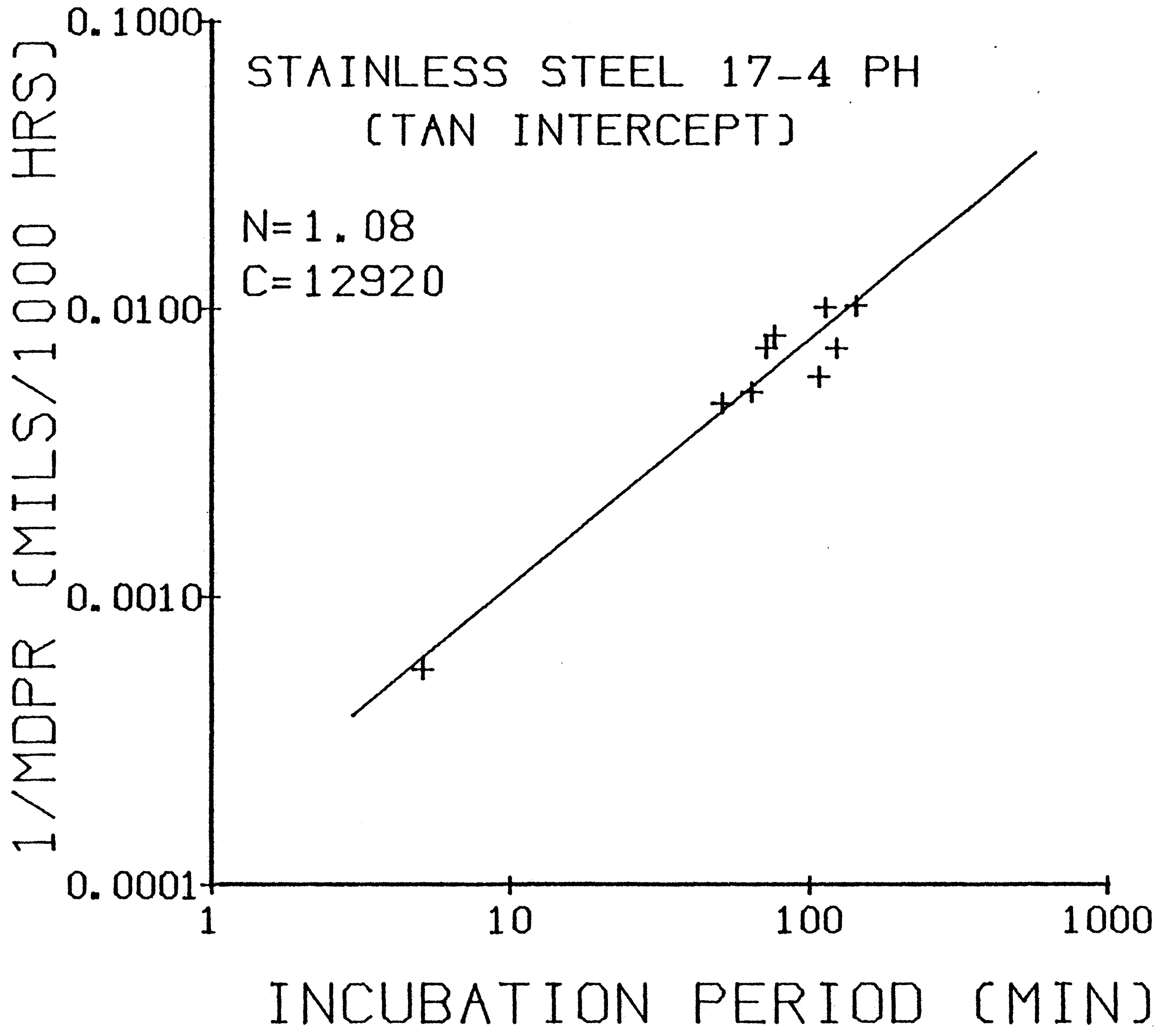
* *

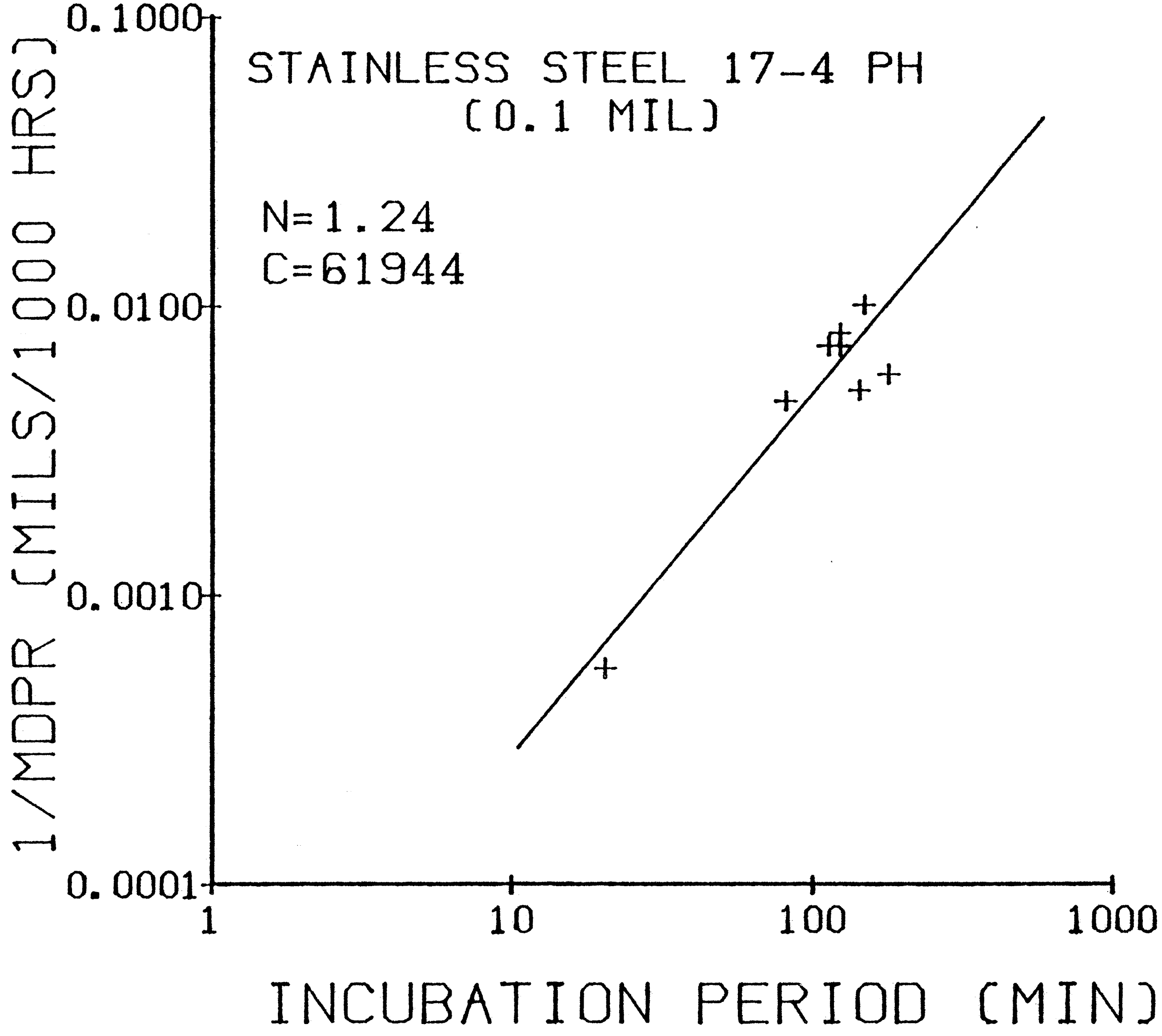
2) PLOTS


ALUMINUM 1100-0
(TAN INTERCEPT)
N=.999
C=4721
1/MDPR (MILS/1000 HRS)
0.00100
0.00010
0.00001
1
10
100
INCUBATION PERIOD (MIN)

