REPORT NO. 472-64

DEVELOPMENT OF A 12 AMPERE-HOUR SEALED SILVER ZINC CELL FOR SATELLITE APPLICATIONS

CONTRACT NO. NAS 5-3351

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

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OCTOBER 1964

OCTOBER
1964

TABLE OF CONTENTS

REPORT NO. 472-64
HR12(S) CELL FOR
SATELLITE APPLICATIONS
NASA

OCTOBER
1964

OBJECT

The object of this contract was the development of a 12 ampere-hour, high rate, sealed silver-zinc cell for satellite applications, capable of meeting the requirements outlined in contract No. NAS 5-3351. The requirements are as follows:

1. The cell shall be hermetically sealed in a plastic case.
2. It shall have at least a 3 year activated shelf life.
3. It shall be capable of a minimum of 500 shallow cycles of up to 50% of the nominal capacity taken out on each cycle, for 30 minutes and recharged in 150 minutes.
4. It shall be capable of charge at constant current or modified constant potential.
5. It shall be operational within the temperature range of 14°F to 120°F at a pressure of 10^{-9} mm of mercury.
6. It shall be capable of meeting environmental requirements as outlined in MIL-E-5272C(ASG).

OCTOBER
1964

ABSTRACT

Several cell types, incorporating the latest parameters of sealed silver-zinc system, were designed to meet the NASA requirements. All the cells were tested on the 3 hour cycling period (30 minutes discharge, followed by recharge in 150 minutes).

Early designs performed poorly, failing after about 50 cycles. The reason for failure was found to be poor charge acceptance of the cells, at high current density due to electrolyte starvation in the positive compartment.

Two approaches were tried to facilite the electrolyte diffusion to the positive plates. One of them was the use of low concentration KOH. It proved to be notably successful in extending the cycling life of the cells, since its low viscosity allows an easy diffusion. Cells tested with 31% KOH ran about 160 cycles before failure. The low concentration KOH has, however, a serious drawback: it accelerates the attack on the separators, cutting down the wet life of the cells. For this reason, its use was abandoned.

Another approach, was the use of a positive interseparator capable of retaining large amounts of electrolyte. Although several materials with a good electrolyte retention were available, they all had a common drawback. Their excessive thickness precluded their use, except at the cost of a drastic reduction in the amount of active materials. A new separator material, developed by the Pellon Corporation, consisting of highly calendered, non woven polyamide fibers, which combines a large electrolyte retention with a reasonable thickness, was tested. Cells built with this interseparator showed a high efficiency at the 3 hour cycling regime. A battery tested with these cells failed after 180 cycles, because of shape change of the negative electrodes, which is the main limiting factor for the life of silver-zinc cells.

The final design (called HR12(S)-1, based on the aforementioned battery, with minor modifications, is not expected to fulfill all the requirements of the NASA specification. It will, however, come as close as possible to it, within the present state of the art for high rate silver-zinc cells.

Specific items where the cell will probably be below requirements are:

a) Shelf life: the separator system used in the HR-12(S)-1 may not provide a 3 year activated shelf life if the cell is stored at room temperature or higher. The use of heavier separators would not allow the cell to be recharged in 150 minutes (and would decrease the amount of active materials within the same envelope).

b) The number of shallow cycles depends on the depth of discharge (percentage of nominal capacity taken out on each cycle). If the maximum of 50% is used, the cell will probably not be able to run 500 cycles, but at 25% it should exceed that number.

c) The test temperature has also an important effect on the cycling life of the cell. The best performance is expected at temperatures close to the upper limit (120°F), while low temperatures have a definitely harmful effect.

OCTOBER
1964

CELL DESIGN AND EXPERIMENTAL RESULTS

A. First series of designs

The first designs followed the general outlines of the 25 ampere-hour cell (HR25(S)) which was the first commercial sealed silver-zinc cell developed by Yardney. The separator system was heavy, attempting to meet the 3 years wet life requirement.

Design No. 1 (cells 1 to 3)

a) Positive electrodes

Description: Porous plate prepared from finely divided silver and an expaned silver grid ("EXMET") by rolling and sintering method.

Number per cell: 6

Plate size: 1-29/32"W x 3-1/8"H x .002"Th.

Weight of active material per plate: 10.15 grams

b) Negative electrodes

Description: Porous plate consisting of two half-thickness plates and a current collecting silver wire loop, pressed together. Each half-thickness plate is prepared by extrusion method from zinc oxide powder containing 2% of mercuric oxide and a small proportion of rayon fibers and an organic binder (CMC)

Number per cell: 7

Plate size: 1-29/32"W x 3-1/8"H x .042"Th.

Weight of zinc oxide per plate: 11.2 grams

c) Separator system

Positive plates are wrapped in the separator material in pairs to form U-shaped two-plate units.

The wrap consists of (starting from the positive plate):

One layer of VN2.5 (nylon fabric, treated by Yardney "Vitanyze" process)

One layer of PVA (polyvinyl alcohol membrane)

Three layers of C-19 (cellophane membrane, treated by Yardney C-19 process)

Each negative plate is contained in an individual PVA bag.

The negative plates are disposed between the arms of the U shaped positive units, between the units and outside the end units, to provide an alternate plate assembly having negative plates at both ends.

d) Electrolyte
40% solution of potassium hydroxide, substantially saturated with zinc oxide.

Design No. 2 (cells 4 to 6)
Same as design No. 1, except that the content of mercuric oxide was 2.5%.

Testing
Cells were given three formation cycles, according to the following regime:
charge: 1.0 amp to 2.05 Volts.
discharge: 10 amp to 1.10 Volts.

After formation, cells were sealed and given 9 manual cycles at the same rates as specified above. The results are summarized in table I.

It may be seen from table I that the outputs varied widely from cell to cell and from cycle to cycle, in spite of the low rates of charge and discharge used. This variable (and mostly below normal) performance is characteristic of cells with irrigation problems (low rate of diffusion of electron carrying ions through the highly resistant separators).

This observation on the preliminary cycling results was confirmed during the high rate tests. The cells were scheduled to be placed on an automatic cycler, in a 100 minute cycling period consisting of a 65 minute charge and a 35 minute discharge, with 8 ampere-hours output on each discharge (as required in the original NASA specification, which was later modified). A few manual cycles, run at the charge and discharge rates corresponding to the 100 minute, 50% depth of discharge cycling regime revealed the inability of the cell to perform properly at that regime (fully discharged cell accepted only 5 to 7 ampere-hours of charge). Therefore the plans to place the cells on automatic cycler were dropped.

No significant difference was observed in the performance of cell using 2% or 2.5% mercuric oxide.

B. Second series of designs
Several variations on the separator system were tried. Besides, in some designs, the amount of active materials was decreased for a looser cell pack (tight cell packs are often subject to irrigation problems).

Design No. 3 (cells 7 and 8)
a) Positive plates
Same as for design No. 1.

b) Negative plates
Same as for design No. 1.

c) Separator system
Wrapping method as for design No. 1. Separators:
1. One turn of VN2.5
2. Five turns of C-19
Negative electrodes not wrapped.

d) Electrolyte
Same as for design No. 1.

Design No. 4 (cells 9 and 10)
a) Positive plates
Same as for desing No. 1, except:
Weight of active silver: 9.2 grams per plate
Thickness: .020"

b) Negative plates
Same as for design No. 1, except:
Weight of zinc oxide: 9.7 grams per plate
Thickness: .039"

c) Separator system and electrolyte:
Same as for desing No. 1.

Design No. 5 (cells 11 and 12)
a) Positive plates, negative plates and electrolyte:
Same as for design No. 4

b) Separator system
Same as for design No. 1, except that the turn of VN 2.5 was replaced with 1 turn of P-5 (non woven polyamide fiber sheet)

Design No. 6 (cells 13 and 14)
a) Positive plates, negative plates and electrolyte:
Same as for design No. 4.

b) Separator system:
Same as for design No. 3.

Testing
Cells were given 2 formation cycles and 10 manual cycles at various rates of charge. Results are summarized in table 2.

It may be seen from these results that the cells with PVA separator perform poorly, compared with those using C-19 only. On the basis of this conclusion and results on other silver-zinc cells revealing that the PVA is very strongly attacked by the electrolyte at high temperatures and its electrolytical resistance at low temperature is very high, this material was abandoned. This was done reluctantly, since the PVA is an excellent silver stopper, thus considerably prolonging the shelf life of the cells.

The preliminary tests on cell 9 to 12 (with PVA) did not justify any attempt to put them on automatic cycling, even though the cycling period had been changed from 100 minutes to 3 hours. The performance of these cells at the 2.4 and 3.0 amp charging rates was clearly below requirements.

Cells 7, 8, 13 and 14 (with C-19 only as main separator) although seriously affected by the high charge rates (loosing up to one third of their normal capacity) still yielded outputs close to the nominal capacity of the cell (12 ampere-hours).

Practically no difference was found between cells with different cell pack tightness, therefore it was concluded that the reason of poor performance of cells 1 to 6 (designs 1 and 2) was not caused by a tight cell pack.

Cells 7 and 8 were put on automatic cycler, on a 3 hour cycling period. However, the charge time was 120 minutes (instead of 150) and the discharge was run at 6 amp for 60 minutes, (instead of 12 amp for 30 minutes) since at the time the final NASA specificationswere not yet received. The two cell battery ran 55 cycles, over a period of 7 days, after which the end of discharge voltage fell below 2.50 volts (1.25 V per cell). This was considered as a criterium of failure and the test was stopped.

Cells 13 and 14, put on automatic cycling at the same regime failed for the same reason after 52 cycles.

After failure, cells were given two low rate cycles (charge at 1.0 amp). Their capacity on the second cycle was as follows:

Cell No:	7	8	13	14
Ampere-hours output:	11.5	12.9	12.0	11.7

Cells were dissected and found to be in good condition. The shape change of the negative electrodes was very limited.

In the light of these result it was concluded that the main reason for the early failure of cells 7, 8, 13 and 14 was still poor irrigation. Therefore, the next designs were conceived with the purpose of eliminating or minimising that problem.

C. Third series of designs

Although it was known beforehand that low concentration KOH solutions attack strongly the separators and accelerate the rate the penetration of silver through the separators, thus shortening the wet life of the cells, it was decided to try them, since their low viscosity allows an easy circulation of electrolyte through the separator system improving the charge acceptance of the cells.

This approach proved successful, as will be shown by the test results, and the possibility of using it for the final design of the HR-21(S) cell was seriously considered. Fortunately an alternate method of improving the positive electrode irrigation, without the drawbacks of the low concentration KOH, was found later.

OCTOBER
1964

Design No. 7 (cells 15 and 16)
Same as design No. 3 (cells 7 and 8), except that:

a) The width of positive and negative electrodes was increased to 1-31/32".

b) Accordingly, the amount of active materials was increased by approximately 3%.

c) The electrolyte was 25% KOH, saturated with ZnO.

Design No. 8 (cells 17 and 18)
Same as design No. 7, except that 31%KOH was used in lieu of 25%.

Design No. 9 (cells 19 and 20)
Same as design No. 4, (cells 9 and 10) except that 25% KOH, saturated with ZnO was used in lieu of the 40% solution and the plate width was increased to 1-31/32, with a corresponding increase in the amount of active material.

Testing
Cells were given two formation cycles followed by six manual cycles for a preliminary evaluation. Results are summarized in table 3.

The performance of all the cells was, in general, satisfactory, and it was decided to put cells 17 and 18 in automatic cycler, as a two cell battery. The cycling regime was in agreement with the latest NASA specification.

The cells ran 155 cycles before failure, due to low end-of-discharge voltage. The pressure of the cells was constantly checked (the cells were adapted with pressure gauges) and it never exceeded 35 psig.

Figures 1 to 9 show the discharge-charge voltage characteristics of the battery after 20, 40, 60, 80, 100, 120, 140, 150 and 155 cycles. The curves were obtained with an Esterline - Angus voltage recorder which permanently monitored the battery voltage. As may be seen by the discharge curves in successive cycles, the failure was gradual. The discharge voltage was practically constant for the first 100 cycles; the first signal of impending failure can be seen by cycle 120, when a very slight dip appeared just at the end of discharge. The dip was somewhat more pronounced by cycle 140 (about 2.77 volts), it reached 2.7 Volts by cycle 150 and slightly over 2.0 volts on cycle 155.

It should be noted that an incorrect adjustment of the charge resistance resulted in a higher charging rate than the specified 2.4 amps. For that reason the duration of the charges was less than 150 minutes (of figs. 1 to 9). This may have had the effect of cutting somewhat short the cycling life of the battery.

After failure, both cells were given two manual cycles at low rate. On the second discharge cell No. 17 yielded 7.0 ampere-hours and cell No. 18, 7.9 ampere-hours. These outputs pass the cycling requirement (6.0Ah) by only a narrow margin and did not justify further testing.

The cells were dissected and the following was found:

a) The amount of silver in the separator, although not very high (about 10% of the original active silver in the cell), is substantial considering the very short wet life of the cells.

b) The separators were mechanically weak (although far from the breakdown point) when compared to separators from cells with similar history, filled with 40 or 44% KOH.

c) The shape change of the negative electrodes was considerable: about 50% of the area of the plates was washed out. The failure of the cells was probably due to this reason.

d) The positive plates had large dark areas (silver oxides) at the top and at the sides, corresponding to the areas of the negatives where the active material was thin or missing altogether.

D. Fourth series of designs

Besides the low concentration KOH, another way to improve the irrigation of the cell pack, is the use of very absorbent materials around the cell electrodes, especially the positive electrode. Several of these materials were available long before the beginning of this contract but all of them were too thick to be taken in consideration, since the use of any of them would seriously reduce the amount of active materials, and therefore, the initial capacity of the cells. However, by the end of 1963 a new material (or rather an improvement of an old one) developed by the Pellon Corp., consisting of highly calendered, non woven polyamide fibers, was being tested in some of our cells. This material, called P-5, combines an excellent electrolyte absorbtion with a relatively low thickness. Besides it is very resistant to the attack of the KOH and the silver.

It was thought convenient to try this material on the NASA cells, and a new series of designs were built and tested.

Design No. 10 (cells 21 to 23)
(All non mentioned design characteristics are identical to those of design No. 1).

a) Positive plates
Weight of silver powder: 10.5 grams
Size: 1-31/32" wide x 3-1/8" high x .022" thick

b) Negative plates
Weight of zinc oxide mix per plate: 11.1 grams
Size: 1-31/32" wide x 3-1/8" high x .038 thick

c) Separator system
1) One turn of P-5
2) Five turns of C-19
Negative plates not wrapped.

Design No. 11 (cells 24 to 26)
Same as design No. 10, except:
a) Weight of silver powder per plate: 9.6 grams
b) Thickness of positive plates: .020"
c) Separator system
   1) One turn of P-5
   2) Four turns of C-19
   3) One turn of P-5

Testing
Cells were given two formation cycles and after sealing, 3 manual cycles.

From the results obtained in these preliminary tests (see table 4) it may be seen that the performance of the cells at the rates required for the 3 hour cycling period was quite satisfactory. On the basis of the above results all cells were placed on automatic cycling, divided in two batteries of 3 cells each.

a) Cells 21, 22 and 23
This battery ran 120 cycles. Figures 10 to 14 illustratethe battery voltage characteristics at different stages of its cycle-life. In addition, the individual cell pressures have been recorded. The maximum pressure reached by any cell was 30 psig.

The battery failed as in previous tests, because of low end of discharge voltage. A slight dip at the end of discharge was already observed by cycle 80, however, it only became significant after 110 cycles.

b) Cells 23, 24 and 25
The performance of this battery, which ran 182 cycles is illustrated in figures 15 to 24.

Since the design of this battery, with minor modifications, was used for the 32 cells shipped NASA, we shall examine its performance in detail.

Table 4 shows the capacity of the cells in deep cycles. On cycles 1, 2 and 3, when the cycling rates were the same as used in the 3 hour cycling period, the capacity ranged from 17.0 to 20.2 ampere-hours, a very good output considering the high rate of charge and the amount of active material in the cells.

For a better interpretation of the voltage characteristics of the battery, it should be noted that there was an intercell voltage drop of about .2V, because the cells were connected with wires instead of standard connectors.

A close examination of figures 15 to 24 points out the following:

a) The battery end of discharge voltage decreased steadily after cycle 80 as shown in the following table:

Cycle No.	End of Discharge Voltage
5	4.08
20	4.03
40	4.01
60	4.02
80	4.08
100	3.95
120	3.91
140	3.89
160	3.85
180	3.70
182	3.50

b) The shape of the discharge curves indicates that on cycle 5, about 75% of the discharge took place at the silver peroxide plateau. Although this proportion decreased slowly with cycling, even on cycle 180 it was at least 40%. The high proportion of the discharge at the peroxide plateau means that the silver electrodes were properly charged throughout the whole test, and therefore, the battery failure was not caused by insufficient charge acceptance by the positive electrodes.

c) Further study of the discharge curves leads to the discovery that, after the battery voltage dropped to the monoxide level it did not keep a steady plateau, but sloped down to the very end of discharge. This slope was not very pronounced at the beginning of the cycling, but increased cycle by cycle, becoming very steep by cycle 180. The absence of a steady monoxide plateau voltage in a cell (or battery) is a sign of negative electrode failure.

d) The pressure of the cells remained low throughout the whole testing program. The maximum pressure recorded in any cell was 18 psig.

