UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

20295

RESTRICTED

MAY ' 1993
ORIGINAL – ENGLISH

ALUMINIUM ELECTROLYSIS PROCESS EVALUATION AND CONTROL

TECHNICAL REPORT

ON THE EXPERT MISSION CARRIED OUT IN INDIA
FROM 1st FEBBRUARY TO 24th MAY '1993
DP/ IND/88/015/11–05

PREPARED BY : DR. J. HORVATH

BACKSTOPPING OFFICER : DR. T. GROF DIO /T/MET/

UNITED NATION'S INDUSTRIAL DEVELOPMENT ORGANISATION.

ABSTRACT

The present report on "Aluminium Electrolysis Process Evaluation and Control" is a result of the expert mission DP/IND/88/015/11-05 carried out in India from 28th Jan. to 29th May (with briefing and debriefing). This expert mission carried out, is second phase of the total period 12 months.

According to the terms of reference during the expert mission the following activities were undertaken :

1) Training course for the counterpart staff / scientists of the Centre and plant personnels.

2) Assisting the measurements on electrolysis cells through a special mobile van and evaluation of process data .

3) Offering assistance in preparation of detailed energy and material balance of aluminium electrolysis cell.

4) Preparation of technical proposals for improvement of cell operation.

5) Preparation of detailed programme for the establishment and location of carbon and electrolysis laboratories.

All these activities have been carried out and details are provided in the report, followed by conclusions, proposals and recommendations.

PARTICIPANTS IN MEASURING AND EVALUATION:

U B AGRAWAL	Aluminium process technologist
A AGNIHOTRI	Aluminium process modelling
A K BASU	Electrodes raw materials
S DAS GUPTA	Electrolysis
K G DESHPANDE	Cell operation
G S SENGAR	Coordinator

TABLE OF CONTENTS

LIST OF ANNEXURES

9)	Annexure - IX	Measured data, conclusions and recommendations as per work plan
10)	Annexure - X	Further measuring programme based on mobile van taking into account the modernisation programme of BALCO smelter
11)	Annexure - XI	Description of the facilities available for measurment and monitoring of state and operation of the electrolysis cells March 1993
12)	Annexure - XII	Record notes of discussions between KAISER and JNARDDC at BALCO, Korba 1st May 93
13)	Annexure- XIII	Proposal for measurement and data eveluation on BALCO electrolysis cells for KATSI May 1993
14)	Annexure - XIV	Specifications and procurement of nitride bonded silicon carbide crucible and tube
15)	Annexure - XV	Calculations of energy modulation for INDAL

INTRODUCTION

This report has been written by Dr. J. Horvath based on the expert mission carried out in India under UNDP/UNIDO Project DP/IND/88/015 - Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC). This 4 months mission is second part of 12 months expert assignment.

According to the job description DP/IND/88/015/11-05 with post title "Expert in Aluminium Electrolysis Process Evaluation and Control", as per Annexure - I, the expert was required :

- to provide training for the staff / scientists of Centre.
- to assist in the measurements and process evaluation
- to assist in preparation of evaluation of aluminium electrolysis cell operation
- to prepare the cooperation programme between KATSI and JNARDDC

In addition to the job description some constructive suggestions have been given to the expert at debriefing in UNIDO Vienna by Mr. Dr.T.Grof, BSO, and UNDP New Delhi byMr.L.Bredal and at JNARDDC, Nagpur by Dr. J.Zambo, CTA and Dr. T.Ramachandran, NPD . Job description and suggestions formed the basis for the schedule programme prepared at beginning or this mission (Annexure -II).

It can be noticed in the schedule programme, that the activities and duties as per the job description were extended by preparation of establishment for carbon and electrolysis laboratories.

ACTIVITIES

Itinerary and list of main activities following the job description, as per Annexure I and the programme on mission as per Annexure II are described below :

A. <u>Training programme for the counterpart staff / scientists.</u>

To prepare for the establishment of laboratories in the centre a training programme was organised. The objectives of this training programme were as follows :

- to understand the principles of measuring methods and functions of the equipments which are to be installed.

- to understand the background of the high performance smelter technology. This programme was used to prepare the revitalisation program for BALCO.

The material for the training course is enclosed (Annexure-III).

The outcome of this training programme was satisfactory and the outputs are available in the Centre's archive.

Training programme was also held at Bharat Aluminium Company, Korba to train the personnel for preparation of revitalization progrmme. The list of the participants is enclosed (Annexure-IV).

A lecture was organised for training of NALCO personnel at Angul in the field of "Basics of Aluminium Electrolysis ". In this lecture 22 executives from E-1 to E-7 grade and one supervisor were present (Annexure VIII).

B. Preparation for measuring process and technological tests at BALCO and heat flux measurements at NALCO

During last 4 month mission in India, the JNARRDDC experts carried out some measurements in BALCO smelter on 13 experimental pots from 5th June to 29th June 1992. Based on these experiments, some conclusions were drawn by the expert on the status of the cells and recommendations made for improvement were submitted to the BALCO management. The latter found these experiments very useful and requested JNARDDC to continue these measurements on other sets of cells. The main target of experiments carried out by expert during this mission was, to realise the proposals and recommendations in practice. This programme is the so-called "Revitalisation programme", for reaching normal cell operation.

The main steps of the proposed programme were the following:

- removal of deposit and sludge by keeping low alumina content in the bath
- removal of broken bath from the deck plate to avoid sludge formation and improve the alumina feeding technology
- increasing cell voltage (set point) to increase the stability of cell operation
- adjustment of bath and metal levels to reach the normal level (the normal level is less than the cell cavity)
- adjustment of alumina layer on the crust to achieve normal alumina feeding technology.

The material was given to Mr P N Sharma G M (Works) for discussions (Annexure -V).

After disscussion the "Revitalisaion programme" was agreed to by BALCO. More detailed work programme was prepared with close cooperation of BALCO experts (Annexure VI).

Drs Ramachandran and Zambo discussed different R &D projects with NALCO management (Annexure VII). On the basis of these discussions, some common projects were agreed upon. The first task was to clarify technical points of these selected projects and prepare a programme for their implementation.

The second task was to carry out heat flux measurements on cathode shell of modified and control pots .

C. Evaluation of the measuring process at BALCO and NALCO.

As mentioned above, the main objective of the revitalization programme was to achieve normal cell operation. Some important conclusions drawn from the experiments carried out during this period relating to the existing technology are the following :

Unfortunately due to improper feeding technology at BALCO, present from the time of installation of pots have resulted in extensive risk of sludge formation. The increased sludge in the cathode bottom has resulted in unstable cell operation. In order to compensate for the above said factor of high sludge formation and achieve a stable operation, the metal level was increased and set point was decreased. Presently the set voltage is 0.3 volts lower than actual set point as per the voltage balance of these cells. This indicates that the present cells are being operated at low ACD which has led to instable cell operation i.e. sick cells.

During the experimental period, the first step was removal of sludge by introducing a special crust breaking and alumina feeding technology. After a period of one week no sludge was found at the cathode bottom. This sludge removal gives a possibility to decrease liquid level i.e. bath/metal. Some typical data of changes in bath and metal level are shown in Fig No. 1. The experimental results were summarized in File No. 7 (Smelter) (at JNARDDC).

After increasing the set point, cell operation was observed to be more stable. As a result anode effect value was increased and the Si content in metal was decreased. The experimental data of metal quality were summarised in File No. 8 (Smelter) (at JNARDDC). These observations and data indicate that the cell operation approched normalcy.

Simultaneously with the above action the deck plate was cleaned for all the experimental pots. Broken bath was removed from the deck plate area in order to avoid any risk of sludge formation.

Typical data of metal quality and set point changing are shown in Fig 2.

During the experiments the following traditional and non traditional measurements were performed :

-anode voltage drop
-cathode voltage drop
-electrolyte temperature and composition
-anode leg
-anode-cathode distance

These non traditional measuring data can be found in File No. 9 (Smelter) (at JNARDDC). The anode and cathode current distribution also was measured and data can be found in File No. 10 (Smelter) (at JNARDDC). Some typical anode and cathode current distribution data can be seen in Fig. 3.

On the basis of experiments/measurements carried out during this mission, following parameters were achieved :

- on six experimental cells the normal state was adjusted, based on data and analysis of last year's measurments
- sludge and deposit removed from "Young "cells
- liquid level decreased to 48 cm from 60cm
- anode casing decreased

- removal of hard deposit on "old" cells was not possible by special alumina feeding technology, thus removal of hard deposit was possible only manually. The risk of iron picking was increased
- For proper adjustment of heat balance of the cells, following actions are needed:

    - improving anode and cathode current distribution
    - one reason for large volume of skimming generation is poor anode current distribution
    - to approach proper heat balance
    - broken bath addition and bath tapping are needed
    - improve the anode effect killing procedure
    - introducing process monitoring, that was determined during the last year

The main conclusion of the revitaization programme is:

- revitalization of each cell is required , in this period all cells indicate abnormal operation

For introducing pot controller system the basic requirement is normal cell state and narrow range of fluctuation in the operational parameters. So it is extremely important to reach normal cell operation before the insatallation of pot controllers.

Evaluation of measuring process at NALCO :

NALCO experts requested to carry out heat flux measurements in four control and four experimental pots which were

Control pots	Experimental pots
B-004	B-005
A-004	A-002
A-030	A-029
A-094	A-106

The heat flux measurements were done for the bottom of cathode shell at 18 different points and 24 different points on long side of cathode shell. All measuring data was handed over to NALCO experts, and same measuring data can be found in File No. 11 (Smelter) (at JNARDDC).

The proper thermal design for long cathode life can be achieved by :

- adequate ledge formation

- proper location of bath eutectic crystalization isotherm.

Heat flux measurements on long side of cathode shell were carried out on metal and bath level. The results for two typical cells are summarized in the Table I .

TABLE I : Heat flux (W/m^2) on long sides of cathode shell

Measuring pots	1	2	3	4	5	6	Total
Control pot A-094							
Bath level	3286	4920	4617	4422	3238	5571	4342
Metal level	3877	3847	3881	4878	4676	4523	4280
Modified pot A-106							
Bath level	3444	3512	4442	4455	3806	5103	4127
Metal level	4072	3488	3838	4457	3663	4277	3966

The heat flux data for all the eight cells of NALCO can be found in File No. 12 (Smelter) (at JNARDDC)

Heat flux measurements on bottom cathode shell carried out at 24 different points. The results for two typical cells are summarized in the Table II.

TABLE II : Heat flux (W/m^2) on cathode bottom

Measuring pots	1	2	3	4	5	6	Total
Control pot A - 094							
Side 1	741	984	832	658	1372	1462	1008
Centre	571	1294	1091	1359	1498	1839	1276
Side 2	694	1202	966	1029	1151	950	999
Modified pot A - 106							
Side 1	558	1065	1370	1606	1586	879	1178
Centre	505	1356	1480	1352	1635	2064	1399
Side 2	724	1422	1179	1816	1744	1444	1388

D. Preparatory work for cooperation between Kaiser Aluminium Technical Services Inc. (KATSI) and Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC)

During last year's mission a proposal was prepared by experts of JNARDDC in cooperation with counterparts at BALCO for improvement of cell status. The objective of this proposal was to achieve maximum benefits with miniumum investment and changes in cell construction , with laying emphasis on improvements in technology and / or work routine.

The Director and Chief technical adviser of JNARDDC discussed with BALCO management about the participation of JNARDDC in modernisation programme that the main work would be carried out by Kaiser Aluminium Technical Services Inc. (KATSI). There after it was decided to send a description of capabilites of JNARDDC in the field of aluminium electrolysis to KATSI.

This description was handed over to Kaiser representative in BALCO. The Kaiser representative expressed his satisfaction over the equipments installed in mobile van, for carrying out all measurements required by KATSI (Annexure X).

Kaiser representative requested JNARDDC to prepare a proposal for transfer of available measuring data and evaluation, which were collected by JNARDDC during measurements in June 1992 and revitalisation programme in May 1993. This proposal was prepared and handed over to Mr Dhameja of KATIS.

E . OTHER ACTIVITIES

i) At beginning of the expert mission the following materials were handed over to JNARDDC :

- Data on thermodynamical properties of materials used during the electrolysis from JANAF Thermochemical Table

- Possibilities of 5 N purity aluminium Production

- Calculation of heat isotherm in cathode lining (User's guide in English)

- Description of user's guide of the carbon test (On floppy disk)

ii) During the expert mission a meeting was organised with representatives of Norton firm. The objective of this meeting was to determine the technical specification of silicon nitride, which will be used in electrolysis laboratory later on. The proposal of Norton firm is enclosed (Annexure XIV). It is recommended to buy these material before installation of electrolysis laboratory.

iii) The effect of power interruption on energy consumption and production was calculated for Indian Aluminium Company. The results of calculations are enclosed (Annexure XV).

The most important task carried out during the expert mission was to prepare the details for installation of carbon and elecrolysis laboratories.

Following description of standard methods on carbon laboratory on requested were decided:

- ISO 6257 Sampling pitch for electrode
- ISO 5940 Detrmination of softening point by ring and ball method
- ISO 6372 Sampling procedure
- ISO 687 Sampling procedure

Two measuring procedures are requested in electrolysis laboratory :

- method for determination of electrical conductivity of cryolite - alumina melt
- determination of liquidus temperature in cryolite-alumina melts

A list of items to be procured before insatallation of carbon and electrolysis laboratories was prepared.
This list includes :

- the accessories, consumables and chemicals
- main specificatios for the offers

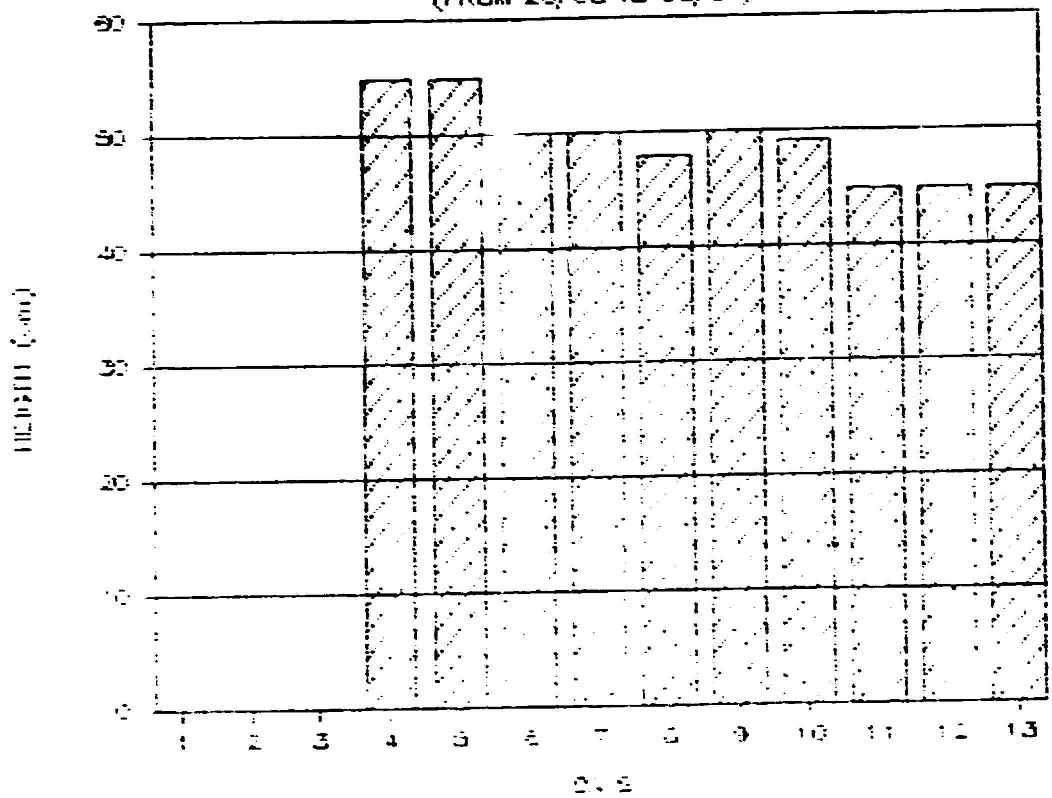
This programme was realised with very close cooperation with Mr Basu (carbon laboratory) and Mr Das Gupta (electrolysis laboratory). This list was handed over to general services department of the centre for collection of offers and procurement on 30th April 1992

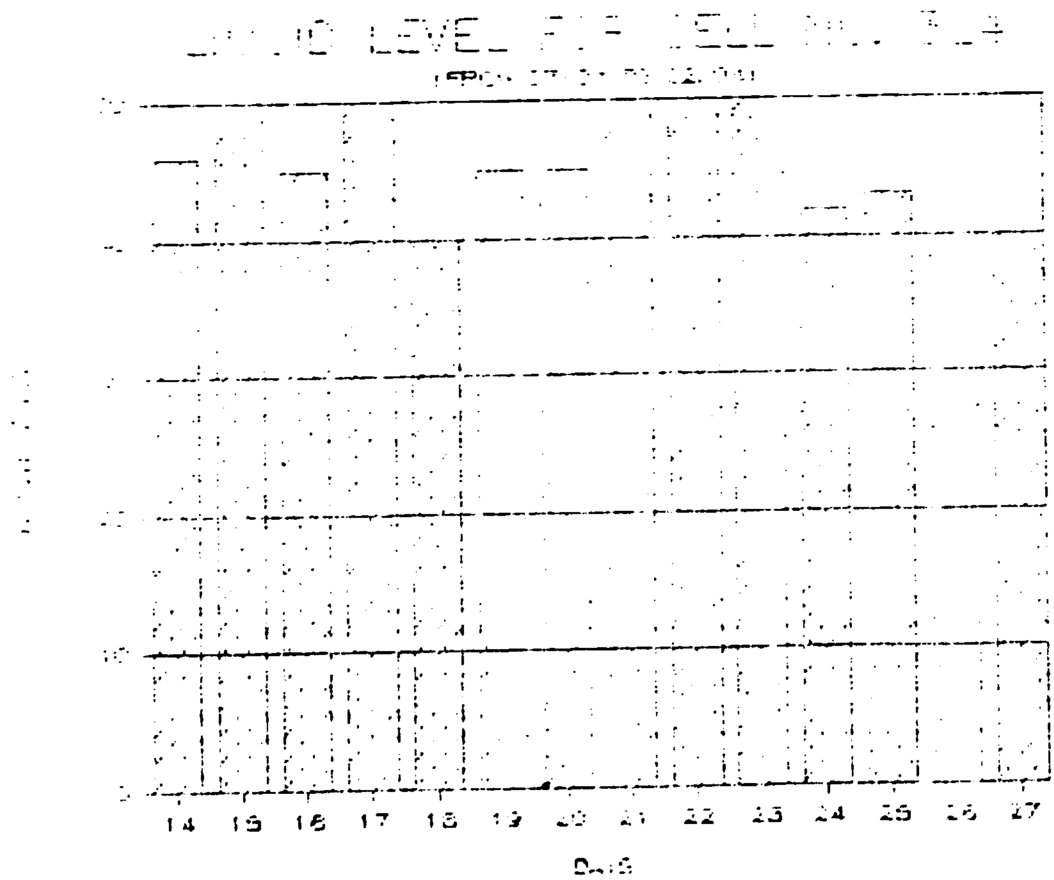
The most important item as per the expert is the furnaces for electrolysis laboratory, immediate action is needed for purchase.

FIGURE (S) 1

LIQUID LEVEL FOR CELL NO. 324

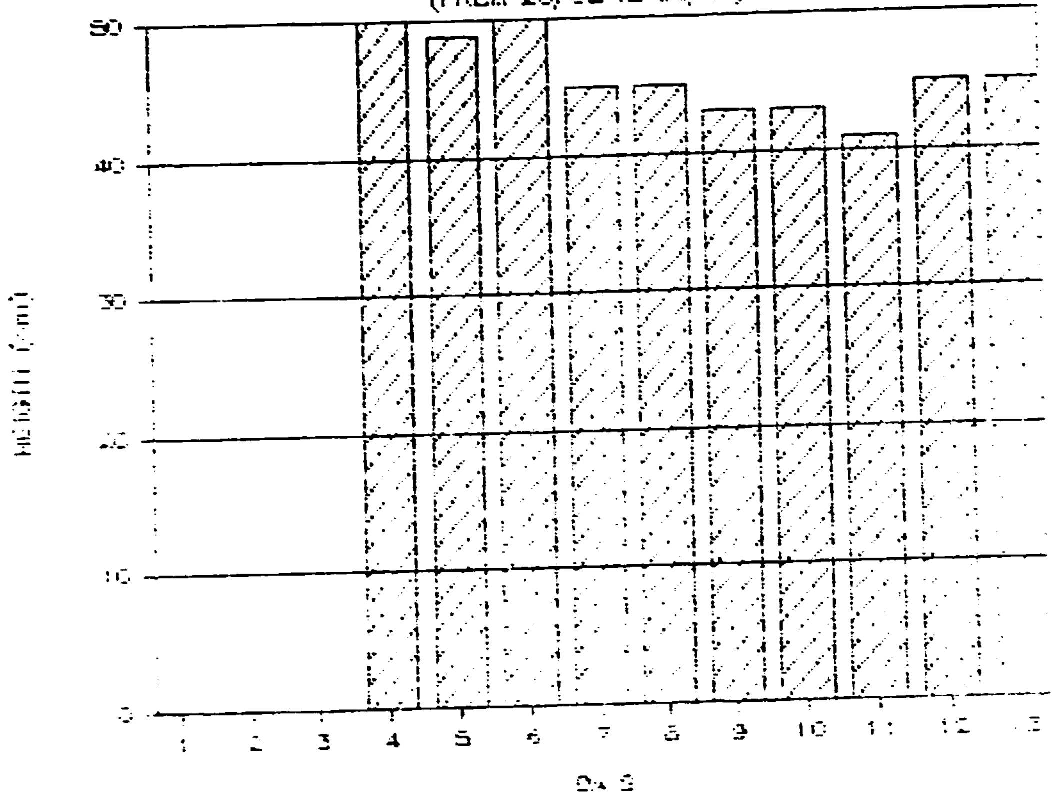
(FROM 20/03 TO 06/04)



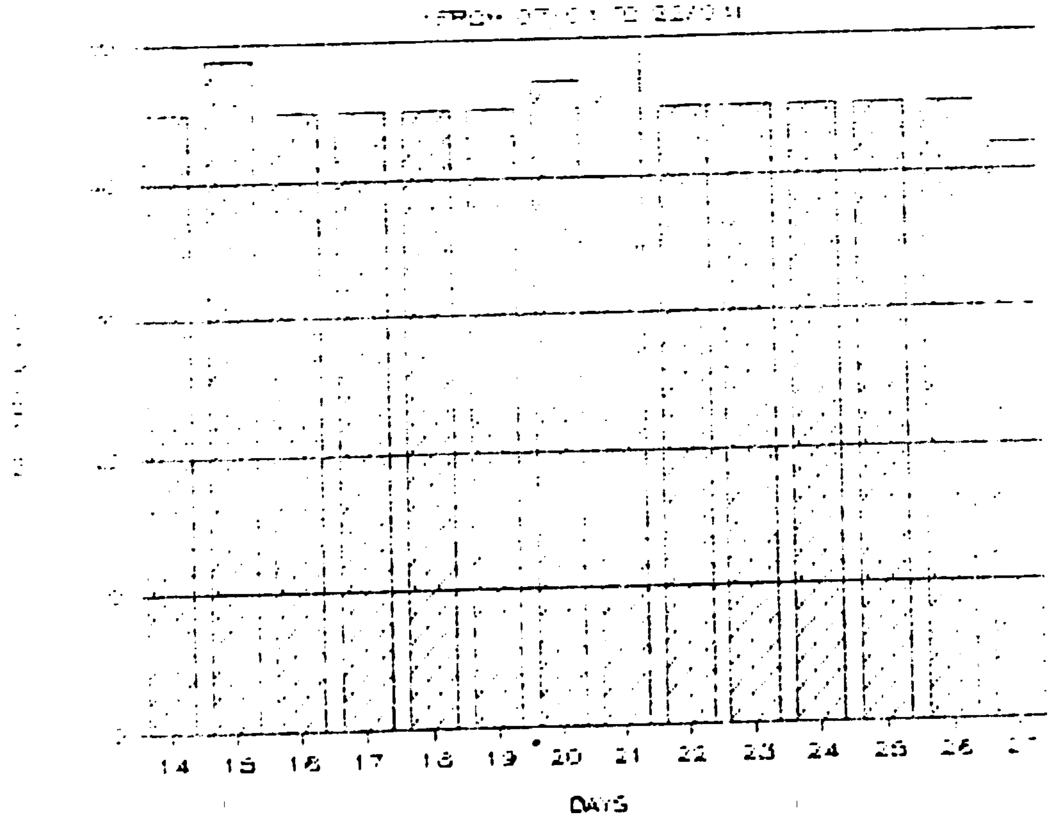


LIQUID LEVEL FOR CELL NO. 325

(FROM 20/03 TO 06/04)

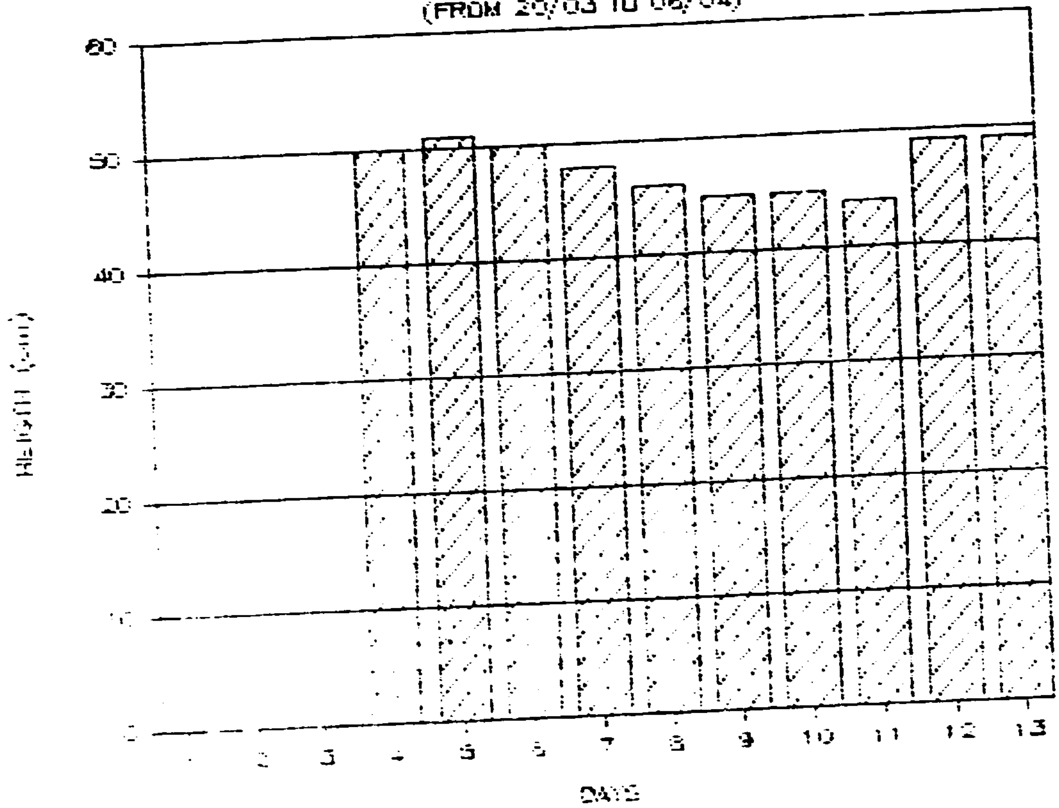


LIQUID LEVEL FOR CELL NO.

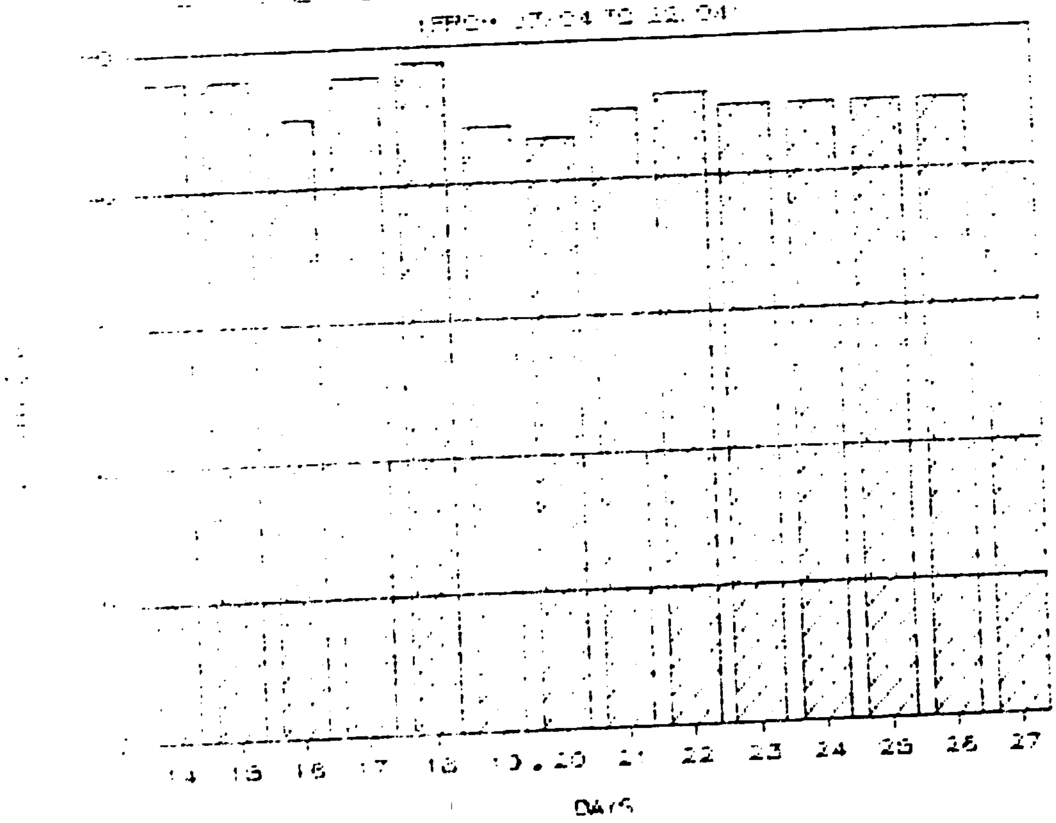


LIQUID LEVEL FOR CELL NO. 326

(FROM 20/03 TO 06/04)

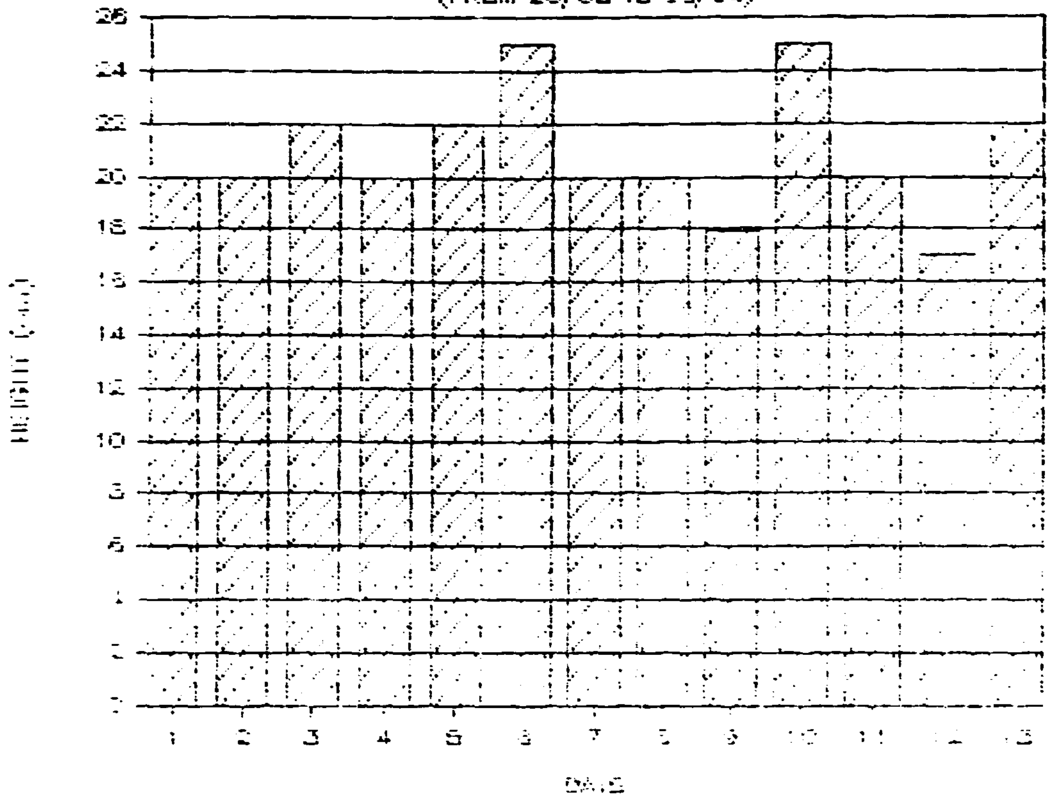


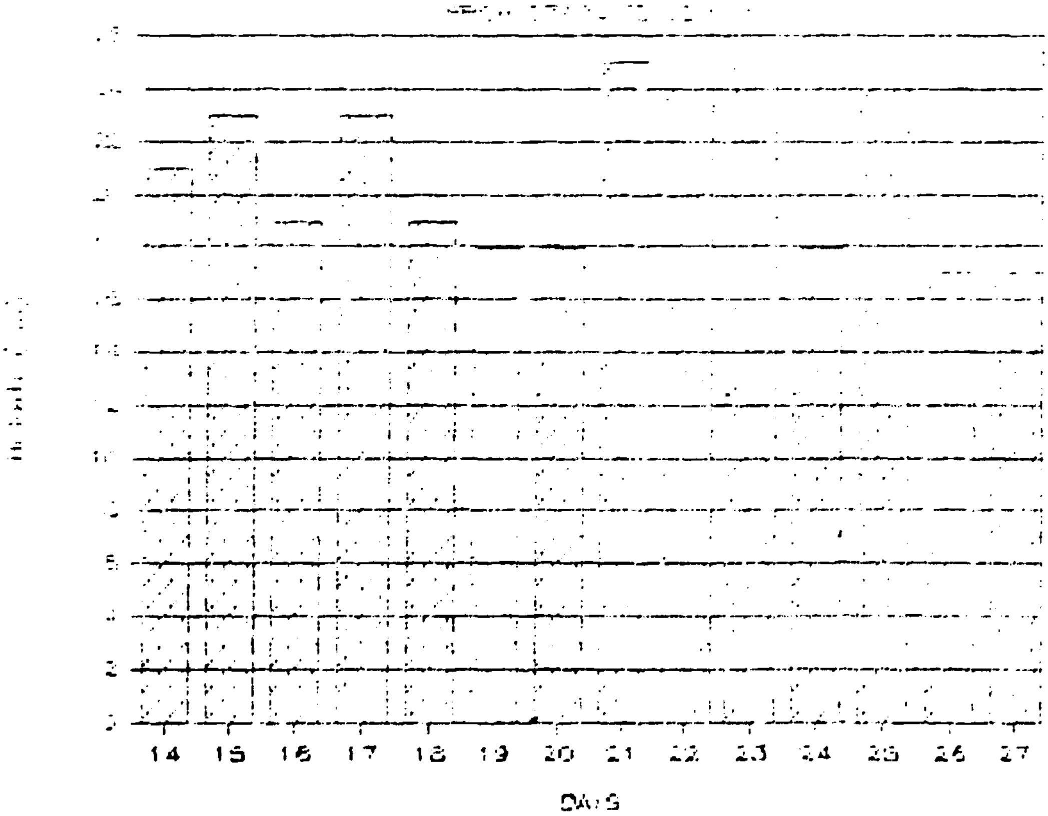
LEVEL FOR CELL NO.

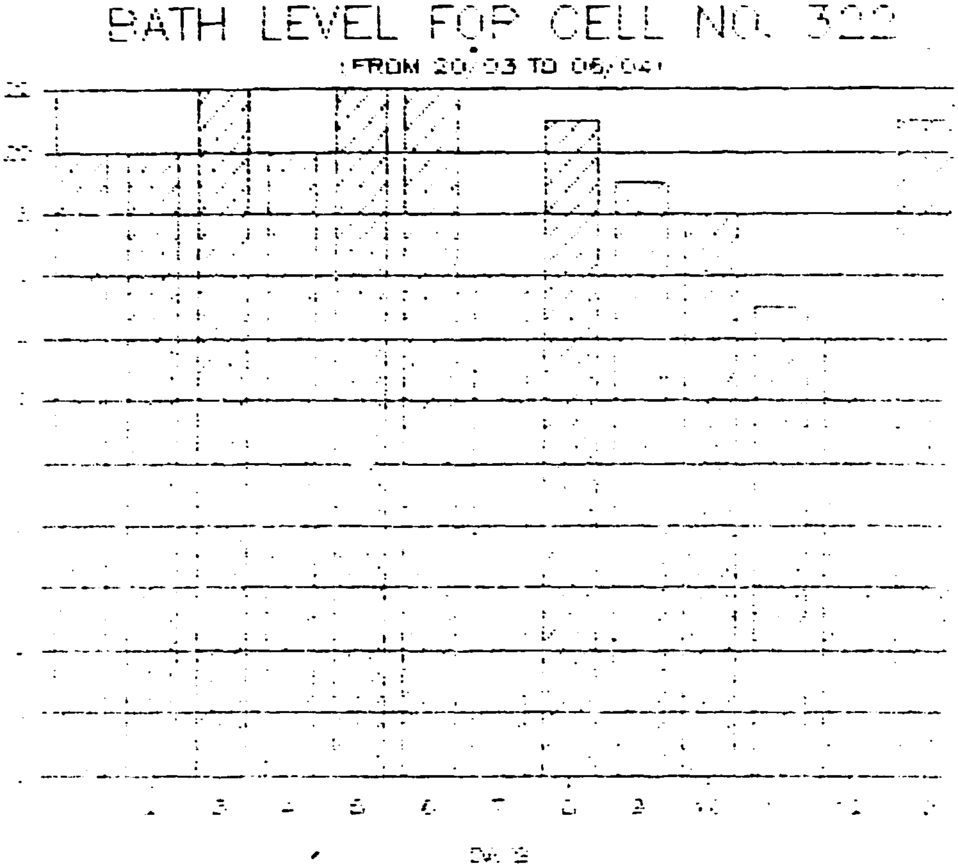


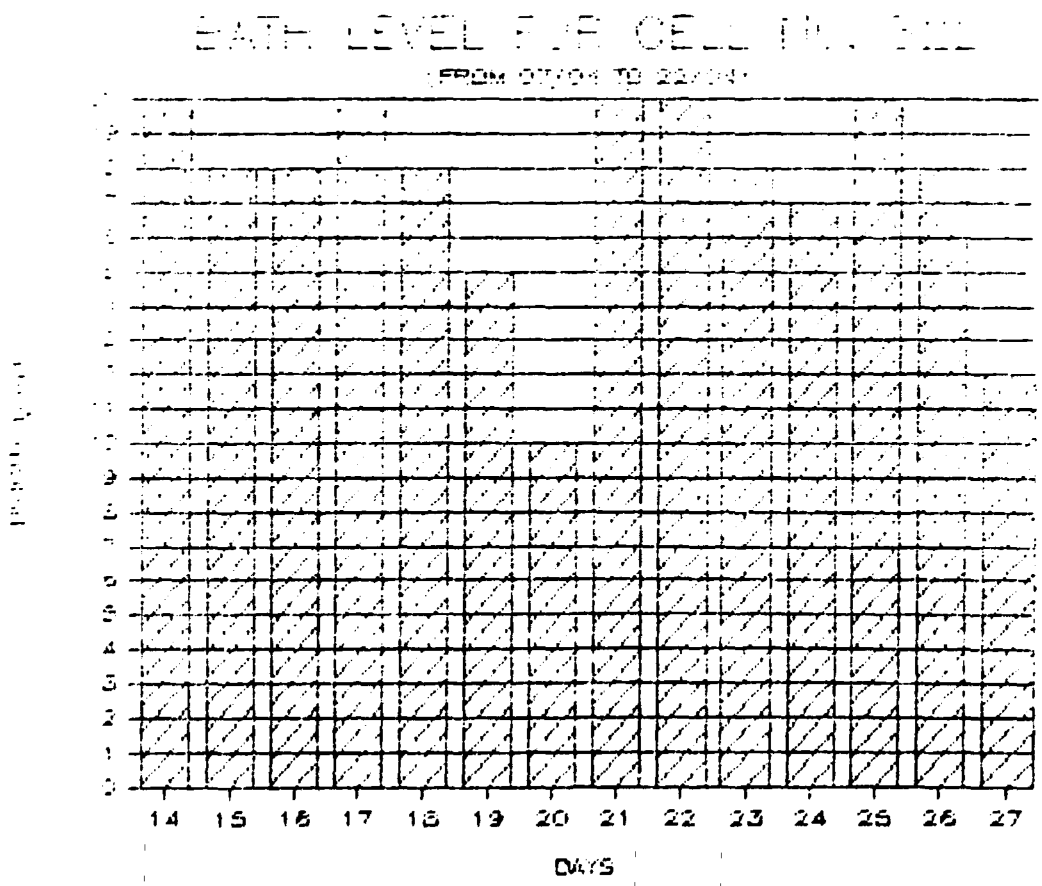
BATH LEVEL FOR CELL NO. 321

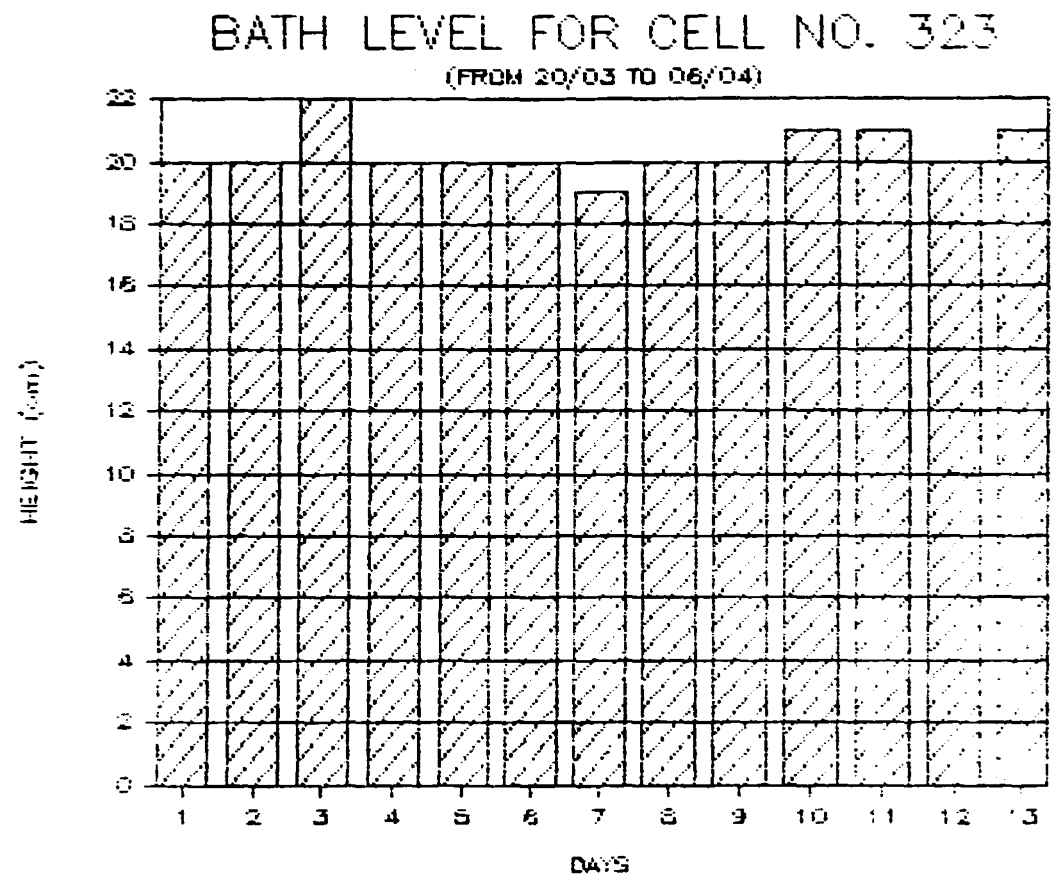
(FROM 20/03 TO 26/04)

