

UNIVERSITY OF MICHIGAN

Department of Mechanical Engineering  
Cavitation and Multiphase Flow Laboratory

VIBRATORY FACILITY CAVITATION DAMAGE TESTS:  
SYNTHETIC SEA WATER

M.E. 490 report

to

Prof. F. G. Hammitt

by

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Supported by Aerojet Liquid Rocket Company - P.O. # 005899

June, 1977



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PART I

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## INTRODUCTION:

The purpose of our experiments is to determine the incubation period and the MDRR (Max) averaged of two material: SS I7-4 and Titanium Alloy under various conditions of suppression pressure and intensity on the Amplifier .

The following report summarizes results in our vibratory damage facility for the two material in synthetic sea water.

## WORK ITEM PERFORMED:

(a) We first tested 3 I7-4 SS and 2 Titanium specimen at a suppression pressure of 2 Bar and the setting on the amplifier was 6 and 7.5 respectively .This first test was done to get an idea of how these materials behave.

(b) Then we tested 1 I7-4 SS and 1 Titanium. Test conditions were: 1 Bar, same setting on amplifier as previous test.

(c) We finally tested 1 I7-4 SS at 1 Bar and the setting was 5; and 1 Titanium specimen at 1 Bar , setting: 4.

note: All the tests were done at room temperature ( 80F ):

SUMMARY OF RESULTS (Table I)

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<u>MATERIAL</u> Run #	<u>PRESSURE</u> (Bar)	<u>SETTING</u> (div.)	<u>Inc. Period</u> (min)	<u>MDPR</u> (mils/100hrs)
SS17-4 #1	2	6	5	180
SS17-4 #2	1	6	105	17.4
Ti #3	2	7.5	3	100
Ti #4	1	7.5	75	9.8
SS17-4 #5	1	5	110	10
Ti #6	1	4	90	4.1

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SUMMARY OF RESULTS (Table II)

(Runs #1 - #4)

MATERIAL	SETTING	RATIO OF		$\eta^*$
		Inc. Periods	MDPR's	
SS17-4	6	$105/5 = 21$	$180/17.4 = 10.3$	0.77
Titanium	7.5	$75/3 = 25$	$100/9.8 = 10.2$	0.72

$$* \left( \frac{\text{Inc. Period 1}}{\text{Inc. Period 2}} \right)^n = \left( \frac{\text{MDPR 2}}{\text{MDPR 1}} \right)$$

Runs #1-5 and #3-6

Material	Ratio of Inc. Per.	MDPR	$\eta^*$
SS 17-4	$110/5 = 22$	$180/10 = 18$	.935
Titanium	$90/3 = 30$	$100/4.1 = 24.4$	.939

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## CONCLUSION:

1. The  $MDPR_{max}$  (Aver.) is about 1.8 x greater for the SS I7-4 than for the Titanium.

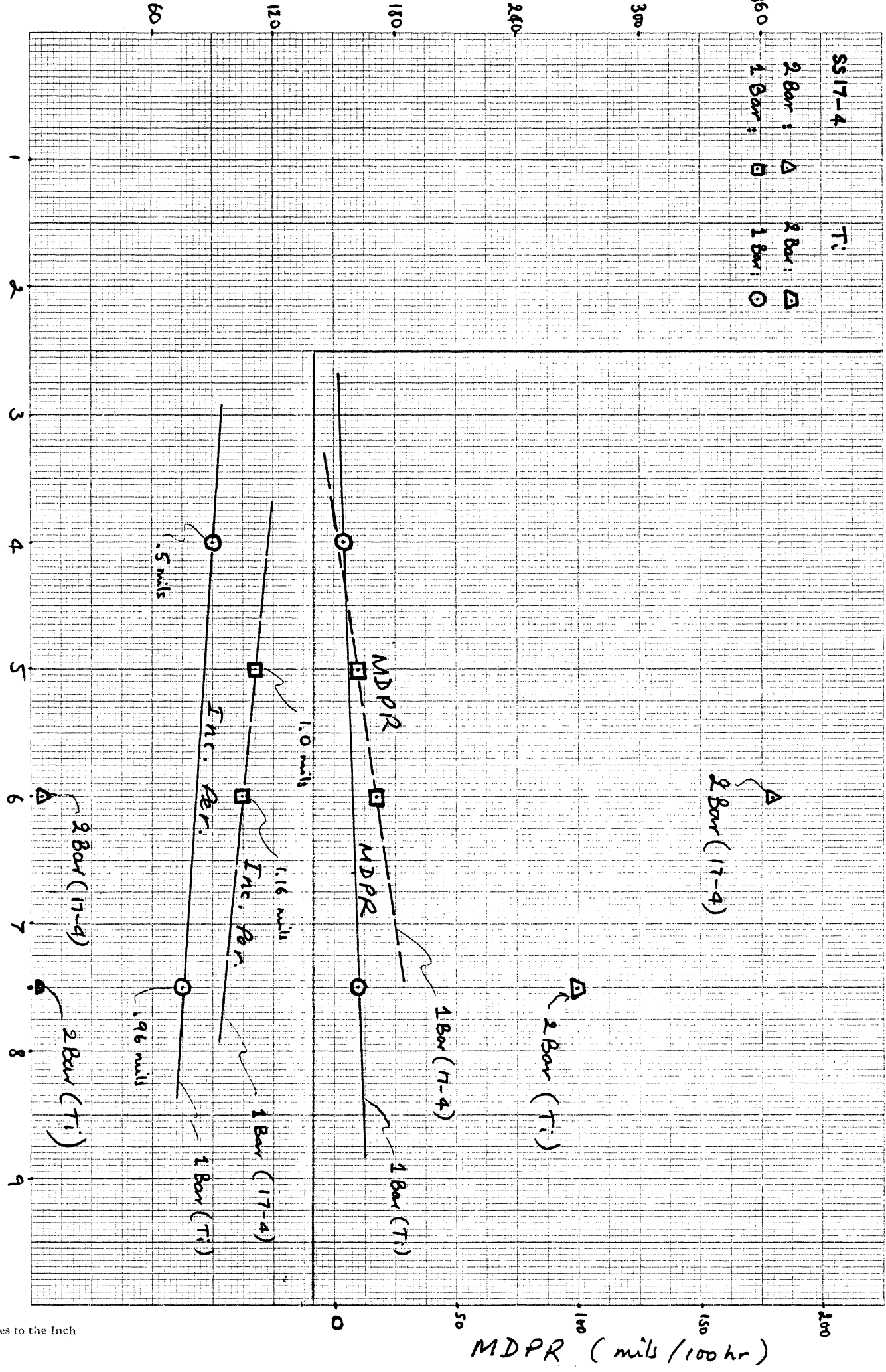
2. The Incubation Period is also greater for the Stainless Steel, we found 5 min. vs 3 min. (for 2 Bar), 105 min. vs. 75 min. (for 1 Bar) and 110 min. vs. 90 min. (for 1 Bar but lower intensity).

3. The steady state rate appears to be a continuous oscillation either increasing or decreasing .

4. The factor  $n$  calculated was close to the value expected (0.7) for 1<sup>st</sup> set (we found 0.72, 0.77), but  $n \approx 94$  (full set). See Table II.



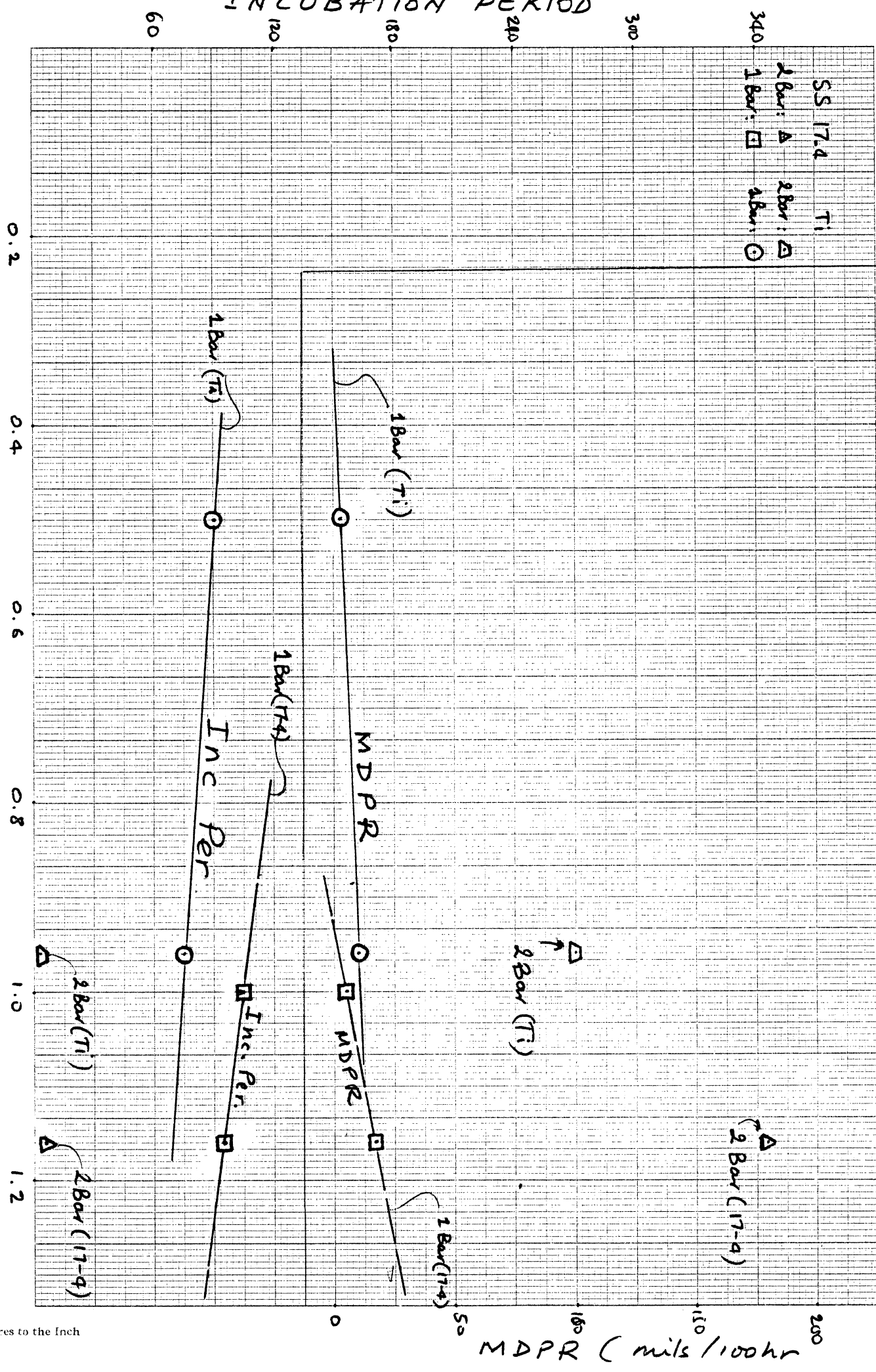
# INCUBATION PERIOD (min)



res to the Inch

MDPR (mils/100 hr)

# INCUBATION PERIOD



res to the Inch

MDPR (mils/100hr)

+++++

P A R T I I

+++++



Run #					
Date					
Ultrasonic Horn					
Material and #					
Specimen Thickness					
Cavitating Fluid	water	water	water	water	water
Depth of Fluid	4.5"	4.5"	4.5"	4.5"	4.5"
Submergence	1.5"	1.5"	1.5"	1.5"	1.5"
Argon Pressure					
Frequency	20 kHz	20 kHz	20 kHz	20 kHz	20 kHz
Amplitude	2 mil	2 mil	2 mil	2 mil	2 mil
Ammeter Setting					
Variac Setting					
Bath Temp.					
Initial Fluid Temp.					
Final Fluid Temp.					
Starting Time					
Completion Time					
Length of Run					
Initial Exp. Time Weight					
Final Exp. Time Weight					
Weight Loss					
Corr. Weight Loss					
Operator					
Comments					

(2nd run)

MATERIAL DAMAGE SHEET

Material SS17-4  
Number 4

RUNNING CONDITIONS

Pen Setting 6 Temperature 80°F  
Power Pressure 2 Bar  
Approx. Date 05/15/77 Torque  
Re-run

SEA WATER

BASIS FOR CALCULATIONS

Density 7.78 g/cm<sup>3</sup> Area 0.235 in<sup>2</sup>  
DP Factor  $c = (dA/18.35)^{-1}$

Comments:

$$MDPR /_{MAX} = 1.00 \text{ mils/hr}$$

$$\text{Incubation period} \approx 5.5 \text{ min}$$

DATA

Time Interval (min)	Cumulative Time (min)	Weight Loss (mg)	Cumulative Weight Loss (mg)	MDPR mils/hr	Cumulative MDP
4	4	0.1	0.1	0.050	
2	6	0.1	0.2	0.100	
2	8	0.1	0.3	0.100	
2	10	1.0	1.3	1.001	
2	13	0.2	1.5	0.133	
3	16	0.1	1.6	0.067	
3	21	0.7	2.3	0.280	
5	26	0.8	3.1	0.320	
10	36	0.8	3.9	0.160	
10	46	0.7	4.6	0.140	
10	56	2.8	7.4	0.561	