After the battery failure, its cells were given two low rate cycles (charge at 1.0 Amp, discharge at 6.0 Amp). Their output on the second discharge was as follows:

Cell No:	24	25	26
Ampere-hours output:	7.2	6.7	7.5

The cells were dissected after the second discharge and immediately it became obvious that the shape change of the negative electrodes was the cause of their failure. Large areas at the top and at the sides of the negative electrodes were either missing or very thin; the corresponding areas of the positive plates were fully or partially charged. The positive plates were in good condition and so was the separator system.

E. Final design

As mentioned earlier, the final design was almost entirely based on design No. 11 (cells 24 to 26).

That decision was primarily based on the cycling life of the cells, the longest that could be obtained compatible with a reasonable wet life and with an adequate protection against early shorts.

a) Case, cover, hardware and potting

The case, cover, hardware and external dimensions of the cells were entirely identical to those of the 12 Ampere-hour sealed silcad cell previously shipped to NASA (YS12(S)-1). A control drawing (YEC dwg. 8760) for the cell is attached to this report (figure 25).

b) Positive electrodes

1. Description: Porous plate prepared from finely divided silver powder and an expanded silver grid ("EXMET") by rolling and sintering method. The silver powder is manufactured by Yardney Chemical Corp., New York, N.Y. and the grid is supplied by Exmet Corp., New York, N.Y.

2. Number per cell: 6

3. Size: 1-31/32"Wx3-1/8"Hx.020"Th.

4. Weight of active material per plate: 9.6 grams.

c) Negative electrodes

1. Description: Porous plate consisting of two half-thickness electrodes and a current collecting silver wire loop, pressed together. Each half-thickness plate is prepared by extrusion method from zinc oxide powder, containing 2% of mercuric oxide and a small proportion of rayon fibers and an organic binder (CMC). Suppliers:
For zinc oxide: New Jersey Zinc Co., New York, New York
For mercuric oxide: J.T. Baker Co., New York, New York

For CMC powder: Hercules Powder Co.,
New York, New York
For rayon fibers: American Viscose Corp.,
New York, New York

2. Number per cell: 7

3. Size: 1-31/32"W x 3-1/8"H x .042"Th.

4. Weight of zinc oxide per plate: 9.7 grams.

d) Separator system and wrapping method
Positive plates are wrapped in the separator material in pairs, to form U-shaped two-plate units.

The wrap consists of (starting from the positive plate):

One layer of P-5 (non-woven polyamide fiber sheet)

Four layers of C-19 (celophane membrane, treated by Yardney C-19) process.)

One layer of P-5

Each negative plate is covered on both sides with a layer of Aldex paper.

The negative plates are disposed between the arms of the U-shaped positive units, between the units and outside the end units, to provide an alternate plate assembly, having negative plates at both ends.

e) Electrolyte
The electrolyte is a 40% solution of potassium hydroxide, substantially saturated with zinc oxide.

f) General cell characteristics
1. Total weight of silver (including conductor and leads): 68.0 grams.

2. Total weight of active silver: 57.6 grams.

3. Total weight of zinc, present as zinc oxide: 54.5 grams.

4. Total weight of mercuric oxide: 1.4 grams.

5. Active zinc to active silver weight ratio: 0.945

6. Overall cell dimensions:(potted, including terminals): 5-5/8"H x 2-9/16"W x 1-1/16"Th.

7. Overall cell volume: 15.35 cu. in.

F. Cell construction, formation and pre-delivery tests

42 cells, of the final design, as described above, were manufactured in one production lot in our New York plant. From this amount, 32 cells were selected for shipment to NASA (divided in 2-10 cell batteries plus 12 individual cells) and the other 10 were retained for further testing in our laboratories. The cells were numbered 2 through 42 and given 2 formation cycles, as follows:

	Charge	Discharge
Cycle 1	1.0 Amp to 2.05V	10 Amp to 1.10V
Cycle 2	1.2 Amp to 2.05V	10 Amp to 1.10V

Immediately thereafter the cells were temporarily sealed by means of a plastic disc cemented on the valve seat and given a third cycle, charging at 2.4 Amp to 1.99V and discharging at 12Amp to 1.30Volts.

Table 5 summarized the results obtained on cycles 2 and 3, for each cell. On the basis of the output obtained on cycle 3 (run at the same rates as required for the NASA test program) the following cells were selected for battery No. 1:

Nos. 3, 5, 7, 8, 16, 24, 25, 27, 29 and 32.

As may be seen, the output of these cells ranged from 21.6 to 21.9 ampere-hours, forming a very well balanced battery. The cells were potted without further tests and after assembling them in a battery, were packed for shipment.

At the same time, the following cells were selected for our laboratory tests, and therefore, eliminated from the NASA order:

Nos. 10, 12, 13, 18, 26, 28, 30, 31, 42 and 43.

Electrolyte level. All 42 cells of the final production lot, and also all previous test cells from designs 1 to 11, were filled with 40 cc's of electrolyte. This amount covers the cell pack to approximately the top of the plates when the cells are fully charged, but it is much lower (sometimes there is no apparent level) in discharged cells. For reasons that will be discussed later, no electrolyte was removed from any of the test cells. The same criterium was followed for the 10 cells of battery No. 1, since NASA requested 10 cells with "maximum electrolyte" (cf change order #3 to contract No. NAS 5-3351). In the same order, it was requested that the balance of the cellsbe filled at "proper level required for sealed cells".

After cycle No. 3, the seal of 22cells (balance of the order) was opened and after a full charge, the electrolyte level was adjusted to approximately 50% of the plate height. In order to get this level, it was necessary to remove an average of 3.8 cc's from each cell (maximum 4.7 cc's, minimum 2.6 cc's). After electrolyte removal, the cells were discharged, resealed and given one additional cycle, identical to cycle 3. The outputs of all 22 cells are summarized in table 6.

Battery No. 2 was formed on the basis of the above results. The following cells were selected:

Nos. 15, 17, 19, 23, 33, 35, 36, 39, 40 and 41,

with output ranging from 20.4 to 21.8 ampere-hours.

The rest of the cells had an output range of 17.0 to 19.6 ampere-hours.

The effect of the electrolyte removal on cell capacity will be discussed later.

After this additional cycle, the 22 cells were potted, 10 of them (identified above) were assembled to form battery No. 2 and the other 12 were packed individually.

All 32 cells were delivered to NASA in one single shipment.

G. Constant potential charge

As required in article IV of the NASA contract, cells were constant potential charged at 1.97V per cell, at 14, 77 and 120°F.

The cells were identical to Nos. 24 to 26 (design No. 11, which differs from the final design only in minor details).

Three batteries of three cells each were put on a constant potential charger at each of the aforementioned temperatures. The potential on the bus-bars of the C.P. charger was set at 3x1.97=5.91V, and checked with a Hewlett-Packard model 3440A Digital Voltmeter (0.1% accuracy).

The cells were interconnected with very low resistance connectors, stabilized at the respective test temperatures and connected to the bus-bars, without any resistance in series, for 30 days. Individual cell voltages and pressures were monitored at intervals and the results are summarized in tables 7, 8 and 9.

OCTOBER
1964

COMMENTS AND CONCLUSIONS

1. Heavy separator systems do not allow an effective performance of the cells at high rates of charge and discharge involved in a 3 hour - 50% cycling regime. For that reason, separators including a layer of PVA (polyvinyl-alcohol film) and/or PVA bags around the negatives) had to be abandoned for systems using C-19 (specially treated cellophane) only as main separator.

   The cycling life of cells using heavy separators is severely limited by their poor charge acceptance at the test regime, since those separators offer an excessive resistance to electrolyte and ion displacements in and out of the positive electrode compartment, which are necessary for a normal operation of the cells.

2. Low concentration KOH solutions, improve considerably the charge acceptance of the cells, and therefore, their cycling life. This improvement is due to the low viscosity of such solutions, which eliminates or minimizes the irrigation difficulties mentioned in paragraph 1.

   However, low concentration KOH seriously attacks the separator system of the cells and, at the same time, accelerates the attack of the silver on the separators. Both actions take place mainly as a function of wet life and temperature, rather that cycling life. For that reason, cells tested for cycling life immediately or within a short period of time after activation, at room temperature or below, will not suffer the effects of the low concentration solutions, but those effects will be predominant after long periods of storage in the activated condition.

3. The use of highly absorbent interseparator materials, wrapping the positive electrodes or both the positives and negatives, by keeping a permanent supply of electrolyte in the elctrode areas, ensures an efficient cell irrigation even at high rates of charge and discharge.

   Thus, this approach brings the same advantages as the low concentration KOH, without its drawbacks.

   One of these absorbent materials, the P-5 (highly calendered, non-woven polyamide fiber sheets) was used in the final design of the HR-12(S) cell, both as a positive and negative interseparator.

4. When the problem of poor charge acceptance was eliminated, the shape change of the negative electrodes became the limiting factor for the cycle life of the cell. This problem which is the main drawback of the silver-zinc system, is object of a continuous effort directed to minimize it.

5. One of the most controversial problems in the design of sealed cells, is the amount of electrolyte that should be put into each cell. Electrolyte starved cells (so called because all the electrolyte is absorbed by the cell pack leaving no free electrolyte in the cell case) or cells with low electrolyte level, have the advantage of a higher rate of gas recombination, since the area of the electrodes exposed to contact with gas is

large. For this reason, cells can withstand overcharge for a substantially longer time than electrolyte flooded cells. It should be noted, however, that at high rates of charge (like those used for the HR12(S)), once the oxygen evolution starts, the pressure build-up is very rapid, and even under the best circumstances (electrolyte starved cell, with low density electrodes and a loose cell pack) the rate of recombination is only a small fraction of the rate of gas formation.

Cells with low electrolyte level have the disadvantage of yielding a lower capacity. Since the low capacity is due to inadequate irrigation of the cell pack, a much more serious drawback results: the performance of the cells is not reliable, with large capacity differences from cell to cell and from cycle to cycle. A battery formed with cells on those conditions, in spite of its better overcharge capability, will perform poorly due to cell unbalance, and what is worse, its operation involves the constant risk of failure by bursting of one or more cells.

Electrolyte flooded cells (so called because the free electrolyte in the cell case completely covers the cell pack) or cells with a high level of electrolyte have low overcharge capability, but a very good silver utilization and uniform capacity. (cf table 5, showing the initial performance of the cells shipped to NASA).

We have supplied to NASA under this contract cells with two levels of electrolyte, a: level to full electrode height, and b: level to half electrode height.

It is possible that in the future, cells might be built which can operate efficiently in the electrolyte starved condition; as a matter of fact, our Research Department is actively engaged in investigations to develop such a cell, but in the meanwhile, the opposite approach is to be preferred, relying on a relatively low voltage cut-off and especially on a very uniform cell to cell performance, to avoid excessive pressure build-up on charge. On the other hand, the probability of generating gas on discharge due to the reversal of a cell, is very remote in a ten cell battery.

6. The performance of cells of the various preliminary designs and cells of the final design, has been discussed and documented in the sections dealing with each particular design. A summary of all designs and their performance on the 3 hour cycling period may be found in table 10.

7. As mentioned in the abstract of this report, the HR12(S)-1 cell is not expected to meet all the NASA requirements. Some suggestions to optimise its performance are listed below.

   a) Storage: for maximum wet life, cells should be stored at room temperature, or better, at low temperature. High temperatures are definitely harmful.

b) Cycling: the NASA specifications requires a maximum depth of discharge of 50% of nominal capacity. Although we have run all out tests at the 50% regime, data available* in other types, of sealed silver zinc cells, at various temperatures, indicates that the cycling life is increased by an average of 95% if the depth of discharge is reduced to 37.5%. A further reduction to 25% allows a 320% increase in the number of cycles.

c) Cycling temperature: the best performance is obtained at room temperature or higher. Although the cell is operable at low temperatures, its cycling life is seriously affected.

*Testing of Yardney Sealed Silver Zinc cells (25AH) by Inland Testing Corp. (Contr.: AF33(657)-8450)

BY_____DATE_____ SUBJECT_____ SHEET NO._____OF_____

CHKD. BY_____DATE_____ _____ JOB NO._____

_____ _____ _____

TABLE 1

CELLS 1 TO 6 : PERFORMANCE IN DEEP CYCLES

CELL No →	1	2	3	4	5	6
CYCLE No ↓	AMPERE-HR OUTPUT ↓					
F-1	13.0	12.6	12.6	13.5	13.0	14.0
F-2	18.3	17.0	16.5	17.0	14.2	16.0
F-3	19.5	17.9	20.2	17.7	17.7	17.3
1	19.4	15.3	21.0	18.3	19.6	19.1
2	16.5	11.2	13.3	12.5	15.0	10.0
3	18.3	15.9	20.0	13.3	11.2	12.3
4	20.2	15.2	21.0	16.7	14.3	14.8
5	17.9	14.2	14.6	13.2	17.3	15.4
6	11.5	12.2	15.0	13.8	11.3	12.7
7	15.9	*	14.2	16.7	17.5	14.3
8	17.0		14.9	15.9	15.0	15.9
9	12.7		12.9	11.8	12.1	13.0

* CELL DEVELOPED HIGH RESISTANCE DUE TO AN ACCIDENTAL OVERCHARGE AND WAS LEFT ON STAND.

CYCLING REGIME

CHARGE : 1.5 AMP TO 2.00 V (2.05 ON FORMATION CYCLES)

DISCHARGE : 1C AMP TO 1.00 V

BY_____ DATE_____ SUBJECT_____ SHEET NO._____ OF_____

CHKD. BY_____ DATE_____ JOB NO._____

TABLE 3

CELLS 15 TO 20 : PERFORMANCE IN DEEP CYCLES

CELL No →			15	16	17	18	20
CYCLE No.	RATE OF CHARGE	RATE OF DISCHARGE	AMPERE-HOURS OUTPUT				
F-1	12 Amp	3 Amp	16.1	17.2	13.0	18.0	17.1
F-2	12	6	17.0	14.0	18.5	18.5	17.5
1	12	6	16.0	8.8	17.9	19.0	13.0
2	24	6	11.9	[illegible]	13.0	19.0	11.0
3	24	12	11.2	14.1	11.6	16.1	[illegible]
4	24	12	10.1	14.[illegible]	14.2	16.1	15.2
5	24	12	11.3	15.8	14.0	17.8	17.1
6	24	12	9.8	15.9	15.2	17.2	17.2

NOTE : CELL 19 SHORTED DURING THE FIRST FORMATION CYCLE, DUE TO A MECHANICAL FAILURE

BY_____DATE_____ SUBJECT_____ SHEET NO._____OF_____

CHKD. BY_____DATE_____ JOB NO._____

TABLE 2

CELLS 7 TO 14 : PERFORMANCE IN DEEP CYCLES

CELL No →			7	8	9	10	11	12	13	14
CYCLE No	RATE OF CHARGE	RATE OF DISCHARGE	AMPERE-HOURS OUTPUT							
F-1	12 Amp	10 Amp	16.7	16.5	12.0	11.3	11.2	11.7	16.5	16.7
F-2	12	10	19.5	19.9	13.5	15.1	13.5	12.1	16.1	17.3
1	12	5	14.1	18.5	14.6	16.3	15.5	15.6	14.1	12.6
2	12	5	16.5	18.6	14.0	11.5	10.6	9.6	14.2	17.0
3	3	6	10.0	10.3	–	–	–	–	10.4	10.3
4	3	6	11.5	10.3	–	–	–	–	11.4	12.6
5	3	6	17.0	16.5	12.0	17.5	10.5	12.0	17.5	17.5
6	1.5	6	10.7	10.4	10.0	10.2	9.7	9.0	16.5	16.6
7	1.5	6	17.5	16.0	9.0	11.5	9.5	9.0	15.5	15.0
8	2.4	6	14.0	15.4	5.3	10.2	7.1	4.7	13.9	14.3
9	3	6	12.1	11.5	9.0	9.0	10.5	–	11.5	12.0
10	3	6	11.5	13.7	–	–	–	–	12.5	13.5

NOTE. CELLS 9 TO 12 WERE GIVEN A THIRD FORMATION CYCLE AT THE SAME RATES AS F-1 AND F-2. OUTPUTS WERE AS FOLLOWS:

CELL No	:	9	10	11	12
AMPERE-HOUR OUTPUT	:	9.1	12.6	11.1	13.3

BY_____DATE_____ SUBJECT_____ SHEET NO_____OF_____

CHKD. BY_____DATE_____ _____ JOB NO._____

_____ _____ _____

TABLE 4

CELLS 21 TO 26 : PERFORMANCE IN DEEP CYCLES

CELL NO ⟶			21	22	23	24	25	26
CYCLE No	RATE OF CHARGE	RATE OF DISCHARGE	AMPERE HOURS OUTPUT					
F-1	1.2 Amp	5 Amp	21.2	21.6	20.1	20.1	20.3	19.7
F-2	1.2	6	21.6	20.5	21.3	20.1	20.1	19.9
1	2.4	12	18.6	18.6	16.2	17.0	18.0	18.0
2	2.4	12	21.1	19.6	16.0	*	19.1	17.3
3	2.4	12	21.2	19.3	16.5	20.2	20.2	19.6

* Cell was drilled (to relieve high pressure due to an accidental reversal) and repotted.

