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TEXAS INSTRUMENTS
INCORPORATED

HEAT STERILIZABLE Ni-Cd BATTERY DEVELOPMENT

Jet Propulsion Laboratory
Contract No. 951972

Report for Fourth Quarter
1 April to 30 June 1968

by

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metallurgical materials division

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Abstract

The objective of this work is the development of heat-sterilizable, hermetically sealed Ni-Cd cells for space applications. Electrochemical characterization of control sealed cells as well as sealed cells for factorial experiment for design optimization is completed. Performance data as a function of cycle life for two separators, two concentrations and two levels of pore fill are presented. Although the technical feasibility of heat-sterilization of sealed Ni-Cd cells has been established, several practical problems have been encountered in the statistical studies. One of these is the lack of cell to cell uniformity. Another one is the gradual decrease in the cell capacity on cycling [illegible] for cells that have not gone through heat-sterilization. The cause for this variation in the capacity appears to be associated with the physical-mechanical properties of the separator and not with the positive or negative plates. The cause of the capacity degradation after sterilization also appears to be related to the same factors. These factors are now being investigated.

Physico-chemical characterization of the positive and negative plates before and after sterilization is underway.

X-ray diffraction of plates did not detect the formation of any new phases during sterilization. The $Ni(OH)_2$ in the positive plate became more ordered or of larger particle size during sterilization; however, nearly returned to its initial state upon continued cycling. The crystallite size of the $Cd(OH)_2$ was too large to permit detection of any change.

I. INTRODUCTION

This is the fourth quarterly progress report on the heat-sterilizable nickel-cadmium battery development under Jet Propulsion Laboratory Contract No. 951972, sponsored under NASA Contract NAS-7-100, Task Order No. RD-26. The object of this contract is to perform research and development work leading to the design, development, fabrication and testing of sealed, rechargeable, nickel-cadmium cells capable of heat-sterilization.

The heat sterilization requirements include testing at 135°C for type approval, and 125°C testing for flight acceptance. At the 135°C sterilization temperature, the heating rate is 19°C/hour. The chamber is cooled at the same rate at which it was heated. Two such cycles are required. For preliminary testing one 120-hour cycle may be used.

The specific tasks under this contract are divided into three broad catagories: (1) electrochemistry involving statistical and other experiments for characterizing and optimizing electrodes, electrolyte and separators for heat-sterilizable Ni-Cd cell, (2) case design for hermetically sealed, heat-sterilizable cells, and (3) fabrication and evaluation of rectangular, 4 AH sealed cells before and after heat-sterilization.

The work under task 2 on the case and seal design for hermetically sealed, heat-sterilizable cells has already been completed and reported in the previous progress reports under this contract. The emphasis now is to determine and correct the causes of the capacity degradation and increased polarization of sterilized cells using both model control experiments as well as sealed, sterilizable Ni-Cd cells of the rectangular design. The work performed during the fourth quarter is reported here.

II Electrochemical Investigations

2.1 Behavior of Sealed Control Cells.

Electrochemical characterization of sealed, control cells made with heat-sterilizable polypropylene separator type FT 2140 with various amounts of 30% KOH is continuing on automatic charge-discharge cycle facilities. Table I gives typical data for capacity during discharge for cells with Pellon FT 2140 type polypropylene separator for 16 thru 50 cycles. Similar data for cycles 1 thru 15 were reported in the preceding progress report together with the cycle data for sealed cells containing Pellon 14019 separator for up to 59 cycles. It appears that electrolyte levels of 60 and 70% of the free pore volume are too low as indicated by extremely low capacity and discharge efficiency. The optimum electrolyte range appears to be between 70 and 90%. Since previous experience has shown that the rate of oxygen diffusion from the positive to the negative plate and its recombination is a function of the electrolyte amount, (pressure build up in general increasing exponentially with increase in the electrolyte fill level), pore fills of 90% and above are generally not desirable. Further work on the electrolyte optimization should therefore be limited to the range of 70 to 90% pore fill.

It should be noted that there is a gradual decrease in the delivered capacity as a function of cycle number. This is one of the critical problems that is being worked on now. Another problem that must

TABLE 1

PERFORMANCE DATA FOR HEAT-STERILIZABLE, SEALED RECTANGULAR, Ni-Cd CONTROL CELLS (UNSTERILIZED) WITH POLYPROPYLENE FT-2140 SEPARATOR ON CONTINUOUS CYCLING @ 22°C

Cell No.	% Pore Fill	Cycle No.	Charge Data				Discharge	
			Amp.	Hrs	AH Input	ECP PSIA	Amp.	AH Output
1	60	16	1.0	5	5.0	15.7	2.0	3.100
2	60	16	1.0	5	5.0	48.7	2.0	2.118
3	70	16	1.0	5	5.0	60.2	2.0	3.718
4	70	16	1.0	5	5.0	59.2	2.0	3.766
5	80	16	1.0	5	5.0	62.7	2.0	4.152
6	80	16	1.0	5	5.0	61.7	2.0	4.100
7	90	16	1.0	5	5.0	51.7	2.0	4.152
8	90	16	1.0	5	5.0	62.2	2.0	3.766
1	60	17	1.0	5	5.0	15.7	2.0	3.018
2	60	17	1.0	5	5.0	48.7	2.0	2.118
3	70	17	1.0	5	5.0	60.7	2.0	3.718
4	70	17	1.0	5	5.0	52.7	2.0	3.752
5	80	17	1.0	5	5.0	53.7	2.0	4.134
6	80	17	1.0	5	5.0	59.7	2.0	4.100
7	90	17	1.0	5	5.0	46.7	2.0	4.118
8	90	17	1.0	5	5.0	61.7	2.0	3.752
1	60	18	0.400	17	6.8	15.7	2.0	2.452
2	60	18	0.400	17	6.8	28.2	2.0	1.766
3	70	18	0.400	17	6.8	57.2	2.0	3.200
4	70	18	0.400	17	6.8	52.7	2.0	3.252
5	80	18	0.400	17	6.8	73.7	2.0	3.818
6	80	18	0.400	17	6.8	76.7	2.0	3.818
7	90	18	0.400	17	6.8	50.2	2.0	3.952
8	90	18	0.400	17	6.8	50.7	2.0	3.684
1	60	19	0.400	17	6.8	15.7	2.0	2.566
2	60	19	0.400	17	6.8	29.7	2.0	1.766
3	70	19	0.400	17	6.8	60.7	2.0	3.152
4	70	19	0.400	17	6.8	55.7	2.0	3.152
5	80	19	0.400	17	6.8	76.7	2.0	3.666
6	80	19	0.400	17	6.8	60.7	2.0	3.618
7	90	19	0.400	17	6.8	54.7	2.0	3.618
8	90	19	0.400	17	6.8	51.7	2.0	3.718

TABLE 1

PERFORMANCE DATA FOR HEAT-STERILIZABLE, SEALED RECTANGULAR, Ni-Cd CONTROL CELLS (UNSTERILIZED) WITH POLYPROPYLENE FT-2140 SEPARATOR ON CONTINUOUS CYCLING @ 22°C

Cell No.	% Pore Fill	Cycle No.	Charge Data				Discharge	
			Amp.	Hrs	AH Input	ECP PSIA	Amp.	AH Output
1	60	20	0.400	17	6.8	15.7	2.0	2.052
2	60	20	0.400	17	6.8	28.7	2.0	1.452
3	70	20	0.400	17	6.8	60.7	2.0	2.984
4	70	20	0.400	17	6.8	56.7	2.0	3.000
5	80	20	0.400	17	6.8	77.7	2.0	3.500
6	80	20	0.400	17	6.8	57.7	2.0	3.484
7	90	20	0.400	17	6.8	52.7	2.0	3.866
8	90	20	0.400	17	6.8	50.7	2.0	3.718
1	60	25	0.400	17	6.8	14.7	2.0	1.600
2	60	25	0.400	17	6.8	27.7	2.0	1.266
3	70	25	0.400	17	6.8	62.7	2.0	2.752
4	70	25	0.400	17	6.8	52.7	2.0	2.718
5	80	25	0.400	17	6.8	74.7	2.0	3.534
6	80	25	0.400	17	6.8	54.7	2.0	3.318
7	90	25	0.400	17	6.8	50.7	2.0	3.752
8	90	25	0.400	17	6.8	45.7	2.0	3.752
1	60	30	0.400	17	6.8	15.7	2.0	1.266
2	60	30	0.400	17	6.8	27.2	2.0	1.218
3	70	30	0.400	17	6.8	67.7	2.0	2.652
4	70	30	0.400	17	6.8	61.7	2.0	2.852
5	80	30	0.400	17	6.8	73.7	2.0	3.634
6	80	30	0.400	17	6.8	51.7	2.0	3.352
7	90	30	0.400	17	6.8	48.7	2.0	3.584
8	90	30	0.400	17	6.8	41.2	2.0	3.700
1	60	35	0.400	17	6.8	15.7	2.0	1.118
2	60	35	0.400	17	6.8	26.7	2.0	1.118
3	70	35	0.400	17	6.8	68.7	2.0	2.652
4	70	35	0.400	17	6.8	23.7	2.0	2.684
5	80	35	0.400	17	6.8	74.7	2.0	3.566
6	80	35	0.400	17	6.8	44.7	2.0	3.300
7	90	35	0.400	17	6.8	45.7	2.0	3.700
8	90	35	0.400	17	6.8	35.7	2.0	3.784

PERFORMANCE DATA FOR HEAT-STERILIZABLE, SEALED RECTANGULAR, Ni-Cd CONTROL CELLS (UNSTERILIZED) WITH POLYPROPYLENE FT-2140 SEPARATOR ON CONTINUOUS CYCLING @ 22°C

Cell No.	% Pore Fill	Cycle No.	Charge Data				Discharge	
			Amp.	Hrs	AH Input	ECP PSIA	Amp.	AH Output
1	60	40	0.400	17	6.8	15.7	2.0	1.084
2	60	40	0.400	17	6.8	25.7	2.0	1.100
3	70	40	0.400	17	6.8	67.7	2.0	2.518
4	70	40	0.400	17	6.8	-	2.0	-
5	80	40	0.400	17	6.8	74.7	2.0	3.384
6	80	40	0.400	17	6.8	57.2	2.0	3.352
7	90	40	0.400	17	6.8	44.7	2.0	3.584
8	90	40	0.400	17	6.8	31.7	2.0	3.734
1	60	45	0.400	17	6.8	14.7	2.0	0.866
2	60	45	0.400	17	6.8	25.7	2.0	0.884
3	70	45	0.400	17	6.8	66.7	2.0	2.352
4	70	45	0.400	17	6.8	-	2.0	-
5	80	45	0.400	17	6.8	74.7	2.0	3.134
6	80	45	0.400	17	6.8	53.7	2.0	3.234
7	90	45	0.400	17	6.8	44.7	2.0	3.300
8	90	45	0.400	17	6.8	28.7	2.0	3.752
1	60	50	0.400	17	6.8	15.7	2.0	1.152
2	60	50	0.400	17	6.8	24.7	2.0	1.300
3	70	50	0.400	17	6.8	65.7	2.0	2.218
4	70	50	0.400	17	6.8	-	2.0	-
5	80	50	0.400	17	6.8	69.7	2.0	3.034
6	80	50	0.400	17	6.8	71.7	2.0	3.066
7	90	50	0.400	17	6.8	41.7	2.0	3.218
8	90	50	0.400	17	6.8	24.7	2.0	3.752

be solved before undertaking an extensive statistical design experiment is to control the uniformity of cells which at present is not satisfactory. However, because of the effectiveness of factorial or fractional factorial design experiments in the optimization of the cell design parameters work is continuing in a parallel effort on the factorial design experiments.

Factorial Design Experiments: Electrochemical characterization of heat-sterilizable, sealed, Ni-Cd cells designed for statistical experiments has been completed during this quarter. The factors selected for this initial design are given in Table II. Typical capacity versus cycle data are given in Table III and in summarized form for typical cells in Figures 1 to 8. Again, there is some variation in the delivered capacity as a function of cycle number and this aspect is being investigated now. These cells will be subjected to heat sterilization at 135°C for 64 hours. On completion of the sterilization routine, these cells will be characterized again, both electrochemically and physically, using x-ray, electron-microscopy and other tools as necessary.

An analysis of data in Table III reveal the following:

1. There is still considerable variation from cell to cell among apparantly identical cells under identical test conditions. The causes for this variation are not at present known and a program to systematically determine and eliminate the causes responsible for this variation.

Table II

Ni-Cd RECTANGULAR CELLS FACTORIAL DESIGN EXPERIMENT
WITH 8 POSITIVE AND 9 NEGATIVE PLATES

Designation	Factors	Factor Levels Low(o)	High(1)
A	Nature of Separator, Type Polypropylene	#14019	#FT2140
B	Concentration of KOH, % by weight	30%	34%
C	Amount of Electrolyte (% Pore Fill)	70%	80%
D	Heat Treatment	Unsterilized	Sterilized

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	1	.400	17.0	6.8	1.444	49.7	6.06	2.0	3.552	22.2	6.08	71.6
2	0	0	0	0	1	.400	17.0	6.8	1.437	----		2.0	2.966	----		59.8
3	0	0	0	0	1	.400	17.0	6.8	1.435	----	6.43	2.0	3.418	----	6.80	68.9
4	0	0	0	0	1	.400	17.0	6.8	1.452	----	6.57	2.0	3.584	----	6.88	72.3
5	0	0	1	0	1	.400	17.0	6.8	1.447	42.7	6.68	2.0	3.600	25.7	6.73	72.6
6	0	0	1	0	1	.400	17.0	6.8	1.433	----		2.0	3.252	----		65.6
7	0	0	1	0	1	.400	17.0	6.8	1.458	----	6.54	2.0	3.566	----	7.00	71.9
8	0	0	1	0	1	.400	17.0	6.8	1.458	----	6.96	2.0	3.866	----	7.20	77.9
9	0	1	0	0	1	.400	17.0	6.8	Not Charged							
10	0	1	0	0	1	.400	17.0	6.8								
11	0	1	0	0	1	.400	17.0	6.8	1.449	----	6.25	2.0	3.718	----	6.74	75.0
12	0	1	0	0	1	.400	17.0	6.8	1.452	----	6.34	2.0	3.952	----	6.76	79.7
13	0	1	1	0	1	.400	17.0	6.8	1.445	66.2	6.71	2.0	3.934	47.2	6.63	79.3
14	0	1	1	0	1	.400	17.0	6.8	1.416	----	8.43	2.0	3.600	----	8.36	72.6
15	0	1	1	0	1	.400	17.0	6.8	1.449	----	7.14	2.0	4.052	----	7.56	81.7
16	0	1	1	0	1	.400	17.0	6.8	1.451	----	6.32	2.0	3.852	----	6.78	77.7

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	1	.400	17.0	6.8	1.434	28.7	8.55	2.0	3.284	16.7	8.18	66.2
18	1	0	0	0	1	.400	17.0	6.8	1.443	----		2.0	2.684	----		54.1
19	1	0	0	0	1	.400	17.0	6.8	1.450	----	7.21	2.0	3.466	----	7.58	69.9
20	1	0	0	0	1	.400	17.0	6.8	1.451	----	4.53	2.0	3.500	----	4.75	70.6
21	1	0	1	0	1	.400	17.0	6.8	1.448	18.7	7.60	2.0	3.718	12.7	7.10	75.0
22	1	0	1	0	1	.400	17.0	6.8	1.438	----		2.0	3.100	----		62.5
23	1	0	1	0	1	.400	17.0	6.8	1.450	----	7.94	2.0	3.184	----	8.26	64.2
24	1	0	1	0	1	.400	17.0	6.8	1.456	----	7.26	2.0	3.252	----	7.56	65.6
25	1	1	0	0	1	.400	17.0	6.8	1.433	25.7	7.90	2.0	3.352	16.2	8.24	67.6
26	1	1	0	0	1	.400	17.0	6.8	1.424	----	9.37	2.0	3.018	----	10.00	60.8
27	1	1	0	0	1	.400	17.0	6.8	1.448	----	6.90	2.0	3.266	----	7.32	65.8
28	1	1	0	0	1	.400	17.0	6.8	1.446	----	7.98	2.0	3.566	----	8.60	71.9
29	1	1	1	0	1	.400	17.0	6.8	1.410	84.7	1.84	2.0	3.084	48.2	7.67	62.2
30	1	1	1	0	1	.400	17.0	6.8	1.428	----	8.36	2.0	3.452	----	8.64	69.6
31	1	1	1	0	1	.400	17.0	6.8	1.443	----	6.03	2.0	3.384	----	6.54	68.2
32	1	1	1	0	1	.400	17.0	6.8	1.450	----	7.19	2.0	3.418	----	7.58	68.9

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	2	.400	17.0	6.8	1.413	72.7	6.23	2.0	3.618	37.7	6.03	72.9
2	0	0	0	0	2	.400	17.0	6.8	1.412	----		2.0	2.618	----		52.8
3	0	0	0	0	2	.400	17.0	6.8	1.419	----	6.52	2.0	2.984	----	7.13	60.2
4	0	0	0	0	2	.400	17.0	6.8	1.424	----	6.73	2.0	3.284	----	7.32	66.2
5	0	0	1	0	2	.400	17.0	6.8	1.414	84.7	6.88	2.0	3.666	52.7	6.90	73.9
6	0	0	1	0	2	.400	17.0	6.8	1.409	----		2.0	2.966	----		59.8
7	0	0	1	0	2	.400	17.0	6.8	1.429	----	6.66	2.0	3.366	----	7.34	67.9
8	0	0	1	0	2	.400	17.0	6.8	1.429	----	7.11	2.0	3.534	----	7.70	71.2
9	0	1	0	0	2	.400	17.0	6.8	1.430	64.7	8.16	2.0	3.718	37.7	7.72	75.0
10	0	1	0	0	2	.400	17.0	6.8	Not Charged							
11	0	1	0	0	2	.400	17.0	6.8	1.427	----	6.40	2.0	3.600	----	7.03	72.6
12	0	1	0	0	2	.400	17.0	6.8	1.425	----	6.42	2.0	3.700	----	7.06	74.6
13	0	1	1	0	2	.400	17.0	6.8	1.346	64.7	6.46	2.0	3.418	49.7	3.99	68.9
14	0	1	1	0	2	.400	17.0	6.8	1.399	----	8.30	2.0	2.336	----	7.65	47.1
15	0	1	1	0	2	.400	17.0	6.8	1.427	----	7.19	2.0	3.700	----	7.84	74.6
16	0	1	1	0	2	.400	17.0	6.8	1.429	----	6.41	2.0	3.852	----	7.09	77.7