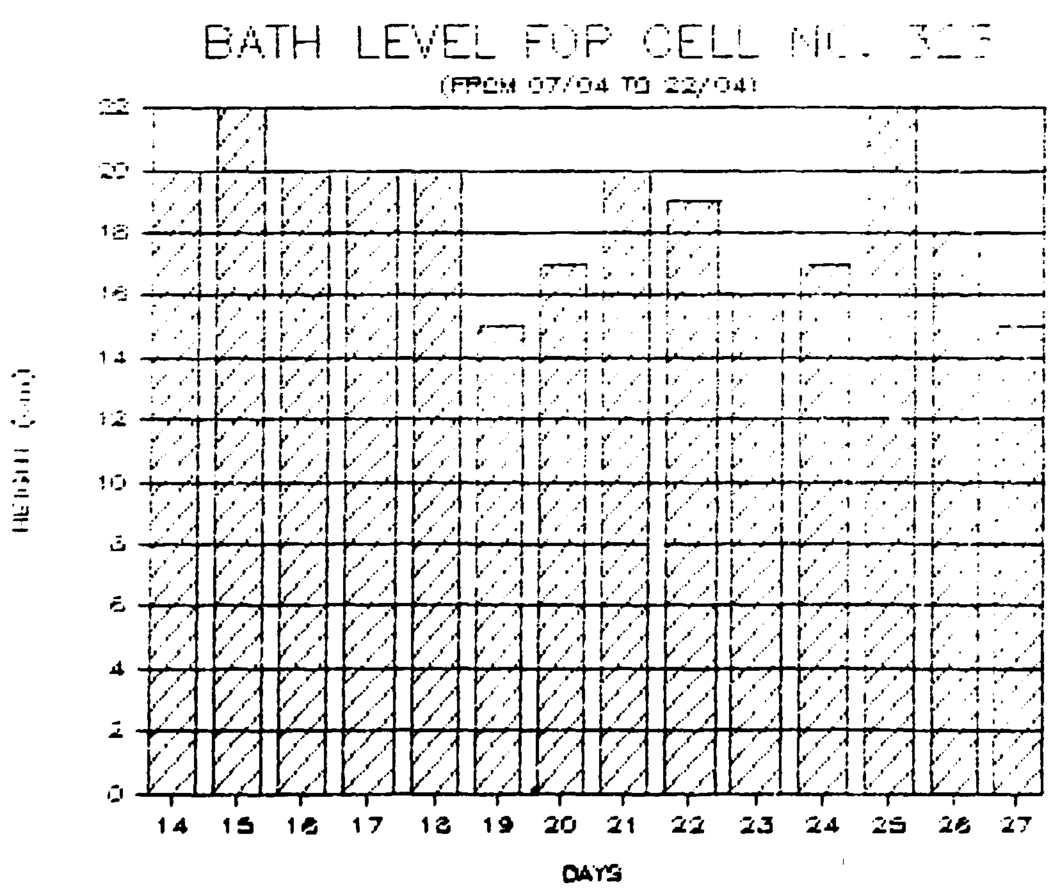





BATH LEVEL FOR CELL NO. 322
(FROM 20/03 TO 06/04)

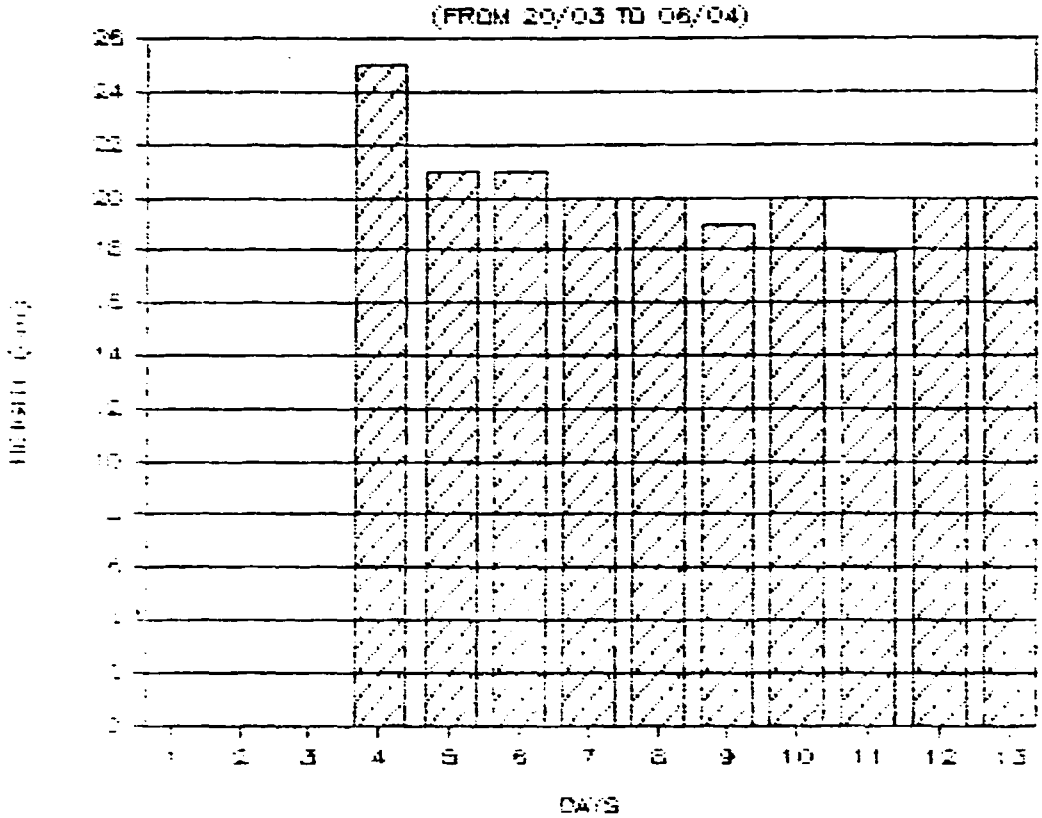

BATH LEVEL FOR CELL NO. 322
(FROM 07/04 TO 22/04)
14
15
16
17
18
19
20
21
22
23
24
25
26
27
DAYS


BATH LEVEL FOR CELL NO. 323
(FROM 20/03 TO 06/04)
HEIGHT (cm)
DAYS

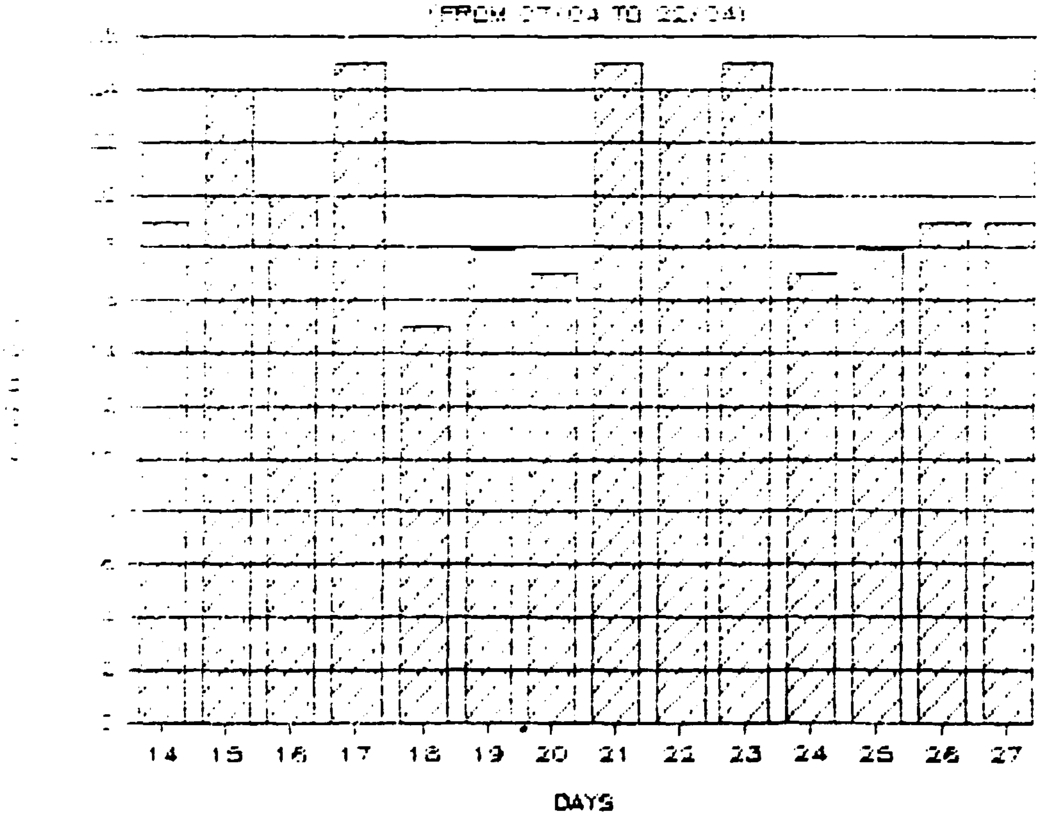

BATH LEVEL FOR CELL NO. 323
(FROM 07/04 TO 22/04)
HEIGHT (cm)
DAYS

BATH LEVEL FOR CELL NO. 324

(FROM 20/03 TO 06/04)

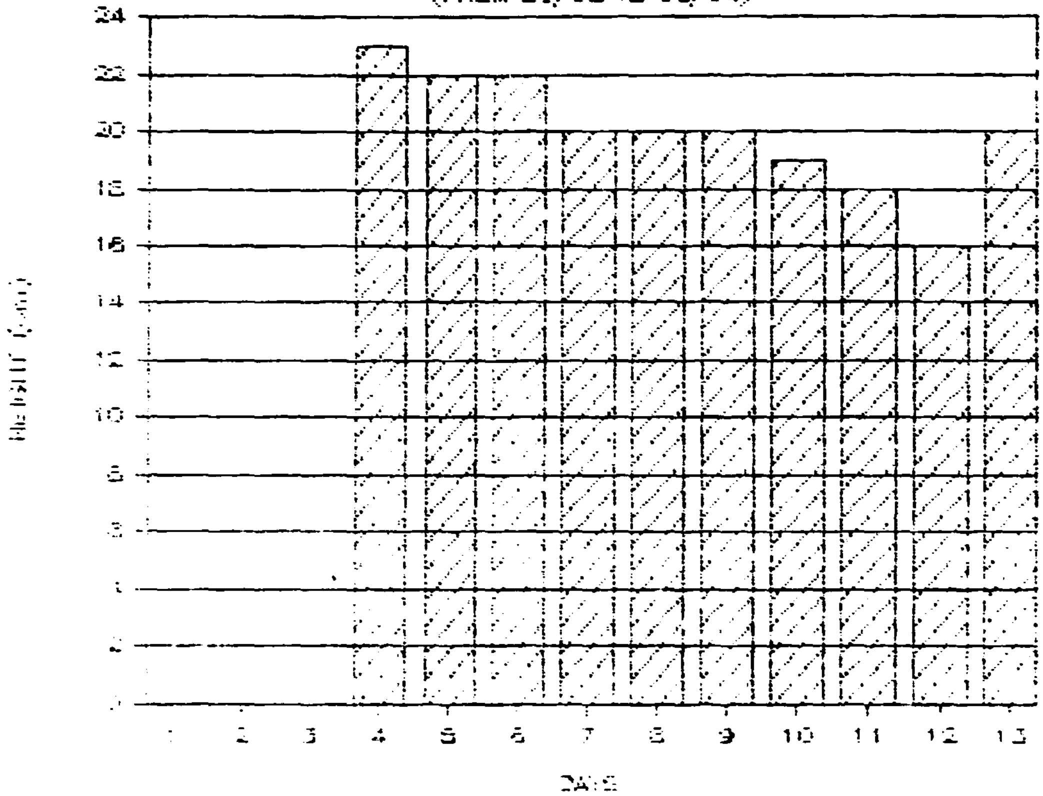


BATH LEVEL FOR CELL NO. 324



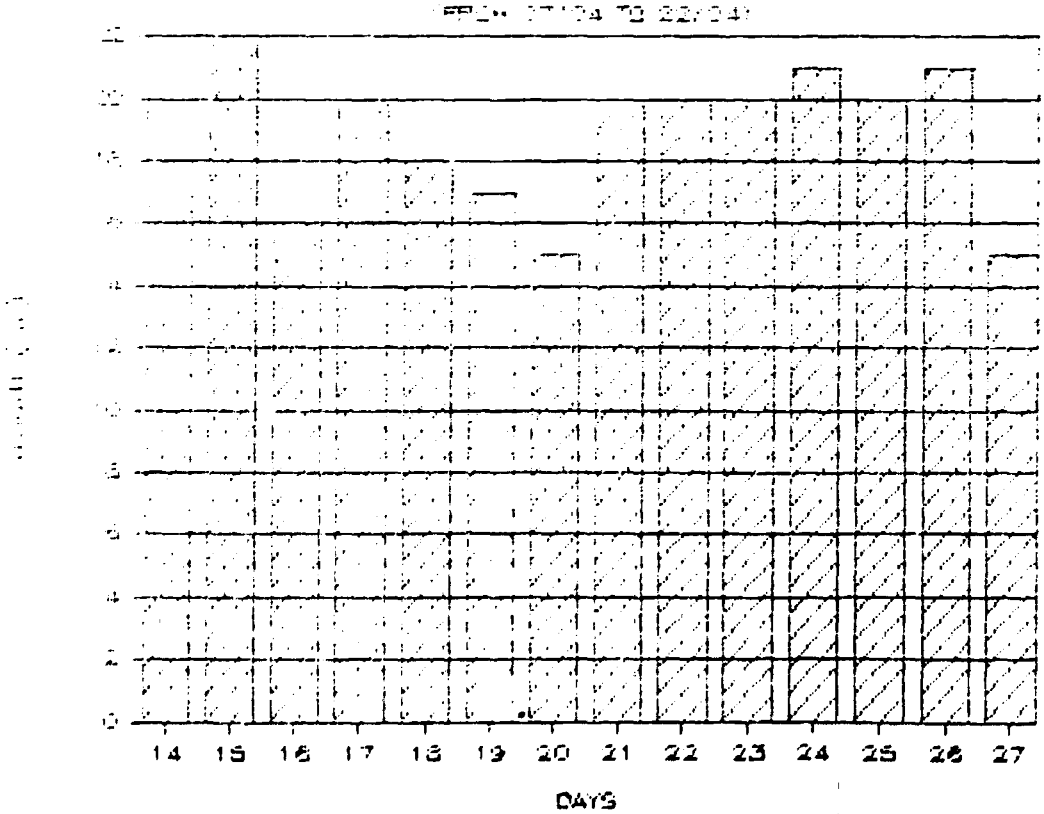
BATH LEVEL FOR CELL NO. 326

(FROM 20/03 TO 06/04)



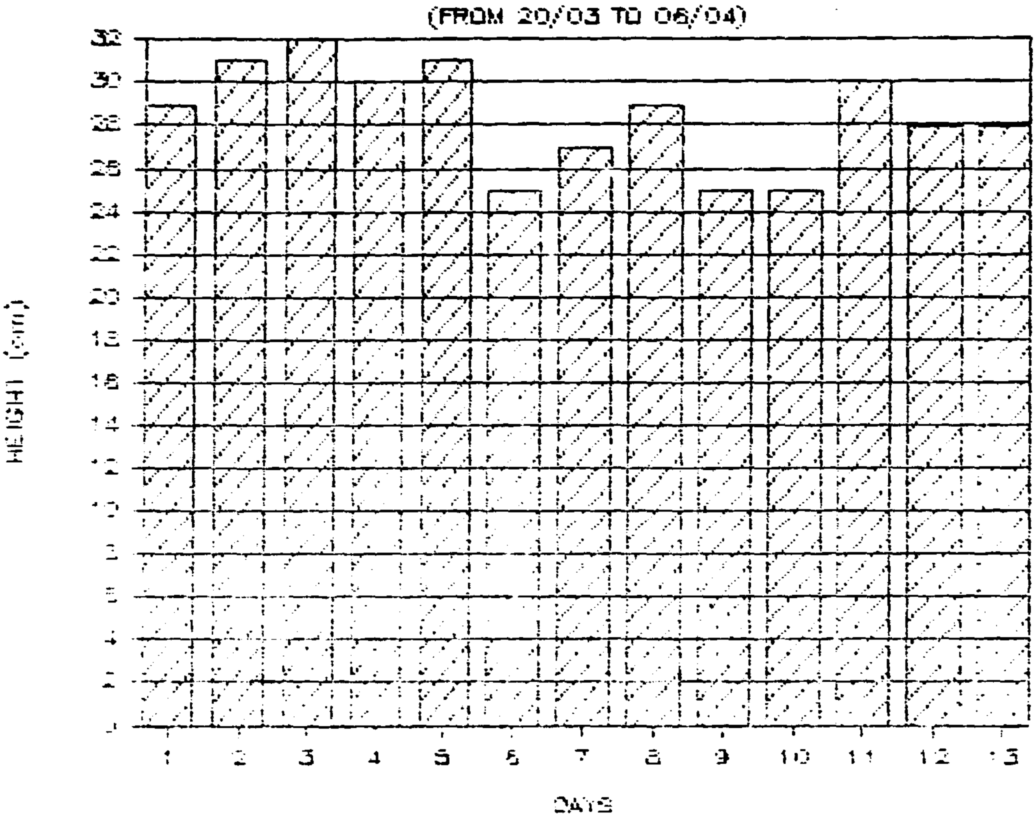
BATH LEVEL FOR CELL NO. 326

(FROM 07/04 TO 22/04)



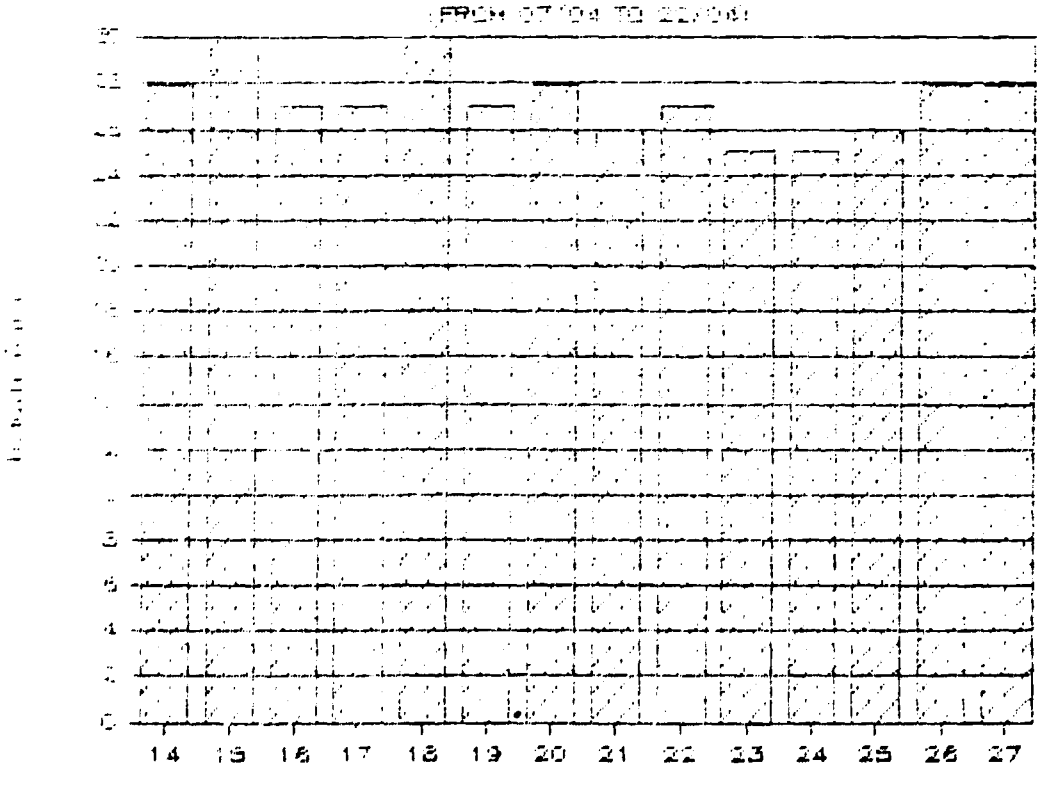
METAL LEVEL FOR CELL NO. 321

(FROM 20/03 TO 06/04)



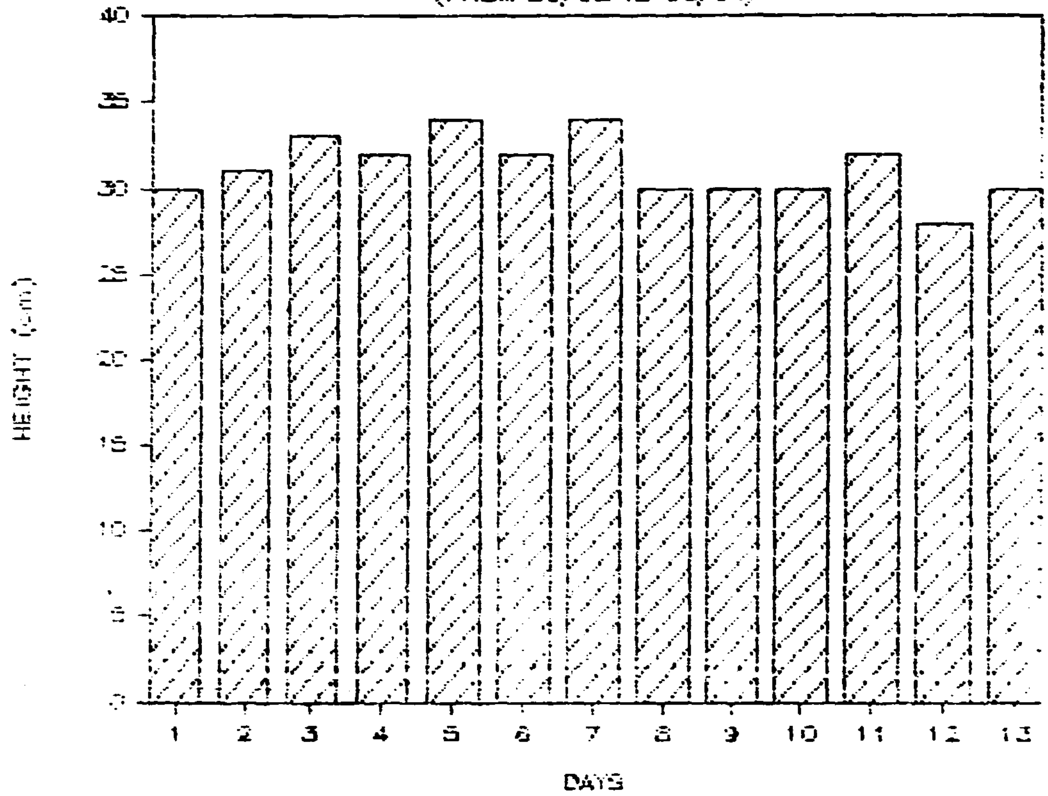
METAL LEVEL FOR CELL NO. 321

(FROM 07/04 TO 22/04)



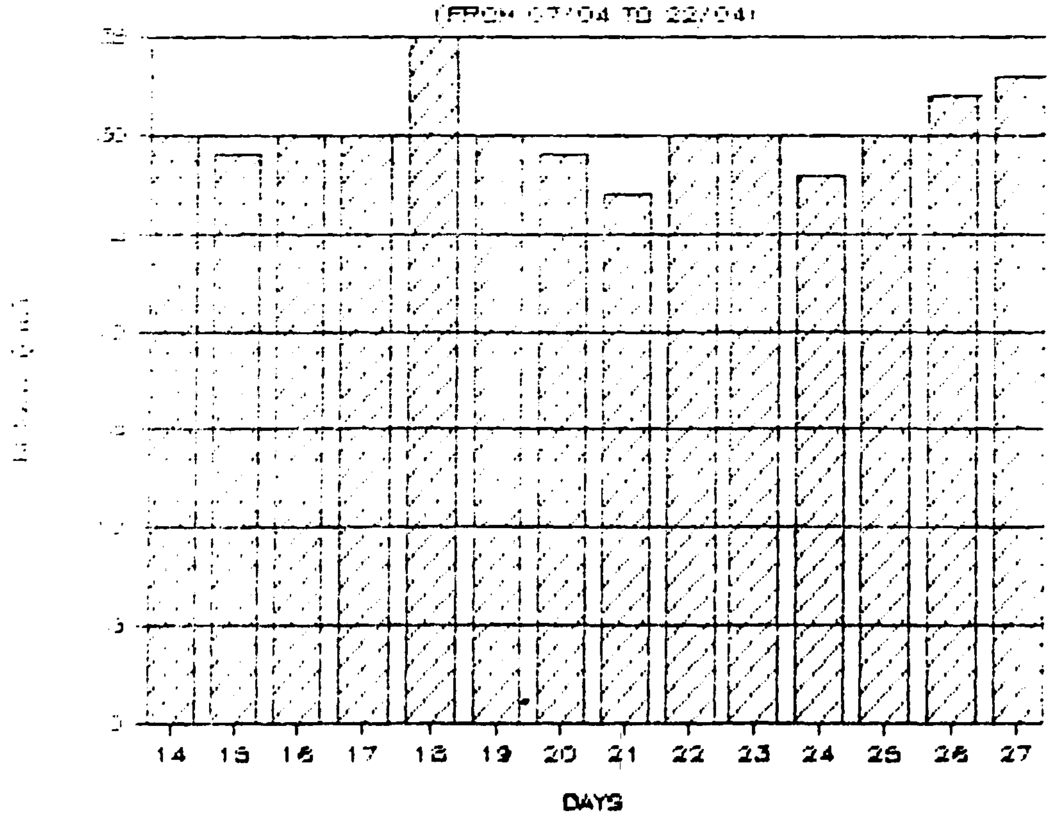
METAL LEVEL FOR CELL NO. 322

(FROM 20/03 TO 06/04)



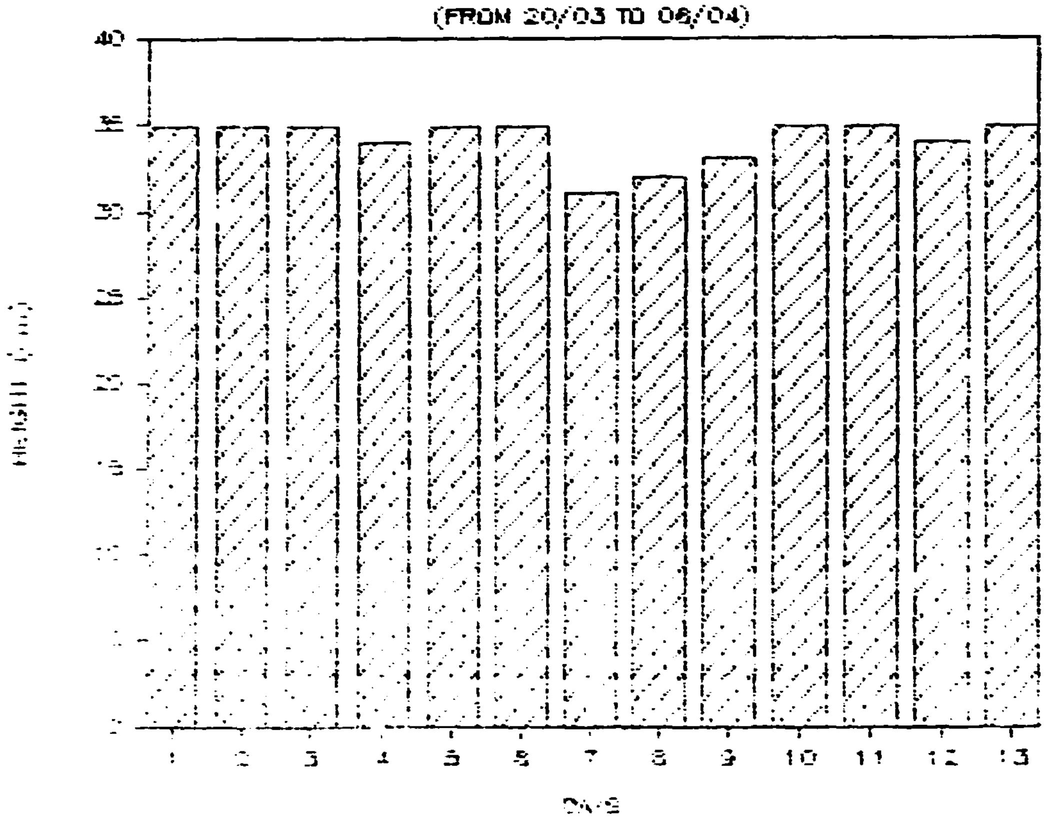
METAL LEVEL FOR CELL NO. 322

(FROM 07/04 TO 22/04)

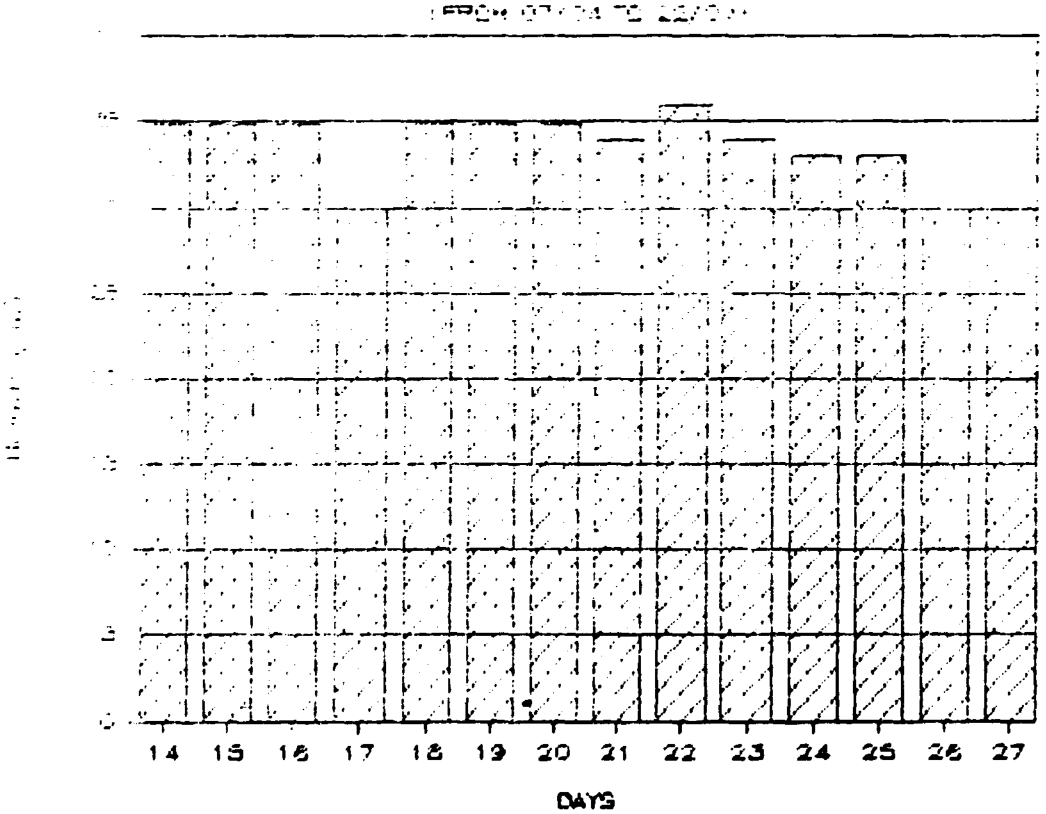


METAL LEVEL FOR CELL NO. 323

(FROM 20/03 TO 06/04)

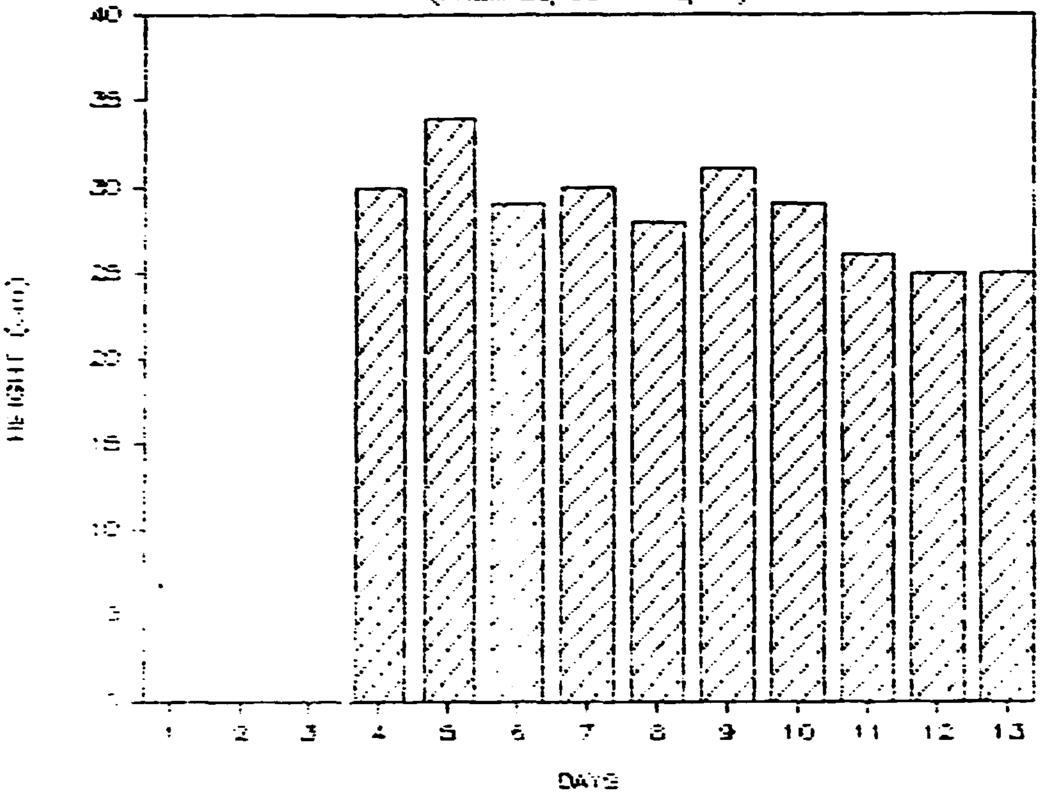


METAL LEVEL FOR CELL NO. 323

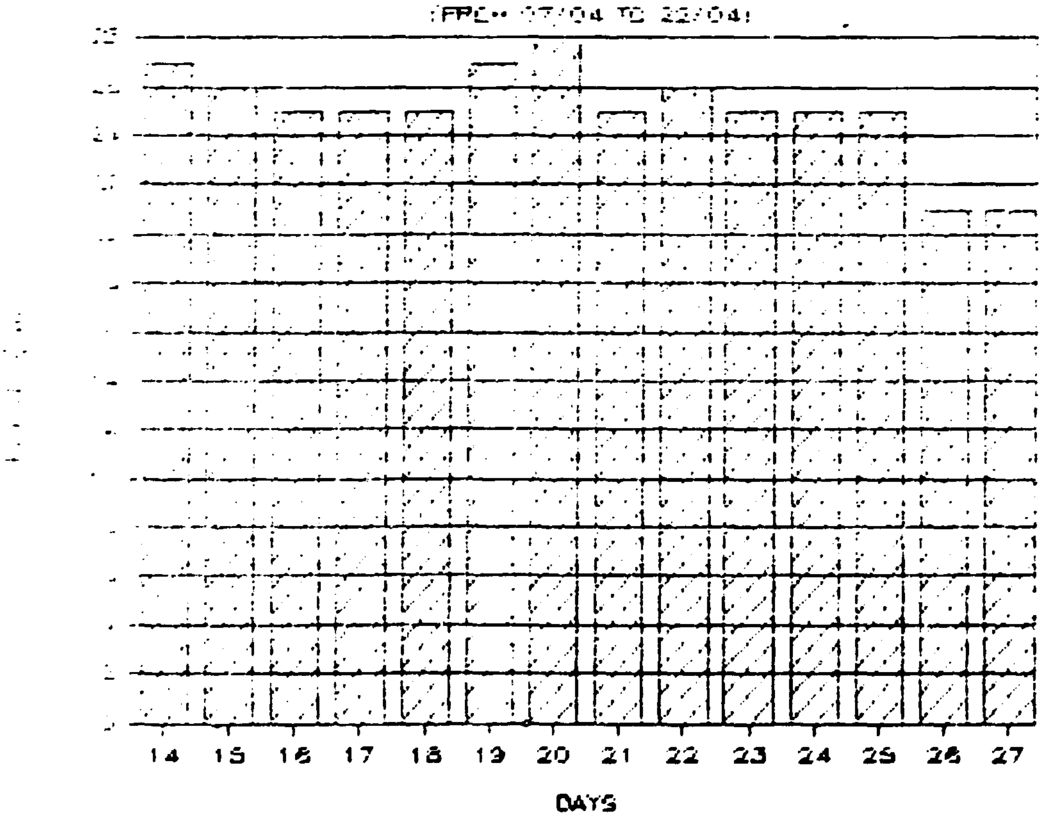


METAL LEVEL FOR CELL NO. 324

(FROM 20/03 TO 06/04)

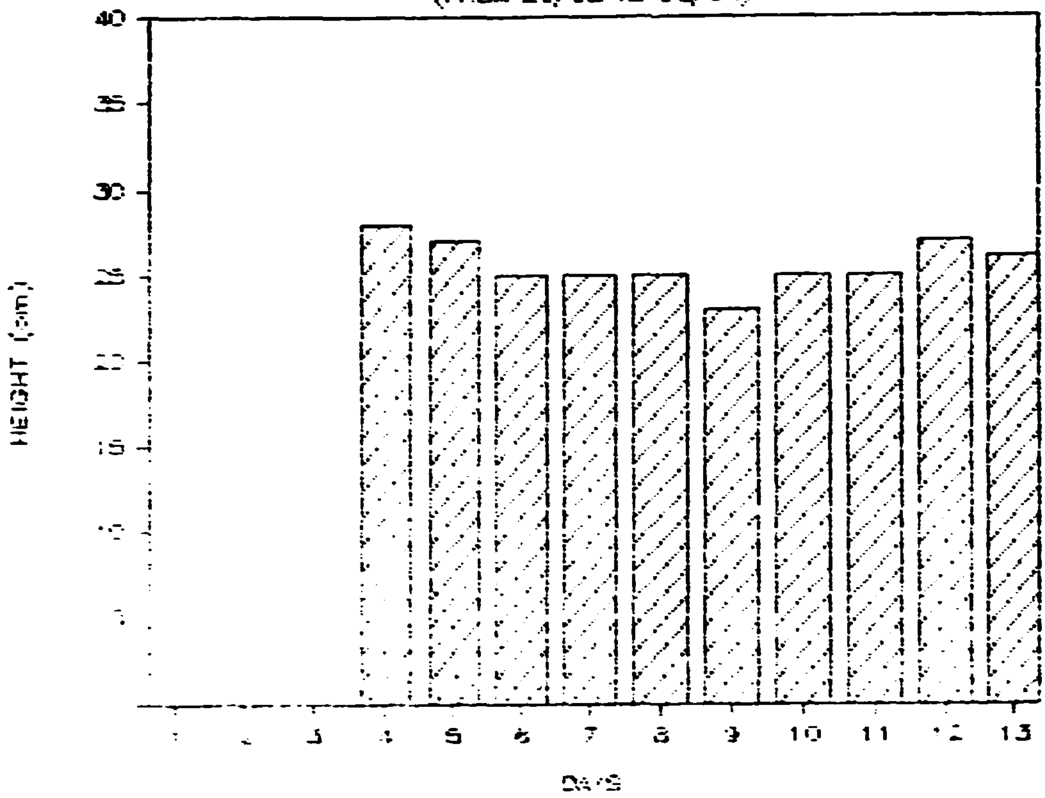


METAL LEVEL FOR CELL NO. 324



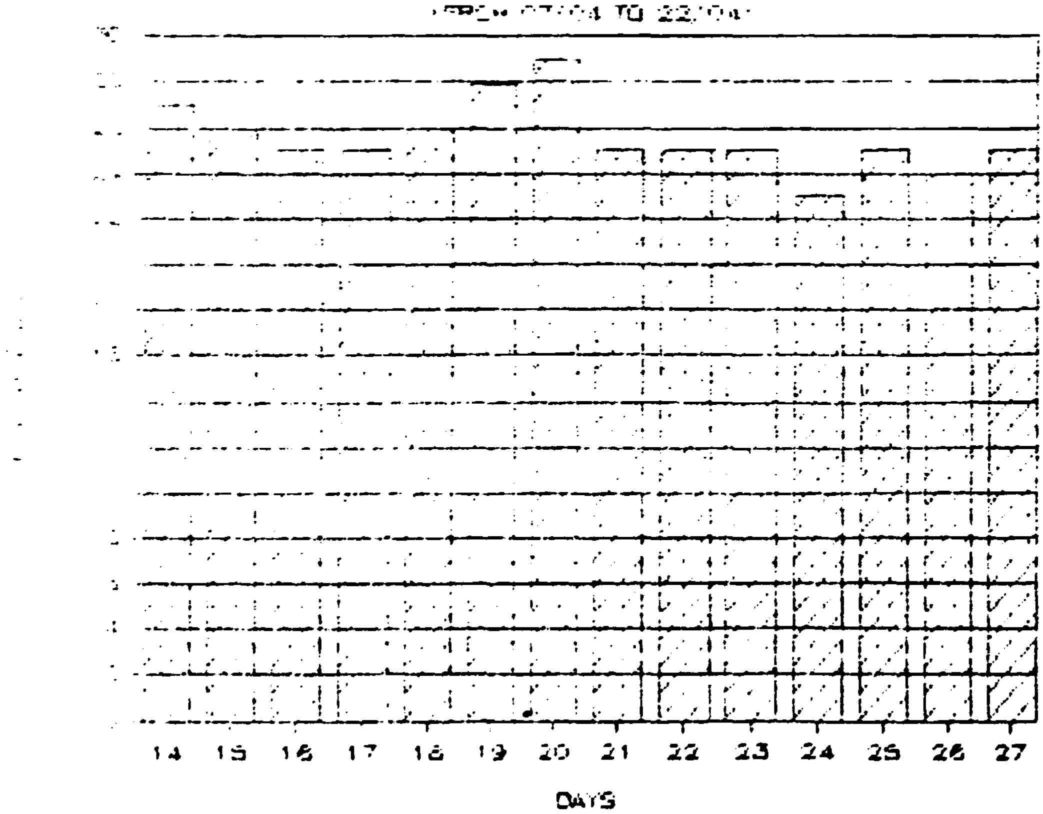
METAL LEVEL FOR CELL NO. 325

(FROM 20/03 TO 06/04)