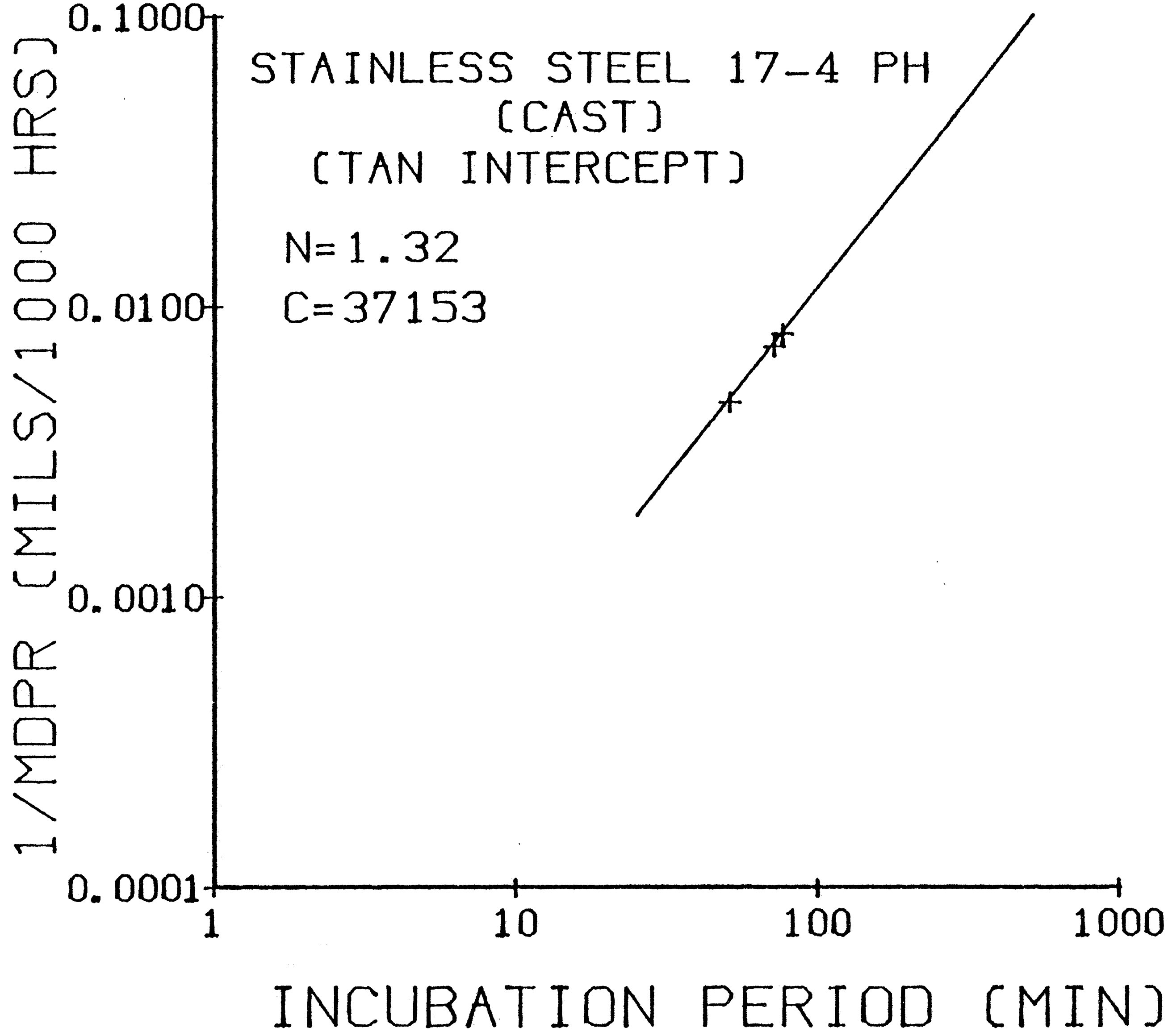


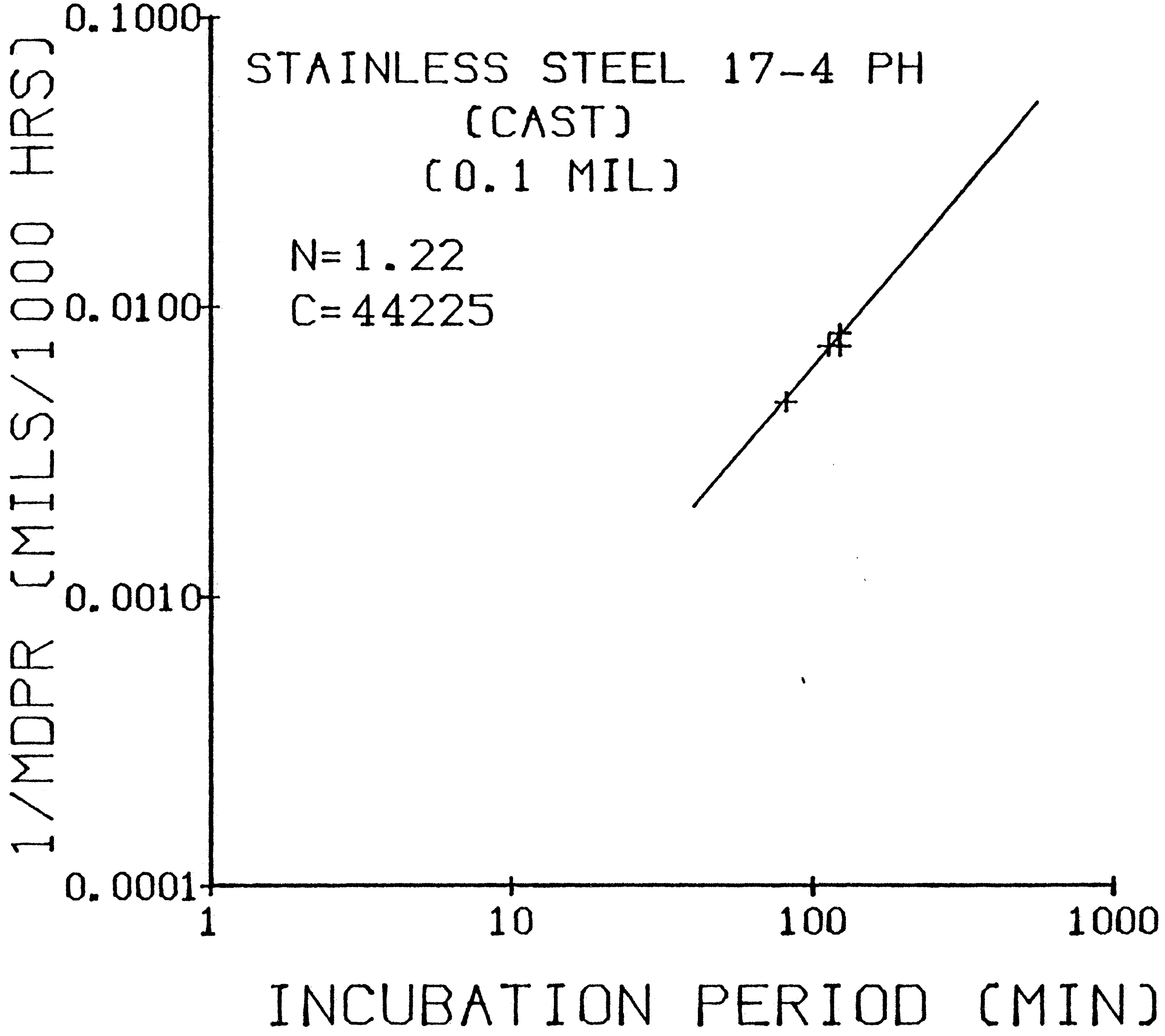
Note: This line was drawn without using the lower most point, which was inconsistent with the rest of the data.