TABLE II

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE III

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	2	.400	17.0	6.8	1.379	39.7	8.75	2.0	2.984	18.7	8.16	60.2
18	1	0	0	0	2	.400	17.0	6.8	1.418	----		2.0	2.352	----		47.4
19	1	0	0	0	2	.400	17.0	6.8	1.426	----	7.53	2.0	3.084	----	7.97	62.2
20	1	0	0	0	2	.400	17.0	6.8	1.428	----	4.88	2.0	2.966	----	5.28	59.8
21	1	0	1	0	2	.400	17.0	6.8	1.427	22.7	7.86	2.0	4.284	0.7	6.99	86.4
22	1	0	1	0	2	.400	17.0	6.8	Not Charged							
23	1	0	1	0	2	.400	17.0	6.8	1.426	----	7.70	2.0	2.752	----	8.49	55.5
24	1	0	1	0	2	.400	17.0	6.8	1.437	----	7.07	2.0	3.266	----	7.78	65.8
25	1	1	0	0	2	.400	17.0	6.8	1.406	24.7	8.14	2.0	3.084	24.7	8.55	66.2
26	1	1	0	0	2	.400	17.0	6.8	1.399	----	9.46	2.0	2.534	----	8.58	51.1
27	1	1	0	0	2	.400	17.0	6.8	1.421	----	6.93	2.0	2.884	----	7.71	58.1
28	1	1	0	0	2	.400	17.0	6.8	1.421	----	8.24	2.0	3.134	----	9.05	63.2
29	1	1	1	0	2	.400	17.0	6.8	1.413	29.7	7.52	2.0	2.734	46.7	7.81	55.1
30	1	1	1	0	2	.400	17.0	6.8	1.401	----	8.27	2.0	3.052	----	7.74	61.5
31	1	1	1	0	2	.400	17.0	6.8	1.421	----	6.17	2.0	2.918	----	6.83	58.8
32	1	1	1	0	2	.400	17.0	6.8	1.424	----	7.12	2.0	3.000	----	7.89	60.5

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	3	.400	17.0	6.8	1.425	68.2	6.12	2.0	3.500	34.7	5.74	70.6
2	0	0	0	0	3	.400	17.0	6.8	1.422	---			2.234	----		45.0
3	0	0	0	0	3	.400	17.0	6.8	No Charge							
4	0	0	0	0	3	.400	17.0	6.8	1.419	----	7.12	2.0	3.118	----	7.00	62.9
5	0	0	1	0	3	.400	17.0	6.8	1.421	81.7	6.63	2.0	3.266	44.7	6.54	65.8
6	0	0	1	0	3	.400	17.0	6.8	1.415	----		2.0	2.752	----		55.5
7	0	0	1	0	3	.400	17.0	6.8	1.425	----	7.00	2.0	3.284	----	6.98	66.2
8	0	0	1	0	3	.400	17.0	6.8	1.423	----	7.45	2.0	3.352	----	7.36	67.6
9	0	1	0	0	3	.400	17.0	6.8	1.424	68.7	7.88	2.0	3.634	35.7	7.42	73.3
10	0	1	0	0	3	.400	17.0	6.8	1.404	----		2.0	3.518	----		70.9
11	0	1	0	0	3	.400	17.0	6.8	1.423	----	6.68	2.0	3.500	----	6.72	70.6
12	0	1	0	0	3	.400	17.0	6.8	1.421	----	6.79	2.0	3.518	----	6.74	70.9
13	0	1	1	0	3	.400	17.0	6.8	1.343	61.2	6.45	2.0	2.734	48.7	62.1	55.1
14	0	1	1	0	3	.400	17.0	6.8	1.406	----		2.0	3.118	----		62.9
15	0	1	1	0	3	.400	17.0	6.8	1.426		7.56	2.0	3.652		7.49	73.6
16	0	1	1	0	3	.400	17.0	6.8	No Charge							

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	3	.400	17.0	6.8	1.378	47.7	8.83	2.0	2.534	18.7	7.59	51.1
18	1	0	0	0	3	.400	17.0	6.8	1.135	----		2.0	1.934	----		40.0
19	1	0	0	0	3	.400	17.0	6.8	1.420	----	8.11	2.0	2.566	----	7.98	51.7
20	1	0	0	0	3	.400	17.0	6.8	1.420	----	5.11	2.0	2.666	----	5.16	53.7
21	1	0	1	0	3	.400	17.0	6.8	1.427	65.7	7.77	2.0	3.766	-0.3	6.68	75.9
22	1	0	1	0	3	.400	17.0	6.8	1.427	----		2.0	3.018	----		60.8
23	1	0	1	0	3	.400	17.0	6.8	1.422	----	8.16	2.0	2.766	----	7.96	55.8
24	1	0	1	0	3	.400	17.0	6.8	1.437	----	7.57	2.0	3.418	----	7.34	68.9
25	1	1	0	0	3	.400	17.0	6.8	1.408	63.7	8.84	2.0	2.168	24.7	8.02	52.8
26	1	1	0	0	3	.400	17.0	6.8	1.405	----	9.30	2.0	2.234	----	9.18	45.0
27	1	1	0	0	3	.400	17.0	6.8	1.415	----	7.40	2.0	2.784	----	7.34	56.1
28	1	1	0	0	3	.400	17.0	6.8	1.414	----	8.93	2.0	2.766	----	8.69	55.8
29	1	1	1	0	3	.400	17.0	6.8	1.330	38.7	7.20	2.0	1.984	48.7	7.07	40.0
30	1	1	1	0	3	.400	17.0	6.8	1.410	----	8.17	2.0	2.818	----	8.31	56.8
31	1	1	1	0	3	.400	17.0	6.8	1.413	----	6.55	2.0	2.666	----	6.41	53.7
32	1	1	1	0	3	.400	17.0	6.8	1.419	----	7.50	2.0	2.900	----	7.42	58.5

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	4	.400	17.0	6.8	Not Charged							
2	0	0	0	0	4	.400	17.0	6.8	1.430	----		2.0	2.484	----		50.1
3	0	0	0	0	4	.400	17.0	6.8	1.433	----	6.86	2.0	3.600	----	6.53	72.6
4	0	0	0	0	4	.400	17.0	6.8	1.415	----	7.14	2.0	3.034	----	6.86	61.2
5	0	0	1	0	4	.400	17.0	6.8	1.428	69.7	5.89	2.0	3.634	23.2	6.23	73.3
6	0	0	1	0	4	.400	17.0	6.8	1.421	----		2.0	3.066	----		61.8
7	0	0	1	0	4	.400	17.0	6.8	1.421	----	6.99	2.0	3.300	----	6.77	66.5
8	0	0	1	0	4	.400	17.0	6.8	1.418	----	7.48	2.0	3.284	----	7.06	66.2
9	0	1	0	0	4	.400	17.0	6.8	1.426	67.7	7.71	2.0	3.684	27.7	7.83	74.3
10	0	1	0	0	4	.400	17.0	6.8	1.406	----		2.0	3.052	----		61.5
11	0	1	0	0	4	.400	17.0	6.8	1.419	----	6.84	2.0	3.452	----	6.57	69.6
12	0	1	0	0	4	.400	17.0	6.8	1.415	----	6.85	2.0	3.500	----	6.52	70.6
13	0	1	1	0	4	.400	17.0	6.8	1.345	66.7	6.36	2.0	2.813	50.2	6.69	56.8
14	0	1	1	0	4	.400	17.0	6.8	1.408	----		2.0	3.184	----		64.2
15	0	1	1	0	4	.400	17.0	6.8	1.398	----	7.64	2.0	2.618	----	7.58	52.8
16	0	1	1	0	4	.400	17.0	6.8	1.436	----	6.80		4.018	----	6.68	81.0

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment

ELECTROCHEMICAL PERFORMANCE DATA

FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	4	.400	17.0	6.8	1.411	54.7	8.77	2.0	2.384	19.2	8.37	48.1
18	1	0	0	0	4	.400	17.0	6.8	1.121	----			2.000	----		40.3
19	1	0	0	0	4	.400	17.0	6.8	1.417	----	8.09	2.0	2.418	----	7.58	48.7
20	1	0	0	0	4	.400	17.0	6.8	1.418	----	5.16	2.0	2.534	----	4.68	51.1
21	1	0	1	0	4	.400	17.0	6.8	1.430	77.7	7.63	2.0	3.452	18.2	7.32	69.6
22	1	0	1	0	4	.400	17.0	6.8	1.405	----		2.0	2.934	----		59.2
23	1	0	1	0	4	.400	17.0	6.8	1.422	----	8.17	2.0	2.784	----	7.75	56.1
24	1	0	1	0	4	.400	17.0	6.8	1.438	----	7.45	2.0	3.452	----	7.11	69.6
25	1	1	0	0	4	.400	17.0	6.8	1.408	69.7	9.34	2.0	2.552	28.2	8.45	51.5
26	1	1	0	0	4	.400	17.0	6.8	1.409	----	8.38	2.0	2.234	----	8.70	45.0
27	1	1	0	0	4	.400	17.0	6.8	1.410	----	8.20	2.0	2.634	----	7.94	53.1
28	1	1	0	0	4	.400	17.0	6.8	1.413	----	8.87	2.0	2.566	----	8.49	51.7
29	1	1	1	0	4	.400	17.0	6.8	1.331	38.7	7.38	2.0	2.034	26.7	7.41	41.0
30	1	1	1	0	4	.400	17.0	6.8	1.419	----	9.40	2.0	2.800	----	9.72	56.5
31	1	1	1	0	4	.400	17.0	6.8	1.411	----	6.54	2.0	2.634	----	6.25	53.1
32	1	1	1	0	4	.400	17.0	6.8	1.418	-	7.48	2.0	2.818	----	7.27	56.8

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	5	.400	17.0	6.8	1.437	68.7	5.97	2.0	3.900	22.7	6.17	78.6
2	0	0	0	0	5	.400	17.0	6.8	1.439	----		2.0	2.766	----		55.8
3	0	0	0	0	5	.400	17.0	6.8	1.415	----	6.42	2.0	3.318	----	6.62	66.9
4	0	0	0	0	5	.400	17.0	6.8	1.413	----	6.79	2.0	3.152	----	6.88	63.5
5	0	0	1	0	5	.400	17.0	6.8	1.433	74.7	6.23	2.0	3.318	71.7	6.70	66.9
6	0	0	1	0	5	.400	17.0	6.8	1.434	----		2.0	3.300	----		66.5
7	0	0	1	0	5	.400	17.0	6.8	1.419	----	6.56	2.0	3.452	----	6.72	69.6
8	0	0	1	0	5	.400	17.0	6.8	1.418	----	7.03	2.0	3.434	----	7.12	69.2
9	0	1	0	0	5	.400	17.0	6.8	1.431	66.7	7.88	2.0	3.866	26.7	7.93	77.9
10	0	1	0	0	5	.400	17.0	6.8	1.417	----		2.0	3.400	----		68.5
11	0	1	0	0	5	.400	17.0	6.8	1.419	----	6.37	2.0	3.600	----	6.63	72.6
12	0	1	0	0	5	.400	17.0	6.8	1.415	----	6.45	2.0	3.652	----	6.60	73.6
13	0	1	1	0	5	.400	17.0	6.8	1.421	76.7	6.39	2.0	3.366	44.7	6.86	67.9
14	0	1	1	0	5	.400	17.0	6.8	1.417	----		2.0	3.466	----		69.9
15	0	1	1	0	5	.400	17.0	6.8	1.397	----	7.12	2.0	2.852	----	7.25	57.5
16	0	1	1	0	5	.400	17.0	6.8	1.425	----	6.29	2.0	3.884	----	6.56	78.3

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	5	.400	17.0	6.8	1.416	55.7	8.87	2.0	2.418	19.7	8.54	48.7
18	1	0	0	0	5	.400	17.0	6.8	1.414	----		2.0	2.134	----		43.0
19	1	0	0	0	5	.400	17.0	6.8	1.415	----	7.63	2.0	2.566	----	7.61	51.7
20	1	0	0	0	5	.400	17.0	6.8	1.416	----	4.72	2.0	2.666	----	4.83	53.7
21	1	0	1	0	5	.400	17.0	6.8	1.354	63.7	7.27	2.0	3.200	20.7	7.38	64.5
22	1	0	1	0		.400	17.0	6.8	1.422	----		2.0	2.800	----		56.5
23	1	0	1	0	5	.400	17.0	6.8	1.422	----	7.64	2.0	3.118	----	7.83	62.9
24	1	0	1	0	5	.400	17.0	6.8	1.436	----	6.94	2.0	3.618	----	7.24	72.9
25	1	1	0	0	5	.400	17.0	6.8	1.411	72.7	8.80	2.0	2.634	26.7	9.01	53.1
26	1	1	0	0	5	.400	17.0	6.8	1.409	----	9.05	2.0	2.266	----	8.83	45.7
27	1	1	0	0	5	.400	17.0	6.8	1.408	----	6.95	2.0	2.884	----	7.72	58.1
28	1	1	0	0	5	.400	17.0	6.8	1.412	----	9.19	2.0	2.684	----	9.53	54.1
29	1	1	1	0	5	.400	17.0	6.8	1.408	47.7	7.22	2.0	2.218	29.7	7.64	44.7
30	1	1	1	0	5	.400	17.0	6.8	1.416	----	8.20	2.0	2.866	----	8.07	57.8
31	1	1	1	0	5	.400	17.0	6.8	1.411	----	6.07	2.0	2.766	----	6.30	55.8
32	1	1	1	0	5	.400	17.0	6.8	1.417	----	6.92	2.0	2.984	----	7.27	60.2

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	6	.400	17.0	6.8	1.432	69.7	5.93	2.0	4.052	23.7	6.14	81.7
2	0	0	0	0	6	.400	17.0	6.8	1.436	----		2.0	2.634	----		53.1
3	0	0	0	0	6	.400	17.0	6.8	1.412	----	6.62	2.0	3.134	----	6.94	63.2
4	0	0	0	0	6	.400	17.0	6.8	1.413	----	7.00	2.0	3.066	----	7.27	61.8
5	0	0	1	0	6	.400	17.0	6.8	1.361	74.7	6.27	2.0	3.152	49.7	6.43	63.5
6	0	0	1	0	6	.400	17.0	6.8	1.426	----		2.0	3.300	----		66.5
7	0	0	1	0	6	.400	17.0	6.8	1.419	----	6.78	2.0	3.384	----	7.08	68.2
8	0	0	1	0	6	.400	17.0	6.8	1.418	----	7.26	2.0	3.352	----	7.44	67.6
9	0	1	0	0	6	.400	17.0	6.8	1.427	67.7	7.56	2.0	4.000	24.7	7.65	80.6
10	0	1	0	0	6	.400	17.0	6.8	1.409	----	8.09	2.0	3.234	----	8.05	65.2
11	0	1	0	0	6	.400	17.0	6.8	1.418	----	6.55	2.0	3.500	----	6.95	70.6
12	0	1	0	0	6	.400	17.0	6.8	1.414	----	6.66	2.0	3.552	----	6.96	71.6
13	0	1	1	0	6	.400	17.0	6.8	1.416	62.7	6.22	2.0	2.984	54.7	6.74	60.2
14	0	1	1	0	6	.400	17.0	6.8	1.414	----	8.14	2.0	3.418	----	8.02	68.9
15	0	1	1	0	6	.400	17.0	6.8	1.403	----	7.36	2.0	2.852	----	7.57	57.5
16	0	1	1	0	6	.400	17.0	6.8	1.420	----	6.57	2.0	3.734	----	6.90	75.3

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	6	.400	17.0	6.8	1.404	59.7	8.46	2.0	2.466	21.7	8.16	49.7
18	1	0	0	0	6	.400	17.0	6.8	-----	----	8.46	2.0	2.152	----		43.4
19	1	0	0	0	6	.400	17.0	6.8	1.412	----	7.72	2.0	2.584	----	7.91	52.1
20	1	0	0	0	6	.400	17.0	6.8	1.412	----	4.72	2.0	2.652	----	4.87	53.5
21	1	0	1	0	6	.400	17.0	6.8	1.431	56.7	7.25	2.0	3.484	16.7	7.24	70.2
22	1	0	1	0	6	.400	17.0	6.8	1.418	----		2.0	2.984	----		60.2
23	1	0	1	0	6	.400	17.0	6.8	1.420	----	7.98	2.0	3.118	----	8.16	62.9
24	1	0	1	0	6	.400	17.0	6.8	1.437	----	7.29	2.0	3.584	----	7.53	72.3
25	1	1	0	0	6	.400	17.0	6.8	1.409	82.7	8.75	2.0	2.618	37.7	9.21	52.8
26	1	1	0	0	6	.400	17.0	6.8	1.407	----	9.00	2.0	2.300	----	8.94	46.4
27	1	1	0	0	6	.400	17.0	6.8	1.413	----	7.26	2.0	2.952	----	7.54	59.5
28	1	1	0	0	6	.400	17.0	6.8	1.409	----	9.52	2.0	2.684	----	10.45	54.1
29	1	1	1	0	6	.400	17.0	6.8	1.413	59.7	7.17	2.0	2.218	38.7	7.57	44.7
30	1	1	1	0	6	.400	17.0	6.8	1.413	----	8.15	2.0	3.000	----	8.21	60.5
31	1	1	1	0	6	.400	17.0	6.8	1.409	----	6.31	2.0	2.766	----	6.56	55.8
32	1	1	1	0	6	.400	17.0	6.8	1.416	----	7.24	2.0	2.918	----	7.64	58.8

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	7	.400	17.0	6.8	1.432	70.7	6.03	2.0	4.100	31.2	6.41	82.7
2	0	0	0	0	7	.400	17.0	6.8	1.409	----	8.01	2.0	2.600	----	8.14	52.4
3	0	0	0	0	7	.400	17.0	6.8	1.412	----	6.76	2.0	3.184	----	7.41	64.2
4	0	0	0	0	7	.400	17.0	6.8	1.415	----	7.20	2.0	3.152	----	7.37	63.5
5	0	0	1	0	7	.400	17.0	6.8	1.367	49.7	6.00	2.0	2.934	38.7	6.40	59.2
6	0	0	1	0	7	.400	17.0	6.8	1.423	----	7.10	2.0	3.400	----	7.00	68.5
7	0	0	1	0	7	.400	17.0	6.8	1.423	----	6.90	2.0	3.500	----	7.24	70.6
8	0	0	1	0	7	.400	17.0	6.8	1.421	----	7.36	2.0	3.452	----	7.74	69.6
9	0	1	0	0	7	.400	17.0	6.8	1.425	73.7	7.53	2.0	4.000	34.7	7.85	80.6
10	0	1	0	0	7	.400	17.0	6.8	1.414	----	7.92	2.0	3.234	----	7.72	65.2
11	0	1	0	0	7	.400	17.0	6.8	1.422	----	6.64	2.0	3.666	----	7.15	73.9
12	0	1	0	0	7	.400	17.0	6.8	1.418	----	6.80	2.0	3.666	----	7.13	73.9
13	0	1	1	0	7	.400	17.0	6.8	1.374	65.7	6.27	2.0	2.934	53.2	6.83	59.2
14	0	1	1	0	7	.400	17.0	6.8	1.421	----	7.73	2.0	3.552	----	7.62	71.6
15	0	1	1	0	7	.400	17.0	6.8	1.410	----	7.43	2.0	3.100	----	7.79	62.5
16	0	1	1	0	7	.400	17.0	6.8	1.423	----	6.67	2.0	3.700	----	7.26	74.6