TABLE [redacted]

HR 12(S)-1

	CYCLE 2		CYCLE 3			CYCLE 2		CYCLE 3	
CELL NO.	INPUT (Ah)	OUTPUT (Ah)	INPUT (Ah)	OUTPUT (Ah)	CELL NO.	INPUT (Ah)	OUTPUT (Ah)	INPUT (Ah)	OUTPUT (Ah)
2	24.4	22.5	22.0	21.6	23	24.6	21.8	22.3	22.0
3	24.4	22.8	22.4	21.8	24	24.4	20.6	21.8	21.6
4	25.2	23.0	22.6	22.6	25	24.5	21.3	22.2	21.8
5	24.4	22.6	22.3	21.8	26	25.0	20.0	21.1	20.6
6	24.7	22.8	22.1	21.4	27	24.3	21.0	22.2	21.6
7	24.2	23.0	22.5	21.8	28	24.5	21.8	22.1	21.2
8	24.5	22.8	22.5	21.9	29	24.2	20.8	22.5	21.9
9	24.3	22.1	21.9	21.4	30	24.4	21.0	21.8	21.0
10	24.3	20.5	21.2	20.6	31	24.6	21.1	22.0	21.2
11	24.5	21.3	23.0	22.4	32	24.5	21.6	22.5	21.9
12	24.2	20.6	21.7	21.0	33	24.3	20.3	22.5	22.2
13	24.8	21.5	21.7	21.0	34	24.4	21.7	21.8	21.4
14	24.7	21.3	21.9	21.2	35	24.4	22.5	23.0	22.5
15	24.6	21.1	21.9	21.4	36	24.5	22.5	23.0	22.2
16	24.9	21.0	22.3	21.9	37	24.5	22.5	23.1	22.5
17	25.2	21.6	23.2	22.6	38	24.5	21.2	22.6	22.0
18	25.0	20.3	21.2	20.7	39	24.0	21.7	22.8	22.0
19	24.9	21.8	21.8	21.2	40	24.5	22.0	22.8	22.2
20	24.3	22.5	22.7	22.5	41	24.5	21.7	23.1	22.6
21	24.9	19.8	21.8	21.2	42	23.5	19.5	21.1	20.7
22	24.9	21.5	22.3	22.0	43	23.3	21.0	21.6	21.2

NOTE:

	CHARGE	DISCHARGE
CYCLE 2	1.2A to 2.05 V	10A to 1.10 V
CYCLE 3	24A to 1.99 V	12A to 1.30 V

BY _____ DATE _____ SUBJECT _____ SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____ JOB NO. _____

BY_____DATE_____ SUBJECT_____ SHEET NO_____OF_____

CHKD. BY_____DATE_____ _____ JOB NO._____

_____ _____ _____

TABLE 6

40 12(A)-1 CELLS PERFORMANCE IN CYCLE 5

CELL No	AMPERE HOURS OUTPUT	CELL No	AMPERE-HOURS OUTPUT
2	132	22	191
4	174	23	212
6	195	25	205
9	190	31	192
11	172	35	201
14	170	36	213
15	214	37	193
17	213	38	213
19	218	39	205
20	196	40	210
21	195	41	206

NOTE : CHARGE : 24 Amps to 1.90 V

DISCHARGE 12 Amps to 1.30 V

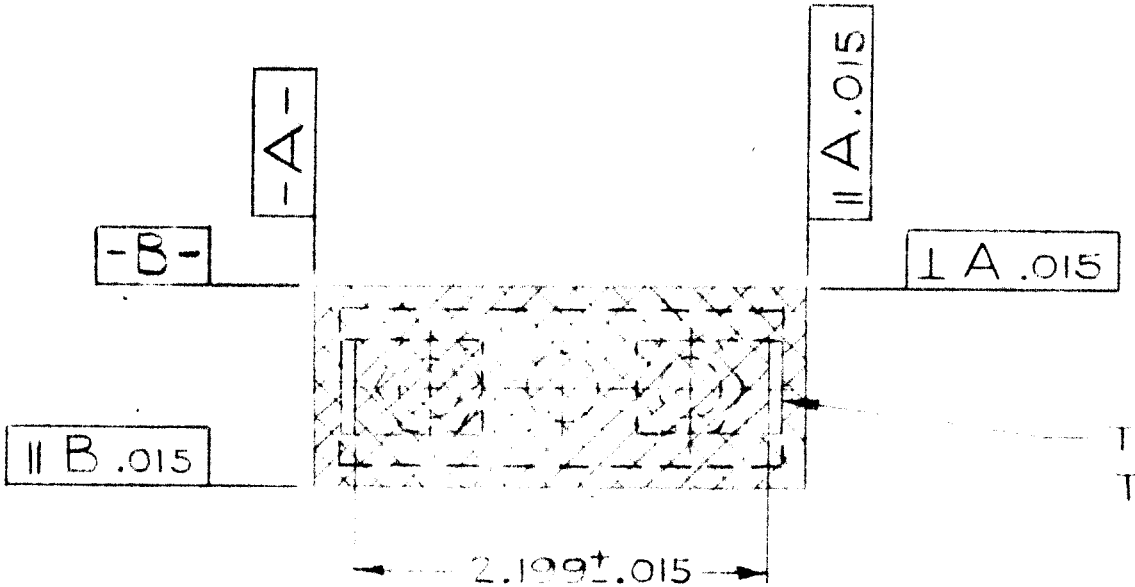
BY_____ DATE_____ SUBJECT_____ SHEET NO_____ OF_____

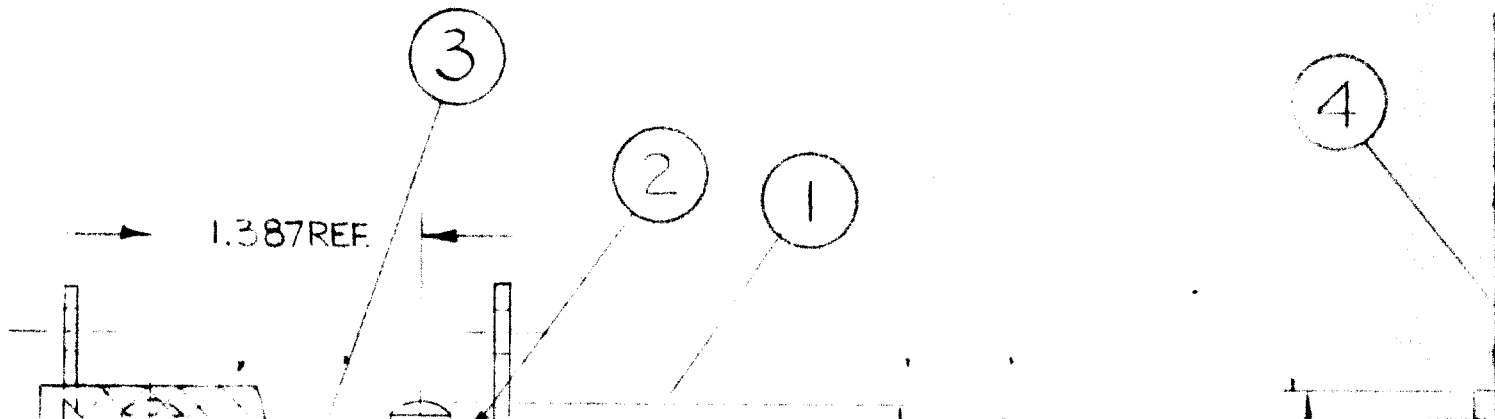
CHKD. BY_____ DATE_____ JOB NO_____

TABLE 7

CONSTANT POTENTIAL CHARGE AT 77°F (1.97 V/cell)

TIME	Cell No 21		Cell No 25		Cell No 26		TIME	Cell No 27		Cell No 28		Cell No 29	
	VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)		VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)
20 SEC	197	9	198	12	196	10	8 DAYS	197	7.5	196	10.5	197	9
30 MIN	197	9	199	13	203	17	9 "	196	7	197	10.5	197	9
1 HOUR	196	9	200	14	202	14	10 "	196	7	197	10	197	8
2 HOURS	197	9	200	22	202	16	12 "	196	7	197	9.5	197	8
4 "	196	8.5	200	24	202	20	14 "	196	7	197	9.5	196	7.5
6 "	199	8	200	22.5	200	12	16 "	197	7	197	9	196	7.5
24 "	196	10.5	197	14	197	13	18 "	196	7	196	8.5	196	7
2 DAYS	196	10	197	13	196	12	20 "	197	6.5	197	8.5	197	7
3 "	197	9.5	196	12.5	197	11	22 "	196	6.5	197	8	197	6.5
4 "	197	9	197	12	196	11	24 "	197	6	197	8	196	6.5
5 "	196	9	197	11.5	197	10.5	26 "	197	6	197	8	197	6
6 "	196	8.5	197	11.5	196	10	28 "	197	5.5	196	7.5	196	6
7 "	196	8	197	11	197	10	30 "	197	5.5	197	7.5	197	5.5



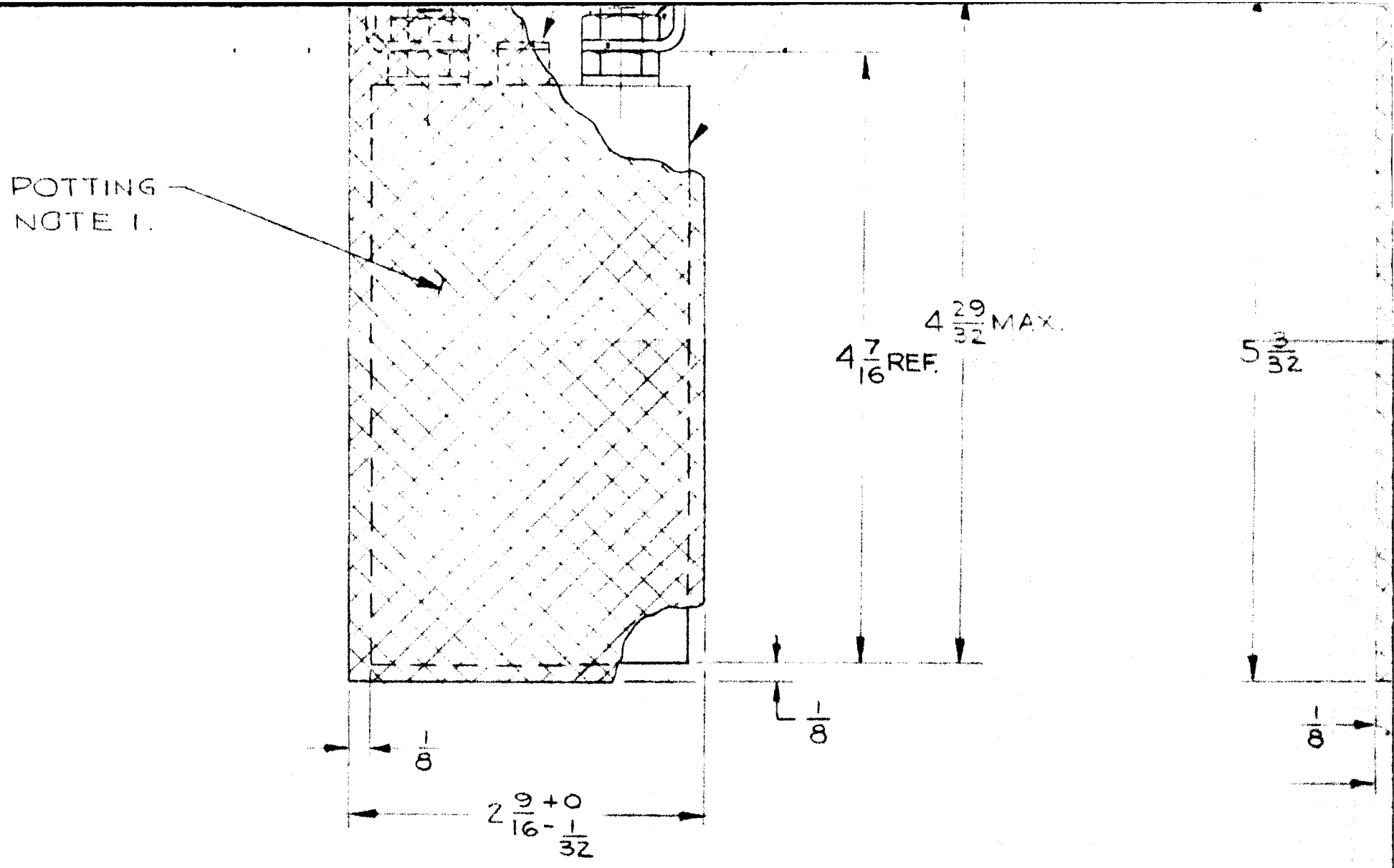


REVISIONS			
SYM	DESCRIPTION	DATE	APPROVAL

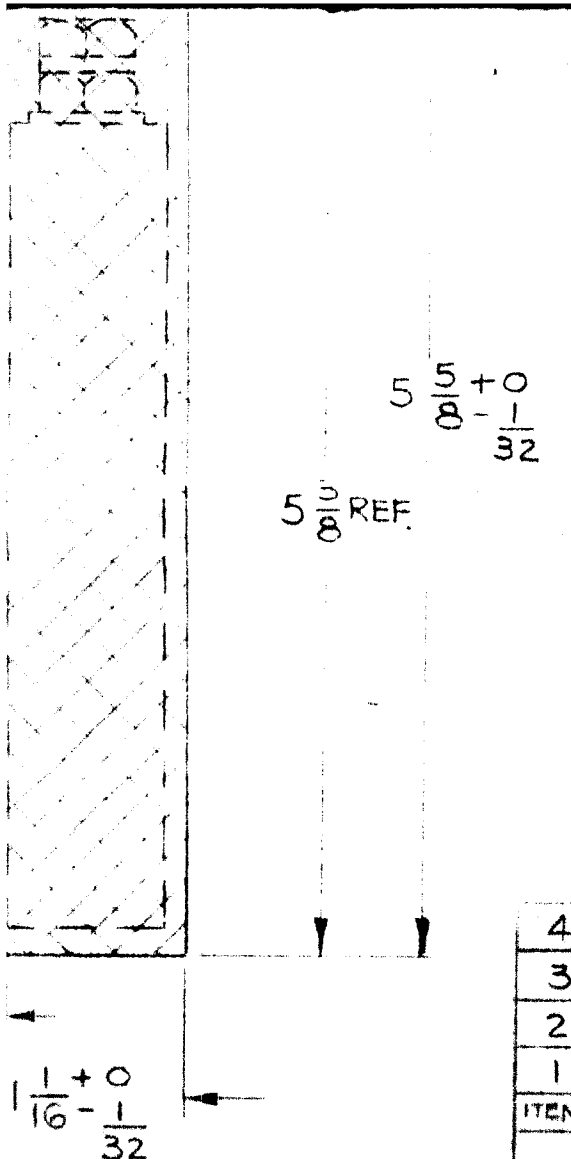
LEL
T.I.R.

NOTES:

1. POTTING PROCEDURE PER YP-331.
2. MFG. STDS PER YP-197.



NEXT ASSY	USED ON	NEXT ASSY	FINAL AS
APPLICATION		QTY REQD	



ITEM	REQD	PART NO.	DESCRIPTION	MATL	MATL SPEC	UNIT WT
4	2	8057	CONNECTOR			
3	1	— — —	DISC, 7/16 DIA. X .050 THK	CYMAC	OR C-11	
2	2	2226-3	NUT, HEX 5/16-24			
1	1	8759	12 AH CELL ASSEMBLY			

LIST OF MATERIAL

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON
FRACTIONS ± 1/64 DECIMALS .X ± .XX ± .XXX ± .005 ANGLES ± 1°/2

MATL

FINISH

DRAWN BY E. ZIEDINS	DATE 5-27-64	
CHECKED BY	DATE	
PROJECT ENGR	DATE	
APPROVED BY	DATE 6/	
QUALITY ASSURANCE DAVID GONZALEZ	6/2/64	

SEALED CELL ASSEMBLY
12 AH

YARDNEY ELECTRIC CORP.
NEW YORK 13, N.Y.

DWG NO. 8760 REV.

