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Summary of the report:

Corrosion testing of 43 anodized aluminium name plates has been performed. The name plates have been exposed to natural seawater under various exposure conditions and in a salt spray chamber. In general very good corrosion resistance was demonstrated. The present report is a translated version of the original report issued in Norwegian (see below). The translation has been done by Adamant Märk system. The translated version has been approved by MARINTEK (August 1991).

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CORROSION TEST OF ANODIZED  
Al-NAME PLATES - METALPHOTO

Research engineer Helge Moving

COMMISSION REPORT

**MARINTEK**  
SINTEF GROUP



**REPORT**  
**REPORT**

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## 1. INTRODUCTION

Åge Børresen Stempelfabrik A/S manufactures anodized aluminium name plates intended for use in the Offshore Industry. The name plates consist of a base plate of aluminium (minimum 99% Al) which have been produced in a special way giving it the name of Metalphoto. The principle of this method is described later in chapter 4. MARINTEK was given the order to test the corrosion resistance of these name plates. The test programme was suggested by MARINTEK and was also completed in their laboratories. A complete description of the test is given in chapter 5. Åge Børresen Stempelfabrik A/S was particularly interested in finding out if the name plates tended to be sensitive to pitting corrosion and to galvanic corrosion. A closer description of these forms of corrosion is given in chapter 3.

## 2. CONCLUSIONS

The test comprised 43 sample name plates of aluminium. Some of the name plates have been exposed to sea water under various simulated corrosion conditions while others have been tested in a salt spray chamber.

Submerged in sea water the name plates have shown very good corrosion resistance. Damages made by MARINTEK in the surface of the name plates do not appear to influence this good resistance in any degree worth mentioning. One should, however, avoid direct contact between the name plate and carbon steel as this may lead to attacks along the edges of the name plates. We should, however, mention that offshore structures are cathodically protected which should lower the corrosion potential in a favourable way. The tests have shown that the aluminium name plates are protected against corrosion even when they have direct contact with a submerged, cathodically protected steel structure.

When exposed in a salt spray chamber the name plates do not have quite such a good corrosion resistance but considering how tough these tests really are the name plates are approved in this test. A small problem might be the runoffs sticking to the surface of the name plate but these runoffs are easily wiped off.

As stated earlier for the name plates submerged in sea water a direct contact between the aluminium name plate and steel in salt spray chamber environments should be avoided. Likewise it is not advisable to mount the name plates in such a way that they can cause salt gatherings as this might cause galvanic contact between the name plate and the underlying material. It is therefore of importance that the aluminium name plates are mounted with a good distance to the steel background, minimum 5 mm. This can e.g. be achieved by mounting the name plates on plastic spacers. If plastic screws are not used plastic lead-throughs must be used so that the screws are not in direct contact with the name plate.

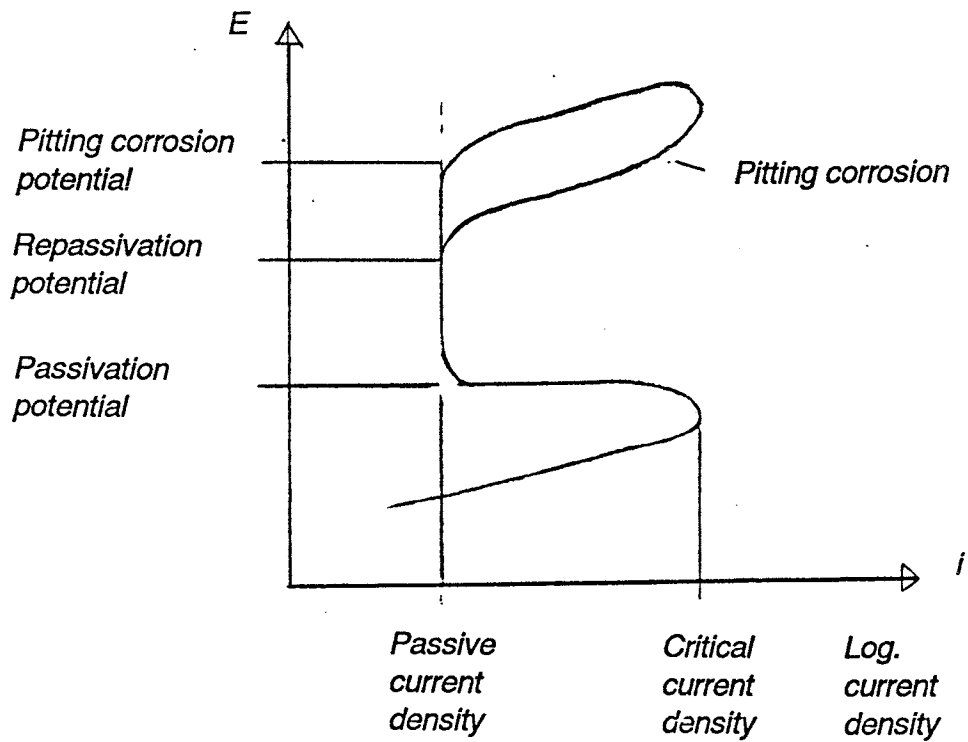
To what degree the abovementioned regulations should apply, possibly in connection with sealing of the edges of the name plate, must be decided due to the actual application. To decide the corrosivity of an environment please refer to Norsk Standard NS5415, Corrosion protective systems for steel constructions (Korrosjonshindrende systemer for stålkonstruksjoner).

### **3. CORROSION FORMS**

Corrosion can be defined in several ways but usually the word means "reaction between a metallic material and the surrounding medium." In this particular case we were especially interested in two different forms of corrosion, viz. pitting corrosion and galvanic corrosion.

#### **3.1. Pitting Corrosion / 1 /**

Pitting corrosion develops on more or less passivated metals and alloys on corrosive mediums containing aggressive ions like e.g. chlorine and bromine. When the electrode potential in addition exceeds a critical value, the pitting corrosion potential, pitting corrosion is initiated. This is schematically shown in *fig. 1*.



*Fig.1* : Anodic over voltage curve for an active – passive metal in an environment giving pitting corrosion.

Pitting corrosion is characterized as narrow pits with a radius having the same size as the depth of the pit or smaller. The pits can have various forms but a common characteristic is the sharp border line that it forms to the remaining passive metal surface. See also *fig.2*.



*Fig. 2.* : Various pit forms by pitting corrosion.

Pitting corrosion is a dangerous form of corrosion as the metal in many cases can be perforated without any obvious preliminary warning due to narrow or covered pits. Due to the local pit sites it is difficult to calculate the corrosion speed beforehand.

Aluminium is easily exposed to pitting corrosion in chloride bearing media without the corrosion necessarily needing to be serious. All metals can be given an artificial voltage level (potential). This is done either by connecting the metal to other metals or by employing an external voltage from a direct-current source. By polarizing of aluminium to more positive potentials than the pitting corrosion potential the attacks will be more severe. The magnesium alloys and the manganese alloys are the aluminium alloys which beside the technically pure aluminium stands up best in sea water. The aluminium alloys containing copper and zinc are generally seen less resistant to corrosion.

A method for testing the resistance of a material to pitting corrosion is to make a polarization curve electrochemically. Explained in simple terms this means that adjust the voltage level is adjusted either step by step or as a continuous process. By measuring the resulting current between the sample (here the aluminium name plate) and a counter electrode the corrosion resistance of the materials can be defined. From such a curve one can determine the pitting corrosion potential. In addition to this the free corrosion potential must be measured. This is the potential (voltage) to which a metal naturally adjusts in a given environment.

If the free corrosion potential is lower than the pitting corrosion potential there is no danger of pitting corrosion being initiated. It is, however, important to understand that a pitting attack which has already been initiated can propagate at potentials which are lower than the pitting potential. Thus, if the potential of the samples is higher (more positive) than the pitting potential even "only for a short while" a pitting corrosion attack can start. However, neither initiation nor propagation of the attack can take place at potentials lower than the repassivation potential for the material in the actual environment.

### **3.2. Galvanic corrosion /1/**

When a noble metal is being connected to a less noble metal the corrosion of the last one will increase while the corrosion of the first one will decrease in intensity. The only necessary condition for this being that there is an electrolytical connection between the two metals so that the result is a closed circuit. Most metals will be more noble than aluminium under these conditions. To begin with it is therefore very unsuitable to connect aluminium to e.g. stainless steel or carbon steel in a freely corroding condition.

Fig. 3 shows examples of galvanic corrosion.

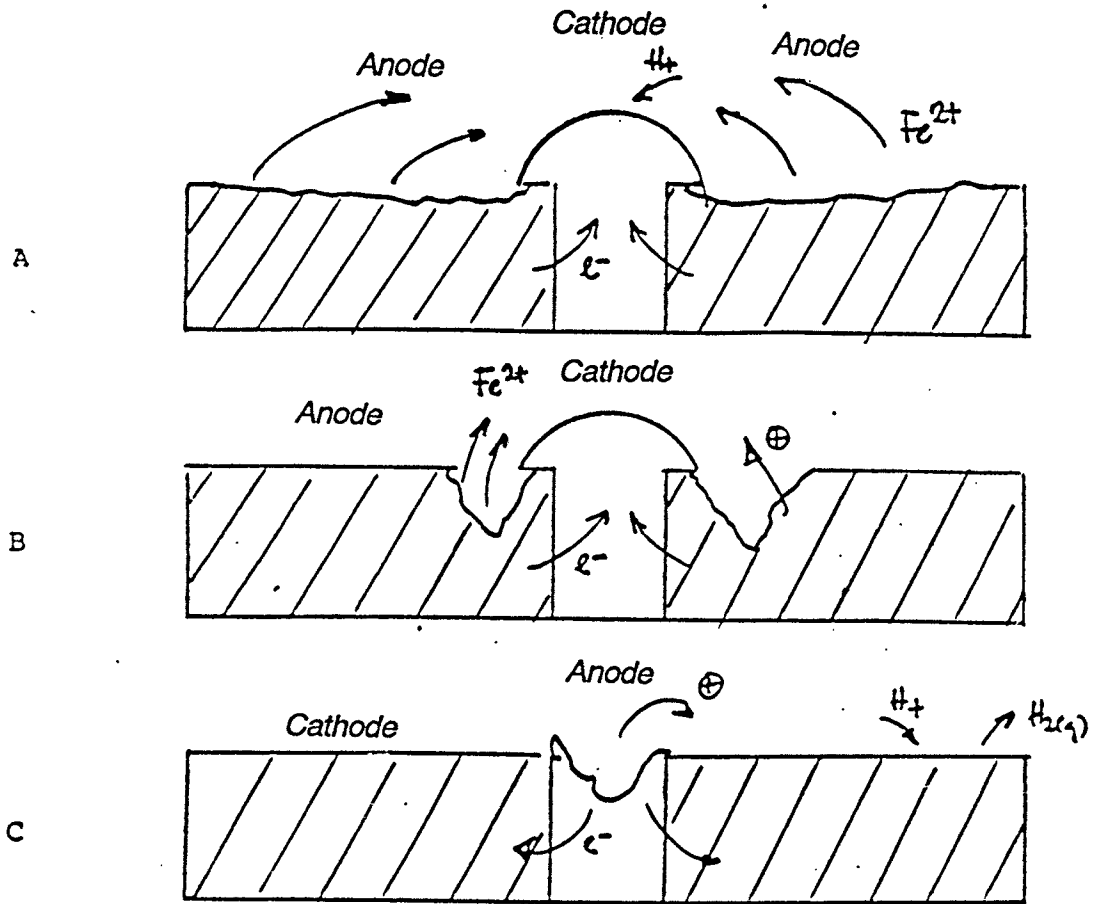


Fig. 3 : Galvanic corrosion: screw and plate made of different materials.

- A. Shows a noble screw, a less noble plate and an electrolyte with a conductive substance.
- B. Shows a noble screw, a less noble plate and an electrolyte with a not so good conductive substance.
- C. Shows a noble plate and a less noble screw.

The risk for galvanic corrosion can partly be anticipated when using a galvanic series. A practical galvanic series showing the corrosion potential for different metals in sea water is given in fig. 4 /2/.



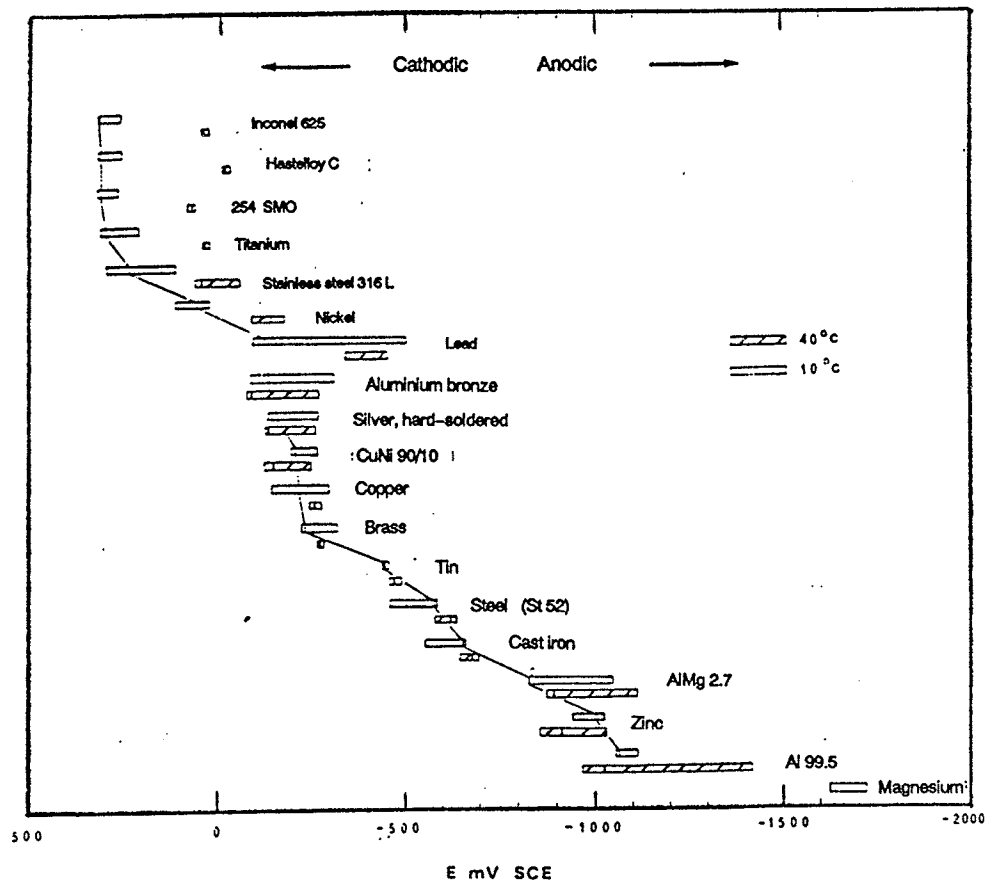


Fig. 4 : Galvanic series for sea water at 10 °C and 40 °C. The materials have been arranged due to the average values of the corrosion potentials shown during the last 10 days of exposure at 10 °C. The rectangles show the variation during the significant part of the exposure time [2].

If no more complete data exists the galvanic series for the actual environment can be used in the following way:

- a. When  $\Delta E_{korr}$  (i.e. the difference in the corrosion potential for two different kinds of materials)  $< 50$  mV for two materials the connection will only cause minor changes in the corrosion rate (i.e. if the relation between the areas of the anode and the cathode is not very unfavourable or if the less noble material is exposed to a definite local corrosion, e.g. pitting corrosion).

b. When  $\Delta E_{\text{korr}} > 50 \text{ mV}$  there is a risk that the less noble material might corrode faster after being connected to the noble material. It should be mentioned that the potential difference between the metals is not a reliable tool for calculating the corrosion rate increase.