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	7	.400	17.0	6.8	1.378	60.7	8.48	2.0	2.534	23.7	8.38	51.1
18	1	0	0	0	7	.400	17.0	6.8	1.416	----	9.78	2.0	2.266	----	9.64	45.7
19	1	0	0	0	7	.400	17.0	6.8	1.416	----	7.89	2.0	3.084	----	8.14	62.2
20	1	0	0	0	7	.400	17.0	6.8	1.417	----	4.82	2.0	3.118	----	5.06	62.9
21	1	0	1	0	7	.400	17.0	6.8	1.378	50.7	7.03	2.0	3.152	23.7	7.38	63.5
22	1	0	1	0	7	.400	17.0	6.8	1.417	----	8.95	2.0	3.024	----	8.84	61.2
23	1	0	1	0	7	.400	17.0	6.8	1.423	----	8.07	2.0	3.284	----	8.39	66.2
24	1	0	1	0	7	.400	17.0	6.8	1.443	----	7.41	2.0	3.700	----	7.70	74.6
25	1	1	0	0	7	.400	17.0	6.8	1.409	84.7	8.03	2.0	2.700		8.69	54.4
26	1	1	0	0	7	.400	17.0	6.8	1.411	----	8.91	2.0	2.418	----	8.60	48.7
27	1	1	0	0	7	.400	17.0	6.8	1.418	----	7.40	2.0	3.066	----	7.73	61.8
28	1	1	0	0	7	.400	17.0	6.8	1.413	----	10.06	2.0	2.852	----	10.80	57.5
29	1	1	1	0	7	.400	17.0	6.8	1.366	44.7	7.08	2.0	1.984		7.71	40.0
30	1	1	1	0	7	.400	17.0	6.8	1.418	----	8.05	2.0	3.134	----	7.76	63.2
31	1	1	1	0	7	.400	17.0	6.8	1.412	----	6.38	2.0	2.918	----	6.68	58.8
32	1	1	1	0	7	.400	17.0	6.8	1.419	----	7.33	2.0	3.052	----	7.76	61.5

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	8	.400	17.0	6.8	1.411	61.7	8.72	2.0	2.518	17.7	8.12	50.8
18	1	0	0	0	8	.400	17.0	6.8	1.414	----	9.13	2.0	2.100	----	9.69	42.3
19	1	0	0	0	8	.400	17.0	6.8	1.418	----	7.94	2.0	2.784	----	7.99	56.1
20	1	0	0	0	8	.400	17.0	6.8	1.420	----	4.95	2.0	2.866	----	5.06	57.8
21	1	0	1	0	8	.400	17.0	6.8	1.344	42.7	7.19	2.0	3.018	14.7	7.18	60.8
22	1	0	1	0	8	.400	17.0	6.8	1.416	----	8.50	2.0	2.800	----	8.88	56.5
23	1	0	1	0	8	.400	17.0	6.8	1.427	----	8.21	2.0	3.452	----	8.28	69.6
24	1	0	1	0	8	.400	17.0	6.8	1.439	----	7.50	2.0	3.866	----	7.71	77.9
25	1	1	0	0	8	.400	17.0	6.8	1.411	84.7	8.55	2.0	2.766	18.7	8.54	55.8
26	1	1	0	0	8	.400	17.0	6.8	1.408	----	8.53	2.0	2.234	----	8.79	45.0
27	1	1	0	0	8	.400	17.0	6.8	1.423	----	7.52	2.0	3.452	----	7.80	69.6
28	1	1	0	0	8	.400	17.0	6.8	1.415	----	10.34	2.0	2.866	----	10.77	57.8
29	1	1	1	0	8	.400	17.0	6.8	1.324	86.7	7.30	2.0	1.752	19.7	7.41	35.3
30	1	1	1	0	8	.400	17.0	6.8	1.416	----	7.80	2.0	2.934	----	8.06	59.2
31	1	1	1	0	8	.400	17.0	6.8	1.415	----	6.47	2.0	3.100	----	6.71	62.5
32	1	1	1	0	8	.400	17.0	6.8	1.420	----	7.45	2.0	3.200	----	7.76	64.5

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	8	.400	17.0	6.8	1.430	67.7	6.20	2.0	4.118	10.7	6.07	83.0
2	0	0	0	0	8	.400	17.0	6.8	1.408	----	7.74	2.0	2.518	----	8.47	50.8
3	0	0	0	0	8	.400	17.0	6.8	1.418	----	6.92	2.0	3.284	----	7.18	66.2
4	0	0	0	0	8	.400	17.0	6.8	1.421	----	7.31	2.0	3.318	----	7.45	66.9
5	0	0	1	0	8	.400	17.0	6.8	1.327	49.7	6.42	2.0	2.566	35.7	6.34	51.7
6	0	0	1	0	8	.400	17.0	6.8	1.421	----	6.95	2.0	3.184	----	7.16	64.2
7	0	0	1	0	8	.400	17.0	6.8	Not Charged							
8	0	0	1	0	8	.400	17.0	6.8	1.425	----	7.50	2.0	3.634	----	7.69	73.3
9	0	1	0	0	8	.400	17.0	6.8	1.424	68.7	7.91	2.0	3.984	14.7	7.55	80.3
10	0	1	0	0	8	.400	17.0	6.8	1.410	----	7.52	2.0	2.900	----	7.96	58.5
11	0	1	0	0	8	.400	17.0	6.8	1.427	----	6.86	2.0	3.884	----	7.18	78.3
12	0	1	0	0	8	.400	17.0	6.8	1.422	----	6.94	2.0	3.766	----	7.11	75.9
13	0	1	1	0	8	.400	17.0	6.8	1.336	61.7	6.37	2.0	2.500	38.2	6.36	50.4
14	0	1	1	0	8	.400	17.0	6.8	1.419	----	7.55	2.0	3.334	----	7.73	67.2
15	0	1	1	0	8	.400	17.0	6.8	Not Charged							
16	0	1	1	0	8	.400	17.0	6.8	1.428	----	6.81	2.0	3.934	----	7.07	79.3

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	9	.400	17.0	6.8	1.422	65.7	6.02	2.0	3.752	29.7	5.95	75.6
2	0	0	0	0		.400	17.0	6.8	1.402	-	7.71	2.0	2.218	-	7.92	44.7
3	0	0	0	0		.400	17.0	6.8	1.413	-	6.76	2.0	3.052	-	7.20	61.5
4	0	0	0	0		.400	17.0	6.8	1.417	-	7.25	2.0	2.918	-	7.44	58.8
5	0	0	1	0	9	.400	17.0	6.8	1.421	69.7	6.38	2.0	3.618	54.7	6.09	72.9
6	0	0	1	0		.400	17.0	6.8	1.415	-	6.89	2.0	3.034	-	6.74	61.2
7	0	0	1	0		.400	17.0	6.8	1.422	-	6.92	2.0	3.318	-	7.20	66.9
8	0	0	1	0		.400	17.0	6.8	1.421	-	7.38	2.0	3.300	-	7.74	66.5
9	0	1	0	0	9	.400	17.0	6.8	1.419	66.7	7.81	2.0	3.618	32.7	7.53	72.9
10	0	1	0	0		.400	17.0	6.8	1.405	-	7.64	2.0	2.866	-	7.53	57.8
11	0	1	0	0		.400	17.0	6.8	1.422	-	7.33	2.0	3.400	-	7.74	68.5
12	0	1	0	0		.400	17.0	6.8	1.417	-	6.74	2.0	3.634	-	7.02	73.3
13	0	1	1	0	9	.400	17.0	6.8	1.355	43.7	6.19	2.0	2.052	35.7	6.24	41.4
14	0	1	1	0		.400	17.0	6.8	1.412	-	7.54	2.0	3.118	-	7.49	62.9
15	0	1	1	0		.400	17.0	6.8	1.419	-	7.33	2.0	3.400	-	7.74	68.5
16	0	1	1	0		.400	17.0	6.8	1.423	-	6.74	2.0	3.634	-	7.02	73.3

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	9	.400	17.0	6.8	1.373	60.7	8.91	2.0	2.266	27.2	8.01	45.7
18	1	0	0	0		.400	17.0	6.8	1.411	-	9.86	2.0	2.016	-	9.62	40.6
19	1	0	0	0		.400	17.0	6.8	1.418	-	8.04	2.0	2.484	-	8.01	50.1
20	1	0	0	0		.400	17.0	6.8	1.418	-	5.04	2.0	2.552	-	5.18	51.5
21	1	0	1	0	9	.400	17.0	6.8	1.369	41.7	7.17	2.0	2.666	22.2	6.97	53.7
22	1	0	1	0		.400	17.0	6.8	1.411	-	8.62	2.0	2.734	-	8.82	55.1
23	1	0	1	0		.400	17.0	6.8	1.421	-	8.14	2.0	3.084	-	8.27	62.2
24	1	0	1	0		.400	17.0	6.8	1.430	-	7.46	2.0	3.434	-	7.64	69.2
25	1	1	0	0	9	.400	17.0	6.8	1.408	84.7	8.75	2.0	2.666	44.7	9.71	53.7
26	1	1	0	0		.400	17.0	6.8	1.404	-	8.68	2.0	2.184	-	8.64	44.0
27	1	1	0	0		.400	17.0	6.8	1.421	-	7.48	2.0	3.152	-	7.77	63.5
28	1	1	0	0		.400	17.0	6.8	1.414	-	10.49	2.0	2.552	-	11.07	51.5
29	1	1	1	0	9	.400	17.0	6.8	1.350	29.7	7.29	2.0	1.500	23.7	7.07	30.2
30	1	1	1	0		.400	17.0	6.8	1.412	-	7.81	2.0	2.952	-	7.84	59.5
31	1	1	1	0		.400	17.0	6.8	1.413	-	6.49	2.0	2.784	-	6.65	56.1
32	1	1	1	0		.400	17.0	6.8	1.418	-	7.35	2.0	2.918	-	7.65	58.8

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	10	.400	17.0	6.8	- Not Charged -				-	-	-	-
2	0	0	0	0		.400	17.0	6.8	- Not Charged -				-	-	-	-
3	0	0	0	0		.400	17.0	6.8	1.418	-	6.85	2.0	3.034	-	7.43	61.2
4	0	0	0	0		.400	17.0	6.8	1.418	-	7.36	2.0	3.100	-	7.60	62.5
5	0	0	1	0	10	.400	17.0	6.8	1.432	64.7	6.57	2.0	4.052	14.7	6.01	81.7
6	0	0	1	0		.400	17.0	6.8	1.423	-	7.47	2.0	3.418	-	7 46	68.9
7	0	0	1	0		.400	17.0	6.8	1.422	-	7.01	2.0	3.384	-	7.27	68.2
8	0	0	1	0		.400	17.0	6.8	1.419	-	7.45	2.0	3.334	-	7.68	67.2
9	0	1	0	0	10	.400	17.0	6.8	1.423	66.2	8.16	2.0	3.900	15.7	7.38	78.6
10	0	1	0	0		.400	17.0	6.8	1.421	-	8.21	2.0	3.152	-	8.35	63.5
11	0	1	0	0		.400	17.0	6.8	1.421	-	6.94	2.0	3.500	-	7.30	70.6
12	0	1	0	0		.400	17.0	6.8	1.417	-	7.01	2.0	3.400	-	7.20	68.5
13	0	1	1	0	10	.400	17.0	6.8	1.420	66.2	6.71	2.0	3.034	55.7	6.14	61.2
14	0	1	1	0		.400	17.0	6.8	1.425	-	8.15	2.0	3.434	-	8.20	69.2
15	0	1	1	0		.400	17.0	6.8	1.417	-	7.54	2.0	3.318	-	7.80	66.9
16	0	1	1	0		.400	17.0	6.8	1.423	-	6.86	2.0	3.734	-	7.24	75.3

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DAT
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	10	.400	17.0	6.8	1.410	63.7	8.87	2.0	2.384	20.2	7.97	48.1
18	1	0	0	0		.400	17.0	6.8	1.420	-	10.09	2.0	2.166	-	10.52	43.7
19	1	0	0	0		.400	17.0	6.8	1.415	-	8.17	2.0	2.466	-	8.29	49.7
20	1	0	0	0		.400	17.0	6.8	1.417	-	5.12	2.0	2.500	-	5.28	50.4
21	1	0	1	0	10	.400	17.0	6.8	1.433	65.7	7.56	2.0	3.184	22.2	7.08	64.2
22	1	0	1	0		.400	17.0	6.8	1.422	-	9.46	2.0	3.052	-	9.72	61.5
23	1	0	1	0		.400	17.0	6.8	1.420	-	8.27	2.0	3.066	-	8.44	61.8
24	1	0	1	0		.400	17.0	6.8	1.431	-	7.63	2.0	3.384	-	7.86	68.2
25	1	1	0	0	10	.400	17.0	6.8	1.418	82.2	11.73	2.0	2.866	27.2	8.82	57.8
26	1	1	0	0		.400	17.0	6.8	1.414	-	9.27	2.0	2.400	-	9.50	48.4
27	1	1	0	0		.400	17.0	6.8	1.420	-	7.72	2.0	3.152	-	8.00	63.5
28	1	1	0	0		.400	17.0	6.8	1.430	-	10.99	2.0	2.534	-	11.67	51.1
29	1	1	1	0	10	.400	17.0	6.8	1.327	38.2	7.31	2.0	1.918	22.7	7.16	38.7
30	1	1	1	0		.400	17.0	6.8	1.420	-	8.32	2.0	3.100	-	8.51	62.5
31	1	1	1	0		.400	17.0	6.8	1.412	-	6.70	2.0	2.800	-	6.88	56.5
32	1	1	1	0		.400	17.0	6.8	1.417	-	7.61	2.0	2.918	-	7.92	58.8

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	11	.400	17.0	6.8	1.378	65.7	8.97	2.0	2.618	24.7	9.45	52.8
18	1	0	0	0		.400	17.0	6.8	1.425	-	10.25	2.0	2.466	-	10.55	49.7
19	1	0	0	0		.400	17.0	6.8	1.417	-	8.67	2.0	2.434	-	8.47	49.1
20	1	0	0	0		.400	17.0	6.8	1.419	-	5.36	2.0	2.484	-	5.48	50.1
21	1	0	1	0	11	.400	17.0	6.8	1.346	45.7	7.44	2.0	3.166	19.7	8.33	63.8
22	1	0	1	0		.400	17.0	6.8	1.426	-	9.46	2.0	3.300	-	9.72	66.5
23	1	0	1	0		.400	17.0	6.8	1.424	-	8.95	2.0	3.000	-	8.65	60.5
24	1	0	1	0		.400	17.0	6.8	1.434	-	8.28	2.0	3.452	-	8.04	69.6
25	1	1	0	0	11	.400	17.0	6.8	1.419	77.2	9.77	2.0	3.166	33.7	10.81	63.8
26	1	1	0	0		.400	17.0	6.8	1.416	-	9.20	2.0	2.618	-	9.37	52.8
27	1	1	0	0		.400	17.0	6.8	1.425	-	8.36	2.0	3.100	-	8.18	62.5
28	1	1	0	0		.400	17.0	6.8	1.417	-	11.95	2.0	2.518	-	11.92	50.8
29	1	1	1	0	11	.400	17.0	6.8	1.330	36.7	7.65	2.0	1.952	24.7	8.48	39.4
30	1	1	1	0		.400	17.0	6.8	1.423	-	8.28	2.0	3.300	-	8.48	66.5
31	1	1	1	0		.400	17.0	6.8	1.417	-	7.18	2.0	2.718	-	6.99	54.8
32	1	1	1	0		.400	17.0	6.8	1.420	-	8.22	2.0	2.834	-	8.09	57.1

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	11	.400	17.0	6.8	1.434	65.7	6.60	2.0	4.184	20.7	6.97	84.4
2	0	0	0	0		.400	17.0	6.8	1.423	-	8.28	2.0	2.952	-	8.76	59.5
3	0	0	0	0		.400	17.0	6.8	1.422	-	7.45	2.0	2.884	-	7.36	58.1
4	0	0	0	0		.400	17.0	6.8	1.424	-	7.96	2.0	3.066	-	7.70	61.8
5	0	0	1	0	11	.400	17.0	6.8	1.459	70.7	6.71	2.0	4.466	50.7	7.16	90.0
6	0	0	1	0		.400	17.0	6.8	1.433	-	7.39	2.0	3.752	-	7.46	75.6
7	0	0	1	0					- Not Charged -				-	-	-	-
8	0	0	1	0		.400	17.0	6.8	1.426	-	8.07	2.0	3.200	-	7.92	64.5
9	0	1	0	0	11	.400	17.0	6.8	1.424	65.7	8.19	2.0	4.034	21.7	8.61	81.3
10	0	1	0	0		.400	17.0	6.8	1.420	-	8.21	2.0	3.400	-	8.32	68.5
11	0	1	0	0		.400	17.0	6.8	1.427	-	7.54	2.0	3.518	-	7.50	70.9
12	0	1	0	0		.400	17.0	6.8	1.422	-	7.56	2.0	3.500	-	7.34	70.6
13	0	1	1	0	11	.400	17.0	6.8	1.341	52.7	6.69	2.0	2.700	39.7	7.17	54.4
14	0	1	1	0		.400	17.0	6.8	1.427	-	8.07	2.0	3.666	-	8.15	73.9
15	0	1	1	0					- Not Charged -				-	-	-	-
16	0	1	1	0		.400	17.0	6.8	1.428	-	7.62	2.0	3.366	-	7.43	67.9