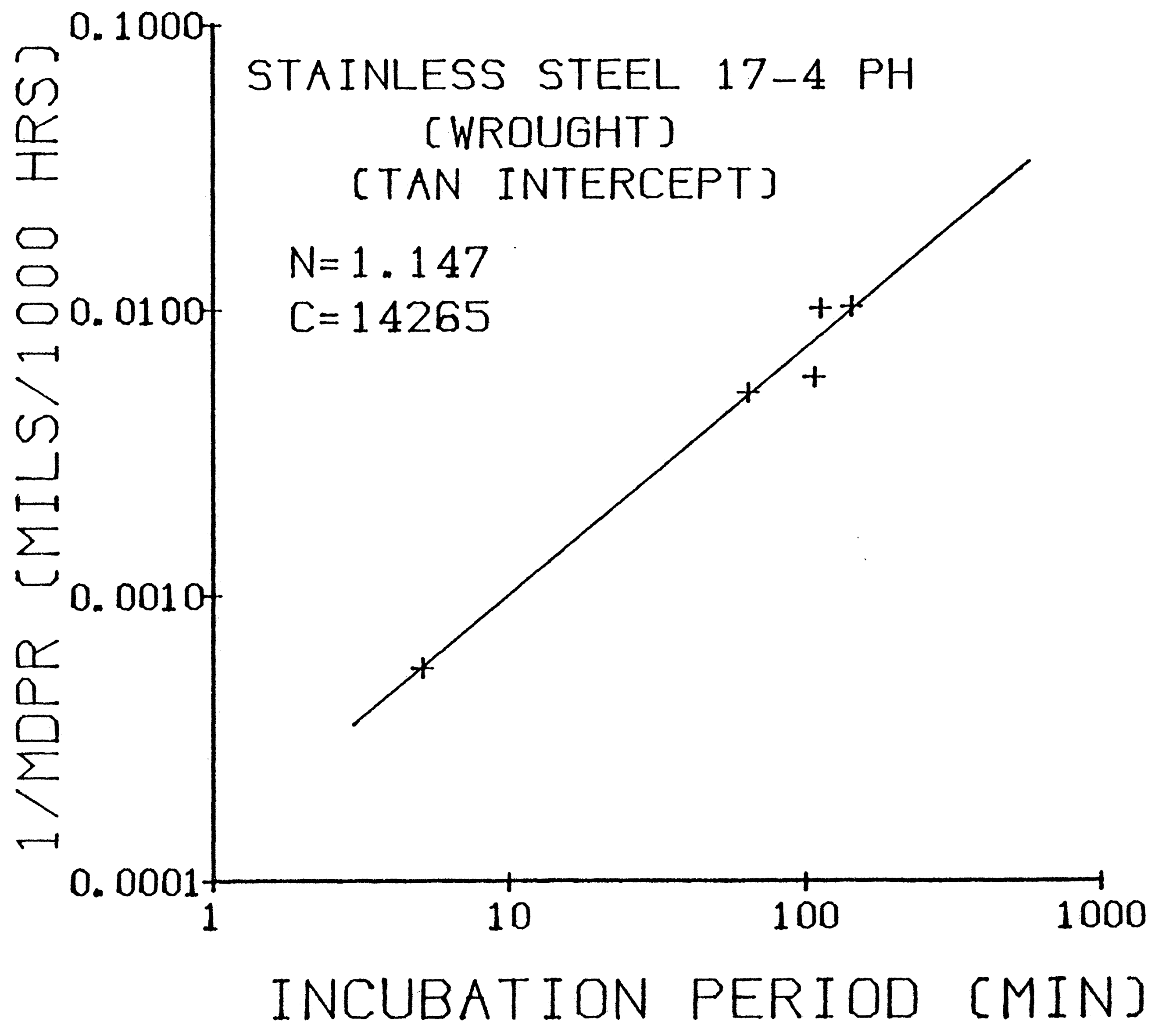

STAINLESS STEEL 17-4 PH
(TAN INTERCEPT)
N=1.08
C=12920
1/MDPR (MILS/1000 HRS)
0.1000
0.0100
0.0010
0.0001
1
10
100
1000
INCUBATION PERIOD (MIN)