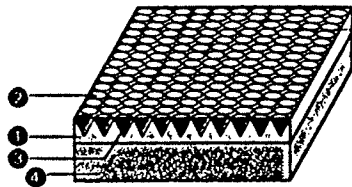
When the less noble material is acting as a very efficient cathode even the connection between equally big areas can be dangerous.

c. When the area of the cathode is a lot bigger than the area of the anode the corrosion speed of the anode can increase strongly even at small differences between the corrosion potentials of the materials.

#### 4. DESCRIPTION OF THE NAME PLATES

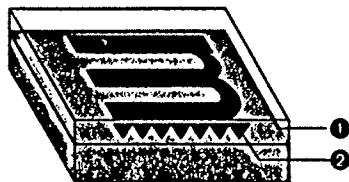
##### 4.1. Production of the name plates /3/

A cross section of an unexposed and unsealed plate is shown in *fig. 5* whereas a cross section of an exposed and sealed plate is shown in *fig.6*.



1. Anodized layer
2. Unsealed pores
3. Photosensitive material
4. Aluminium metal

*Fig. 5* : Cross section of an unexposed and unsealed plate.



1. Clear sealed anodic layer
2. Trapped deposits of exposed silver form the image

*Fig. 6* : Cross section of an exposed and sealed plate.

Since the image is not on top of the surface but inside the metal, imbedded in the glass-clear anodized layer, it cannot be destroyed unless you destroy the metal itself.

The anodized layer is sapphire-hard (hardness 9) and protects the image from scratching and fading. The processed plates are furthermore impervious to moisture, solvents, lubricants, fungus, weathering, most corrosive atmospheres and temperature extremes.

#### **4.2. The design of the test samples.**

The test samples were produced by Åge Børresens Stempelfabrikk A/S. The size of the test samples was 208 x 121 x 0,8 mm.

The following types of samples were tested:

1. Name plate with intact surface.
2. Name plate with a scratch on the surface (approx. 20  $\mu\text{m}$  deep and 65–70 long).
3. Name plates with a ground defect on the surface (approx. 200  $\mu\text{m}$  deep and covering an area of approximately 35 mm<sup>2</sup>).

The defects on the test name plates were produced by MARINTEK.

## 5. TEST DESCRIPTION

### 5.1. Testing programme

In all 43 test name plates were exposed in two different main environments:  
Sea water and Salt spray chamber.

The samples were tested in accordance with the following testing programme:

Environment	No of samples						Corrosion resistance
	Intact plate	Plate with scratch	Plate with machined surface	Mounted plate	Plate with insulated edge		
Sea water, free exposure	2	2	2	2	2		Very good
Sea water, galvanically coupled	2	2	2				Bad
Sea water, polarized to -800 mV Ag/AgCl, KCl	2						Very good
Sea water, polarized to -1050 mV Ag/AgCl, KCl	2						Very good
Sea water, anodic polarization curve	3						Very good
Sea water, cathodic polarization curve	2						Very good
Sea water, partly submerged, free exposure	2	1	1				Very good
Salt spray chamber	2	2	2	2			Good/bad
Salt spray chamber, galvanically coupled	2	2	2	2			Very bad

### **Sea water, free exposure**

The samples were equipped with leads to measure the free corrosion potential. The free corrosion potential were measured as a function of exposure time vs. a Silver/Silver Chloride reference electrode (Ag/AgCl, KCl). The samples were weighed before and after exposure and the loss of weight was established.

### **Sea water, galvanically coupled**

The samples were connected with leads to measure the galvanic potential and the galvanic current. Each sample plate was connected galvanically to a sample of C-steel (Carbon steel). The area ratio was 4:1. Galvanic potential and current were measured as a function of exposure time. The samples were weighed before and after exposure and the loss of weight was established.

### **Sea water, polarized to $-800$ mV and $-1050$ mV Ag/AgCl, KCl**

By a cathodic protection of an offshore structure with common sacrificial anodes  $-800$  mV is the highest potential that steel can have and  $-1050$  mV is the lowest potential. Hence two samples were polarized to  $-800$  mV and two samples were polarized to  $-1050$  mV. This was done with a so called potentiostat. Leads were connected to the samples to measure current and potential. The development of the current was measured as a function of exposure time. The samples were weighed before and after exposure to establish loss of weight.

### **Sea water, anodic polarization curve**

Leads were connected to the samples to enable electrochemical measuring. The samples were exposed freely until anodic hysteresis was done which took place after 8 days of free exposure of the first sample and after 87 days of free exposure of the second sample.

The first sample was polarized to  $-800$  mV, Ag/AgCl, KCl a few hours before the anodic polarization curve was established.

The samples were polarized 200 mV in the anodic direction and then back to -800 mV. The second sample was polarized 150 mV in the anodic direction direct from the corrosion potential and then back to the corrosion potential. Potential steps of 10 mV were used and a duration of 10 minutes on each step was applied.

### **Sea water, cathodic polarization curve**

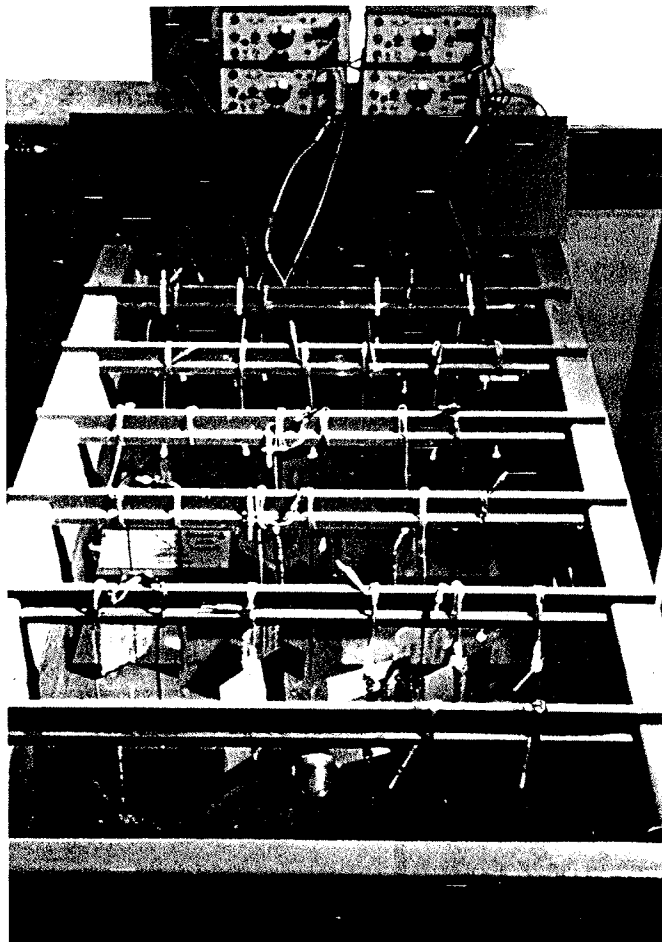
Leads were connected to the test samples for electrochemical measurements. The test plates were exposed freely up to the point when the cathodic sweep was done. On the first sample the cathodic sweep was done after 9 days of free exposure and the second sample was submitted to the cathodic sweep after 39 days of free exposure. Both samples were polarized in steps of 10 mV with a duration of 4 minutes. The samples were polarized from the free corrosion potential level and 200 mV in the cathodic direction and then back to the corrosion potential.

### **Salt spray chamber**

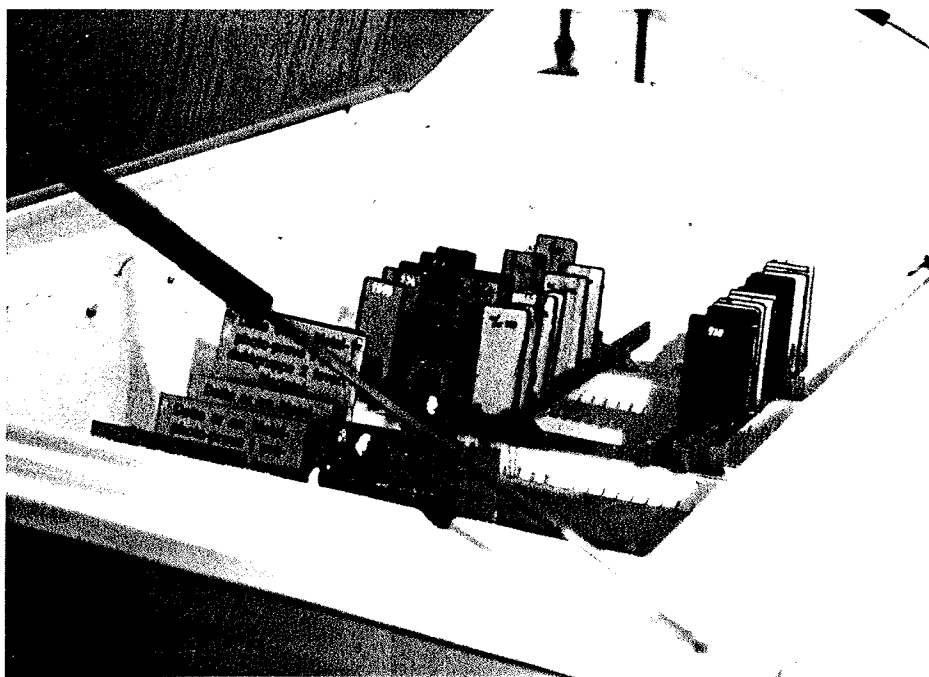
The samples were exposed in a spray consisting of a 5% NaCl solution at 35°C in accordance with ASTM Standard B117-85.

The samples were weighed before and after exposure and loss of weight was established.

## 5.2 Apparatus



Photograph No 1: Name plate exposed in sea water.



Photograph No 2: Name plate exposed in salt spray chamber.

## 6. RESULTS

43 aluminium plates have been exposed in two different environments. Environment 1 was pure sea water and environment 2 was a standard salt spray chamber test developed for testing of coatings used in marine environments.

The results have been divided into two subsections regarding the exposure environments. Section 6.1. deals with plates exposed to natural sea water (environment 1) and section 6.2. deals with plates which were exposed to the environment of the salt spray chamber (environment 2).

In environment 1 the corrosion resistance is evaluated by using potential curves, current density curves, polarization curves, weight loss calculations and visual inspection.

In environment 2 only weight loss calculations and visual inspection are possible.

All potentials referred to were measured against Ag/AgCl, KCl reference electrodes.

The total exposure time was 113 days.

After ending the exposure all plates were cleaned from corrosion products and wiped dry. The loss of weight was then calculated (table 1) and finally a visual inspection was made.

### 6.1. Environment 1: Natural Sea Water

Environment 1 describes the tests done in natural sea water. The following samples were exposed:

Plates 1 – 2 :	without defect	freely*
Plates 3 – 4 :	with scratch	freely*
Plates 5 – 6 :	with machined defect	freely*
Plates 7 – 8 :	mounted plate	freely*
Plates 42 – 43:	insulated edges	freely*
Plates 24 – 25:	partly submerged, without defects	freely*
Plate 26 :	partly submerged, with scratch	freely*
Plate 27 :	partly submerged, with machined defect	freely*



Plates 19 – 23:	polarization curves done	freely*
Plates 15 – 16:	polarized to –800 mV, without defect	cathodic**
Plates 17 – 18:	polarized to –1050 mV, without defect	cathodic**
Plates 9 – 10 :	without defect	galvanic***
Plates 11 – 12:	with scratch	galvanic***
Plates 13 – 14:	with machined defect	galvanic***

- \* : freely exposed
- \*\* : cathodically polarized
- \*\*\* : galvanically coupled to Carbon steel

The aluminium plates which were exposed under free corrosion showed potential values in the region from –840 to –620 mV with an average of approximately –720 mV (see figures 7 – 14 + figure 18).

All the freely exposed plates had at least on one occasion reached –670 mV (the pitting potential). This implied that pitting corrosion could have been initiated on all plates. At the visual inspection pitting corrosion was found on all plates with the exception of the plates with the insulated edges ( plates 42 – 43). These plates showed no pitting at all. All the pitting was found along the edges of the plate and the pits were roughly of the same size on all the freely exposed plates. The attacks were, however, so small that a magnifying glass had to be used to detect the pits. When using a microscope the maximum depth of the pits was established to be 40  $\mu\text{m}$ .

The defects that in various degrees had been made on the plates do not seem to have any negative effect on corrosion conditions worth mentioning. The loss of weight for the plates with made defects were in the same region as the loss of weight for the plates with no defects, approx. 230 mg.

The partly submerged plates showed exactly the same corrosion pattern as the completely submerged ones. The potential development was the same (see figures 12 – 14) in both cases and there were only suggestions of pit corrosion along the edges of the plates, approx. 70  $\mu\text{m}$ .

The loss of weight was naturally a little less, approx. 170 mg. The reason for this being that corrosion only takes place on the submerged part of the plate. Due to this fact the area where corrosion can take place is smaller and therefore the loss of weight smaller on a partly submerged plate than on the completely submerged ones (see photograph 3).

The mounted plates also only had suggestions of pit corrosion along the edges but these plates showed a significantly greater loss of weight than the other freely exposed plates. The reason for this was that the back sides of the mounted plates were equipped with double-sided tape before exposure. During the exposure this tape partly dissolved resulting in the higher loss of weight.

The plates on which polarization measurements were done are also to be regarded as freely exposed plates. The polarization might, however, have worsened the corrosion condition of the plates. It definitely has for the plates that were polarized anodically. Figure 18 shows that the potential values are widely spread and that various degrees of pitting can be expected. The visual inspection does, however, show only suggestions of pit corrosion along the edges of all the plates with depths of approx.  $40\ \mu\text{m}$ .

The loss of weight is somewhat greater for these plates than for the other freely exposed ones, approx. 300 mg. The explanation for this is that these plates mainly must be looked upon as freely exposed plates. One must then take into account certain individual differences in weight loss as is the fact for the other freely exposed plates. For the plates that were polarized anodically it means that this polarization can cause pit corrosion initiation. For the plates that were subjected to cathodic polarization pitting will not be initiated but a local increase of the pH value will result in slightly higher pitting corrosion rates. If we look at the current density curves for these plates one can from the anodic polarization curves (figures 24 – 25) note that the current density increases strongly at a potential of approx.  $-670\ \text{mV}$ . This is the so called pitting potential.

Figures 26 – 27 show the current density for the cathodically polarized plates. Like the curves show the current density does not increase to any extent worth mentioning at a continued polarization after the potential has reached approx.  $-1000\ \text{mV}$ . Here the limiting current for oxygen reduction has been reached. Such a limiting current is characteristic for the maximum corrosion rate that a material can have in a given environment where the oxygen reduction is the rate setting step.

The corrosion conditions for the plates were improved when the cut edges were insulated by the use of a vinyl tar painting system. We could not find any corrosion attacks on these plates even though the potential on one of the plates was all the way up to  $-620$  mV. Such a potential normally means that pitting corrosion can be initiated but the paint that was used to insulate the edges does effect the potential measuring. To what extent the potential can be influenced depends on the insulating effect of the painting system and it can therefore be difficult to evaluate the potential directly.

The aluminium plates that were cathodically polarized to  $-800$  and  $-1050$  mV did no show any tendency for pitting at the visual inspection. This was what we also expected as the potential for these plates lay lower than the pitting potential.

Figures 22 – 23 show the current density development for plates polarized to  $-800$  and  $-1050$  mV respectively. The current density curves do not represent any corrosion but the protective current that prevents the plates from reaching their natural free corrosion potential. Like the curves show it takes more current to polarize the plates all the way down to  $-1050$  mV than it takes for a polarization to  $-800$  mV.

An additional effect that appears at  $-1050$  mV is the hydrogen development reaction. This also contributes to the increase of the current value.

The aluminium plates that were connected to steel showed a stable potential development progress (see figures 15 – 17). Figures 19 – 21 show the current density development for galvanic connected plates with various kinds of created defects. The current density is here an expression for the corrosion rate for this particular aluminium. This means that the higher the current density the more powerful the corrosion attack. This depends on the fact that the aluminium plates (edges + created defects) act like a sacrificial anode when they are connected to the steel plate. You can also note that the current density increases over time.