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	12	.400	17.0	6.8	1.429	64.7	6.51	2.0	4.118	16.2	6.07	83.0
2	0	0	0	0	12	.400	17.0	6.8	1.422	-	8.66	2.0	2.900	-	8.86	58.5
3	0	0	0	0	12	.400	17.0	6.8	1.419	-	7.18	2.0	2.934	-	7.17	59.2
4	0	0	0	0	12	.400	17.0	6.8	1.426	-	7.61	2.0	3.284	-	7.43	66.2
5	0	0	1	0	12	.400	17.0	6.8	1.422	75.7	6.90	2.0	4.284	48.2	6.56	86.4
6	0	0	1	0	12	.400	17.0	6.8	1.435	-	7.63	2.0	3.752	-	7.56	75.6
7	0	0	1	0	12	.400	17.0	6.8	1.428	-	7.36	2.0	3.334	-	7.21	67.2
8	0	0	1	0	12	.400	17.0	6.8	1.425	-	7.72	2.0	3.284	-	7.54	66.2
9	0	1	0	0	12	.400	17.0	6.8	1.410	64.7	8.23	2.0	3.966	17.2	7.71	80.0
10	0	1	0	0	12	.400	17.0	6.8	1.423	-	8.47	2.0	3.400	-	8.48	68.5
11	0	1	0	0	12	.400	17.0	6.8	1.428	-	7.24	2.0	3.752	-	7.19	75.6
12	0	1	0	0	12	.400	17.0	6.8	1.421	-	7.26	2.0	3.434	-	7.09	69.2
13	0	1	1	0	12	.400	17.0	6.8	1.357	54.7	6.56	2.0	2.766	38.2	6.50	55.8
14	0	1	1	0	12	.400	17.0	6.8	1.429	-	8.38	2.0	3.718	-	8.34	75.0
15	0	1	1	0	12	.400	17.0	6.8	1.428	-	7.85	2.0	3.552	-	7.71	71.6
16	0	1	1	0	12	.400	17.0	6.8	1.431	-	7.32	2.0	3.584	-	7.15	72.3

TABLE III

Ni Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	12	.400	17.0	6.8	1.413	64.7	9.18	2.0	2.566	22.7	8.61	51.7
18	1	0	0	0	12	.400	17.0	6.8	1.426	-	10.50	2.0	2.534	-	10.81	51.1
19	1	0	0	0	12	.400	17.0	6.8	1.419	-	8.22	2.0	2.534	-	8.10	51.1
20	1	0	0	0	12	.400	17.0	6.8	1.421	-	5.06	2.0	2.566	-	5.11	51.7
21	1	0	1	0	12	.400	17.0	6.8	1.364	39.7	7.54	2.0	3.118	17.2	7.45	62.9
22	1	0	1	0	12	.400	17.0	6.8	1.424	-	10.08	2.0	3.352	-	10.33	67.6
23	1	0	1	0	12	.400	17.0	6.8	1.426	-	8.58	2.0	3.084	-	8.31	62.2
24	1	0	1	0	12	.400	17.0	6.8	1.438	-	7.89	2.0	3.552	-	7.69	71.6
25	1	1	0	0	12	.400	17.0	6.8	1.417	82.7	9.87	2.0	3.084	31.7	7.73	62.2
26	1	1	0	0	12	.400	17.0	6.8	1.416	-	9.59	2.0	2.634	-	9.61	53.1
27	1	1	0	0	12	.400	17.0	6.8	1.429	-	8.06	2.0	3.100	-	7.85	62.5
28	1	1	0	0	12	.400	17.0	6.8	1.417	-	11.39	2.0	2.600	-	11.49	52.4
29	1	1	1	0	12	.400	17.0	6.8	1.358	34.7	7.73	2.0	2.000	22.7	9.67	40.3
30	1	1	1	0	12	.400	17.0	6.8	1.423	-	8.61	2.0	3.334	-	8.67	67.2
31	1	1	1	0	12	.400	17.0	6.8	1.418	-	6.90	2.0	2.784	-	6.70	56.1
32	1	1	1	0	12	.400	17.0	6.8	1.418	-	7.88	2.0	2.866	-	7.71	57.8

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	13	.400	17.0	6.8	1.434	64.7	6.42	2.0	4.118	18.7	6.14	83.0
2	0	0	0	0		.400	17.0	6.8	1.422	-	8.86	2.0	2.784	-	8.94	56.1
3	0	0	0	0		.400	17.0	6.8	1.416	-	7.10	2.0	3.200	-	7.09	64.5
4	0	0	0	0		.400	17.0	6.8	1.420	-	7.63	2.0	3.500	-	7.44	70.6
5	0	0	1	0	13	.400	17.0	6.8	1.452	73.7	6.63	2.0	4.300	52.7	6.45	86.7
6	0	0	1	0		.400	17.0	6.8	1.437	-	7.64	2.0	3.784	-	7.52	76.3
7	0	0	1	0		.400	17.0	6.8	1.425	-	7.33	2.0	3.584	-	7.16	72.3
8	0	0	1	0		.400	17.0	6.8	1.424	-	7.68	2.0	3.534	-	7.50	71.2
9	0	1	0	0	13	.400	17.0	6.8	1.428	63.2	7.98	2.0	3.984	19.7	7.59	80.3
10	0	1	0	0		.400	17.0	6.8	1.424	-	8.48	2.0	3.366	-	8.33	67.9
11	0	1	0	0		.400	17.0	6.8	1.423	-	7.24	2.0	3.866	-	7.25	77.9
12	0	1	0	0		.400	17.0	6.8	1.418	-	7.31	2.0	3.566	-	7.06	71.9
13	0	1	1	0	13	.400	17.0	6.8	1.414	57.7	6.60	2.0	3.000	46.7	6.37	60.5
14	0	1	1	0		.400	17.0	6.8	1.431	-	8.37	2.0	3.752	-	8.20	75.6
15	0	1	1	0		.400	17.0	6.8	1.418	-	7.90	2.0	3.700	-	7.72	74.6
16	0	1	1	0		.400	17.0	6.8	1.426	-	7.33	2.0	3.918	-	7.12	79.0

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	13	.400	17.0	6.8	1.416	64.7	8.86	2.0	2.634	25.7	8.49	53.1
18	1	0	0	0		.400	17.0	6.8	1.428	-	10.36	2.0	2.584	-	10.82	52.1
19	1	0	0	0		.400	17.0	6.8	1.416	-	8.34	2.0	2.666	-	8.16	53.7
20	1	0	0	0		.400	17.0	6.8	1.418	-	5.25	2.0	2.684	-	5.27	54.1
21	1	0	1	0	13	.400	17.0	6.8	1.424	48.7	7.54	2.0	3.266	22.2	7.34	65.8
22	1	0	1	0		.400	17.0	6.8	1.429	-	11.64	2.0	3.418	-	11.43	68.9
23	1	0	1	0		.400	17.0	6.8	1.424	-	8.59	2.0	3.366	-	8.30	67.9
24	1	0	1	0		.400	17.0	6.8	1.436	-	7.91	2.0	3.652	-	7.70	73.6
25	1	1	0	0	13	.400	17.0	6.8	1.419	81.2	9.64	2.0	3.134	37.2	9.73	63.2
26	1	1	0	0		.400	17.0	6.8	1.420	-	9.58	2.0	2.652	-	9.57	53.5
27	1	1	0	0		.400	17.0	6.8	1.423	-	8.07	2.0	3.418	-	7.88	68.9
28	1	1	0	0		.400	17.0	6.8	1.415	-	11.55	2.0	2.752	-	11.64	55.5
29	1	1	1	0	13	.400	17.0	6.8	1.428	76.7	7.74	2.0	3.252	39.7	7.51	65.6
30	1	1	1	0		.400	17.0	6.8	1.424	-	8.52	2.0	3.334	-	8.53	67.2
31	1	1	1	0		.400	17.0	6.8	1.412	-	6.93	2.0	3.034	-	6.74	61.2
32	1	1	1	0		.400	17.0	6.8	1.416	-	7.87	2.0	3.100	-	7.75	62.5

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	14	.400	17.0	6.8	1.393	64.7	8.90	2.0	2.652	22.7	8.39	53.5
18	1	0	0	0		.400	17.0	6.8	1.420	-	10.73	2.0	2.734	-	14.08	55.1
19	1	0	0	0		.400	17.0	6.8	1.419	-	8.11	2.0	2.666	-	7.95	53.7
20	1	0	0	0		.400	17.0	6.8	1.419	-	5.11	2.0	2.666	-	5.10	53.7
21	1	0	1	0	14	.400	17.0	6.8	1.399	48.7	7.57	2.0	3.352	18.7	7.35	67.6
22	1	0	1	0		.400	17.0	6.8	1.420	-	11.45	2.0	3.600	-	14.60	72.6
23	1	0	1	0		.400	17.0	6.8	1.425	-	8.36	2.0	3.334	-	8.06	67.2
24	1	0	1	0		.400	17.0	6.8	1.441	-	7.72	2.0	3.600	-	7.46	72.6
25	1	1	0	0	14	.400	17.0	6.8	1.419	84.7	10.42	2.0	3.152	34.7	9.46	63.5
26	1	1	0	0		.400	17.0	6.8	1.414	-	9.52	2.0	2.884	-	12.14	58.1
27	1	1	0	0		.400	17.0	6.8	1.425	-	7.88	2.0	3.452	-	7.66	69.6
28	1	1	0	0		.400	17.0	6.8	1.418	-	11.25	2.0	2.734	-	11.44	55.1
29	1	1	1	0	14	.400	17.0	6.8	1.433	75.7	7.85	2.0	3.452	27.7	7.50	69.6
30	1	1	1	0		.400	17.0	6.8	1.419	-	8.45	2.0	3.652	-	10.85	73.6
31	1	1	1	0		.400	17.0	6.8	1.417	-	6.72	2.0	3.084	-	6.56	62.2
32	1	1	1	0		.400	17.0	6.8	1.420	-	7.70	2.0	3.134	-	7.52	63.2

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	14	.400	17.0	6.8	- Over	Discharged -		2.0				
2	0	0	0	0		.400	17.0	6.8	1.413	-	[illegible]7	2.0	3.100	-	11.13	62.5
3	0	0	0	0		.400	17.0	6.8	1.418	-	6.91	2.0	3.266	-	6.90	65.8
4	0	0	0	0		.400	17.0	6.8	1.424	-	7.42	2.0	3.518	-	7.27	70.9
5	0	0	1	0	14	.400	17.0	6.8	1.444	66.7	6.84	2.0	4.500	43.7	6.39	90.7
6	0	0	1	0		.400	17.0	6.8	1.420	-	7.55	2.0	4.184	-	9.70	84.4
7	0	0	1	0		.400	17.0	6.8	1.427	-	7.12	2.0	3.666	-	6.92	73.9
8	0	0	1	0		.400	17.0	6.8	1.425	-	7.47	2.0	3.518	-	7.29	72.9
9	0	1	0	0	14	.400	17.0	6.8	1.404	63.7	8.11	2.0	4.066	14.7	8.11	82.0
10	0	1	0	0		.400	17.0	6.8	1.416	-	8.39	2.0	3.618	-	10.61	72.9
11	0	1	0	0		.400	17.0	6.8	1.425	-	7.10	2.0	3.834	-	7.09	77.3
12	0	1	0	0		.400	17.0	6.8	1.420	-	7.11	2.0	3.552	-	6.87	71.6
13	0	1	1	0	14	.400	17.0	6.8	1.394	54.7	6.54	2.0	3.084	38.7	6.54	62.2
14	0	1	1	0		.400	17.0	6.8	1.422	-	8.29	2.0	4.184	-	10.53	84.4
15	0	1	1	0		.400	17.0	6.8	1.419	-	7.64	2.0	3.534	-	7.54	71.2
16	0	1	1	0		.400	17.0	6.8	1.429	-	7.23	2.0	3.966	-	6.91	80.0

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
17	1	0	0	0	15	.400	17.0	6.8	1.408	63.7	8.59	2.0	2.634	19.7	9.18	53.1
18	1	0	0	0		.400	17.0	6.8	1.421	-	10.21	2.0	2.666	-	11.67	53.7
19	1	0	0	0		.400	17.0	6.8	1.416	-	8.30	2.0	2.666	-	8.55	53.7
20	1	0	0	0		.400	17.0	6.8	1.417	-	5.26	2.0	2.652	-	5.32	53.5
21	1	0	1	0	15	.400	17.0	6.8	1.438	62.7	7.02	2.0	3.418	16.7	7.75	68.9
22	1	0	1	0		.400	17.0	6.8	1.424	-	11.11	2.0	3.534	-	10.99	71.2
23	1	0	1	0		.400	17.0	6.3	1.422	-	8.49	2.0	3.352	-	8.62	67.6
24	1	0	1	0		.400	17.0	6.8	1.439	-	7.80	2.0	3.618	-	7.95	72.3
25	1	1	0	0	15	.400	17.0	6.8	1.419	84.7	9.43	2.0	3.166	22.7	10.65	63.8
26	1	1	0	0		.400	17.0	6.8	1.415	-	8.97	2.0	2.852	-	10.13	57.5
27	1	1	0	0		.400	17.0	6.8	1.424	-	8.00	2.0	3.500	-	8.21	70.6
28	1	1	0	0		.400	17.0	6.8	1.415	-	11.40	2.0	2.700	-	11.97	54.4
29	1	1	1	0	15	.400	17.0	6.8	1.439	77.7	7.37	2.0	3.452	10.7	8.22	69.6
30	1	1	1	0		.400	17.0	6.8	1.422	-	7.93	2.0	3.518	-	8.90	70.9
31	1	1	1	0		.400	17.0	6.8	1.415	-	6.77	2.0	3.000	-	6.96	60.5
32	1	1	1	0		.400	17.0	6.8	1.417	-	7.73	2.0	3.134	-	8.03	63.2

TABLE III

Ni-Cd Rectangular Cells; Factorial Design Experiment
ELECTROCHEMICAL PERFORMANCE DATA
FOR FACTOR DESCRIPTION AND LEVELS SEE TABLE II

Cell No.	Factors				Cycle No.	Charge Data						Discharge Data; 1.0V Cut Off				
	A	B	C	D		Amp.	Hrs.	AH Input	ECV Volts	ECP PSIA	ECR mΩ	Amp	AH Output	EDP PSIA	EDR mΩ	Eff. %
1	0	0	0	0	15	.400	17.0	6.8	1.444	65.7	6.15	2.0	4.234	22.7	6.73	85.4
2	0	0	0	0		.400	17.0	6.8	1.421	-	8.18	2.0	2.966	-	8.86	59.8
3	0	0	0	0		.400	17.0	6.8	1.425	-	7.06	2.0	3.434	-	7.32	69.2
4	0	0	0	0		.400	17.0	6.8	1.421	-	7.61	2.0	3.584	-	7.69	72.3
5	0	0	1	0	15	.400	17.0	6.8	1.455	78.7	6.50	2.0	4.418	39.7	6.79	89.1
6	0	0	1	0		.400	17.0	6.8	1.427	-	7.09	2.0	4.084	-	7.96	82.3
7	0	0	1	0		.400	17.0	6.8	1.425	-	7.24	2.0	3.734	-	7.41	75.3
8	0	0	1	0		.400	17.0	6.8	1.425	-	7.57	2.0	3.700	-	7.83	74.6
9	0	1	0	0	15	.400	17.0	6.8	1.427	65.7	7.67	2.0	4.052	4.7	8.23	81.7
10	0	1	0	0		.400	17.0	6.8	1.419	-	7.90	2.0	3.500	-	8.76	70.6
11	0	1	0	0		.400	17.0	6.8	1.422	-	7.26	2.0	3.834	-	7.55	77.3
12	0	1	0	0		.400	17.0	6.8	1.416	-	7.29	2.0	3.552	-	7.44	71.6
13	0	1	1	0	15	.400	17.0	6.8	1.424	63.7	5.95	2.0	3.184	40.7	6.60	64.2
14	0	1	1	0		.400	17.0	6.8	1.423	-	7.79	2.0	4.016	-	8.56	81.0
15	0	1	1	0		.400	17.0	6.8	1.415	-	7.74	2.0	3.452	-	8.01	69.6
16	0	1	1	0		.400	17.0	6.8	1.427	-	7.16	2.0	4.000	-	7.42	80.6

2. There is a gradual decrease in the capacity from cycle to cycle. There are indications that this may be due to a lack of control over the mechanical properties, particularly core compression of the pack. This aspect is being investigated more thoroughly.

3. The capacity of the cells with 60% to 70% pore fill is too low and higher than 70% pore fill is indicated for satisfactory capacity.

4. From an electrochemical point of view, the polypropylene separator 14019 appears to be slightly better although its mechanical properties are not as good as FT 2140 brand. Work will continue with both the separators until there is clear evidence to reject one or the other on continued testing.

The capacity data as a function of cycle number are plotted in Figures 1 to 8 for convenience in observing trends with cycle number.

Physico-Chemical Characterization of Plates: X-ray diffraction and scanning electron microscopic studies of the positive and negative plates at various stages of sterilization and cycling were continued. Considerable time was devoted to an understanding and interpretation of x-ray diffraction data.