SCALE 1/1 WT CALC ACT SHEET OF

BY_____DATE_____ SUBJECT_____ SHEET NO._____OF_____

CHKD. BY_____DATE_____ _____ JOB NO._____

_____ _____ _____

TABLE 8

CONSTANT POTENTIAL CHARGE AT 120°F (1.97 V/cell)

TIME	CELL No 30		CELL No 31		Cell No 32		TIME	CELL No 30		CELL No 31		CELL No 32	
	VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)		VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)
30 SEC	195	7	196	10	195	9	8 DAYS	197	11.5	197	15.5	196	12
30 MIN	[illegible]	8	195	11	195	10	9 "	197	11	197	16	196	11.5
1 HOUR	195	8	196	11	196	10	10 "	196	10.5	198	16	197	11
2 HOURS	195	8	197	11	195	10	12 "	197	10	197	15	196	11
4 "	196	8.5	196	11.5	197	10	14 "	195	10	198	15	197	11
6 "	196	10	195	13	197	11	16 "	196	11	197	15.5	198	11
24 "	197	11.5	196	14	197	12	18 "	197	14	197	17	197	13
2 DAYS	197	12.5	197	15.5	195	12.5	20 "	197	13.5	197	17.5	196	13.5
3 "	196	12.5	195	15.5	196	12.5	22 "	196	12	197	16	198	13
4 "	196	11.5	197	14.5	197	12	24 "	197	11	197	15	197	12
5 "	195	12.5	198	15	197	13	26 "	195	10	198	13.5	197	11
6 "	197	9	196	15	197	12.5	28 "	195	10	197	14	195	11
7 "	196	11.5	196	15.5	196	12	30 "	198	11	196	14.5	197	11.5

BY_____ DATE_____ SUBJECT_____ SHEET NO._____ OF_____

CHKD. BY_____ DATE_____ JOB NO._____

TABLE 9

CONSTANT POTENTIAL CHARGE AT 14°F (1.97 V per cell)

TIME	CELL No 33		CELL No 34		CELL No 35		TIME	CELL No 33		CELL No 34		CELL No 35	
	VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)		VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)	VOLTAGE (VOLTS)	PRESSURE (PSIG)
30 SEC	190	8	2.05	12	1.92	14	8 DAYS	196	16	197	28.5	196	21.5
30 MIN	195	10	199	21	194	16	9 "	197	16.5	197	28.5	196	21.5
1 HOUR	194	10.5	200	24	195	17	10 "	197	16.5	196	28.5	197	21
2 HOURS	196	12	195	25	196	18	12 "	196	16.5	198	28.5	197	20.5
4 "	195	12.5	197	25.5	197	18	14 "	196	16.5	198	28.5	197	20.5
8 "	196	13	196	26	197	18.5	16 "	197	17	197	28	197	19.5
24 "	196	14	196	27	198	19	19 "	196	17	195	28	197	19
2 DAYS	197	14.5	197	27.5	196	20	20 "	197	16.5	197	27.5	196	19.5
3 "	196	15	196	27.5	196	20.5	22 "	196	16.5	196	27.5	198	19.5
4 "	197	15.5	197	28	196	20.5	24 "	197	16	197	27	197	18
5 "	197	15.5	197	28	197	21	26 "	198	15.5	197	26.5	196	17
6 "	196	16	197	28	198	21	29 "	196	15	197	26	197	16.5
7 "	197	16	196	28.5	196	21.5	30 "	197	14.5	196	26	197	16.5

TABLE 10

SUMMARY OF DESIGN CHARACTERISTICS AND PERFORMANCE AT THE 3 HOUR CYCLING PERIOD

DESIGN NO	CELL Nos	PLATE AREA in^2	KOH CONCENTR. %	MASS OF ACTIVE SILVER grams	MASS OF ACTIVE ZINC grams	ZINC TO SILVER RATIO	SEPARATOR SYSTEM (7) FROM POSITIVE TO NEGATIVE ELECTRODES	No OF CYCLES ON THE 3 HR REGIME
1 (1)	1,2,3	5.96	40	60.0	62.6	1.03	1T VN2.5/1T PVA/3T C-19/1PVA bag on neg.	0 (3)
2	4,5,6	5.96	40	60.0	62.3	1.02	1T VN2.5/1T PVA/3T C-19/1PVA bag on neg.	0 (3)
3	7,8	5.96	40	60.5	62.6	1.04	1T VN2.5/5T C-19	55 (4)
4	9,10	5.96	40	55.2	51.3	0.93	1T VN2.5/1T PVA/3T C-19/1PVA bag on neg.	- (5)
5	11,12	5.96	40	55.2	54.3	0.98	1T P-5/1T PVA/3T C-19/1PVA bag on neg.	- (5)
6	13,14	5.96	40	55.2	54.3	0.98	1T VN2.5/5T C-19	52 (4)
7	15,16	6.15	25	62.8	64.7	1.03	1T VN 2.5/5T C-19	Not Tested
8	17,18	6.15	31	62.8	64.7	1.03	1T VN 2.5/3T C-19	155
9	19,20	5.96	25	55.6	54.3	0.97	1T VN 2.5/1T PVA/3T C-19/1PVA bag on neg	Not Tested
10	21,22,23	6.15	40	62.8	60.9	0.97	1T P-5/5T C-19	120
11	24,25,26	6.15	40	57.5	60.9	1.06	1T P-5/4T C-19/1T P-5	182
FINAL	(2)	6.15	40	57.5	54.3	0.95	1T P-5/4T C-19/1T P-5	(6)

1T = 1 layer

NOTES:
(1) Cells of design No 2 have 2.5% HgO in negative electrodes. All other cells contain 2%.
(2) Includes 32 cells shipped to NASA. (HR 12(5)-1 cells).
(3) Tested on a 100 minutes cycling period.
(4) Cell charged for 120 min. and discharged for 60 min.
(5) Preliminary tests did not justify further testing
(6) A 5 cell battery is presently tested at YEC. 100 cycles to date.
(7) See body of report for separator symbols.

GENERAL CHARACTERISTICS

Number of plates: 6 posit., 7 neg. ff.
Cell dimensions: see dwg No 8760 (fig 25)
Cell overall volume 15.3 cu.in.

BY_____ DATE_____ SUBJECT_____
CHKD. BY_____ DATE_____
SHEET NO_____ OF_____
JOB NO_____

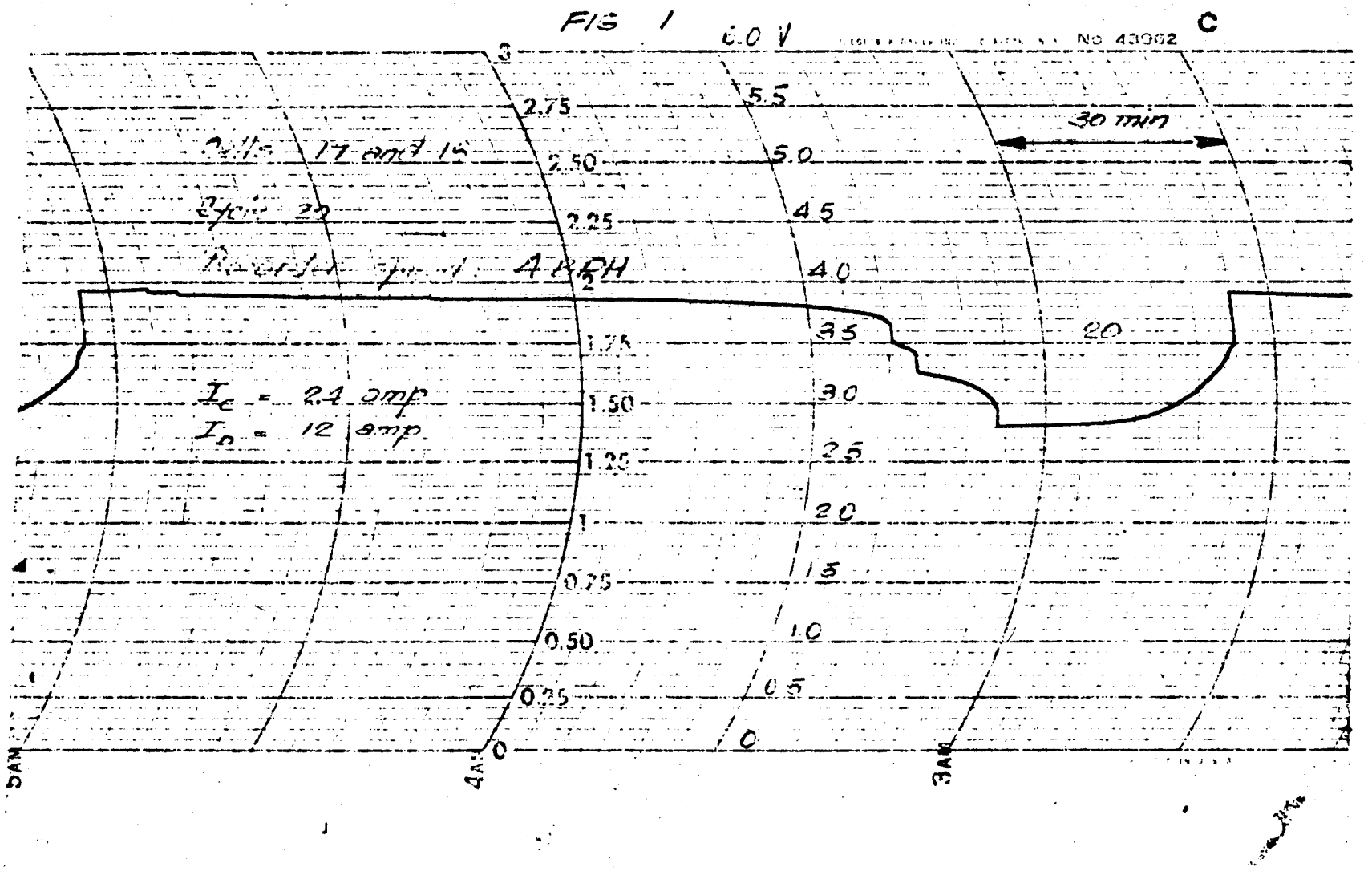


FIG 1
C.O V
No 43062
C
30 min
Cells 17 and 15
Cycle 23
Record No. 1 4 APH
I_c = 24 amp
I_d = 12 amp
3
2.75
2.50
2.25
1.75
1.50
1.25
1
0.75
0.50
0.25
0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
20