Run #					
Date					
Ultrasonic Horn					
Material and #					
Specimen Thickness					
Cavitating Fluid	water	water	water	water	water
Depth of Fluid	4.5"	4.5"	4.5"	4.5"	4.5"
Submergence	1.5"	1.5"	1.5"	1.5"	1.5"
Argon Pressure					
Frequency	20 kHz	20 kHz	20 kHz	20 kHz	20 kHz
Amplitude	2 mil	2 mil	2 mil	2 mil	2 mil
Ameter Setting					
Variac Setting					
Bath Temp.					
Initial Fluid Temp.					
Final Fluid Temp.					
Starting Time					
Completion Time					
Length of Run					
Initial Exp. Time Weight					
Final Exp. Time Weight					
Weight Loss					
Cur. Weight Loss					
Operator					
Comments					

(3rd run)

MATERIAL DAMAGE SHEET

Material SS17-4  
Number 5

RUNNING CONDITIONS

Setting: 6 Temperature 80°F  
Power Pressure 2 Bar  
Approx. Date 05/18/77 Torque  
rerun

SEA WATER

BASIS FOR CALCULATIONS

Density 778 g/cm<sup>3</sup> Area 0.235 in<sup>2</sup>  
DP Factor  $c = (2A 16.39)^{-1}$

Comments:

$$MDRR / MAX = 4.005 \text{ mils/hr}$$

$$\text{Inactivation Period} \approx 5 \text{ min}$$

DATA

Time Interval (min)	Cumulative Time (min)	Weight Loss (mg)	Cumulative Weight Loss (mg)	MDPR (mils/hr)	Cumulative MDP
3 min	3	0	0	0	
2 min	5	0.3	0.3	0	
3.5	8.5	0.8	1.1	4.005	
0.5	9	0.2	1.2	0.801	
0.5	9.5	0.1	1.3	0.400	
0.5	10	0.3	1.6	1.200	
5	15	1	2.6	0.400	
5	20	0.9	3.1	0.360	
5	25	1.2	4.3	0.411	
5	30	0	4.3	0	
15	45	0.7	5.0	0.093	
15	60	1.5	6.5	0.186	
15	75	1	7.5	0.133	
15	90	0.9	8.4	0.120	
15	105	1.3	9.7	0.174	
15	120	1.1	10.8		



Run #					
Date					
Ultrasonic Horn					
Material and #					
Specimen Thickness					
Cavitating Fluid	water	water	water	water	water
Depth of Fluid	4.5"	4.5"	4.5"	4.5"	4.5"
Submergence	1.5"	1.5"	1.5"	1.5"	1.5"
Argon Pressure					
Frequency	20 kHz	20 kHz	20 kHz	20 kHz	20 kHz
Amplitude	2 mil	2 mil	2 mil	2 mil	2 mil
Ammeter Setting					
Variac Setting					
Bath Temp.					
Initial Fluid Temp.					
Final Fluid Temp.					
Starting Time					
Completion Time					
Length of Run					
Initial Exp. Time					
Initial Weight					
Final Exp. Time					
Final Weight					
Weight Loss					
Cum. Weight Loss					
Operator					
Comments					



Run #					
Date					
Ultrasonic Horn					
Material and #					
Specimen Thickness					
Cavitating Fluid	water	water	water	water	water
Depth of Fluid	4.5"	4.5"	4.5"	4.5"	4.5"
Submergence	1.5"	1.5"	1.5"	1.5"	1.5"
Argon Pressure					
Frequency	20 kHz	20 kHz	20 kHz	20 kHz	20 kHz
Amplitude	2 mil	2 mil	2 mil	2 mil	2 mil
Ameter Setting					
Variac Setting					
Bath Temp.					
Initial Fluid Temp.					
Final Fluid Temp.					
Starting Time					
Completion Time					
Length of Run					
Initial	Exp. Time				
	Weight				
Final	Exp. Time				
	Weight				
Weight Loss					
Cum. Weight Loss					
Operator					
Comments					



Run #					
Date					
Ultrasonic Horn					
Material and #					
Specimen Thickness					
Cavitating Fluid	water	water	water	water	water
Depth of Fluid	4.5"	4.5"	4.5"	4.5"	4.5"
Submergence	1.5"	1.5"	1.5"	1.5"	1.5"
Argon Pressure					
Frequency	20 kHz	20 kHz	20 kHz	20 kHz	20 kHz
Amplitude	2 mil	2 mil	2 mil	2 mil	2 mil
Ammeter Setting					
Variance Setting					
Bath Temp.					
Initial Fluid Temp.					
Final Fluid Temp.					
Starting Time					
Completion Time					
Length of Run					
Initial	Exp. Time				
	Weight				
Final	Exp. Time				
	Weight				
Weight Loss					
Cum. Weight Loss					
Operator					
Comments					



Run #					
Date					
Ultrasonic Horn					
Material and #					
Specimen Thickness					
Cavitating Fluid	water	water	water	water	water
Depth of Fluid	4.5"	4.5"	4.5"	4.5"	4.5"
Submergence	1.5"	1.5"	1.5"	1.5"	1.5"
Argon Pressure					
Frequency	20 kHz	20 kHz	20 kHz	20 kHz	20 kHz
Amplitude	2 mil	2 mil	2 mil	2 mil	2 mil
Ameter Setting					
Variac Setting					
Bath Temp.					
Initial Fluid Temp.					
Final Fluid Temp.					
Starting Time					
Completion Time					
Length of Run					
Initial Exp. Time					
Initial Weight					
Final Exp. Time					
Final Weight					
Weight Loss					
Cum. Weight Loss					
Operator					
Comments					

2nd run)

### MATERIAL DAMAGE SHEET

Material Titanium  
Number 3

#### RUNNING CONDITIONS

Mag Setting: 7.5  
Power  
Approx. Date 05/23/77  
rerun  
Temperature 80°F  
Pressure 2 Bar  
Torque

#### SEA WATER

#### BASIS FOR CALCULATIONS

Density 4.43 g/cm<sup>3</sup>  
DP Factor  $c = \frac{1}{2A} 16.39$   
Area .235 in<sup>2</sup>

Comments:

$$\frac{MDPR}{MAX} = 1.29 \text{ mils/hr}$$

$$\text{Incubation Period} \approx 3.1 \text{ min}$$

#### DATA

Time Interval (min)	Cumulative Time (min)	Weight Loss (mg)	Cumulative Weight Loss (mg)	MDPR mil/hr	Cumulative MDP
1	1	0	0	0	
1	2	0	0	0	
1.5	3.5	0.3	0.3	1.05	
2.5	6	1.1	1.4	1.29	
5	11	0.9	2.3	0.63	
10	21	0.7	3.2	0.32	
10	31	1.2	4.4	0.42	
14	45	1.7	6.1	0.43	
15	60	1.5	7.6	0.35	
15	75	2.6	10.2	0.61	
15	90	1.3	11.5	0.30	
15	105	1.1	12.6	0.26	
15	120	1.1	13.7	0.26	



Run #					
Date					
Ultrasonic Horn					
Material and #					
Specimen Thickness					
Cavitating Fluid	water	water	water	water	water
Depth of Fluid	4.5"	4.5"	4.5"	4.5"	4.5"
Submergence	1.5"	1.5"	1.5"	1.5"	1.5"
Argon Pressure					
Frequency	20 kHz	20 kHz	20 kHz	20 kHz	20 kHz
Amplitude	2 mil	2 mil	2 mil	2 mil	2 mil
Ameter Setting					
Verine Setting					
Bath Temp.					
Initial Fluid Temp.					
Final Fluid Temp.					
Starting Time					
Completion Time					
Length of Run					
Initial	Exp. Time				
	Weight				
Final	Exp. Time				
	Weight				
Weight Loss					
Cum. Weight Loss					
Operator					
Comments					

(1st run)

### MATERIAL DAMAGE SHEET

Material	Titanium
Number	5

#### RUNNING CONDITIONS

Turn Setting	: 7.5	Temperature	80°F
% Power	-	Pressure	1 Bar
Approx. Date		Torque	
Prerun			

#### BASIS FOR CALCULATIONS

Density	4.43 g/cm <sup>3</sup>	Area	0.235 in <sup>2</sup>
MDP Factor C	= $\frac{1}{2 \times 16.39}$		

Comments:

$$MDRR / MAX = 0.127 \text{ mils/hr}$$

Incubation period  $\approx$  75 min

#### DATA

Time Interval (min)	Cumulative Time (min)	Weight Loss (mg)	Cumulative Weight Loss (mg)	MDP mils/hr.	Cumulative MDP
15	15				
15	30	.4	0.4	0.070	
15	45	.2	0.6	0.050	
15	60	.0	0.6	0.050	
15	75	.2	0.8	"	
15	90	.0	1.0	"	
15	105	.0	1.0		
15	120	.3	1.3	0.061	
20	140	.2	1.5	0.050	
20	160	.5	2.0	0.074	
20	180	.3	2.3	0.061	
20	200	.7	3.0	0.093	
20	220	.6	3.6	0.086	
20	240	.2	3.8	0.050	
20	260	.5	4.3	0.074	
20	280	.7	5.0	0.093	
30	310	.5	5.5	"	
30	340	.2	5.7	0.074	
30	370	.7	6.4	0.050	
30	400	1.0	7.4	0.093	
30	430	0.7	8.1	0.111	
30	460	0.7	8.8	0.093	
60	520	0.5	9.3	0.074	
60	580	0.8	10.1	0.127	
60	640				

# MATERIAL DAMAGE SHEET

Material TITANIUM  
 Number 12

## RUNNING CONDITIONS

Setting: 4      Temperature 80°F  
 Power 0.5 mil      Pressure 1 Bar  
 Approx. Date \_\_\_\_\_ Torque \_\_\_\_\_  
 Rerun \_\_\_\_\_

## BASIS FOR CALCULATIONS

Density 4.43 g/cm<sup>3</sup>      Area 0.235 in<sup>2</sup>  
 DP Factor c = 1/2A 16.39

Comments:

$$MDPR)_{avg} = 0.041 \text{ mils/hr}$$

$$\text{Inc. Period} \approx 90 \text{ min}$$

## DATA

Time Interval	Cumulative Time	Weight Loss (g)	Cumulative Weight Loss (g)	MDP R	Cumulative MDP
1 hr	1 hr	—	—	0	
1	2	.0005	.0005	0.0293	
1	3	.0007	.0012	0.041	
1	4	.0001	.0013	0.0059	
1	5	.0002	.0015	0.0117	
1	6	.0004	.0019	0.0234	
1	7	.0002	.0021	0.0117	
1	8	—	.0021	0	
1	9	—	.0021	0	

Run #					
Date					
Ultrasonic Horn					
Material and #					
Specimen Thickness					
Cavitating Fluid	water	water	water	water	water
Depth of Fluid	4.5"	4.5"	4.5"	4.5"	4.5"
Submergence	1.5"	1.5"	1.5"	1.5"	1.5"
Argon Pressure					
Frequency	20 kHz	20 kHz	20 kHz	20 kHz	20 kHz
Amplitude	2 mil	2 mil	2 mil	2 mil	2 mil
Amperage Setting					
Voltage Setting					
Bath Temp.					
Initial Fluid Temp.					
Final Fluid Temp.					
Starting Time					
Completion Time					
Length of Run					
Initial Exp. Time					
Weight					
Final Exp. Time					
Weight					
Weight Loss					
Cum. Weight Loss					
Operator					
Comments					