Eight samples of fully discharged positive and negative plate materials representing (1) as received (2) cycled (3 discharge-charge cycles)(3) sterilized and (4) cycled after sterilization were washed free of KOH dried at 100° C and stored in a vacuum desiccator. X-ray diffraction

Fig. 1

FACTORIAL EXPERIMENT: SEALED CELLS

CELL DESIGN: 14019; 30% KOH; 70% FILL

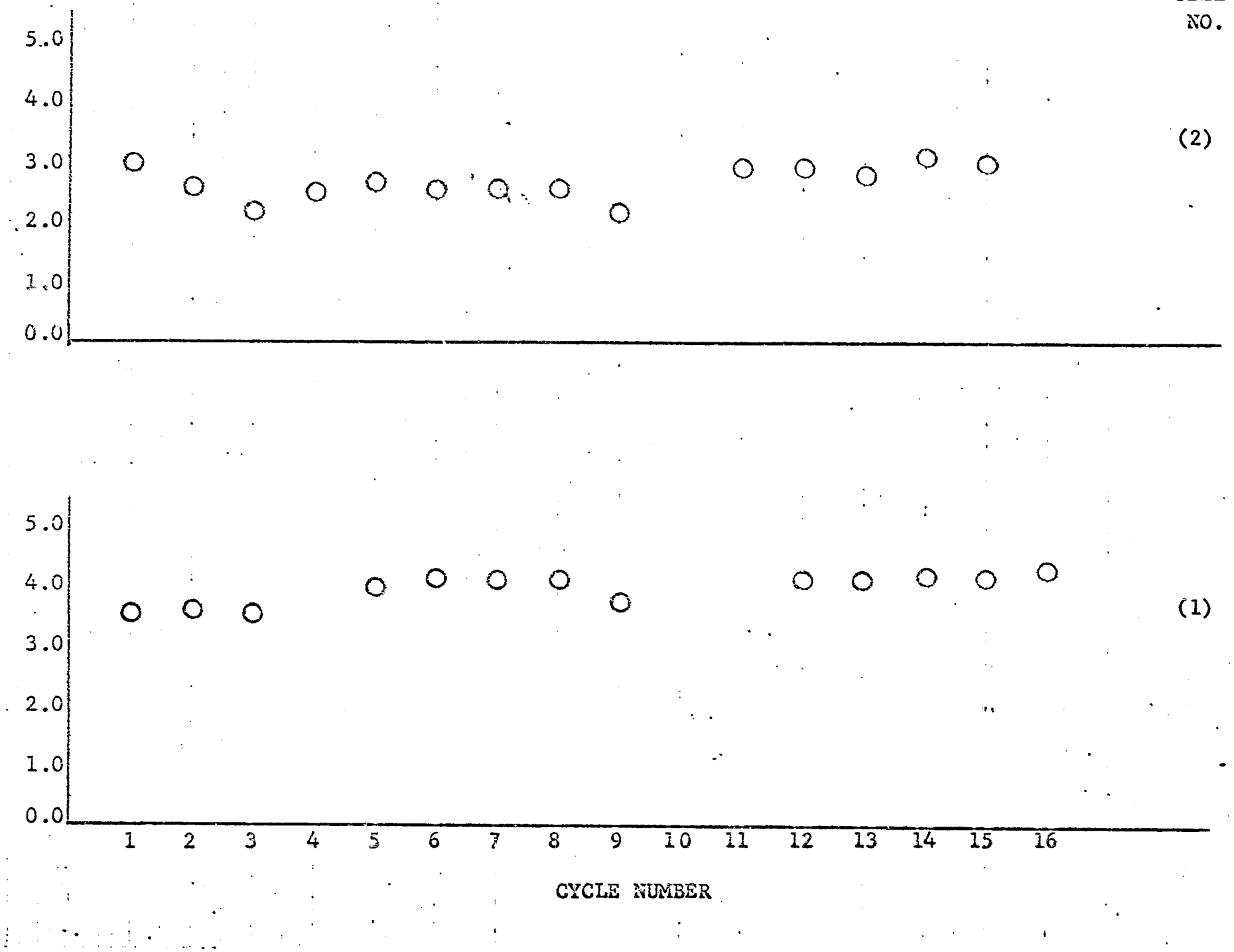


Fig. 2

FACTORIAL EXPERIMENT: SEALED CELLS

CELL DESIGN: 14019; 30% KOH; 80% FILL

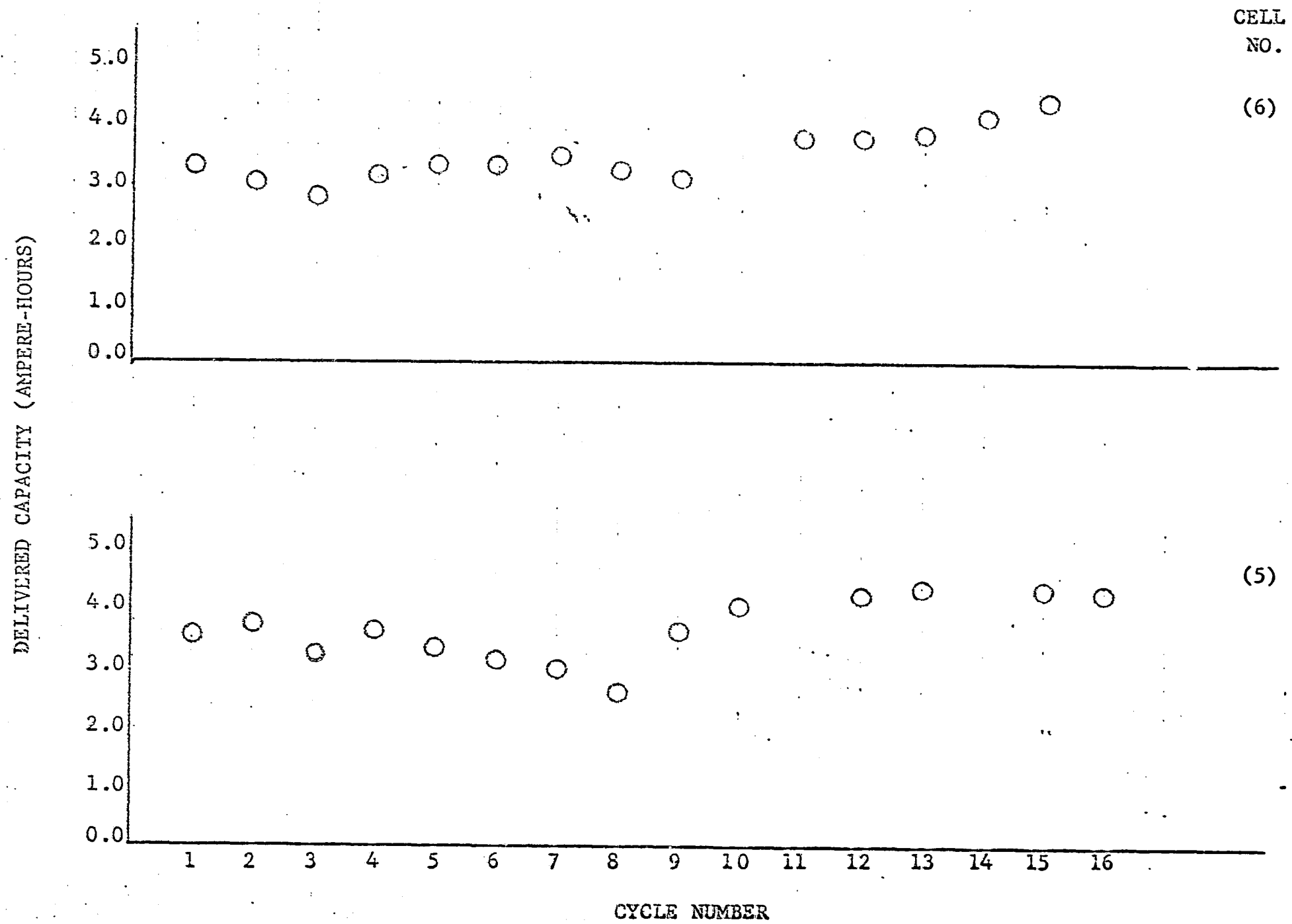


Fig. 3

FACTORIAL EXPERIMENT: SEALED CELLS

CELL DESIGN: 14019; 34% KOH; 70% FILL

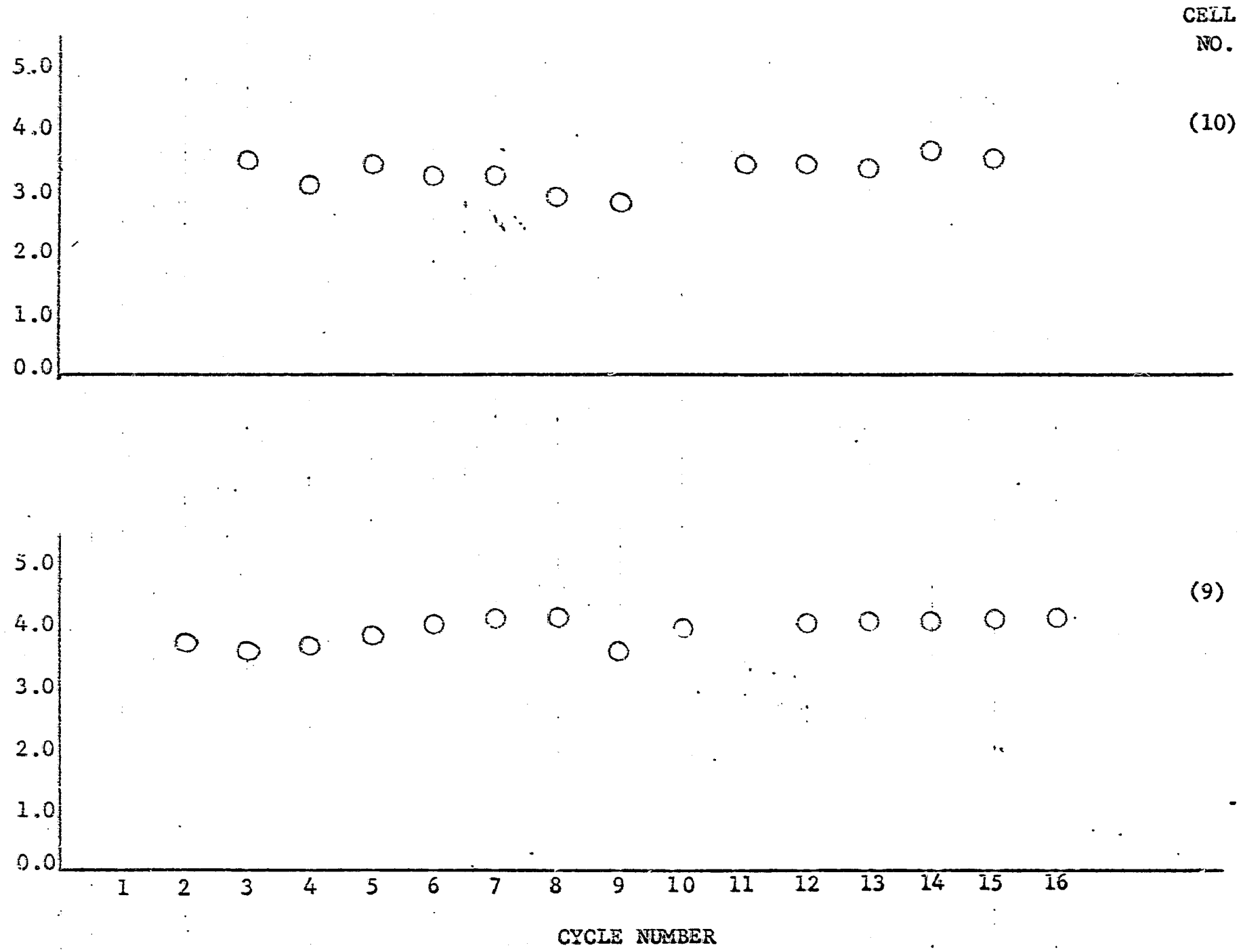


Fig. 4

FACTORIAL EXPERIMENT: SEALED CELLS

CELL DESIGN: 14019; 34% KOH; 80% FILL

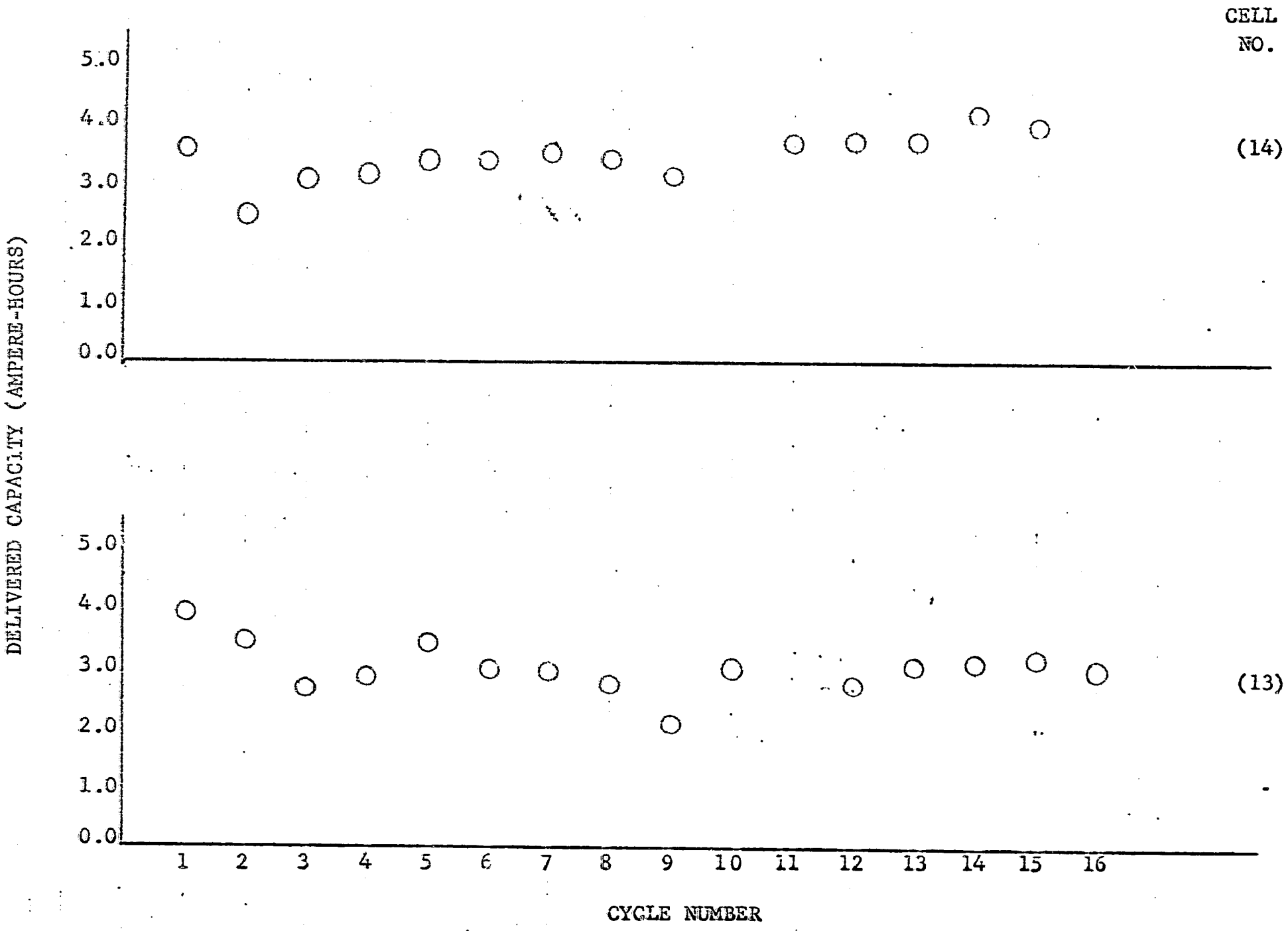


Fig. 5

FACTORIAL EXPERIMENT: SEALED CELLS

CELL DESIGN: FT2140; 30% KOH; 70% FILL

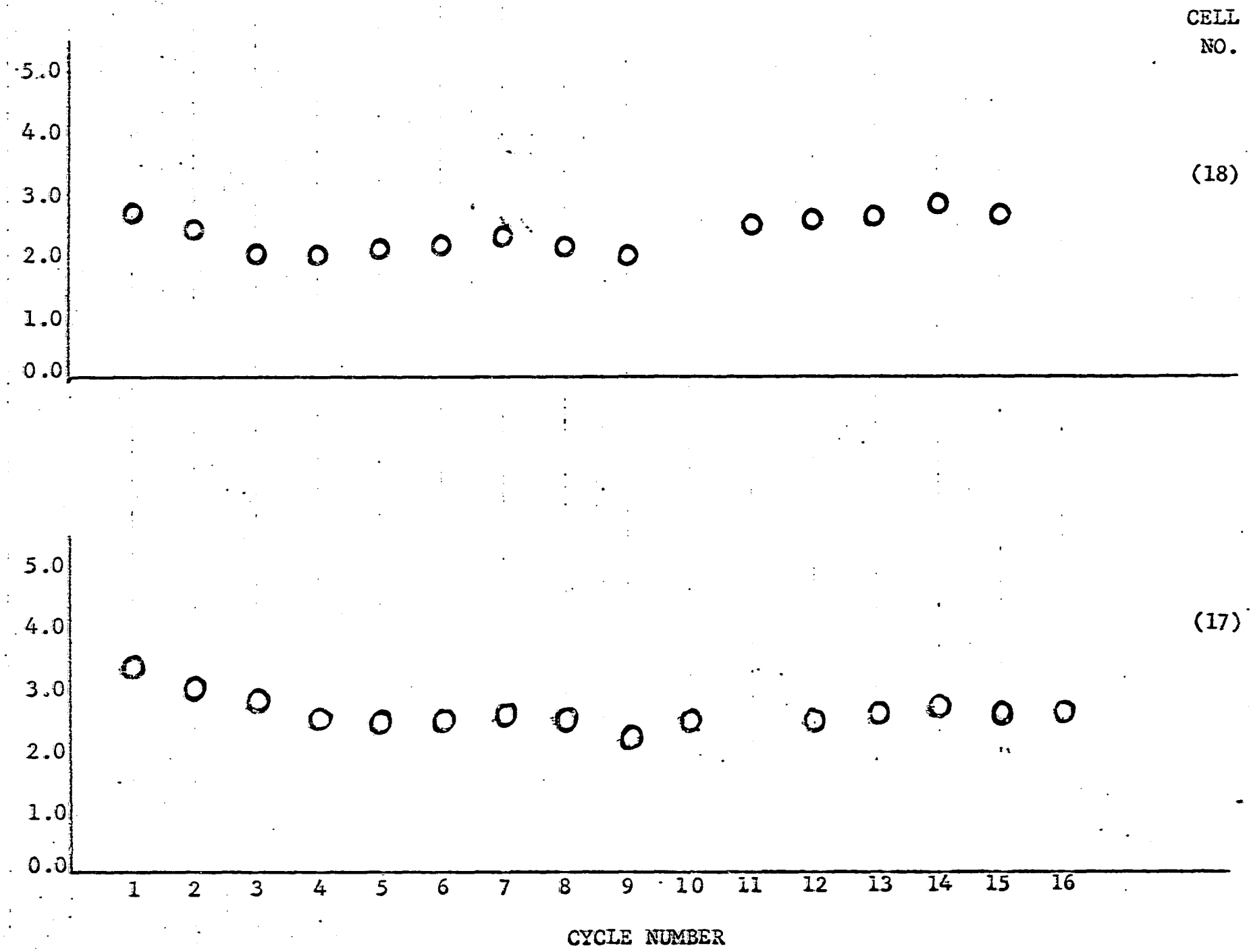


Fig. 6

FACTORIAL EXPERIMENT: SEALED CELLS

CELL DESIGN: FT2140; 30% KOH; 80% FILL

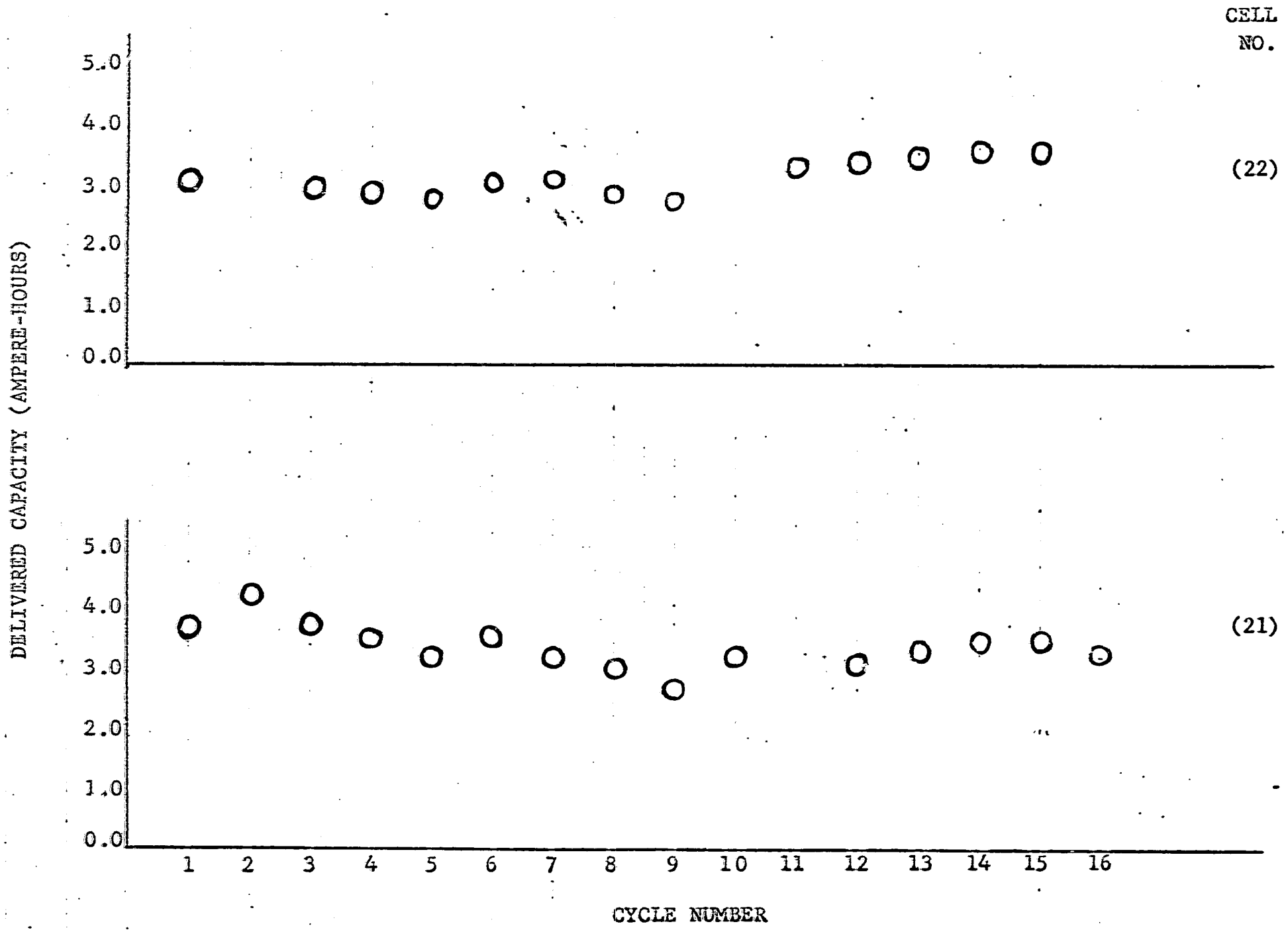


Fig. 7

FACTORIAL EXPERIMENT: SEALED CELLS

CELL DESIGN: FT2140; 34% KOH; 70% FILL

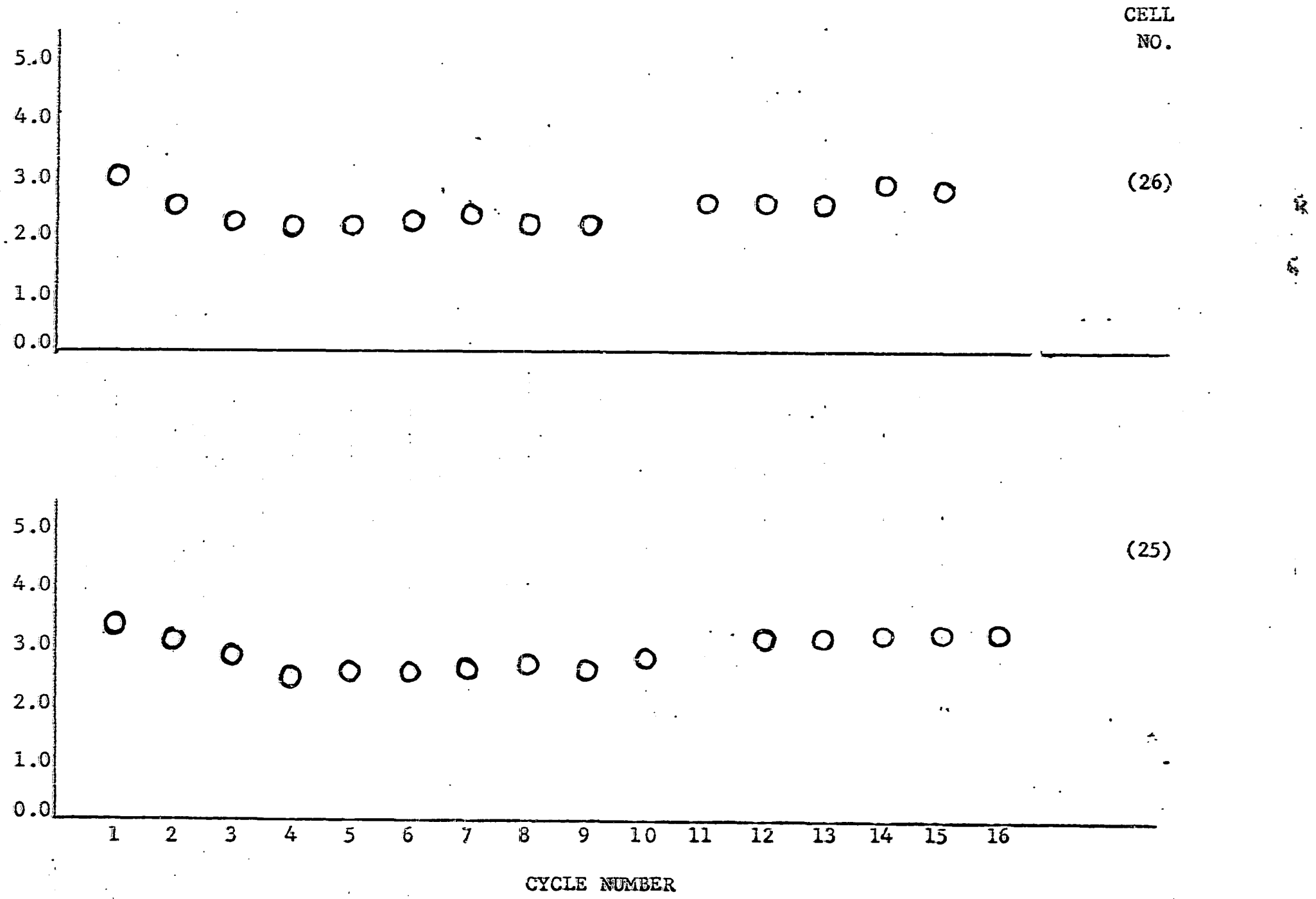
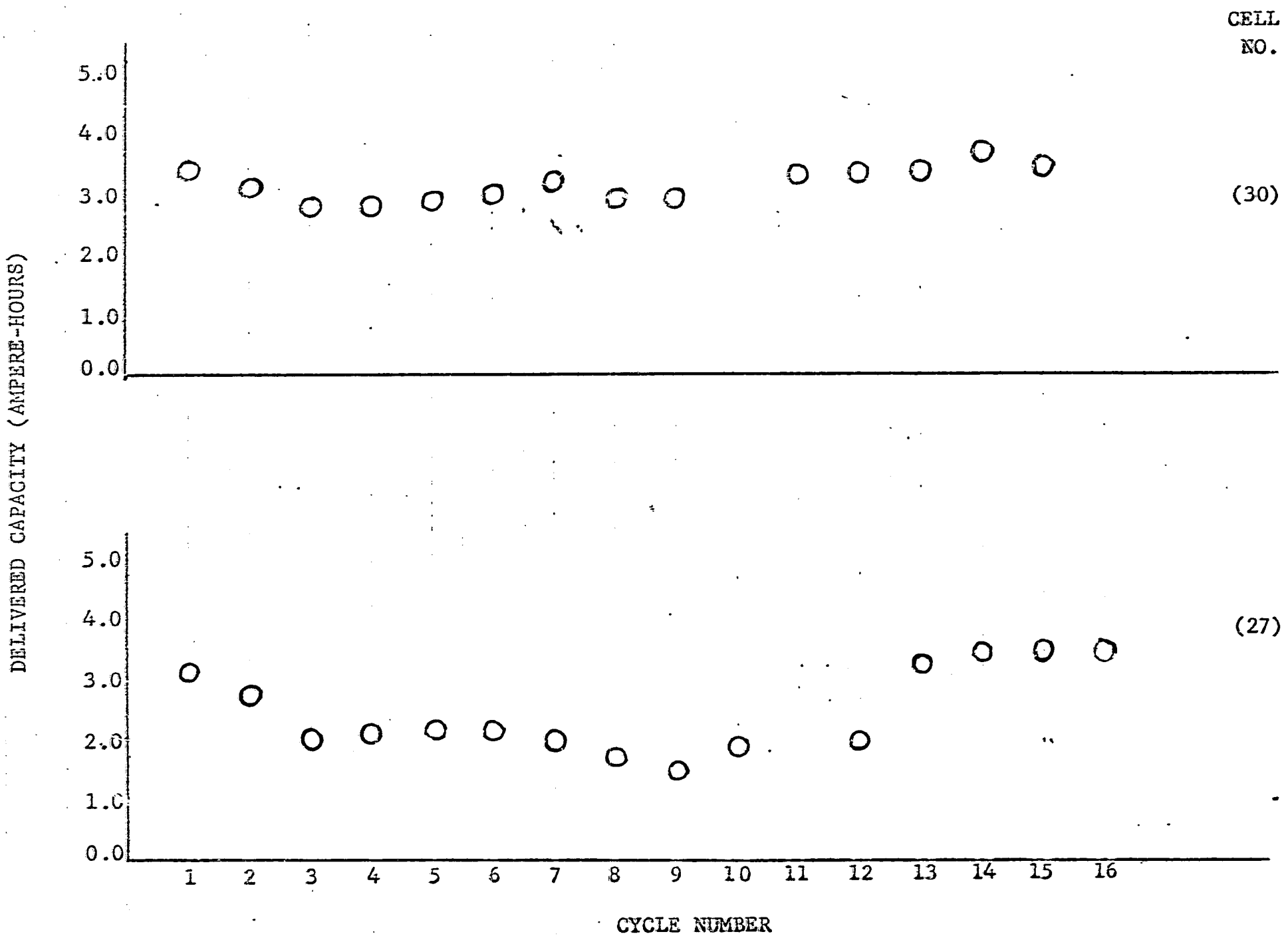


Fig. 8

FACTORIAL EXPERIMENT: SEALED CELLS

CELL DESIGN: FT2140; 34% KOH; 80% FILL



patterns were made of the surface of each sample under the conditions stated in Table IV. The patterns as well as the pattern of a sample of plaque material (without any active material) are shown in Figures 9-17.

Data from these figures and from Table V p. 37 of the 2Q Progress Report were compared with data from the ASTM "Powder Diffraction File". Table V lists principle lines for the specific compounds sought.

Positive Plates: An examination of the patterns for the positive plates shows the presence of $Ni(OH)_2$ and Ni metal. The significant intensity of the Ni peaks (1/3 to 1/2 of those of the Ni plaque.) implies either a relatively thin layer of $Ni(OH)_2$ or exposed Ni plaque.

All $Ni(OH)_2$ lines show broadening implying either small crystallite size or disorder. The presence of the relatively sharp 100 line can be interpreted in two ways. Either the compound exists as relatively thin plates whose base is the 001 plane or in layers in which the spacing in the C direction varies.

An examination of the positive plates after different treatments shows that the $Ni(OH)_2$ lines are sharpest i.e. most ordered or largest size, for the sterilized sample. Cycling after sterilization again broadens the lines returning the material almost to its presterilized condition.

Negative Plates: The lines of patterns from the negative plates

TABLE IV

X-Ray Diffraction
Instrumental Conditions

Radiation	CuK_2	Cu Tube 45KV 35ma full wave rectified with focusing monochromator at detector
Goniometer	Norelco verticle	Take off angle 3° S_D 1° S_R 1° S_S 4°
Detector	Norelco transistorized Scintillation with PHA	850 volts 1.50 base 3.00 window
Data	6°/in log output	Scan 1°/min Chart 10in/hour +.25 offset