With this in mind it was therefore not surprising that these plates had the highest loss of weight amongst the plates that were exposed to sea water, approx. 350 mg. The pitting that was  $800 \mu\text{m}$  deep, was substantially stronger and spread from the edges and down the front of the name plate. Also on these plates you can hardly notice any corrosion effect even though the name plates had been given artificial damages (see photograph no 4).

## 6.2. Environment 2: Salt spray chamber

Environment 2 describes the tests in the salt spray chamber. The following name plates were exposed:

Plates 28 – 29	:	without defect	freely exposed
Plates 30 – 31	:	with scratch	freely exposed
Plates 32 – 33	:	with ground defect	freely exposed
Plates 34 – 35	:	mounted plates	freely exposed
Plates 36 – 37	:	without defect	galvanically coupled to steel
Plates 38 – 39	:	with scratch	galvanically coupled to steel
Plates 40 – 41	:	with ground defect	galvanically coupled to steel

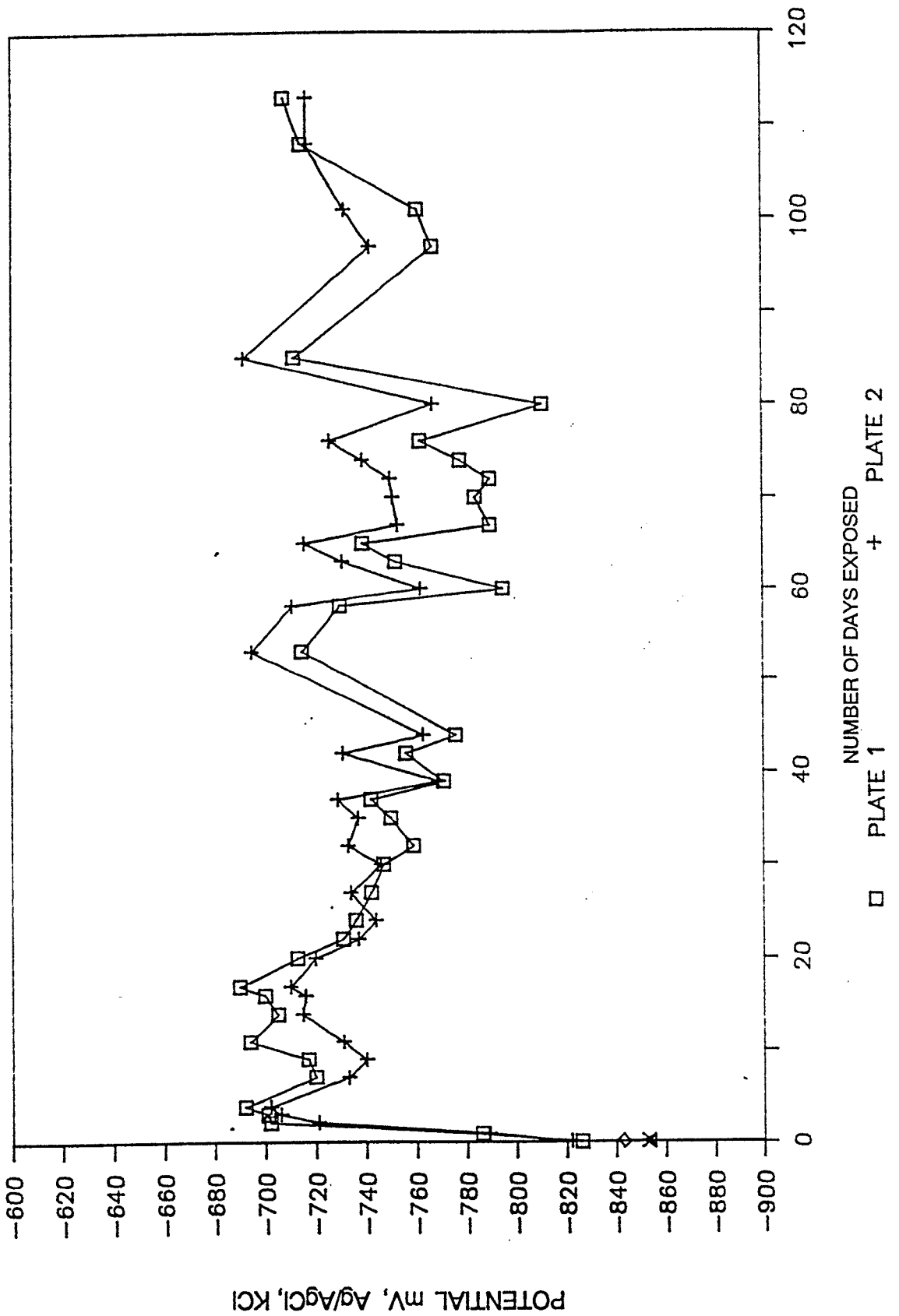
The visual inspection showed pitting along the edges and where the name plates had been equipped with defects for all the freely exposed plates. The pittings here were somewhat stronger than for the freely exposed plates that had been exposed in natural sea water and measured approximately 120  $\mu\text{m}$ . The corrosion products runoff had furthermore etched themselves on to the surface of the name plate and this made the name plate look bad. In spite of the registered pittings none of the freely exposed plates had any noticeable loss of weight. This is due to the fact that the pittings are small but also due to the fact that the corrosion runoffs stick to the surface of the name plate.

The mounted plates showed on the other hand a considerable loss of weight (approximately 1300 mg). This is due to the fact that the double-sided tape on the back of the name plates had partly dissolved causing this considerable loss of weight (*compare chapter 6.1.*) Otherwise the mounted name plates had roughly the same pitting depth as the other freely exposed name plates (*see photograph 6*).

The rest of the plates in the salt spray chamber were galvanically connected so that an aluminium name plate and a steel plate were placed against each other in such a way that they formed a "V". These plates had a very high loss of weight and are partly perforated by corrosion where the aluminium was in contact with the steel. This shows that the mounting of the name plates and the evaluation of the corrosion environment are extremely important to achieve a satisfying life for the name plates (*see photograph 7*) (*compare comments in chapter 6.1.*).

### 6.3. Potential curves

# MEASURING OF POTENTIAL, AI-NAME PLATES WITHOUT DEFECT



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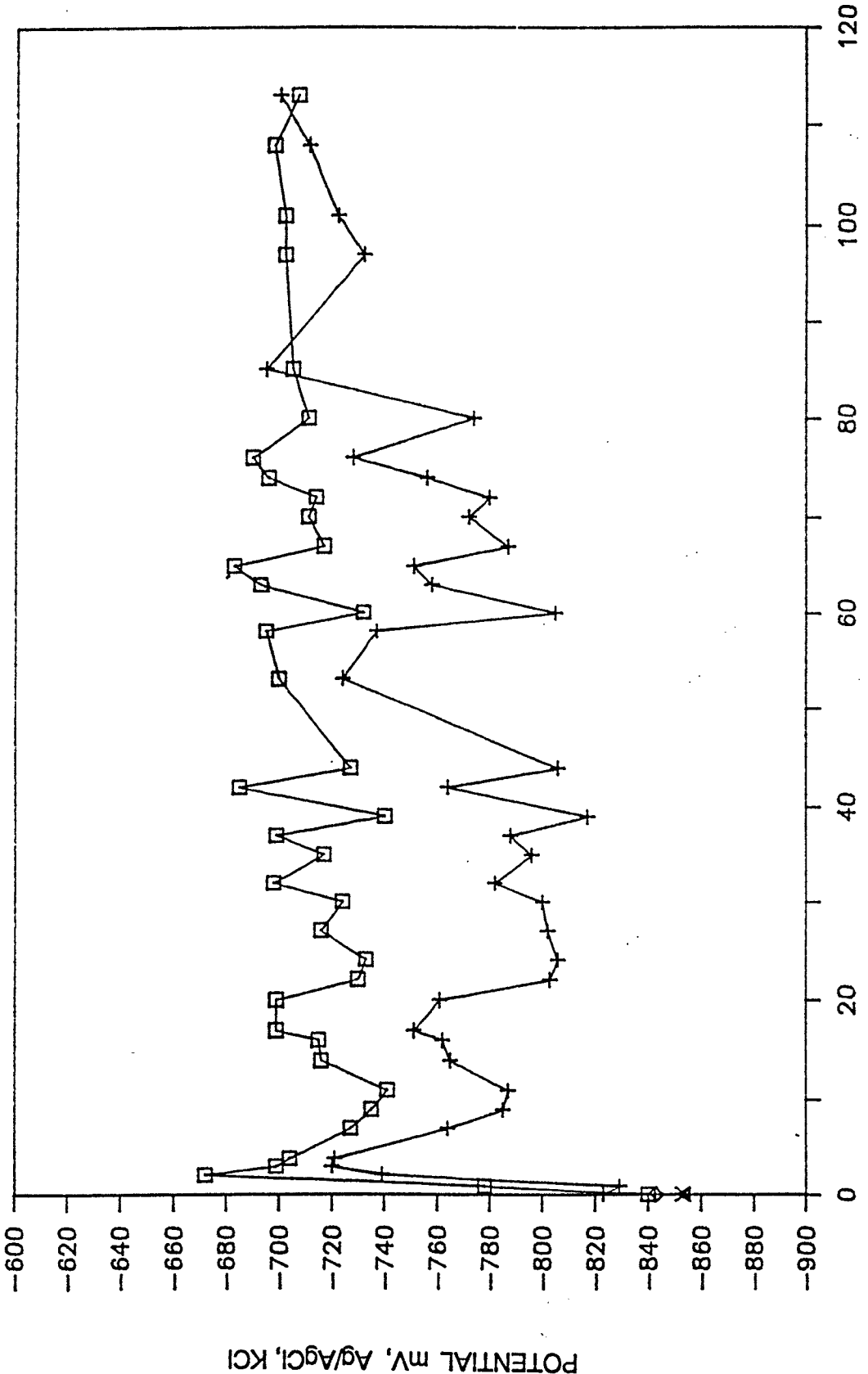
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FIGURE NO.

7

# MEASURING OF POTENTIAL, AI-NAME PLATES

WITH SCRATCH

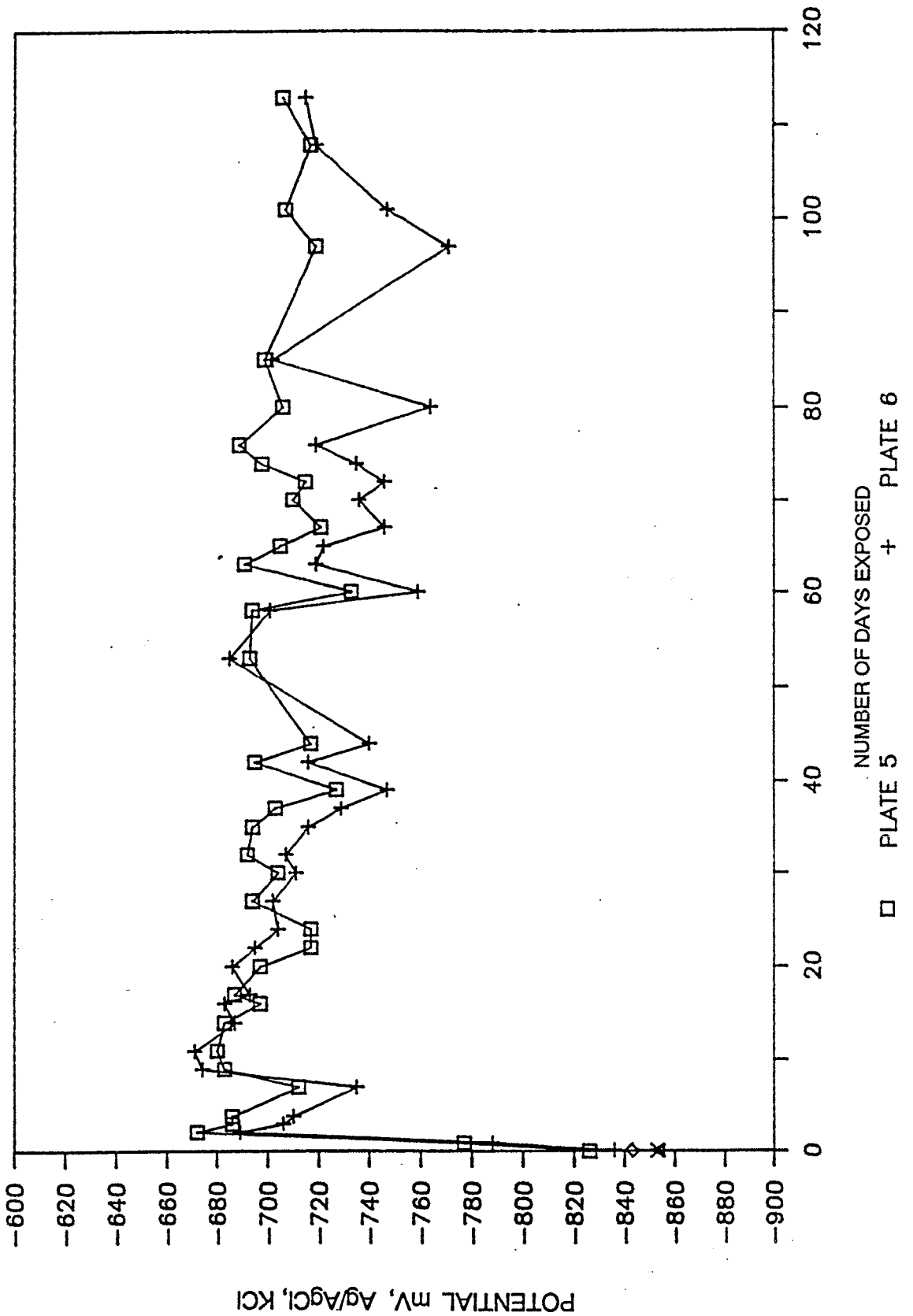


□ PLATE 3  
+ PLATE 4

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	FIGURE NO. 8

# MEASURING OF POTENTIAL, AI-NAME PLATES

WITH MACHINED DEFECT



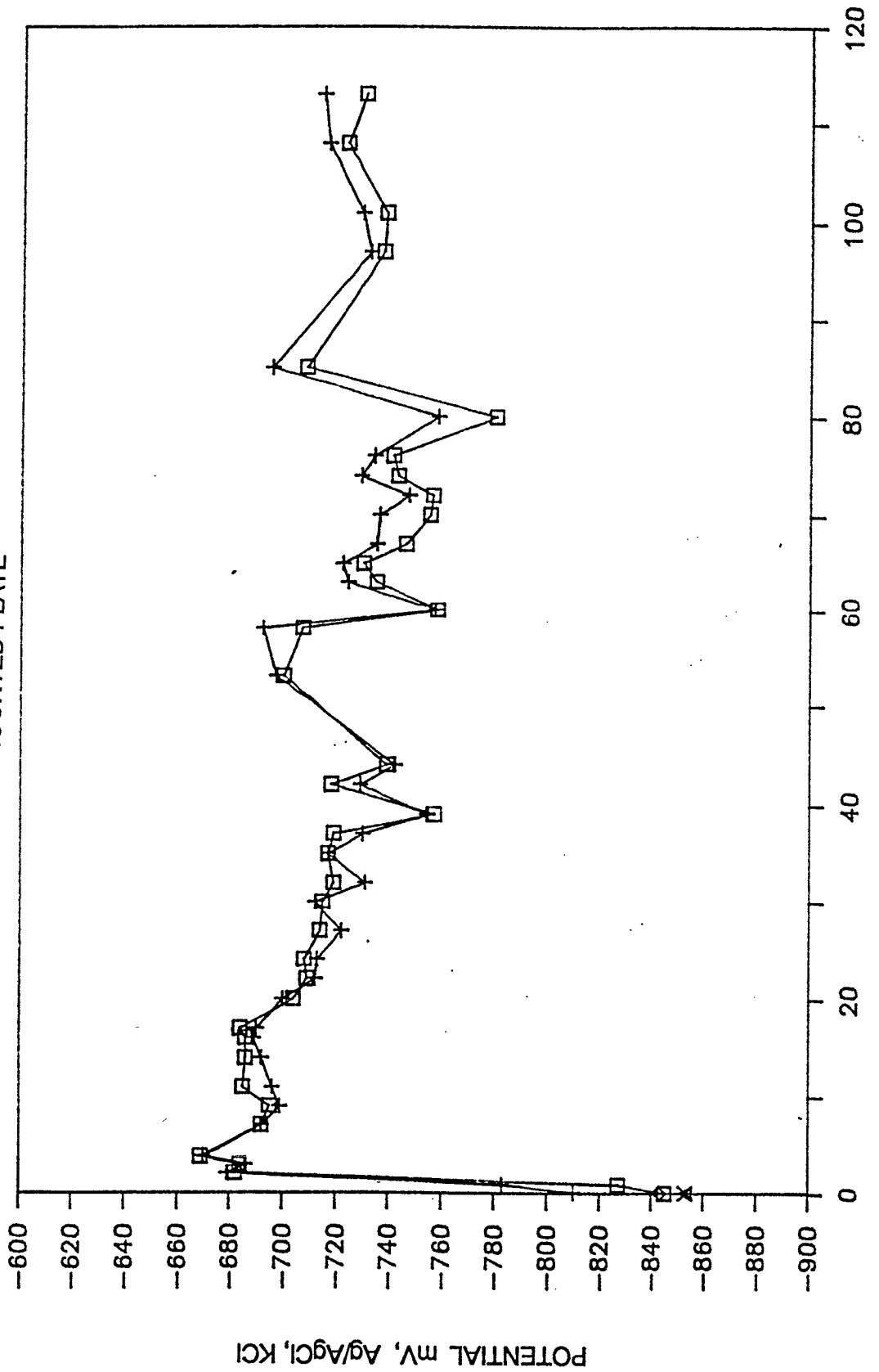
NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S