1st Run

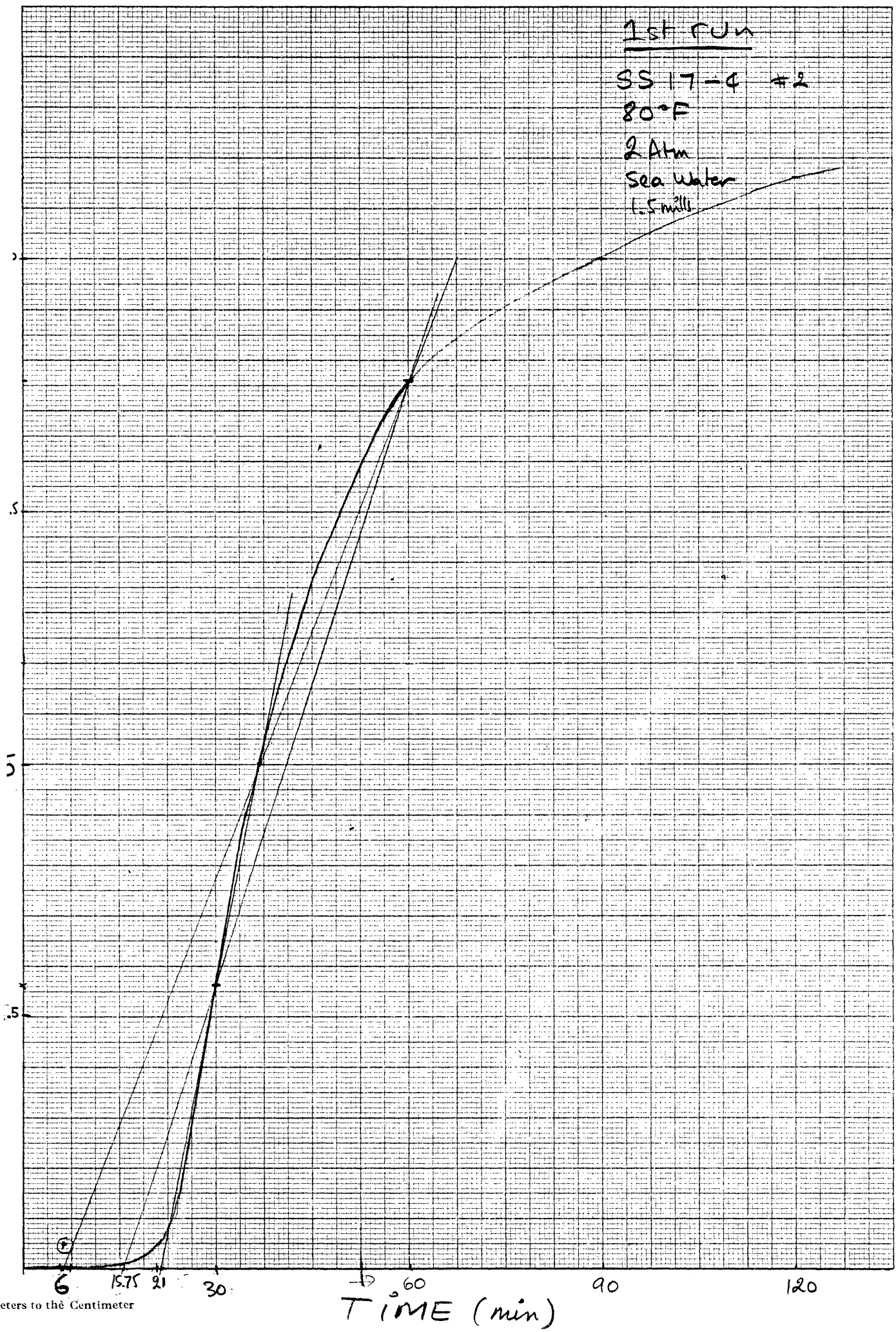
SS 17-4 #2

80°F

2 Atm

Sea Water

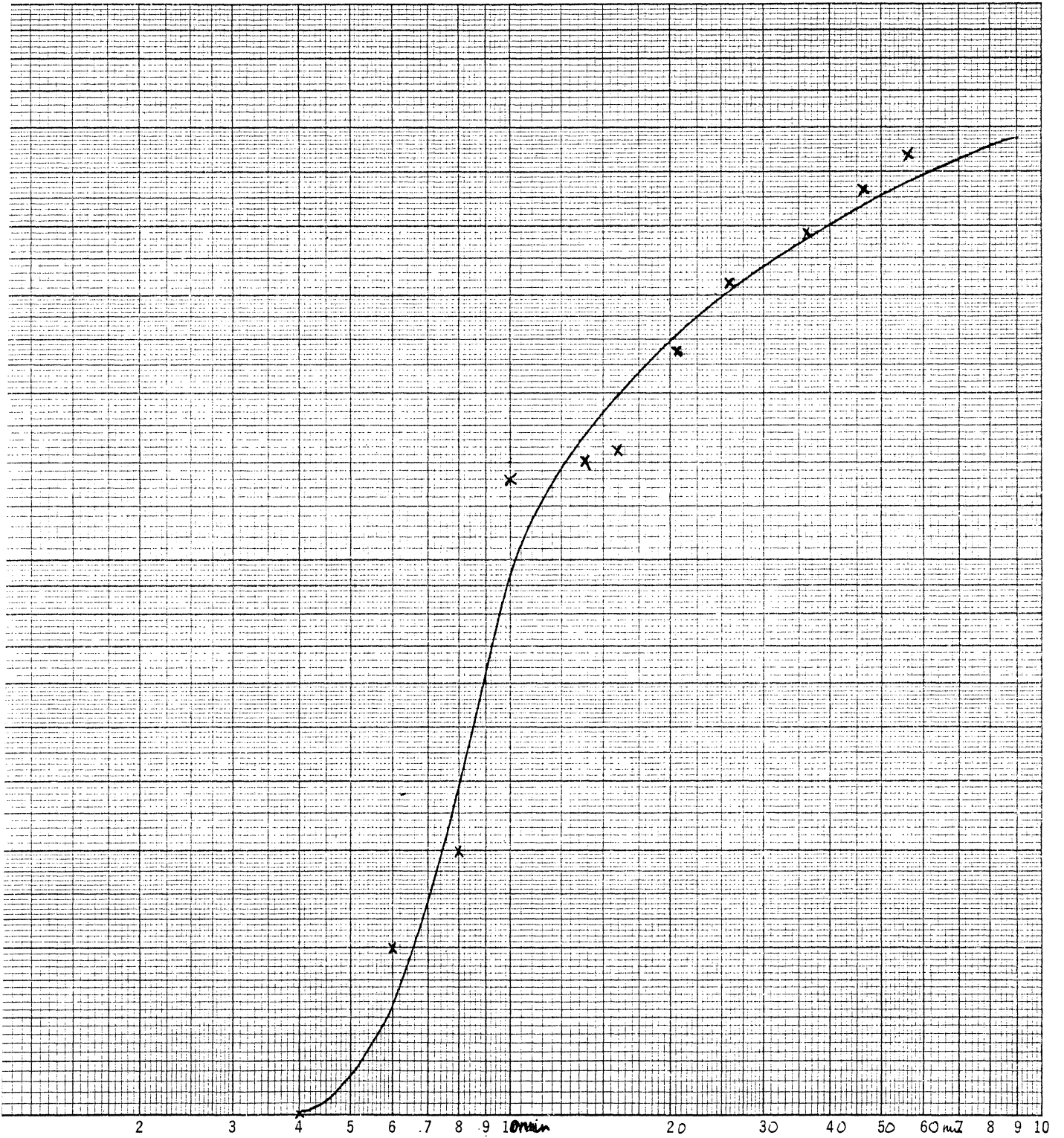
1.5 milli



2nd run

SS 17-4

1.5 mills, 80°F, 2 Atm, Sea Water

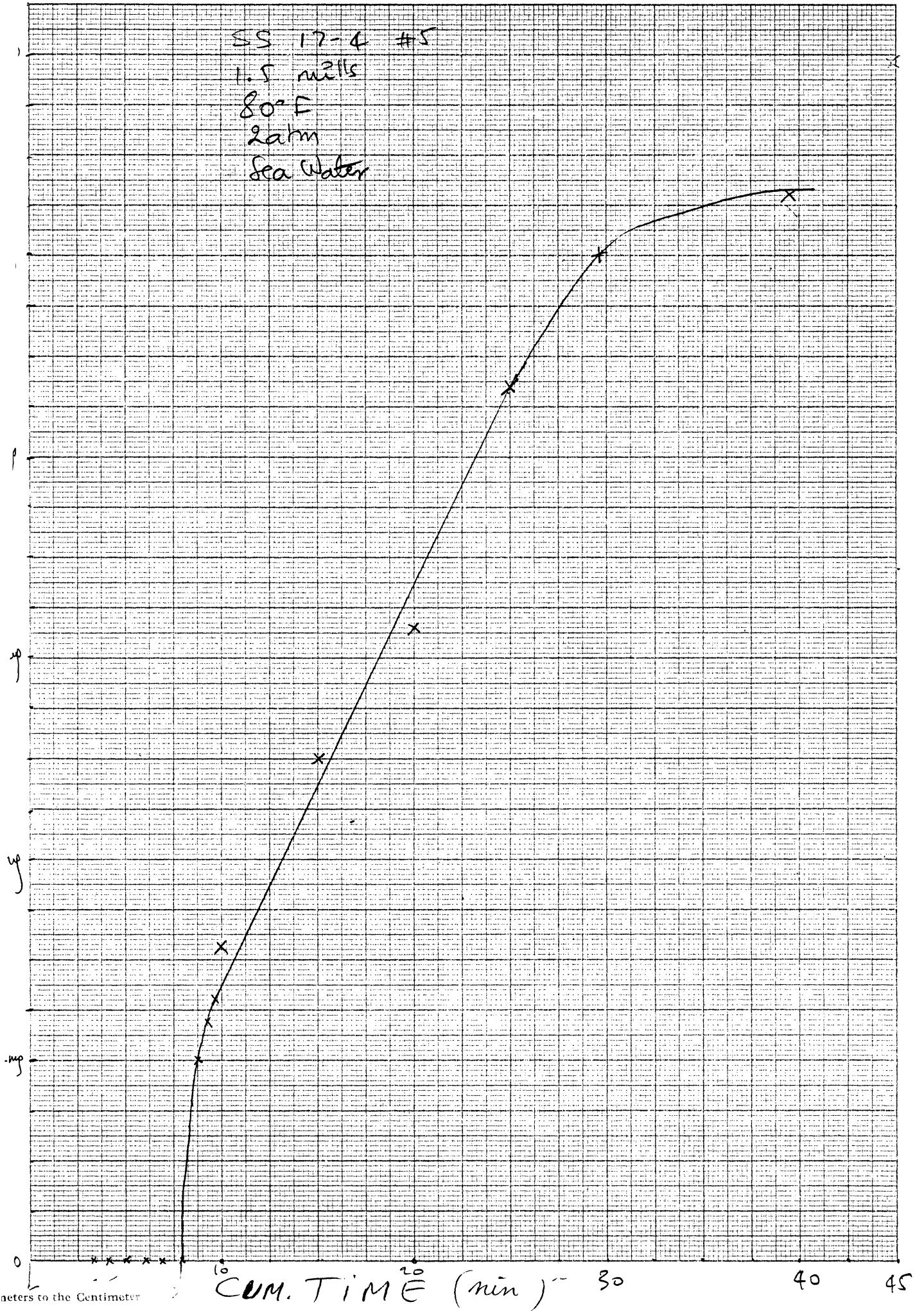


CUMULATIVE TIME (min)

NORMAL

3 run

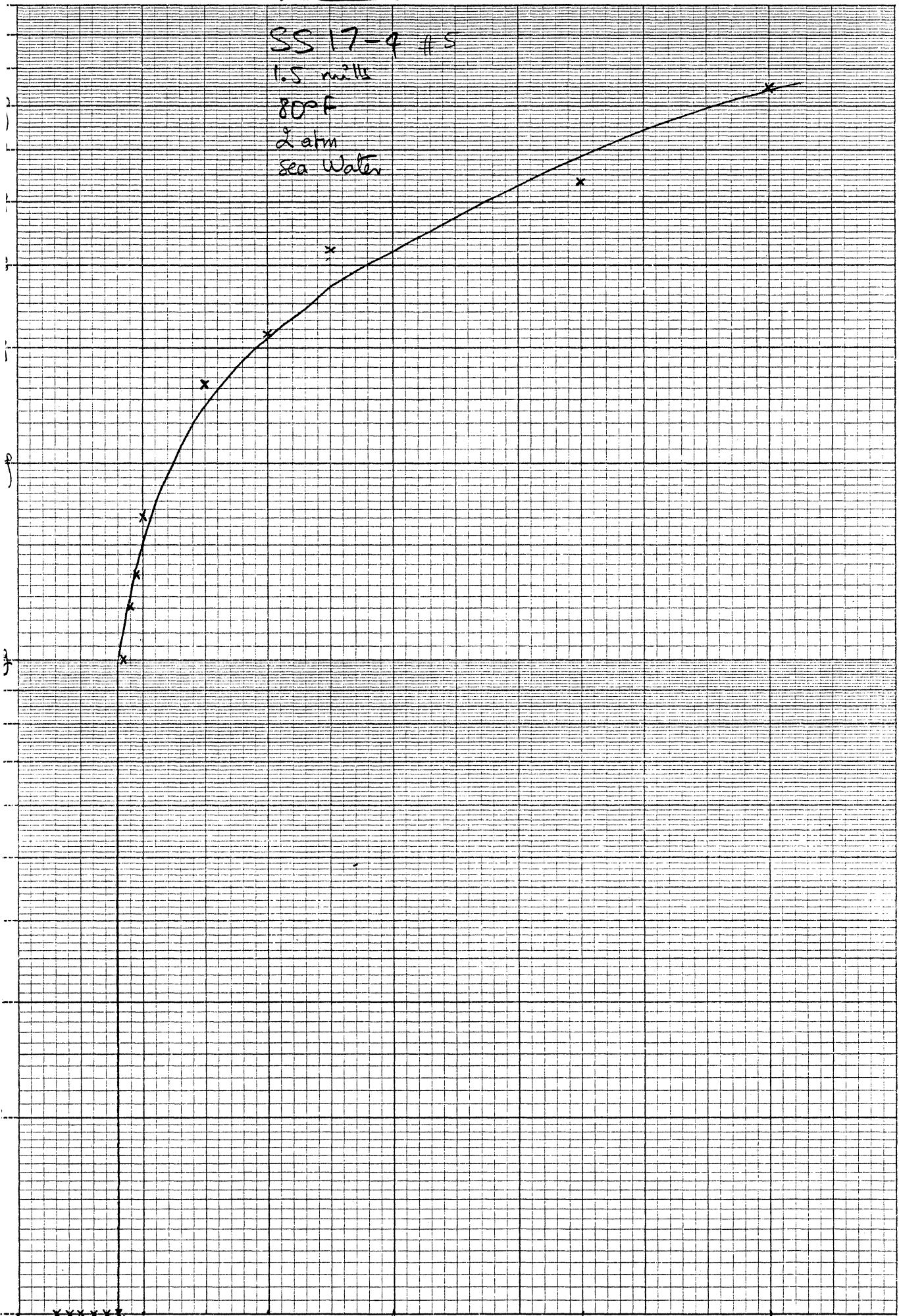
SS 17-4 #5  
1.5 mills  
80°F  
2 atm  
Sea Water