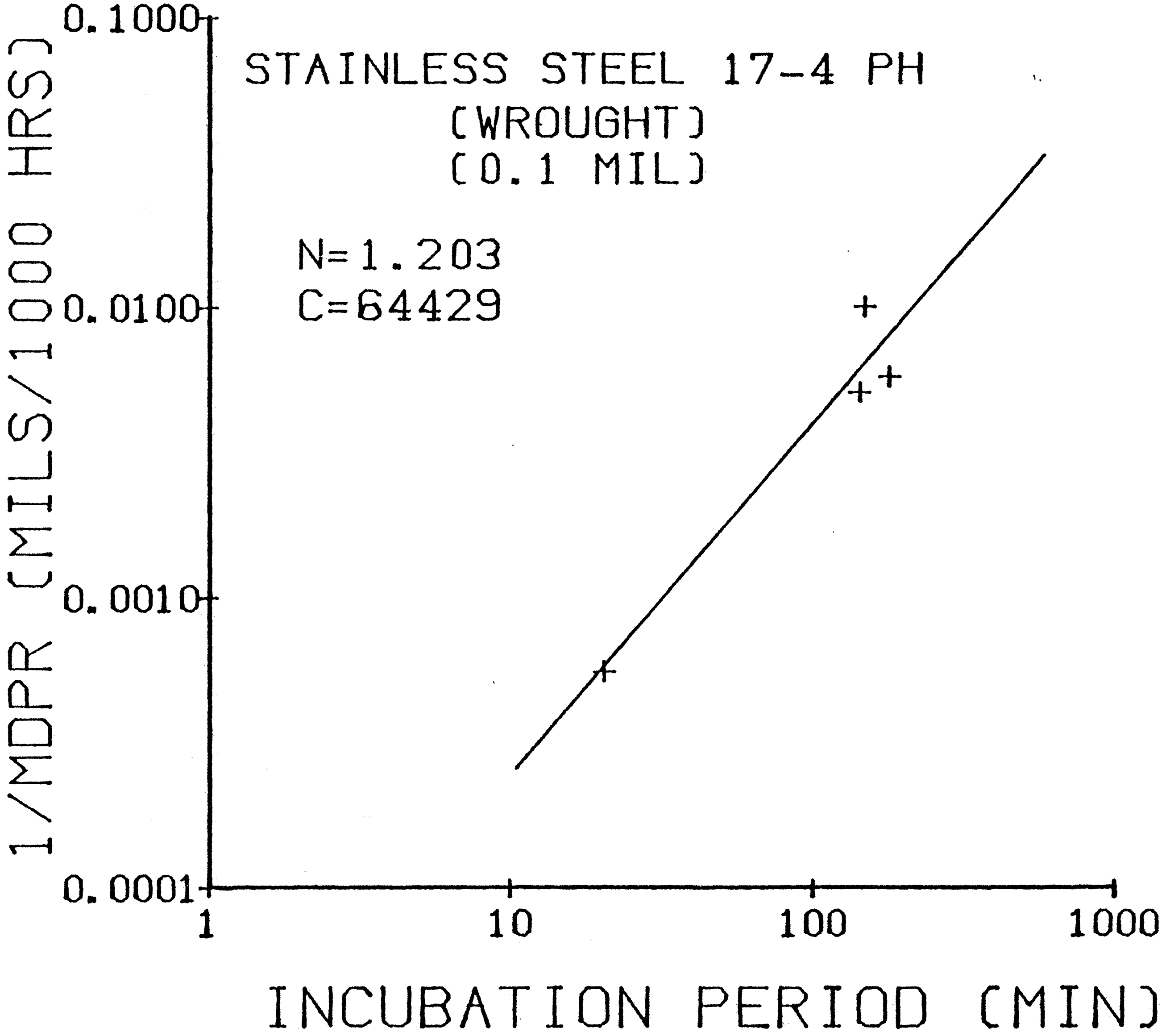
STAINLESS STEEL 17-4 PH
(0.1 MIL)
N=1.24
C=61944
1/MDPR (MILS/1000 HRS)
0.1000
0.0100
0.0010
0.0001
1
10
100
1000
INCUBATION PERIOD (MIN)