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REPORT NO.
FIGURE NO. 9



# MEASURING OF POTENTIAL, AI-NAME PLATES

MOUNTED PLATE

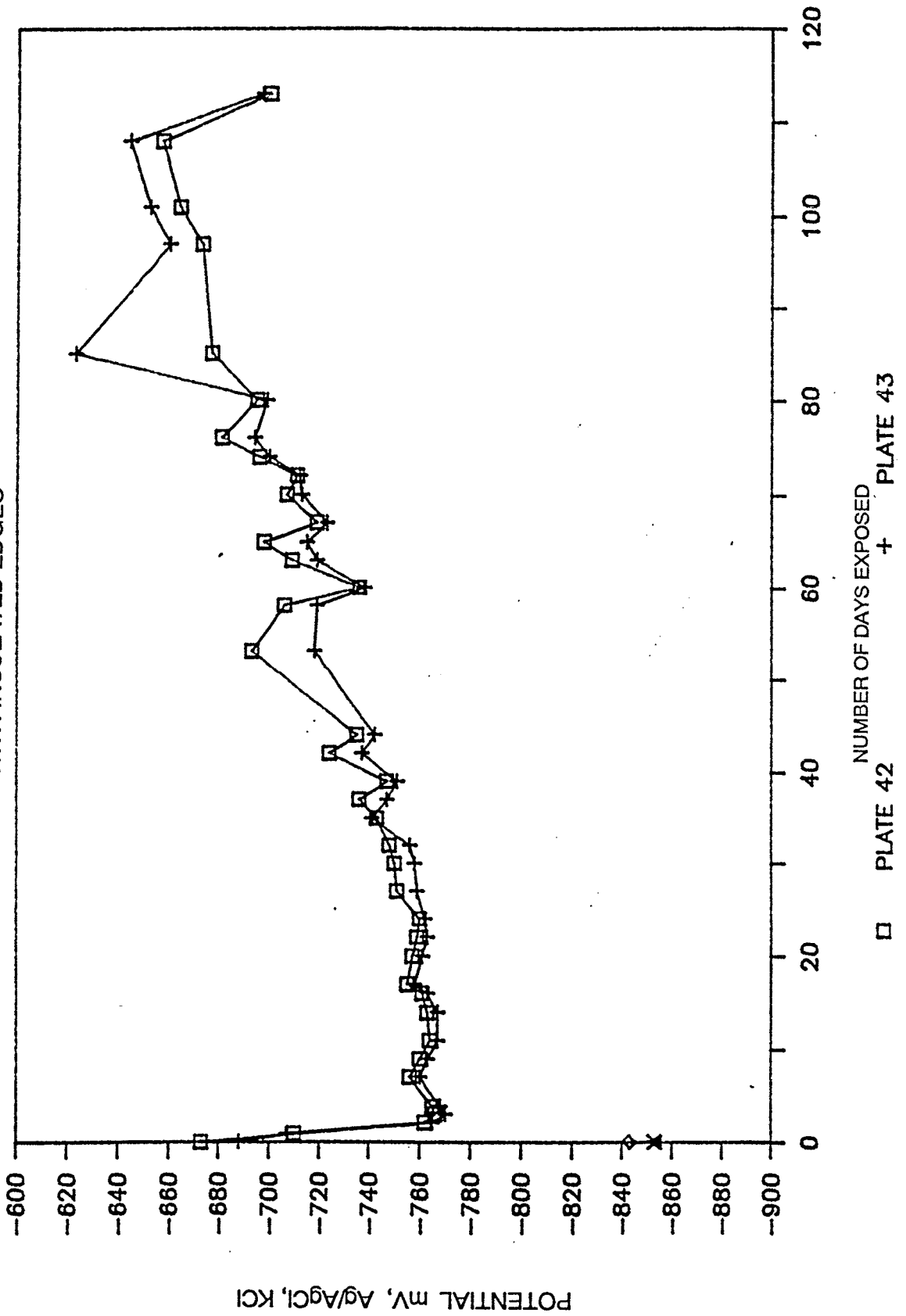


□ PLATE 7  
+ PLATE 8

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	REPORT NO.
	FIGURE NO. 10

# MEASURING OF POTENTIAL, AI-NAME PLATES

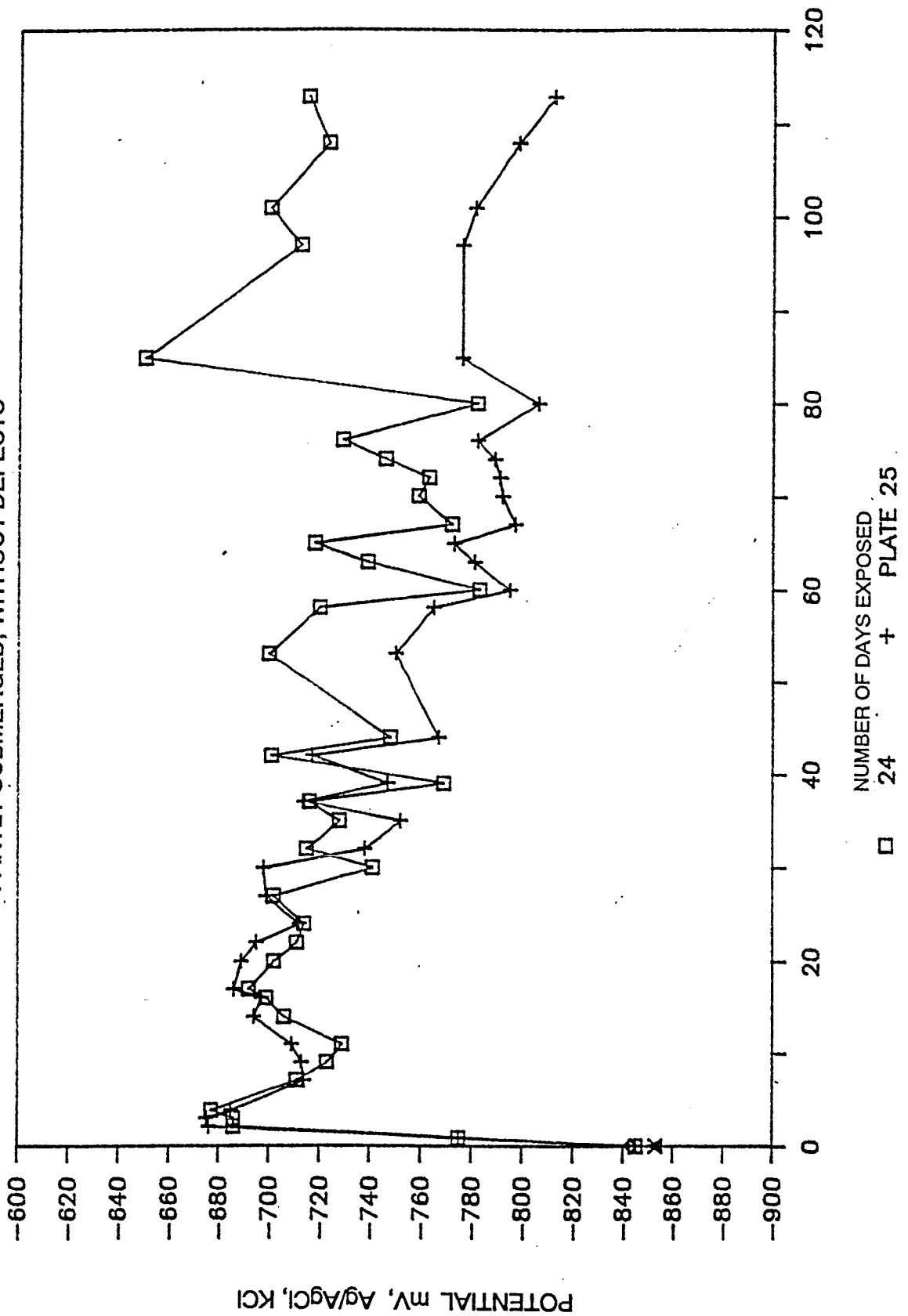
WITH INSULATED EDGES



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	FIGURE NO. 11

# MEASURING OF POTENTIAL, AI-NAME PLATES

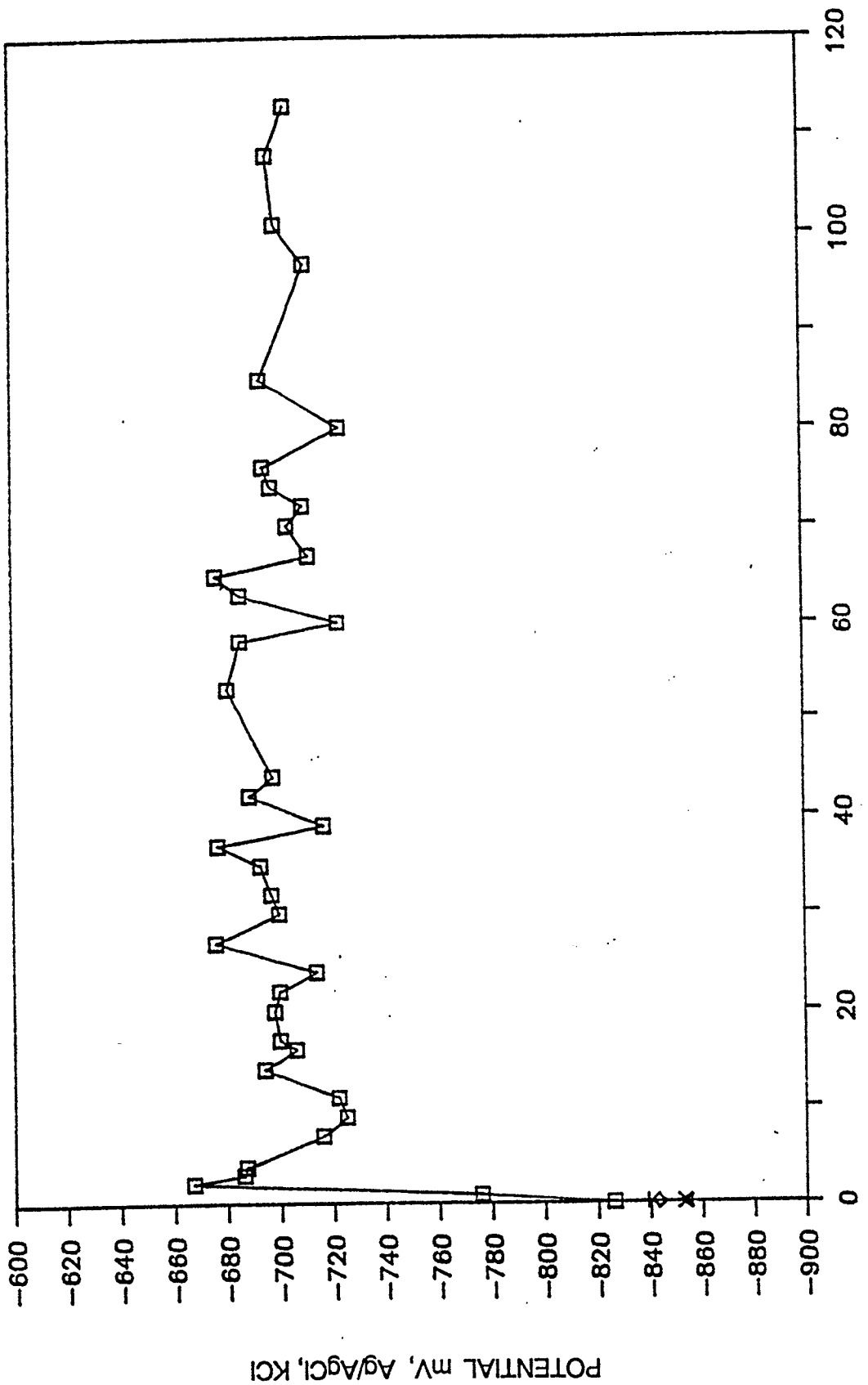
PARTLY SUBMERGED, WITHOUT DEFECTS



NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 12

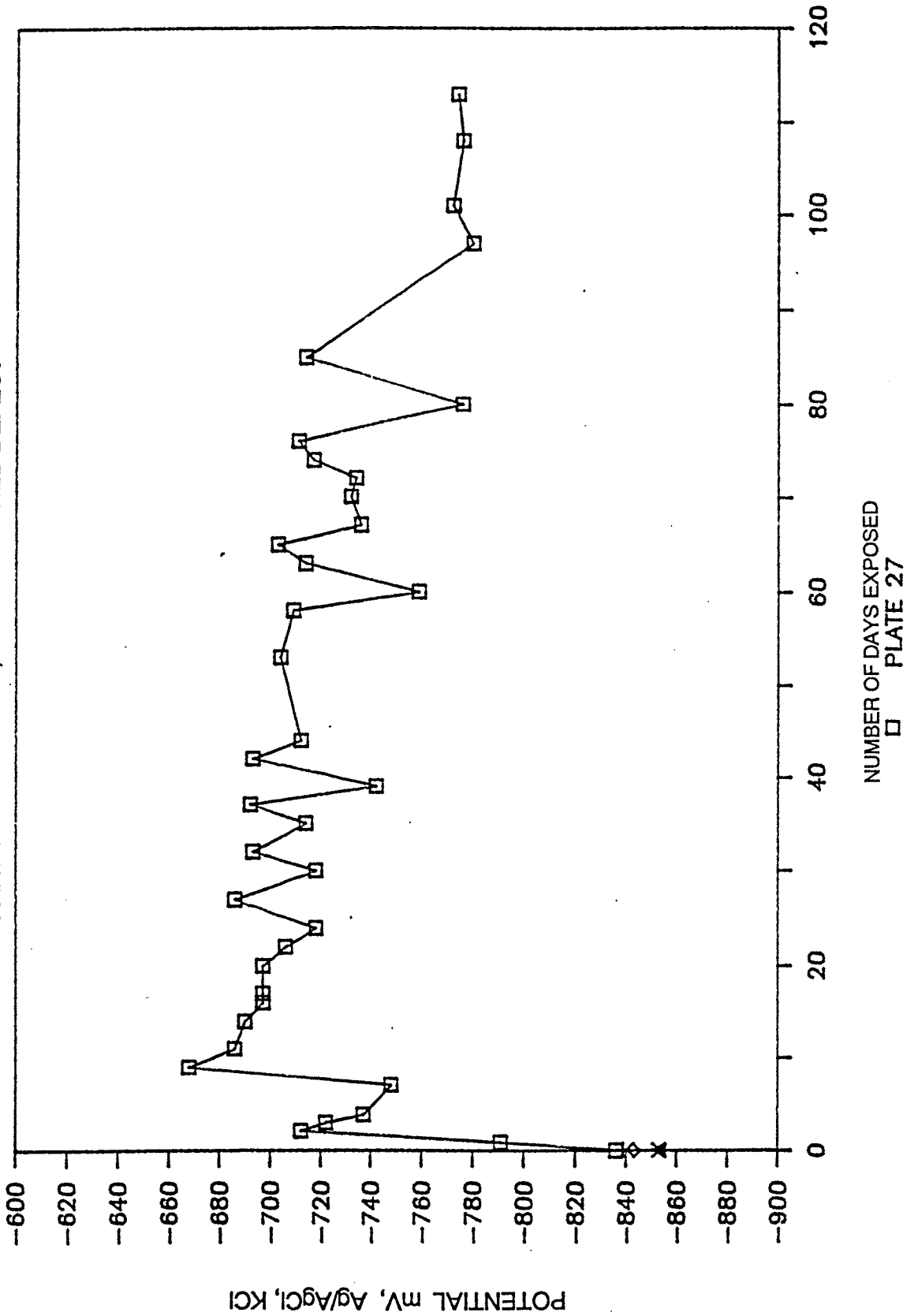
# MEASURING OF POTENTIAL, AI-NAME PLATES