SEMI-LOG

3rd run

SS 17-9 #8  
1.5 mills  
80°F  
2 atm  
Sea Water



xxxxxx  
8.5 min → 10 min

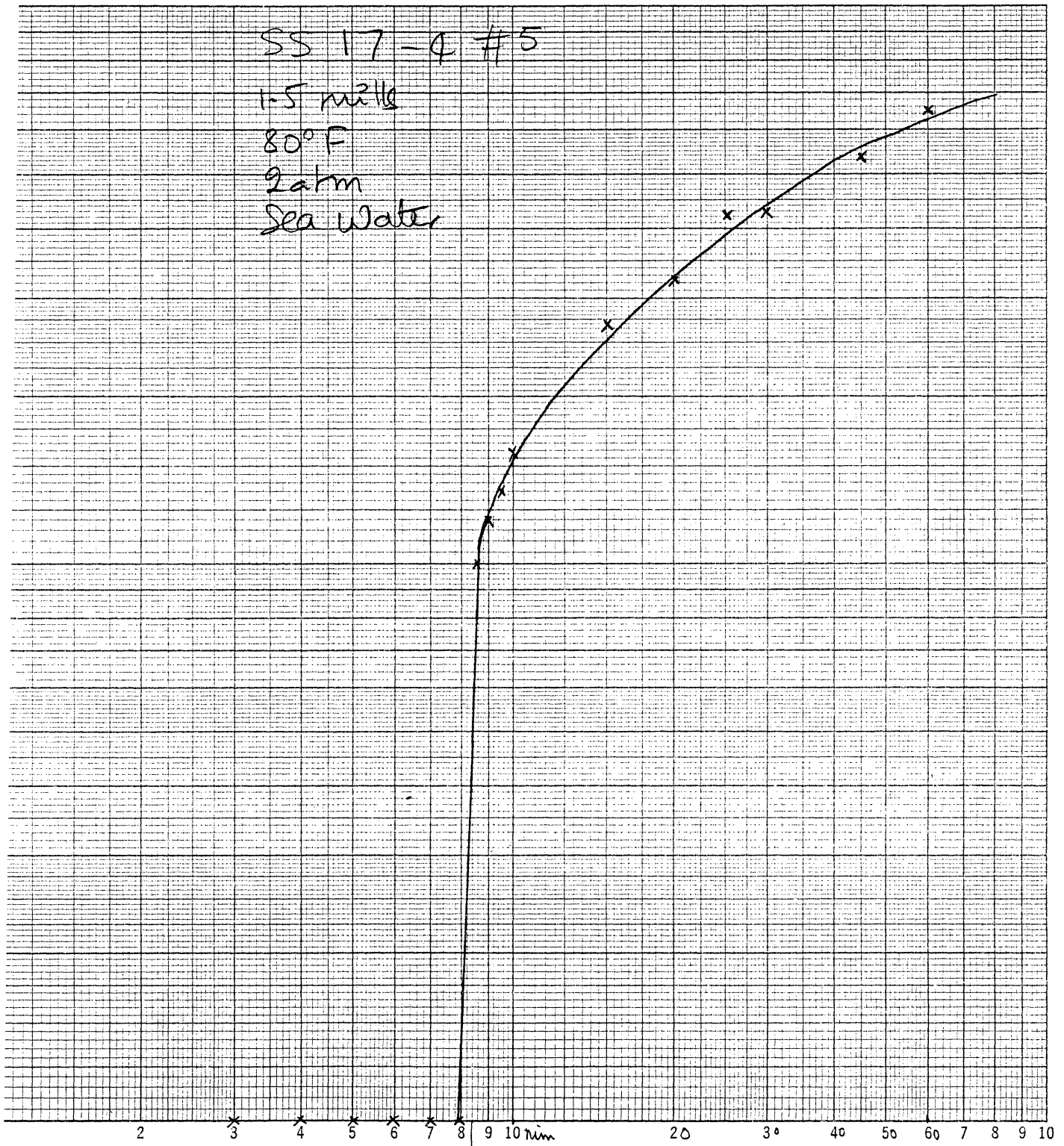
CUM. TIME (min)

60 min



# LOG n LOG plot

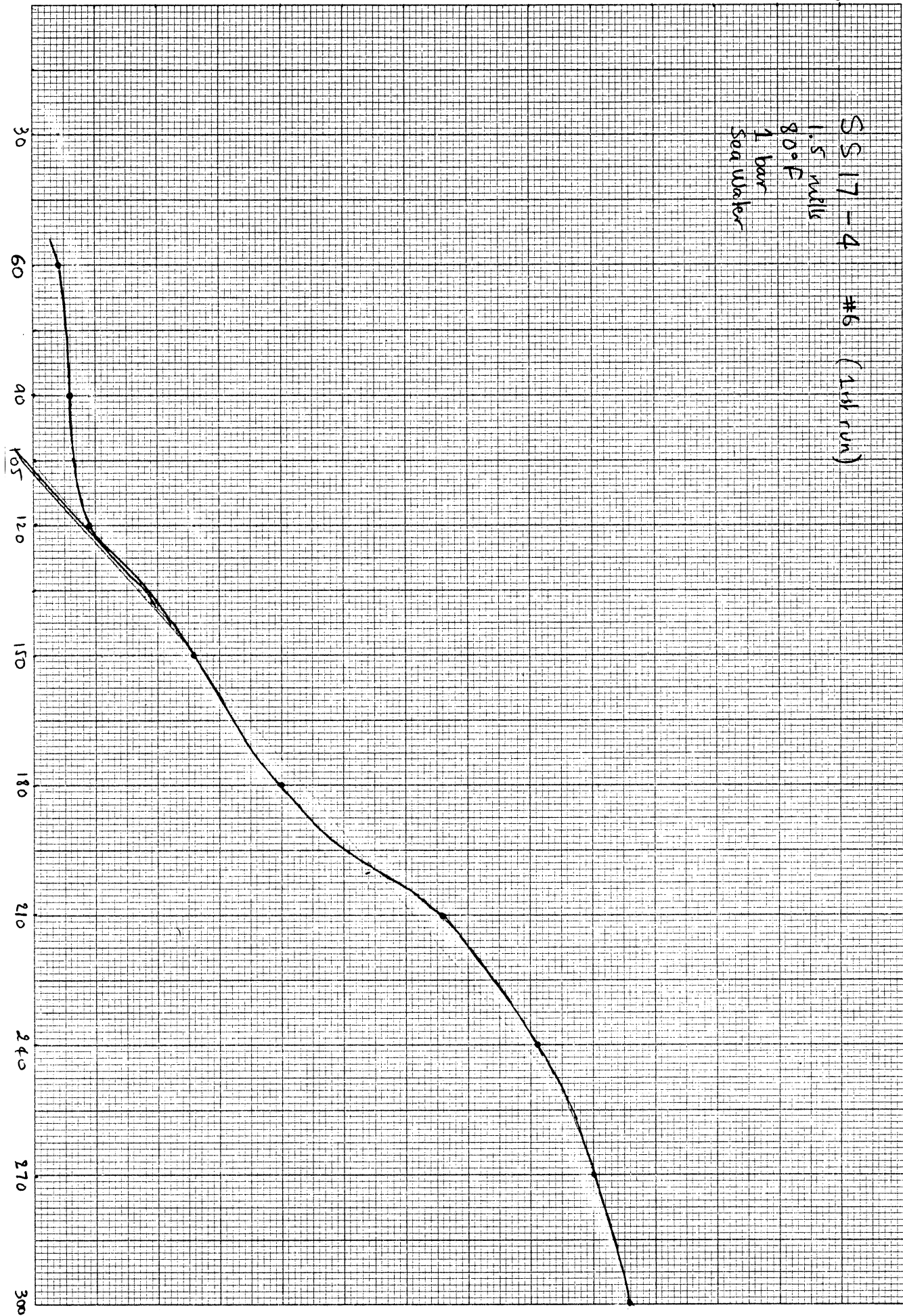
3 RUN

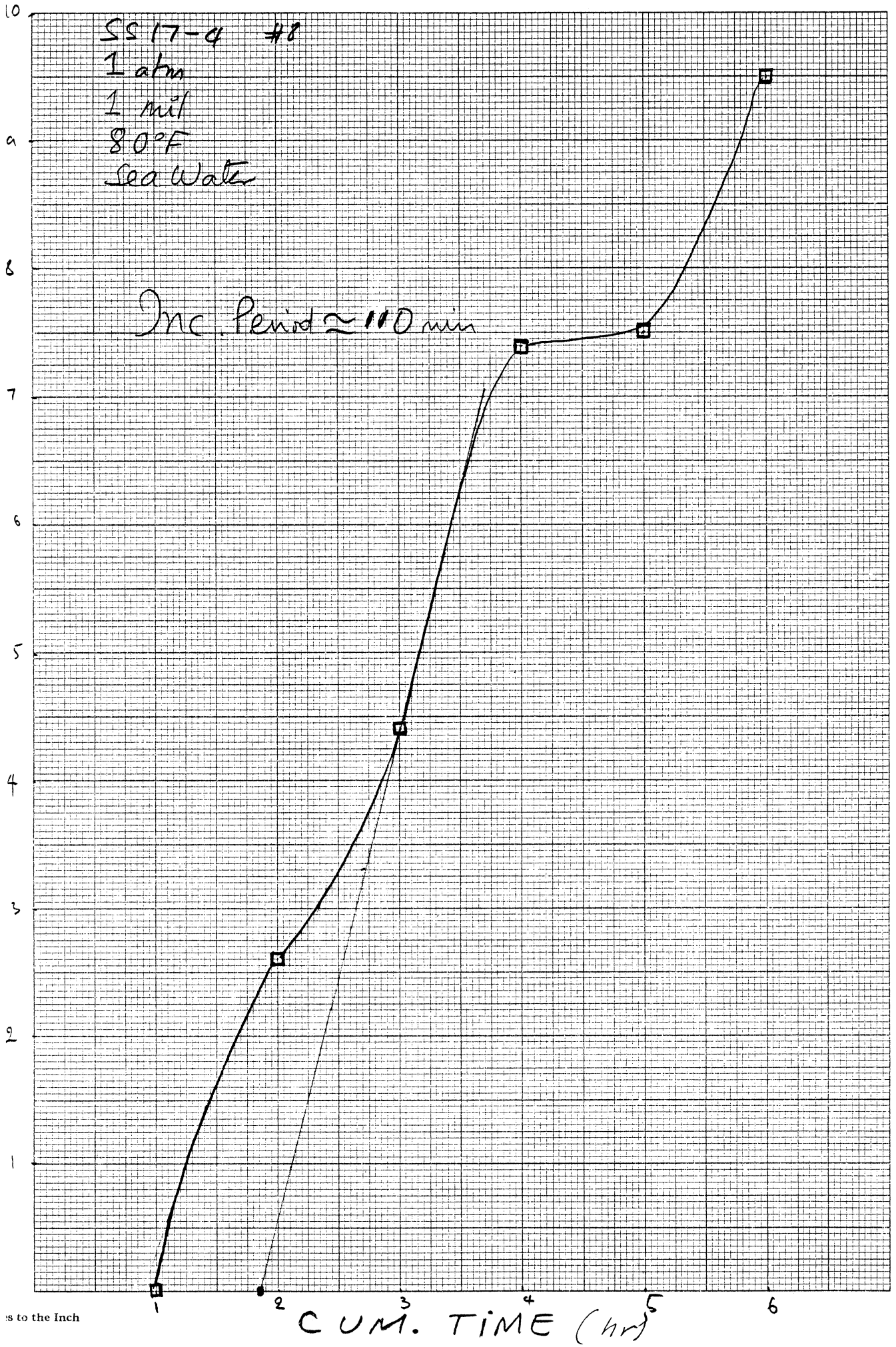


CUM TIME (min)

8.5 min →

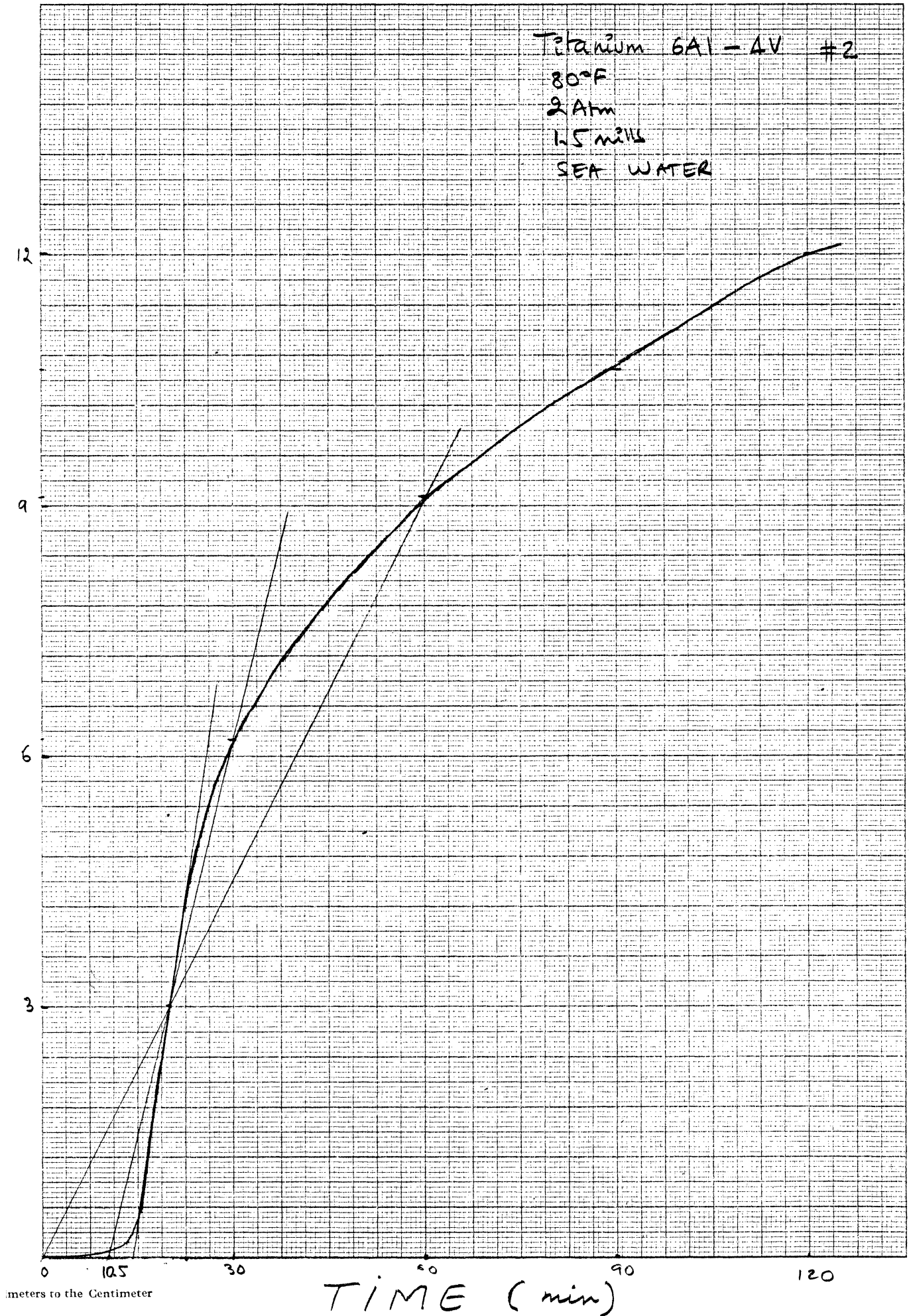
CUMULATIVE WEIGHT LOSS (mg)