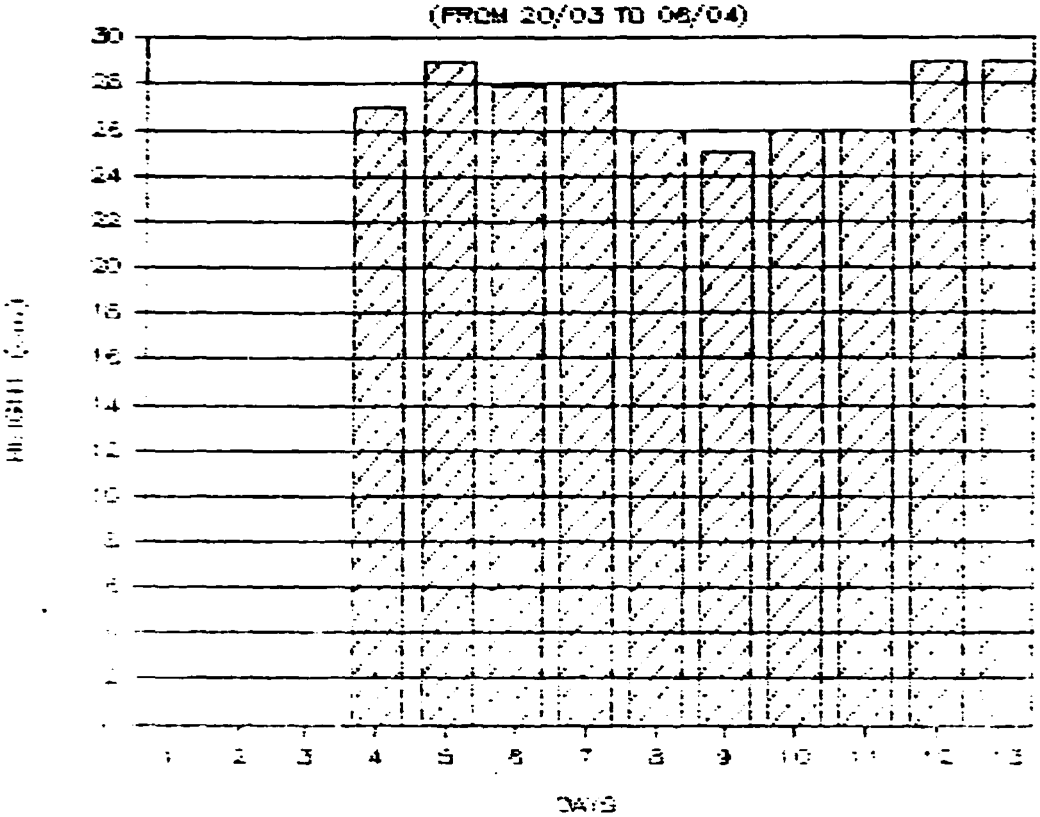
METAL LEVEL FOR CELL NO. 325

(FROM 07/04 TO 22/04)



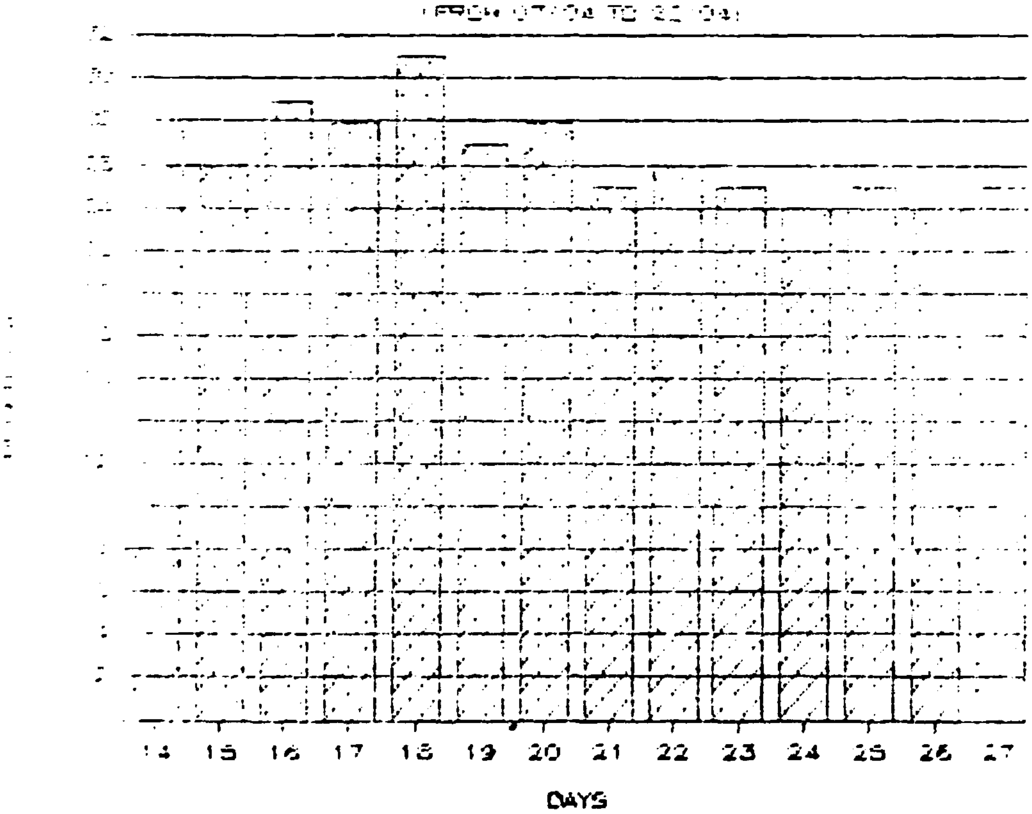
METAL LEVEL FOR CELL NO. 326

(FROM 20/03 TO 06/04)



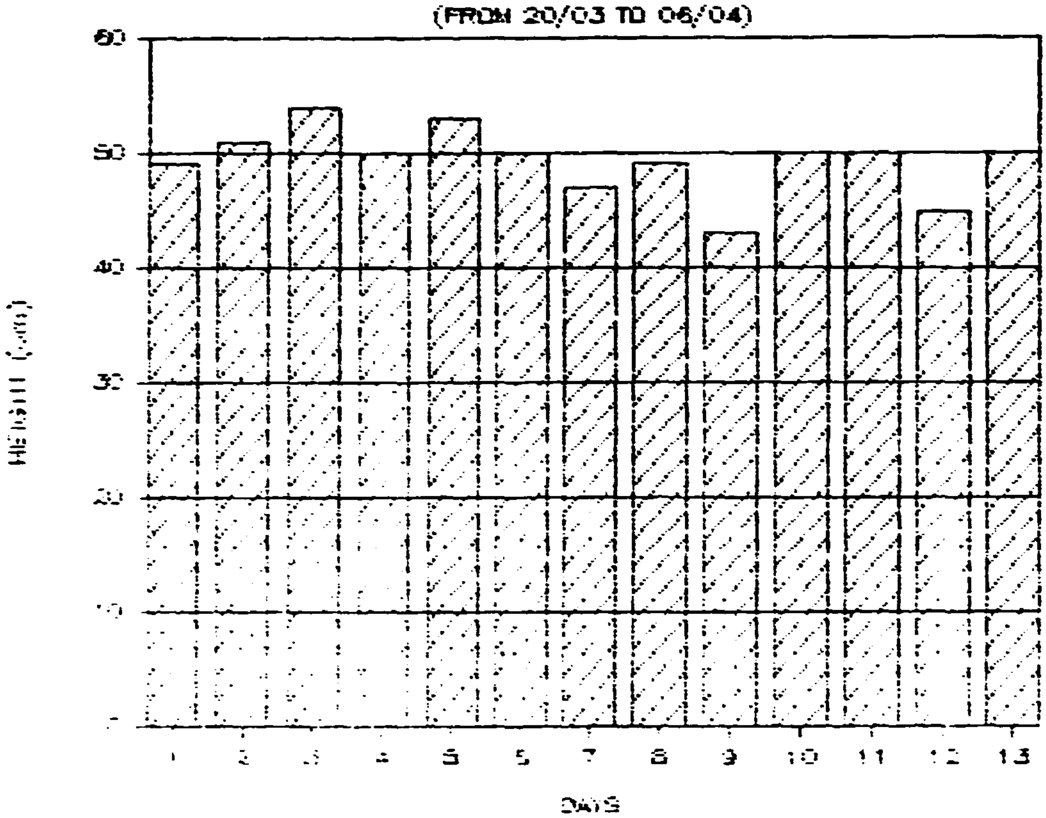
METAL LEVEL FOR CELL NO. [illegible]

(FROM 07/04 TO [illegible])



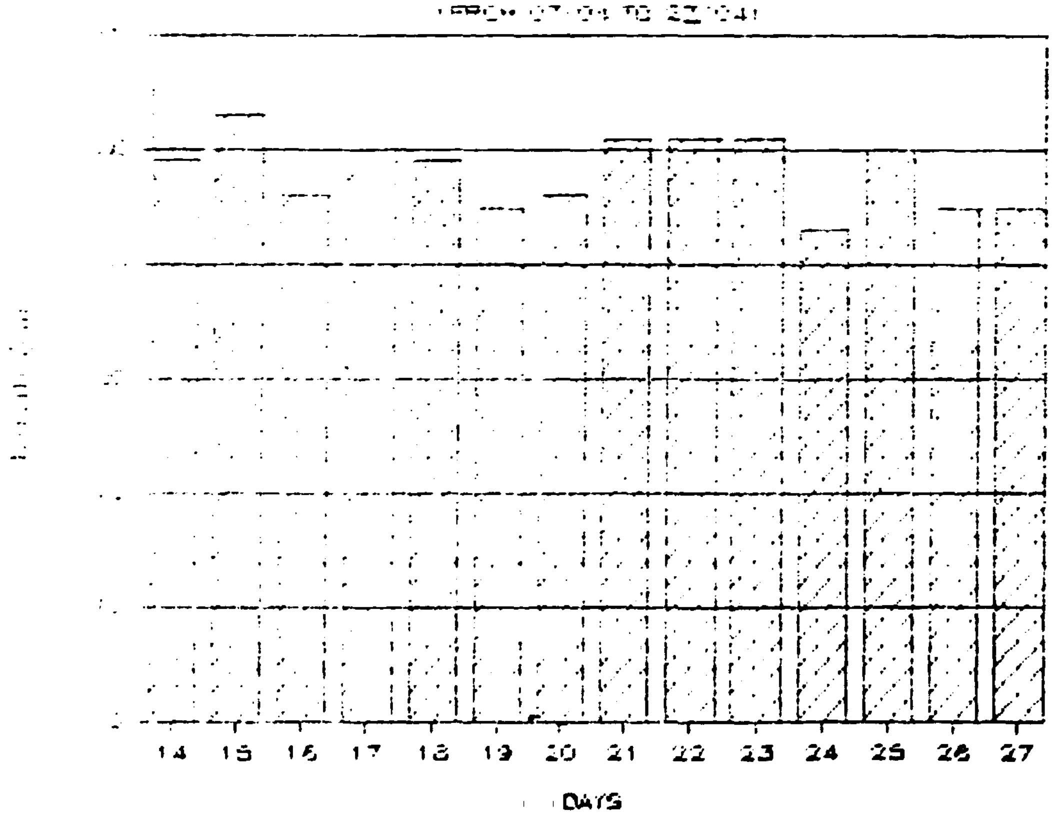
LIQUID LEVEL FOR CELL NO. 321

(FROM 20/03 TO 06/04)



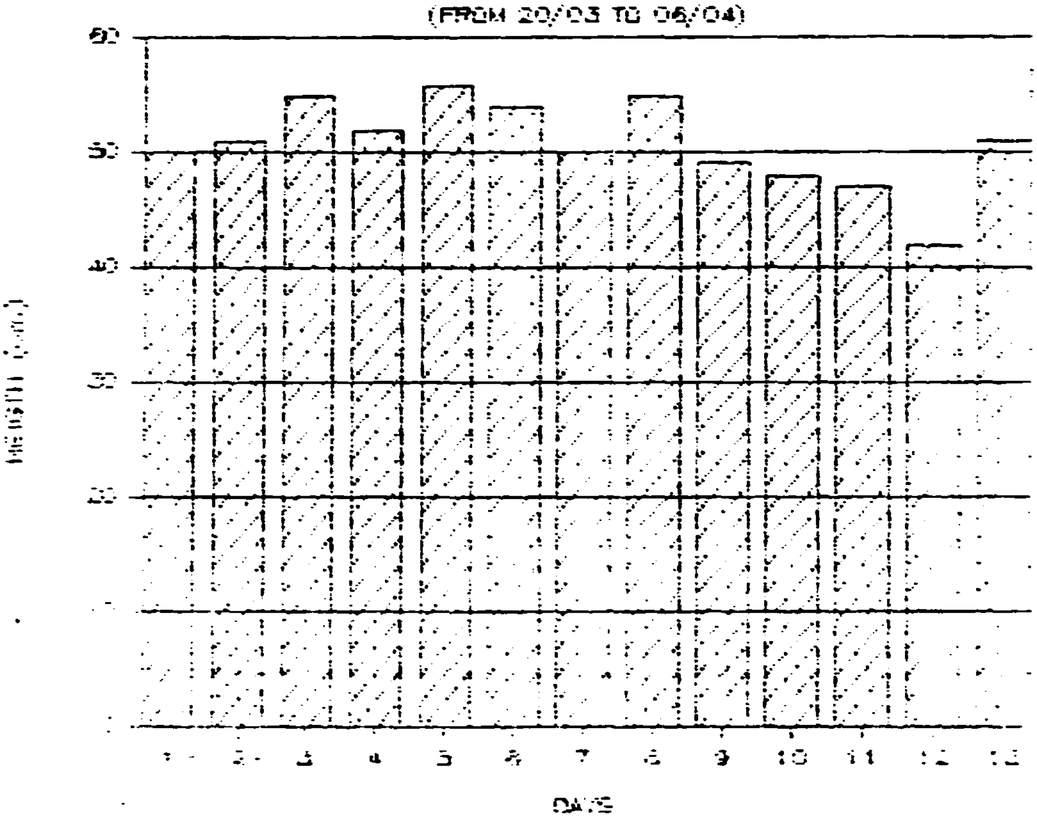
LIQUID LEVEL FOR CELL NO. 321

(FROM 07/04 TO 22/04)



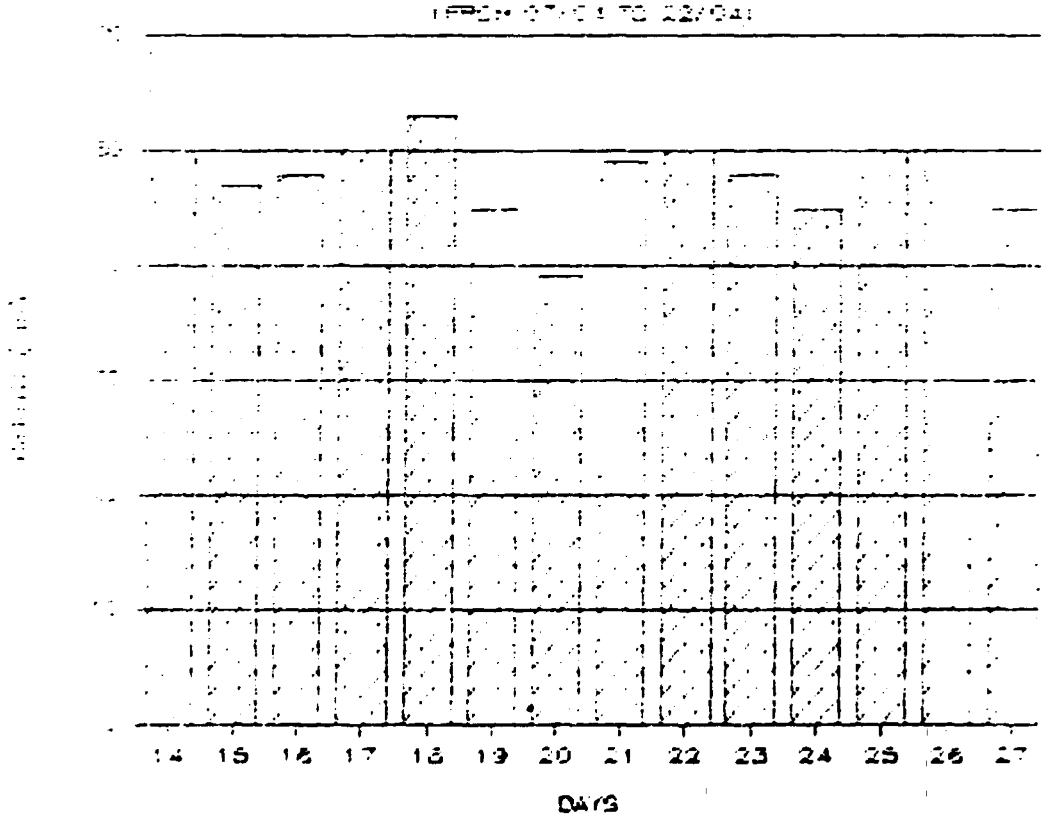
LIQUID LEVEL FOR CELL NO. 322

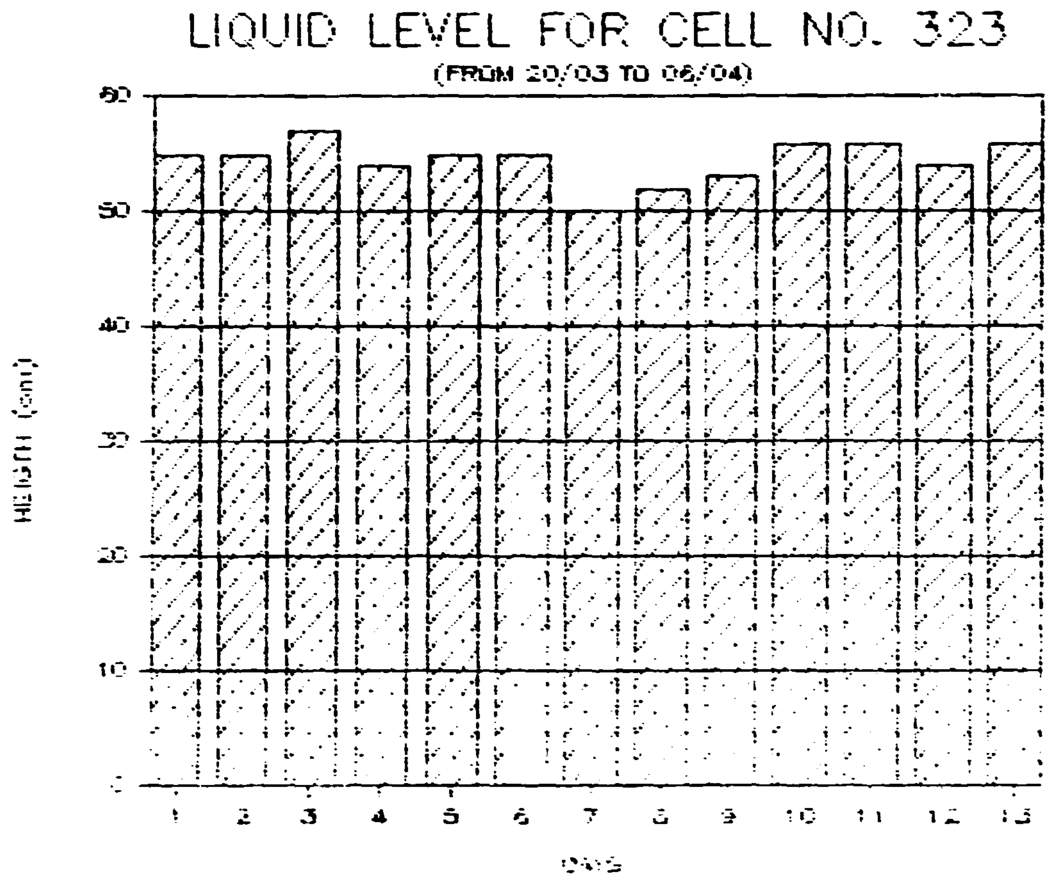
(FROM 20/03 TO 06/04)

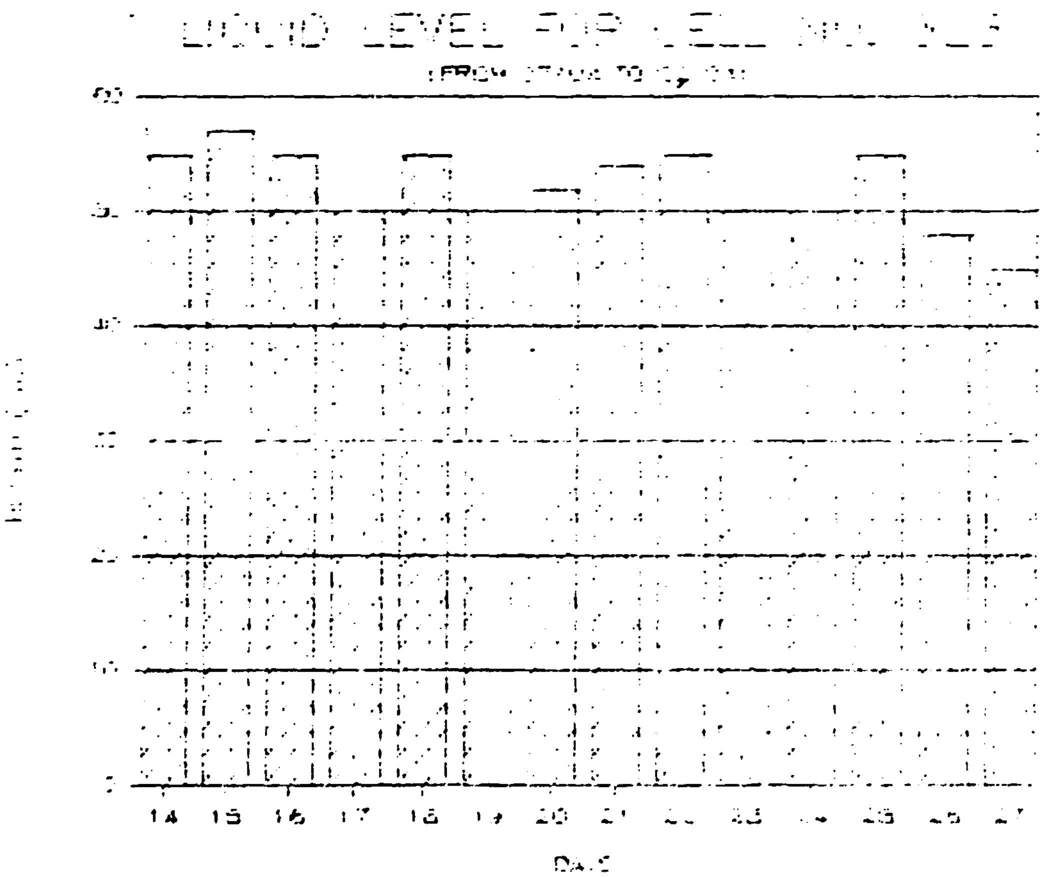


LIQUID LEVEL FOR CELL NO. 322

(FROM 07/04 TO 22/04)

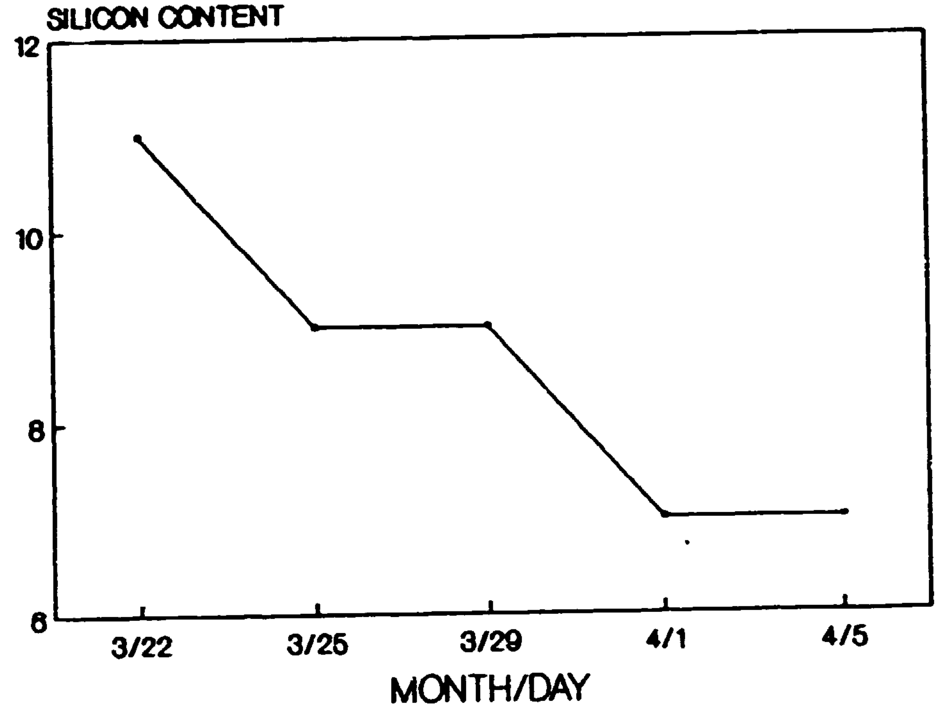



LIQUID LEVEL FOR CELL NO. 323
(FROM 20/03 TO 06/04)
HEIGHT (cm)
DAYS

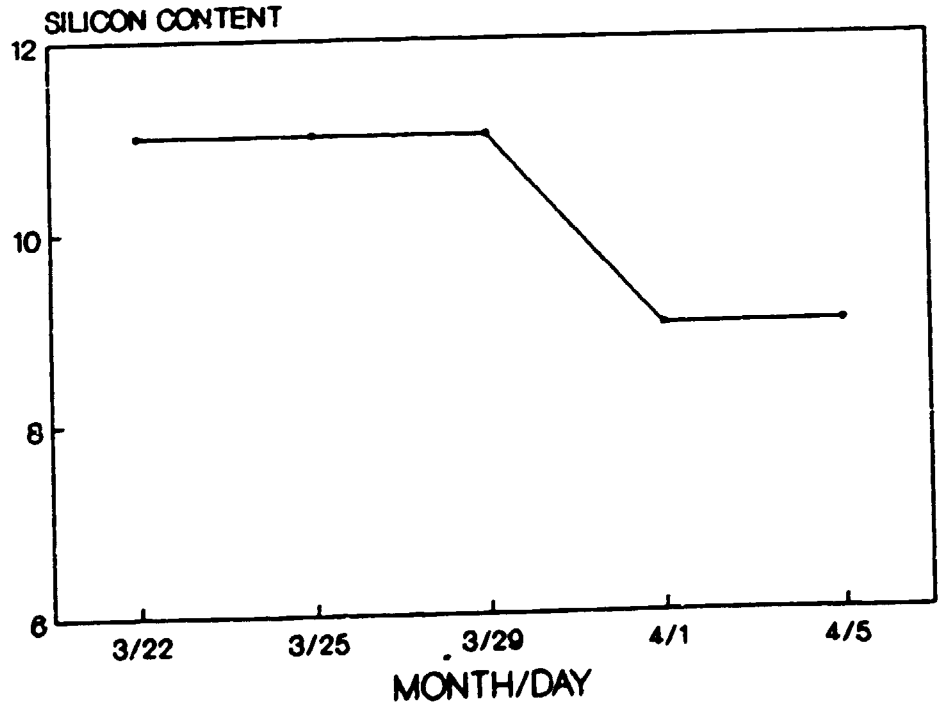


FIGURE(S) 2

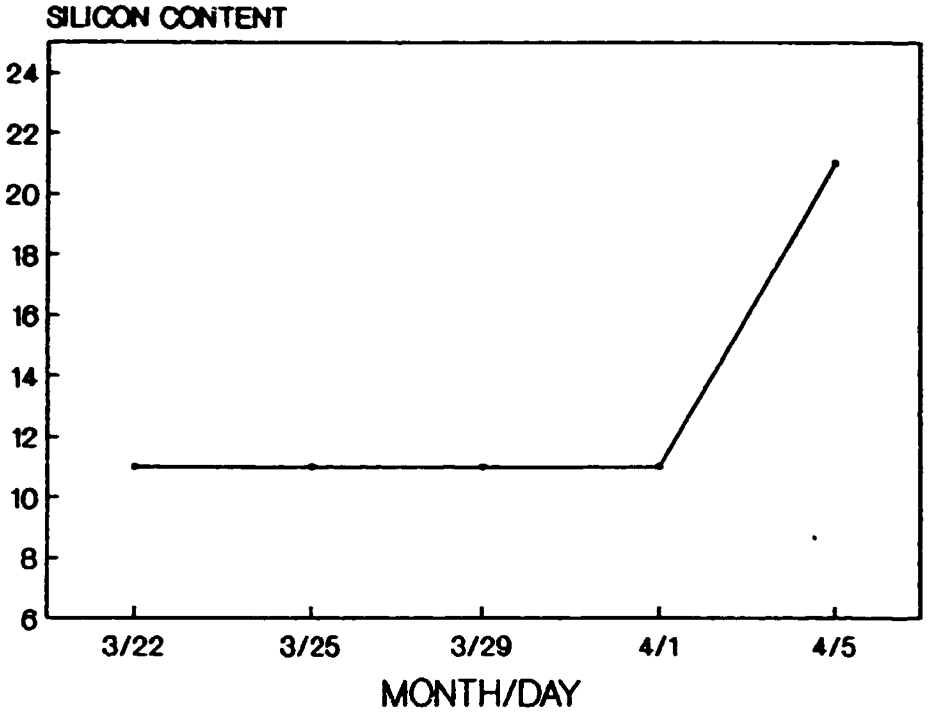
METAL ANALYSIS
(SILICON CONTENT: CELL NO. 321)



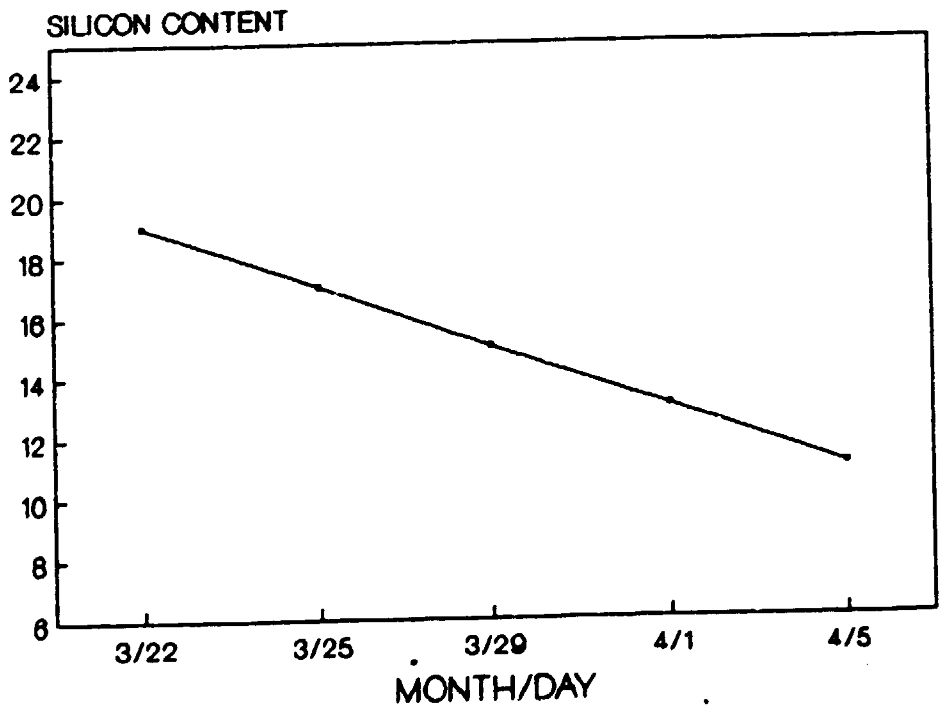
METAL ANALYSIS
(SILICON CONTENT: CELL NO. 322)



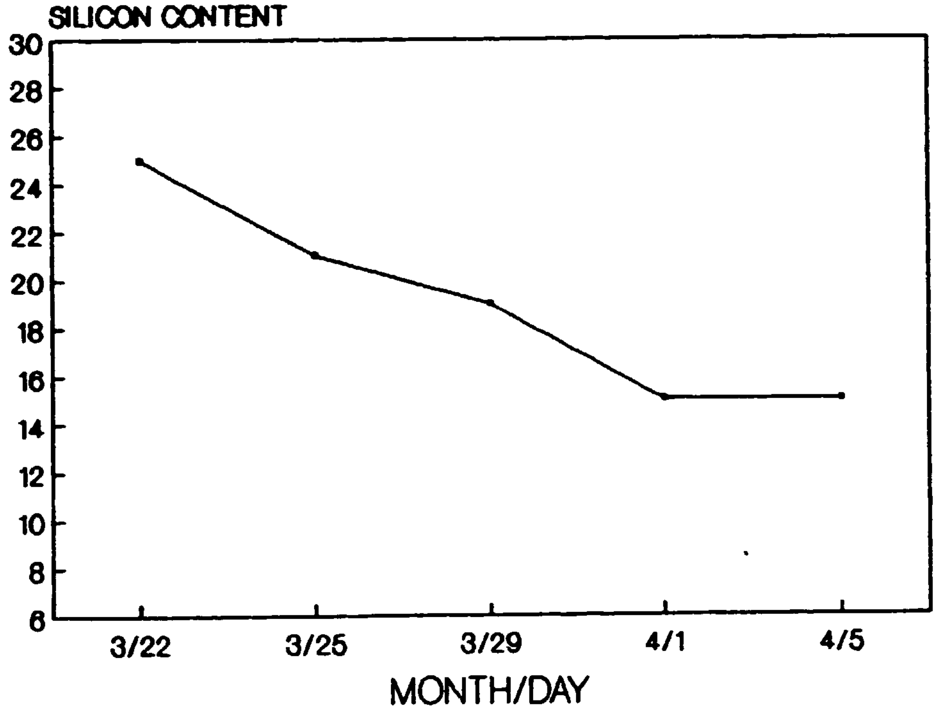
METAL ANALYSIS
(SILICON CONTENT: CELL NO. 323)



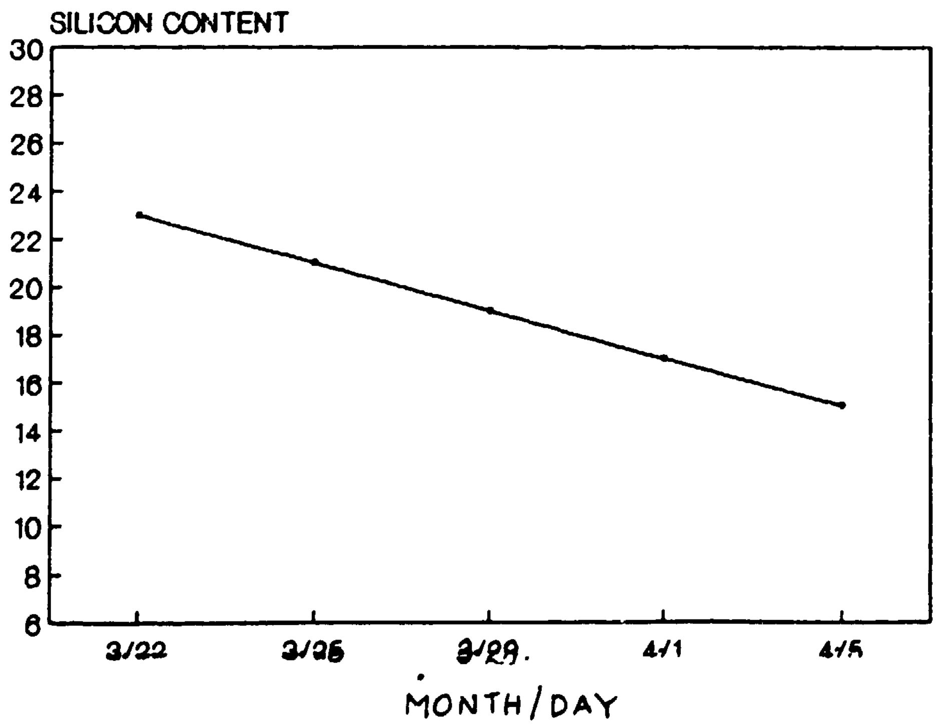
METAL ANALYSIS
(SILICON CONTENT: CELL NO. 324)



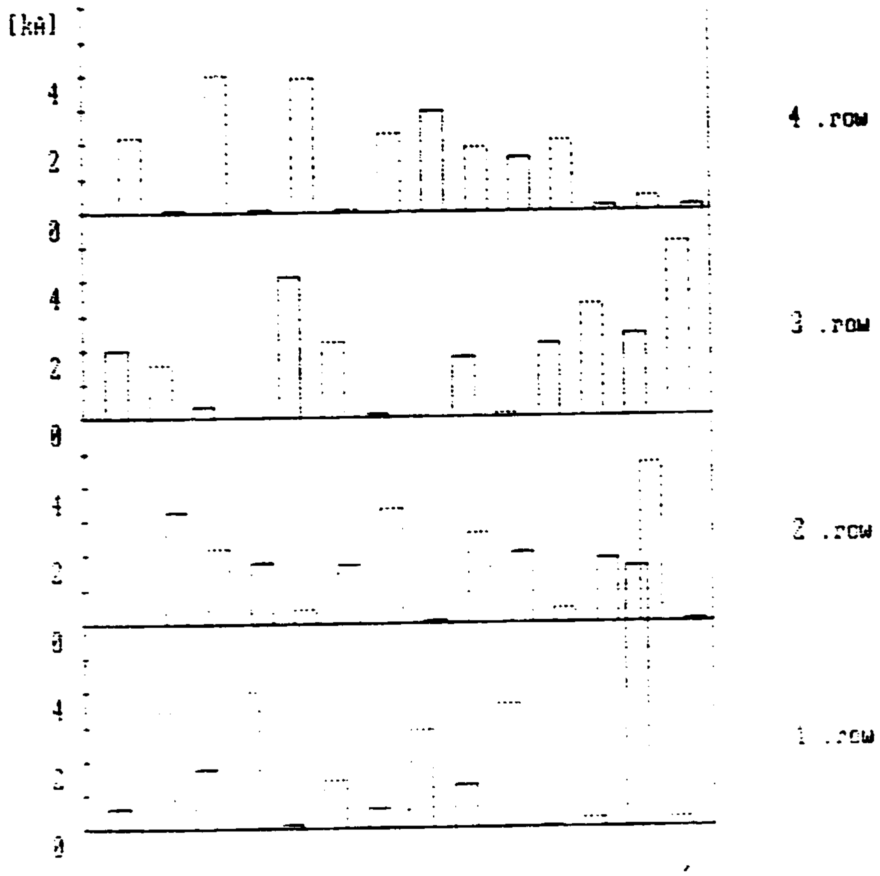
METAL ANALYSIS
(SILICON CONTENT: CELL NO. 325)



METAL ANALYSIS
(SILICON CONTENT: CELL NO. 326)