PARTLY SUBMERGED, WITH SCRATCH



# MEASURING OF POTENTIAL, AI-NAME PLATES

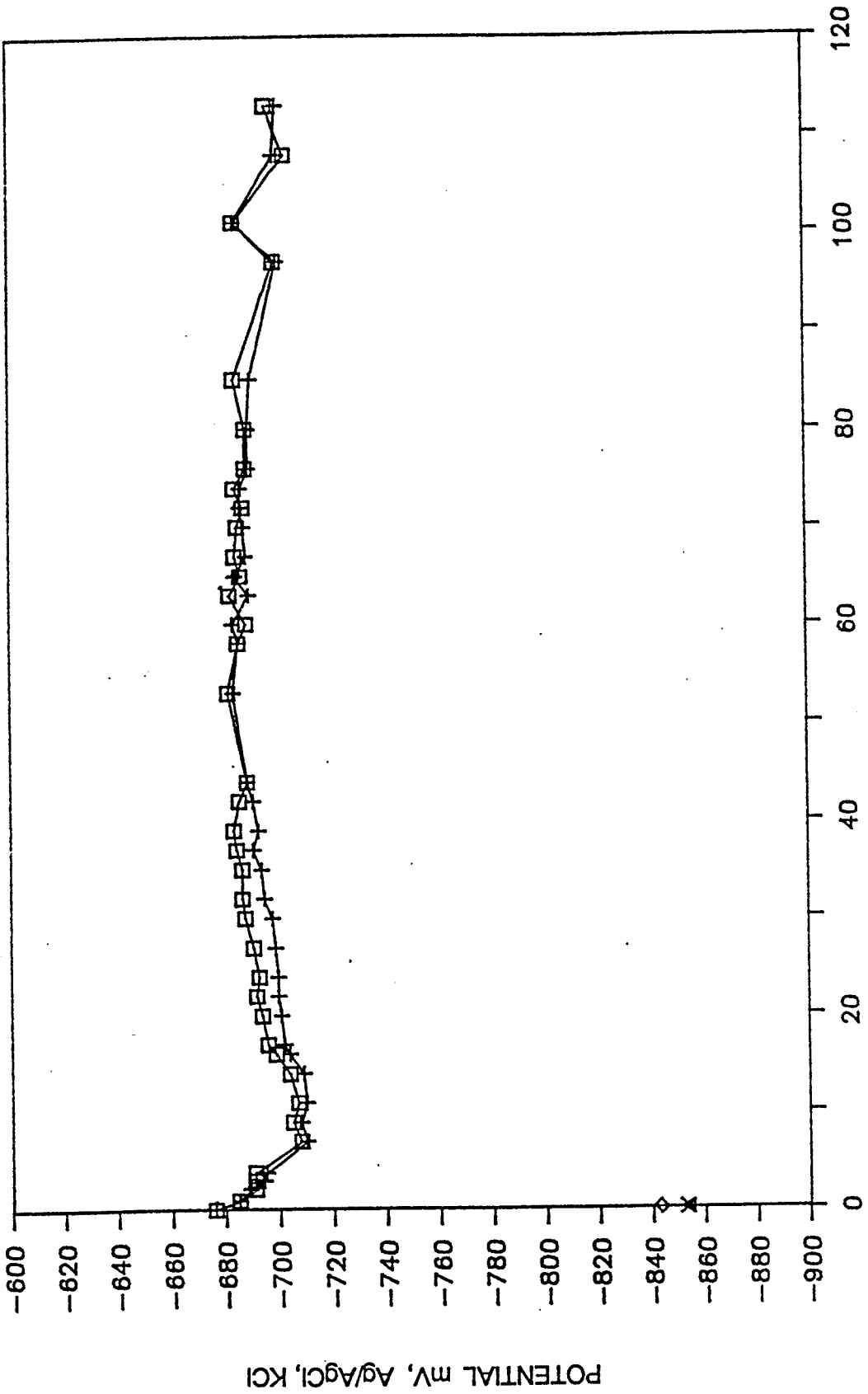
PARTLY SUBMERGED, WITH MACHINED DEFECT



NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 14

# MEASURING OF POTENTIAL, AI-NAME PLATES

GALVANICALLY COUPLED TO CARBON STEEL, WITHOUT DEFECT

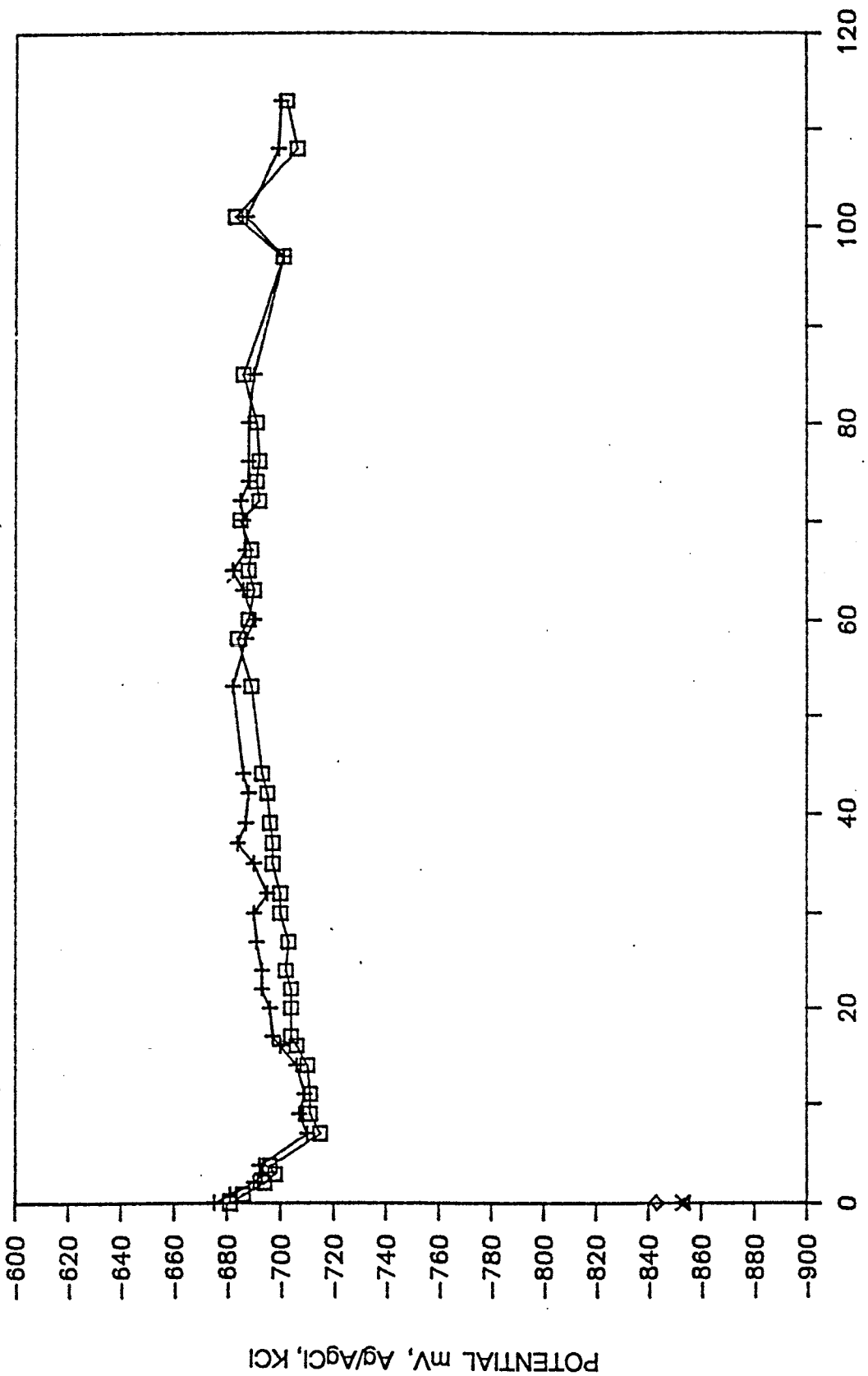


□ 9 + PLATE 10

<p>NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S</p>	PROJECT NO.
	REPORT NO.
	FIGURE NO. 15