FIG 2

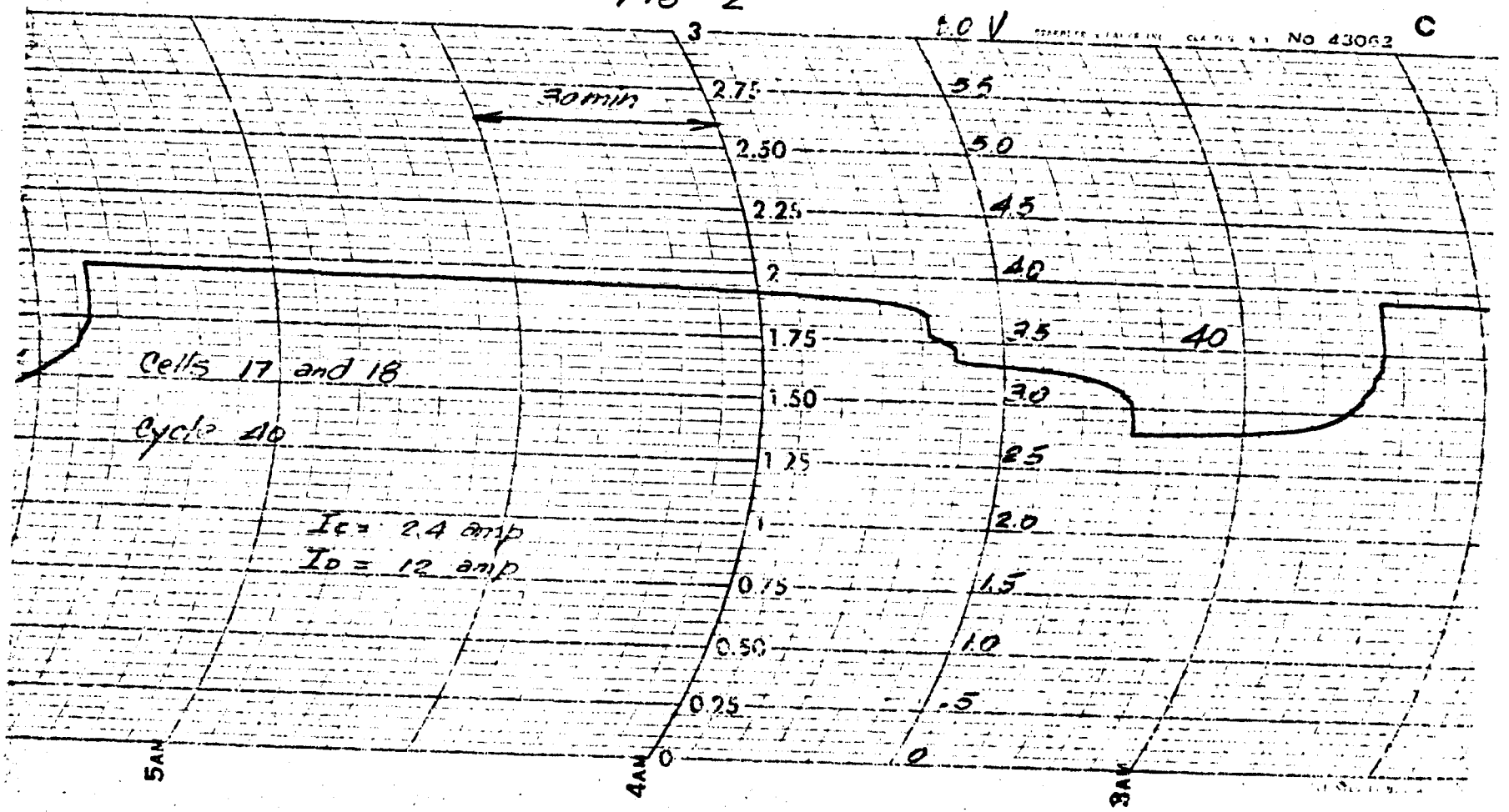
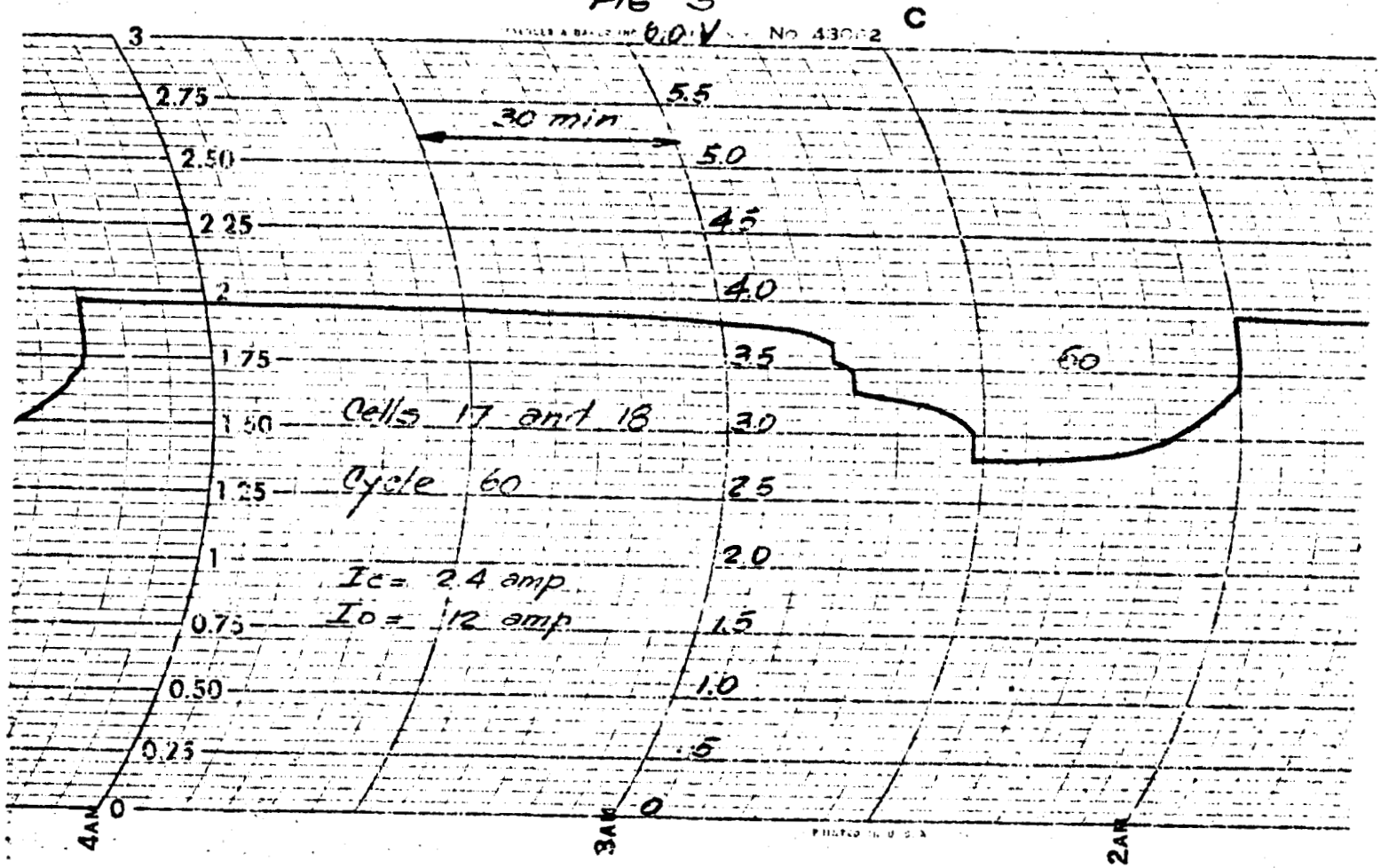
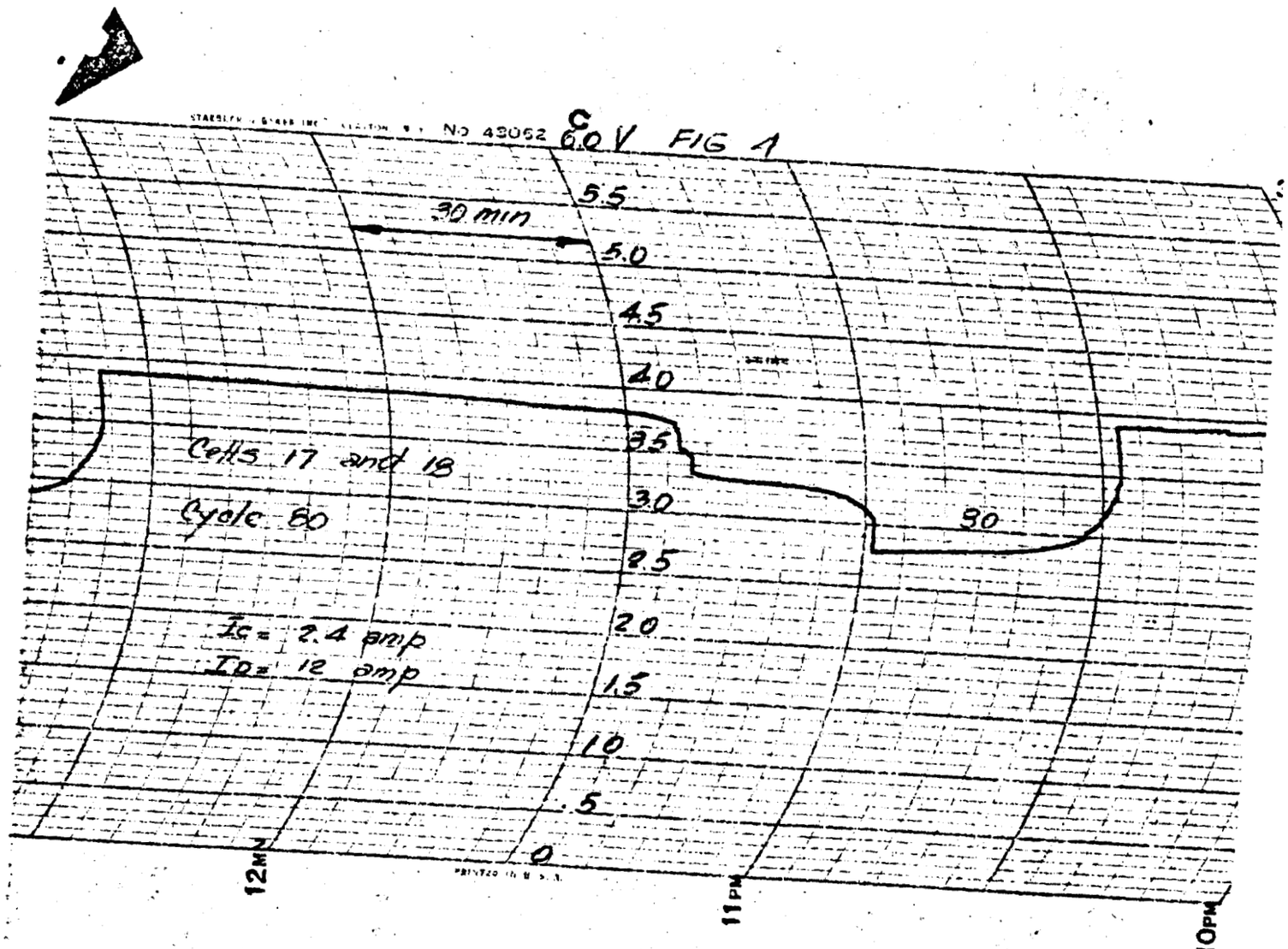
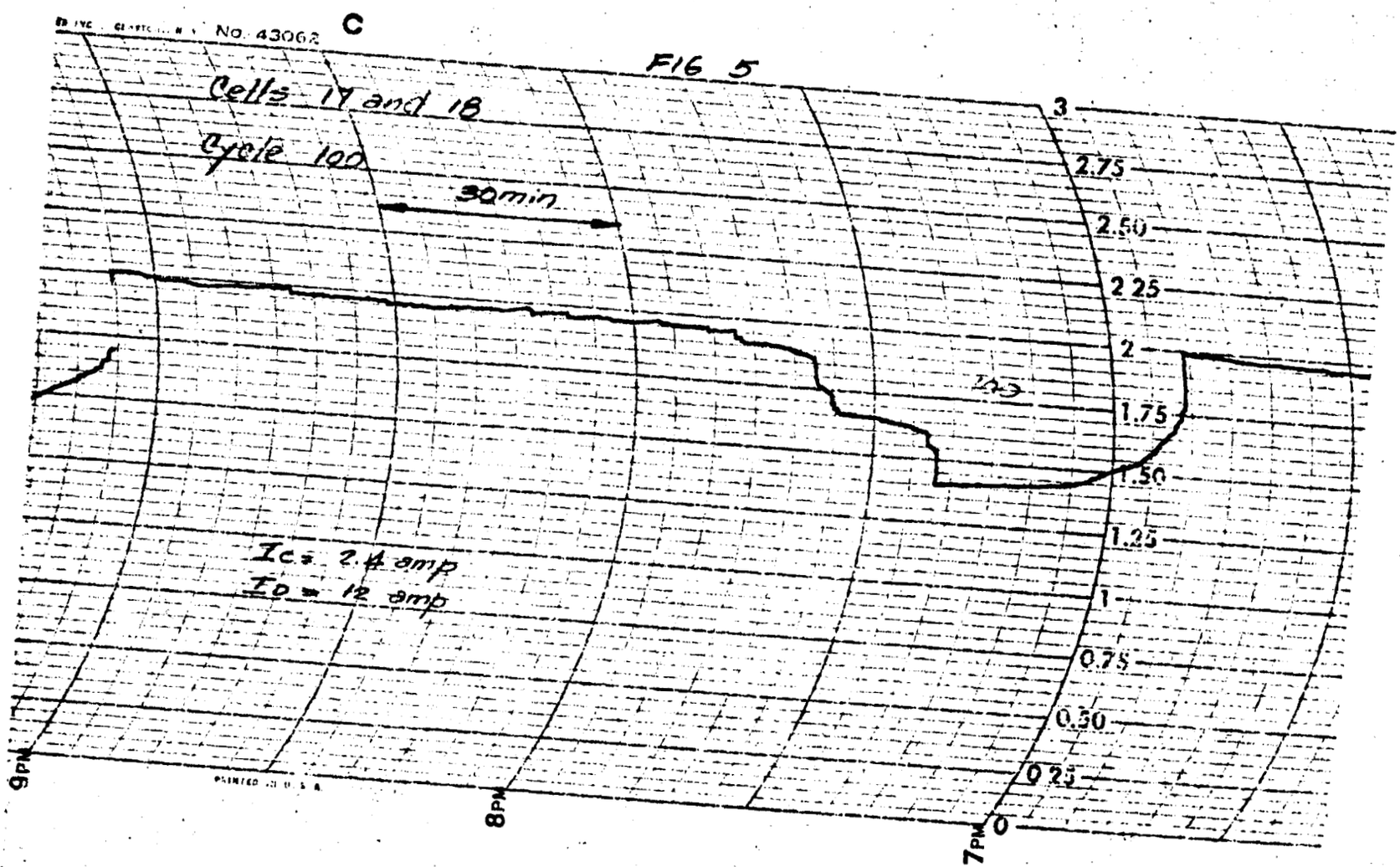

3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
5AM
4AM
3AM
30min
Cells 17 and 18
Cycle 40
I_C = 2.4 amp
I_D = 12 amp
C
No 43062
V
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
40

FIG 3


C
3
2.75
2.50
2 25
2
1 75
1 50
1 25
1
0.75
0.50
0.25
0
4AR
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
3AR
2AR
30 min
60
Cells 17 and 18
Cycle 60
Ic = 2.4 amp
Io = 12 amp


No 43062
6.0 V FIG 1
30 min
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
Cells 17 and 18
Cycle 60
Ic = 2.4 amp
Id = 12 amp
90
12M
11PM
10PM


No. 43062
C
FIG 5
Cells 17 and 18
Cycle 100
30 min
Ic = 2.4 amp
Id = 12 amp
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
9PM
8PM
7PM

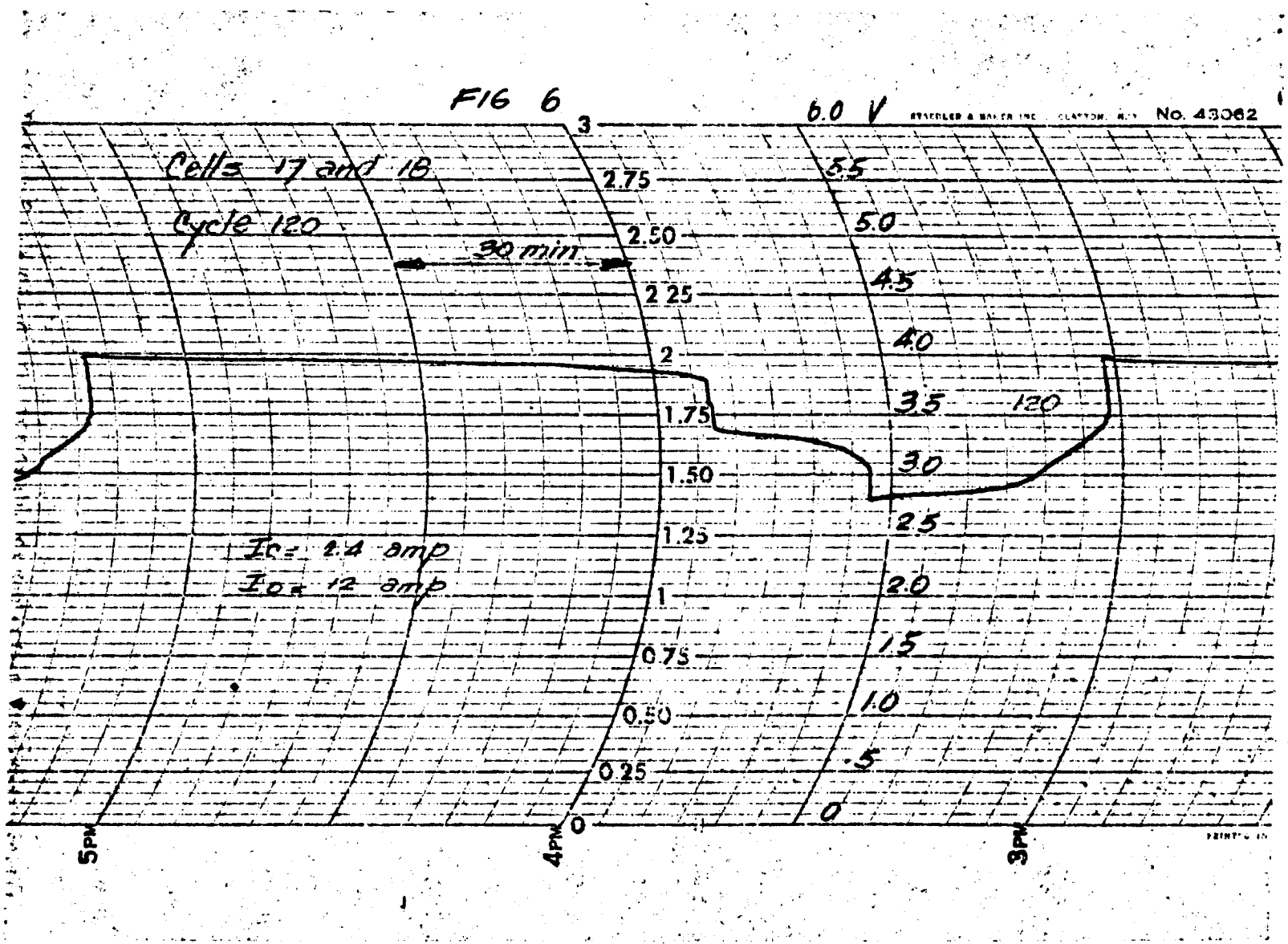


FIG 6
6.0 V
No. 43062
Cell= 17 and 18
Cycle 120
30 min
Ic= 1.4 amp
Io= 12 amp
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
5.5
5.0
4.5
4.0
3.5
120
3.0
2.5
2.0
1.5
1.0
.5
0
5PM
4PM
3PM

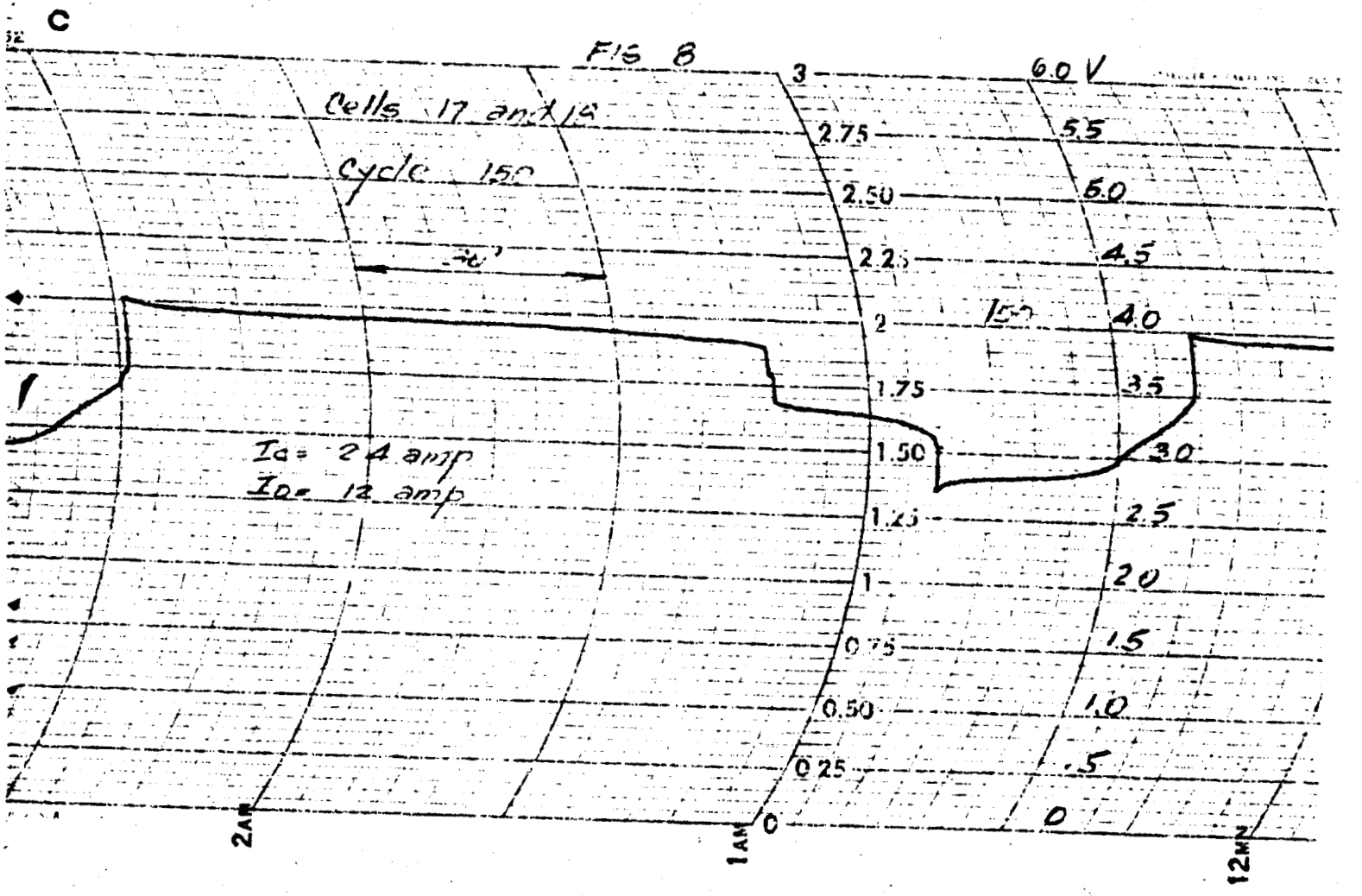

C
FIG 8
Cells 17 and 18
Cycle 150
Ic = 24 amp
Id = 12 amp
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
6.0 V
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
2AM
1AM
12MN