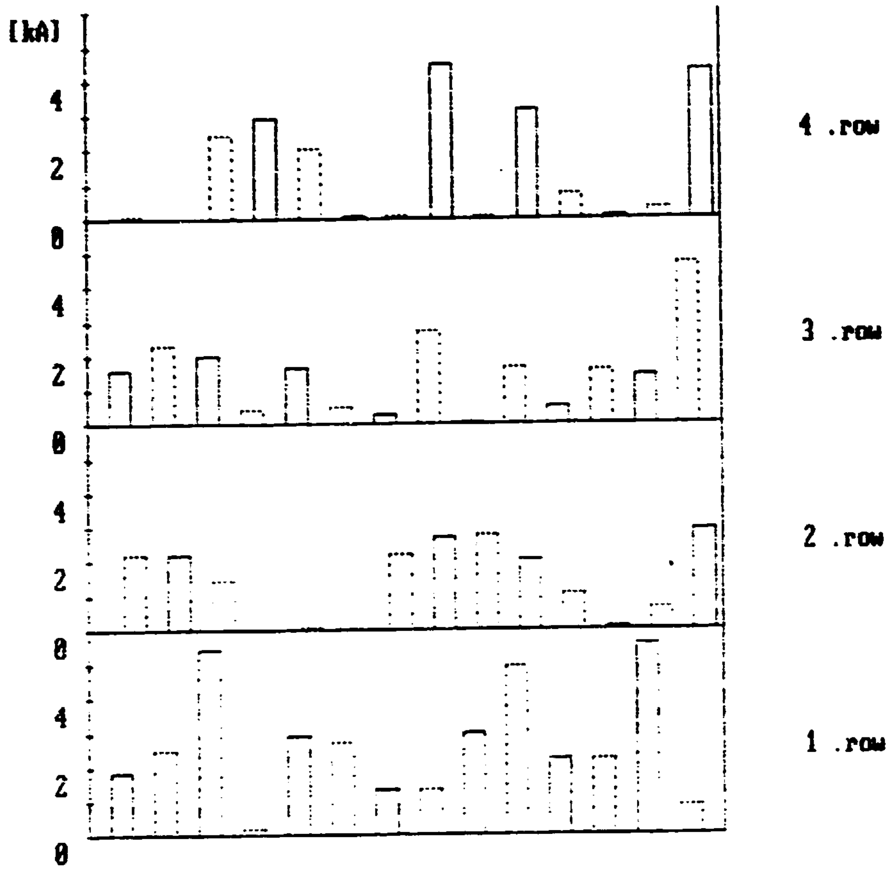


FIGURE(S) 3

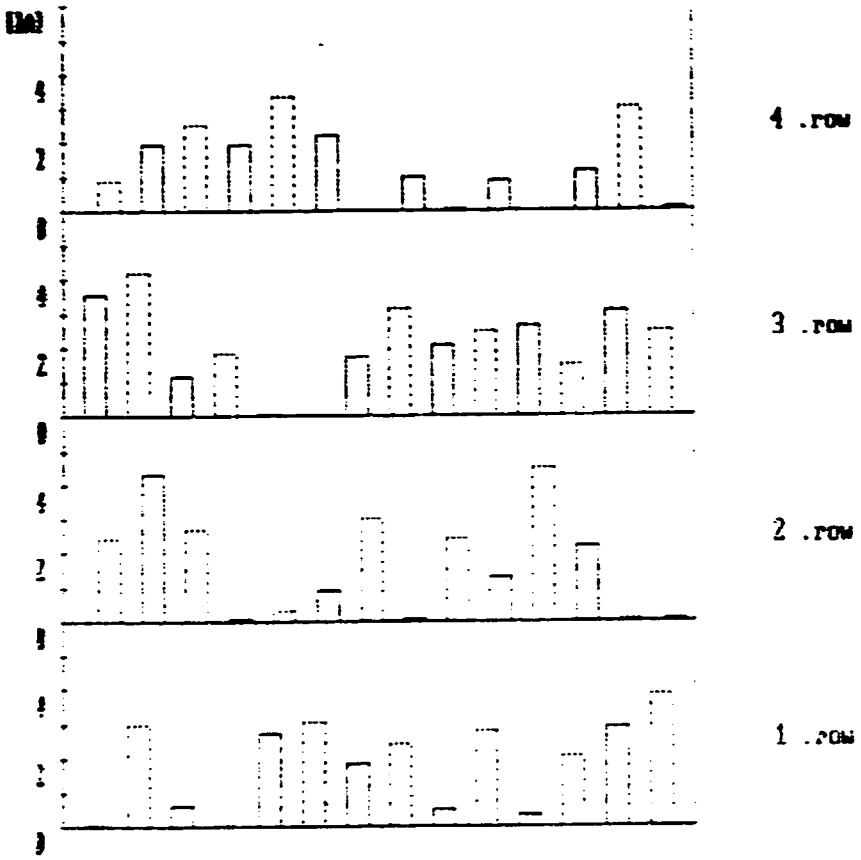


[kA]
4 .row
3 .row
2 .row
1 .row

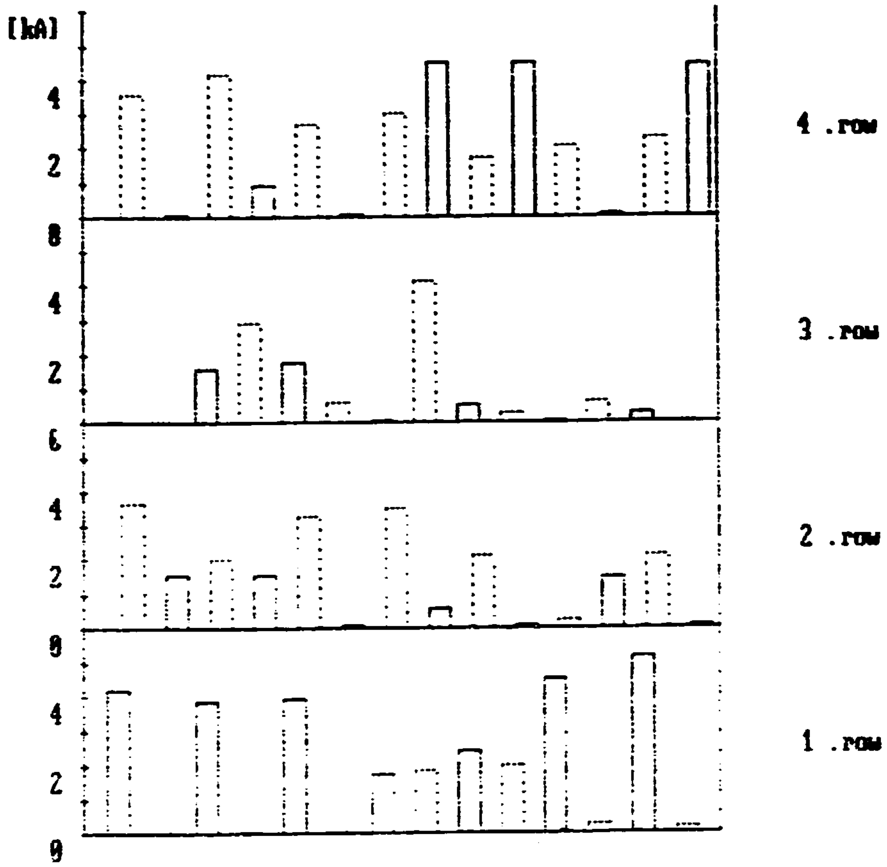
ACD\321-0325.ACD



ACD\321-0414.ACD

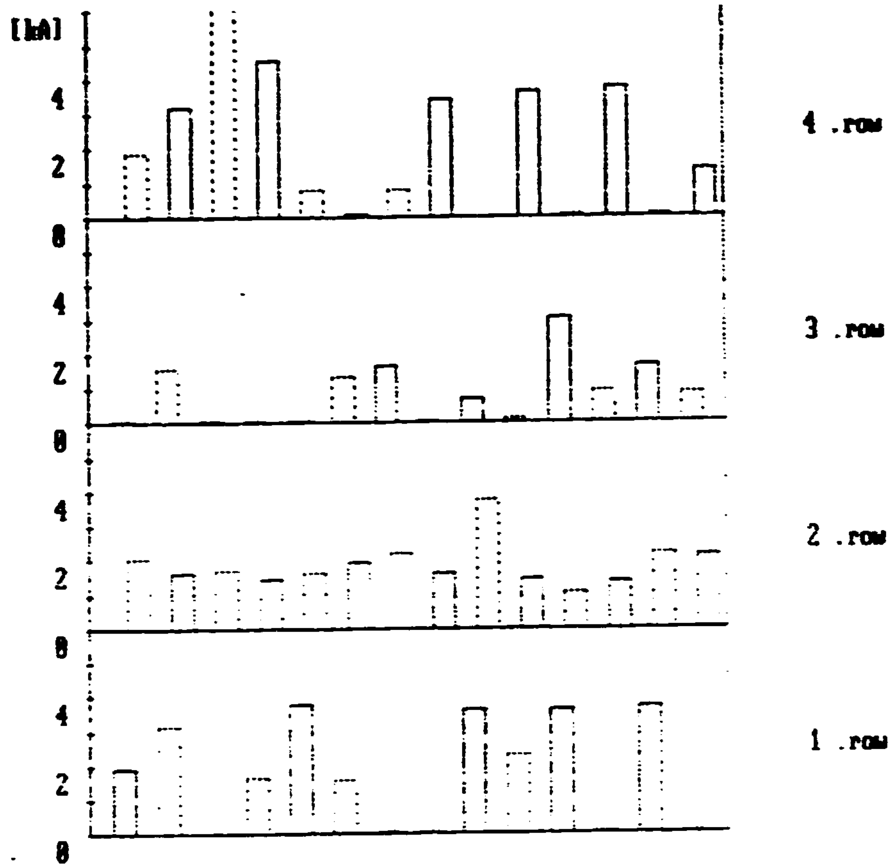


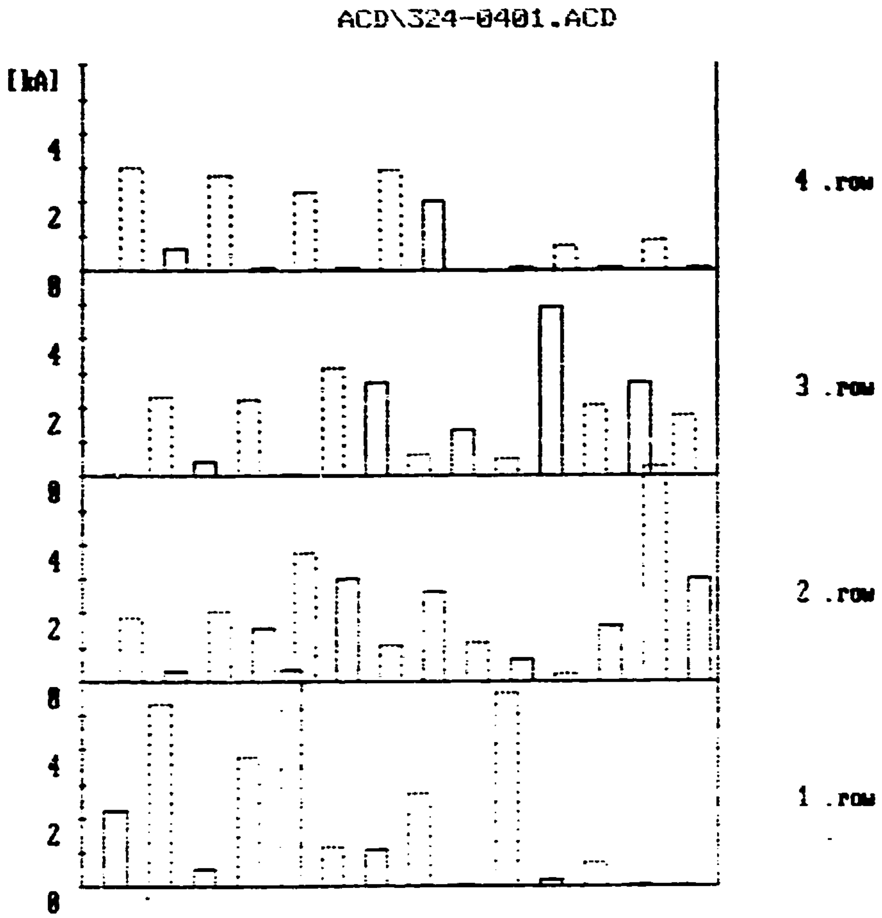
ACD\322-0414.ACD



	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[km]	[km]	[illegible]	[illegible]
[illegible]	[illegible]	14.03	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	1.36	1.77		
[illegible]	[illegible]	1.77	1.59		

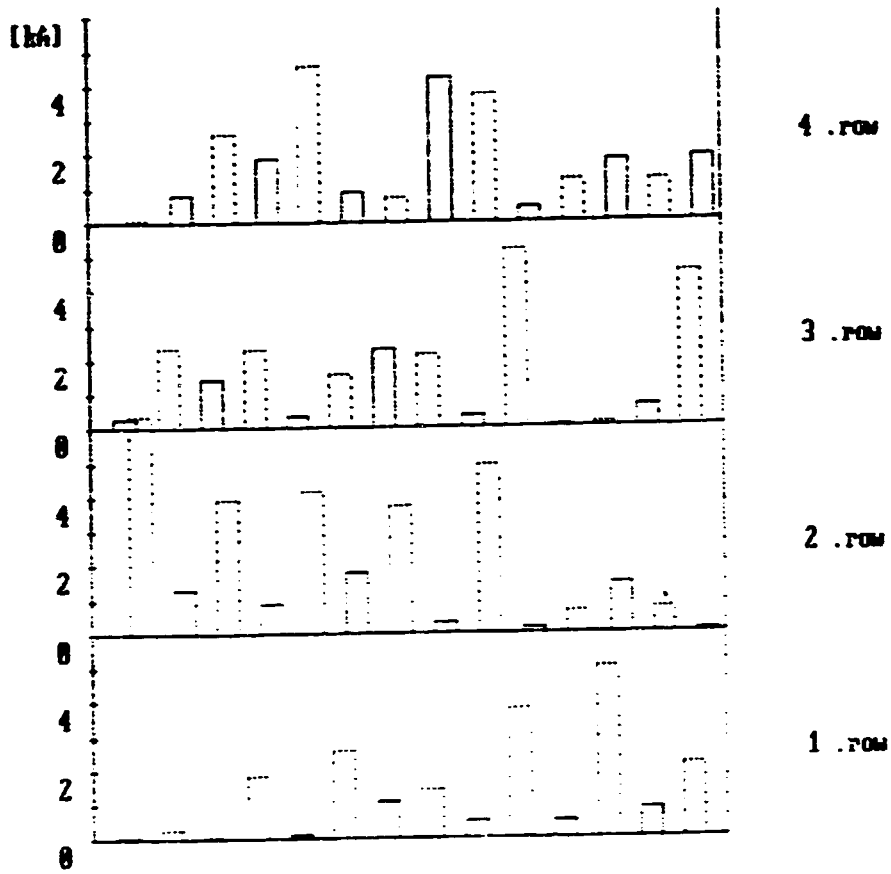
ACD\324-0326.ACD



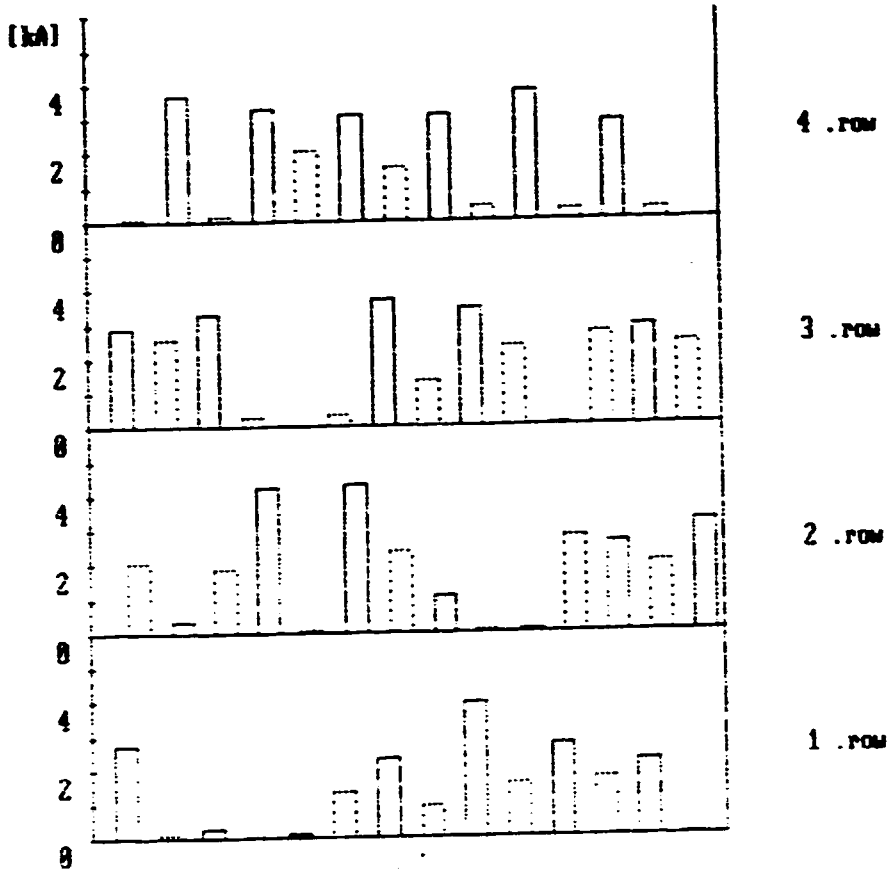

ACD\324-0401.ACD
[kA]
4
2
0
4 .row
3 .row
2 .row
1 .row

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]		

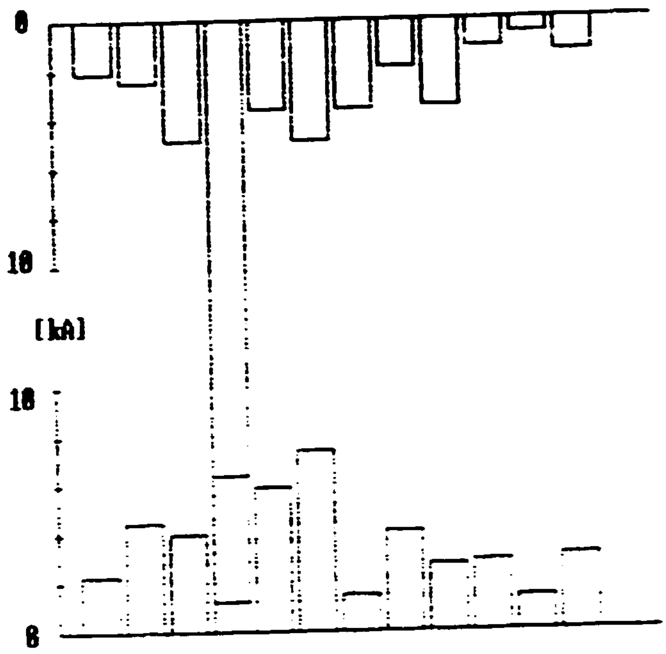
ACD\325-0326.ACD



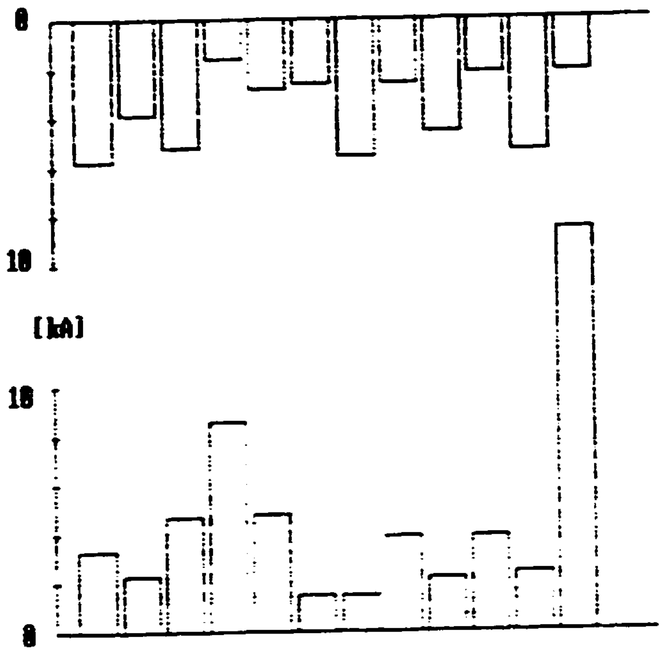
ACD\325-0419.ACD



CCD\322-0414.CCD

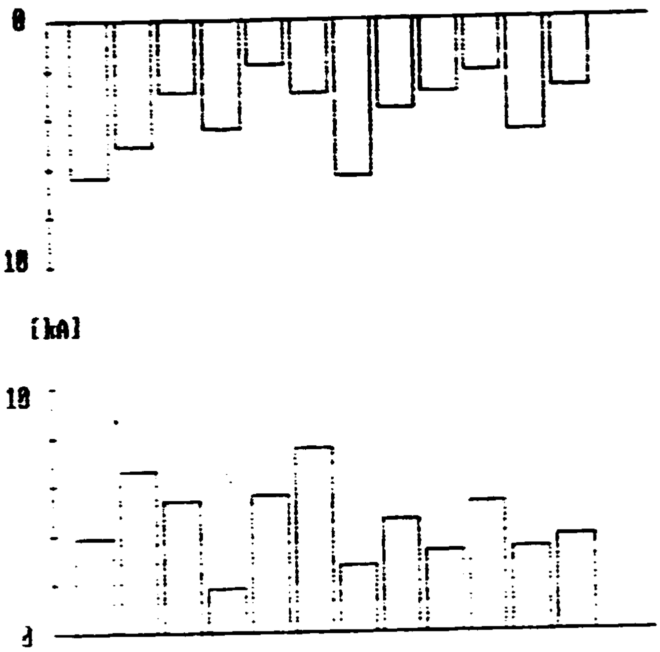


CCD-[illegible]24-0415.CCD



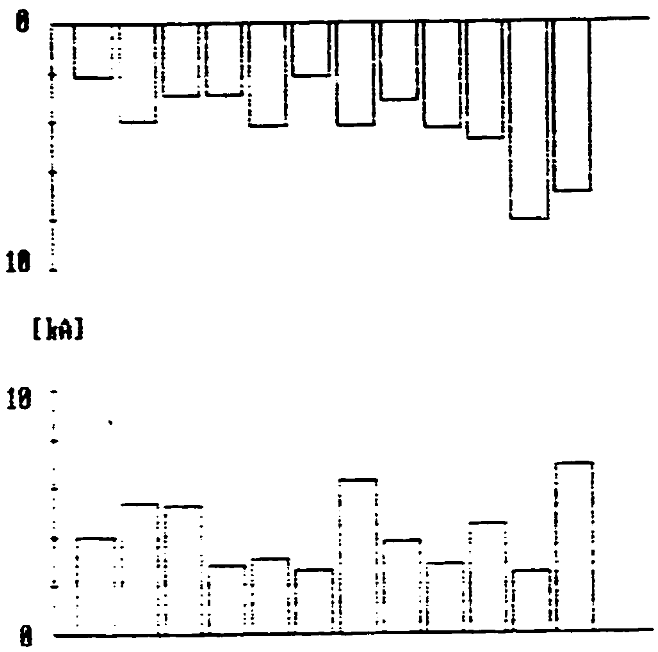
2)

CCD\324-0401.CCD

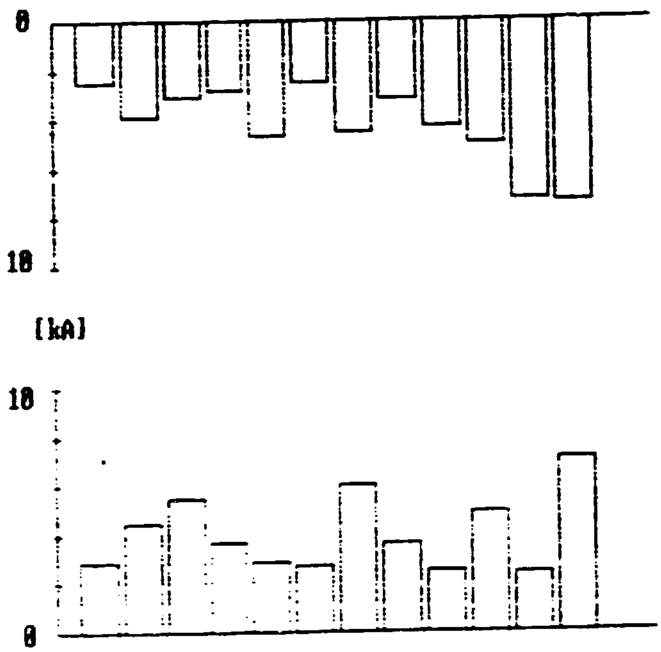


[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

CCD\325-0408.CCD

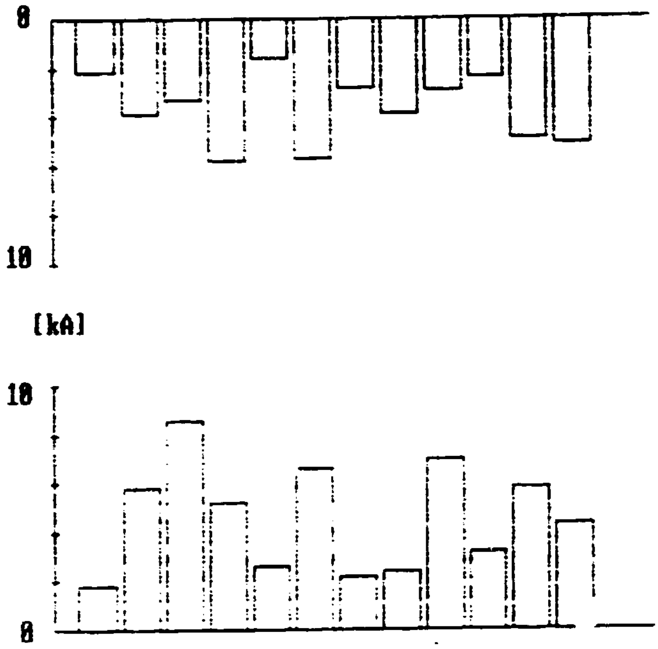


CCD\325-0415.CCD



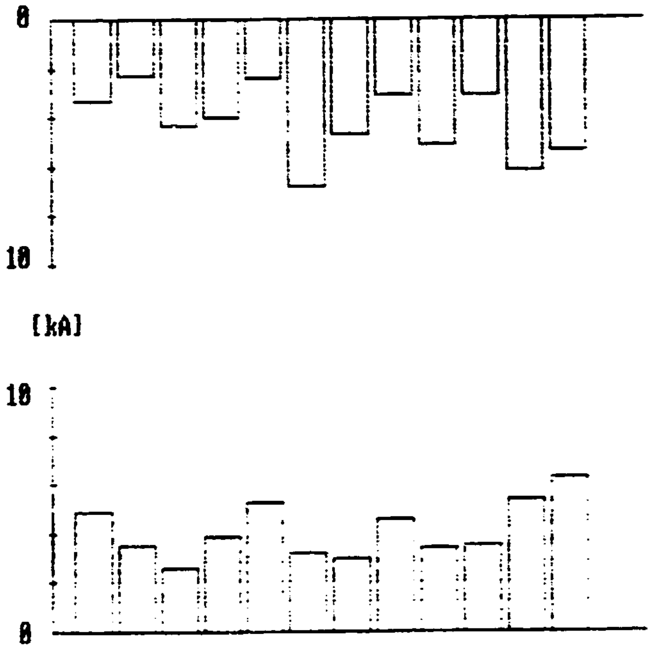
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

CCD\326-0401.CCD



	[illegible]	average	[illegible]
	[illegible]	[kA]	[kA]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

CCD\526-0415.CCD



ANNEXURE I

UNIDO

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

REQUEST FROM THE GOVERNMENT OF INDIA

JOB DESCRIPTION

DP/IND/88/015/11-05

POST TITLE: Expert in aluminium electrolysis process evaluation and control

DATE REQUIRED: September 1991

DURATION: 12 months in split missions as follows: 4 months in 1991, 4 months in 1992, and 4 months in 1993.

DUTY STATION: Nagpur, India, with travel within the country

PURPOSE OF THE PROJECT: The immediate objective of the project is to assist the Government of India in setting up a functioning Aluminium Research, Development and Design Centre consisting of:

a) Alumina Production Research Department
b) Aluminium Electrolysis Department
c) Analytical Research Department
d) General Services, instrumentation and Control Department (incl. Workshop and Maintenance)
e) General Administration and Finance Department

The Centre will develop capability of carrying out the following main functions on behalf of and in co-operation with the bauxite processing/alumina production and aluminium smelter industries in the country:

a) Assimilation and adaptation of available technologies
b) Providing recommendations and ad hoc or applied and analytical research to local industries in process improvement, transfer of technology, etc.
c) Setting up and operating a data bank
d) Providing training of Indian engineers

..../..

DUTIES: The expert will be required to assist in the setting up of the Aluminium Electrolysis Research Department of the Centre, and in particiculer of process evaluation and control laboratory. The expert will undertake and/or assist in research and investigations on aluminium electrolysis process evaluation, monitoring and control.

His main duties will be to:

a) provide training for the counterpart staff/scientists of the Centre in the measurement and monitoring of electrical parameters of the electrolysis cells, (voltage, fluctuations, noise, anodic/cathodic current distribution) as well as thermal state, magnetic field, anode gas composition and gas collection efficiency.

b) assist and train in measurement and evaluation of process data for aluminium electrolysis cells through a special mobile van.

c) assist and train in preparation of detailed energy and material balance of aluminium electrolysis cells.

d) prepare technical proposals for improvement of cells operation based on experimental measurements and process data collected.

The expert is expected to submit progress report after completion of every split mission assignment and a final report.

QUALIFICATION: University degree (preferably Ph.D.) in Chemical, Metallurgical or Electrochemical Engineering. Extensive experience in the experimental/measurement techniques for characterization of aluminium electrolysis cells parameters, evaluation of process data, preparation of energy and material balance of cells.

LANGUAGE: English

BACKGROUND INFORMATION: The Indian aluminium industry looks back to a history of 44 years. The first aluminium smelter (in Alumpars, Kerala) was put into operation in 1943. At present there are five alumina plants in operation and six aluminium smelters with an overall capacity of about 587,000 and 580,000 tonnes per year, respectively. These facilities belong to five aluminium companies, namely Bharat Aluminium Company Ltd. (Balco), Hindustan Aluminium Corporation Ltd. (HINDALCO), the Indian Aluminium Company Ltd. (INDAL), the Madras Aluminium Company Ltd. (MALCO) and the National Aluminium Company Ltd. (NALCO).

aluminium smelting is more than half of the total installed capacity of India. This indicates the decisive influence of the public sector on the future of the industry. The sustained growth and development of the aluminium industry in India, apart from requiring the adoption of suitable long term policies in relation to production management, output, pricing, and fiscal levies, is also in need for technology and market development, which will gradually be handled by the proposed Centre.

During the past years, India became one of the leading countries in the world having substantial bauxite resources, after the discovery of large deposits in the Eastern Coast in the nearly 1970ies. The total bauxite reserves of India are estimated to be of the order of 2,650 million tonnes, which places India on the fifth place in the world list.

With the vast reserves of bauxite and coal in India, the aluminium industry has ambitious plans for a faster growth rate keeping in view the future demand in the foundry and export potentials.

The existing alumina/aluminium plants in India are based almost entirely on technology imported from various sources. Both in the areas of production of alumina and aluminium, a number of technological improvements have taken place in advanced aluminium producing countries. Import of improved technology is not always possible, also its introduction is not feasible in the existing plants. Import of technology necessitates proper assessments to determine its suitability under Indian conditions, the available raw materials, product demands, state of engineering developments, etc. Though research and development work is being carried out by the major aluminium producers in the country, these are mainly directed towards solving their day to day process problems in the plants. No work is done for the development of process know-how and basic engineering. The technologies followed in the existing plants are from various countries/suppliers - KAISER, ALUTERV-FKI, VAMI, ALCAN, MONTECATINI and ALUMINIUM PECHINEY. Apart from the strategic importance of having an indigenous Research, Development and Design Centre for Aluminium, the Centre is expected to save substantial hard currency payments to the foreign partners.

For meeting the estimated demand of aluminium by the turn of the century, substantial additional capacities for alumina and aluminium will have to be set up in the 1990ies. Additional demand for aluminium by the turn of the century, which is in excess of the currently available capacity would be of the order of 440,000 tonnes per annum which at the current selling price of aluminium amounts to Rs. 1180 crores. Considering the payment for know-how, basic engineering and royalties for this additional follow-up stage this would mean an expenditure of at least another Rs. 1.2 billion equivalent to US$ 95 million.

It is to be pointed out that the cost for Establishment of the Aluminium Centre in Nagpur (both Indian Government and UNDP contribution) is of the order of US$ 12.5 million. The financing of operations and further development of the Centre is envisaged by the Government to be secured through a collection of Rs. 100 per tonne of aluminium for aluminium research and development, added to the price of aluminium (established now by the State in India). The funds so generated would serve as financial basis for operation and further extension of the Centre.

When the new aluminium capacity will be established the Centre will be fully functioning and if it contributes to savings of only ten per cent of the expected expenditure for project engineering and royalties, apart from rendering other useful services, its establishment would be fully justified.

It is to be noted that all the leading aluminium producing countries have their own R and D centres. Close interactions among these Centres' Research and educational institutions and industry has enabled numerous technological advances - this example is needed to be followed in India.

In the light of the above, a co-ordinated effort in R and D will be essential for the development of know-how and basic engineering to self-reliance in alumina and aluminium technology needed for the establishment of future plants without need to go for foreign consultancy. Future development of aluminium industry in the country based on indigenous expertise demands the immediate establishment of a self-reliance full-fledged and independent research, development and design centre for aluminium at the national level.

The development objective of the project is to aim at self-reliance in alumina and aluminium production technology and to achieve faster growth of the Indian aluminium industry to meet the domestic demand for aluminium products. This goal will be achieved by setting up of an Aluminium Research, Development and Design Centre at the national level which will be in a position to carry out research and development in the field of bauxite processing, alumina and aluminium production leading to improvement in the existing plants and creating new production facilities. Thus, the output of the project will be physical facilities of an Aluminium Research Development and Design Centre, adequately equipped with specialized research and testing equipment and trained professional staff to render research and development technology in the existing plants and for setting up of new alumina/aluminium production facilities based on indigenous raw materials and natural resources.

with the use of by-products, design improvements for saving of energy and materials, development of new products and alloys. Another particular problem that the Centre is expected to address is emanating from the lack of adequate and uninterrupted power supplies which has led to poor utilization of capacities in the recent past. Investigations into energy saving technologies of alumina and aluminium production will be one of the important tasks that the Centre will have to tackle.

It is expected that once the Centre is established it will meet the fast growing technological service needs of the aluminium industry in India. The Centre will consist of the following departments:

- Aluminina production research department with four laboratories and one pilot plant;

- Aluminium electrolysis research department with four laboratories;

- Analytical research department with three laboratories;

- General services, instrumentations and control department with four sections;

- General administration and finance department with three units.

The civil construction works for the Centre started in Nagpur in 1990 and will be finished by 1992-1993. The centre is planned to fully operate/function by 1994-1995.

The assignment of the national staff and procurement of equipment started in 1989-1990. The first R/D works are expected to start in 1991-1992. Training of the staff will be carried out in India and abroad.

For a more detailed information reference could be made to the Project Document and the Detailed Centre Design.

ANNEXURE II

SCHEDULE PROGRAMME

1) Preparation of proposal to introduce the capabilities of the centre for Kaiser Aluminium Technical Service Inc / KATSI /.
   * 10 th February

2) Organization of training programme for new staff members on the background of the laboratory measurements in cryolite alumina melts.
   * 15 th March

3) Finalization of the laboratory equipments in the carbon and electrolysis laboratories
   - Clarification regarding the requirement of consumable materials and chemicals
   * 15 th March

4) Visit to BALCO, Korba smelter
   - To organise and prepare for the revitalization programme
   - To inform the BALCO management about the measurement programme
   - To carry out the first phase of the measurements
   * 4 th April

5) Visit to NALCO, Angul smelter
   - To carry out the heat-flux measurements on the base of schedule programme prepared and agreed upon on last mission
   - To discuss and finalize the next measuring programme
   * 6th April

6) Visit to BALCO, Korba smelter
   - To continue the revitalization programme
   - To discuss the partcipation of JNARDDC with the Kaiser Aluminium Technical Services Inc. expert
   * 3 rd May

7) Ellaboration of the proposal to Kaiser Aluminium Technical Services
   * 7 th May

8) Evaluation of the measuring data
   * 22nd May

9) Mission report preparation
   * 24 th May

THE MAIN ACTIVITIES

1) Training programme for members of the aluminium electrolysis department.

and

Training programme for members of BHARAT ALUMINIUM COMPANY and NATIONAL ALUMINIUM COMPANY.

2) Carrying out measurment programme, revitalisation programme and technological tests at BHARAT ALUMINIUM COMPANY. Korba

and

Heat-flux measurements at NATIONAL ALUMINIUM COMPANY, Angul.

3) Evaluation of "revitalization programme" and heat flux measurements.

4) Preparation of proposal for KAISER ALUMINIUM TECHNICAL SERVICE (KATSI) according to the agreement between BALCO and JNARDDC .

5) Elaboration of the proposal for KAISER TECHNICAL SERVICE (KATSI) in which measurements are to be carried out during BALCO modernization by JNARDDC.

6) Other activities were :

   a) Preparation of the list of equipment accessories. consumables to be procured for carbon and electrolysis laboratories.

   b) Calculation of voltage and energy balance during the energy modulation of INDAL smelter

ANNEXURE III

TRAINING PROGRAMME FOR MEMEBERS OF ALUMINIUM ELECTROLYSIS DEPARTMENT

OBJECTIVES

1) To understand the mesurment methods used for :

- study of cryolite - Alumina melt
- BALCO revitalisation programme
- understanding the background of high performance smelter technology.

2) Principles of measurment methods for process study in cryolite - alumina melts.

Study of anode & cathode processes

In electrochemical processes chemical reaction i.e. oxidation and reduction take place due to potential applied between two electrodes in contacts with electrolyte. The principle for studying the electrochemical reaction and its kinetics is to determine the rate - determining step in the process. The electrochemical reaction is determined by transport phenomenon or chemical reaction due to which this is considered as "diffusion or kinetics limiting current ".

MEASURING METHODS AND TECHNIQUES FOR STUDY OF ELECTROCHEMICAL PROCESS

MEASURING TECHNIQUES

- GALVANOSTATIC
  - CHANGING CURRENT STEP BY STEP
  - CHANGING CURRENT BY IMPLUSE
- POTENTIAL CONTROL
  - PONTENTIOSTATIC
  - POTENTIAL SWEEP

Decomposition potential of cryolite-alumina melt can be determined by the method shown Fig. 1. For determination of decomposition voltage of alumina, the graph obtained can be extrapolated (at inert Pt electrode) as shown in Fig.2.

In Fig. 3 the extrapolated value is the decomposition voltage of alumina in presence carbon electrode and aluminium melt .

The alumina decomposition voltage can also be determined by thermodynamical data - voltage demand for alumina decomposition is 2.1 - 2.2 V without consumable carbon electrodes.

On using carbon electrodes the voltage demand for the decomposition consists of the following voltage components :

a) Equilibrium potential (non-heat generation element, it means the electrochemical work)

b) Depolarisation potential

   i) Overvoltage (heat generated voltage components)
   ii) Carbon burning (heat generation element)

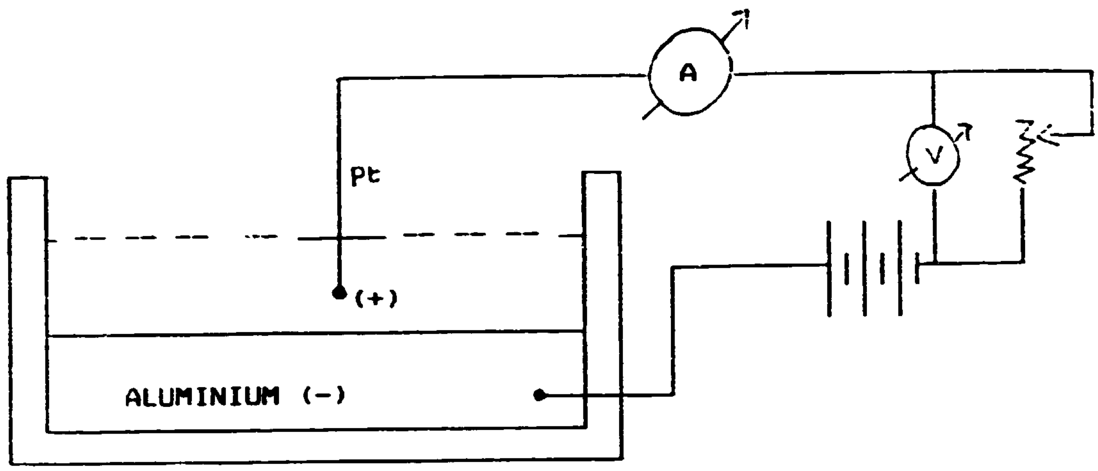


Figure (1)

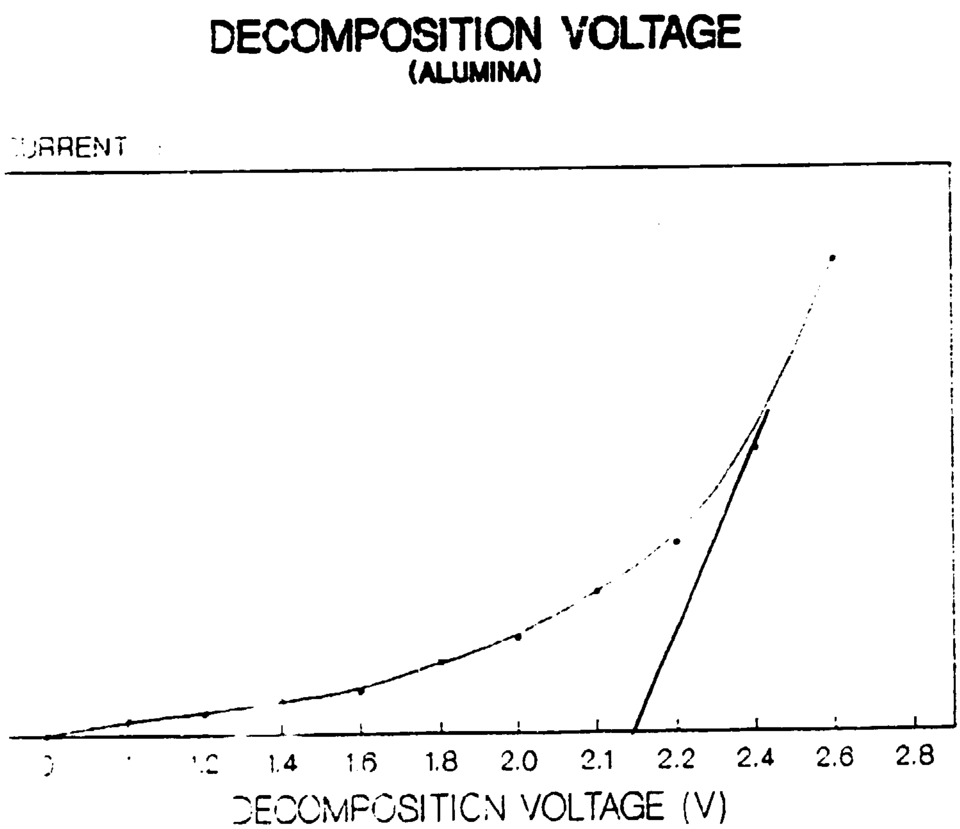


FIGURE (2)

DECOMPOSITION VOLTAGE
(IN PRESENCE OF CARBON ELECTRODE)

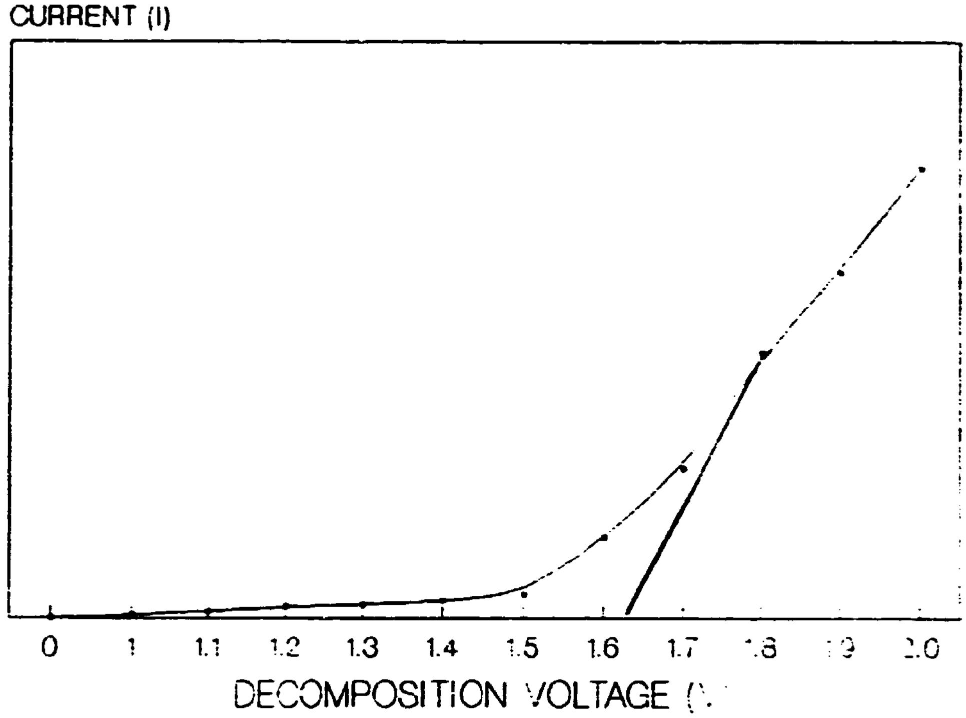


Figure (3)

2.1-2.2 VOLTS

DECOMPOSITION VOLTAGE OF Al_2O_3 1.7V

JOULE'S HEAT IS NEEDED FOR DECOMPOSITION

ANODIC & CATHODIC OVERVOLTAGE 1.1 – 1.2 VOLTS.