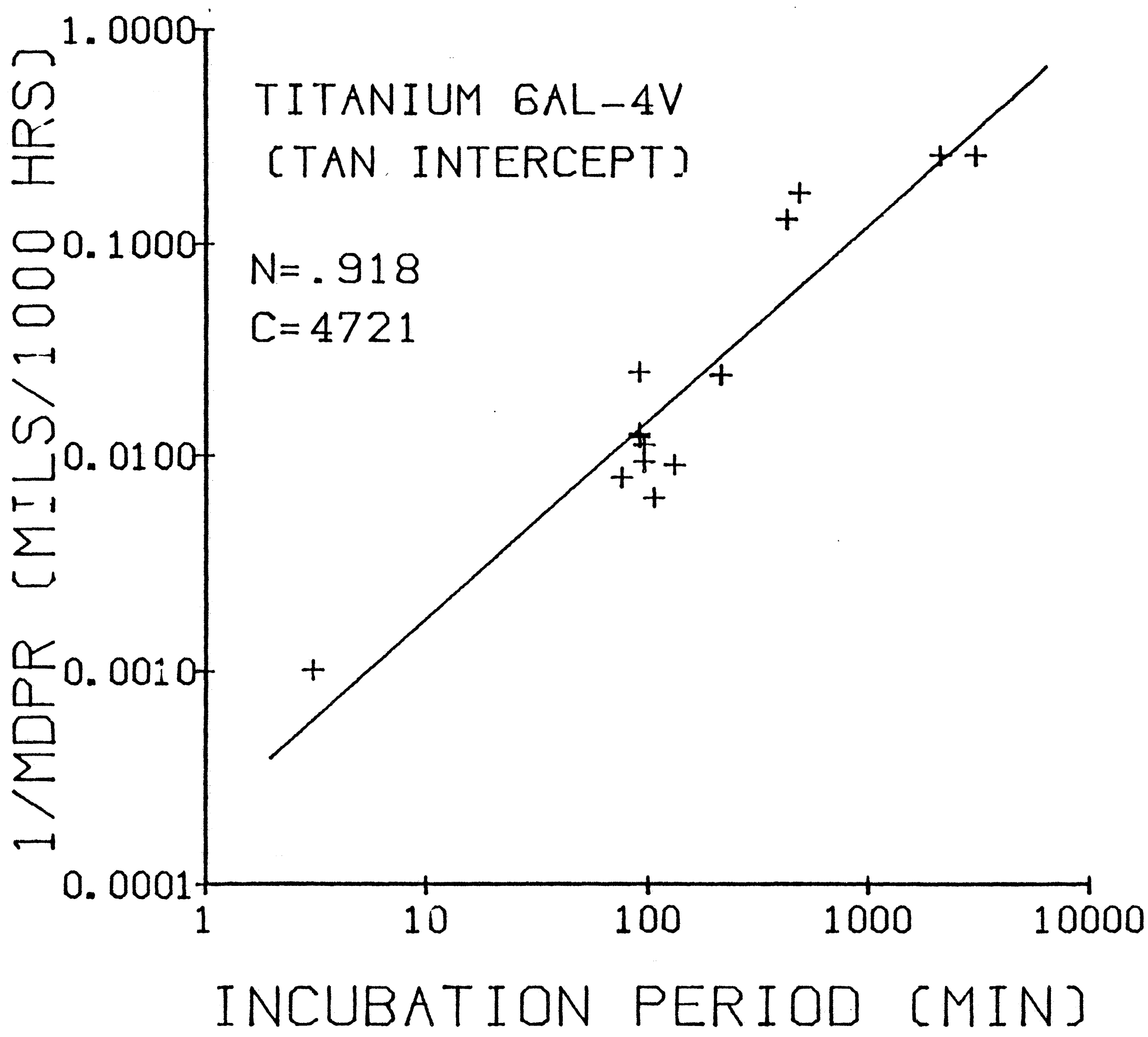

STAINLESS STEEL 17-4 PH
(CAST)
(TAN INTERCEPT)
N=1.32
C=37153
1/MDPR (MILS/1000 HRS)
0.1000
0.0100
0.0010
0.0001
1
10
100
1000
INCUBATION PERIOD (MIN)