1st run

Titanium 6Al-4V #2  
80°F  
2 Atm  
15 mils  
SEA WATER



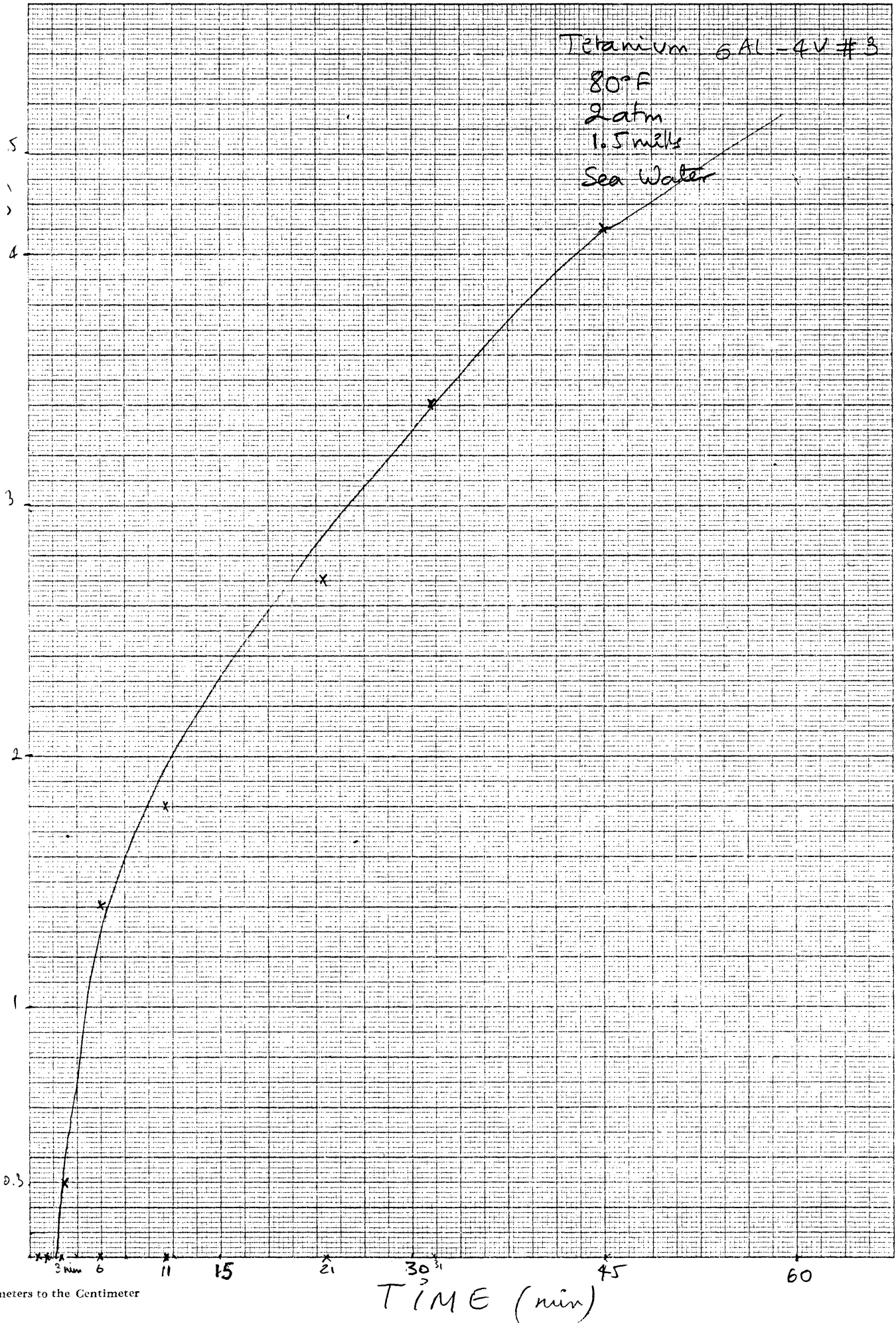
meters to the Centimeter

TIME (min)

Normal - plot

2nd run

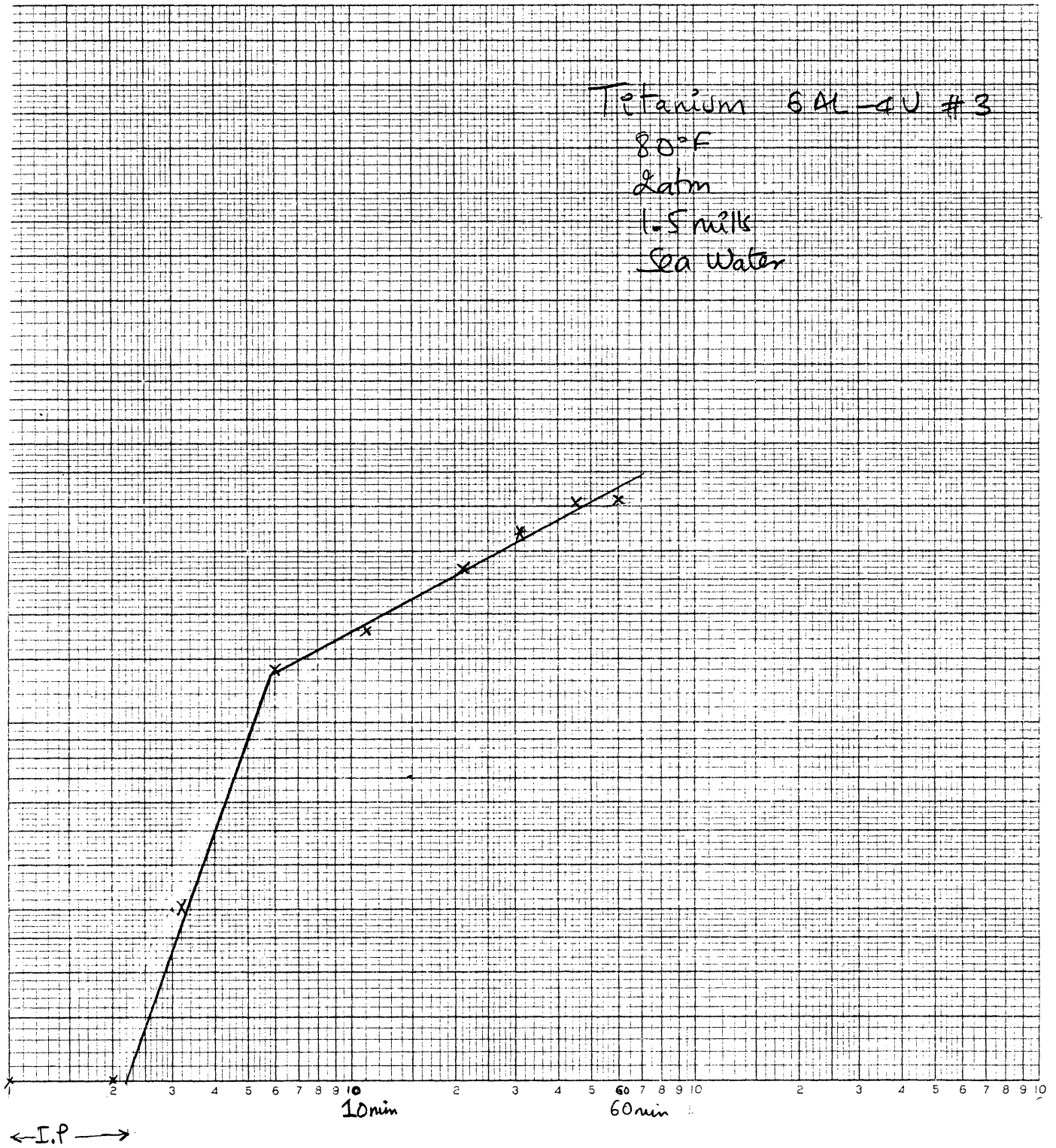
Titanium 6Al-4V #3  
80°F  
2atm  
1.5 mils  
Sea Water



Log-n Log-pld

2nd run

Titanium 6AL-4V #3  
80°F  
Salt  
1.5 milk  
Sea Water



TIME (min)