TABLE V

Principle Lines from ASTM Standards
for CuKα Radiation

Compound Card No	°2θ	I/I_1
Cd 5-0674	38.45 31.86 34.77 47.85	100 65 32 32
CdO 5-0640	33.03 38.32 55.30 63.81	100 88 43 28
$Cd(CO)_3$ 8-456	30.27 23.51 46.49 43.78	100 60 35 25
Ni 4-0854	44.45 51.84 76.34	100 42 21
NiO 4-0835	43.30 37.30 62.90	100 91 57
$Ni(OH)_2$ 14-117	19.27 38.57 33.09 52.14	100 100 45 35
$Cd(OH)_2$ 1-0305	18.86 29.55 35.02	100 63 100
$Cd(OH)_2$ 13-226	18.88 29.48 35.19	70 65 100
BNiOOH 6-0141	18.38 37.30 66.77	100 80 80
γNiOOH 6-0075	12.81 25.96 37.93 43.25	100 80 80 80

TABLE VI

X-Ray Diffraction Lines of $Cd(OH)_2$
for CuKα Radiation

I/I_1	hkl	°2θ
Card No. 1-0305		
100	001	18.86
63	100	29.55
100	101	35.02
40	102	48.93
30	110	52.55
30	111	56.40
13	200	61.34
20	201	64.53
20	112	66.60
15	202	74.68
Card No. 13-226		
70	001	18.88
65	100	29.48
100	101	35.19
7	002	38.47
35	102	49.05
20	110	52.34
6	200	61.26
8	201	64.68
8d	103 112	66.93
6	202	74.47
As Received Sample		
59		18.8
54		29.2
100		35.0
10		38.1
37		48.6
22		52.1
20		55.9
6		60.9
12		64.3
3		66.4?
6		67.0
6		74.5

(Figures 14-17) show little evidence of broadening. The identification of compounds from these patterns is more complex. There is disagreement as to the accepted patterns, the residual spectra due to compounds other than $Cd(OH)_2$ are obtained. These are tabulated in Table VII - with their most probable origin. The variable, low intensity of the Ni lines shows that the nickel substrate is thickly covered with $Cd(OH)_2$. The scanning electron microscopy pictures in figures 18 and 19 show that sterilization results in increased crystal size in the cadmium electrode.

Traces of Cd are found in all samples except those immediately after sterilization and CdO is found in both of the sterilized samples and in one of the samples as received.

Further data are being obtained to better understand the physico-chemical changes occuring during heat sterilization of sealed Ni-Cd cells.

TABLE VII

X-Ray Diffraction Data (Neg. Plate)
Peaks other than $Cd(OH)_2$

As Received		Cycled		Sterilized		Sterilized and Cycled		Assignment
°2θ	c/sec I	°2θ	c/sec I	°2θ	c/sec I	°2θ	c/sec I	
31.9	6	31.9	4	----	----	31.9	5	Cd
32.9	3	----	----	33.1	4	----	----	CdO
----	----	39.2	4	22.9	3	----	----	
----	----	44.5	9	44.6	3	----	----	Ni
48.0	2	----	----	----	----	48.0	3	Cd
----	----	51.8	1	----	----	----	----	Ni
58.9	10	58.8	10	58.9	13	58.9	8	
62.2	2	62.4	3	62.7	3	62.5	5	
----	----	----	----	----	----	71.8	7	

From TABLE V 2nd Quarterly Report

31.9	8	31.8	35	----	----	31.8	8	Cd
----	----	----	----	33.0	5	----	----	CdO
----	----	34.7	31?	----	----	----	----	Cd
44.5	2	44.5	2	44.4	9	44.5	6	Ni
47.9	6	47.8	19	----	----	47.8	6	Cd
59.0	5	----	----	58.8	6	58.7	7	
62.4	6	62.4	19	----	----	62.4	8	
71.8	5	71.7	18	----	----	71.7	7	

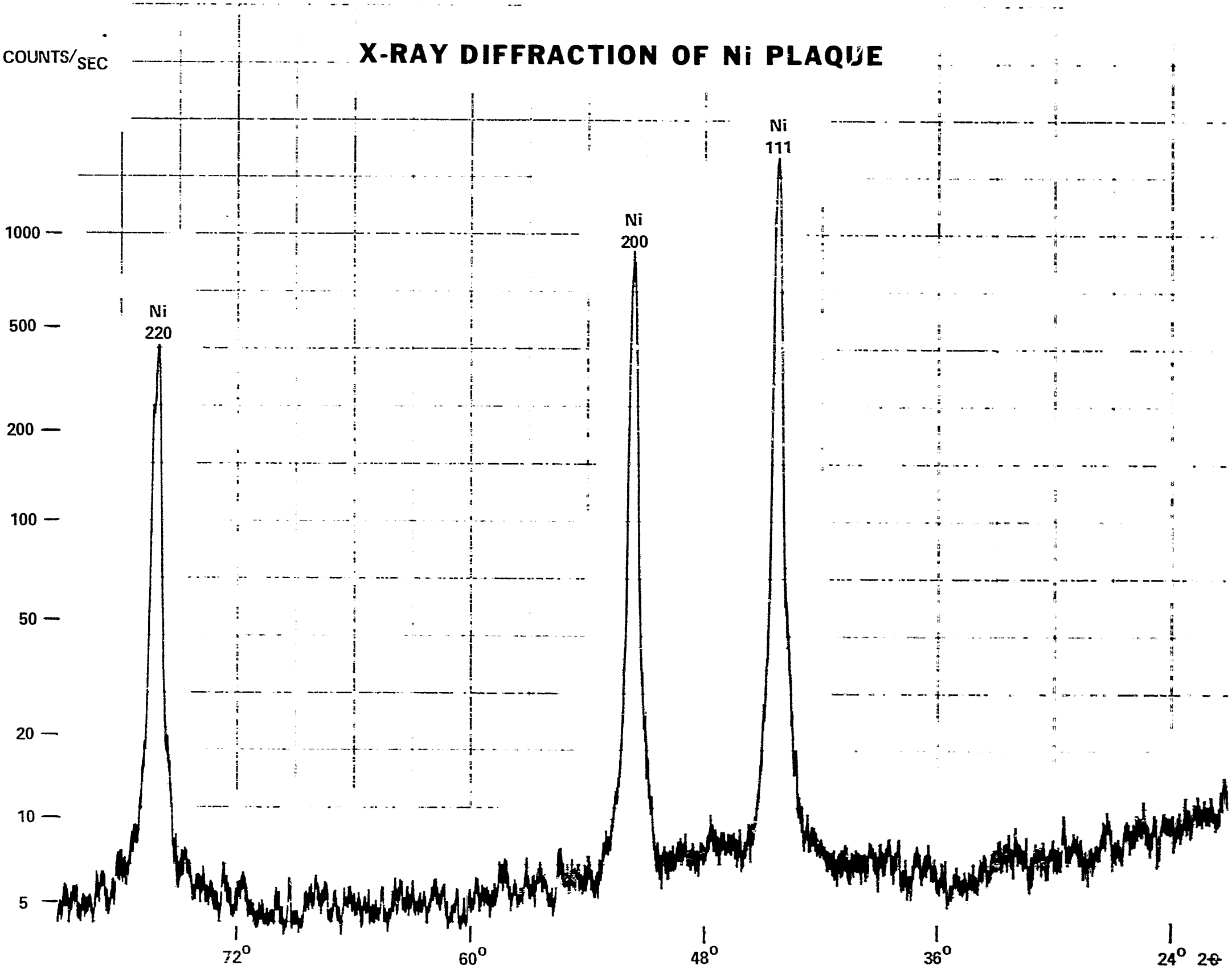

X-RAY DIFFRACTION OF Ni PLAQUE
COUNTS/SEC
1000
500
200
100
50
20
10
5
Ni 220
Ni 200
Ni 111
72°
60°
48°
36°
24°
2θ

Fig 9

X-RAY DIFFRACTION OF POSITIVE (AS RECEIVED)