STAINLESS STEEL 17-4 PH
(CAST)
(0.1 MIL)
N=1.22
C=44225
1/MDPR (MILS/1000 HRS)
0.1000
0.0100
0.0010
0.0001
1
10
100
1000
INCUBATION PERIOD (MIN)

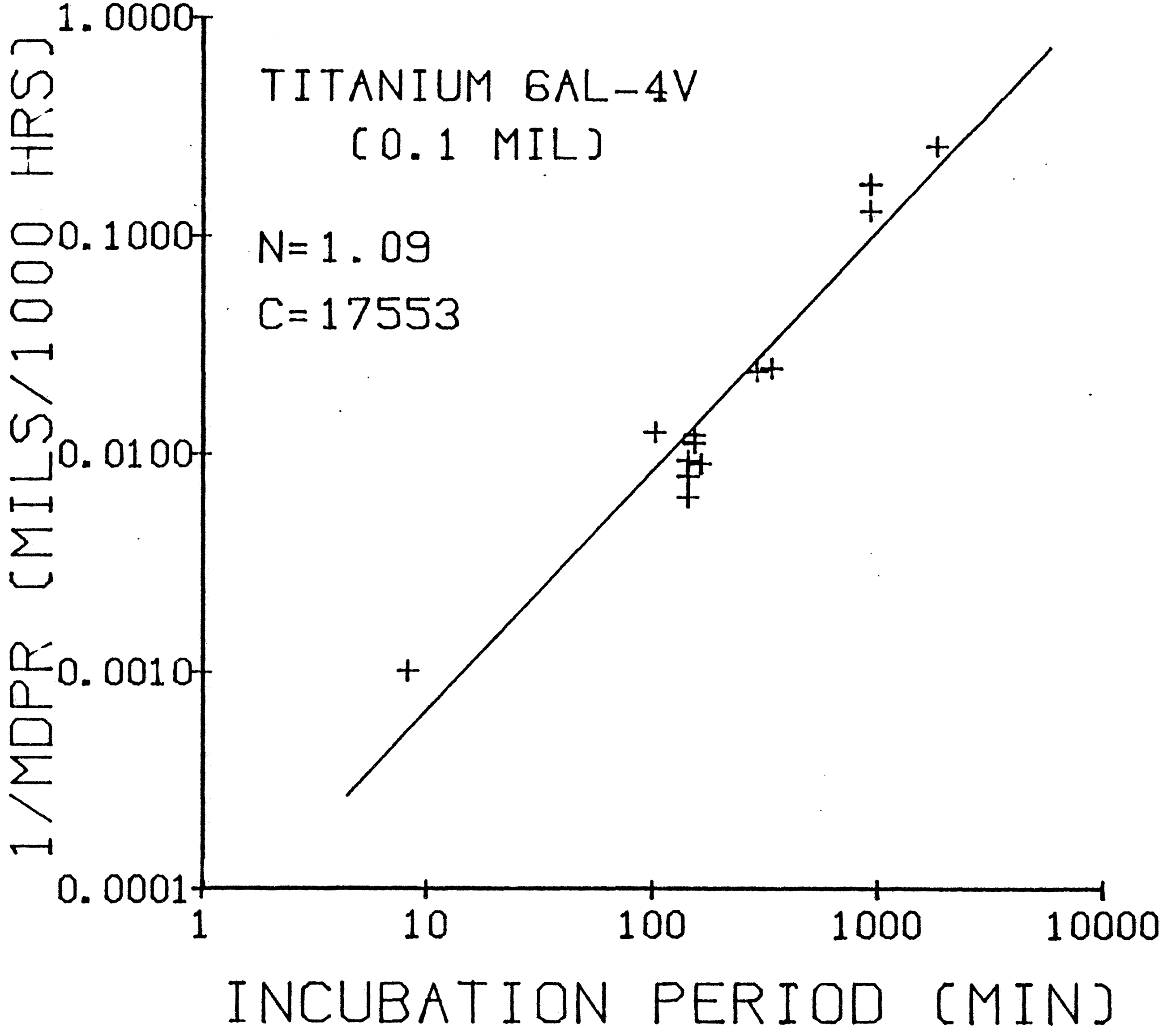


STAINLESS STEEL 17-4 PH
(WROUGHT)
(TAN INTERCEPT)
N=1.147
C=14265
1/MDPR (MILS/1000 HRS)
0.1000
0.0100
0.0010
0.0001
1
10
100
1000
INCUBATION PERIOD (MIN)