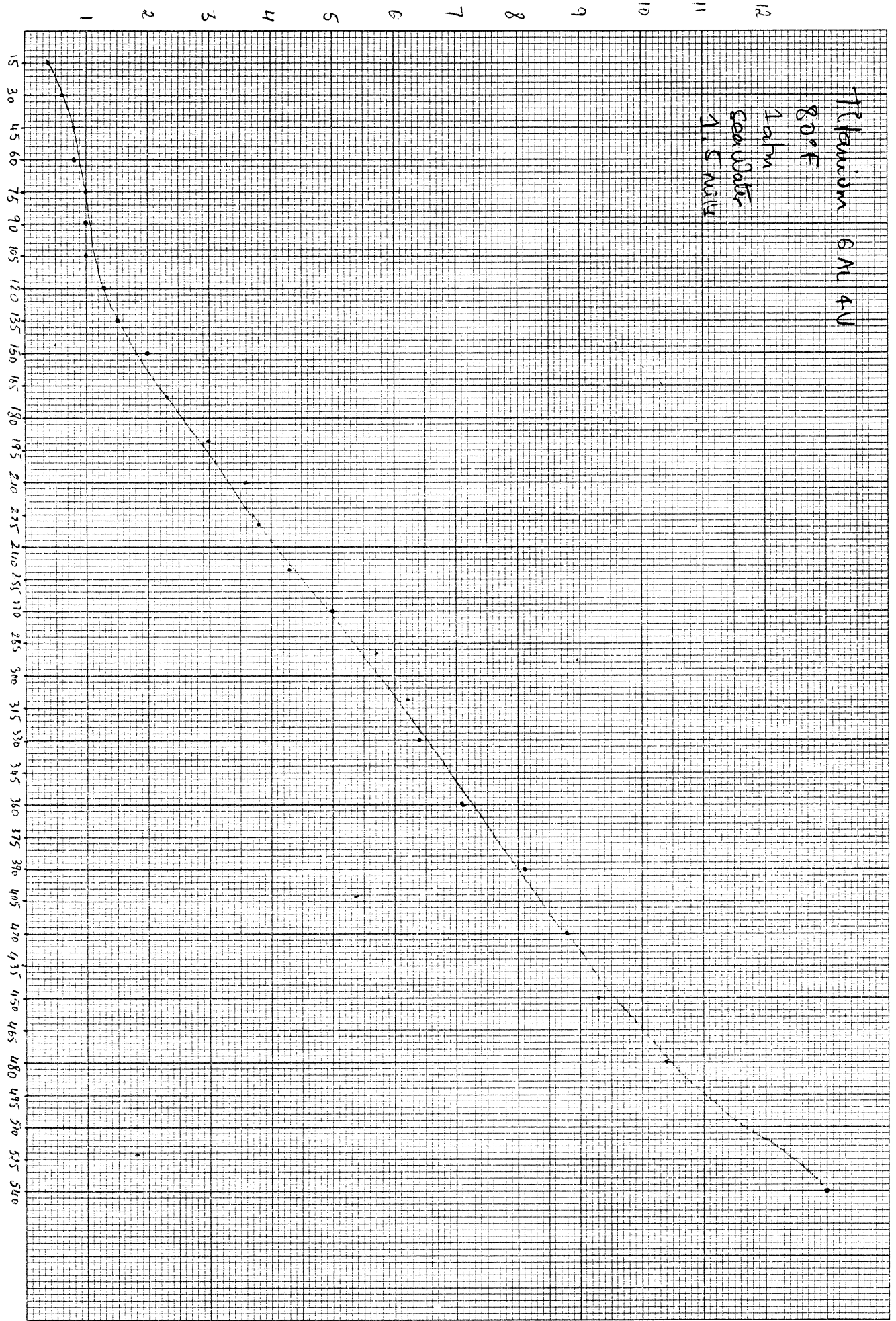
Tilmanston 6M 4U

80°F

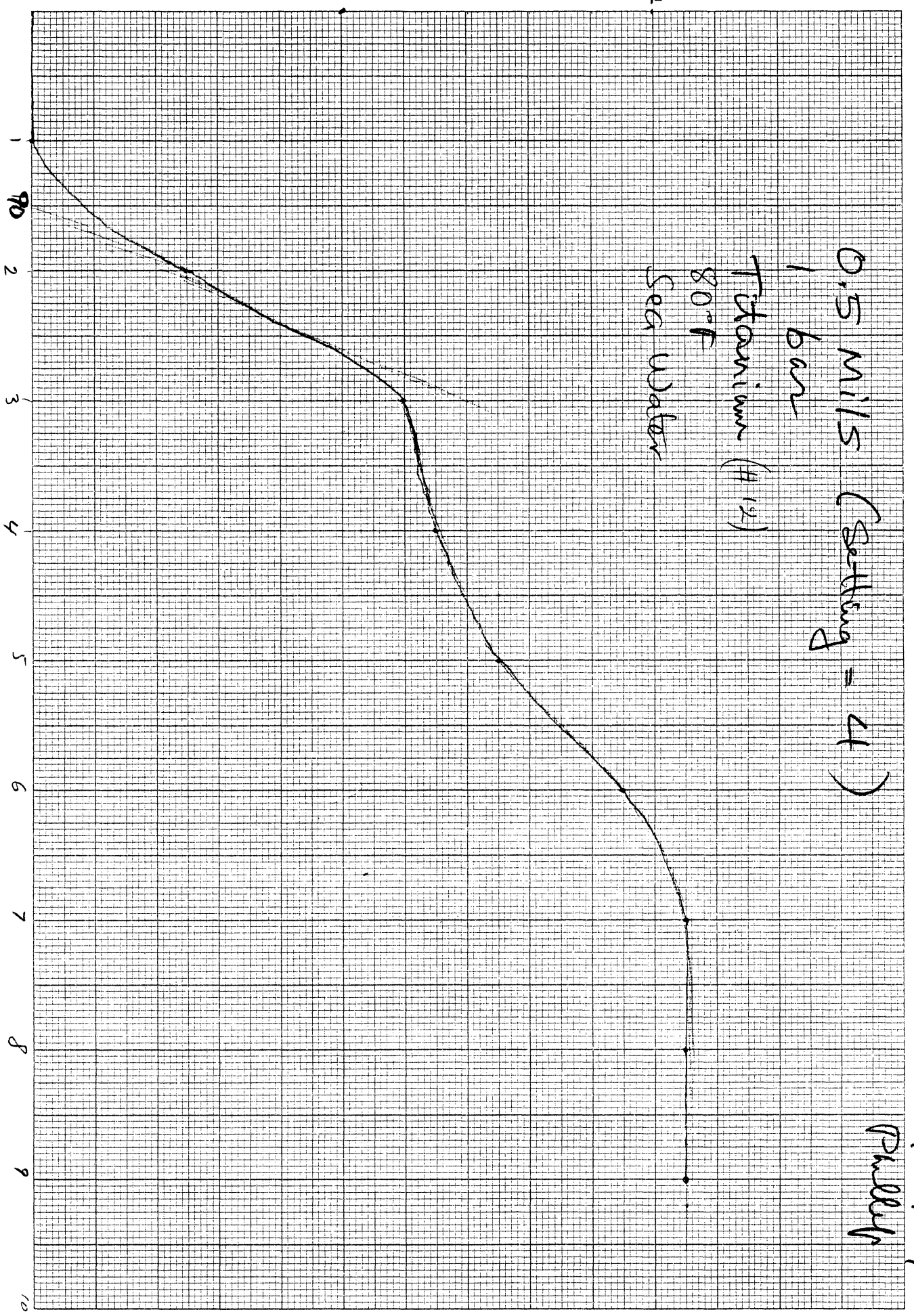
1 atm

Sea Water

1.5 miles



CUM. WEIGHT LOSS (mg)



6/20/77  
Philly



MDPR (x 10<sup>-2</sup> mils/hr)

40

SS 17-4 (J47000)  
80°F  
2 atm  
1.5 mils  
SEA WATER

10

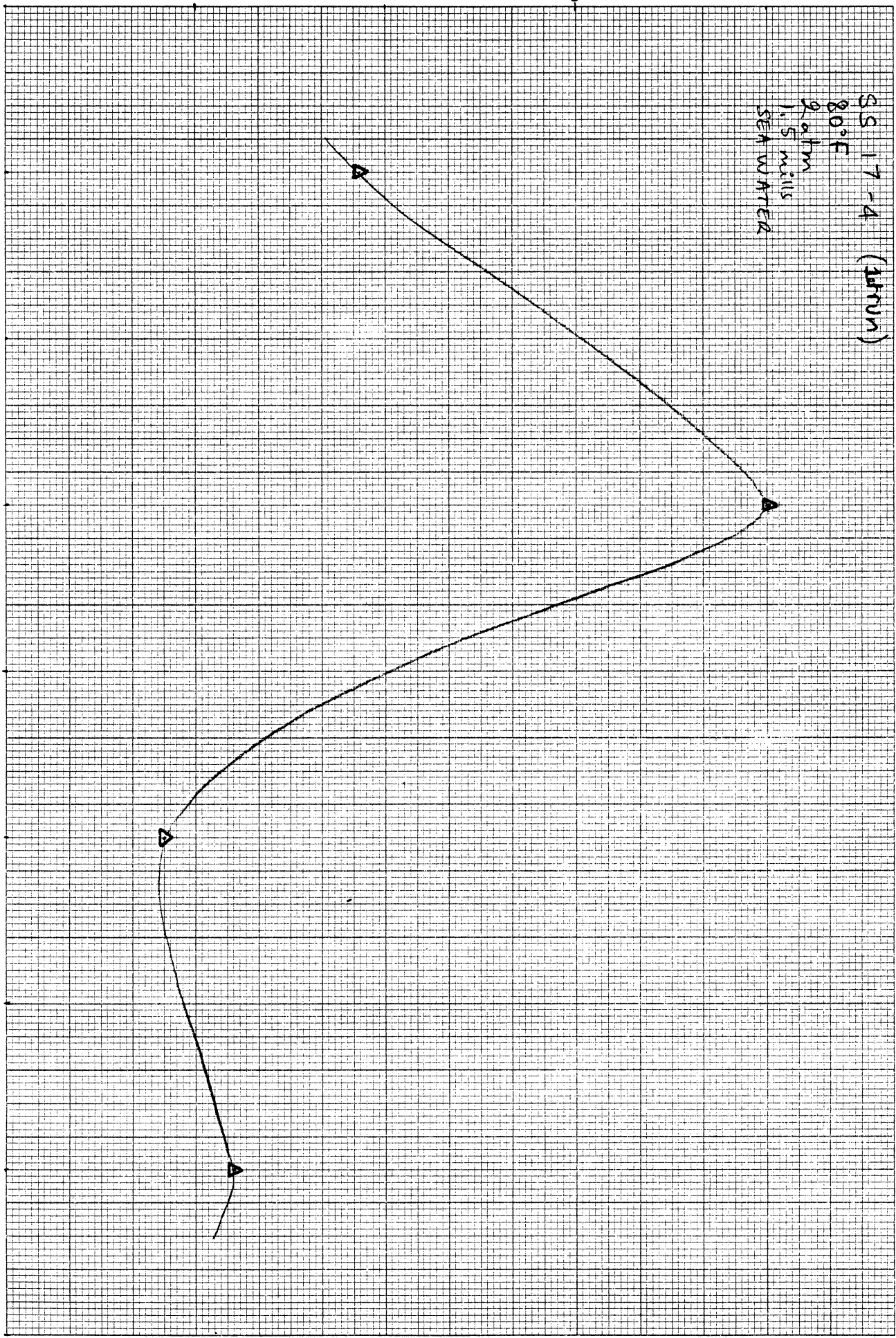
30 min

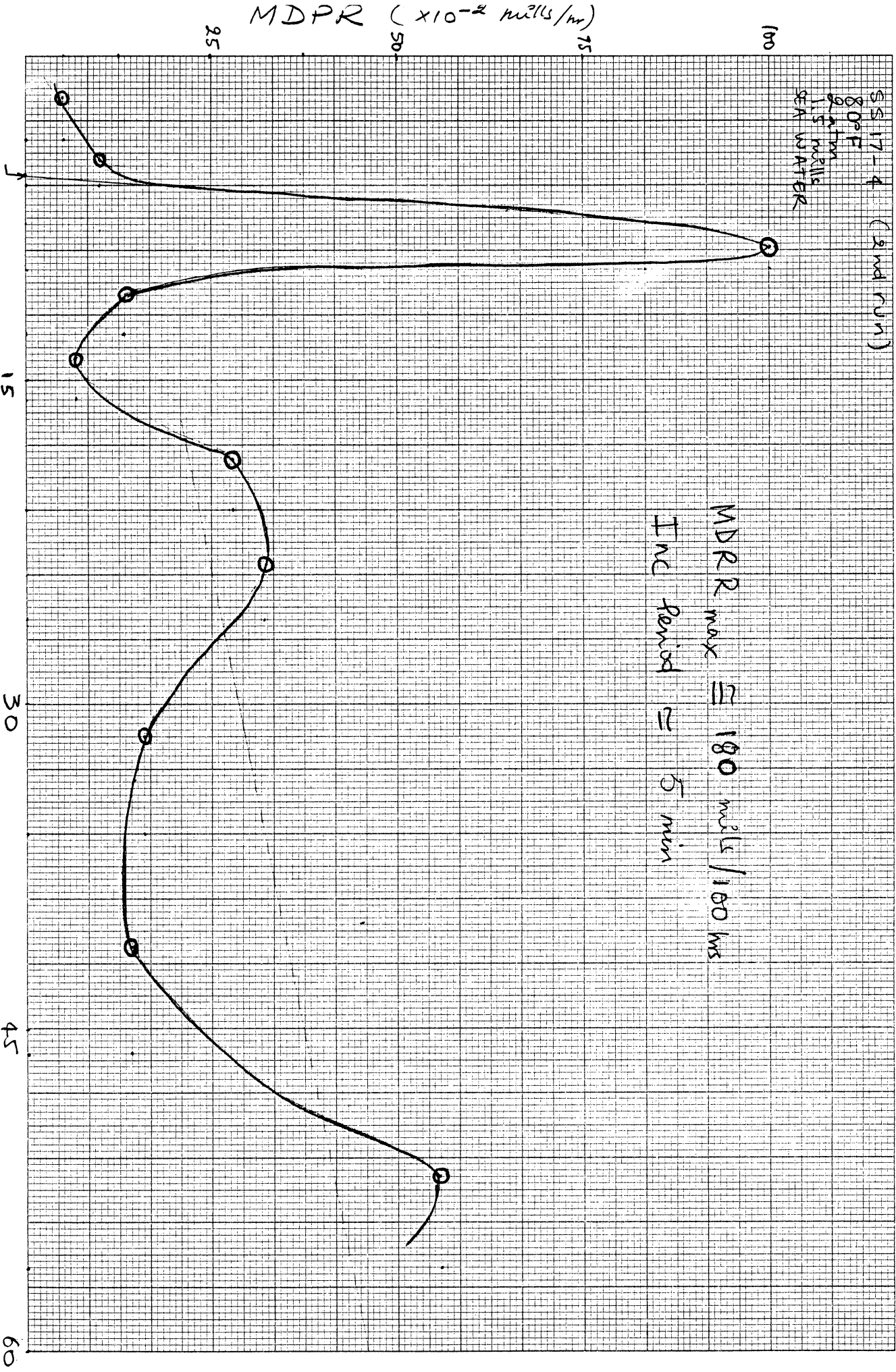
60 min

90 min

120 min

1/80 the Inch





s to the Inch

MDPR ( $\times 10^{-2}$  ml/l/hr)