EQUILIBRIUM POTENTIAL

(THE ELECTROCHEMICAL WORK OF PROCESS.)

The extrapolated decomposition voltage of alumina is not enough for determination of voltage demend for aluminium production. The voltage demand of production is determined by thermodynamic function.

Components of decomposition voltage

1] Equilibrium potential

2] Anodic overvoltage
   i) Diffusion
   ii) Reaction

3] Cathodic overvoltage

METHODS FOR DETERMINATION OF DECOMPOSITION VOLTAGE COMPONENTS

Decomposition Potential

Determination of electromotive force of galvanic cell

$$Al \;|\; Na_3AlF_6 + Al_2O_3 \;|\; CO_2 \;|\; C$$

$$Al \;|\; Na_3AlF_6 + Al_2O_3 \;|\; CO \;|\; C$$

EMF of galvnic elements give the value of equilibrium potential (Fig. 4).

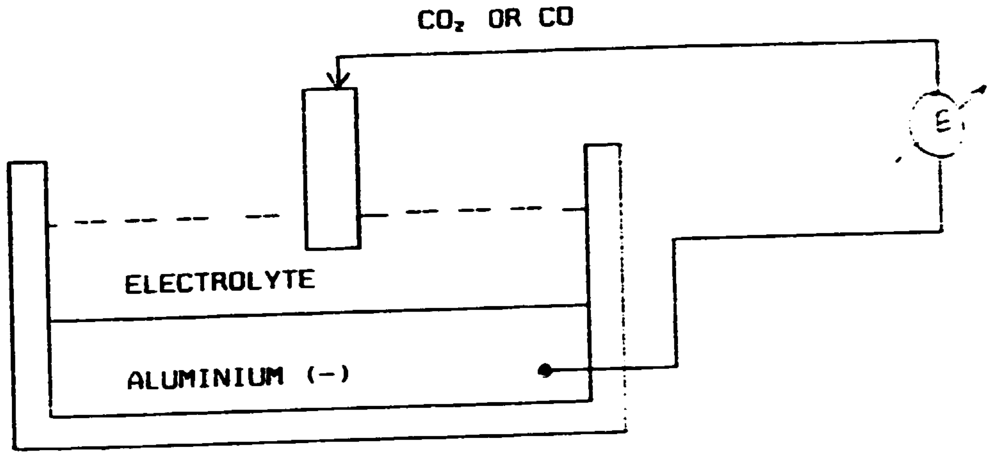


Figure (4)

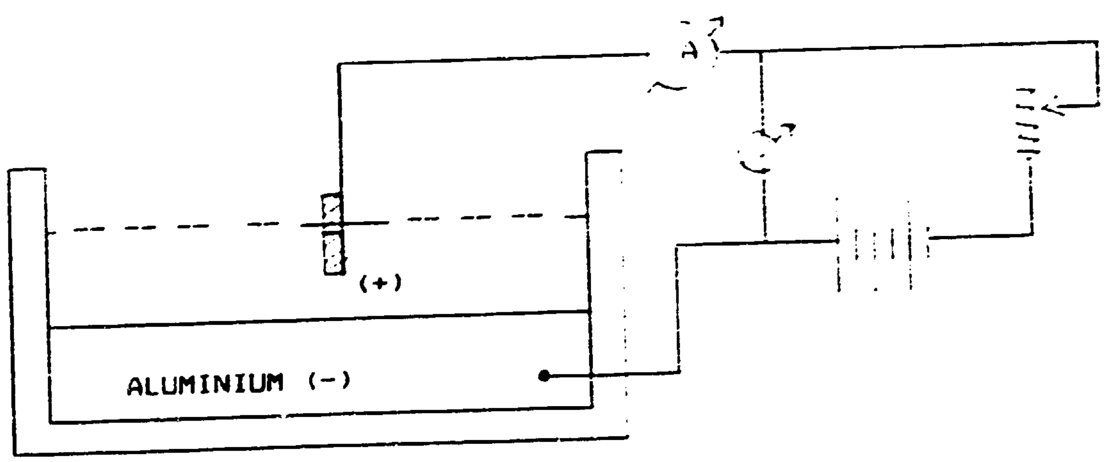


Figure (5)

$E = E^o + (RT / nF)(\ln a_{Al2O3})$

If C_{Al2O3} – saturated in cryolite

$a_{Al2O3} = 1$ so $E = E^o$

Thus we see that E^o-E depends on the activity of alumina in melt

Value of E decreases with increase in CO generation .

DETERMINATION OF ANODIC OVERVOLTAGE ON GRAPHITE IN CRYOLITE-ALUMINA MELTS

If the molten aluminium surface is 100 times higher than anode surface we consider the cathode as a non-polarised electrode. The current is disconnected and the memory oscilloscope reading is taken and plotted as a function of time (see Fig. 6).

In Fig. 6 the vertical voltage drop measured, is known as ohmic voltage drop. The difference between voltage (V_2 - V_3) gives the anodic overvoltage value. V_3 is considered as 'quasi equlibrium potential'.

To separate the electrochemical kinetics measurements during the anode and cathode process, potentiostat and reference electrodes are used. For the study of anodic process, polarisation curves are plotted which are obtained by potential sweep method (Fig 7).

Voltage between the reference electrode & graphite electrode is to be adjusted and the result (as current) is to be measured. This curve is also called the 'SO-CALLED' polarisation curve or voltamogram (Fig. 8).

- Limiting current
  - Diffusion limiting current
  - Kinetic or chemical limiting current

With graphite in cryolite-alumina melt, the form of polarisation curve is as shown in Fig. 9.

ANODIC OVERVOLTAGE
(CRYOLITE-ALUMINA)

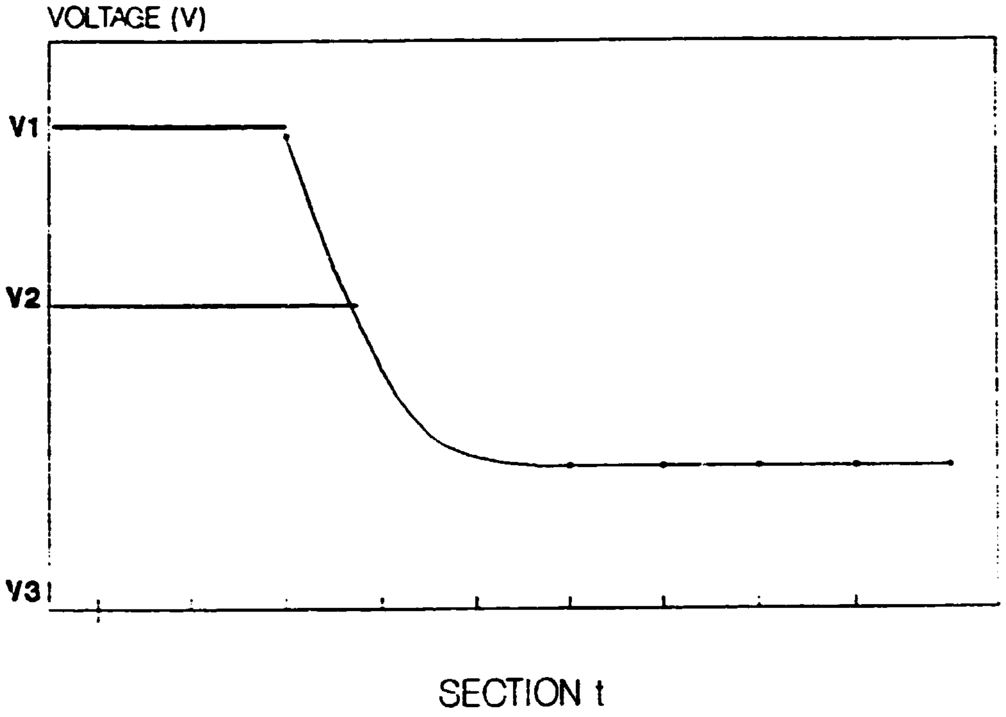


Figure (6)

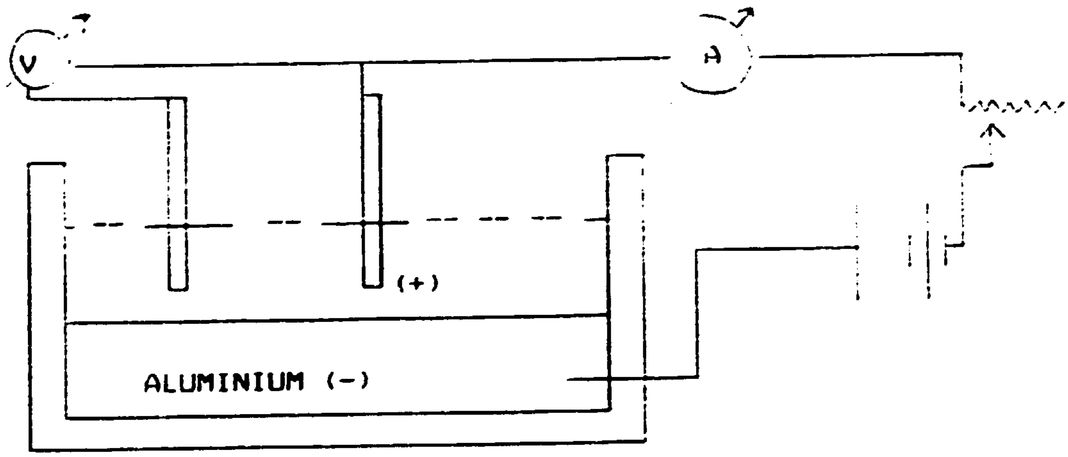


Figure (7)

POLARISATION CURVE

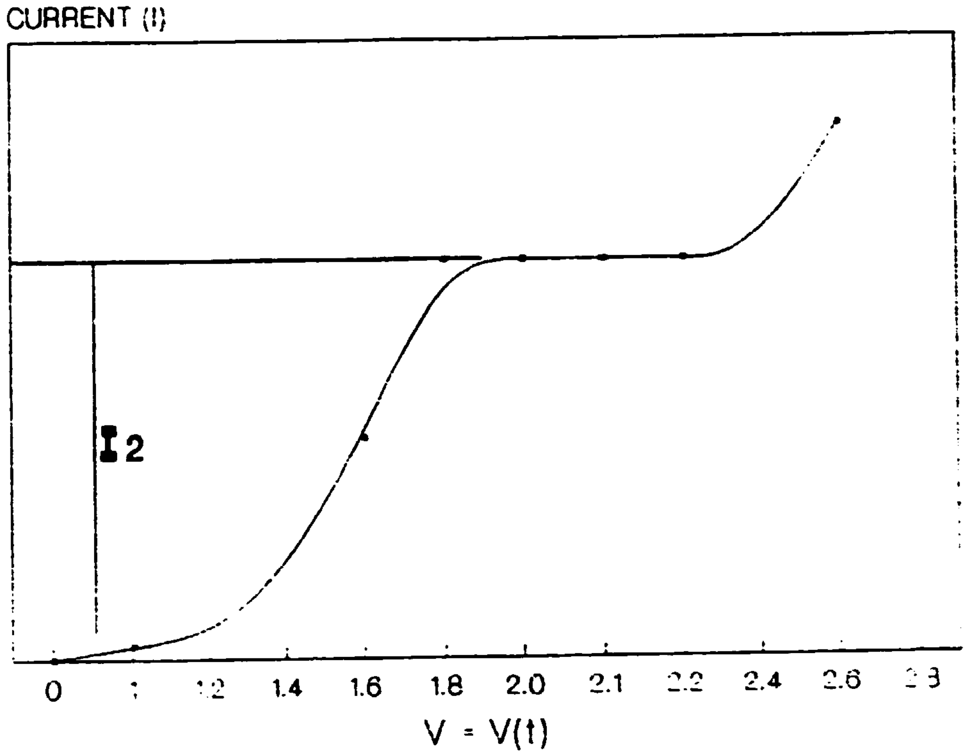


Figure (8)

CRITICAL CURRENT DENSITY

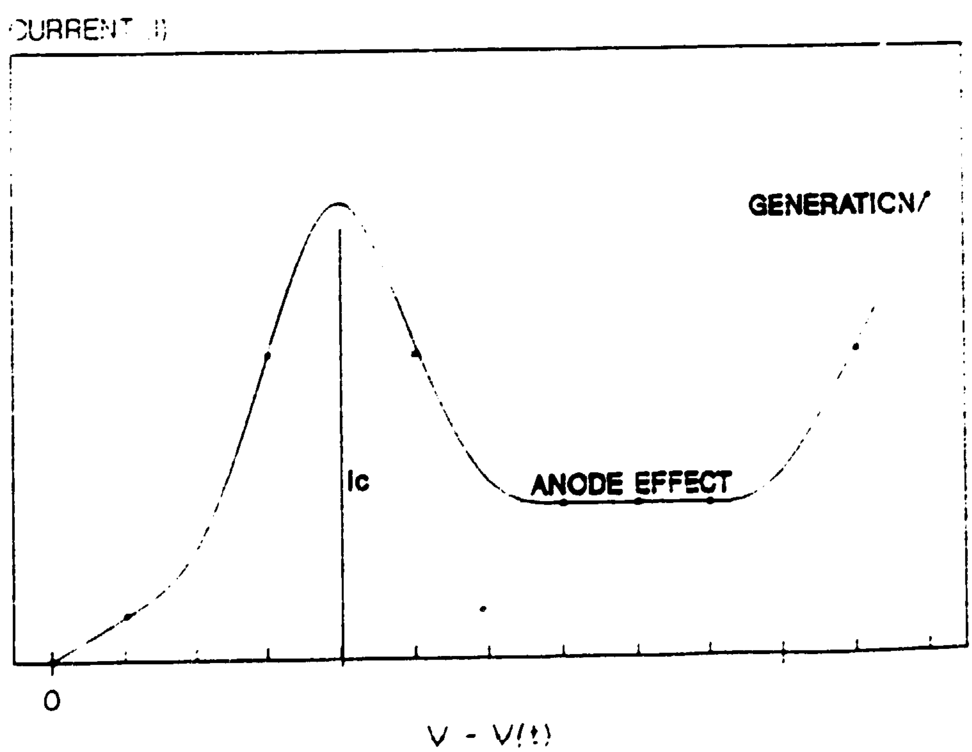


Figure (9)

ELECTROCHEMICAL MEASUREMENTS FOR STUDY OF DISSOLVED ALUMINIUM IN THE BATH

Potential sweep method (Fig 10). Limiting current is proportional to dissolved alumina concentration After calibration by this method the alumina dissolution process can be detected.

Study of alumina dissolution in cryolite melts

1) Test with mixing of molten electrolyte

   This method is suitable to determine the effect of electrolyte composition and superheat on alumina dissolution. In this case the alumina is dispersed in the melt.

2) This is suitable to evaluate the effect of physical - chemical properties of alumina for dissolution. In this case mixing is not used during the test.

The determination of liquidus temperature of bath

Liquidus temperature is determined as shown in Fig 11. After switching off the energy supply unit of furnace, the temperature is to be measured in function of time. Use of Pt crucible in presence of carbon is forbidden.

Electrical conductivity measuring technique for cryolite-alumina melts

The measurement is carried out in following ways :

- artificial bath without carbon, using Pt probe for measurement
- industrial bath in presence of carbon Pt electrode, BN or graphite crucible are used.

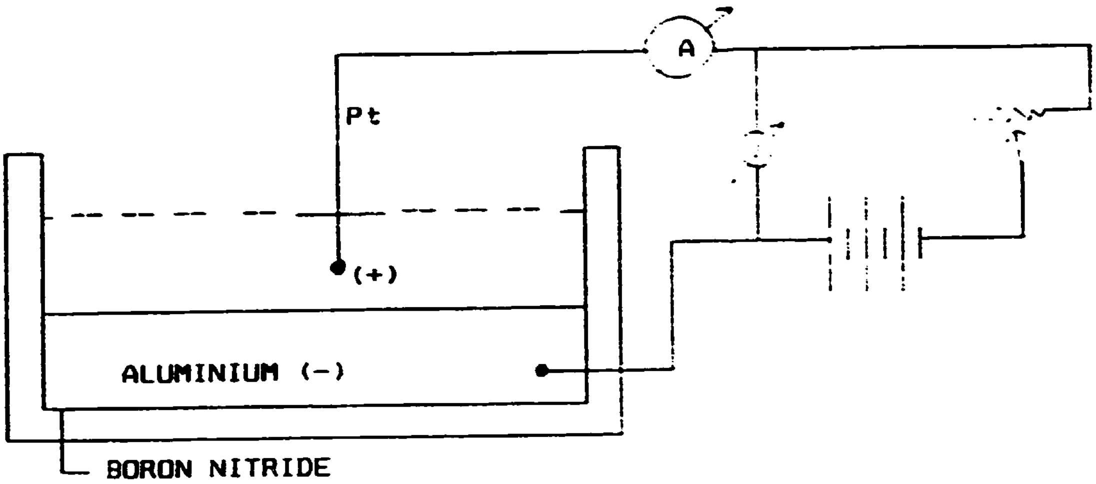


Figure (10)

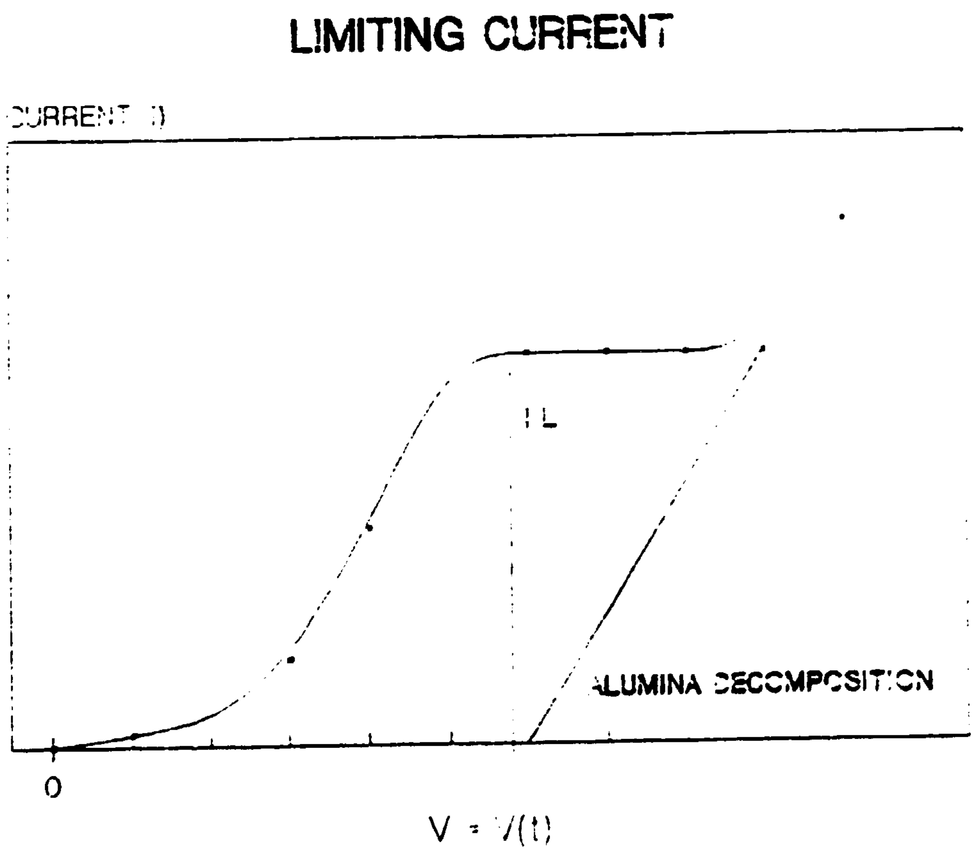


Figure (11)

In the measurement of electrical conductivity, the total impedance of the measuring circuit, Z

$$Z = R_m + X_c + X_l$$

where,

R_m - real resistance
X_c - inductive component of impedance
X_l - capacitive component of impedance

$$R_m = R_o + R_f + k$$

where,

R_o - ohmic resistance of the electrolyte
R_f - the polarization resistance of the electrolyte due to frequency effects
k - the constant resistance between wires

At very high frequency of polarization resistance of electrolyte, R_f is decreased significantly and it's value is neglected

At fixed high frequency R_m is considered the real component of circuit.

The electrolyte conductivity K can be obtained by using :

$$K = \frac{1}{A\,(dR_m/dL)}$$

where.

K - the conductivity of electrolyte
A - cross section area of conductivity cell. it is determined by calibration

dR_m/dL - is measured during the experiment

DISSOLVED ALUMINIUM Vs LIMITING CURRENT

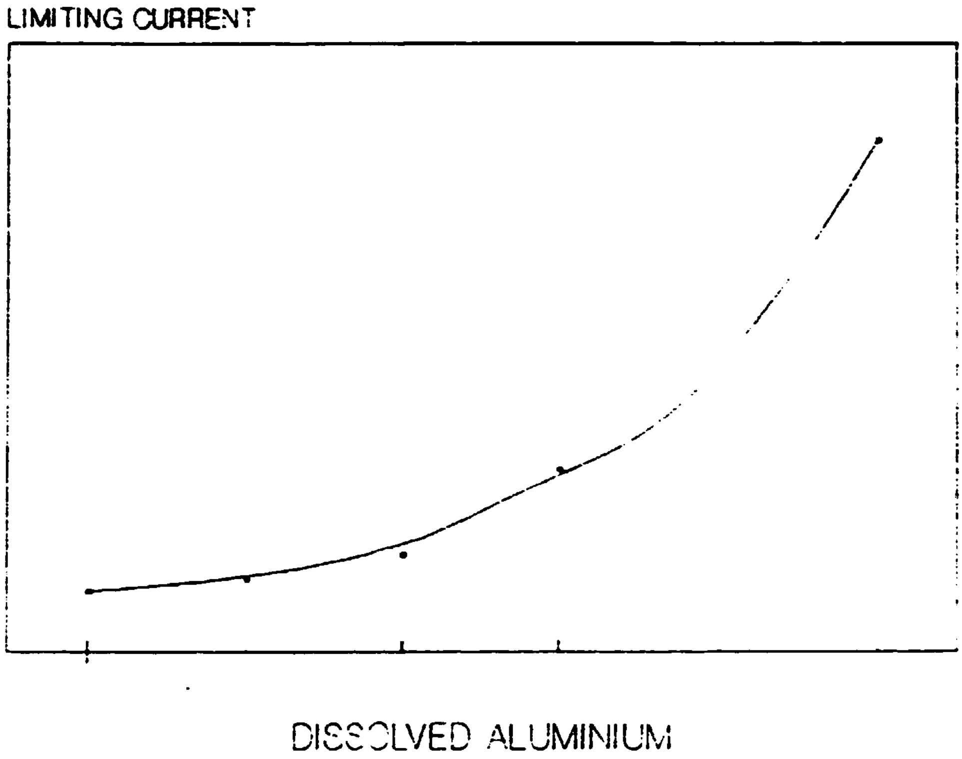
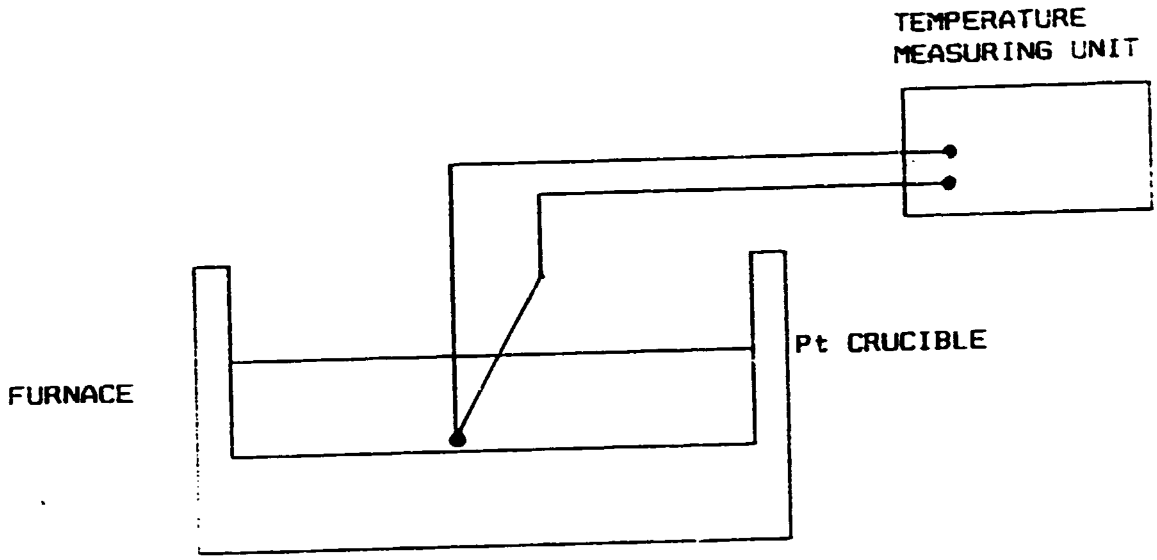
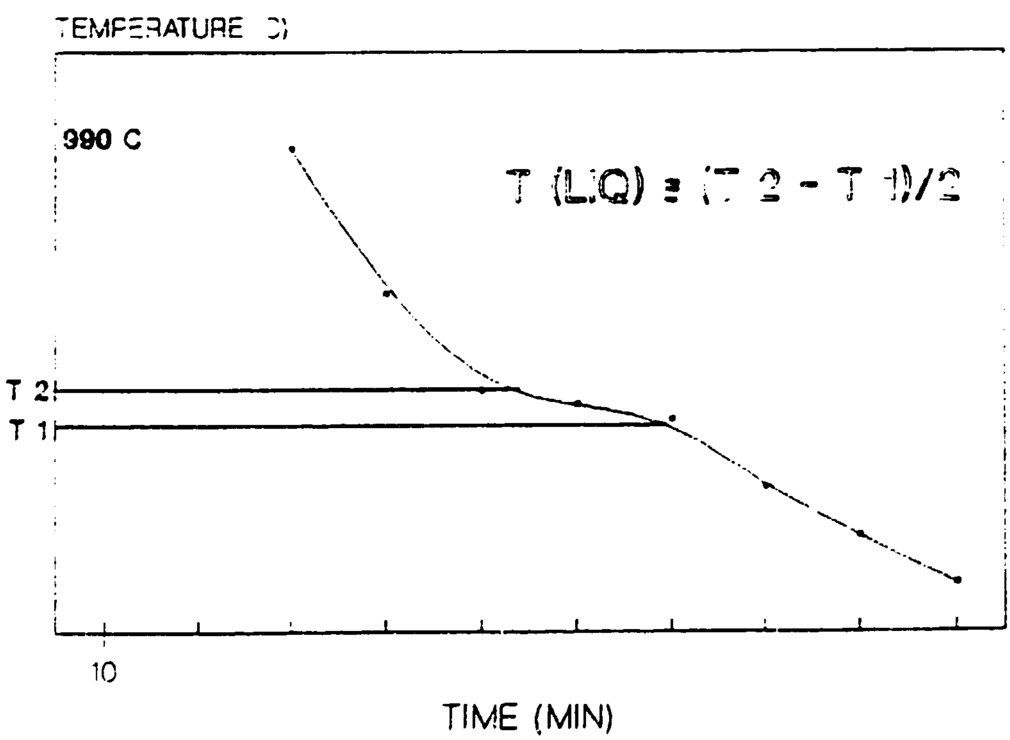
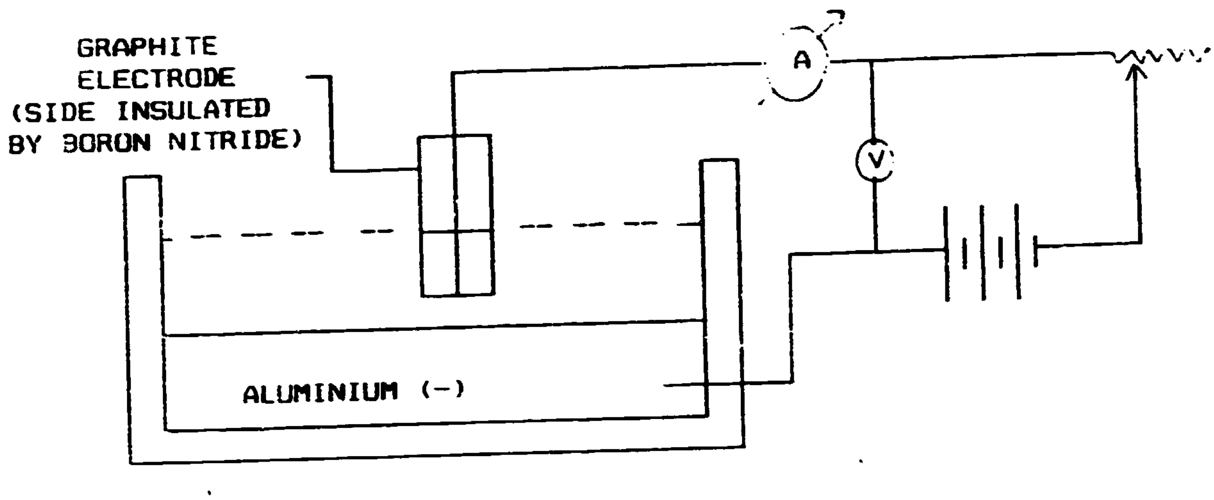


FIGURE (12)

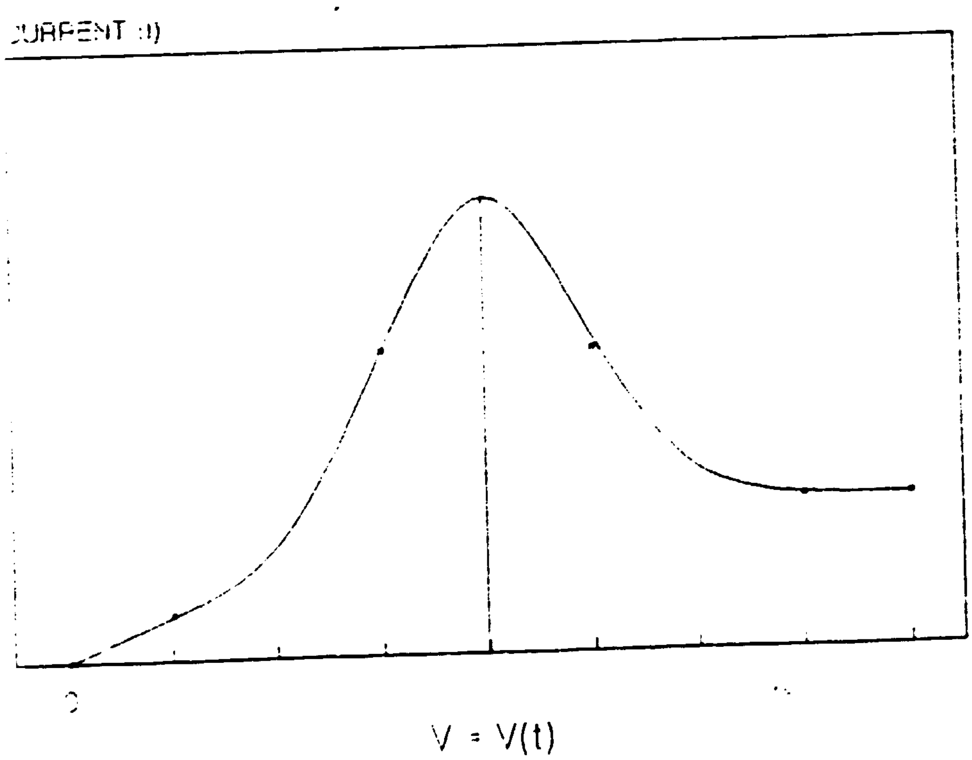
LQUIDUS TEMPERATURE DETERMINATION







POTENTIAL SWEEP METHOD



THE THEORETICAL BACKGROUND OF BALCO REVITALISATION PROGRAMME

Elements of high performance smelting technology

It is known, that the low energy consumption and high current efficiency cell operation are characterised by :

- Compensated magnetic fields
- Voltage/or resistance regulation
- Efficient alumina feeding technology
- Stablized bath composition
- Good frozen progile
- Low superheat

COMPENSATED MAGNETIC FIELDS (BUSBAR ARRANGEMENT : DESIGN AREA)

- Proper anode and cathode current distribution (cell operation)
  - B_Z -vertical magnetic field component minimum

- Reduce the horizontal current in metal
  - clean cathode bottom to decrease horizontal current
  - efficient alumina feeding technology to avoid sludge formation

- Proper frozen profile (cathode design and cell opertion.)

- Low superheat to decrease the aluminium dissolution and provide enough heat for alumina dissolution (cell operation)

SLUDGE PROBLEM

<u>Bottom crust (Hard muck)</u>

This is hard layer of alumina which adheres to the bottom of the cell.

Laboratory results
Corundum - if supercooled -40°c

Conclusion
A bottom crust may form if the cell bottom is too cold.
Why is the isotherm changing in BALCO cells ?

Alumina dissolution:
The rate of alumina dissolution depend on several factors. Most important of which is :
tendency to agglommerate and settle

We can distinguish between the following extreme cases
- Effective dispersion of individual grains
- Extensive agglomeration
- Formation of large particles or lumps, partly dispersed
- Settling of alumina and dissolution of settled material
- Dissolution of top crust by splashing of bath.

Hard thick muck deposit (very hot cell)

Causes
Hard thick muck layer under the anodes

Actions
- get a cover of alumina or cryolite (known bath on the crust of the bath to retain heat)
- stop or reduce alumina feeding to get an anode effect
- continue to operate the cell at reduced alumina feed rate to
  - maintain a low alumina content in the bath
  - higher anode effect frequency
- gradually, lower the cell temperature
  - frequent breaks without alumina additions
  - shunting part of the line current from the cell
  - exchange bath with normal operating cell
  - metal additions

- increase the cell voltage (resistance) i.e. set point temporarily
  -if possible, lower the metal level and increase bath level.

Cause of carbiding is that temperature is over 1050°C and liquid movement out of control. We say carbiding, because more Al_4C_3 dissolves in bath decreasing conductivity so the anode-cathode distance is less than expected which results in back reaction.

- tapping metal and bath
- add cold metal
- add cryolite
- keep cryolite at crushed bath on surface to try to reform crust.
- add dry salt

Raise the voltage to 8-10volts during above actions, slowly voltage will come down to about 6volts by itself.

ANNEXURE IV

LIST OF PARTICIPANTS OF TRAINING PROGRAMME
AT BALCO, KORBA

NAME		DESIGNATION
M.C. GUPTA	-	SENIOR MANAGER (Sm)
R.P. SINGH	-	SENIOR MANAGER (Sm)
M.G. SINGH	-	DEPUTY MANAGER (Sm)
AMIR CHAND	-	SENIOR ENGINEER (Sm)
D.K. BHASIN	-	SENIOR ENGINEER (Sm)
L.K. PANDEY	-	SENIOR ENGINEER (Sm)
S.B. SINGH	-	SENIOR ENGINEER (Sm)
S.K. JULKA	-	SENIOR ENGINEER (Sm)
M.C. GOEL	-	ASSTT. GENERAL FOREMAN
Y.K. TIWARI	-	ASSTT. GENERAL FOREMAN
T. RAMNATH	-	ASSTT. GENERAL FOREMAN
S.K. MITTAL	-	ASSTT. GENERAL FOREMAN
B.K. SINGH	-	FOREMAN
S.N. PATHAK	-	FOREMAN
J.N. DUBEY	-	FOREMAN
B.D. SINGH	-	FOREMAN
H.L. SAHU	-	FOREMAN
R.K. RAM	-	FOREMAN
J.K. TIWARI	-	OPERATOR
D.P. SRIVASTAVA	-	OPERATOR
B.L. SAHU	-	OPERATOR
K.P. PANDEY	-	OPERATOR
S.N. SRIVAS	-	OPERATOR
K.D. VAIDYA	-	OPERATOR
B.L. SHUKLA	-	OPERATOR
P.K. BHASKAR	-	OPERATOR

LIST OF PARTICIPANTS OF TRAINING PROGRAMME
AT BALCO, KORBA

NAME		DESIGNATION
R.P. SINGH	-	SENIOR MANAGER (Sm)
D.K. BHASIN	-	SENIOR ENGINEER (Sm)
Y.K. TIWARI	-	ASSTT. GENERAL FOREMAN
M.C. GOEL	-	ASSTT. GENERAL FOREMAN
S.K. MITTAL	-	ASSTT. GENERAL FOREMAN
B.K. SINGH	-	FOREMAN
S.N. PATHAK	-	FOREMAN
E.V.R. NAIDU	-	FOREMAN
K.N. SINGH	-	OPERATOR
S. KANWAR	-	OPERATOR
S. YADAV	-	OPERATOR
R.P. SINGH	-	OPERATOR
K.D. VAIDYA	-	OPERATOR
B.R. BAIRAGI	-	OPERATOR

ANNEXURE V

SUBJECTS TO BE DISCUSSED WITH Mr. P.N. SHARMA GM(Works) AT KORBA ON 18-19 MARCH 1993

1. Information on discussion with Mr. Azad CMD in Dehi on 15 February 1993

Record Notes on the Meeting is given in Annexure I.

2. Participation in the modernisation project for Korba Smelter

Copy of letter to Kaiser Engineering and TATA Engineering on services offered by JNARDDC Annexure II.

3. Programme for revitalisation and development of aluminium electrolysis cells

Objective of the project is to operate a group of 25 test cells by a joint team of BALCO and JNARDDC and investigate / test the following problems:

3.1 Normalisation of cell operation* by

- removal of deposits and sludges
- removal of broken bath from deck plate
- increasing cell voltage
- adjustment of bath and metal level
- adjustment of alumina layer level in accordance with alumina quality
- demonstration training for room in charge and operators

*To ensure the operation according to the revised operational manual intensive supervision is considered until the computerised control system is installed in the frame of modernisation programme to be contracted.

Detailed description of parameters. work programme and updated operational manual are enclosed (**Annex III**). It is suggested that the present set of 25 cells should include the group of thirteen cells on which work has already been carried out , and special task force should be formed for all the shifts for operation of the test cells. Involvment of the special measuring team of BALCO and JNARDDC is also considered. In view of the very tight time schedule of the international experts in the Centre plant authorities are kindly requested to start the programme - if possible - without delay

3.2 Effect of sludge / deposit removal on need for cathode renewal of revitalised cells

It is considered, that the sludge / deposit may protect the cathode bottom by covering of the existing failures / cracks, therefore after its removal the impurity level in the metal can be increased dramatically and the pot may haveto be shut down for renewal.

3.3 Improvement in metal quality in the revitalised cells

- without changes in quality / impurity level in the raw materials and by immprovement in alumina quality processed

3.4 Development / testing of the elements of the second phase of modernisation programme viz.:

- effect of alumina quality (grain size, impurities etc.) on processing parameters.
- scheduled crust breaking and crust braking with combination of anode effect prediction by introduction of bar breakers
- modification of bath chemistry - increase in excess of AlF_3 / MR 2.85 → 2.65
- modified anode operation - with and without additional cranes and consideration of dry paste technology

During the visit of JNARDDC experts in aluminum electrolysis

- objectives of all development
- required aluminium quality
- detailed work programme and time schedule

for each action is to be prepared

ANNEXURE VI

Record notes of discussion of JNARDDC Experts with Balco Plant personnel on 18th March 1993.

The JNARDDC Team of Experts met Mr.P.N.Sharma, GM(Works) and appraised him and colleagues about the JNARDDC proposal for revitalisation of Korba smelter Plant. A copy of the proposal was handed over to BALCO. The revitalisation proposal was generally agreed upon by BALCO. For detailing of the work programme Mr.R.P.Singh, Sr.Mgr.(Sm) with Dr.Horvath, UNIDO Expert was requested to discuss separately.

The following points were agreed upon:

a) As per the detailed revitalisation plant for the first step 25 cells, namely cell No.301-326 were selected.

b) A training programme for the operators and Supervisors and Room Incharges will be held on 19.3.93 to be followed up by a number of programmes to make the operating personnel conversant with the proposed change in operating parameters/practices and to apprise them about the background for the need of the proposed revitalisation Plan.

c) Initially 3 cells namely 301, 302 & 303 will be selected for removal of sludge as per the proposed plan of action.

d) It was pointed out by the JNARDDC Experts that a special operating crew and a measuring crew will be required to carry out the experiments successfully.

e) Based on the experience of these 3 cells, further cells will be taken up for revitalisation(301-326).

f) Salient features of the revitalisation plan were agreed upon. A step by step listing is enclosed.

g) Duration of experimental period is approximately one month. After this period the Balco's Operators will maintain the decribed parameters, the main actions, practices and disciplines:

SALIENT FEATURE OF REVITALISATION PLAN PROGRAMME

a) For the three selected cells sludge removed action will be taken up by the raising cell voltage, skipping and alumina feeding till the onset of AE while breaking the crust every hour and cell covering to be done by broken bath of 5mm size for cooling the cell.

b) Total liquid level will be brought down to prescribed level 47 cms and cleaning of deck plate, will be done. It is to be noted that big lumps of crust/bath not to be charged into the cell as it increases the risk of sludge formation. If the total height of metal and bath don't reach this level, manual sludge removal is needed.

c) After anode stud pulling extra voltage to be provided to compensate for the higher cell resistance.

d) Routine checking of pots to be done by technical section twice a week. Also required to measure the anode/cathode current distribution.

e) Slowly extending the programme to other cells.

f) Marking of stud flexibles will be done to have better anode current distribution.

g) Burner cleaning, gas hood sealing, lighting up of burners are to be measured.

h) In the second stage the proposed alumina feeding technology is to be introduced with proper alumina levelling.

i) Anode effect voltage is to be monitored regularly, for this purpose digital voltameters will be provided in the experimental pots.