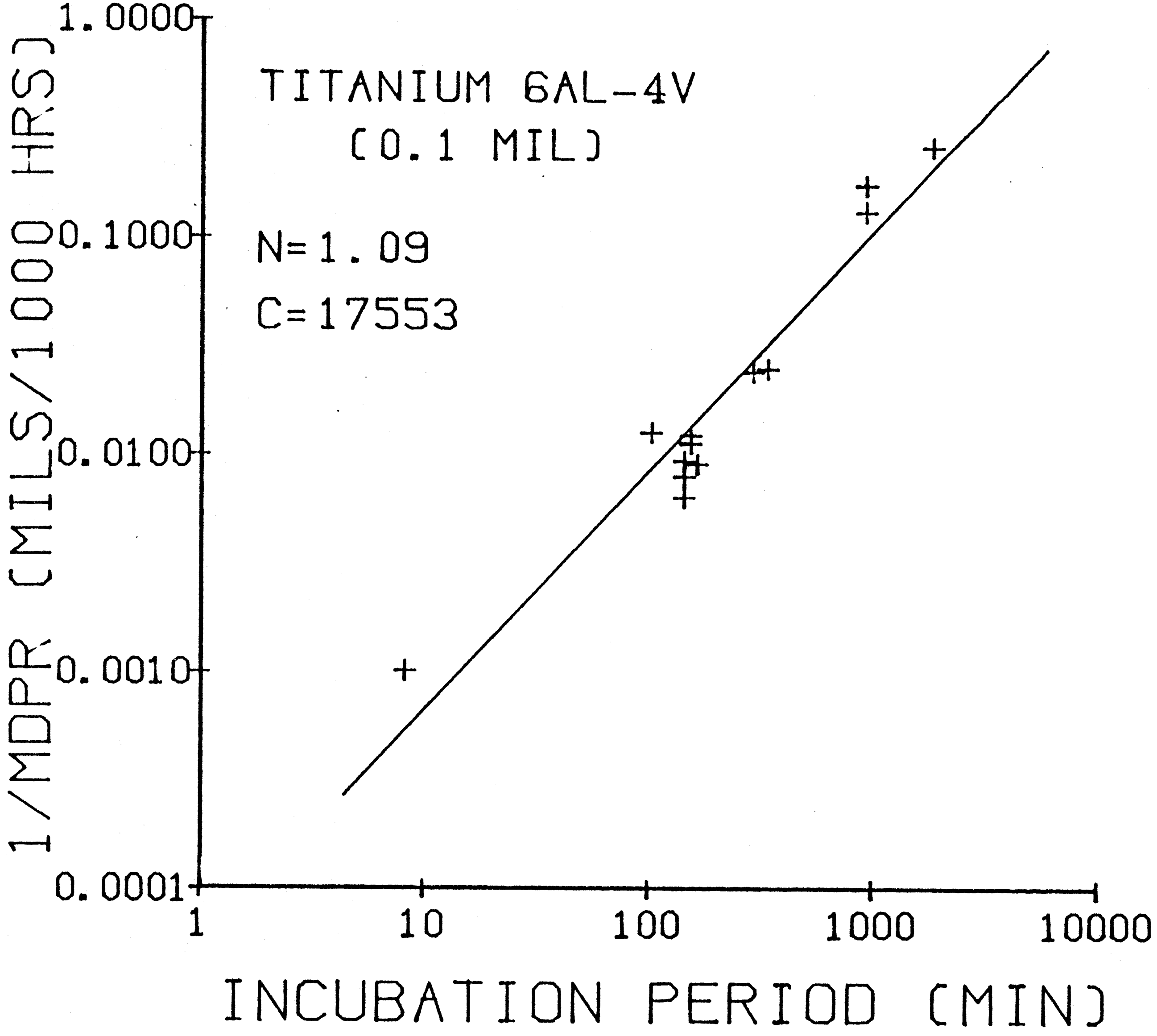

STAINLESS STEEL 17-4 PH
(WROUGHT)
(0.1 MIL)
N=1.203
C=64429
1/MDPR (MILS/1000 HRS)
0.1000
0.0100
0.0010
0.0001
1
10
100
1000
INCUBATION PERIOD (MIN)



1/MDPR (MILS/1000 HRS)
1.0000
0.1000
0.0100
0.0010
0.0001
TITANIUM 6AL-4V
(TAN INTERCEPT)
N=.918
C=4721
1
10
100
1000
10000
INCUBATION PERIOD (MIN)



TITANIUM 6AL-4V
(0.1 MIL)
N=1.09
C=17553
1/MDPR (MILS/1000 HRS)
1.0000
0.1000
0.0100
0.0010
0.0001
1
10
100
1000
10000
INCUBATION PERIOD (MIN)


TITANIUM 6AL-4V
(0.1 MIL)
N=1.09
C=17553
1/MDPR (MILS/1000 HRS)
1.0000
0.1000
0.0100
0.0010
0.0001
1
10
100
1000
10000
INCUBATION PERIOD (MIN)