400

100

30 min

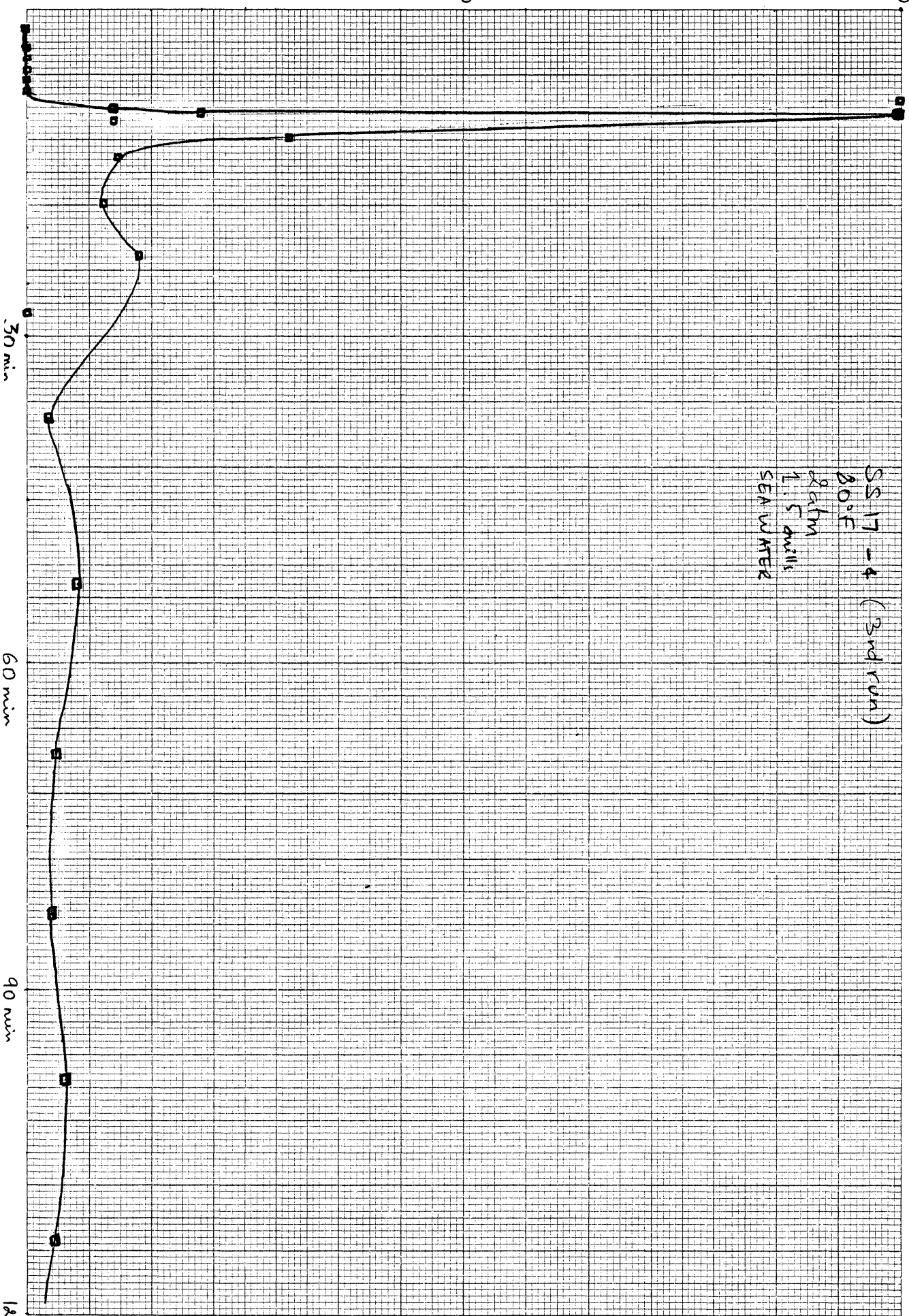
60 min

90 min

120 min

SS 17-4 (3rd run)  
80°F  
2 atm  
1.5 dmils  
SEA WATER

the Inch



MDPR ( $\times 10^{-3}$  mils/hr)

150

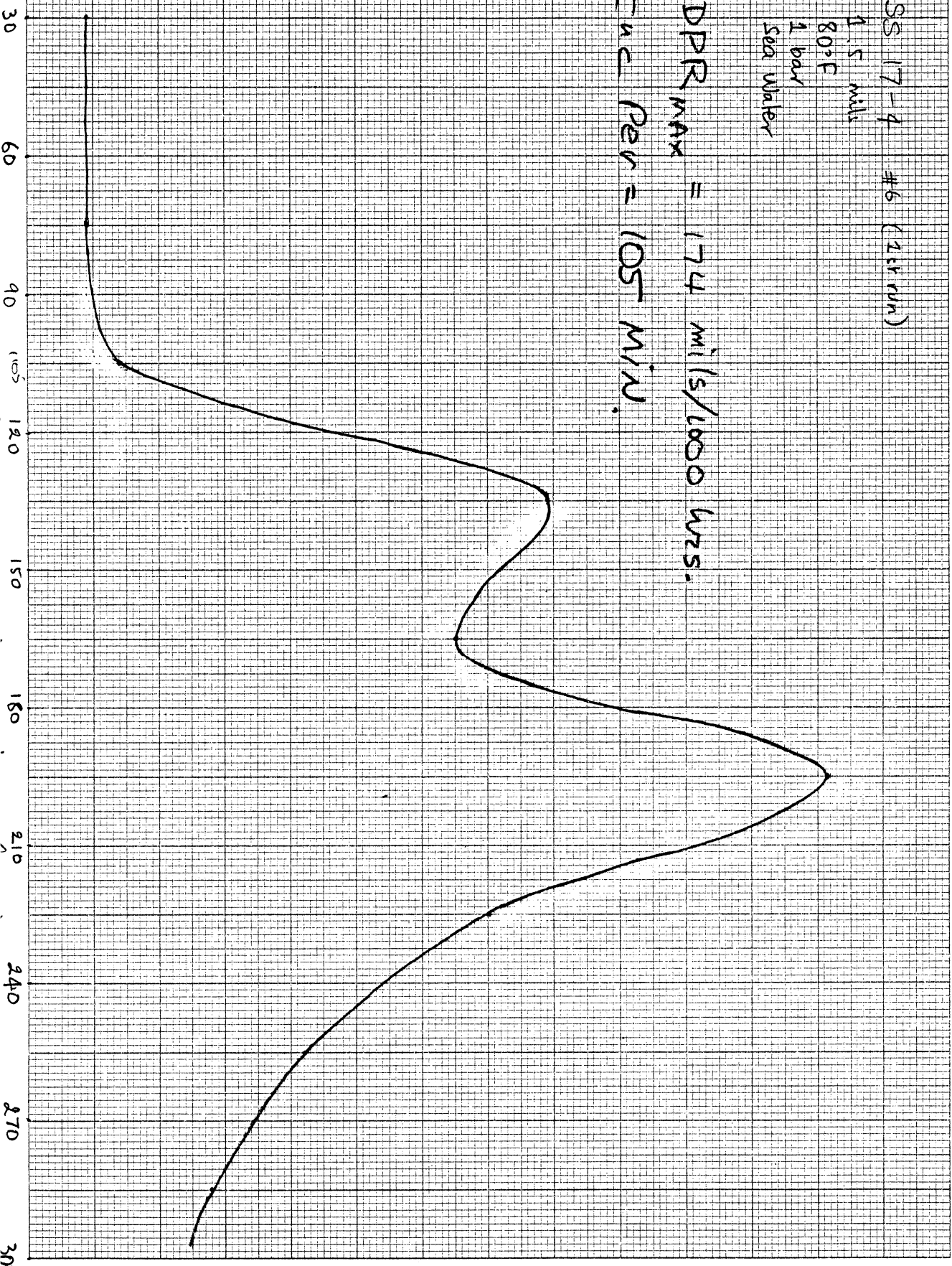
200

50

100

SS 17-4 #6 (21k rpm)  
1.5 mils  
80°F  
1 bar  
Sea water

MDPR<sub>MAX</sub> = 174 mils/1000 hrs.  
Time Per = 105 MIN.



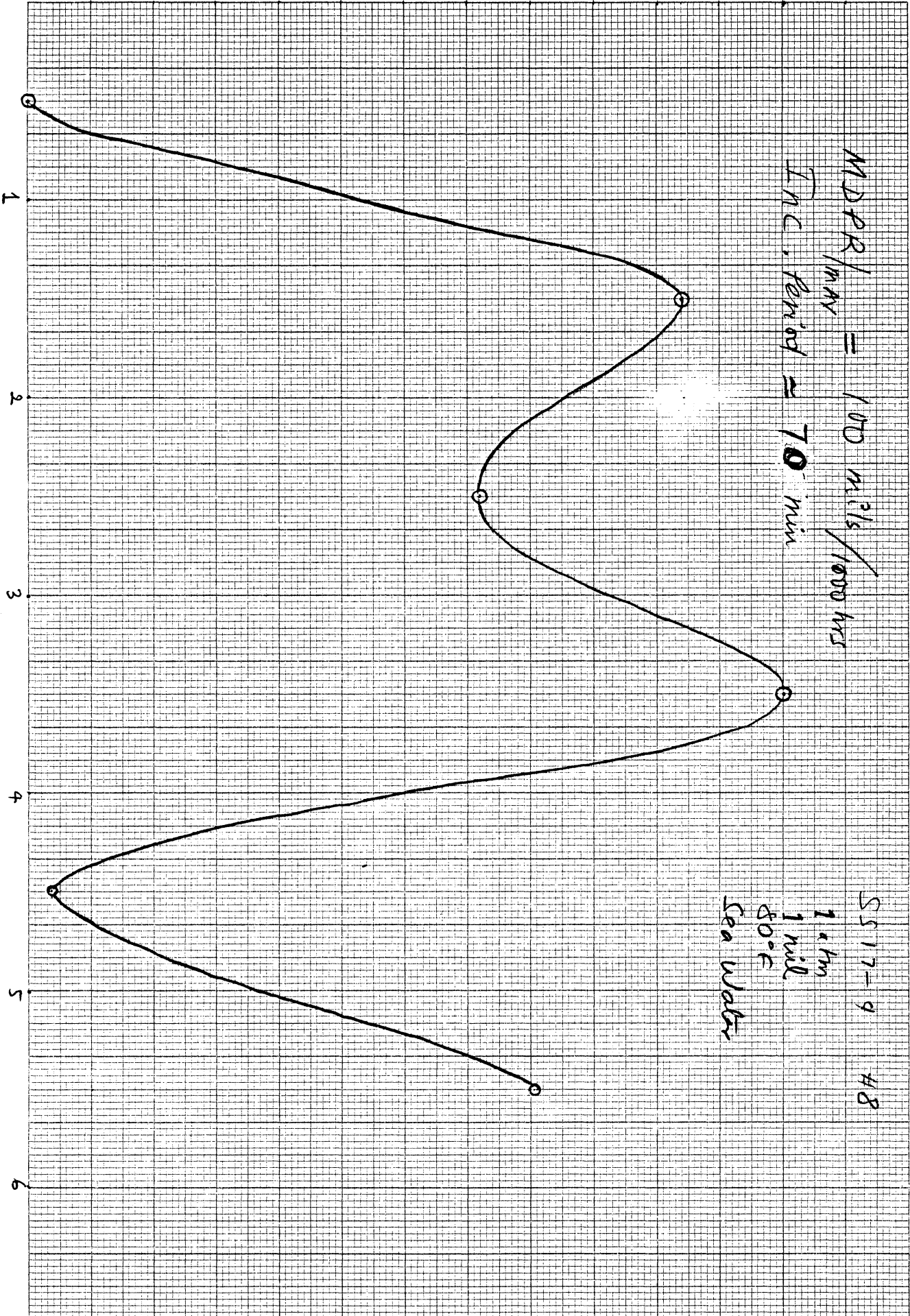
s to the Inch

MDPR<sub>50</sub> (mils/1000hr)

100

MDPR/may = 100 mils/1000 hrs  
INC. Period = 70 min

SS17-9 #8  
1" dia  
1 mil  
80°F  
Sea Water



MDPR ( $\times 10^{-2}$  mils/hr)