# MEASURING OF POTENTIAL, AI-NAME PLATES

GALVANICALLY COUPLED TO CARBON STEEL, WITH SCRATCH

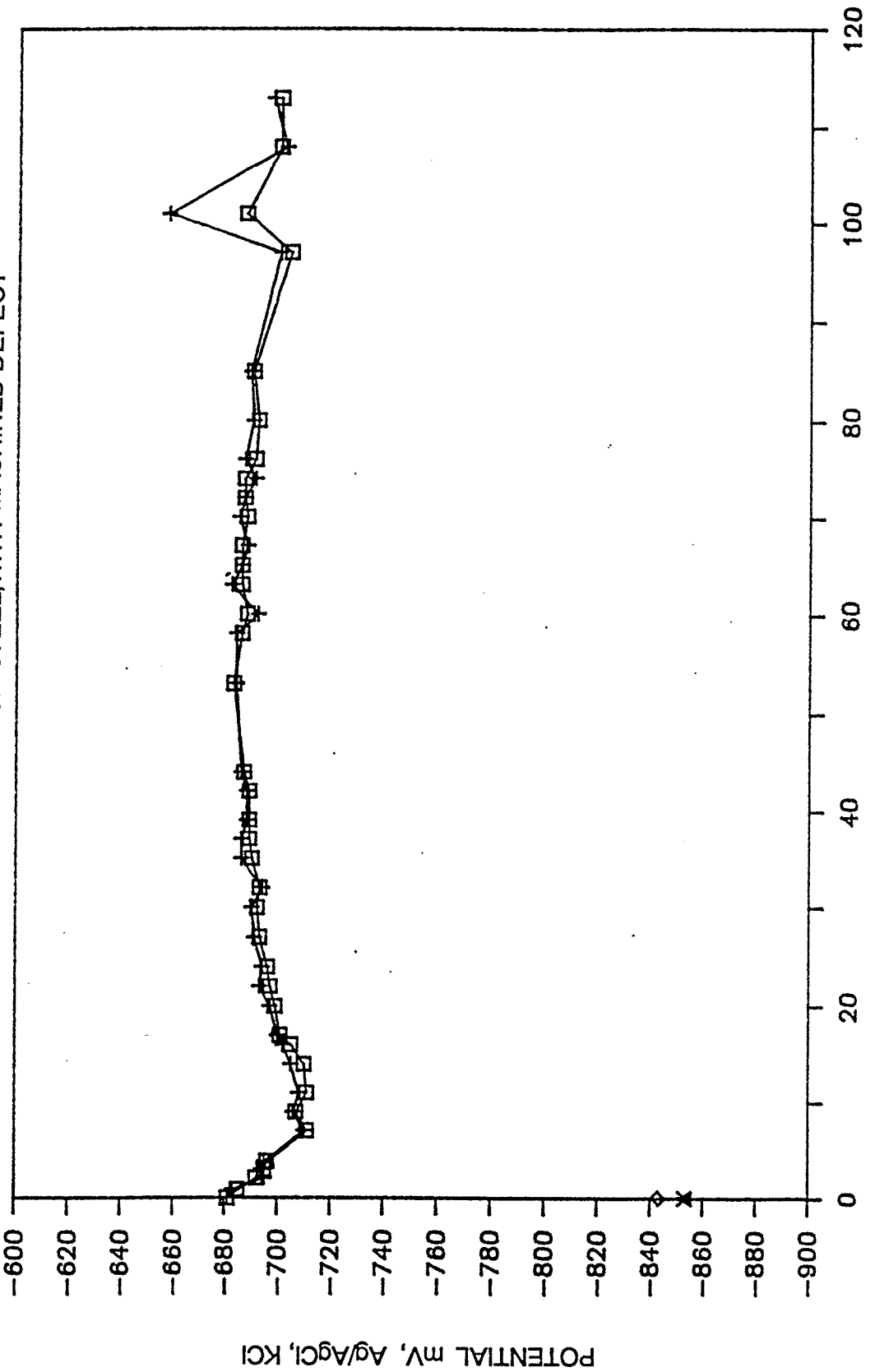


□ PLATE 11  
+ PLATE 12

NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 16

# MEASURING OF POTENTIAL, AI-NAME PLATES

GALVANICALLY COUPLED TO CARBON STEEL, WITH MACHINED DEFECT

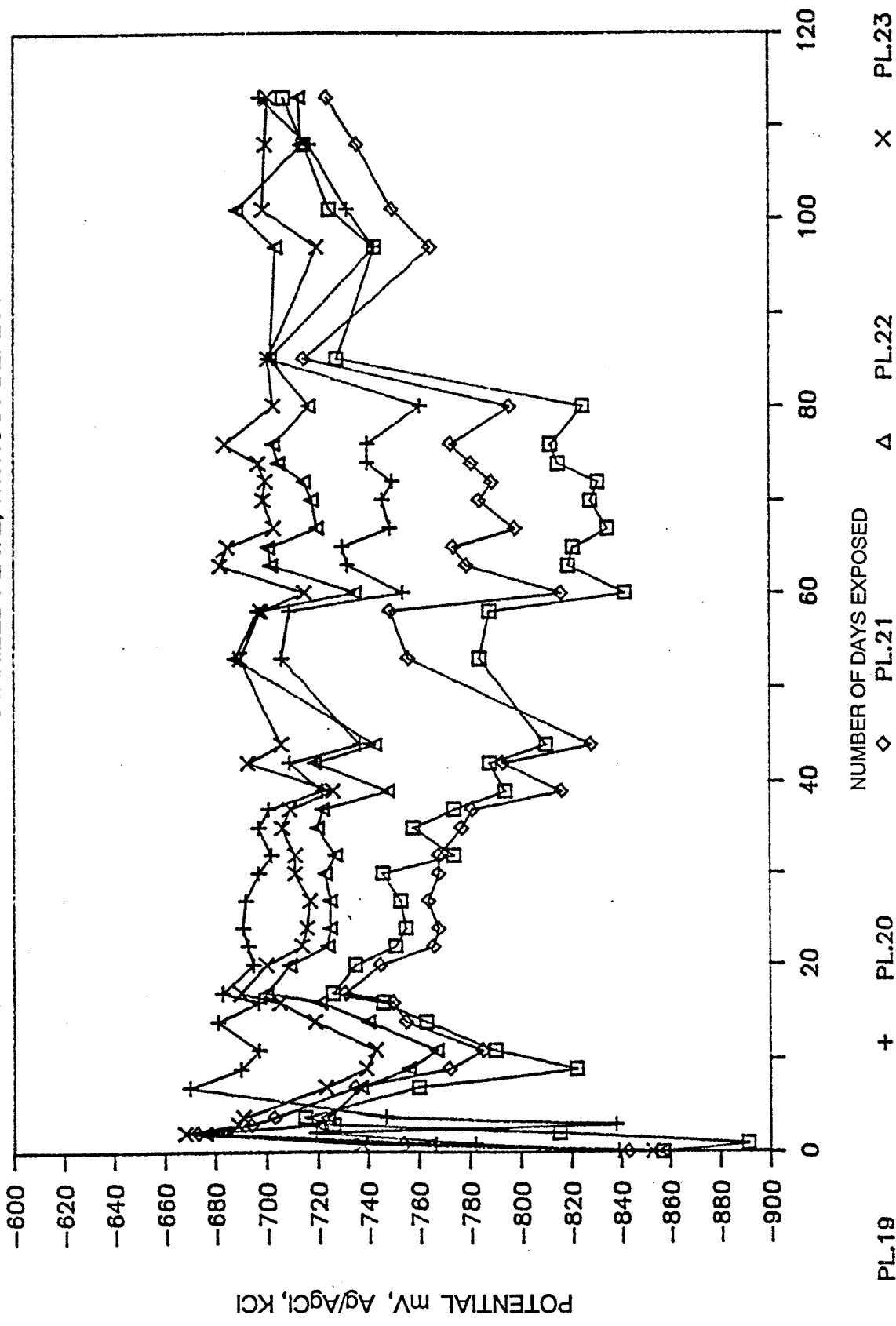


NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 17



# MEASURING OF POTENTIAL, AI-NAME PLATES

POTENTIODYNAMICALLY POLARIZED PLATE, WITHOUT DEFECT

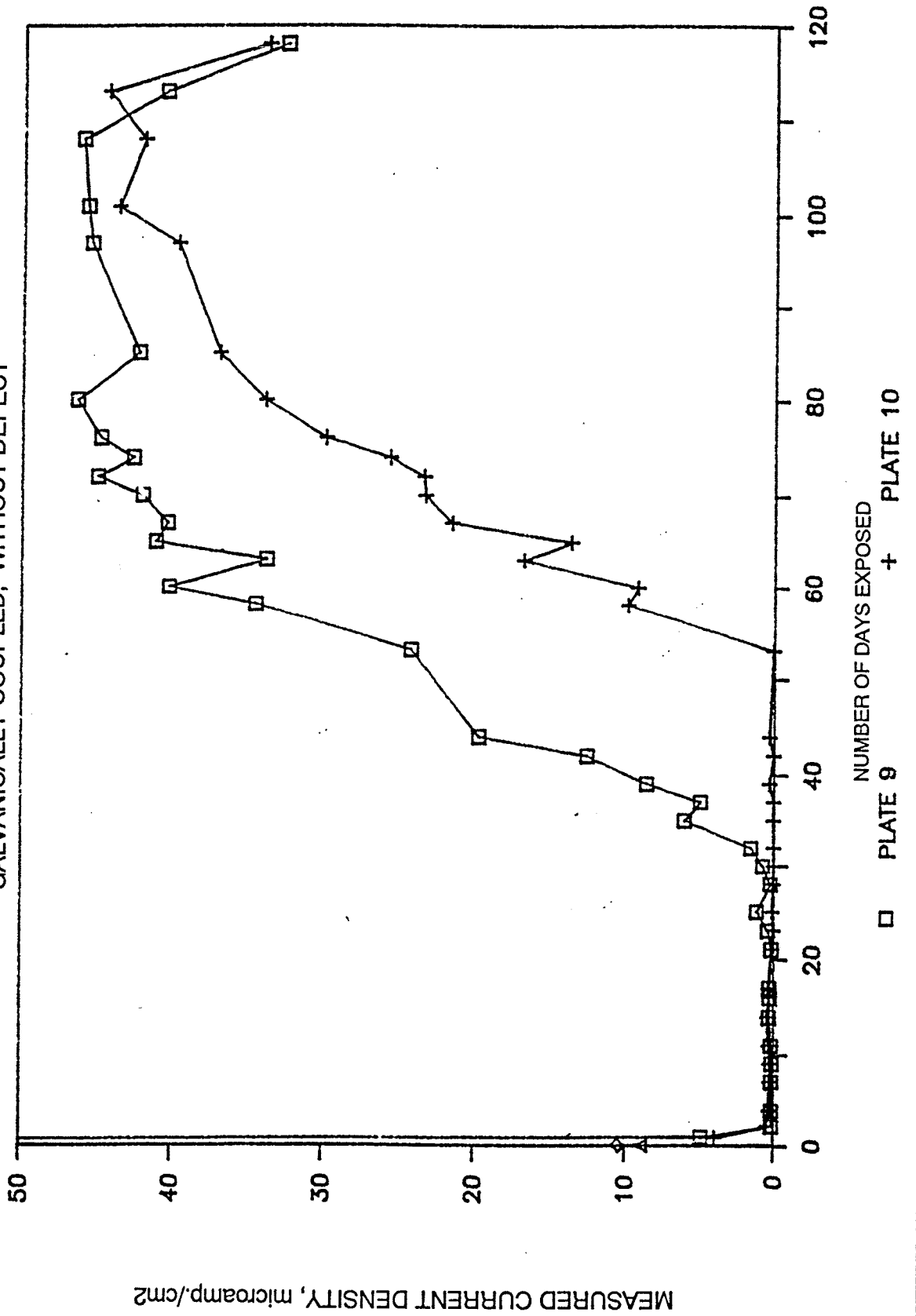


NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 18

## 6.4. Current Density Curves

# MEASURING OF CURRENT DENSITY, AI-NAME PLATES

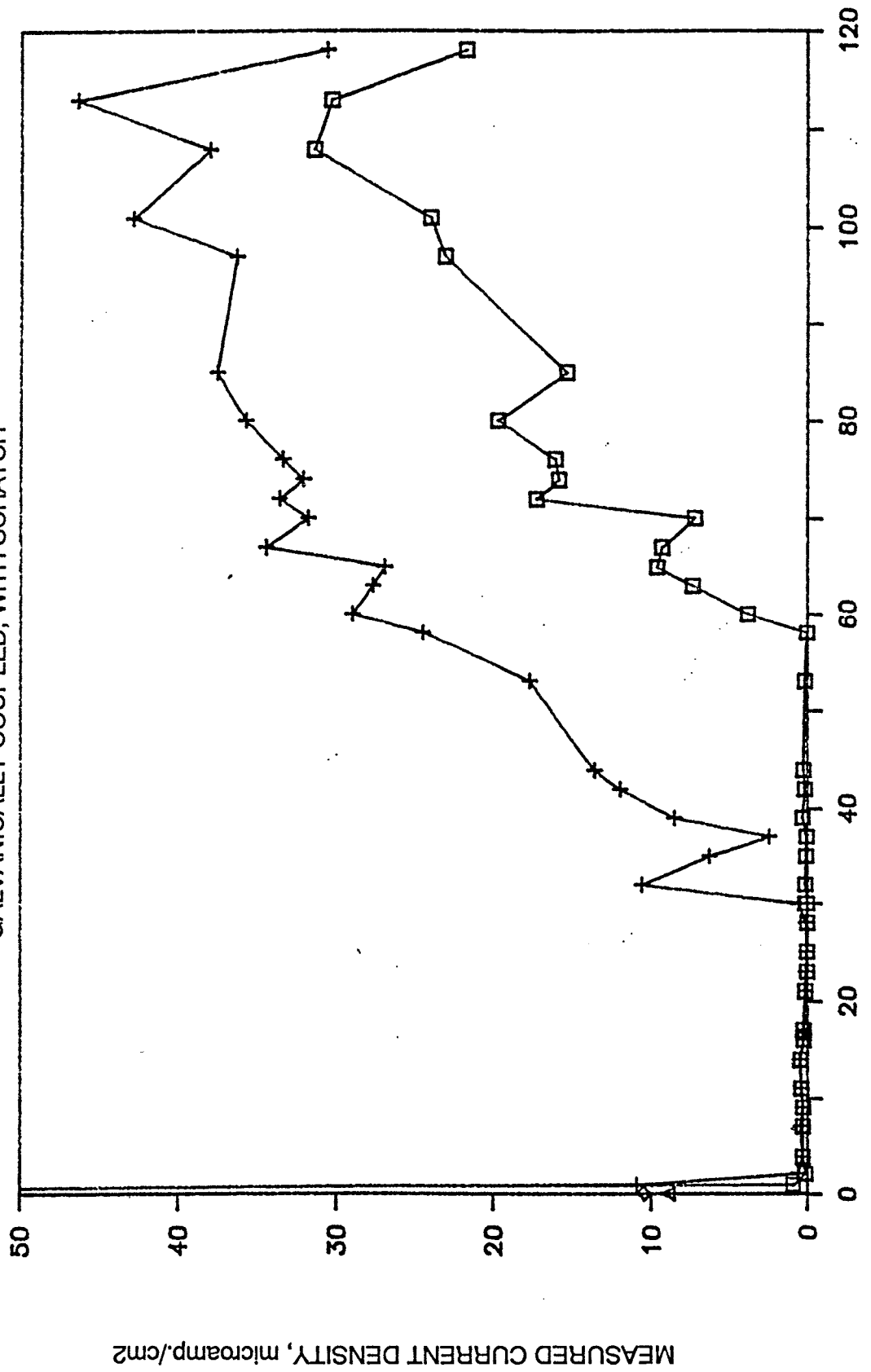