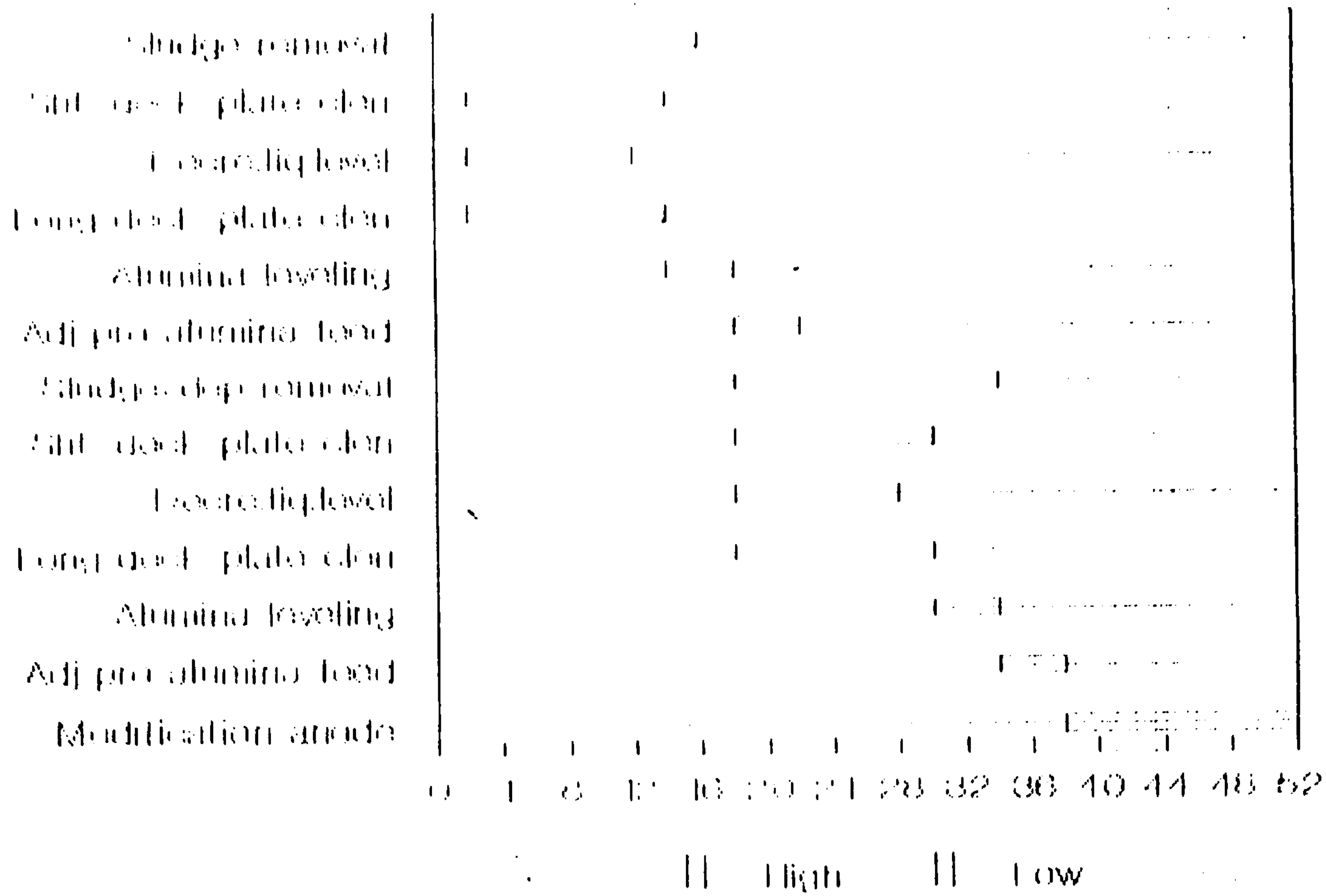
j) The importance of filling up of cell black board was stressed upon as this given very valuable information about cell operation. It was agreed that the same will be done at the earliest.

k) At a later stage this experimental group of 25 cells may be fed with NALCO Alumina for certain period of time to assess the performance of BALCO cells with coarser low alumina.

l) Changing of metal contamination also will be followed during the experimentals, all negotiation of cell operation will improve the metal quality, the effect will be measured.

(R.P.SINGH)
BALCO

(Dr.J.HORVATH)
JNARDDC


Alumina leveling
Adj pro alumina load
Alumina leveling
Adj pro alumina load
Modification anode
32 36 40 44 48 52
High
Low

ANNEXURE VII

RECORD NOTES ON DISCUSSION WITH NALCO MANAGEMENT ON JOINT R & D ACTIVITIES AND OTHER ACTUAL TOPICS
BHUBANESWAR MARCH 4 1993

Participants:

NALCO	JNARDDC
Mr. S.N. Johri	Dr. T.R. Ramachandran
Dr. S.K. Tamotia	Dr. J. Zambo
Mr. L. K. Panda	
Mr. M. L. Kampani	
Mr. N. G. Sharma	
Mr. P. Vidyasagar	
Mr. S.P. Mahapatra	

Drs. Ramachandran and Zambo discussed with Mr. Johri some operational problems with respect to deputation of M/s Vidyasagar and Sharma to the Centre as Deputy Directors. They also sought the cooperation of the ALUMINIUM ASSOCIATION OF INDIA in conducting the Workshop on SPECIAL ALUMINA in Bangalore in October 1993 and the possibilities of holding a meeting of ICSOBA in Visakhapatnam in Feb/March 1994.
The R & D projects were discussed with the managemant of NALCO headed by Mr. Panda and the outcome of the discussions is summarised below:

SELECTED PROJECTS FOR ANGUL SMELTER

1. Thermal **measurements** to be carried out on normal cells and those with modified lining in April '93. To arrive at the right conclusion for the use of indigenous insulation bricks preparatioin of an overall heat balance is required.

2. Overall **measurement** of the state and operation of selected pots. Presently the compensation of magnetic field of pots in the vicinity of those shut down is of interest. therefore magnetic measurements should be started: however preparation of a programme for the complete measurement and evaluation of cell state and operation would be finalised during the next visit of JNARDDC experts.

3. **Utilisation of used pot linings**. It was agreed, that JNARDDC would prepare a literature survey for selecting the possible options. On the basis of general layout and tentative material balance supplied by the Centre, expected investment and operational cost for each technology would be prepared by NALCO Angul Plant.

In the joint techno-economical evaluation the economy of the selected technologies would be compared with the safe method of storage for the used pot lining.

4. **Graphitised cathode blocks** will be installed in 10 pots this year at Angul. It was agreed, that JNARDDC would evaluate the expected changes in heat transfer characteristics in these cells and recommend the way of possible compensation of increased heat losses by better insulation and / or change of operational parameters. The modified pots will be monitored according to the agreed programme.

5. NALCO is interested in joint **activities in anode carbon R & D particularly from the point of view of increased anode** block density. The Centre will prepare detailed infomation on equipment and methods to be implemented and on this basis possible areas of co-operation will be selected.

6. **Modelling of cell construction and operation.** NALCO has a great interest to organise joint activities with the Centre in this field. NALCO is ready to consider all forms of co-operation including fielding volunteers, forming joint team or undertaking any part of a complex programme organised / co-ordinated by the Centre.

7. **Special alumina chemicals.** NALCO has been approached by a cable producer company to supply very fine ATH with low soda content to be used as fire retardant. JNARDDC was requested to consider action for promoting production. The Centre feels that the subject can be handled in the frame of projects on development of special alumina products, to be discussed in the workshop in this area to be held in Bangalore in October 1993.

ANNEXURE VIII

REPORT ON MEASUREMENTS AND DISCUSSION WITH NALCO EXPERTS ANGUL, 6-15 MARCH, 1993.

PARTICIPANTS:

NALCO	JNARDDC
i) MR S B NAYAK	DR J HORVATH (UNIDO)
ii) MR S P MAHAPATRA	MR G S SENGAR
iii) MR P R PAVITHRAN	MR A K BASU
iv) MR S N SINGH	MR A AGNIHOTRI
v) MR K V BHARDWAJ	
vi) MR R N JENA	

I. JNARDDC experts informed NALCO , about their purpose of visit, which was as follows:

1. To carry-out thermal measurements decided in April, 1992.

2. To finalise the measuring programme for selected projects which were decided in Bhubaneswar, 4th March 1993 at NALCO head office.(Annexure-I)

3. To study and collect information on measuring procedure for evaluation of carbonaceous materials.

II. 1. For heat balance of control and experimental pots, NALCO requested to carry out thermal measurement in 4-control and 4-experimental pots, which were:

Control pots	Experimental pots
B-004	B-005
A-004	A-002
A-030	A-029
A-094	A-106

JNARDDC experts carried out measurement for 8-cells as agreed with NALCO in following way:

i) Heat flux measurement was done completely for the cathode shell depending on accessibility of measuring points as discussed with NALCO.

ii) Heat flux measurement from cathode shell bottom was done at 18 different points, based on the temperatureprofile drawn earlier.

iii) Heat flux at 24 different points on the long side of cathode shell at metal and bath level was measured. These measurements were carried out only after removal of the side slabs from the cells as there was no access from zero level.

iv) All measuring data was handed over to NALCO (Annexure- II).

v) JNARDDC experts expressed that these measurements data are very useful for orientation purpose of cathode heat losses, but not for complete evaluation of heat balance in order to extend the modification for complete pot line. NALCO requested JNARDDC to make a preliminary evaluation of thermal balance in these pots, with a view to identify the following:

a) adequacy of measurements for thermal balance, if required measurement scheme may be modified in future.

b) suggest any improvement/change in physical properties of the experimental insulation, HYSIL.

c) suggest any change in parameters of pots with HYSIL insulation.

Similar conclusion can be drawn for graphitised cathode blocks installed (10 pots) in NALCO, on the base of heat flux measurements to be carried out at that time. It is not possible to completely evaluate the heat balance for introduction of change of cathode blocks to whole pot line. NALCO requested JNARDDC to define any other measurements that is required for evaluation and detection small changes in current efficiency and energy balance. JNARDDC will communicate details of measurements required by July, 1993.

For complete evaluation the total heat and energy balance is needed to check the operational changes caused by modification of insulation bricks and cathode.

JNARDDC expressed that the present technology is excellent, but as per information of NALCO experts, they do not have any information on process technology given by technology supplier in order to access any operational changes that may take place after modification.

Unfortunately energy/heat balance which would be suitable for evaluation of above mentioned modification are not available. Any modification may increase risk of unstable cell operation.

Therefore for any modification in existing pots, it is necessary to carry out very detail process study; which will be based on thermal, electrical balance and its changing with function of time.

JNARDDC experts expressed that the mobile van present in JNARDDC gives a oppertunity to study the process technology in very detail for the existing NALCO cells.

Following equipments installed in mobile van can be used for detail process study:

i) Data acquisition system (cell monitoring)
ii) Heat flux meter.
iii) Agema thermovision.
iv) Anode gas analysis (current efficiency).
v) Anode/cathode current distribution measurement with respect to time.

JNARDDC expressed that it is presently ready to carry out heat flux measurements in existing experimental cells and later on 10 graphitised cathode block installed cell also, if required by NALCO.

2. It is also necessary to specify here that as per the item no 3 of (ANNEXURE-I), JNARDDC is ready to carry out magnetic field measurement as and when required by NALCO, to give out data for magnetic field in vicinity of the shut down pots. JNARDDC is ready to measure the different magnetic flux component at different positions near the shut down pots and normal pots in order to study and collect data for the magnetic field compansation problem existing in NALCO. These measurements are proposed in Aug'93.

It is proposed by JNARDDC that to carry out to complete evaluation of exisating & modified pots, it is necessary to carry out detail process study with the help of mobile van.

3. JNARDDC has given a brief documentation to NALCO on role of JNARDDC in Carbon Research Technology (Annexure-III). JNARDDC experts carried a detail discussions with NALCO personnel from Carbon Paste Plant & Anode Baking Plant regarding the evaluation procedures existing in NALCO for Carbonaceous materials. It was informed to NALCO that JNARDDC Carbon laboratory will likely to be installed during the end of Oct'93.

JNARDDC experts informed NALCO that during the installation of Carbon laboratory at Nagpur, JNARDDC will use raw materials for testing from NALCO. The test results will be compared with that of NALCO. As the JNARDDC has a more complex method for evaluation, the results will be sent to NALCO with complete evaluation procedure of data, to be verified out at NALCO end. The JNARDDC and NALCO agreed that after the installation of Carbon laboratory and comparison of Test results, a joint project activity for increase anode bulk density will be taken up in this field.

It is well agreed that by the end of Aug'93 NALCO will be sending the following raw materials to JNARDDC , Nagpur for evaluation:

i)	Coke	-	50 kg.
ii)	Pitch	-	25 kg.
iii)	Green Anode Paste.	-	30 kg.
iv)	Pre-baked anode-core sample.		10 nos.

4. As required by NALCO the utilisation of used Pot-linings , the JNARDDC informed that the literature for the same will be made available by the end of Sept'93.It is recommended by JNARDDC experts to arrange a joint meeting at the end of Sept'93 inorder to process the possible steps in the field of utilisation of spent pot-linings.

5. JNARDDC experts organised a lecture for training of NALCO personnel in the field of 'Basics of Aluminium Electrolysis'. 22 executives from E-1 to E-7 grade and One Supervisor attended the lecture.

6. NALCO has emphasised very much on modelling of Cell construction and operation. JNARDDC informed NALCO about their further plans in this direction. It was decided that the Work-shop on modelling at JNARDDC in Nagpur in last fortnight of Sept'93 will be startingpoint for modelling activities. During the modelling work-shop a joint team wi'l be formed in close cooperation with different Universities, research organisations and aluminium industries. This team and its progress will be coordinated by JNARDDC . NALCO requested that development of models should be a time bound programme, the initial work may be for developping a thermal balance model which should be extended to electric and magnetic models. Models be verified by actual measurement at NALCO. JNARDDC informed NALCO that it has already taken some steps in this direction and will keep NALCO well informed about the progress made.

7. A joint team has to be formed between NALCO and JNARDDC for carrying out detail process study with the help of mobile van. This mobile van studies will be carried out jointly to access the changes in Operation after the modification . In this direction NALCO team will be given a training at JNARDDC Nagpur on the equipments and evaluation procedures.

8. A detail discussion with Add.Gen.Manager Mr.S.B.Nayak, had taken place in the field of calibration of Pot line current measurement, earth leakage current measurements and fore-casting the life of the Potlining and Pot failure mode etc. It was also pointed out by Mr.Nayak to provide detailed technology for welding aluminium Bus-bar /Risers without interrupting D.C current i.e. magnetic field. For all the above points discussed with NALCO, a technical programme will be prepared by JNARDDC at Nagpur and will be sent to NALCO.

9. Heat flux and some Sensors will be transported by JNARDDC to BALCO. Remaining Sensors will be in safe custody of NALCO till the next programme.

NALCO	JNARDDC
S P Mahapatra.	Dr. J Horvath.
P K Pavithran	A Agnihotri

ANNEXURE IX

REPORT

FIRST PHASE

Present report consists of two parts :

I - Measuring data, conclusion and recommendation as per work plan (annexure - I)

II - Further measuring programme based on mobile van and take into account modernization programme

INTRODUCTION

Last year detailed measurements for determination of electric, thermal and magnetic state of BALCO's cells were carried out in close co-operation with BALCO experts from 4th Jun to 28th Jun, 1992.

Following these measurements JNARDDC experts gave a preliminary report on status of BALCO's cells along with conclusions recommendations (annexure - II). Based on these measurements a detailed programme was made by JNARDDC in context with revitalisation programme for modernization of BALCO and handed over to BALCO management (annexure - III).

The revitalisation programme prepared by JNARDDC was discussed with the BALCO management for implementation on 11th March, 1993 and following strategy was agreed upon (annexure - IV)

The main target of revitalisation programme was to reach technological parameters which were summarized in the preliminary report submitted by JNARDDC (annexure - II) in June, 1992. This part of the programme will be considered as first phase of revitalisation programme and after this necessary to follow the second phase of revitalisation programme that was determined on 1 & 2 August, 1992 (annexure - V)

EXPERIMENTAL AND MEASURING RESULTS

In first phase of revitalisation programme, six cells in cell house no. 3 were selected for experimentation, out of which 2 nos. (322 and 323) were old cells and rest (321, 324, 325 and 326) were new. As per the work programme long side crust of these new cells was broken every hour and alumina leveling done on the long sides after breaking. After a period of four to five days set point (cell voltage) was increased for the "young cells". After this increase in voltage there was stable operation observed in the cells. This affect was indicated by lowering of electrolyte temperature, increase in anode effect value and decrease in Si content of the metal.

Next step was to decrease the bath and metal level as per the target height given in the drawing of report submitted to BALCO i.e. 28cm of metal level before tapping and 26cm after tapping and 17-19cm bath level. Because of soft sludge removal from the young cells the metal and bath level was decreased in a safe way. This process was followed by measurements and can be seen in annexure - VI. The changing of electrolyte temperature and Si content in bath can also be seen in annexure - VII. The modified alumina feeding system was established in the young cells and soft sludge was removed with proposed bath and metal height.

During the measuring period deck plate was cleaned and broken bath was removed from deck plate area and big lumps of crust were not charged in cell during that period which decrease the risk of sludge formation at the cathode bottom due to not dissolution of these crust lumps.

For the old cells the situation was more complicated. By introducing the schedule crust breaking system and alumina feeding technology and breaking of long side and short side removed the soft sludge form the cathode bottom of the cells. In these cells the bath and metal level was decreased very slowly, but unfortunately during this lowering of liquid level some abnormality was detected in the cathode current distribution and during these cell operation the liquid level was more than 50cm. Significantly there was high risk of cell leakage from the upper part of cell. On the basis of the measurements and results obtained it was concluded that hard muck cannot be removed form the surface of these cells by above mentioned methods. In this case the hard deposit removal procedure more difficult and it is recommended that the hard deposit should be removed manually and during this hard deposit removal cathode current distribution data should be always be checked. In the process of experiment once hard deposit was removed form cell no. 322 but there was no improvement in cathode current distribution data. see annexure - VIII.

Unfortunately in middle part of the experimentation period skimming in the bath was very high. Due to this high skimming. high frequency of anode effect, sludge at the cathode bottom it was not possible to adjust the set point for temporary period. Thus it was concluded that without removing the carbon skimming it was not possible to successfully continue the experiment. That was the reason it was proposed that carbon skimming should be removed everyday. And simultaneously anode operation section to be consulted frequently for modification in anode current distribution to reduce the carbon skimming. For this a meeting was organised with anode operation section to explain them the importance of anode current distribution and necessary action was proposed for the same annexure - IX).

The main reason in our opinion for the high skimming in the cell is due to improper anode current distribution. After analysing the anode current distribution data and results (annexure ???) it can be concluded that current loading is different for 2 levels and it keeps on changing.

Everyday smelter management was consulted and was explained about the measurement results and problems in the cells with appropriate procedure for resolving the problems (annexure - X).

Heat balance was not proper during the experimentation period due to :

1) Irregular anode effects : The anode effects were very irregular and its frequency was very high . During the anode effect it was not possible to break the sides and feed alumina because manual breaking was a long period job.

2) Skimming generation was very high.

3) Anode current distribution data and cathode current distribution data showed improper current distribution in anode and cathode.

It was agreed with smelter management that it is not possible to solve all these problems in 6 no. of cells and the smelter management proposed not to extend the experiment in 25 no. of cells. During one month experimental period on the base of experiment procedure, smelter management decided that it will continue these experiments in only 3 no. of cell (326, 325 and 324). During second phase the main focus of work will be to follow up and fulfill all the work procedure which were recommended in work plan submitted to BALCO management and was not followed in the period of one month experimental period except for the cathode.

The improper anode current distribution data was a hinderence for adjusting proper cell voltage to compensate for higher resistance. The marking of stud flexible, changing of the studs and proper tightening of the clamps will be done for better anode current distribution. In case of improved anode current distribution by following above procedure but carbon skimming not reduced in that case will be modification in anode paste. All the 13 experimental cells were supplied with digital voltmeter which helped in determining the anode effect value and was very help the data for analysis of pot operation during the experiment.

All cell deck plate was cleaned and removal of crust done as per the work plan.

Some problems was accrued during experiments. The first phase of revitalisation programme of BALCO modernization was successfully completed. the removal of soft sludge. decreasing of metal and bath level and cleaning of deck plate was done as per the programme. This action gives a possibility of good alumina feeding technology, which is the basic requirement of modernisation. On the base of experiment it was concluded that hard sludge is very difficult to remove form the cathode bottom. But very carefully using and necessary cathode current distribution data can be done with lowering the metal level. The experiment clearly indicates that no further improvement during the revitalisation programme without modifying

1 The anode current and cathode current distribution

2) Reducing the skimming generation

Considering the most important things needed for revitalisation can be sen in detail in annexure - V.

FOR BALCO *FOR JNARDDC*

R P SINGH JANOS HORVATH

ANNEXURE X

SECOND PHASE

Problem : [illegible]

1. Bad anode and cathode current distribution.

- Stud ~~[illegible]~~ [illegible] is not [illegible] [illegible]
current distribution: [illegible]

average loading : 1.7[illegible] [illegible]
lower loading : 1.1 [illegible] stud
upper loading : 1.4 [illegible] stud
[illegible] the total loading [illegible]
The difference between the two levels is [illegible].

- Cathode current distribution:

Difference between the north and south [illegible]
[illegible] 1.5 [illegible] - 52.5 [illegible] - 45.[illegible] -
The average loading is 4.17 [illegible] / collector bar.
The difference between the collector bar [illegible]
[illegible] 100 [illegible] collector bar.

2. Collection of all measurements relating [illegible]
cells :

- metal height
- bath height
- anode [illegible]
- [illegible] hood bottom and bath level [illegible]

For this data are needed for evaluation of [illegible]
[illegible]

3. Measurements in middle [illegible] :

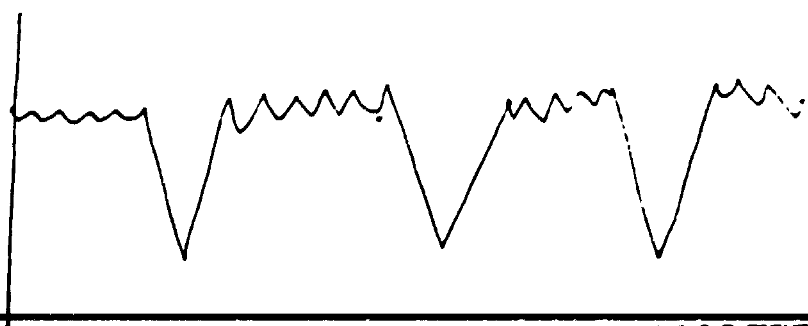
Problem : low ACD distance
high skimming generation.
The ACD - anode-cathode distance is [illegible] low. To
[illegible] the information between the metal and anode the
noise analysis is to be measured.

- Approximately every third hours, the noise of [illegible]
cells (321-326) is to be measured. It is preferable [illegible]
the anode going down.

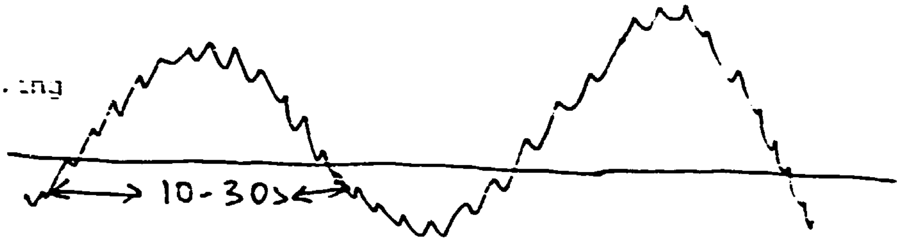
The different kinds of noise are [illegible] :

- spike or grounded anode

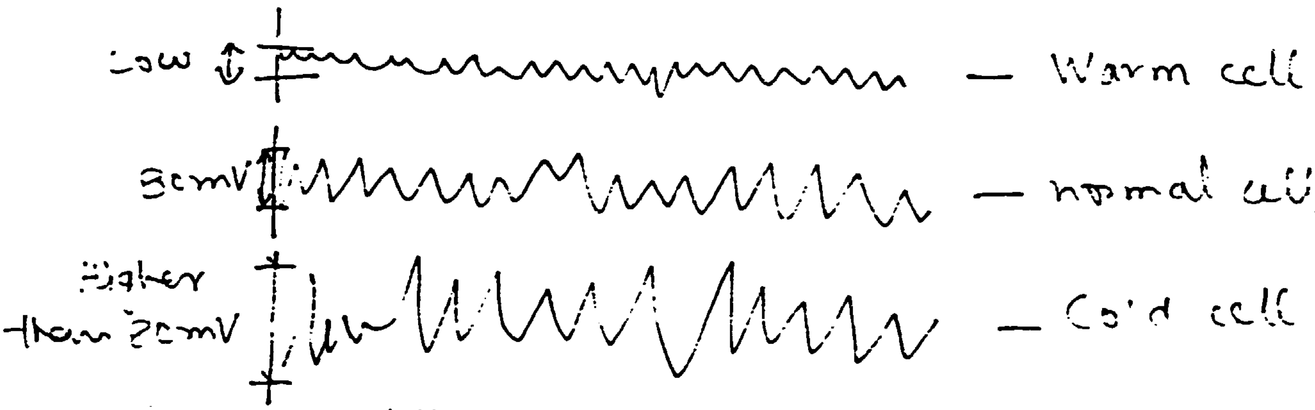
R



Metal waving



- analysis of amplitude of noises gives to a possibility to determine the cell thermal condition.

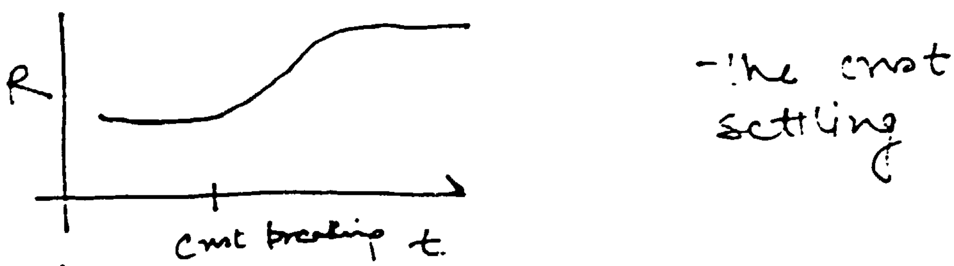


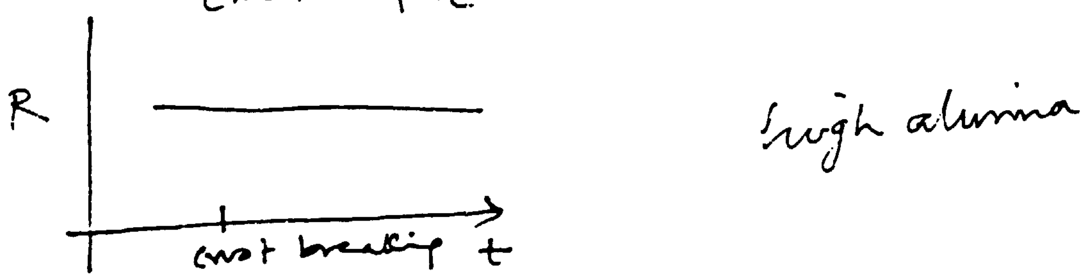
On the basis of these measurements, instructions given in the annexure to be followed (Book was given)

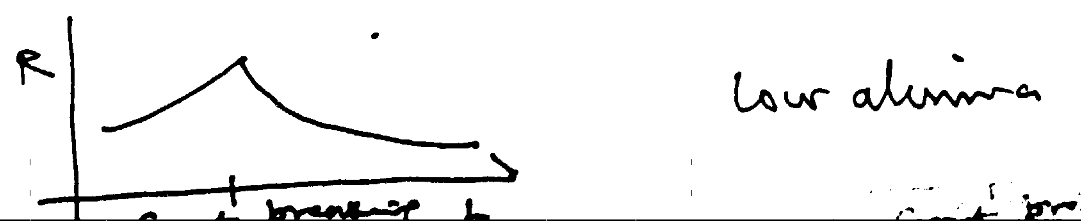
4. Control of alumina content in bath. Trend detection.

Problem : sludge formation.

Before and after the scheduled crust breaking and alumina charging in monitoring mode the resistance time curves are to be measured.

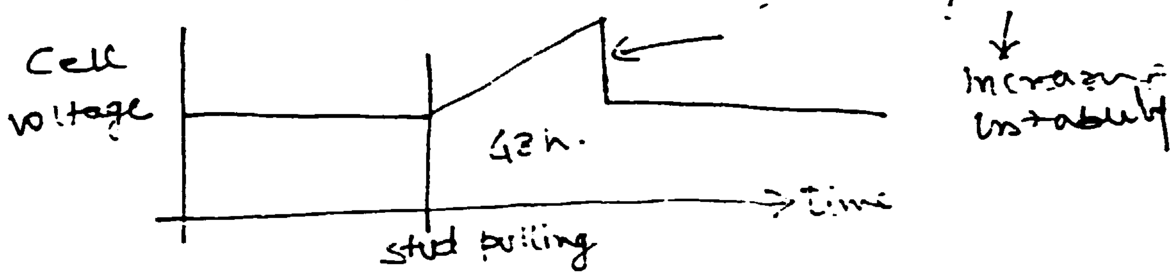




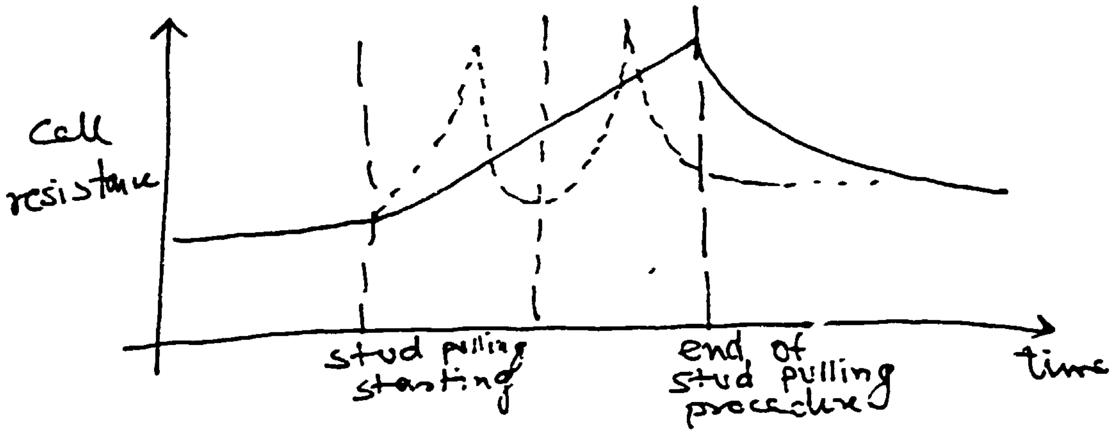


5. Study of the stud pulling effect on all resistance.

Problem : Existing practice



Before stud pulling the alumina content of the bath must be increased. The cell resistance is to be measured in monitoring mode. Anode moving in this measurement period is forbidden.

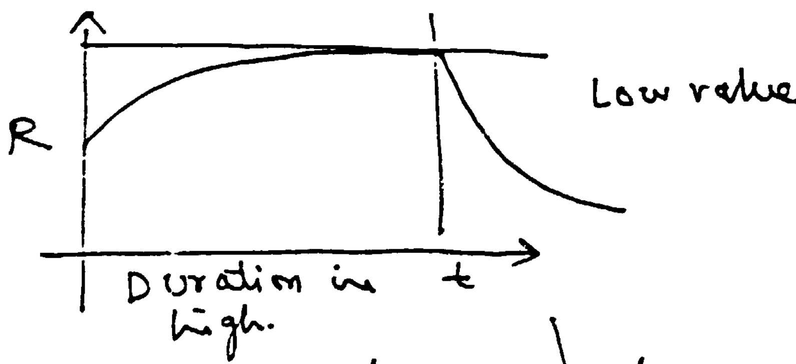


Alumina content in the bath is high during this period

6. Anode effect analysis (night shift)

Problem : Low value (10 ..) and its duration is high.

Existing statures



R. P. SINGH

J. HORVATH

ANNEXURE XI

JAWAHARLAL NEHRU ALUMINIUM RESEARCH DEVELOPMENT AND DESIGN CENTRE NAGPUR

DESCRIPTION OF THE FACILITIES AVAILABLE FOR MEASUREMENT AND MONITORING OF STATE AND OPERATION OF THE ELECTROLYSIS CELLS

MARCH 1993

The **JAWAHARLAL NEHRU ALUMINIUM RESEARCH DEVELOPMENT AND DESIGN CENTRE** is being established in Nagpur by the Government of India with the assistance of UNDP. The Centre has as its constituents the departments of alumina production research, aluminium electrolysis research. analytical techniques and instrumentation and control.

In the frame of the aluminium research department, an electrolysis process monitoring unit was established and appropriate activities already started. The equipments available in this unit include the following:

- 16 channel data acquisition and processing system. including potential separator, filtering procedure and processing software (noise analysis, controlled tapping procedure, anode effect prediction, anode effect parameters, potential distribution in AC gap, EMF etc.
- Heat flow meter (Kem-therm)
- AGA thermovision
- Magnetometer-I for measurements in molten metal
- Magnetometer-II for measurements in pot room air
- Noncontact thermometer
- Temperature measuring unit

As a part of the activities of this unit, the following measurements have already been carried out on a set of cells (thirteen) in Korba in order to characterise the present status of cell operation:

- **all electrical parameters of the cell**
    * noise analysis
    * value and duration of anode effect, resistance change before anode effect
    * cell resistance as function of time for determination of cell routine (stud pulling, alumina feeding, anode position changing)
    * electromotive force (EMF) by current sinking method
    * potential distribution in anode cathode gap

- **thermal state measurements**

  * electrolyte temperature and superheat determination

  * heat flux measurement

  * surface temperature on construction elements

- **magnetic field measurements**

  * magnetic field components in molten metal

  * magnetic field components in potroom

In addition traditional measurements such as anode voltage and electrolyte composition were also made.

The following software programmes are used for evaluation of cell operation :

- **Calculation of voltage and energy balance from measured data**

- **Calculation of magnetic field induction components from measured data**

- **Calculation of anode and cathode current distribution from measured data**

- **Calculation of the voltage losses in ACD-gap**

The complete evaluation system is shown in Annexure I.

To model the cell operation the following computer programmes are used

- **Calculation of heat temperature in cathode lining**

- **Calculation of metal velocity and distortion**

The measuring procedures and the complete evaluation methods are used to determine the energy and voltage balance of cells and to improve the parameters of the existing cells. All the data measured earlier (June 1992) were stored in a computer.

Based on these measurements and the evaluation of results the status of cell operation was determined, and a proposal elaborated for improvement of performance parameters. These measurements and evaluation methods are suitable for improvement of the existing situation by improving the plant discipline and introducing new cell operation procedure.

Results of some typical measurements are indicated in the following section.

- different kinds of noise
  * normal noise (Fig.1 a)
  * wavy (Fig.1 b)
  * noise caused by spike (Fig.1 c)
- EMF values (Fig. 2)
- anode effect on sick pot
  * increasing phase (Fig. 3 a)
  * whole anode effect (Fig. 3 b)
- Process monitoring change of resistance (therefore alumina content) with time (Figs. 4 a,b and c)
- Potential distribution in ACD gap (metal touching) (Fig. 5)
- Typical anode and cathode current distribution (Figs. 6 and 7)
- Heat losses (Table I)
- Magneto-hydrodynamic curves for existing technology (Fig. 8)
- Voltage components in ACD-gap
- Some identification studies for modelling of existing cell (Fig. 9)

All these measuring equipment would be mounted in a mobile van in the next month and the van could be easily moved from one area to another.