FIG 9

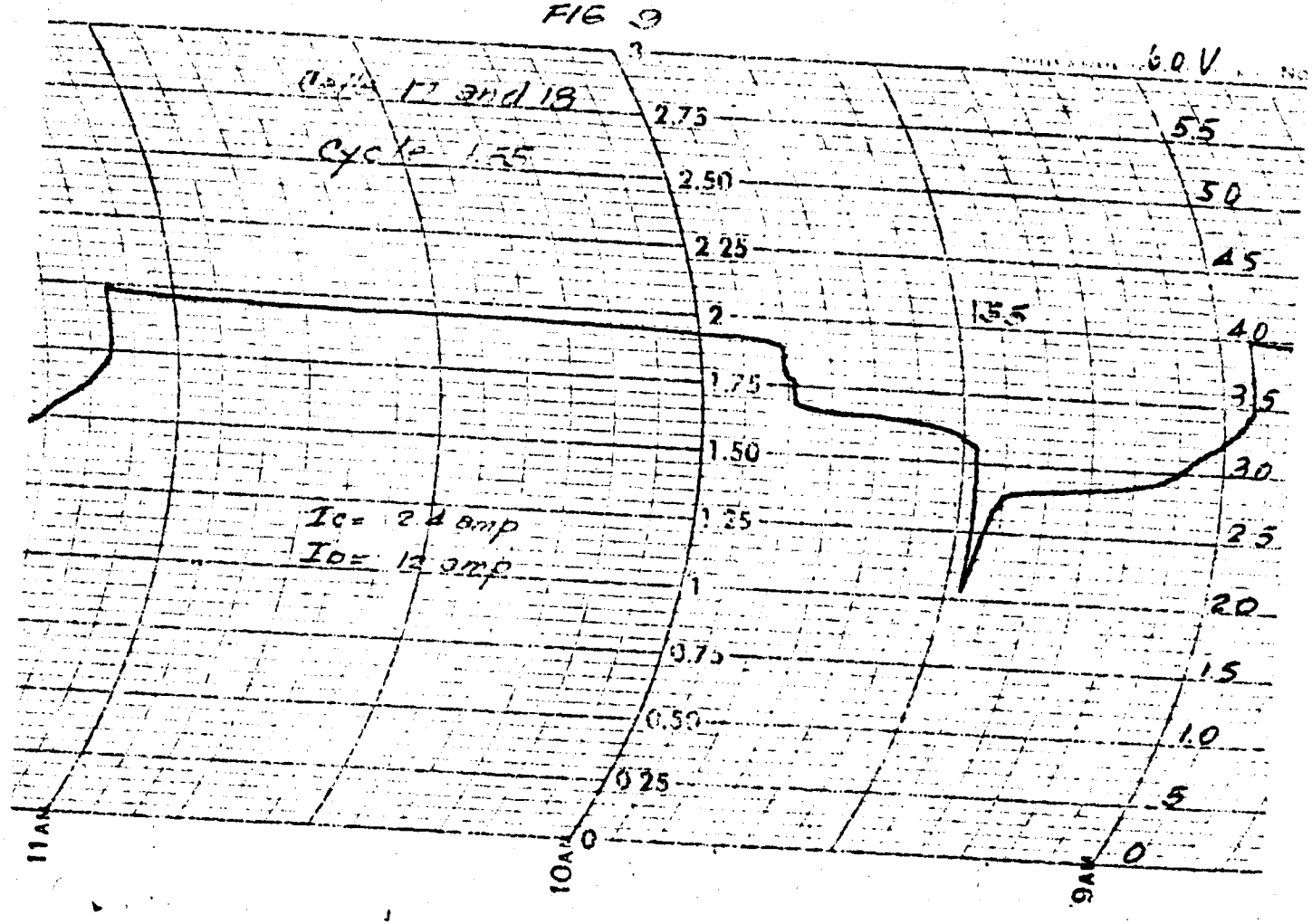
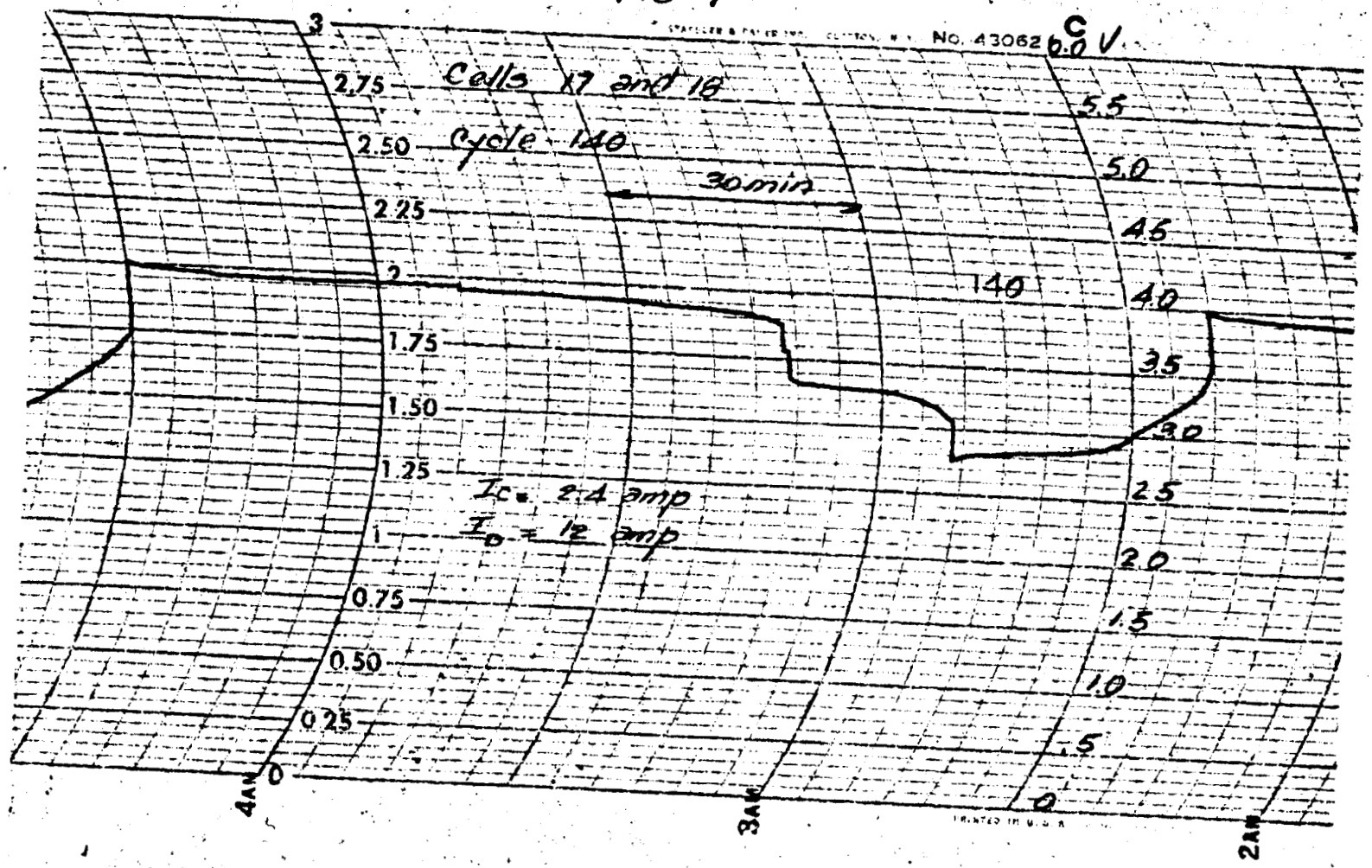
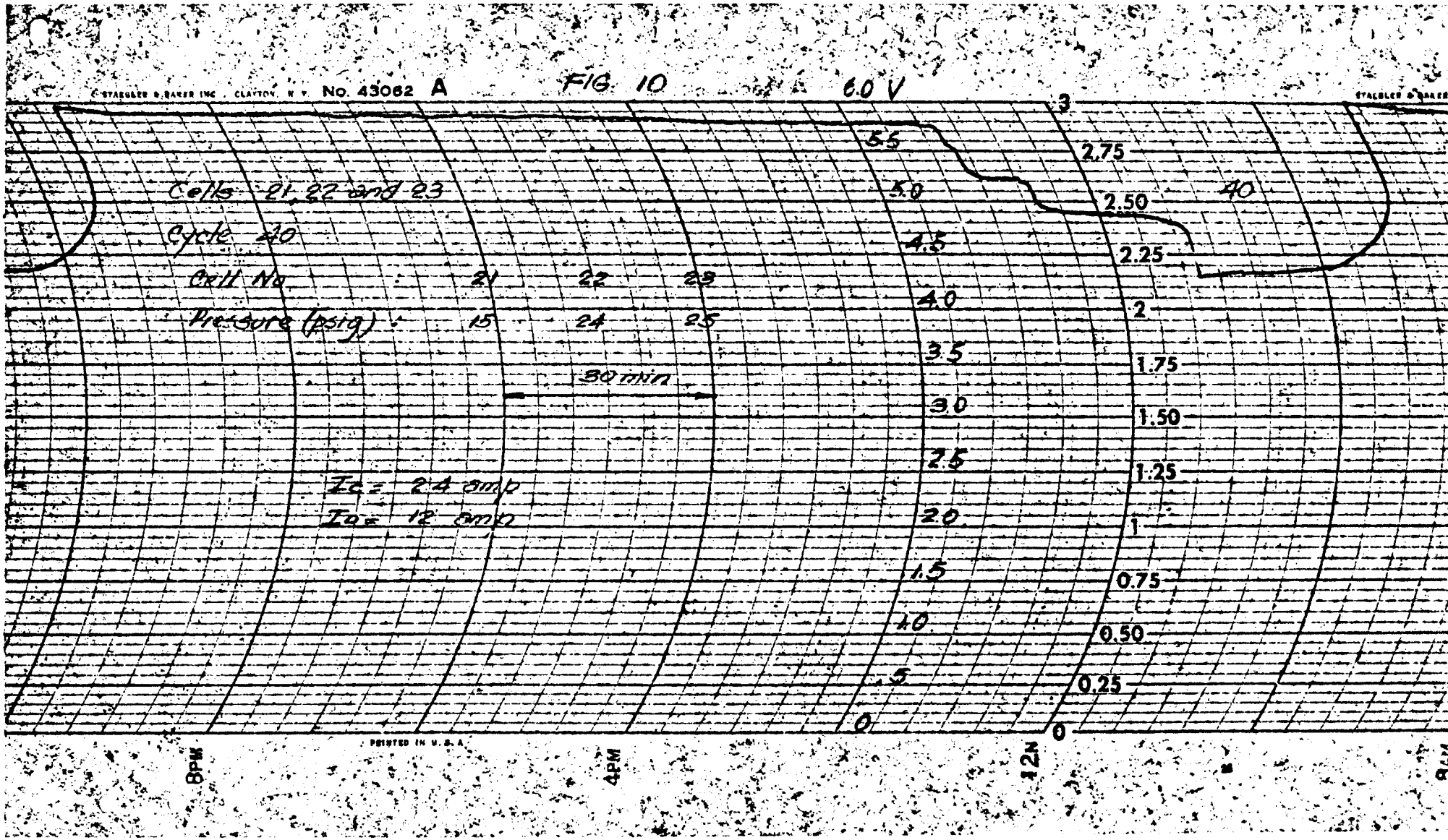

Cells 17 and 18
Cycle 155
Ic= 24 amp
Io= 12 amp
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
11 Amps
10 Amps
9 Amps
6.0 V
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
13.5

FIG 7


No. 43062
C
0.0 V
Cells 17 and 18
Cycle 140
30 min
140
I_c = 2.4 amp
I_D = 12 amp
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
4AM
3AM
2AM


STAEBLER & BAKER INC. CLAYTON, N.Y. No. 43062 A
FIG. 10
6.0 V
Cells 21, 22 and 23
Cycle 40
Cell No. : 21 22 23
Pressure (psig) : 15 24 25
30 min
Ic = 24 amp
Ia = 12 amp
55
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
40
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8PM
4PM
12N