GALVANICALLY COUPLED, WITHOUT DEFECT



NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 19

# MEASURING OF CURRENT DENSITY, AI-NAME PLATES

GALVANICALLY COUPLED, WITH SCRATCH

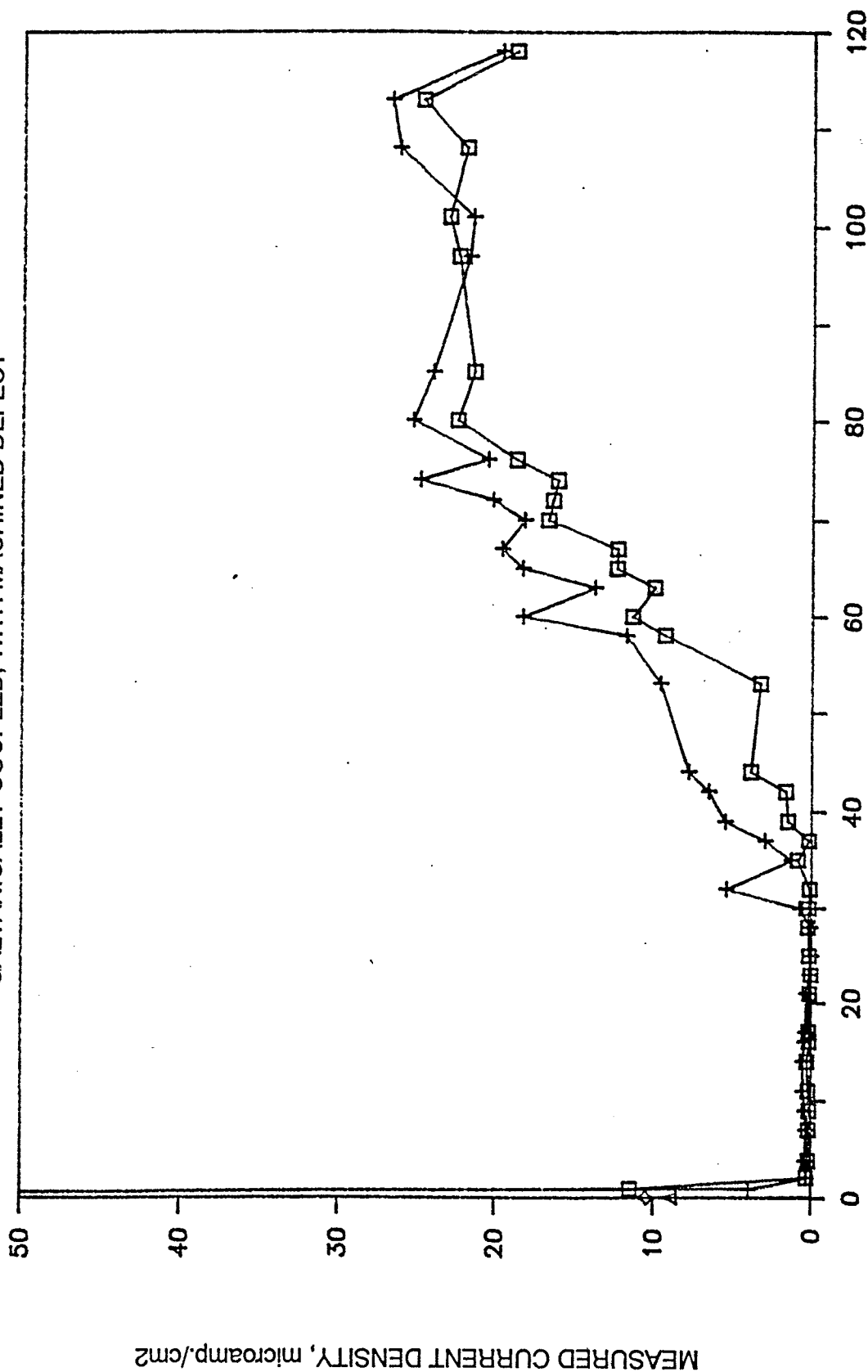


□ PLATE 11  
+ PLATE 12

NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 20

# MEASURING OF CURRENT DENSITY, AI-NAME PLATES

GALVANICALLY COUPLED, WITH MACHINED DEFECT

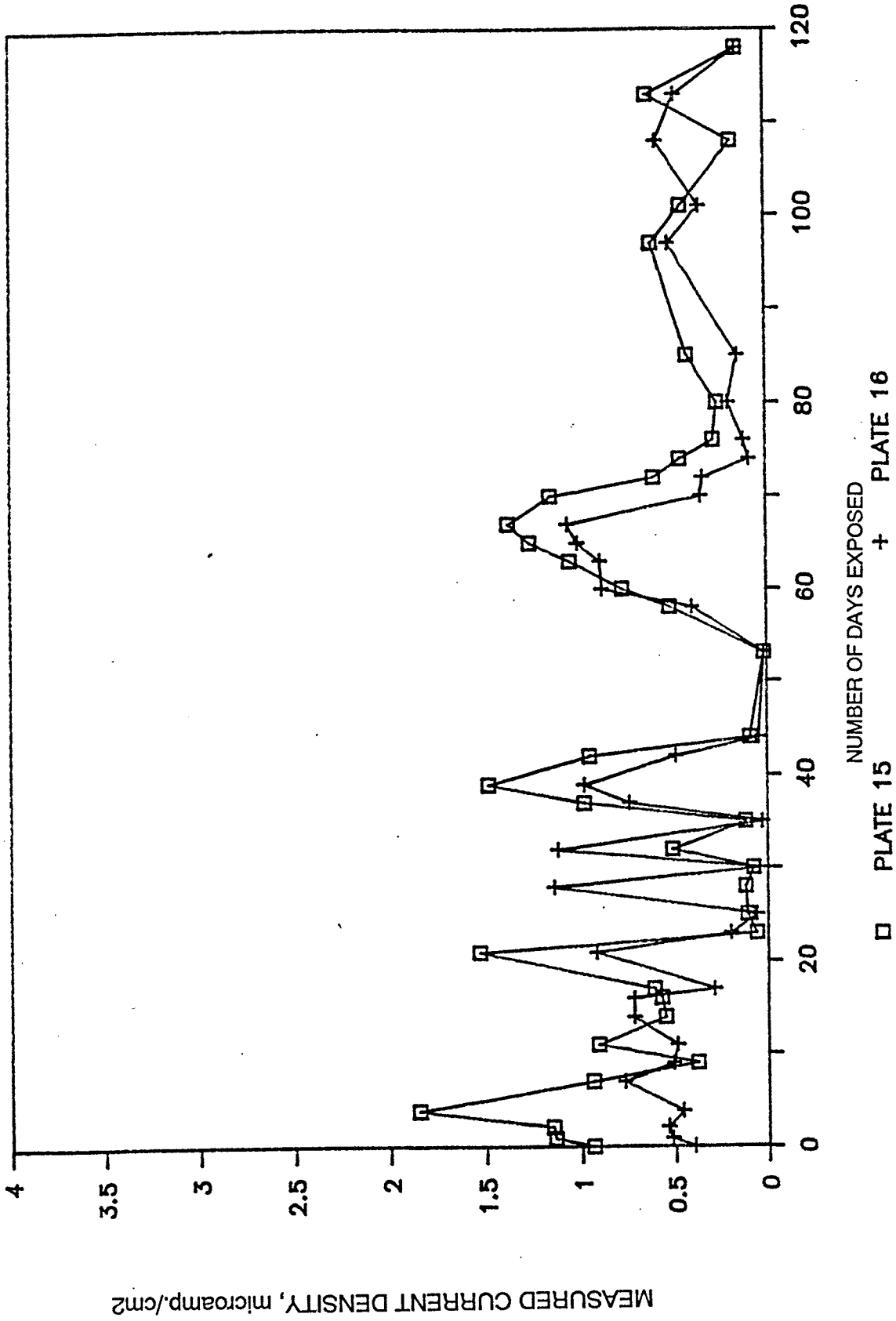


□ PLATE 13  
+ PLATE 14

NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 21

# MEASURING OF CURRENT DENSITY, AI-NAME PLATES

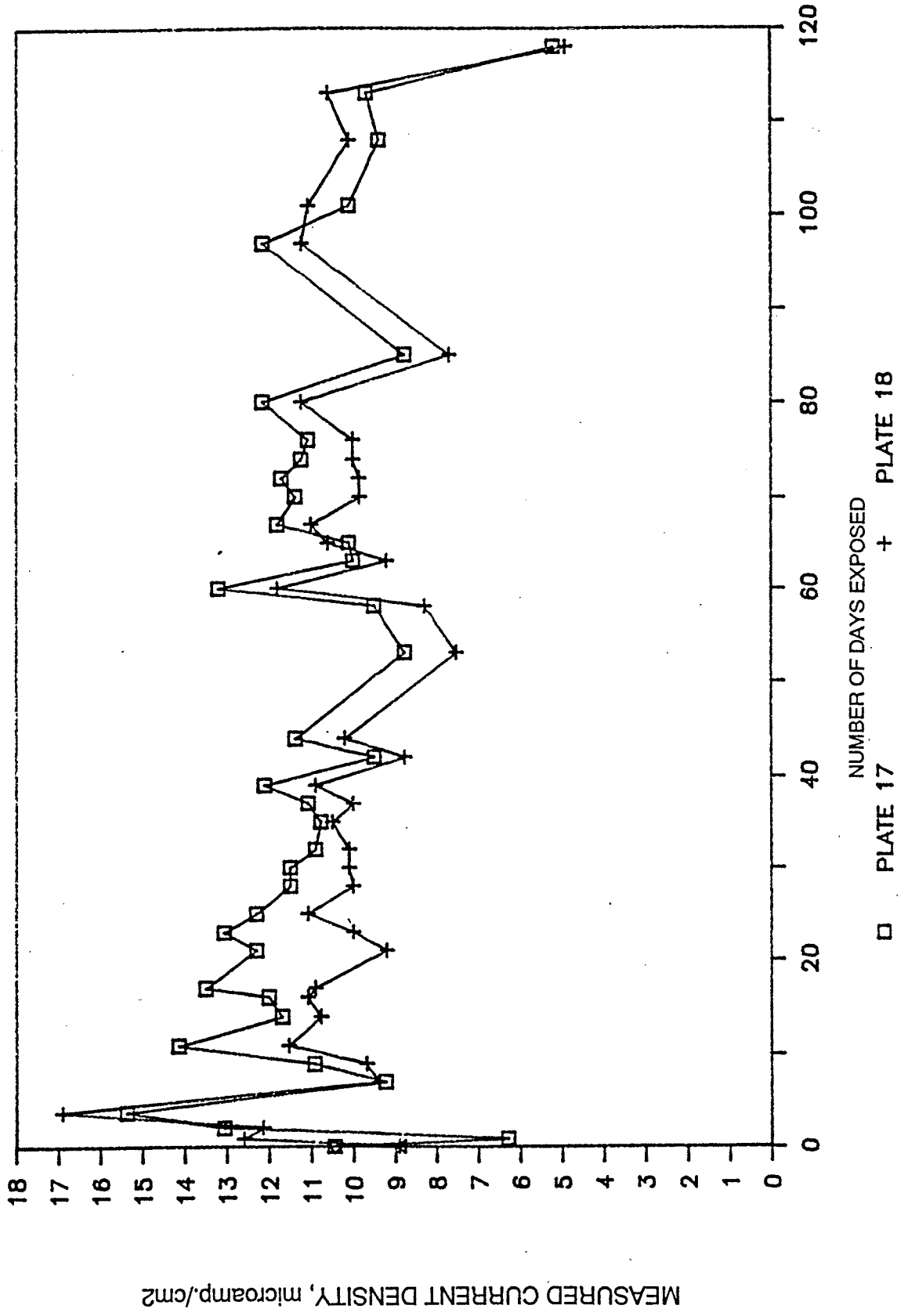
POLARIZED: -800 mV, Ag/AgCl, KCl, WITHOUT DEFECT



NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 22

# MEASURING OF CURRENT DENSITY, AI-NAME PLATES

POLARIZED: -1050 mV, Ag/AgCl, KCl, WITHOUT DEFECT



NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 23

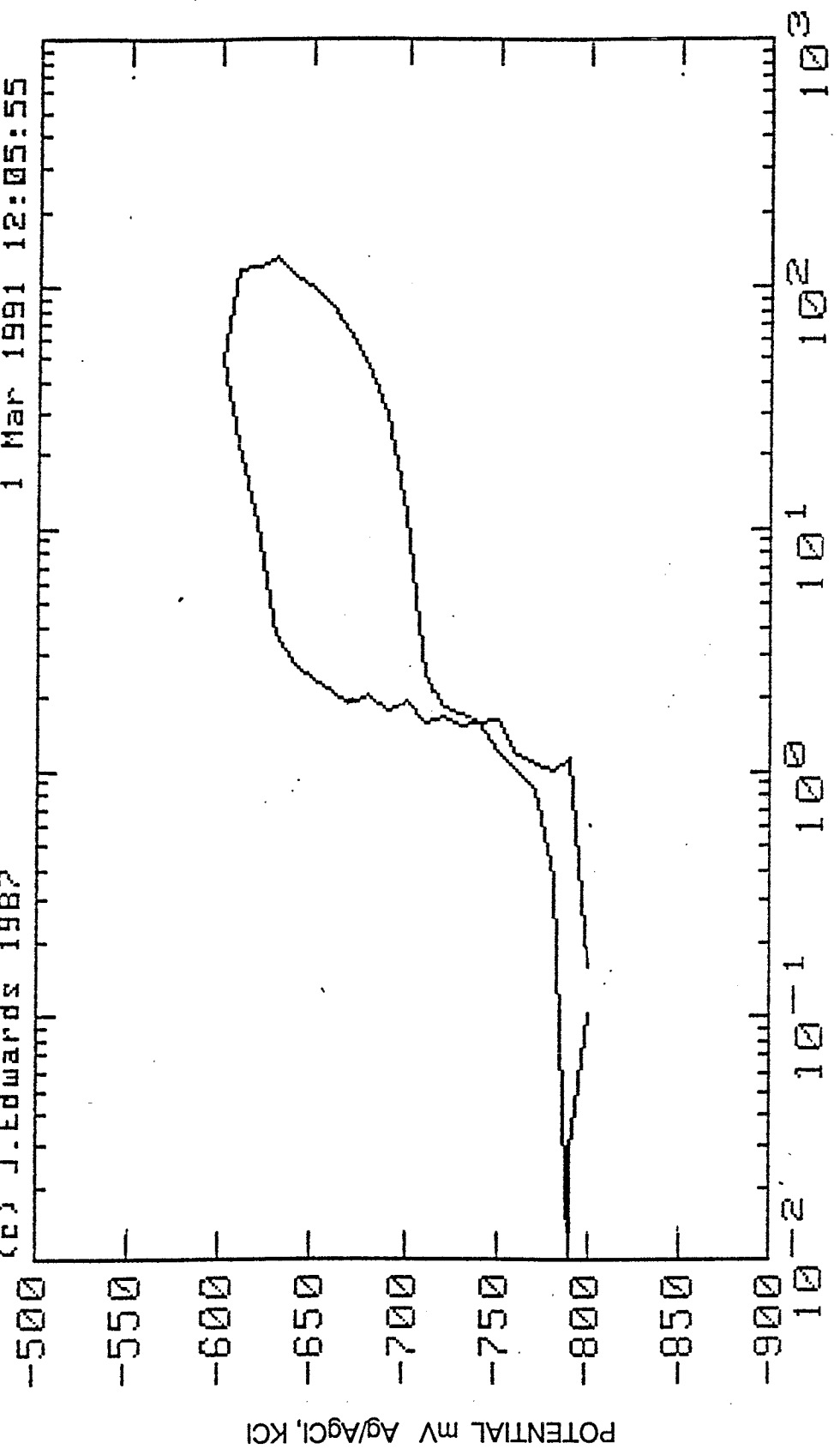
## 6.5. Polarization Curves



# ANODIC POLARIZATION CURVE, PLATE 19

(c) J. Edwards 1987

1 Mar 1991 12:05:55

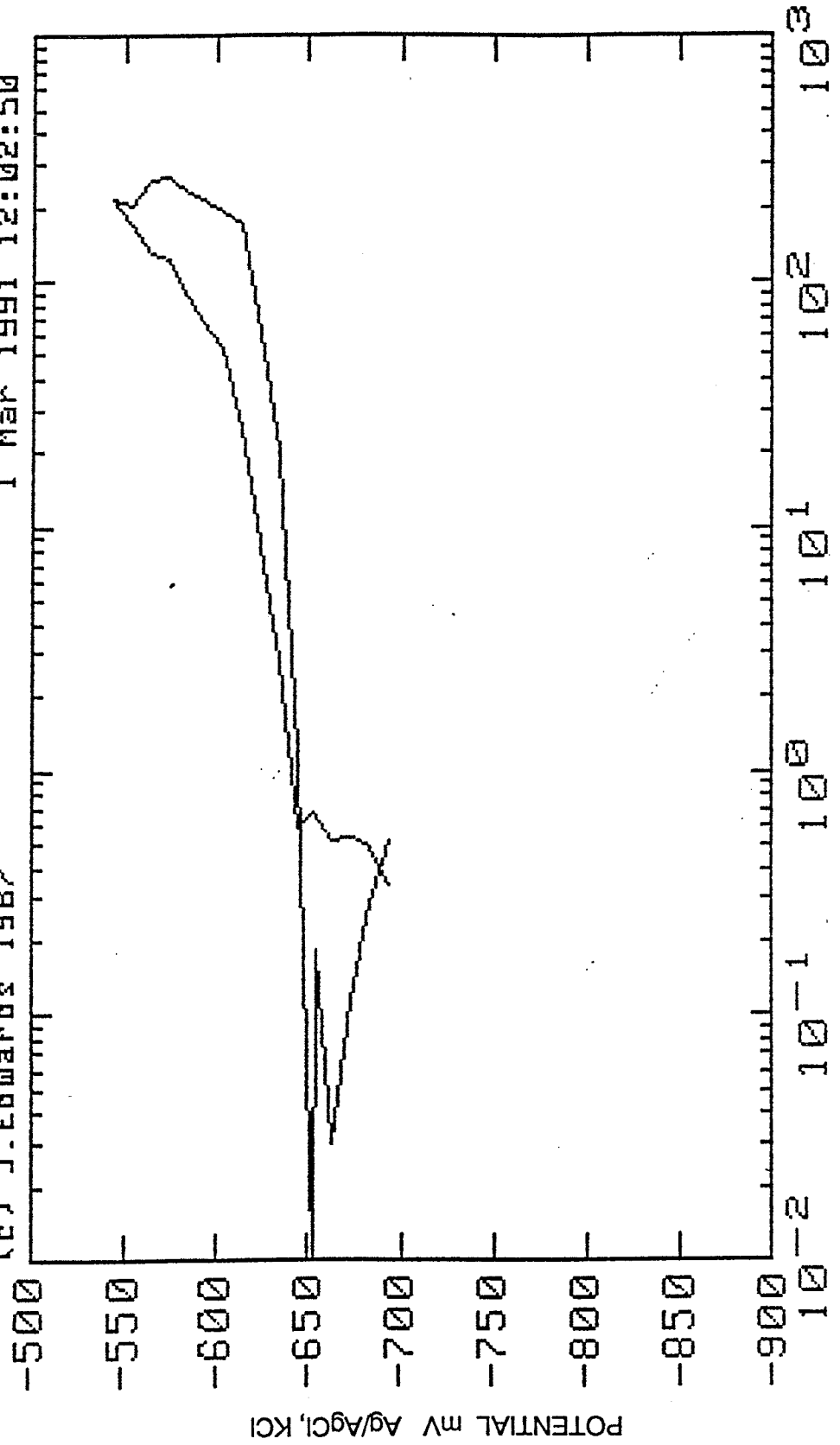


NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 24

# ANODIC POLARIZATION CURVE, PLATE 22

(c) J. Edwards 1987

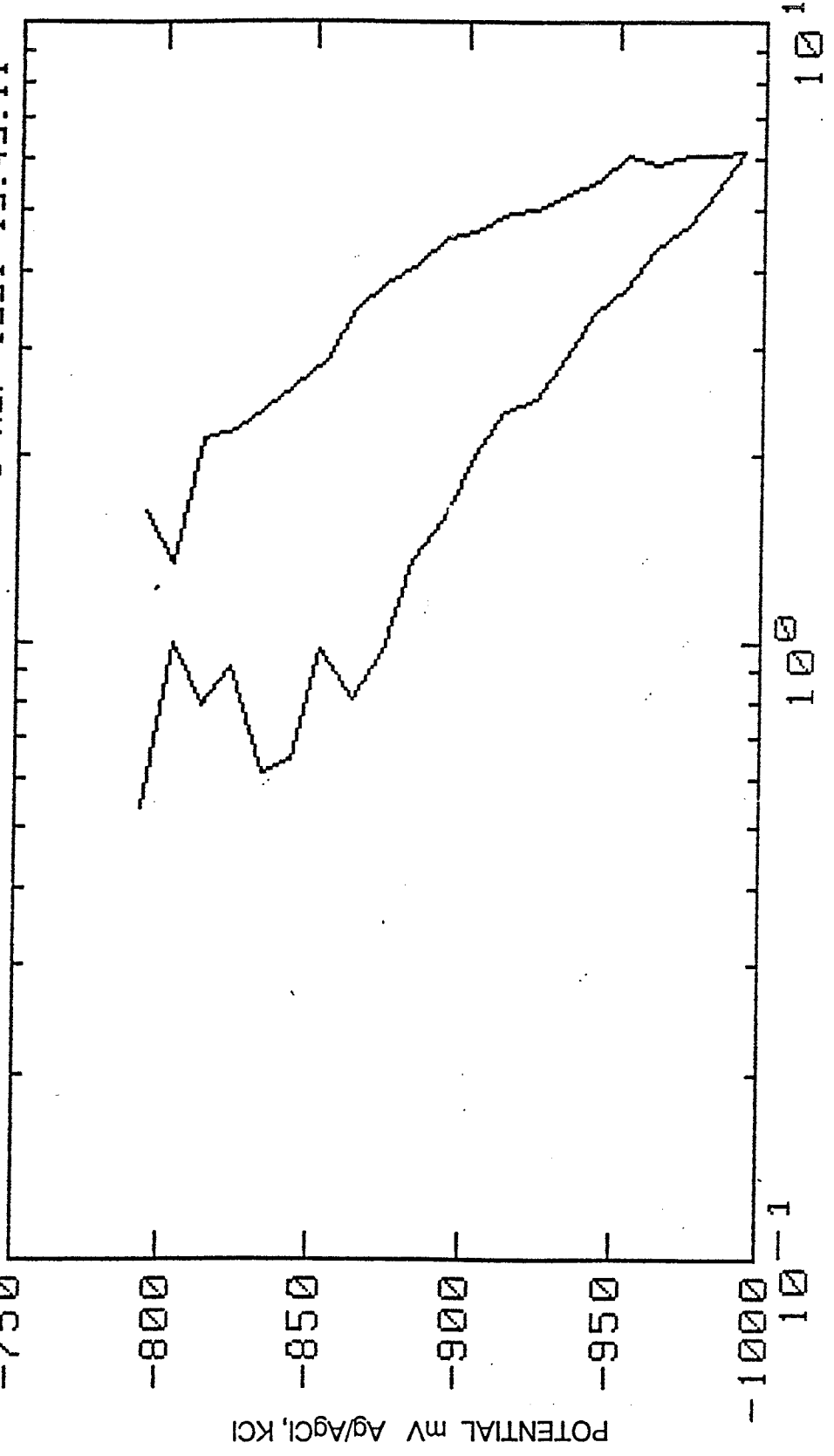
1 Mar 1991 12:02:50



# CATHODIC POLARIZATION CURVE, PLATE 21

(c) J. Edwards 1987

1 Mar 1991 15:45:11

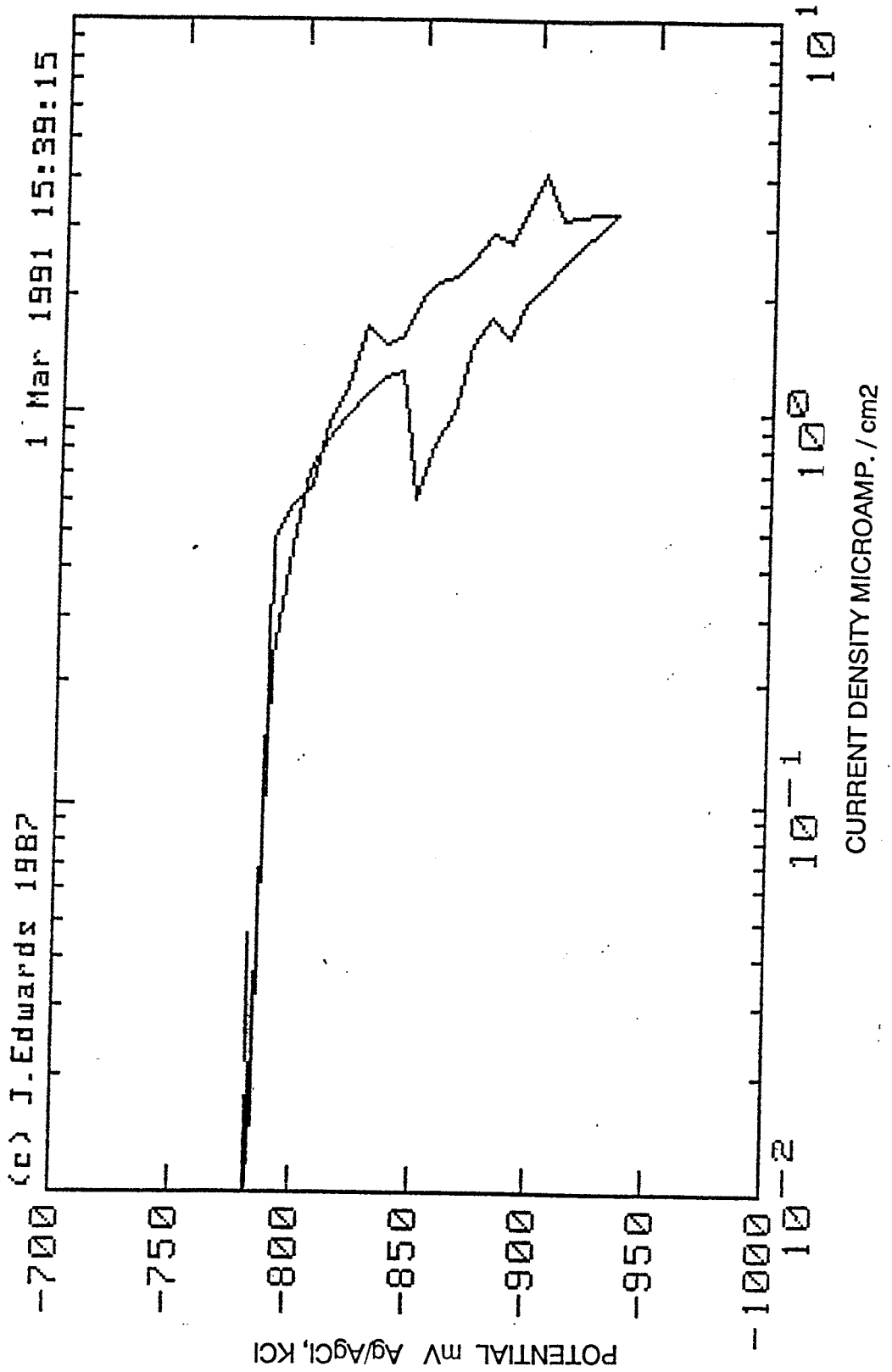


NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 26

# CATHODIC POLARIZATION CURVE, PLATE 23

(c) J. Edwards 1987

1 Mar 1991 15:39:15



NORWEGIAN MARINE TECHNOLOGY RESEARCH INSTITUTE A/S	PROJECT NO.
	REPORT NO.
	FIGURE NO. 27

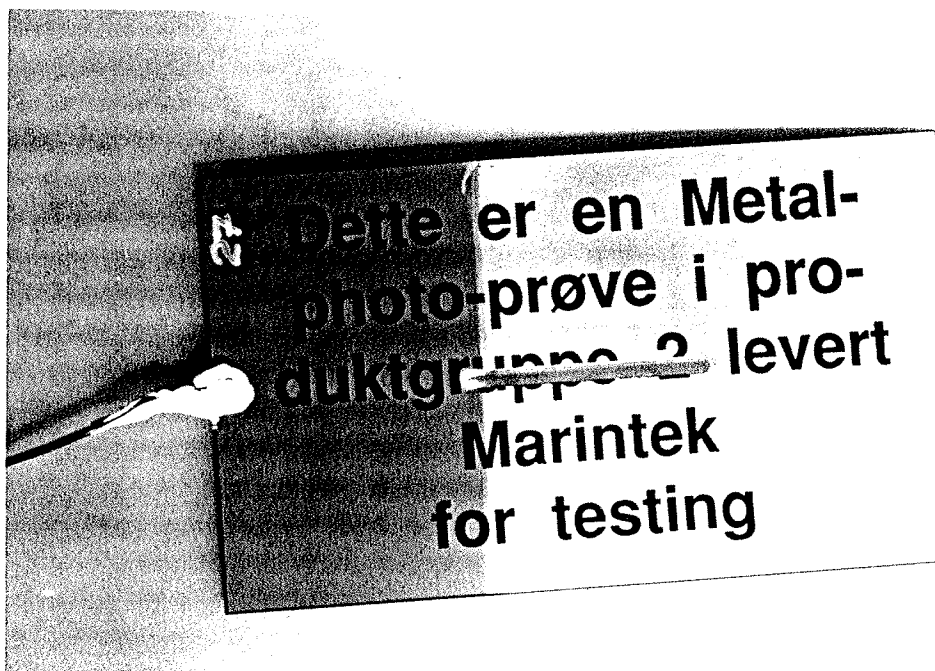
6.6. Table showing loss of weight for Aluminium signs

Plate no	Environment	Defect	Galvanically coupled	Polarization	Weight before exposure (g)	Weight after exposure (g)	Loss of weight (g)	
1	Natural sea water	None	No		72.5392	72.32	0.219	
2		None	No		74.4263	74.20	0.226	
3		Scratch	No		74.6420	74.44	0.202	
4		Scratch	No		73.8827	73.63	0.2527	
5		Machined	No		73.8365	73.61	0.2265	
6		Machined	No		73.5581	73.29	0.2681	
7**		None	No		76.2298	74.85	1.380	
8**		None	No		76.2146	74.75	1.465	
9		None	Yes		74.0539	73.63	0.4239	
10		None	Yes		73.6823	73.35	0.332	
11		Scratch	Yes		74.7250	74.48	0.245	
12		Scratch	Yes		73.5501	73.16	0.39	
13		Machined	Yes		74.1910	73.85	0.341	
14		Machined	Yes		74.6098	74.24	0.369	
15		None	No		74.1829	73.93	0.253	
16		None	No		-800 a	73.7761	73.53	0.246
17		None	No		-800 a	73.4014	73.14	0.261
18		None	No		-1050 b	72.3763	72.12	0.256
19		None	No		-1050 b	72.7507	72.39	0.361
20		None	No		An c	71.6148	71.32	0.2948
21		None	No		An c	73.9428	73.61	0.3328
22		None	No		Cath d	74.3060	74.02	0.286
23		None	No		An c	74.9178	74.65	0.2678
24		None	No		Cath d	73.9868	73.85	0.136
25		None	No			74.2089	74.04	0.169
26		Scratch	No			74.6194	74.45	0.169
27		Machined	No			74.0735	73.89	0.184
42*	None	No			74.6530	74.40	0.253	
43*	None	No			74.5680	74.37	0.198	
28	Salt spray chamber	None	No		55.0590	55.075	0	
29		None	No		54.9434	54.95	0	
30		Scratch	No		58.3938	58.400	0	
31		Scratch	No		58.6337	58.64	0	
32		Machined	No		57.2515	57.27	0	
33		Machined	No		57.5170	57.53	0	
34**		None	No		57.4688	56.14	1.329	
35**		None	No		57.4370	56.22	1.221	
36		None	Yes		65.0312	62.32	2.711	
37		None	Yes		65.0935	61.675	3.418	
38		Scratch	Yes		65.1611	60.01	5.151	
39		Scratch	Yes		65.9328	63.31	2.623	
40		Machined	Yes		65.4550	62.82	2.635	
41		Machined	Yes		65.5558	61.88	3.676	

\* = insulated edges  
\*\* = mounted plate  
a = continuous -800 mV.  
b = continuous -1050 mV.  
c = anodic polarization  
d = cathodic polarization

- /1/ Bardal, E. "Korrosjon og korrosjonsvern", Tapir Forlag 1985
- /2/ Drugli, J., Bardal E. "Rustrie stål, process-og sjøvannssystem. Kompendium for endagsseminar", SINTEF rapport nr STF16 A 89045
- /3/ Reklamebrosjyre ang Metalphoto fra Åge Børresen Stempelfabrikk A/S

### 6.7. Photographs



Photograph 3: Plate No 27 with a ground defect, partly submerged in sea water. Corrosion conditions along the edges and in the ground defect are representative for all plates that were exposed to sea water and that were not coupled steel.



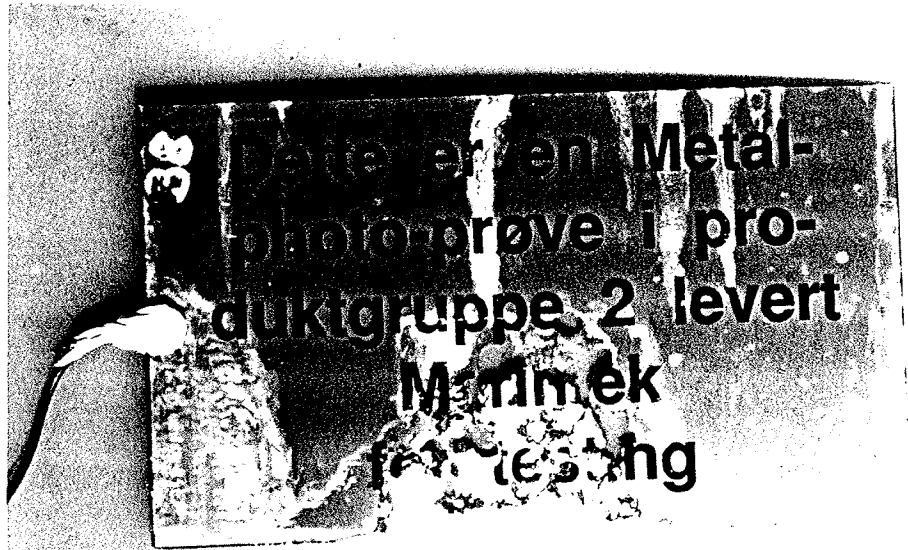
Photograph 4: Plate No 12, completely submerged in sea water, galvanically coupled to steel.



Photograph 5: Plate No 33 with ground defect, exposed in salt spray chamber.



Photograph 6: Plate No 35, exposed in salt spray chamber; mounted plate.



Photograph 7: Plate No 38, exposed in salt spray chamber; galvanically coupled to steel.



## Definitions:

<u>Anodic over voltage:</u>	Potential difference between free corrosion potential and actual potential.
<u>Anodic polarization:</u>	Polarization in positive direction.
<u>Cathodic polarization:</u>	Polarization in negative direction.
<u>Cathodic sweep:</u>	As described under hysteresis but in negative direction.
<u>Corrosion:</u>	Reaction between a metallic material and the surrounding medium.
<u>Current density:</u>	Current per square unit.
<u>Electrode potential:</u>	Potential level of a metal sample.
<u>Free exposure:</u>	Exposure without any electrochemical impact.
<u>Galvanic connection:</u>	Two metals in metallic contact submerged in an electrolyte.
<u>Galvanic corrosion:</u>	See section 3.1.
<u>Galvanic potential:</u>	Potential of the galvanically coupled sample.
<u>Galvanic series:</u>	Ranking of metals according to their potential level in a given environment.
<u>Hydrogen development reaction:</u>	Cathodic reaction. $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$
<u>Hysteresis:</u>	A diagram showing the correlation between the impressed potential and the resulting current. The hysteresis can be cathodic as well as anodic although a cathodic hysteresis is unlikely with aluminium.
<u>Limiting current:</u>	A diffusion controlled corrosion reaction.
<u>mV:</u>	Unit for measuring of milli Volts.

<u>Oxygen reduction:</u>	Cathodic reaction taking place on the cathode. $O_2 + 2H_2 + 4e = 4OH$ .
<u>Passivated metals:</u>	Metals on which a passive layer/film is formed artificially on the surface.
<u>Pitting corrosion:</u>	See section 3.1.
<u>Pitting corrosion potential:</u>	See section 3.1.
<u>Polarization:</u>	A voltage (or current) is used to force the sample away from the free corrosion potential.
<u>Polarized to -800 mV Ag/AgCl, KCl:</u>	Potential level of -800 mV vs. a reference electrode called silver/silver chloride, saturated KCl potassium chloride.
<u>Polarized to -1050 mV Ag/AgCl, KCl:</u>	Potential level of -1050 mV vs. a reference electrode called silver/silver chloride, saturated potassium chloride.
<u>Potential:</u>	The voltage level of a metal.
<u>Potential development:</u>	Development of the potential with exposure time.
<u>Potentiostat:</u>	Electrochemical measuring instrument used to apply a preset potential.
<u>Repassivation potential:</u>	See section 3.1.
<u>Sacrificial anode:</u>	A metal developed with a very low corrosion potential. The sacrificial anode will corrode and impress electrons into the metal to be protected.
<u>Salt spray chamber:</u>	Test chamber used for accelerated tests of components to be used in marine atmospheres. A 5% salt solution is injected along with air to form a salt spray according to given standards.

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