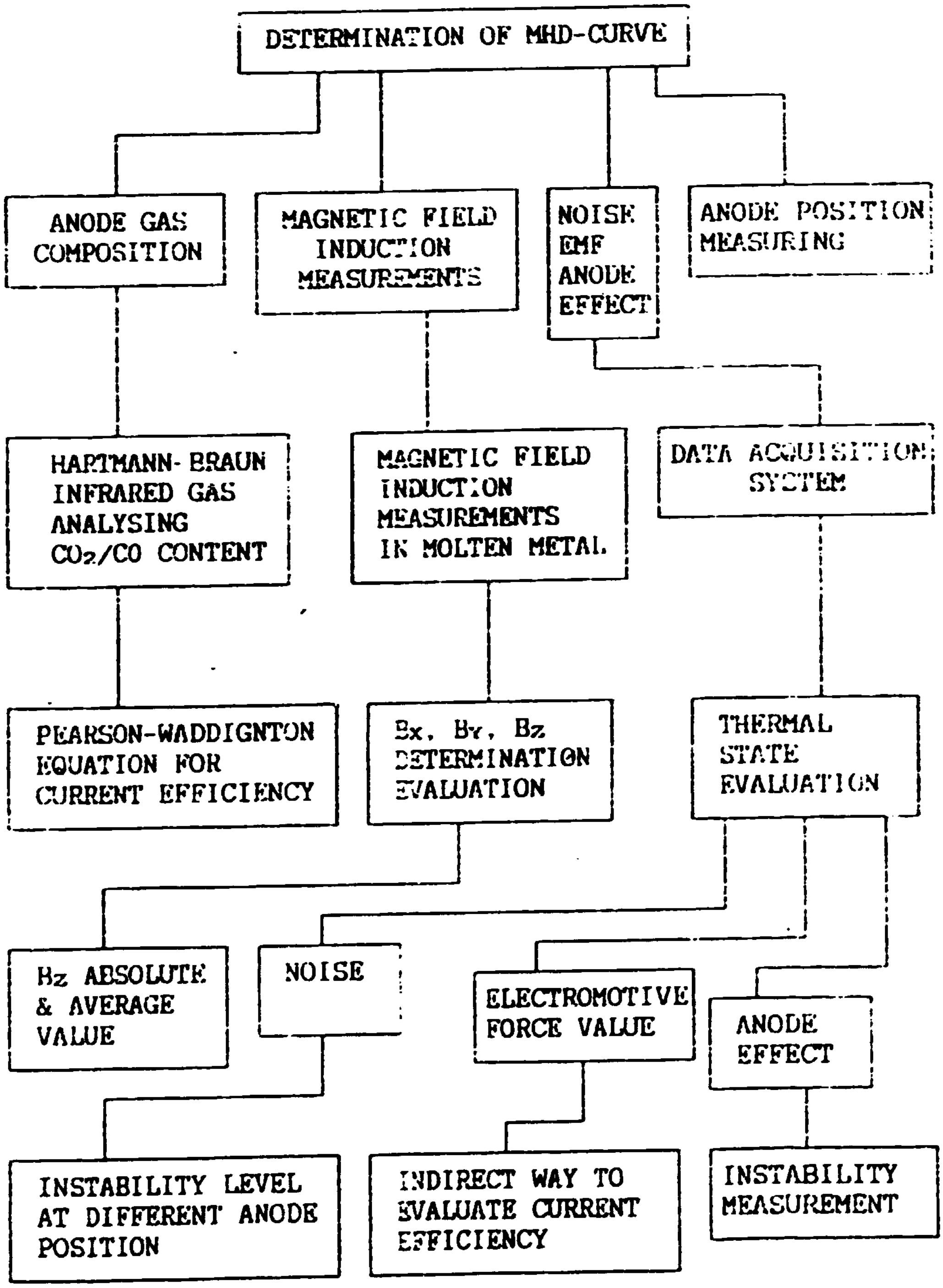

DETERMINATION OF MHD-CURVE
ANODE GAS COMPOSITION
MAGNETIC FIELD INDUCTION MEASUREMENTS
NOISE EMF ANODE EFFECT
ANODE POSITION MEASURING
HARTMANN-BRAUN INFRARED GAS ANALYSING CO2/CO CONTENT
MAGNETIC FIELD INDUCTION MEASUREMENTS IN MOLTEN METAL
DATA ACQUISITION SYSTEM
PEARSON-WADDIGNTON EQUATION FOR CURRENT EFFICIENCY
Bx, By, Bz DETERMINATION EVALUATION
THERMAL STATE EVALUATION
Bz ABSOLUTE & AVERAGE VALUE
NOISE
ELECTROMOTIVE FORCE VALUE
ANODE EFFECT
INSTABILITY LEVEL AT DIFFERENT ANODE POSITION
INDIRECT WAY TO EVALUATE CURRENT EFFICIENCY
INSTABILITY MEASUREMENT

Table I : HEAT LOSSES IN THE CELLS

CONSTRUCTION ELEMENTS	HEAT LOSS (W/m^2)	AREA (m^2)	TOTAL HEAT LOSS (kW)	% HEAT LOSS
Cathode shell bottom	348.83	27	9.5	4
Upper cathode shell(long side)	1929.33	16	31.0	13
Upper cathode shell(short side)	1929.33	5.4	10.49	4.3
Lower cathode shell(long side)	542.43	7	3.8	1.5
Lower cathode shell(short side)	542.43	2.31	1.25	0.5
Anode casing (long side)	3611.95	25	90.3	38
Anode casing (short side)	3611.95	6.5	23.5	10
Anode top	944.00	15	14.16	6
Alumina layer, stud losses etc.	--	--	--	--
Total	--	--	238	100

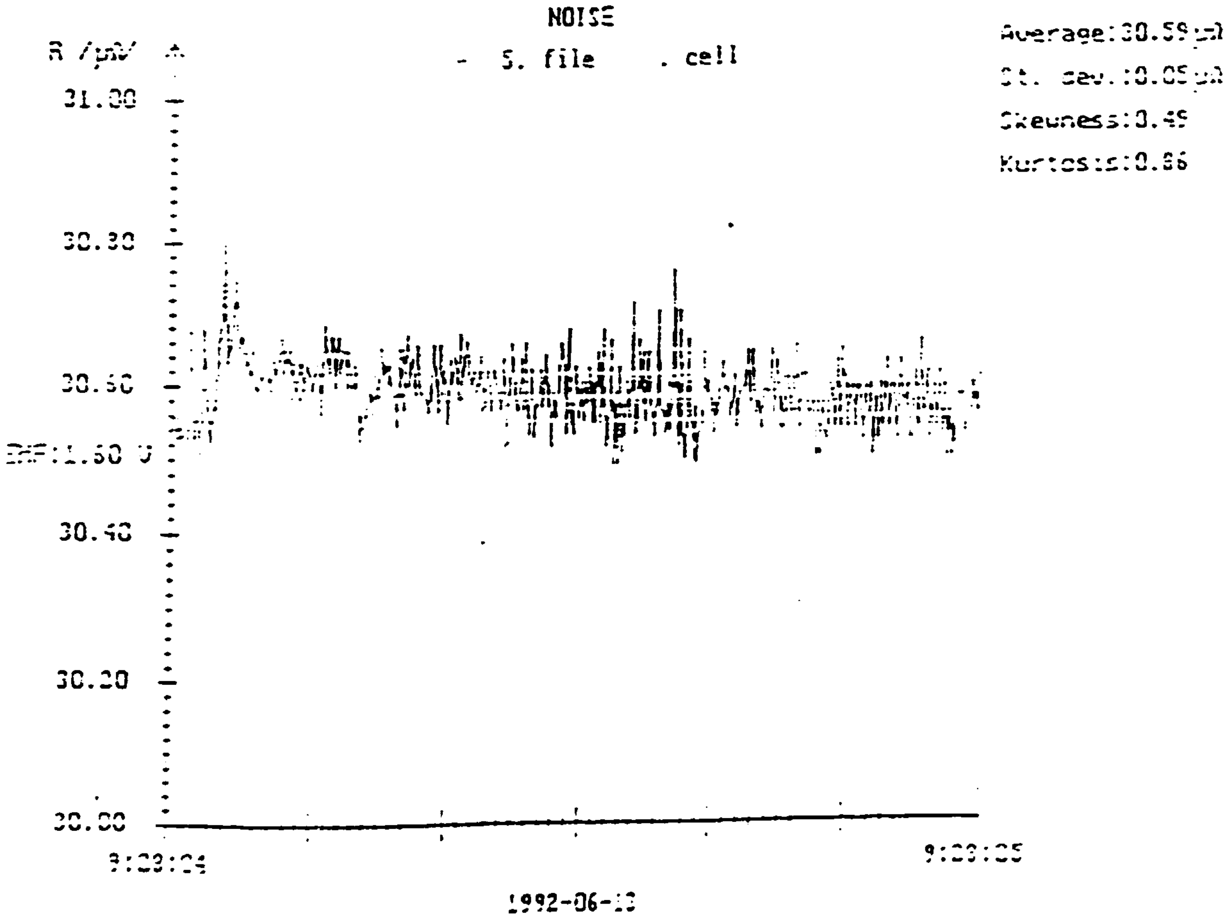

NOISE
R /μΩ
- 5. file . cell
Average:30.59μΩ
Skewness:0.49
31.00
30.80
30.60
30.40
30.20
30.00

Figure : 1 (a)

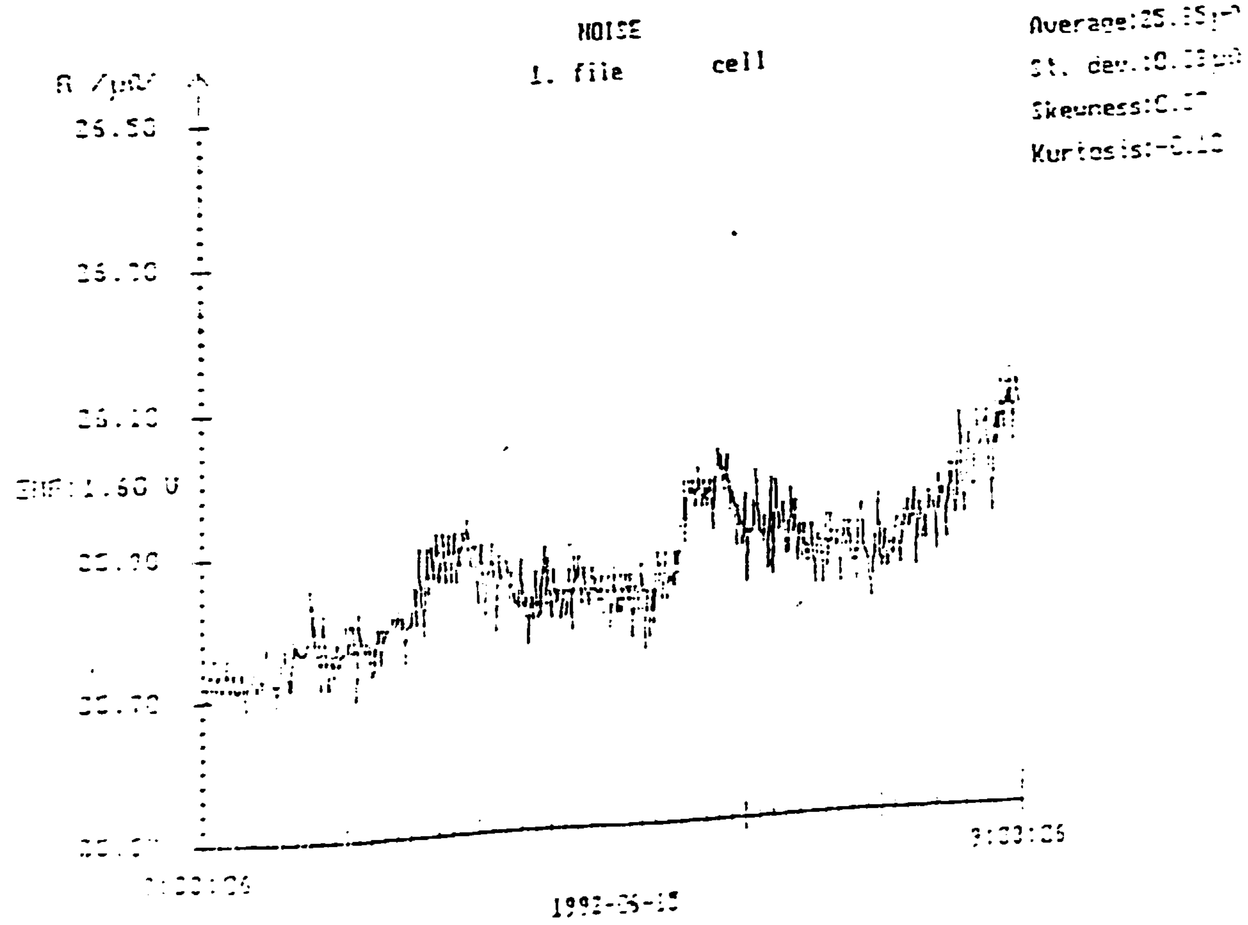


Figure : 1 (b)

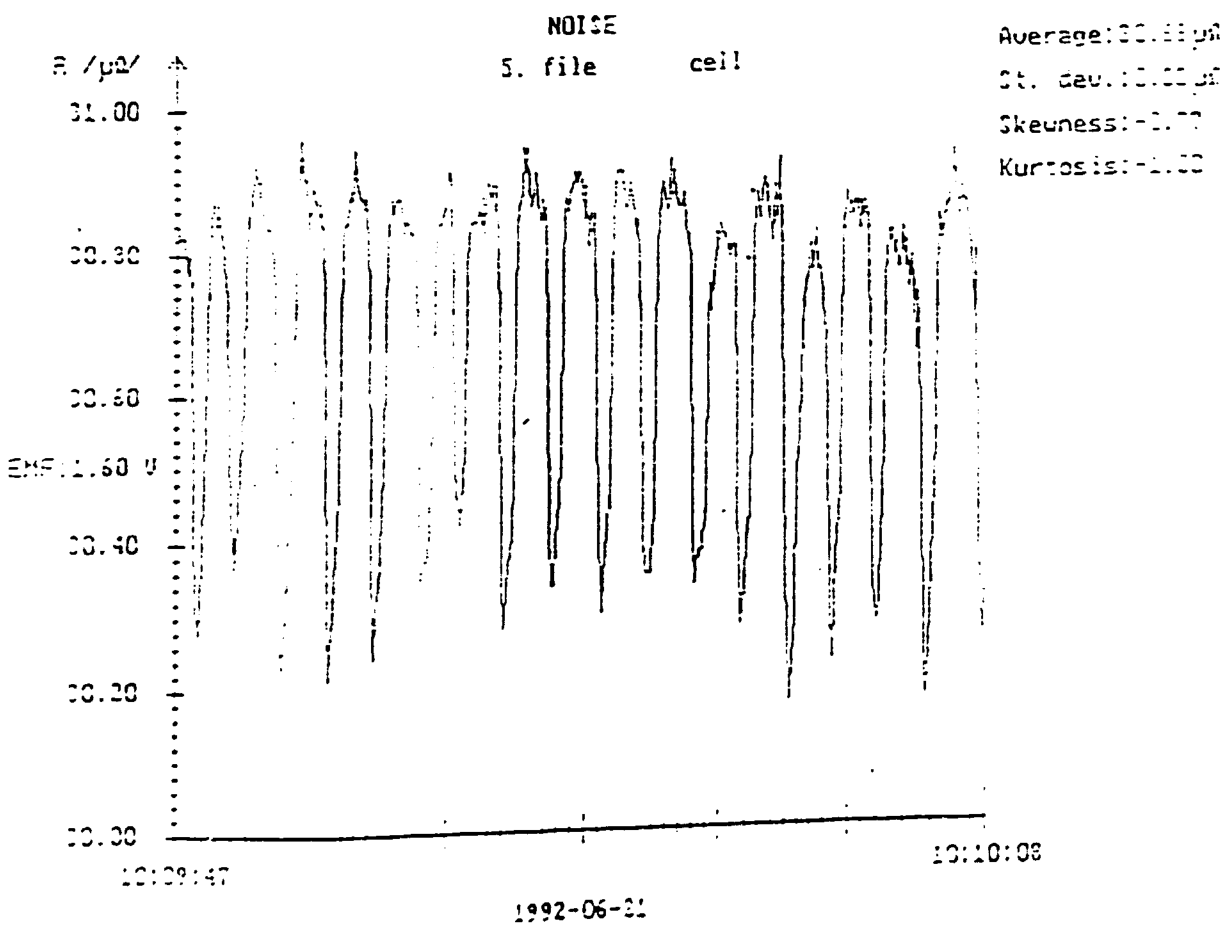


Figure : 1 (c)

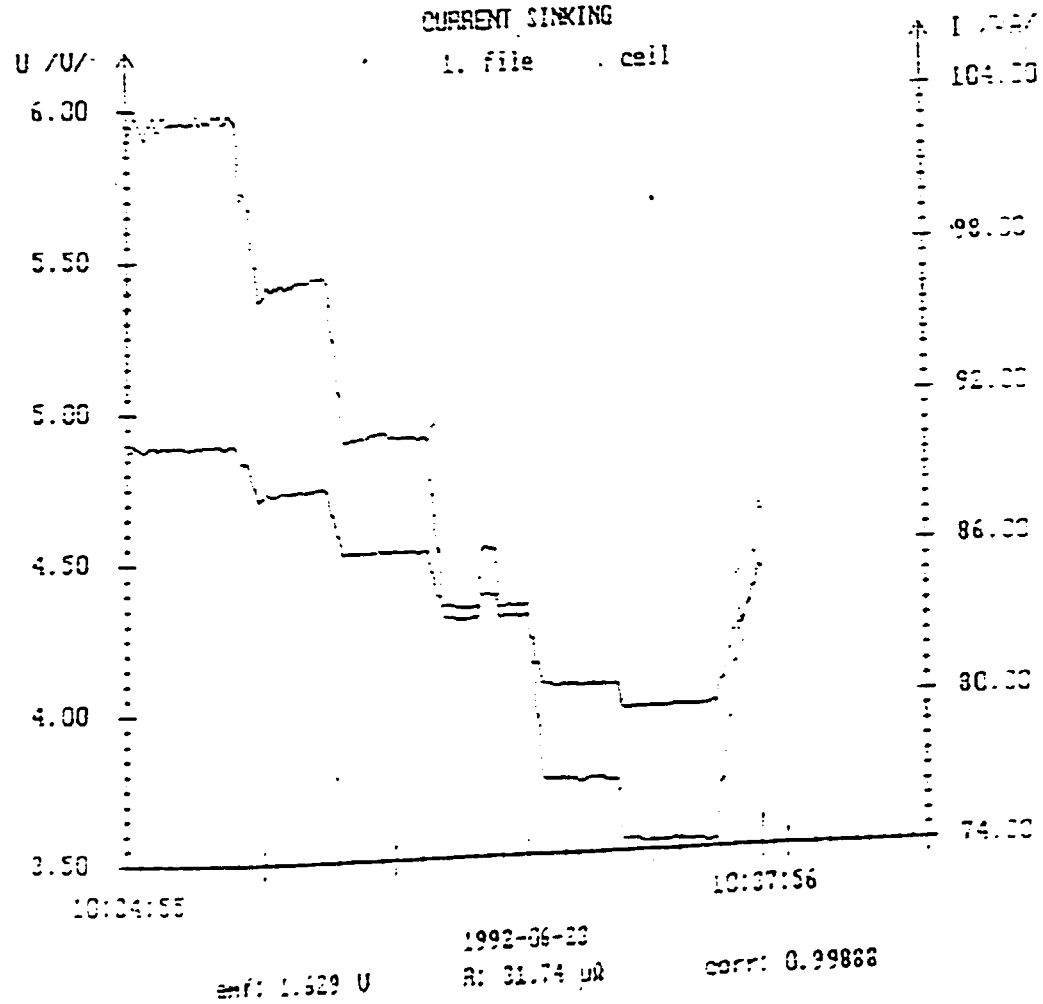

CURRENT SINKING
U /V/
1. file
cell
6.00
5.50
5.00
4.50
4.00
3.50
10:34:55
10:37:56
1992-06-23
emf: 1.629 V
R: 31.74 μΩ
corr: 0.99868

Figure : 2

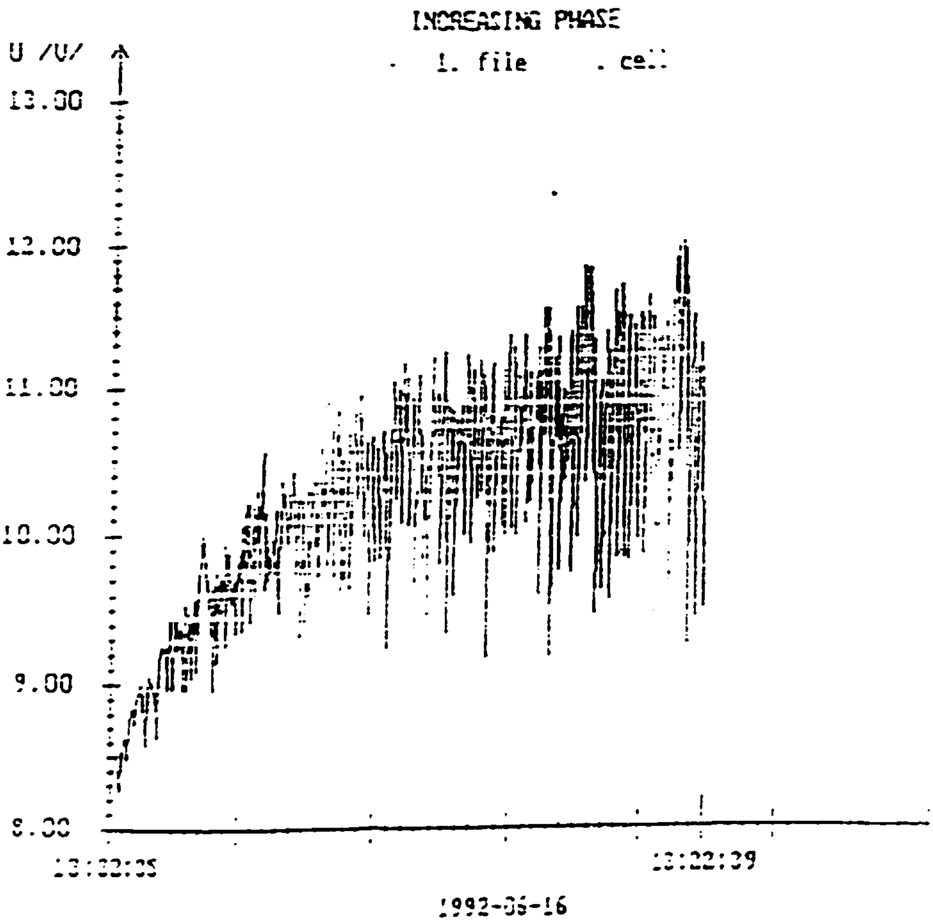


Figure : 3 (a)

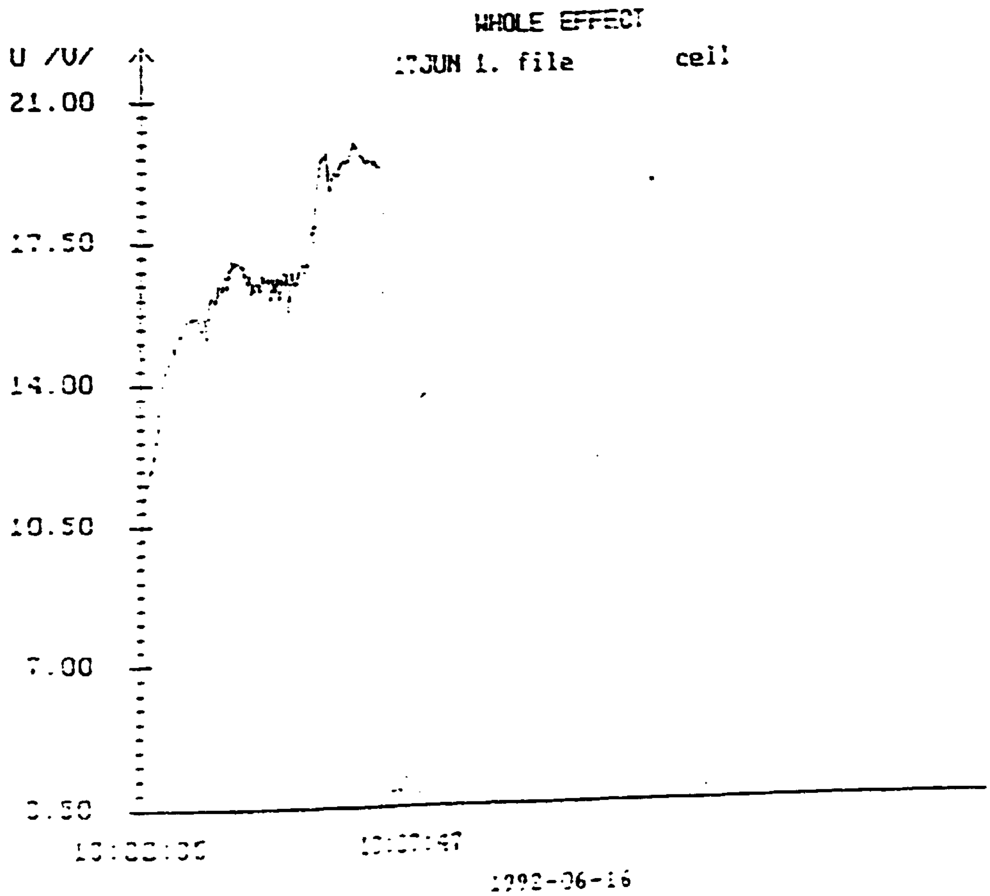
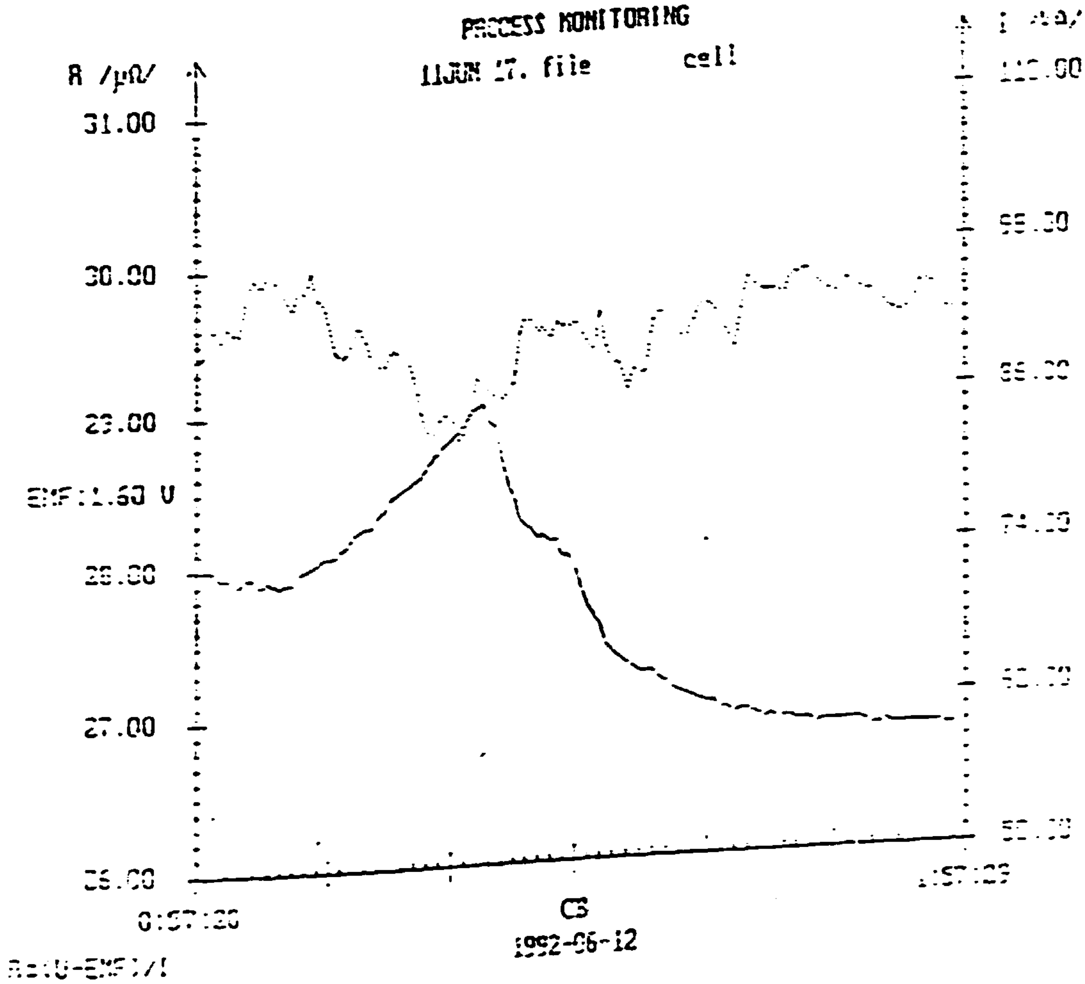


Figure : 3 (b)



PROCESS MONITORING
11JUN 17. file
cell
R /μΩ/
31.00
30.00
29.00
EMF:1.60 V
28.00
27.00
26.00
0:57:20
CS
1992-06-12

Figure 4 (a)

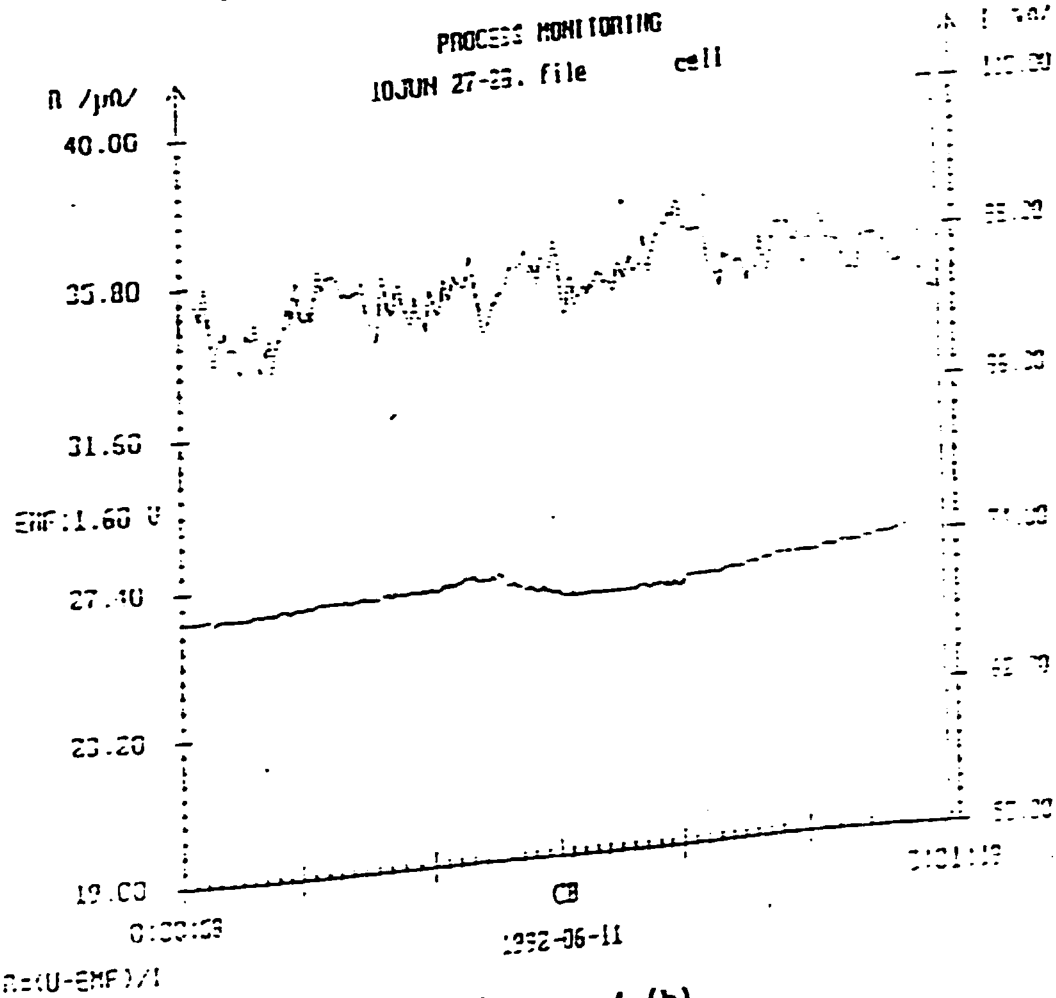

PROCESS MONITORING
10JUN 27-23. file
cell
R /μΩ/
40.00
35.80
31.60
EMF:1.60 V
27.40
23.20
19.00
0:00:03
1992-06-11
CB
R=(U-EMF)/I

Figure : 4 (b)

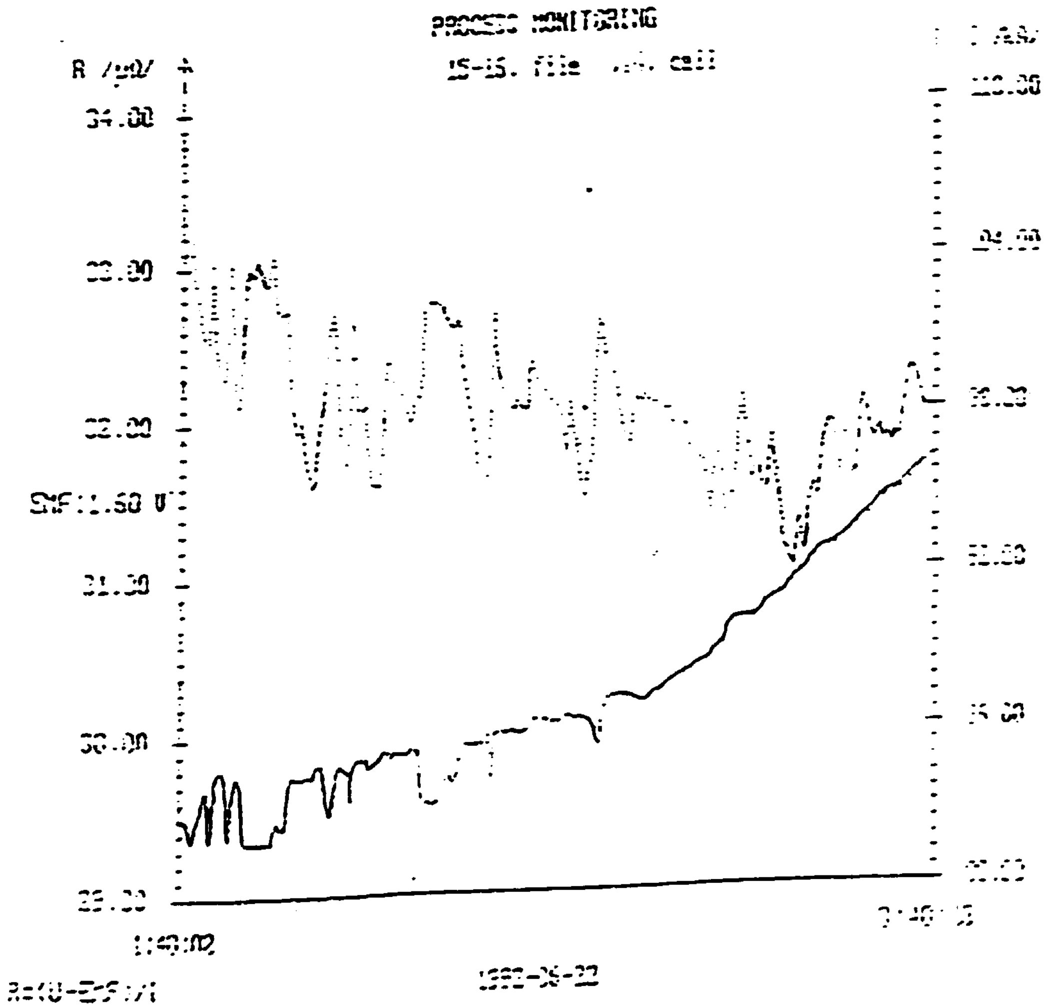


Figure : 4 (c)

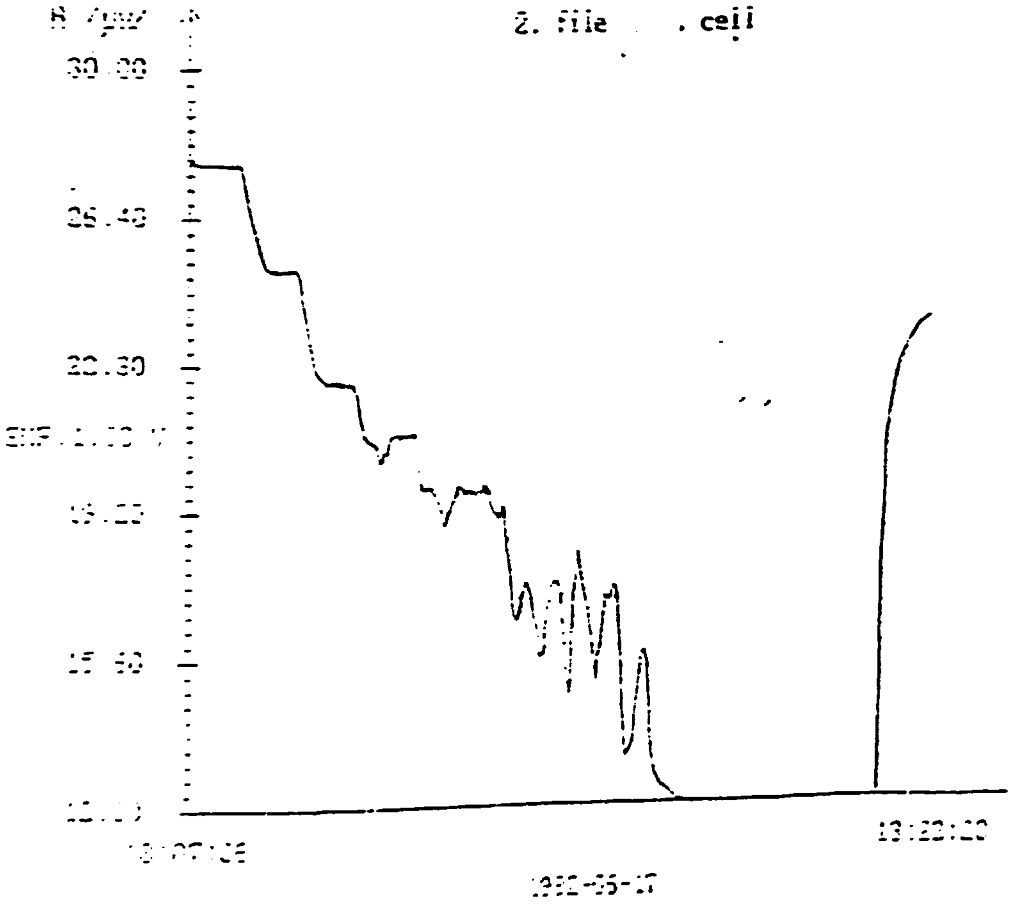
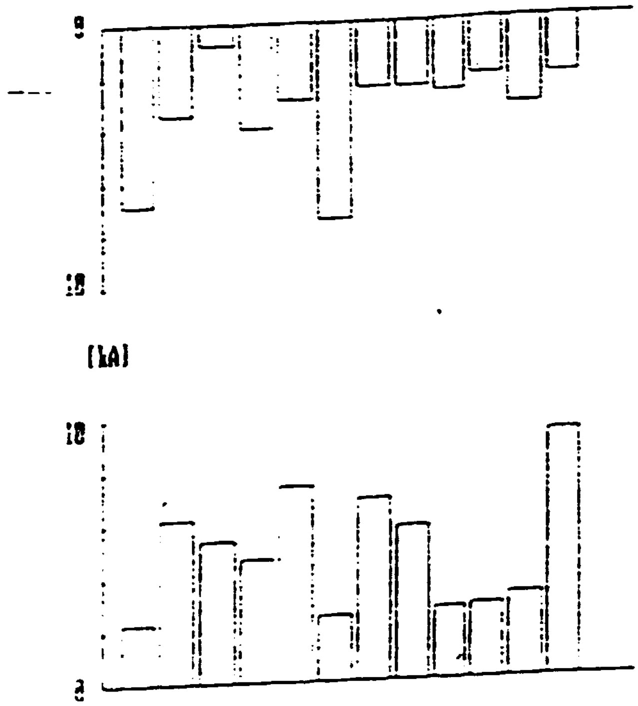
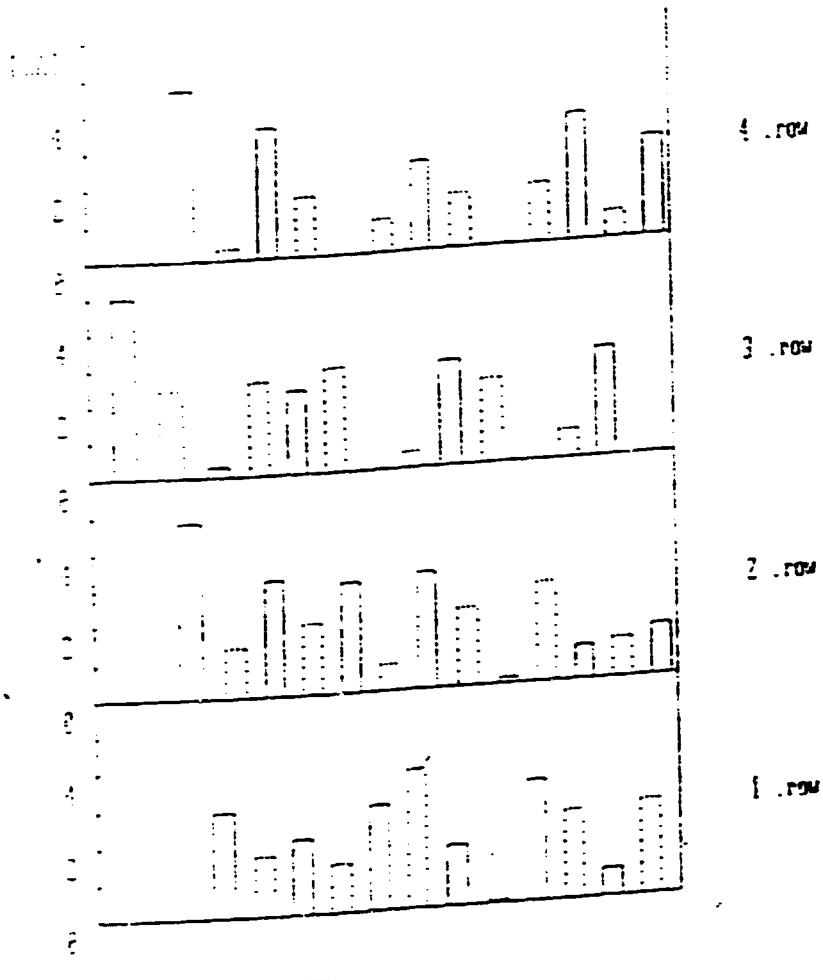


Figure : 5



	Σ current [kA]	Average [kA]	St.dev [kA]
North	40.89	3.41	1.67
South	59.11	4.93	2.18
Σ	100.00	4.17	2.17

Figure : 6



	1. level [IA]	2. level [IA]	3. level [IA]	Average [IA]	St.dev [IA]
4. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.43
3. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.48
2. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.29
1. [illegible]	[illegible]	[illegible]	[illegible]	1.01	1.19
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]		
St.dev	[illegible]	[illegible]	[illegible]		

Figure : 7

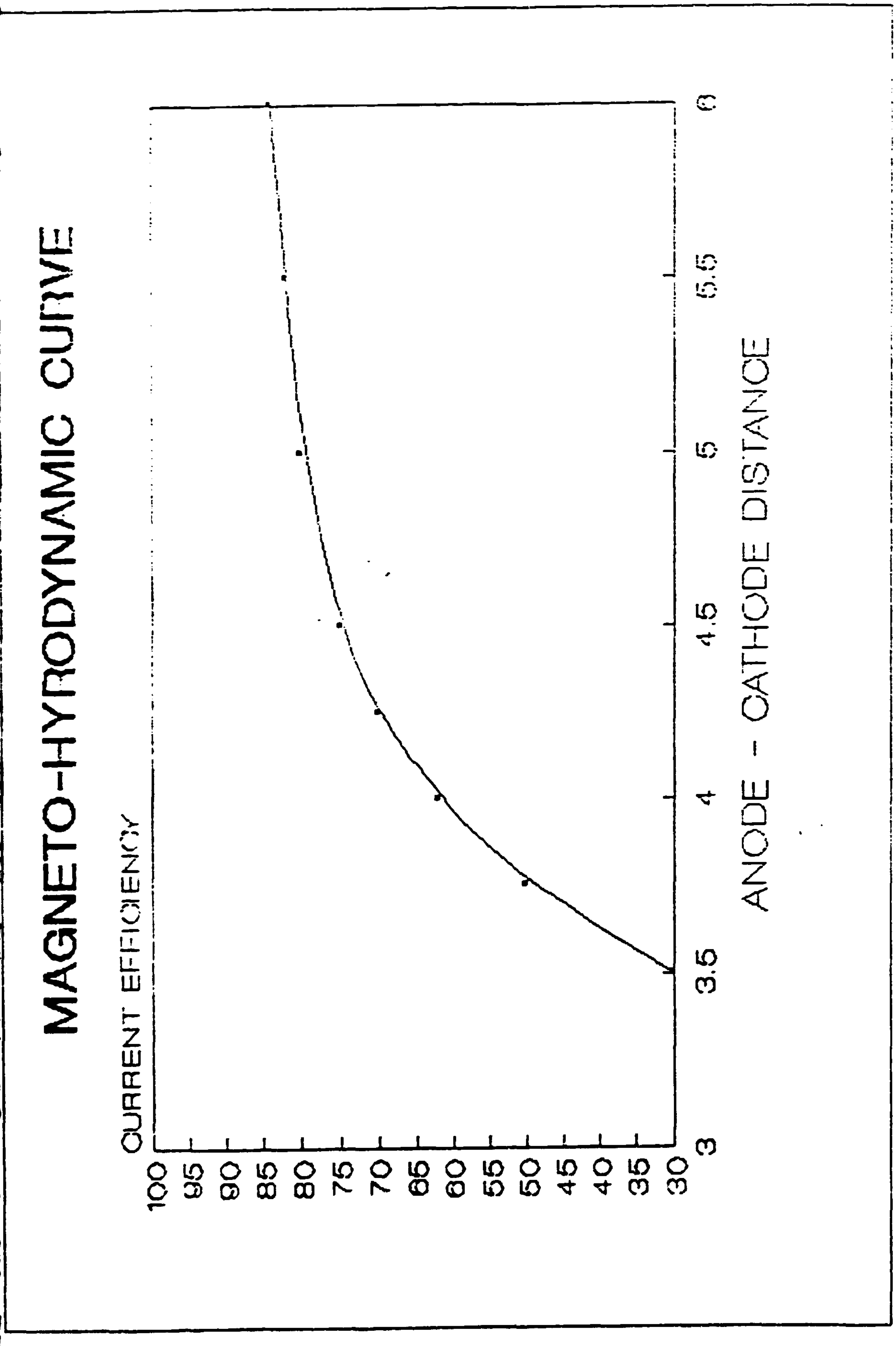
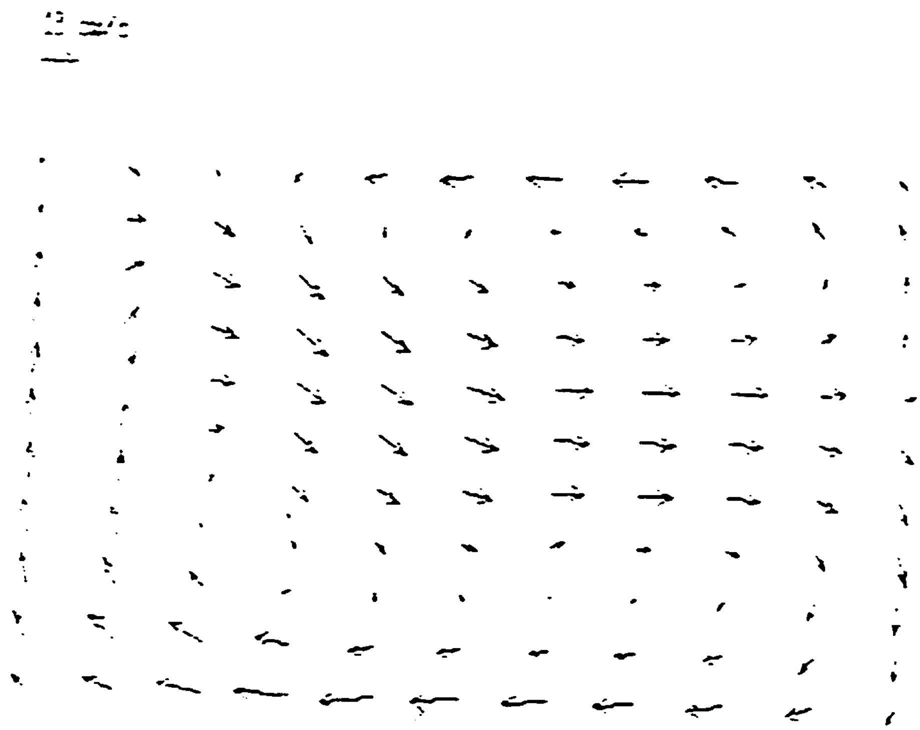
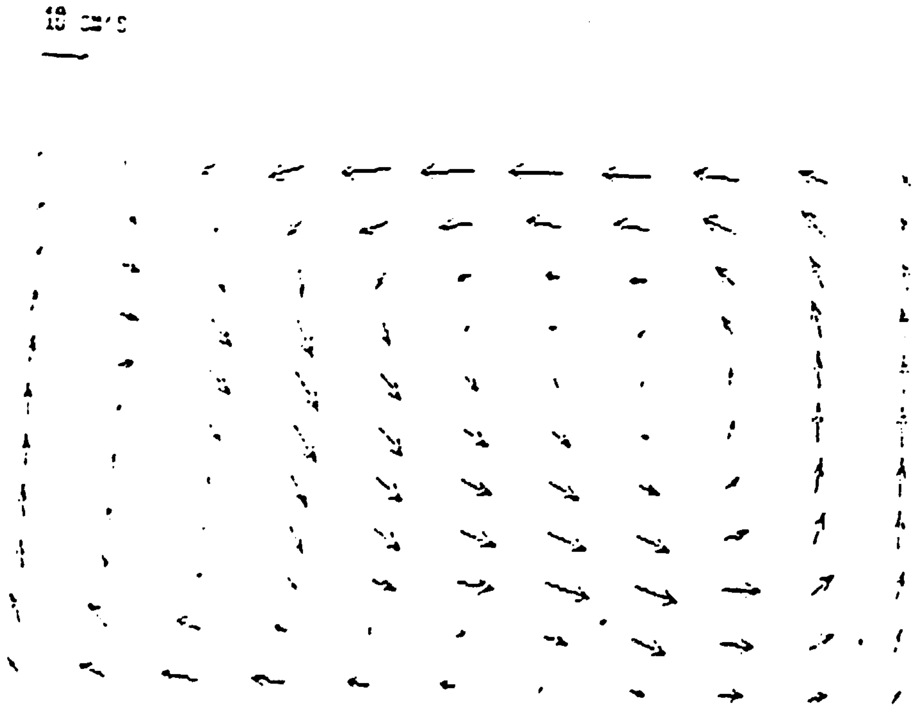