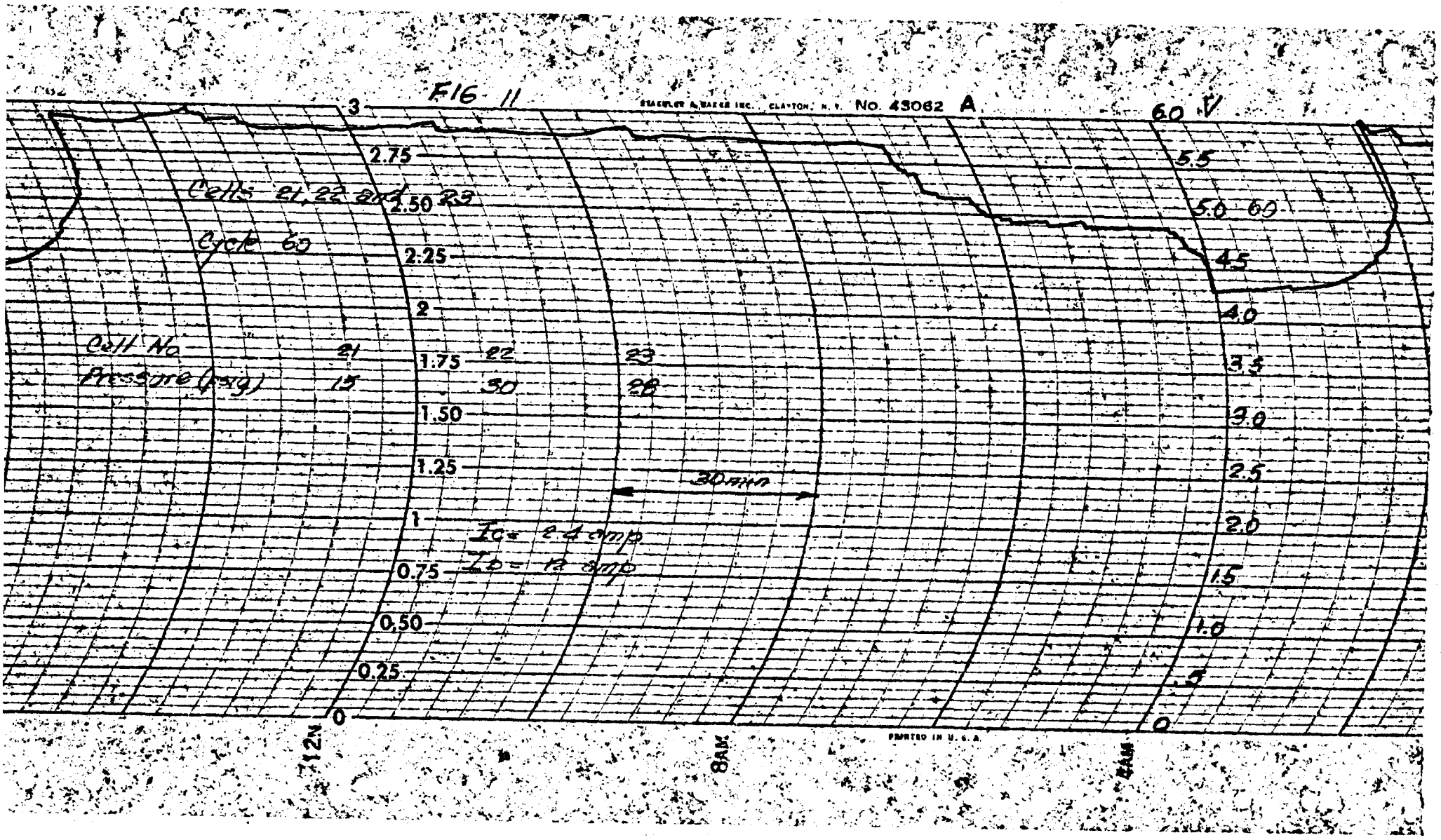
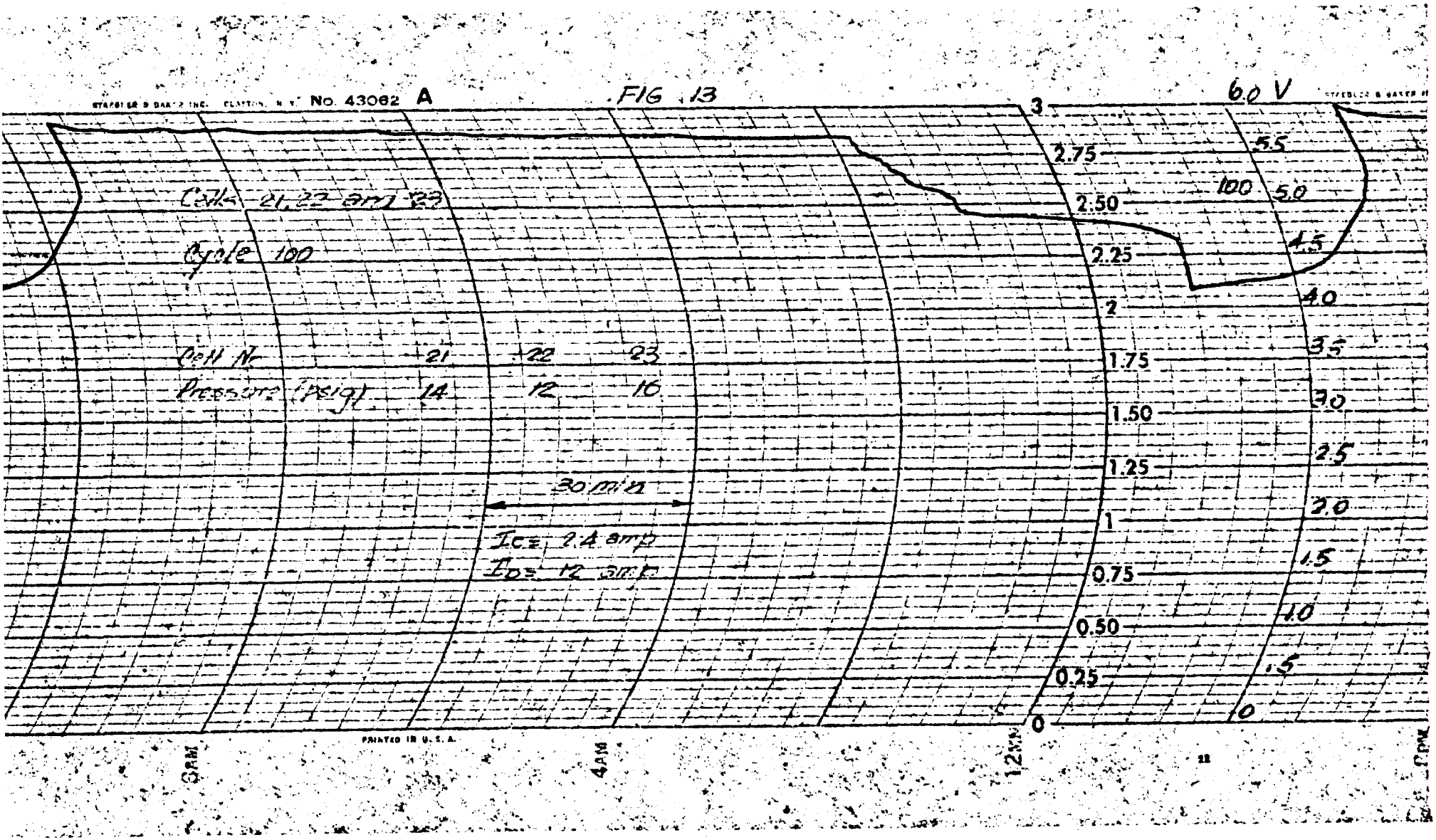
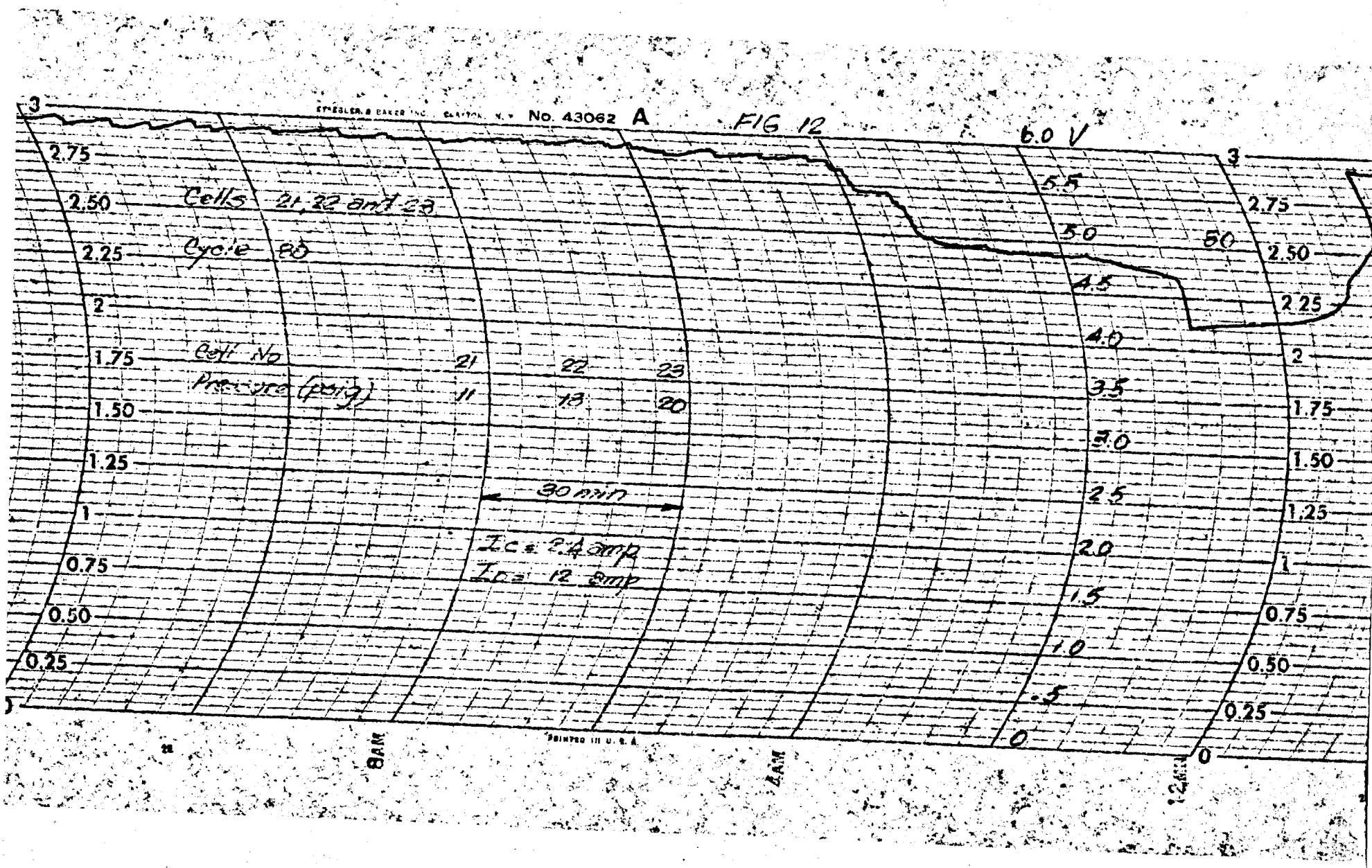


FIG 11
STACEY-BATES INC. CLAYTON, N.Y. No. 45062 A
Cells 21, 22 and 23
Cycle 60
Cell No
Pressure (psig)
21
15
22
30
23
28
30 min
Ic = 2.4 amp
Ib = 12 amp
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
V
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
12N
8AM
4AM
PRINTED IN U.S.A.


No. 43062 A
FIG 13
6.0 V
Cells 21, 22 and 23
Cycle 100
Cell No.
21
22
23
Pressure (psig)
14
12
16
30 min
Ic = 2.4 amp
Id = 12 amp
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
3.0
1.5
1.0
.5
0
100
6AM
4AM
12NN


No. 43062 A
FIG 12
6.0 V
Cells 21, 22 and 23
Cycle 80
Cell No
Pressure (psig)
21
22
23
11
18
20
30 min
Ic = 2.4 amp
Ic = 12 amp
8 AM
2 AM
2 PM

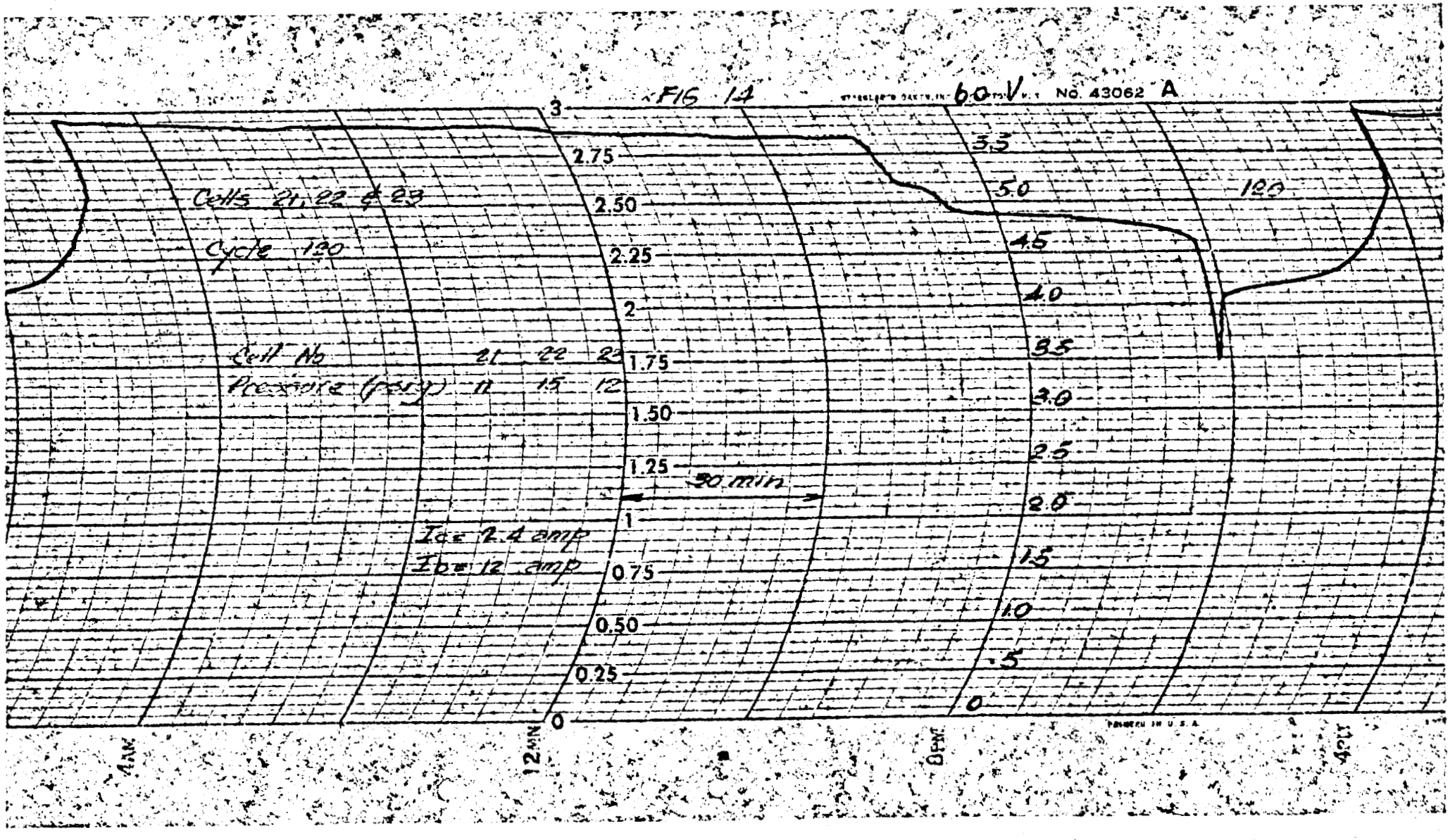
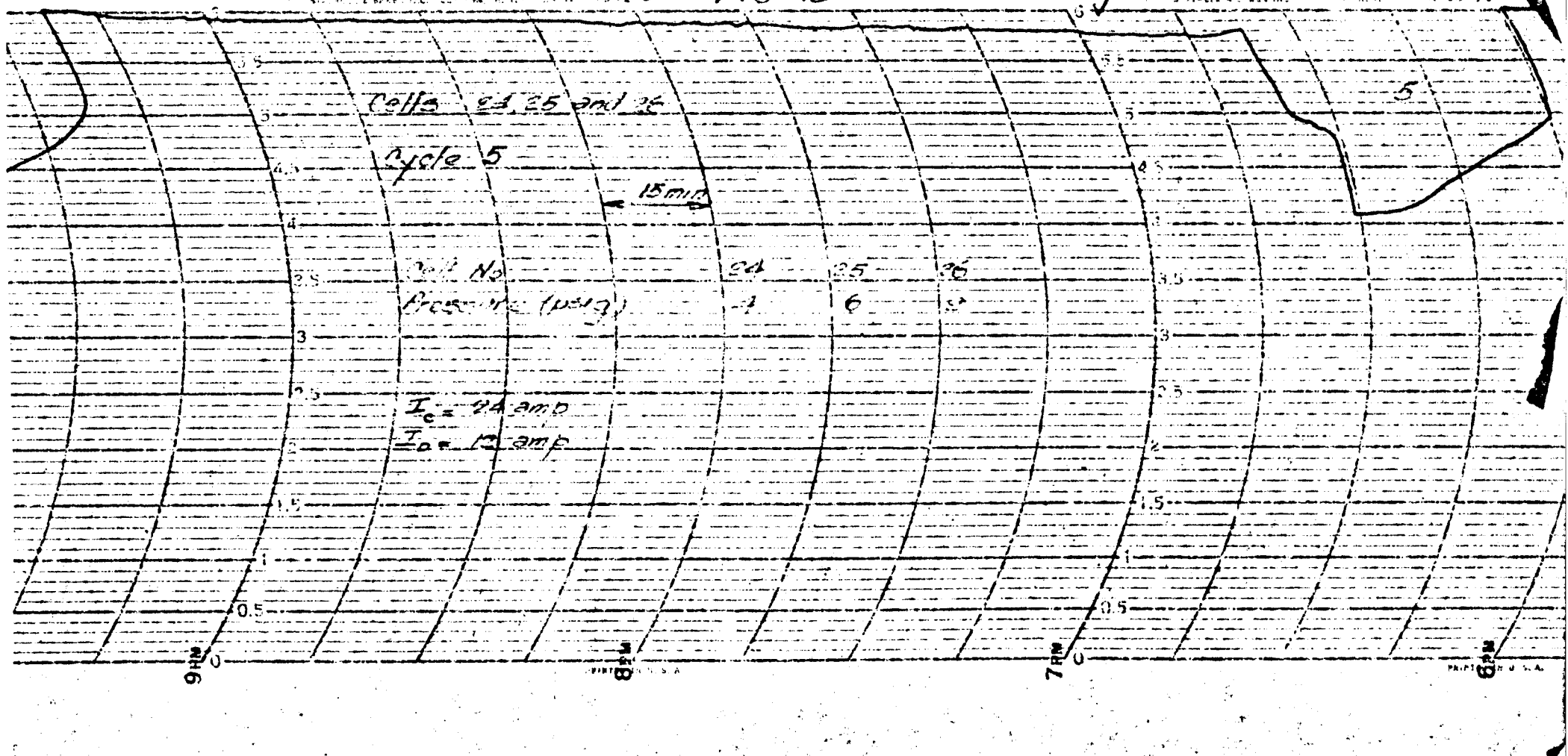
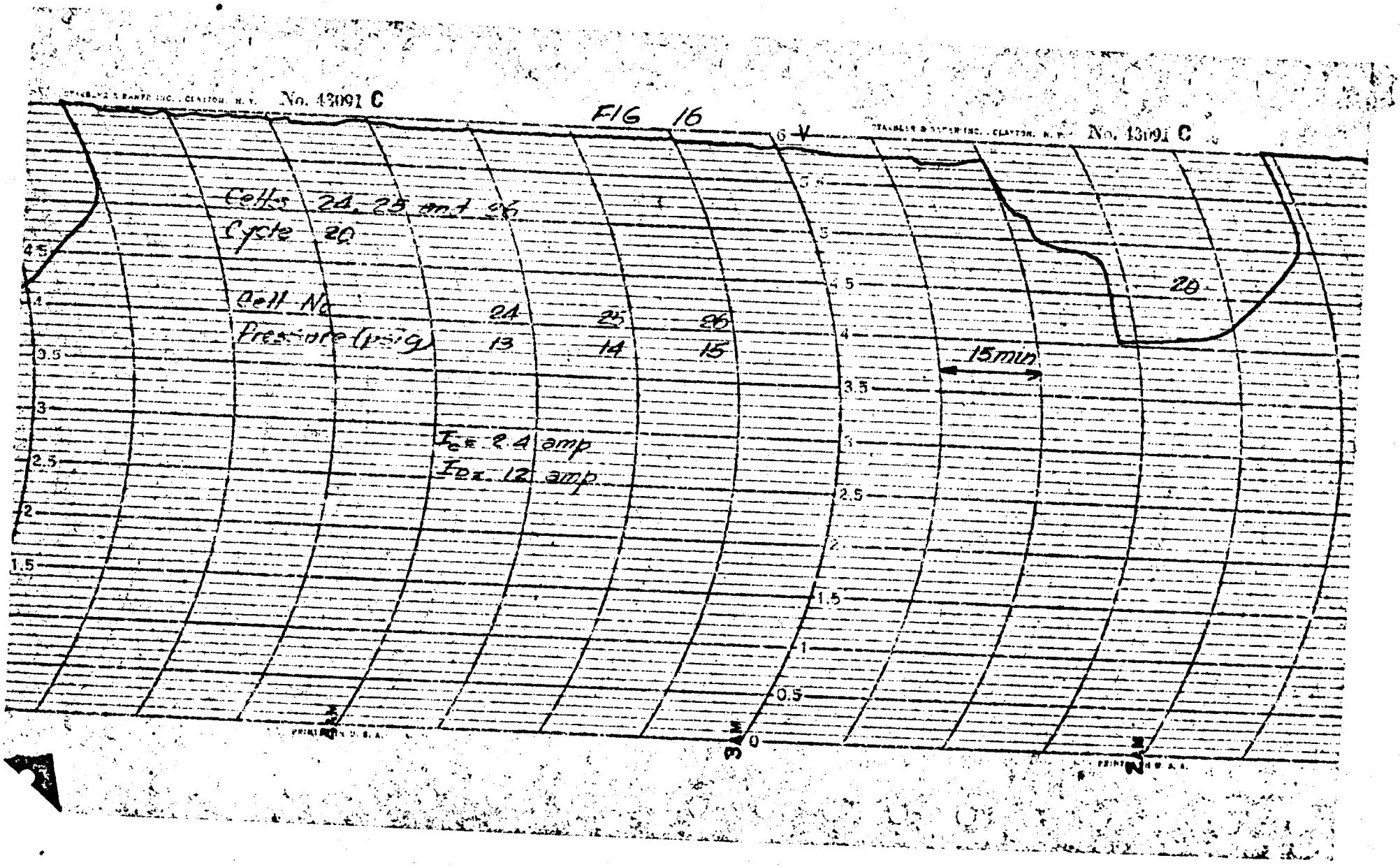
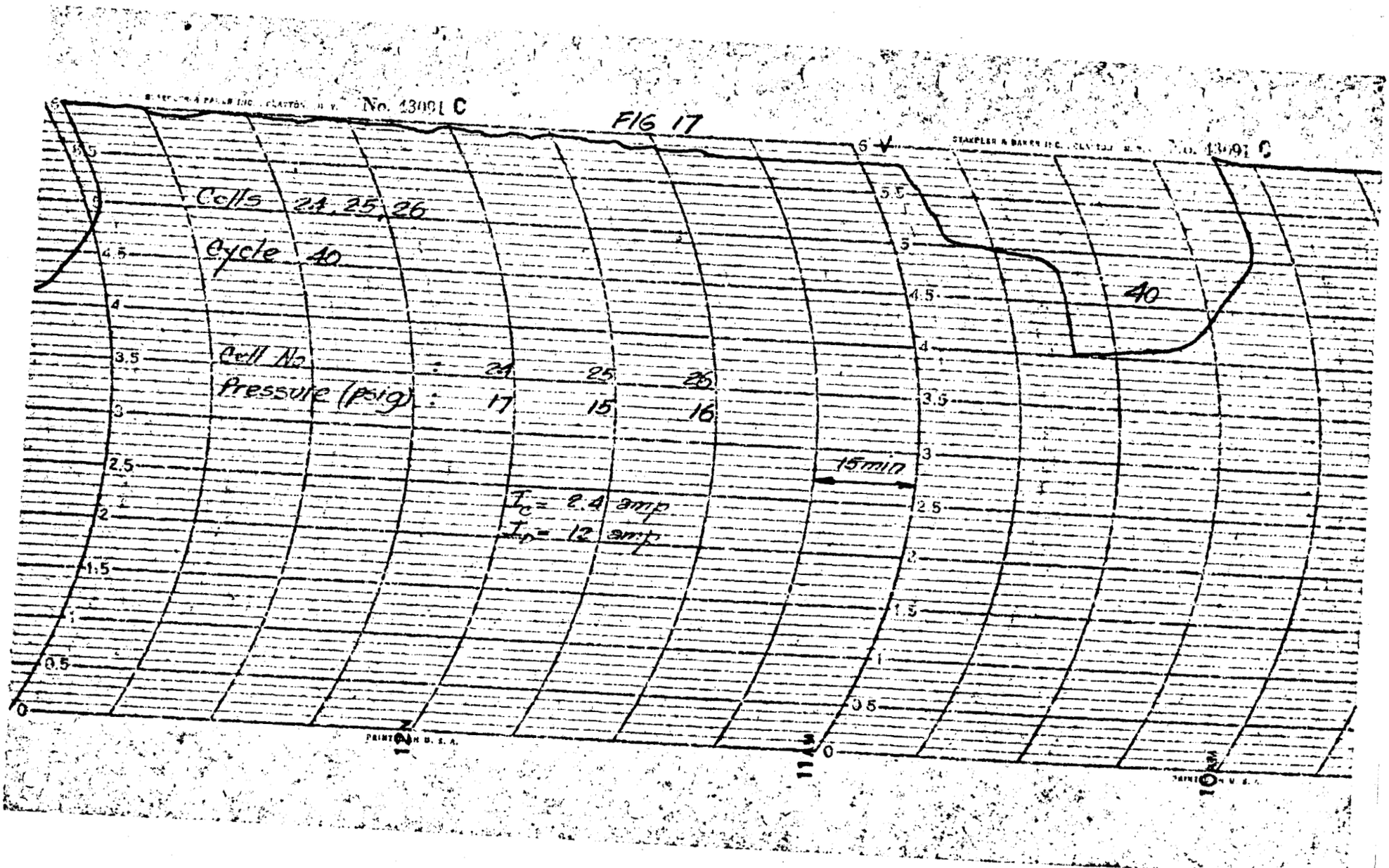