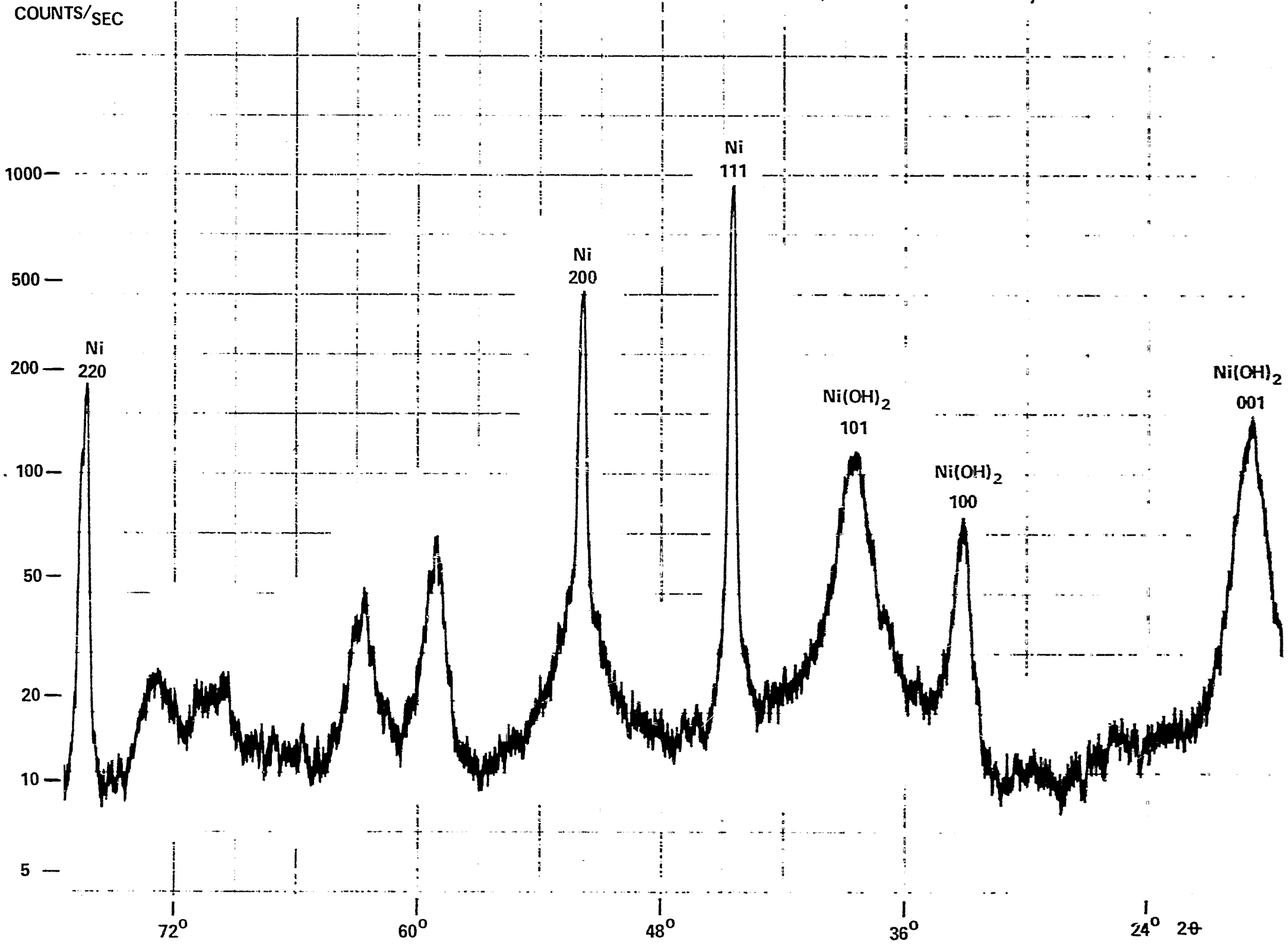


Fig 10

X-RAY DIFFRACTION OF POSITIVE (CYCLED)

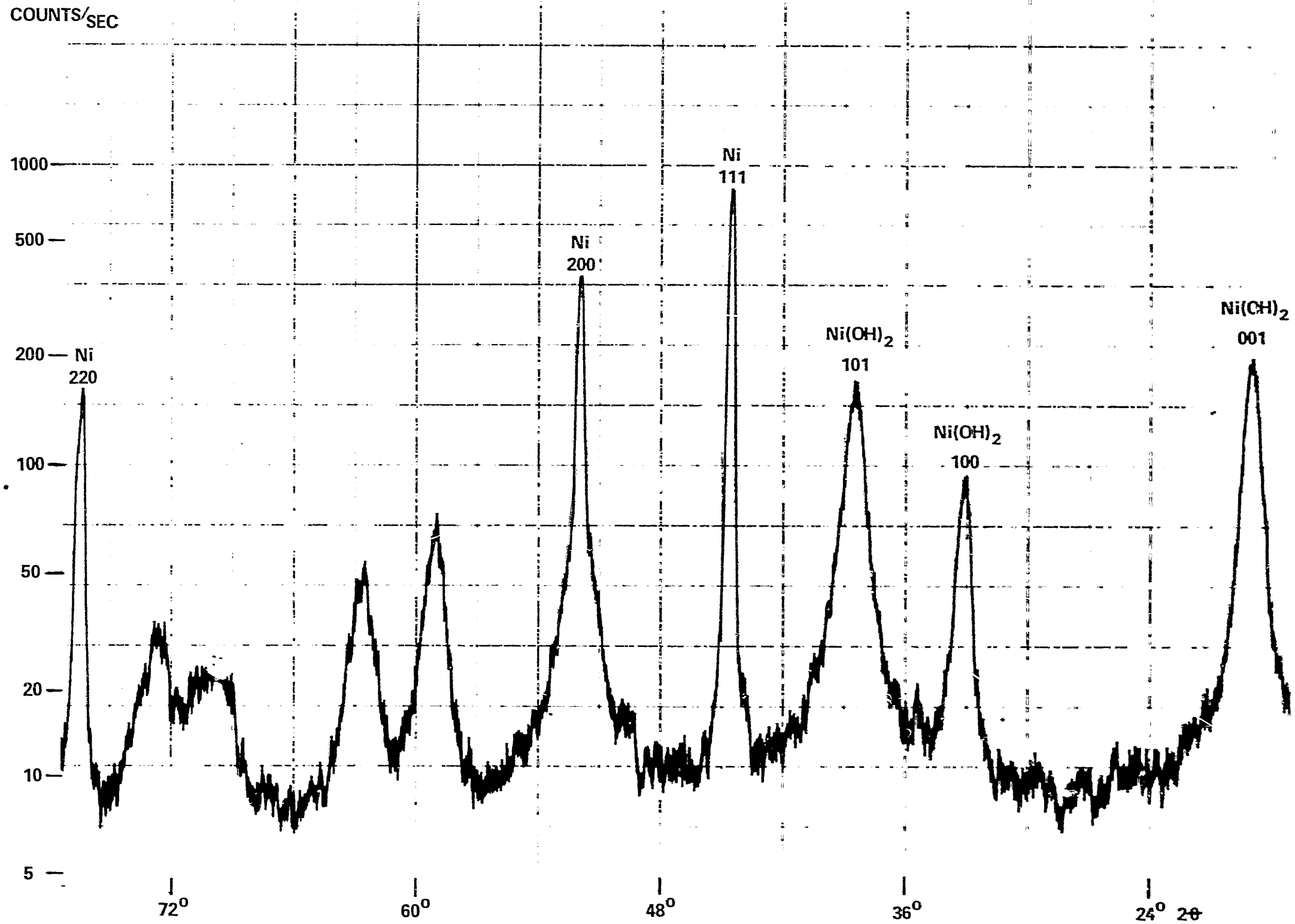


Fig 11

X-RAY DIFFRACTION OF POSITIVE (STERILIZED)

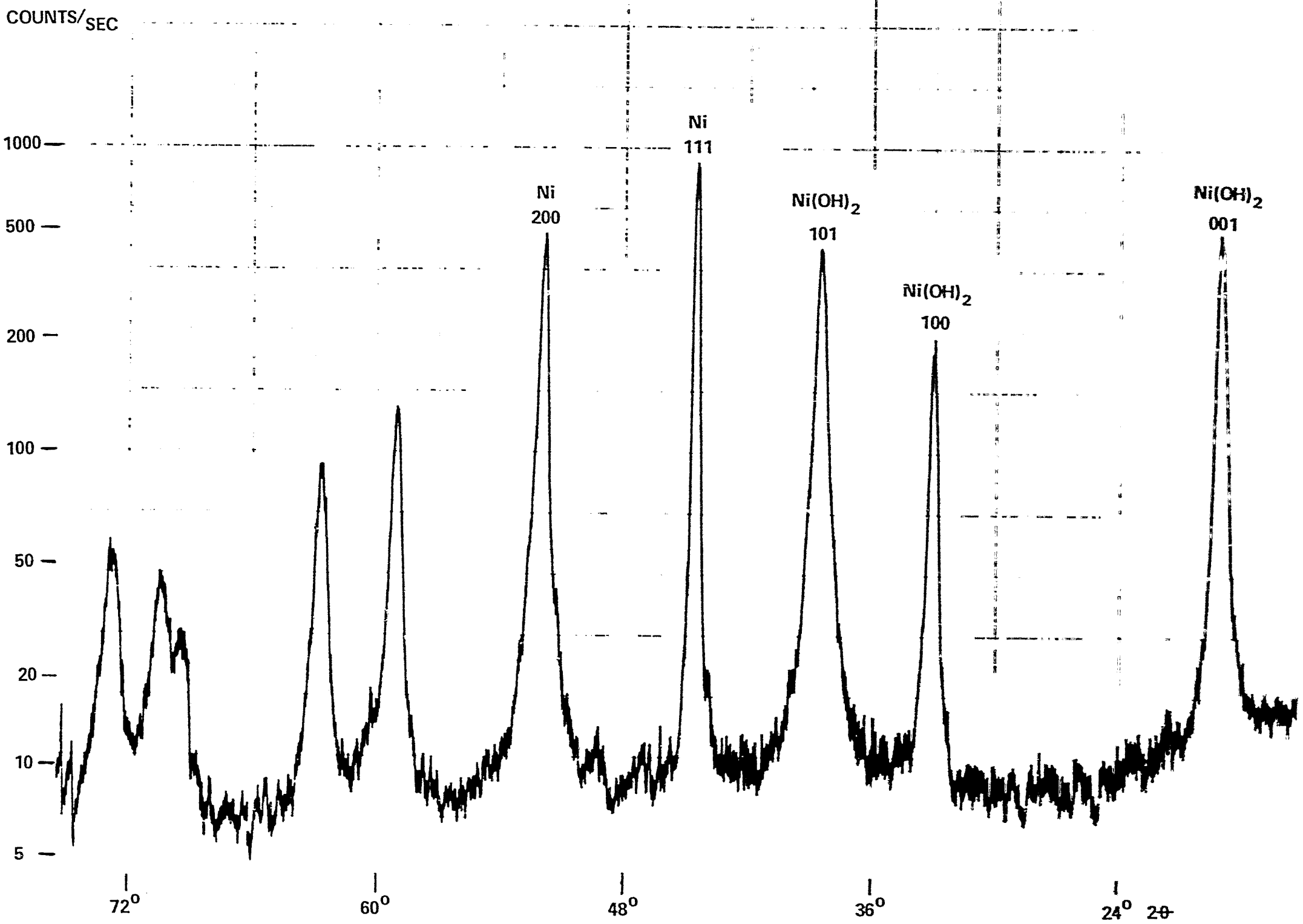


Fig 12

X-RAY DIFFRACTION OF POSITIVE (STERILIZED AND CYCLED)

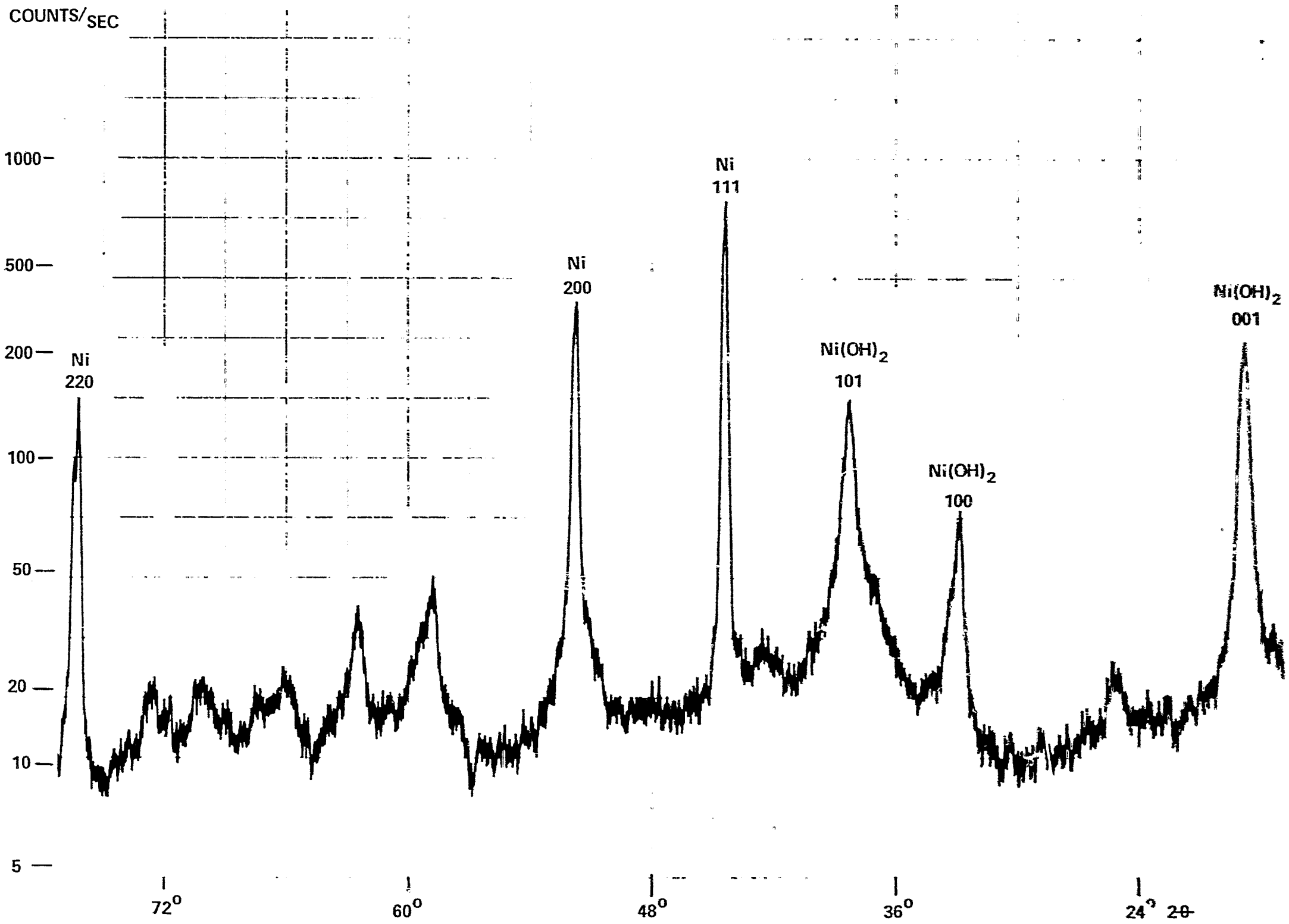


Fig 13

X-RAY DIFFRACTION OF NEGATIVE (AS RECEIVED)

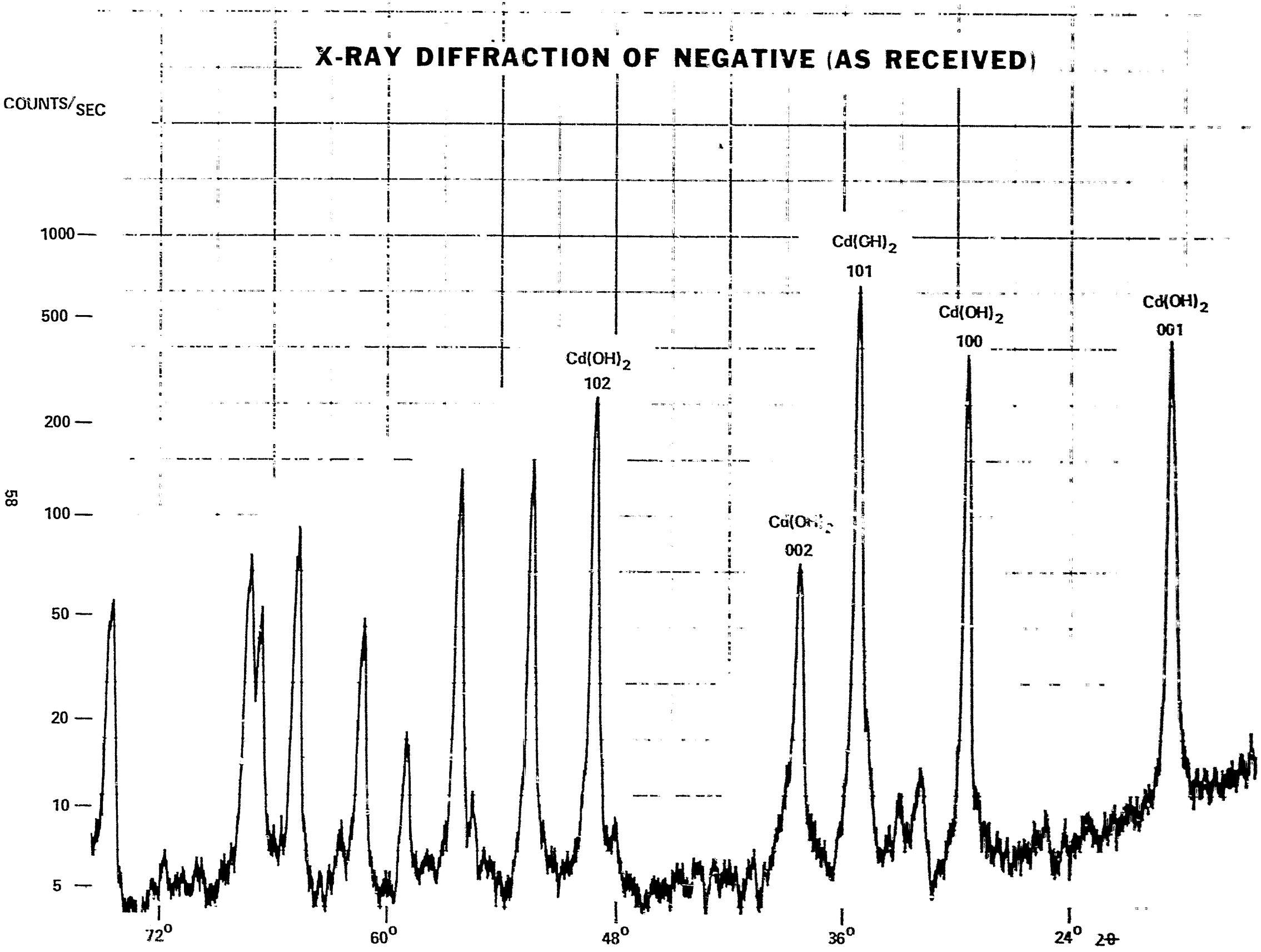


Fig 14

X-RAY DIFFRACTION OF NEGATIVE (CYCLED)