MAGNETO-HYRODYNAMIC CURVE
CURRENT EFFICIENCY
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
3
3.5
4
4.5
5
5.5
6
ANODE - CATHODE DISTANCE

Figure : 8

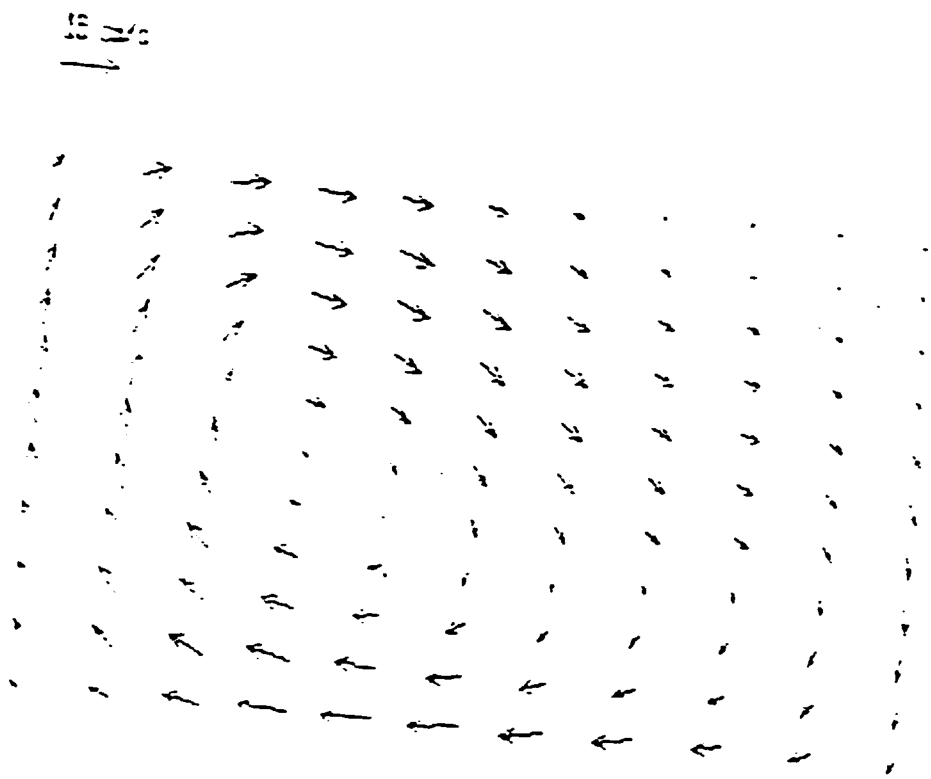


Velocity distribution (METALL)

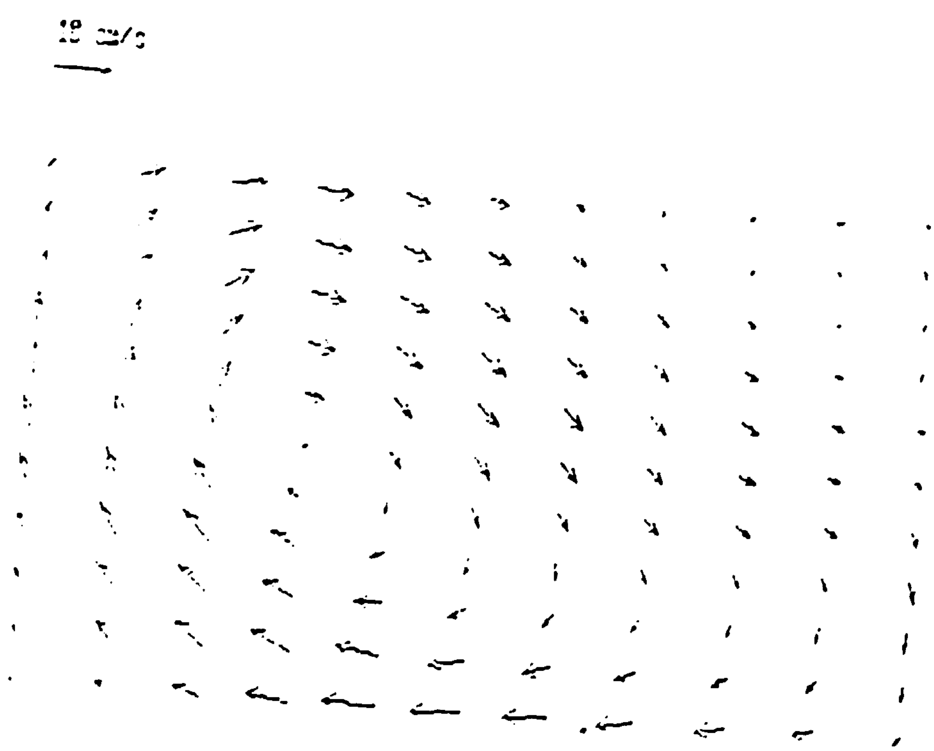


Velocity distribution (METALL)

Figure : 8(b)



Velocity distribution (ELECTROLYTE)



Velocity distribution (ELECTROLYTE)

Figure : 9(a)

ANNEXURE XII

DISCUSSION WITH EXPERT OF KAISER ALUMINIUM
26 APRIL 1993

Discussion was organised by Mr. I.K. Agarwal GM (Planning) in BALCO HQ's in New Delhi, following the earlier contacts of JNARDDC on possible participation of the Centre in the modernisation programme of BALCO's aluminium smelter at Korba.

The following persons were present:

KAISER ALUMINIUM (KA)	TATA ENGINEERING (TE)	BALCO	JNARDDC
Rajiv Dhameja Project Manager	N.K. Manaktala Manager Business Development	I.K. Agarwal GM (Planning) R.L. Khitha Dy. GM	Dr. T.R. Ramachandran Director Dr. J. Zambo CTA

At the outset a brief information on the establishment of JNARDDC and the activities already started in the field of measurements of aluminium electrolysis cells was given by Dr. Ramachandran.

The letter offering the services and information on capability of the Centre in this field has not reached Mr. Dhameja; therefore the data required for the elaboration of engineering for pot control system was discussed in detail. On the basis of discussion

Authorities of the Centre felt, that:

- JNARDDC is presently capable of collecting , measuring and evaluating all the data required for KA to elaborate engineering solution (software) for pot control system
- Reports on measurement carried out in May / June 1992 and proposals for modernisation of BALCO's smelter at Korba consist of all data and information necessary for KA in the present stage of work

JNARDDC could transfer useful information on cell operation in view of:

- the Centre in co-operation with the experts of the company are operating a group of cells at Korba with parameters and work routines set on the basis of measurements and evaluation
- international experts of the Centre are extensively involved in the development and operation of cells similar to or of the same type as those in Korba; they will be available for consultation and co-operation in the Centre from September 1993 to March 1994

JNARDDC in the frame of a bilateral contract with KA are ready to:

- transfer all available data recently collected and measured in connection with modernisation of BALCO smelter at Korba
- carry out any additional measurements - if any - required by KA for the preparation of engineering packages in the present stage
- carry out all measurements required for the fine tuning of pot control system in the phase of operation of test control units

The following actions were agreed:

- experts of JNARDDC would be available at the site on 1st and 2nd May 1993 when Mr. R. Dhameja is at Korba
- the measurement capability of the Centre will be demonstrated and information on the available data and experiences gained with the experimental cells will be provided

In case Mr. Dhameja finds, during the meeting with the experts of the Centre, that the the capability for undertaking measurement and reliability of data to be transferred are satisfactory :

- the list of data needed for KA in the present stage will be discussed and finalised
- measurement programme for the group of cells furnished by experimental control units for fine tuning should be agreed
- any other services (training, supervision etc.) which may be offered to KA / required from JNARDDC should be discussed and recorded

Mr. Dhameja will inform authorities of KA on the outcome of the discussion and the site visit, while JNARDDC would consider and submit to KA the financial aspects of their proposal, when the scope of work is outlined.

RECORD NOTES OF DISCUSSIONS BETWEEN KAISER AND JNARDDC

ON 01 MAY 1993

Kaiser representative Mr Rajiv Dhameja was introduced to JNARDDC team. JNARDDC team had pleasure to introduce brief Mr Rajiv Dhameja on the measuring equipments and capabilities of the equipments which were present in mobile van. He was also briefed about the capabilities of JNARDDC and its activities in BALCO regarding revitalization programme.

After briefing on the measuring equipments and centers capabilities in the field on aluminium smelting, it was discussed in detail with Mr Dhameja about the possibility utilization of these measuring equipments to collect data during the modernization programme of BALCO on the behalf of KATSI.

It was appreciated by Kaiser representative that the equipments in mobile van appeared sufficient enough to carry out all measurements required by KATSI. On detail discussion with Kaiser representative following points were agreed upon:

1) Kaiser representative requested JNARDDC to make available the data and final evaluation relating to the present status of BALCO's cell and results that was reached during the revitalization programme

2) It was informed by Kaiser representative that for the installation of experimental pot controllers, some measurement will be needed and heat flux measurements are needed to determine heat state of cell in this period. As requested, for the description of *Data Acquisition System*, it will be sent to the KATSI centre for the study by experts at their end.

3) Kaiser representative assured JNARDDC that on the basis of material that was handed over to him by JNARDDC and site impression, he will inform the Kaiser management and base on this information Kaiser management will inform the JNARDDC for any other facilities and services required by them.

On the base of the above information and detail discussion with Kaiser representative, it was decided that the JNARRDC will prepare a proposal on the activities, services and necessary requirements and send to Director (Technical Services) Kaiser for his consideration.

FOR KAISER | *FOR JNARDDC TEAM*

RAJIV DHAMEJA | JANOS HORVATH

ANNEXURE XIII

JAWAHARLAL NEHRU ALUMINIUM
RESEARCH DEVELOPMENT AND DESIGN
CENTRE NAGPUR

PROPOSAL FOR MEASUREMENTS AND DATA EVALUATION ON BALCO ELECTROLYSIS CELLS

MAY 1993

JAWAHARLAL NEHRU ALUMINIUM RESEARCH DEVELOPMENT AND DESIGN CENTRE NAGPUR

PROPOSAL FOR MEASUREMENTS AND DATA EVALUATION ON BALCO ELECTROLYSIS CELLS

Based on the discussions held between the representatives of the Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC) and Mr Rajiv Dhameja of Kaiser Aluminium on 26th of April at New Delhi (Annexure - I) and on 1st of May at BALCO, Korba (Annexure - II), a proposal is prepared by the Centre for participation in the modernisation programme of the smelters in the Bharat Aluminium Company by way of making measurements on the electrolysis pots and evaluation of the measured data. Following the record notes of discussions with Mr Rajiv Dhameja at BALCO, Korba, this proposal is divided into three sections, details of which are given below:

SECTION - I

This section basically consists of three parts including,

i All the data (traditional and nontraditional) collected during measurements by the JNARDDC team in June, 1992 for the determination of the cell state. Details are enclosed as Annexure III.

ii Evaluation / recommendation report prepared by JNARDDC to determine the cell state of BALCO smelter with the following contents :

- Analysis of cell operation
- Analysis of voltage components of cell
- Anode voltage drop and anode current distribution
- Bath voltage drop; sludge formation, hard muck removal and skimming generation
- Cathode voltage drop and cathode current distribution
- Voltage balance of existing cell operation
- Abnormalities in cell operation
- Conclusions and recommendations

- Reasons for low current efficiency and high energy consumption

This part also provides information on typical voltage and energy balance for the BALCO cells.

(iii) Revitalisation programme based on the evaluation and recommendations report; this part contains details of revitalisation programme which was prepared on the basis of the evaluation of the measured data and the conclusions drawn from them. It consists of two sub-sections which include all the measurements carried out during the revitalisation programme (March and April 1993) and evaluation of the data collected. The main contents are:

- Information on all the measured traditional and non-traditional data collected during the revitalisation programme.

- Main topics of revitalisation programme that was undertaken for normalisation of the cell operation based on the data/evaluation carried out in June, 1992. The content of this revitalisation programme discussed are as follows:

- Basis of the revitalisation programme

- Main steps of revitalisation programme and the parameters of cell operation achieved after execution of this programme including sludge removal, set point increase, adjustment of metal and bath height, alumina levelling on the crust, anode casing adjustment with respect to bath level and bottom of gas hooding

- Limitations in the implementation of the revitalisation programme including high skimming generation, improper anode current distribution, improper cathode current distribution, anode effect killing problems and hard muck removal problem

All the data collected during the implementation of the revitalisation programme are available; this along with the valuable experience gained by the personnel of the Centre during the implementation of the programme can be shared with KAISER.

SECTION - II

This section consists of two parts including

(i) Measurements required for monitoring the cell behavior- in our opinion one set of measurements will be of immense use for tuning the pot controllers before and after the installation. In this measurement the DATA ACQUISITION SYSTEM can be used for monitoring the cell behavior in detail.

ii) Thermal measurements including heat flux and temperature - the heat flux measurements will be carried out with KEMTHERM heat flux meter and with different heat sensors as required before and after the installation of pot controllers. Temperature measurements for which the heat flux sensors cannot be used, e.g. as in busbars, will be carried out by NON-CONTACT infrared type telethermometer.

SECTION - III

This section consists of a brief introduction to all the equipments housed in a mobile van for carrying out thermal, electrical and magnetic measurements on electrolysis cells and an introductory write-up on the capabilities of the Centre in the field of aluminium smelting (Annexure - IV).

We would also like to add that the Centre will be able to carry out other measurements which in our opinion will be of immense use during the modernisation programme. The measurements are :

- Alumina granulometry
- Bath analysis
- Current efficiency measurement (short term by gas analysis)

CHARGES FOR MEASUREMENTS, DATA EVALUATION AND OTHER RELATED ACTIVITIES

As per the discussions with Mr Rajiv Dhameja we are providing details of charges for undertaking various activities:

1. For section 1 relating to the parts (i), (ii) and (iii), a brief pre-feasibility report will be made available with all the details requested and the charges will be as follows :

DATA	:	
EVALUATION/RECOMMENDATIONS	:	US $ 75,000
REVITALISATION PROGRAMME	:	

2. Charges for the measurements described in section II which will be carried out as per Kaiser's requirements are as follows:

THERMAL MEASUREMENTS

We are able to complete measurements on one cell in a day (24 hrs).

Charges : US $ 500/DAY/POT

DATA ACQUISITION SYSTEM

We are able to monitor 13 cells at a time:

Charges : US $ 600/DAY

Any other facilities and services required by Kaiser Aluminum during the modernisation of BALCO smelter can be provided subject to their availability at the Centre.

NONTRADITIONAL MEASUREMENTS

1- List of data

Noise	- 325 noise data for 13 cells
Anode effect	- Whole, developing and increasing data for 13 cells
Anode and Cathode current distribution	- 15 data for 13 cells
Cell monitoring	- Current, voltage and corrected voltage data for 13 cells for a period of 25 days Stud pulling Alumina content trend detection
EMF value	- 40 data for 13 cells
Metal touching method	- Construction element drop, anode - cathode distance data for typical cell

TRADITIONAL MEASUREMENTS

- Bath temperature
- Metal height
- Bath height
- Cathode drop
- Anode drop

THERMAL MEASUREMENTS

- Heat flux measurements for one typical cell
- Measurements with Thermovision for one typical cell

MAGNETIC FLUX MEASUREMENTS

- Magnetic field components in the molten metal (B_x, B_y, B_z) on 10 points for one typical cell

ANNEXURE XIV

ARMY & NAVY BUILDING, 148 M.G. ROAD, BOMBAY 400 023. TEL. 244727. [illegible] FAX. [illegible]

GRINDWELL NORTON LTD.

March 11, 1992

Jawaharlal Nehru Aluminium
Research Development & Design Centre
Amonta Apartments, Katol Road,
Chhaoni,
Nagpur 440 013.

Kind Attn: Dr. T. R. Ramachandran
Director

Dear Sir,

Sub: Nitride Bonded Silicon Carbide Crucibles & Tubes.

We thank you for the kind courtesy extended to Norton team during their visit to your institute on 3rd March, 1992. We unfortunately could not meet you as you had already left for Delhi.

As discussed with Dr. J. Horvath we are enclosing herewith our quotation for Nitride Bonded Silicon Carbide Crucibles and Tubes. Please note the above material will be manufactured and supplied from our Bangalore works as per specification sheet enclosed.

Thanking you and awaiting for your valued order.

Yours faithfully,
For GRINDWELL NORTON LTD.

[illegible] BORLE
GROUP PRODUCT MANAGER
- TECHNICAL CERAMICS.

Dr Horvath
Mr [illegible]
For necessary action
TRR 22/3/92

Pl send photocopy to Dr Horvath at Korba to get [illegible] reaction.
TRR 22/3/92

Mr B

GRINDWELL
NORTON LTD

March 1?, 1993

JAWAHARLAL NEHRU ALUMINIUM RESEARCH DEVELOPMENT & DESIGN CENTRE

A. PRICE

NITRIDE BONDED SILICON CARBIDE

1. CRUCIBLES (AS PER DRAWING ENCLOSED)

SIZE NO.	A	BD	CB	QTY	UNIT PRICE Rs.	VALUE Rs.
1	120	110	80	50	1243	62150.00
2	100	100	70	50	930	46500.00
3	80	100	70	50	772	38600.00
4	60	100	70	50	618	30900.00

Mould Charges .. .. Rs.4500/- each

2. TUBE (OPEN END) AS PER DRG. ENCLOSED 50 185 9250.00

Size 40 OD x 10 ID x 60 L

Mould Charges Rs.3000/-

3. TUBE (ONE END CLOSED)
AS PER DRAWING ENCLOSED

Size 40 OD x 10 ID x 70 L 50 220 11000.00

Mould Charges Rs.3000/-

B. EXTRA CHARGEABLE

Packing	:	2%
Excise duty	:	20%
CST	:	4% against form 'C'
Freight	:	At Actuals

C. DELIVERY : 10/12 weeks

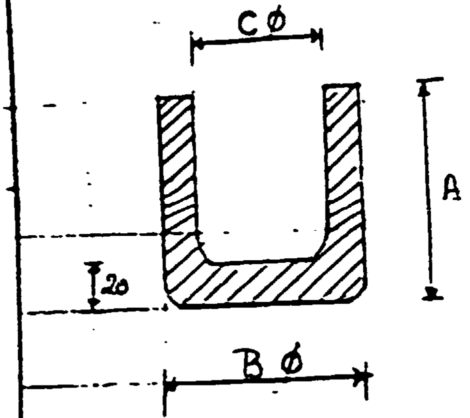
D. PAYMENT TERMS : 30% Advance and balance against proforma invoice.

E. VALIDITY : 4 weeks

For GRINDWELL NORTON LTD.

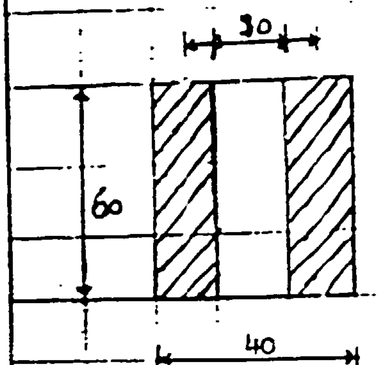
V V SOPLE
GROUP PRODUCT MANAGER
- TECHNICAL CERAMICS.

PRODUCT DRAWING

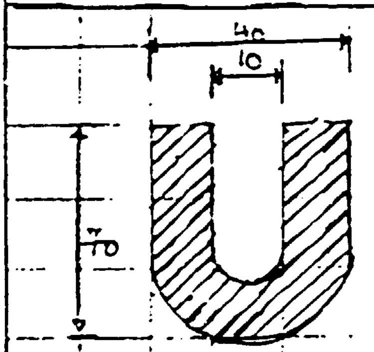


SL.NO	A	B	C
1	120	110	70
2	100	100	70
3	80	100	70
4	60	100	70

CRUCIBLE



TUBE (OPEN ENDED)



DRAWING, NOT TO SCALE

ALL DIMENSIONS IN MM

ONE END CLOSED TUBE

SR. NO.	A	B	C	D	E	F	G	H

PRODUCT	NB-SiC	DATE	2/3/93
CUSTOMER	: Jawaharlal Nehru Al.c	GNO DRG. NO.	SJ 30
CUSTOMER DRG. NO	—	GNO PART NO	SJ 30
CUSTOMER PART NO.	—		

Product Information

Nitride Bonded Silicon Carbide

* Very high strength at elevated temperature
* Non-wetting by non-ferrous metals
* High thermal conductivity
* Excellent emissivity
* High resistance to thermal shocks
* Very high resistance to abrasion
* Resistance to chemical attack
* Low electrical conductivity

* Kiln Furniture like Batts, Hanging Setters, Hollow Bars and Tubes in thinner sections for ceramic industry.
* Hall Cell side walls (in Bricks or other shapes) in electrolytic reduction of aluminium oxide.
* Zinc and Copper smelters tapout and condenser lining.
* Thermocouple Sheath, Launders, Nozzles, Spouts, Feed Stoppers, Spoons etc. in non-ferrous foundries.
* Spray Nozzles in SO_2 Scrubbers.
* Wear resistant lining for pipe bends.

Chemical analysis		
SiC	Min (%)	75
Max. use temperature	(Deg. C)	1500
Bulk Density	Min (g/cm^3)	2.5
Apparent Porosity	Max (%)	18
Modulus of rupture	Min (Kg/cm^2)	
at room temperature		350
at 1250 Deg. C		450
Cold crushing strength	Min (Kg/cm^2)	300
Emissivity		0.94
Thermal conductivity	(W/mk)	15
Electrical Resistivity	(Ohm/mm)	3000

GRINDWELL NORTON LTD.

Industrial Ceramics Division, Army & Navy Building, 148 M.G. Road, Bombay-400 023.
Tel.: 244727 Telex: 011-82840 Fax: 022-2023711.

ANNEXURE XV

VOLTAGE COMPONENTS AND ENERGY BALANCE IN THE AC GAP
AT THE DIFFERENT CURRENT LOADING WITH CONSTANT HEAT LOSSES -

MEASURED DATA

TYPE OF CELL		:	SODERBERG	
CRYOLITE RATIO		:	2.85	
AVERAGE ALUMINA CONTENT	(%)	:	4.50	
CALCIUM-FLUORIDE CONTENT	(%)	:	4.50	
ELECTROLYTE TEMPERATURE	(C)	:	965.00	
AC DISTANCE	(cm)	:	5.00	
LINE CURRENT	(kA)	:	106.00	
ANODE WIDTH	(cm)	:	230	
ANODE LENGTH	(cm)	:	650	
CELL VOLTAGE	(V)	:	[illegible]	
CURRENT MODULATION	(kA)	:		[illegible]
CURRENT EFFICIENCY	(%)	:	84.00	[illegible]
ANODE VOLTAGE DROP	(V)	:	0.35	[illegible]
CATHODE VOLTAGE DROP	(V)	:	0.40	[illegible]
BUSBAR VOLTAGE DROP	(V)	:	0.25	[illegible]
VOLTAGE DROP OF SHORT CIRCUIT	(V)	:	1.00	0.[illegible]

CALCULATED DATA FROM PLANT DATA		:	106 kA	[illegible]
EQUILIBRIUM POTENTIAL	(V)	:	1.227	[illegible]
CATHODIC OVERVOLTAGE	(V)	:	0.065	[illegible]
ANODIC REACTION OVERVOLTAGE	(V)	:	[illegible]	[illegible]
ANODIC DIFFUSION OVERVOLTAGE	(V)	:	0.014	[illegible]
CALCULATED E.M.F.	(V)	:	1.785	[illegible]
SPECIFIC RESISTANCE OF BATH	(ohm cm)	:	0.417	[illegible]
RESISTANCE OF ELECTROLYTE		:	14.0[illegible]	[illegible]
ELECTROLYTE VOLTAGE DROP	(V)	:	1.5[illegible]	[illegible]
VOLTAGE DROP BETWEEN AC GAP	(V)	:	1.5[illegible]	[illegible]
CALCULATED CELL VOLTAGE	(V)	:	[illegible]	[illegible]

CALCULATED OF ENERGY BALANCE AT THE UNCHANGING HEAT LOSSES

LIQUID TEMPERATURE	(C)	:	[illegible]	
SUPERHEAT	(C)	:	17.[illegible]	
VOLTAGE DEMAND OF Al PRODUCTION	(V)	:	1.[illegible]	[illegible]
ENERGY DEMAND OF Al PRODUCTION	(kW)	:	[illegible]	[illegible]
MODIFIED CELL VOLTAGE	(V)	:		[illegible]
MODIFIED AC DISTANCE	(cm)	:		[illegible]
MODIFIED ELECTROLYTE VOLTAGE DROP	(V)	:		[illegible]
HEAT LOSSES	(kW)	:	275.404	[illegible]
ENERGY EFFICIENCY	(%)	:	[illegible]	[illegible]
DAILY PRODUCTION	(kg)	:	7[illegible]	[illegible]
ENERGY CONSUMPTION	(kWh/kg)	:	15.71[illegible]	[illegible]

VOLTAGE COMPONENTS AND ENERGY BALANCE IN THE AC GAP
AT THE DIFFERENT CURRENT LOADING WITH CONSTANT HEAT LOSSES

MEASURED DATA

TYPE OF CELL		:	SDERBERG	
CRYOLITE RATIO		:	2.85	
AVERAGE ALUMINA CONTENT	(%)	:	4.50	
CALCIUM-FLUORIDE CONTENT	(%)	:	4.50	
ELECTROLYTE TEMPERATURE	(C)	:	965.00	
AC DISTANCE	(cm)	:	5.00	
LINE CURRENT	(kA)	:	28.00	
ANODE WIDTH	(cm)	:	150	
ANODE LENGTH	(cm)	:	230	
CELL VOLTAGE	(V)	:	4.34	
CURRENT MODULATION	(kA)	:		25.20
CURRENT EFFICIENCY	(%)	:	84.00	86.00
ANODE VOLTAGE DROP	(V)	:	0.38	0.32
CATHODE VOLTAGE DROP	(V)	:	0.40	0.36
BUSBAR VOLTAGE DROP	(V)	:	0.15	0.14
VOLTAGE DROP OF SHORT CIRCUIT	(V)	:	[illegible]	0.81

CALCULATED DATA FROM PLANT DATA		:	28 kA	25.2 kA
EQUILIBRIUM POTENTIAL	(V)	:	1.2[illegible]	1.227
CATHODIC OVERVOLTAGE	(V)	:	0.07[illegible]	0.066
ANODIC REACTION OVERVOLTAGE	(V)	:	0.490	0.480
ANODIC DIFFUSION OVERVOLTAGE	(V)	:	0.01[illegible]	0.012
CALCULATED E.M.F.	(V)	:	1.80[illegible]	1.784
SPECIFIC RESISTANCE OF BATH	(Ωcm)	:	0.417	0.417
RESISTANCE OF ELECTROLYTE	(μΩ)	:	61.048	61.048
ELECTROLYTE VOLTAGE DROP	(V)	:	1.70[illegible]	1.538
VOLTAGE DROP BETWEEN AC GAP	(V)	:	1.70[illegible]	1.538
CALCULATED CELL VOLTAGE	(V)	:	[illegible]	2.048

CALCULATED OF ENERGY BALANCE AT THE UNCHANGING HEAT LOSSES

LIQUID TEMPERATURE	(C)	:	957.05[illegible]	
SUPERHEAT	(C)	:	17.948	
VOLTAGE DEMAND OF Al PRODUCTION	(V)	:	1.881	1.912
ENERGY DEMAND OF Al PRODUCTION	(kW)	:	52.62[illegible]	48.17[illegible]
MODIFIED CELL VOLTAGE	(V)	:		4.648
MODIFIED AC DISTANCE	(cm)	:		6.26[illegible]
MODIFIED ELECTROLYTE VOLTAGE DROP	(V)	:		1.92[illegible]
HEAT LOSSES	(kW)	:	68.9[illegible]	68.9[illegible]
ENERGY EFFICIENCY	(%)	:	32.02[illegible]	30.62[illegible]
DAILY PRODUCTION	(kg)	:	189.38[illegible]	174.670
ENERGY CONSUMPTION	(kWh/kg)	:	15.40[illegible]	16.103

VOLTAGE COMPONENTS AND ENERGY BALANCE IN THE AC GAP AT THE DIFFERENT CURRENT LOADING WITH CONSTANT HEAT LOSSES

MEASURED DATA

TYPE OF CELL		:	SDERBERG	
CRYOLITE RATIO		:	2.85	
AVERAGE ALUMINA CONTENT	(%)	:	4.50	
CALCIUM-FLUORIDE CONTENT	(%)	:	4.50	
ELECTROLYTE TEMPERATURE	(C)	:	985.00	
AC DISTANCE	(cm)	:	5.00	
LINE CURRENT	(kA)	:	108.00	
ANODE WIDTH	(cm)	:	230	
ANODE LENGTH	(cm)	:	650	
CELL VOLTAGE	(V)	:	4.43	
CURRENT MODULATION	(kA)	:		54.00
CURRENT EFFICIENCY	(%)	:	84.00	90.00
ANODE VOLTAGE DROP	(V)	:	0.35	0.17
CATHODE VOLTAGE DROP	(V)	:	0.40	0.20
BUSBAR VOLTAGE DROP	(V)	:	0.25	0.13
VOLTAGE DROP OF SHORT CIRCUIT	(V)	:	1.00	0.50

CALCULATED DATA FROM PLANT DATA

			108 kA	54 kA
EQUILIBRUM POTENTIAL	(V)	:	1.227	1.227
CATHODIC OVERVOLTAGE	(V)	:	0.065	0.014
ANODIC REACTION OVERVOLTAGE	(V)	:	0.479	0.409
ANODIC DIFFUSION OVERVOLTAGE	(V)	:	0.014	0.007
CALCULATED E.M.F.	(V)	:	1.785	1.656
SPECIFIC RESISTANCE OF BATH	(Ωcm)	:	0.417	0.417
RESISTANCE OF ELECTROLYTE	(Ω)	:	14.099	14.099
ELECTROLYTE VOLTAGE DROP	(V)	:	1.523	0.761
VOLTAGE DROP BETWEEN AC GAP	(V)	:	1.523	0.761
CALCULATED CELL VOLTAGE	(V)	:	2.523	1.261

CALCULATED OF ENERGY BALANCE AT THE UNCHANGING HEAT LOSSES

LIQUID TEMPERATURE	(C)	:	967.052	
SUPERHEAT	(C)	:	17.948	
VOLTAGE DEMAND OF Al PRODUCTION	(V)	:	1.880	1.975
ENERGY DEMAND OF Al PRODUCTION	(kW)	:	203.036	106.675
MODIFIED CELL VOLTAGE	(V)	:		7.076
MODIFIED AC DISTANCE	(cm)	:		30.211
MODIFIED ELECTROLYTE VOLTAGE DROP	(V)	:		4.600
HEAT LOSSES	(kW)	:	275.404	275.404
ENERGY EFFICIENCY	(%)	:	21.395	21.056
DAILY PRODUCTION	(kg)	:	731.176	391.702
ENERGY CONSUMPTION	(kWh/kg)	:	15.716	23.428

VOLTAGE COMPONENTS AND ENERGY BALANCE IN THE AC GAP
AT THE DIFFERENT CURRENT LOADING WITH CONSTANT HEAT LOSSES

MEASURED DATA

TYPE OF CELL		: SDERBERG	
CRYOLITE RATIO		: 2.85	
AVERAGE ALUMINA CONTENT	(%)	: 4.50	
CALCIUM-FLUORIDE CONTENT	(%)	: 4.50	
ELECTROLYTE TEMPERATURE	(C)	: 965.00	
AC DISTANCE	(cm)	: 5.00	
LINE CURRENT	(kA)	: 28.00	
ANODE WIDTH	(cm)	: 150	
ANODE LENGTH	(cm)	: 230	
CELL VOLTAGE	(V)	: 4.34	
CURRENT MODULATION	(kA)	:	14.00
CURRENT EFFICIENCY	(%)	: 84.00	90.00
ANODE VOLTAGE DROP	(V)	: 0.35	0.17
CATHODE VOLTAGE DROP	(V)	: 0.40	0.20
BUSBAR VOLTAGE DROP	(V)	: 0.15	0.08
VOLTAGE DROP OF SHORT CIRCUIT	(V)	: 0.90	0.45
CALCULATED DATA FROM PLANT DATA		: 28 kA	14 kA
EQUILIBRUM POTENTIAL	(V)	: 1.227	1.227
CATHODIC OVERVOLTAGE	(V)	: 0.073	0.022
ANODIC REACTION OVERVOLTAGE	(V)	: 0.490	0.421
ANODIC DIFFUSION OVERVOLTAGE	(V)	: 0.014	0.007
CALCULATED E.M.F.	(V)	: 1.804	1.676
SPECIFIC RESISTANCE OF BATH	(Ωcm)	: 0.417	0.417
RESISTANCE OF ELECTROLYTE	(μΩ)	: 61.048	61.048
ELECTROLYTE VOLTAGE DROP	(V)	: 1.709	0.855
VOLTAGE DROP BETWEEN AC GAP	(V)	: 1.709	0.855
CALCULATED CELL VOLTAGE	(V)	: 2.609	1.305
CALCULATED OF ENERGY BALANCE AT THE UNCHANGING HEAT LOSSES			
LIQUID TEMPERATURE	(C)	: 947.052	
SUPERHEAT	(C)	: 17.948	
VOLTAGE DEMAND OF Al PRODUCTION	(V)	: 1.880	1.975
ENERGY DEMAND OF Al PRODUCTION	(kW)	: 52.639	27.636
MODIFIED CELL VOLTAGE	(V)	:	6.902
MODIFIED AC DISTANCE	(cm)	:	26.136
MODIFIED ELECTROLYTE VOLTAGE DROP	(V)	:	4.476
HEAT LOSSES	(kW)	: 68.965	68.965
ENERGY EFFICIENCY	(%)	: 32.324	21.586
DAILY PRODUCTION	(kg)	: 189.364	101.552
ENERGY CONSUMPTION	(kWh/kg)	: 15.407	22.852

VOLTAGE COMPONENTS AND ENERGY BALANCE IN THE AC GAP
AT THE DIFFERENT CURRENT LOADING WITH VARYING HEAT LOSSES

MEASURED DATA

TYPE OF CELL		:	SDERBERG	
CRYOLITE RATIO		:	2.85	
AVERAGE ALUMINA CONTENT	(%)	:	4.50	
CALCIUM-FLUORIDE CONTENT	(%)	:	4.50	
ELECTROLYTE TEMPERATURE	(C)	:	985.00	
AC DISTANCE	(cm)	:	5.00	
LINE CURRENT	(kA)	:	108.00	
ANODE WIDTH	(cm)	:	230	
ANODE LENGTH	(cm)	:	650	
CELL VOLTAGE	(V)	:	4.43	
CURRENT MODULATION	(kA)	:		86.40
CURRENT EFFICIENCY	(%)	:	84.00	87.50
ANODE VOLTAGE DROP	(V)	:	0.35	0.28
CATHODE VOLTAGE DROP	(V)	:	0.40	0.32
BUSBAR VOLTAGE DROP	(V)	:	0.25	0.20
VOLTAGE DROP OF SHORT CIRCUIT	(V)	:	1.00	0.80

CALCULATED DATA FROM PLANT DATA		:	108 kA	86.4 kA
EQUILIBRUM POTENTIAL	(V)	:	1.227	1.227
CATHODIC OVERVOLTAGE	(V)	:	0.065	0.048
ANODIC REACTION OVERVOLTAGE	(V)	:	0.479	0.456
ANODIC DIFFUSION OVERVOLTAGE	(V)	:	0.014	0.011
CALCULATED E.M.F.	(V)	:	1.785	1.743
SPECIFIC RESISTANCE OF BATH	(Ωcm)	:	0.417	0.417
RESISTANCE OF ELECTROLYTE	(Ω)	:	14.099	14.099
ELECTROLYTE VOLTAGE DROP	(V)	:	1.523	1.218
VOLTAGE DROP BETWEEN AC GAP	(V)	:	1.523	1.218
CALCULATED CELL VOLTAGE	(V)	:	2.523	2.018

CALCULATED OF ENERGY BALANCE AT THE 20 % DECREASED HEAT LOSSES

LIQUID TEMPERATURE	(C)	:	967.052	
SUPERHEAT	(C)	:	17.948	
VOLTAGE DEMAND OF Al PRODUCTION	(V)	:	1.880	1.936
ENERGY DEMAND OF Al PRODUCTION	(kW)	:	203.036	167.241
MODIFIED CELL VOLTAGE	(V)	:		4.486
MODIFIED AC DISTANCE	(cm)	:		7.183
MODIFIED ELECTROLYTE VOLTAGE DROP	(V)	:		1.750
HEAT LOSSES	(kW)	:	275.404	220.324
ENERGY EFFICIENCY	(%)	:	31.395	32.293
DAILY PRODUCTION	(kg)	:	731.176	609.313
ENERGY CONSUMPTION	(kWh/kg)	:	15.716	15.277

VOLTAGE COMPONENTS AND ENERGY BALANCE IN THE AC GAP AT THE DIFFERENT CURRENT LOADING WITH VARYING HEAT LOSSES

MEASURED DATA

TYPE OF CELL	:	SDERBERG	
CRYOLITE RATIO	:	2.85	
AVERAGE ALUMINA CONTENT	(%) :	4.50	
CALCIUM-FLUORIDE CONTENT	(%) :	4.50	
ELECTROLYTE TEMPERATURE	(C) :	985.00	
AC DISTANCE	(cm) :	5.00	
LINE CURRENT	(kA) :	28.00	
ANODE WIDTH	(cm) :	150	
ANODE LENGTH	(cm) :	230	
CELL VOLTAGE	(V) :	4.34	
CURRENT MODULATION	(kA) :		22.40
CURRENT EFFICIENCY	(%) :	84.00	87.50
ANODE VOLTAGE DROP	(V) :	0.35	0.28
CATHODE VOLTAGE DROP	(V) :	0.40	0.32
BUSBAR VOLTAGE DROP	(V) :	0.15	0.12
VOLTAGE DROP OF SHORT CIRCUIT	(V) :	0.90	0.72

CALCULATED DATA FROM PLANT DATA

	:	28 kA	22.4 kA
EQUILIBRUM POTENTIAL	(V) :	1.227	1.227
CATHODIC OVERVOLTAGE	(V) :	0.073	0.057
ANODIC REACTION OVERVOLTAGE	(V) :	0.490	0.466
ANODIC DIFFUSION OVERVOLTAGE	(V) :	0.014	0.011
CALCULATED E.M.F.	(V) :	1.804	1.762
SPECIFIC RESISTANCE OF BATH	(jcm) :	0.417	0.417
RESISTANCE OF ELECTROLYTE	(fj) :	61.048	61.048
ELECTROLYTE VOLTAGE DROP	(V) :	1.709	1.367
VOLTAGE DROP BETWEEN AC GAP	(V) :	1.709	1.367
CALCULATED CELL VOLTAGE	(V) :	2.609	2.067

CALCULATED OF ENERGY BALANCE AT THE 20 % DECREASED HEAT LOSSES

LIQUID TEMPERATURE	(C) :	967.052	
SUPERHEAT	(C) :	17.946	
VOLTAGE DEMAND OF Al PRODUCTION	(V) :	1.880	1.936
ENERGY DEMAND OF Al PRODUCTION	(kW) :	52.639	43.359
MODIFIED CELL VOLTAGE	(V) :		4.399
MODIFIED AC DISTANCE	(cm) :		6.373
MODIFIED ELECTROLYTE VOLTAGE DROP	(V) :		1.743
HEAT LOSSES	(kW) :	68.965	55.172
ENERGY EFFICIENCY	(%) :	32.024	32.931
DAILY PRODUCTION	(kg) :	189.564	157.970
ENERGY CONSUMPTION	(kWh/kg) :	15.407	14.981