100

75

50

25

Titanium 6Al-4V (#2) (1st run)  
1 1/2 mils  
80°F  
2 atm  
sea water

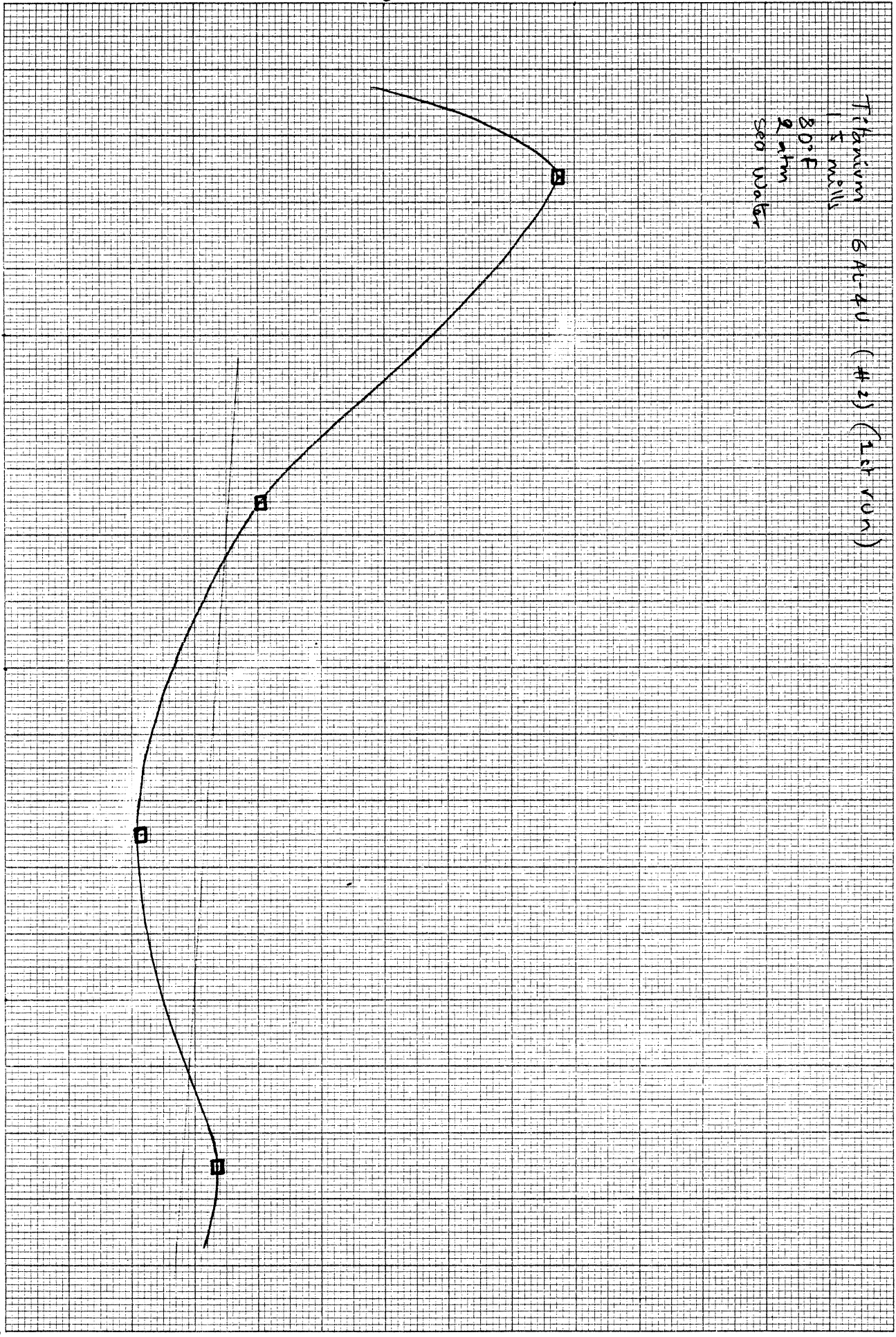
30

60

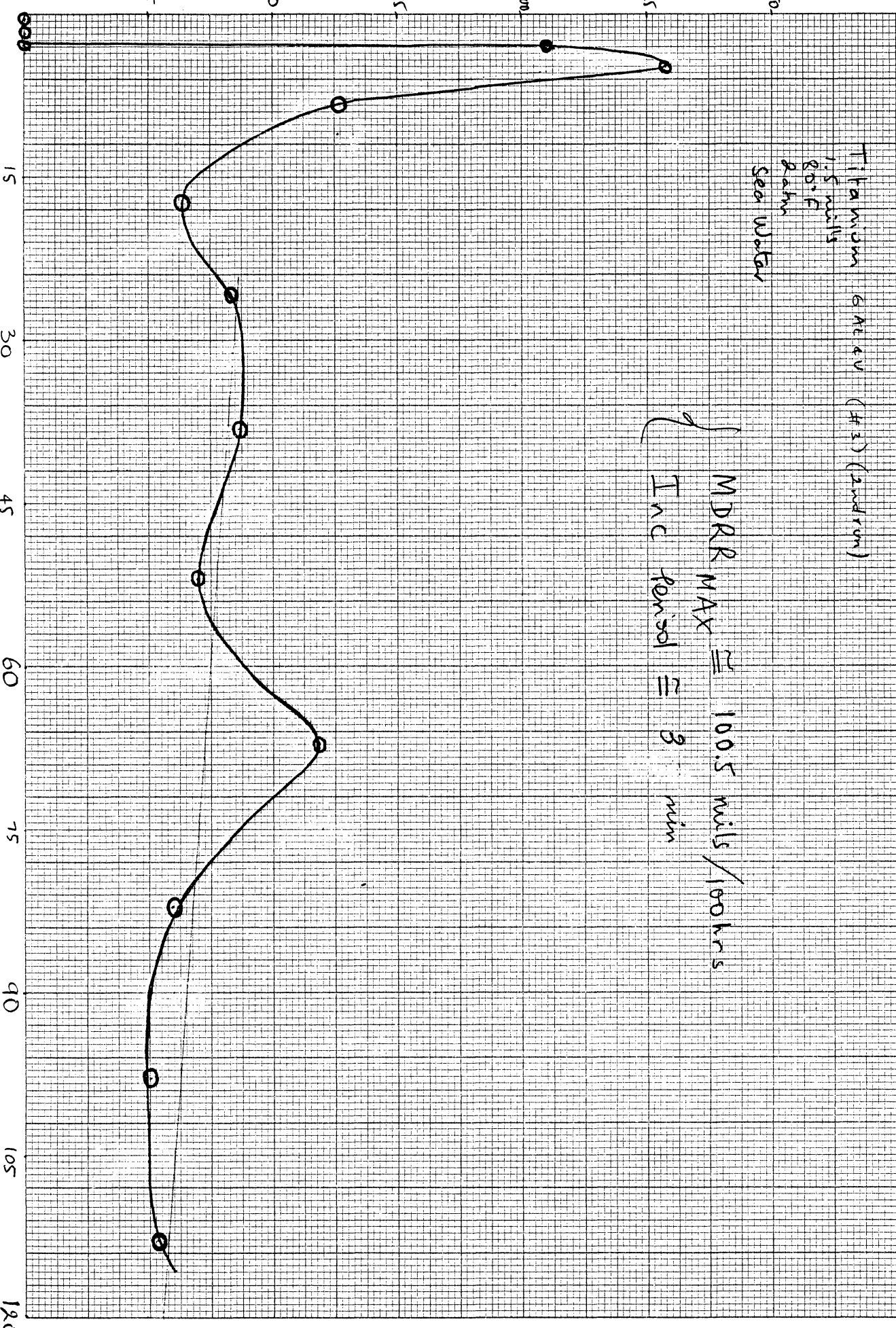
90

120

s to the Inch



MDPR ( $\times 10^{-2}$  mils/hr)



Titanium 6Al4V (#3) (Sandron)  
 1.5 mils  
 80°F  
 24hr  
 Sea Water

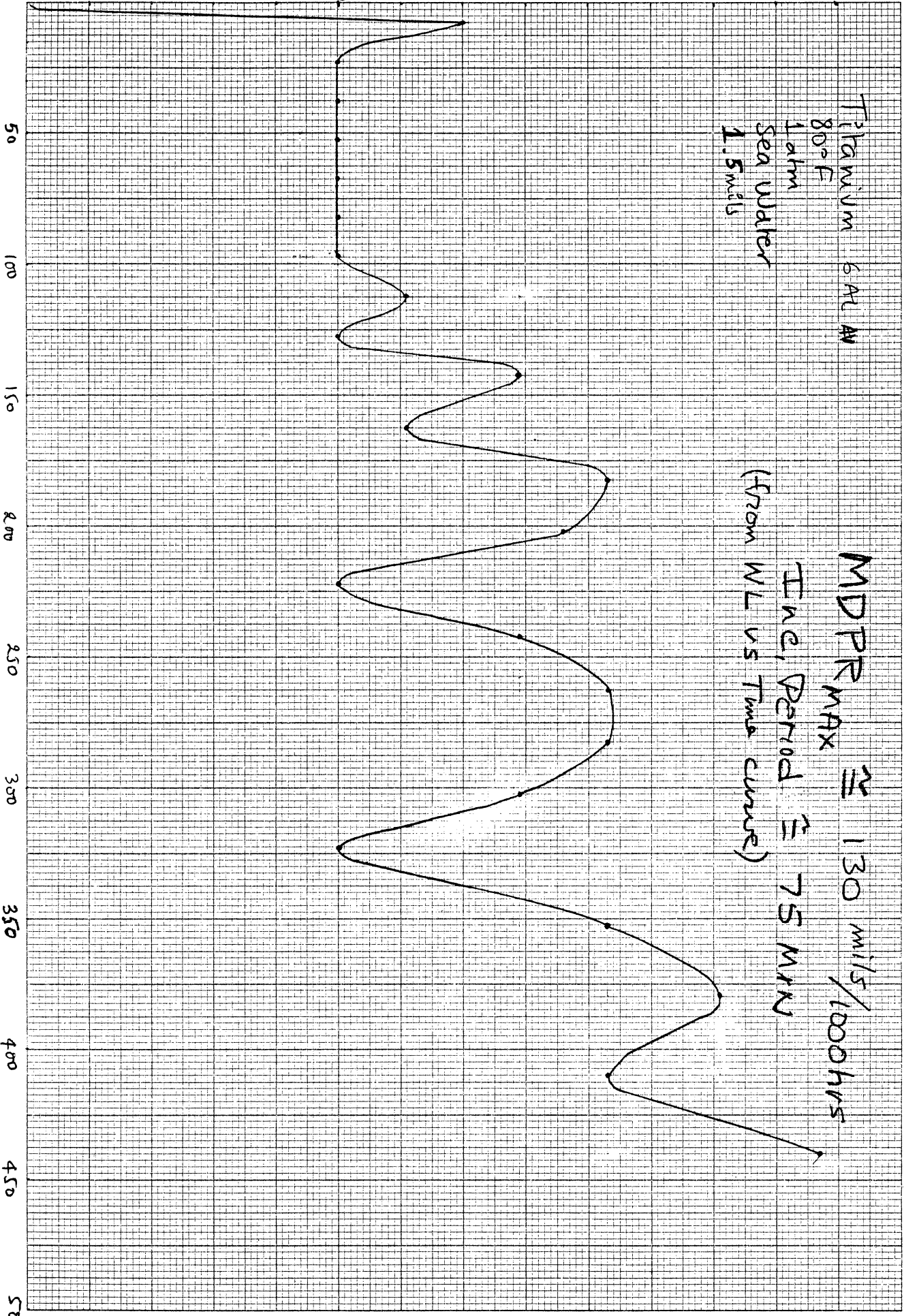
MDRR MAX  $\approx$  100.5 mils/100hrs  
 Inc period  $\approx$  8 min

MDRR (mils/1000 hrs)

130

Titanium 6AL 4V  
80°F  
1 atm  
Sea Udder  
1.5 mils

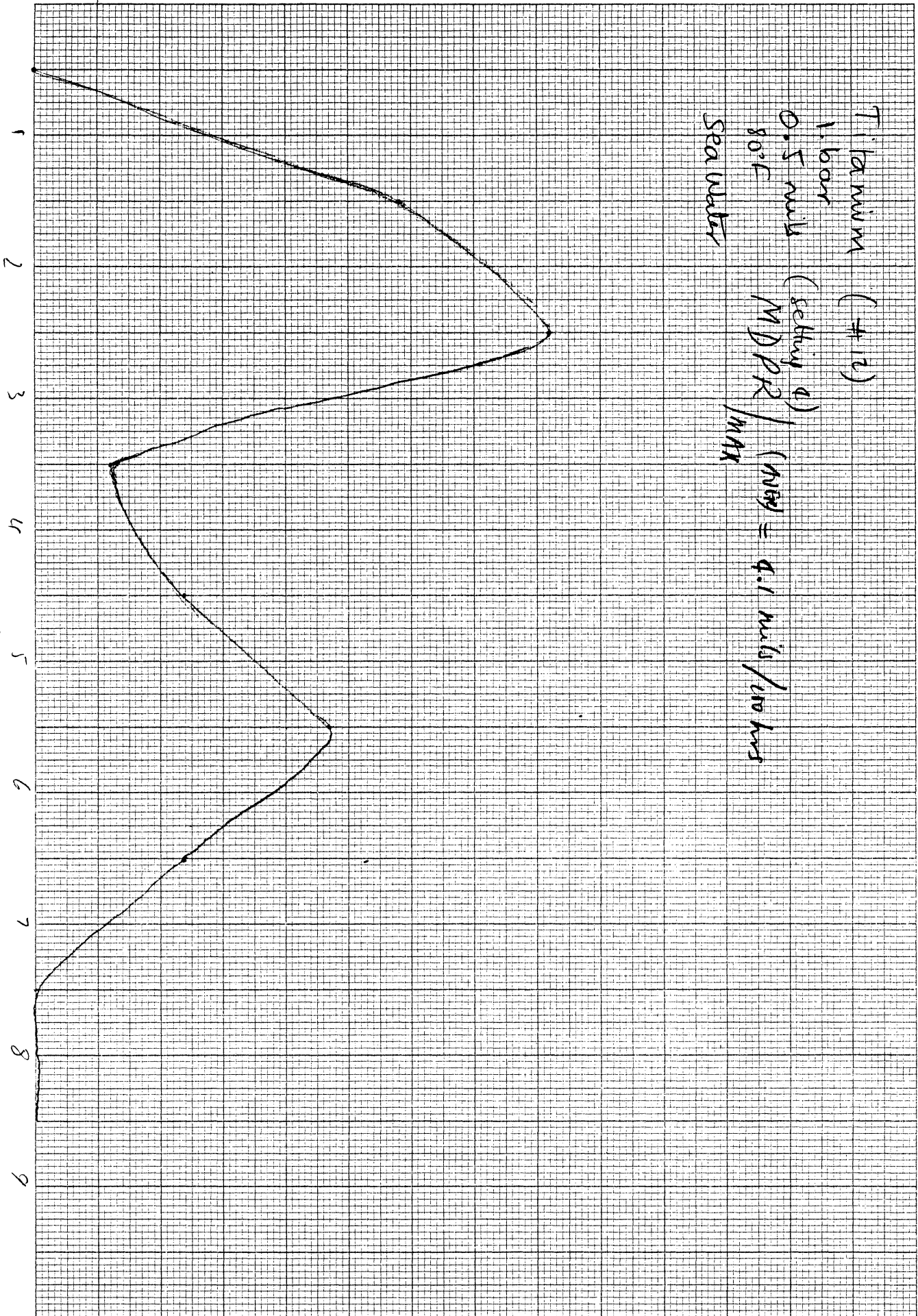
MDRR<sub>MAX</sub> ≈ 130 mils/1000hrs  
Inc. Period ≈ 75 MRN  
(From WL vs Time curve)



6/14/77



MDPR mils/100hrs



Titanium (#12)  
1.6 bar  
0.5 mils  
80°C  
Sea water  
(setting 4)  
MDPR / MAX  
(MAX) = 4.1 mils/100hrs

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