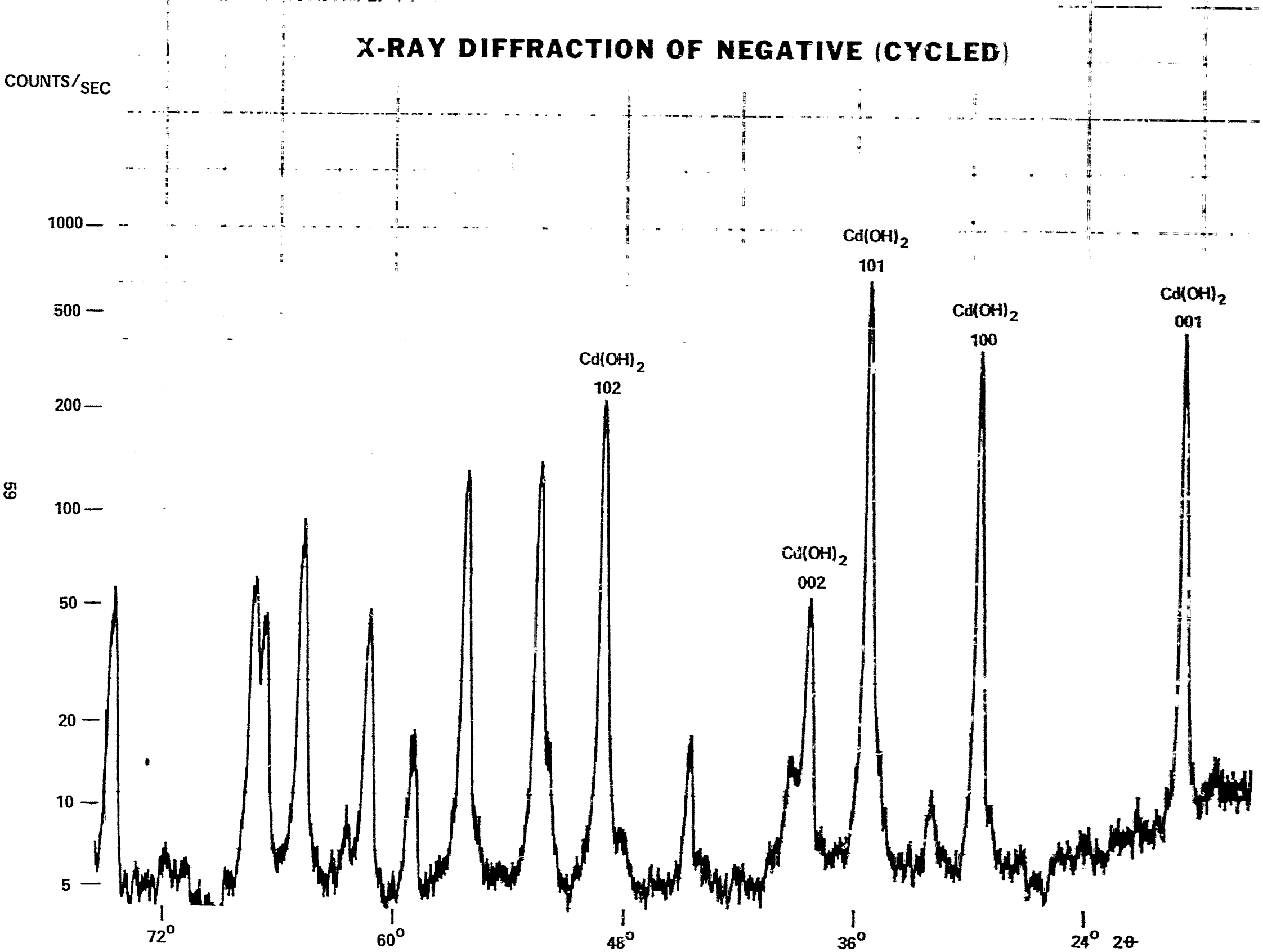


Fig 15

X-RAY DIFFRACTION OF NEGATIVE (STERILIZED)

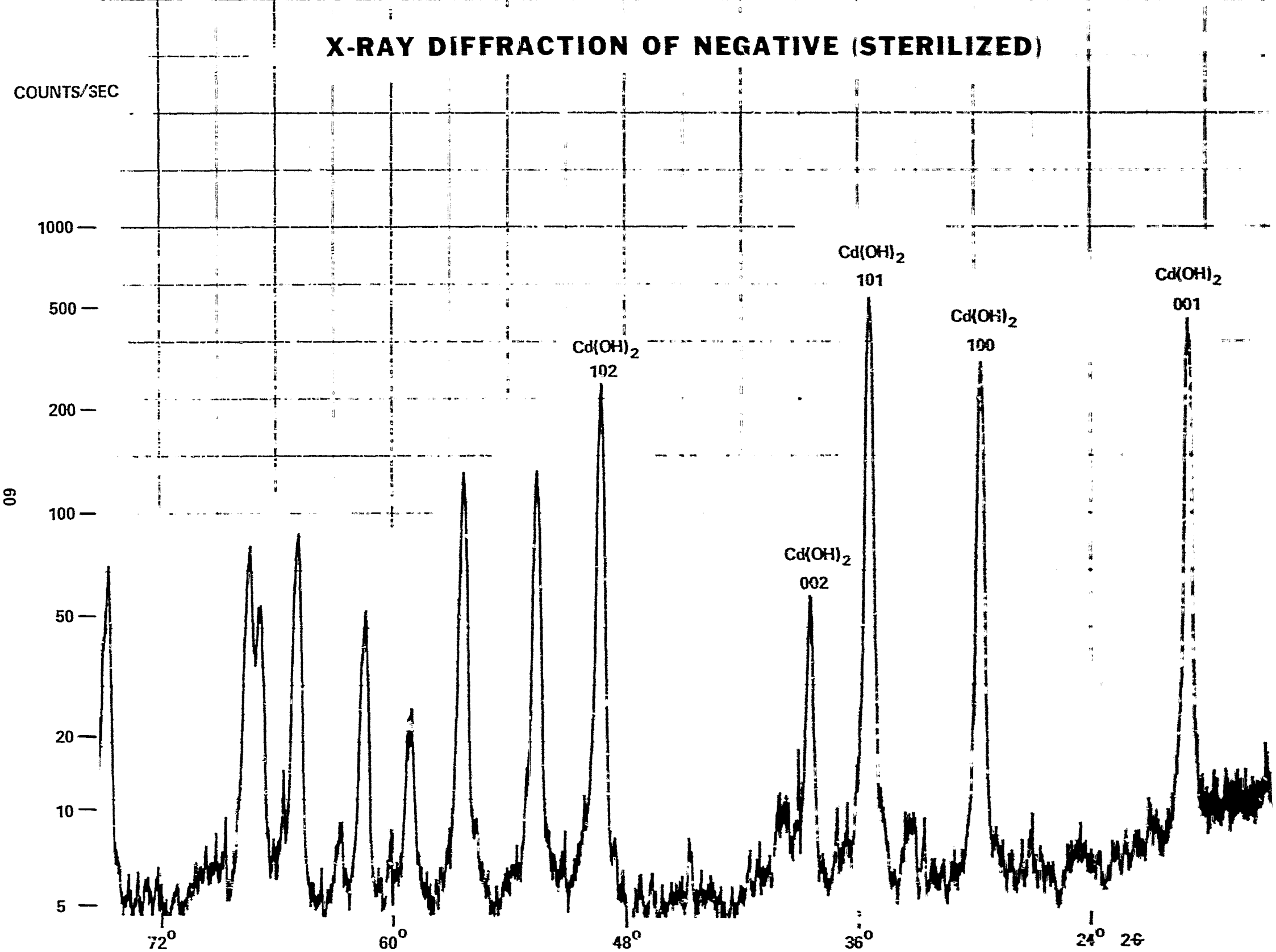


Fig 16

X-RAY DIFFRACTION OF NEGATIVE (STERILIZED AND CYCLED)

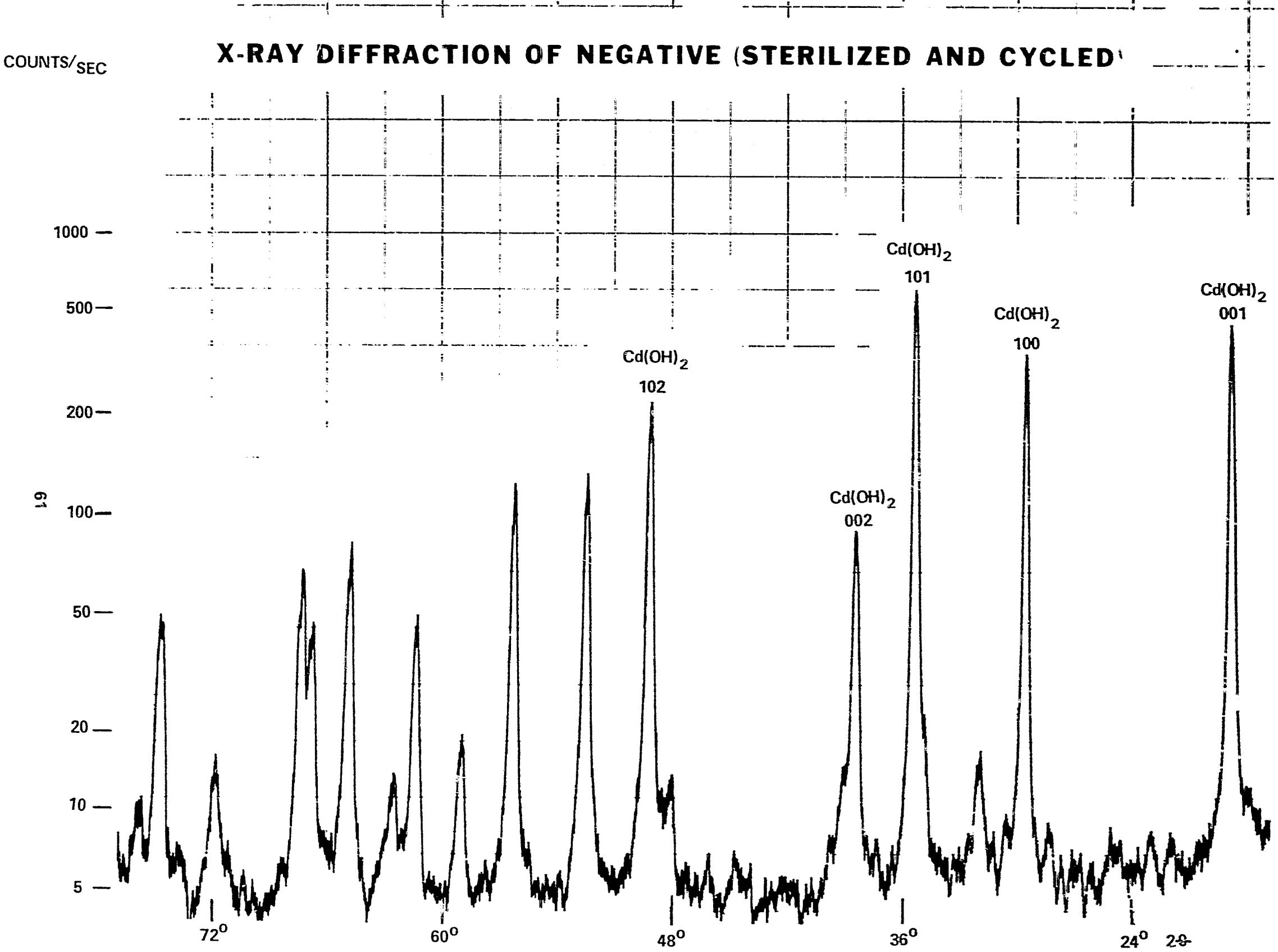
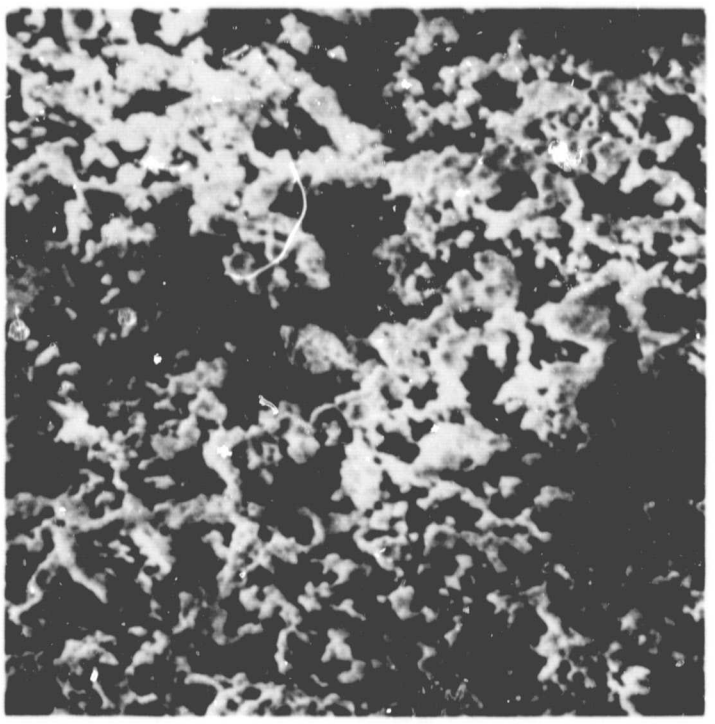


Fig 17

SCANNING ELECTRON MICROSCOPY

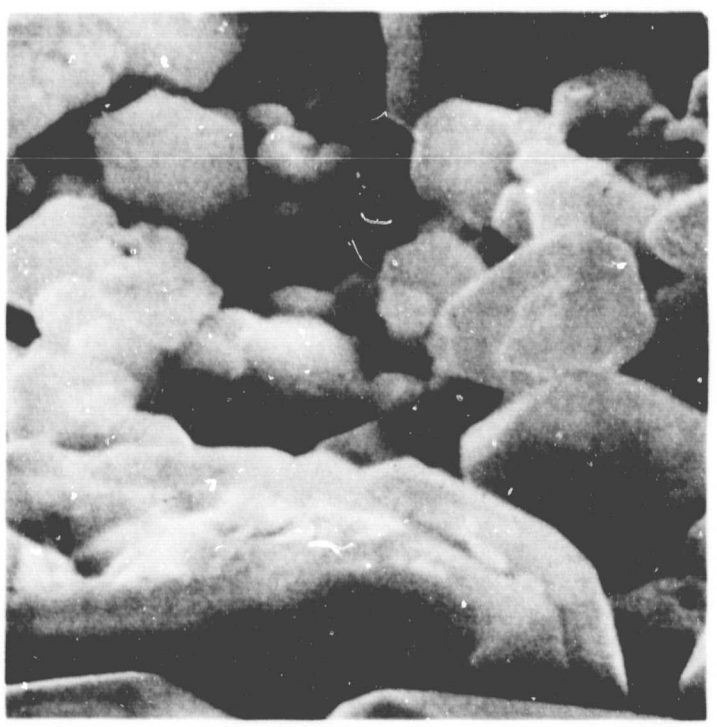


1000X

5000X

NEGATIVE MATERIAL - AS RECEIVED
(FLAT SURFACE)

1000X



5000X

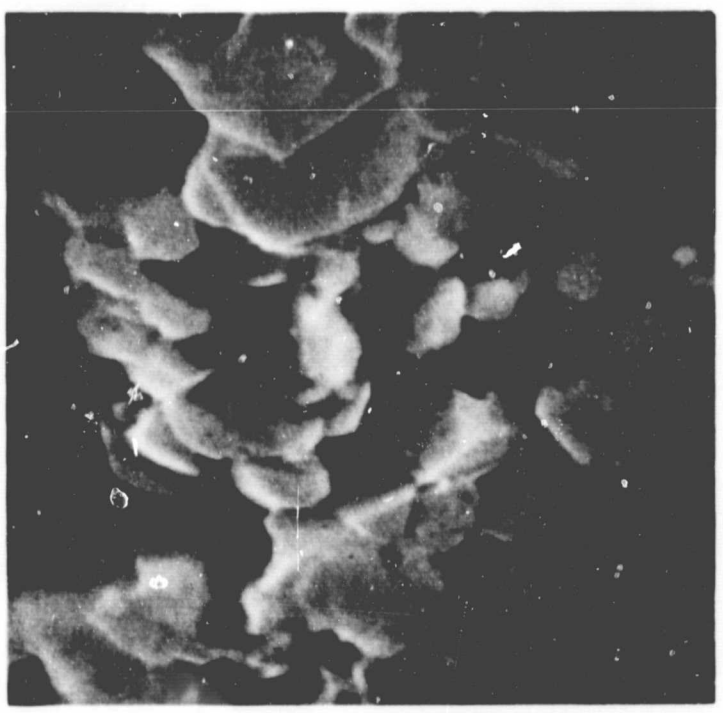
NEGATIVE MATERIAL - STERILIZED
(FLAT SURFACE)

Fig. 18

SCANNING ELECTRON MICROSCOPY

NEGATIVE MATERIAL
AS RECEIVED
(TRANSVERSE SECTION)

5000X



NEGATIVE MATERIAL
STERILIZED
(TRANSVERSE SECTION)

5000X

Fig. 19