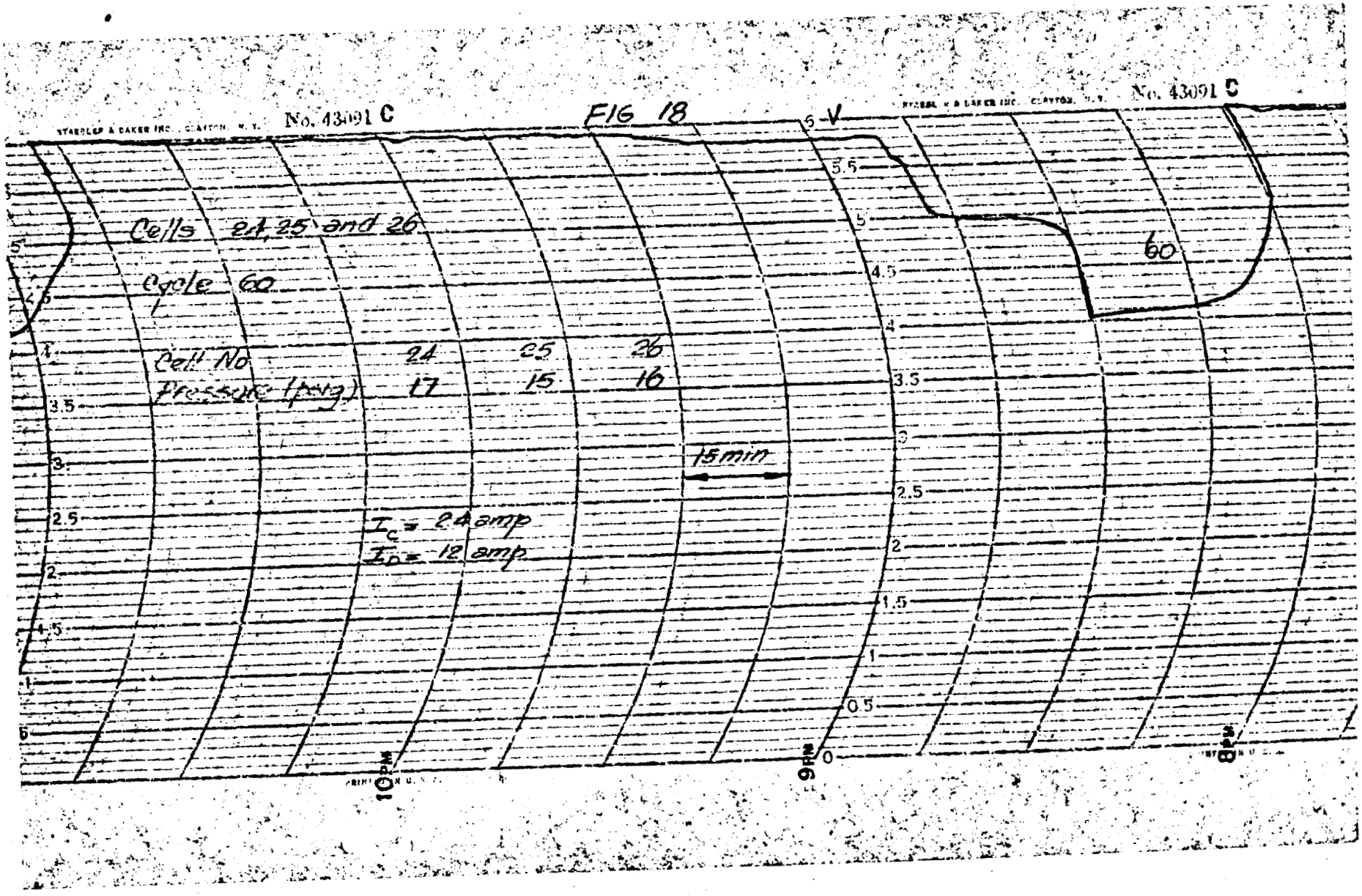
FIG 14
60 V
No. 43062 A
Cells 21, 22 & 23
Cycle 120
Cell No
Pressure (psig)
21 22 23
11 15 12
Ic = 2.4 amp
Ib = 12 amp
30 min
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
3.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
120
4 MIN
12 MIN
0 PSIG
4 PSIG

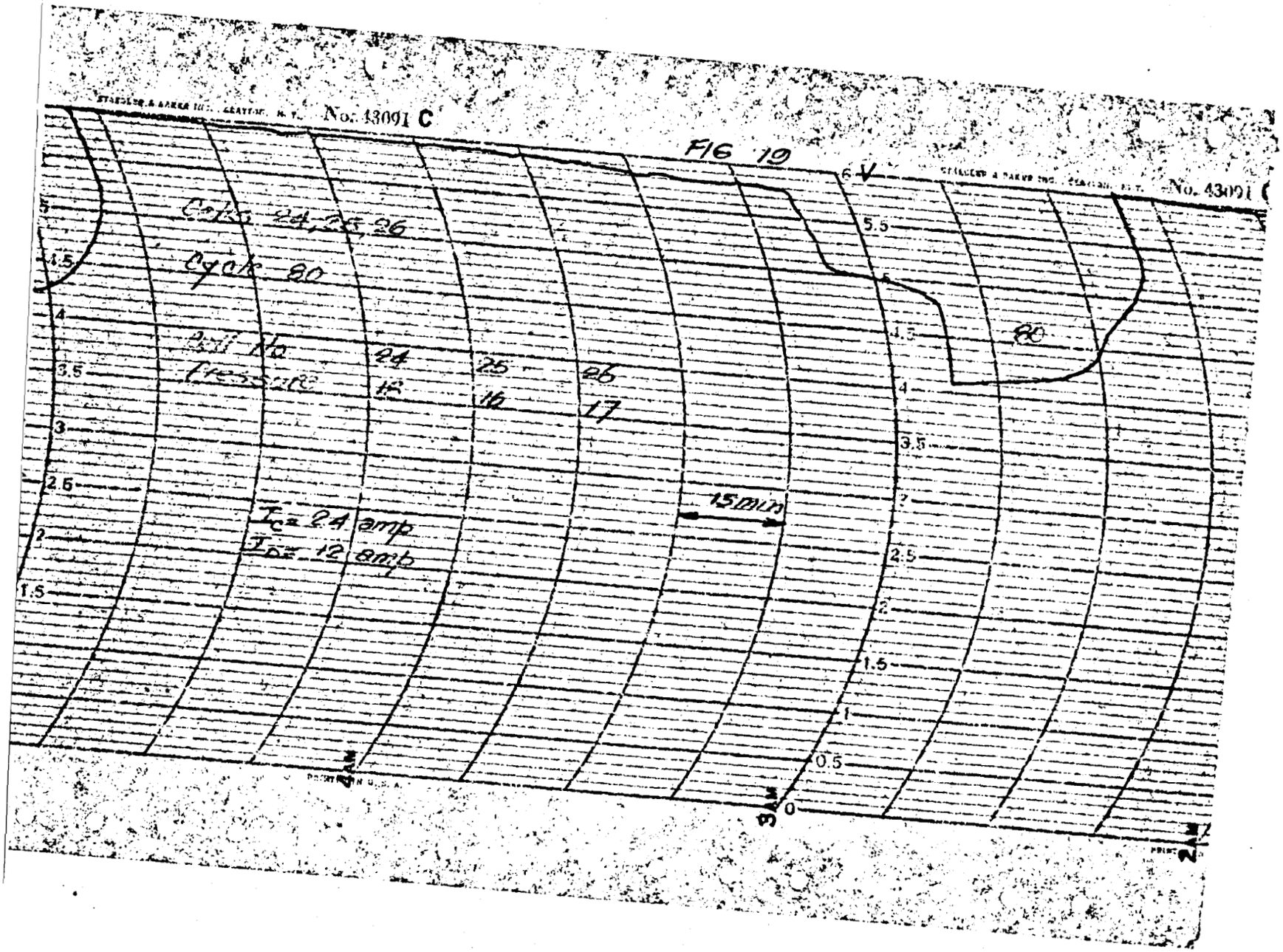
FIG 15

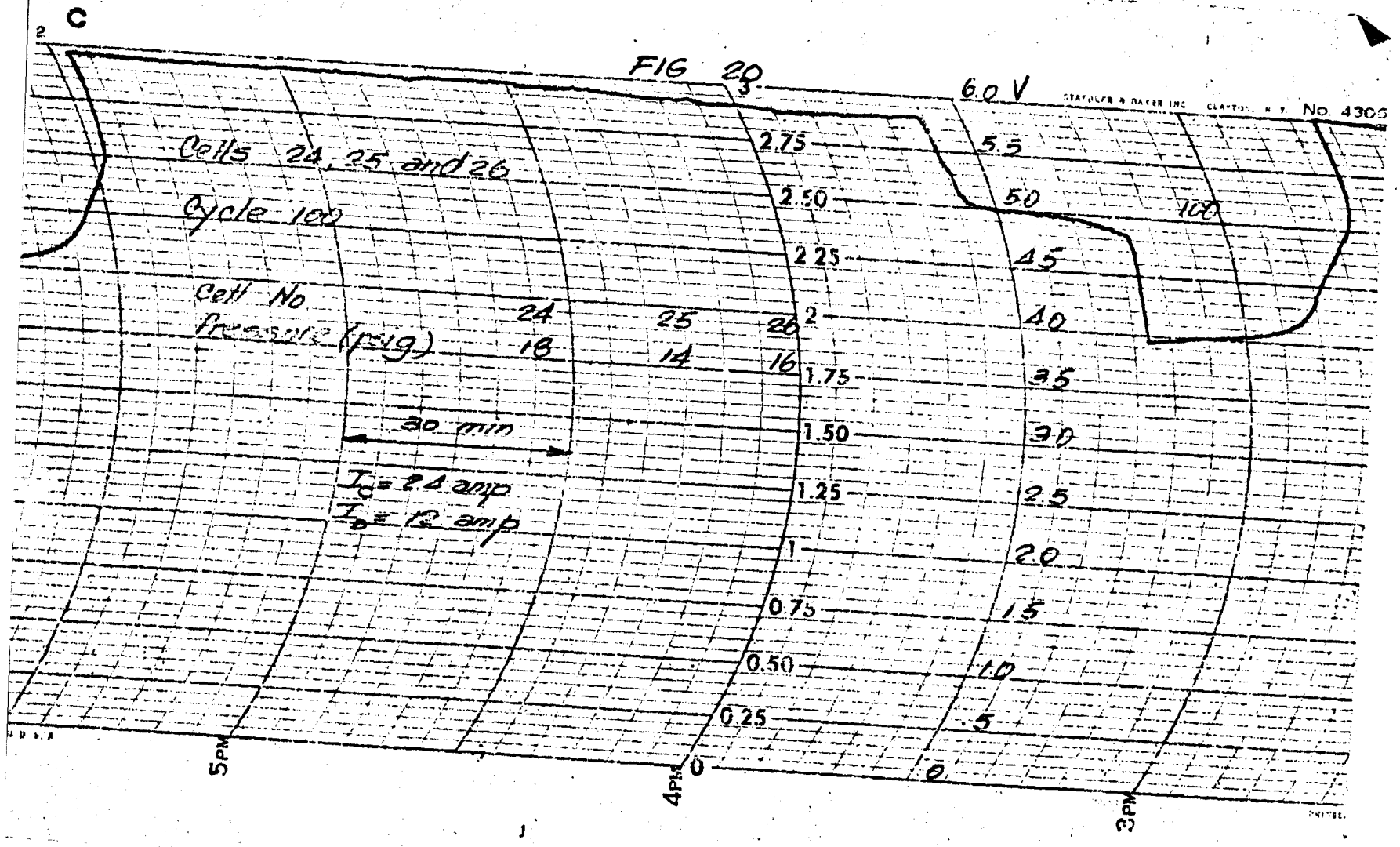

Cells 24, 25 and 26
Cycle 5
15 min
Cell No
24
25
26
Pressure (psig)
4
6
5
I_c = 24 amp
I_a = 12 amp
9 PM
8 PM
7 PM
6 PM

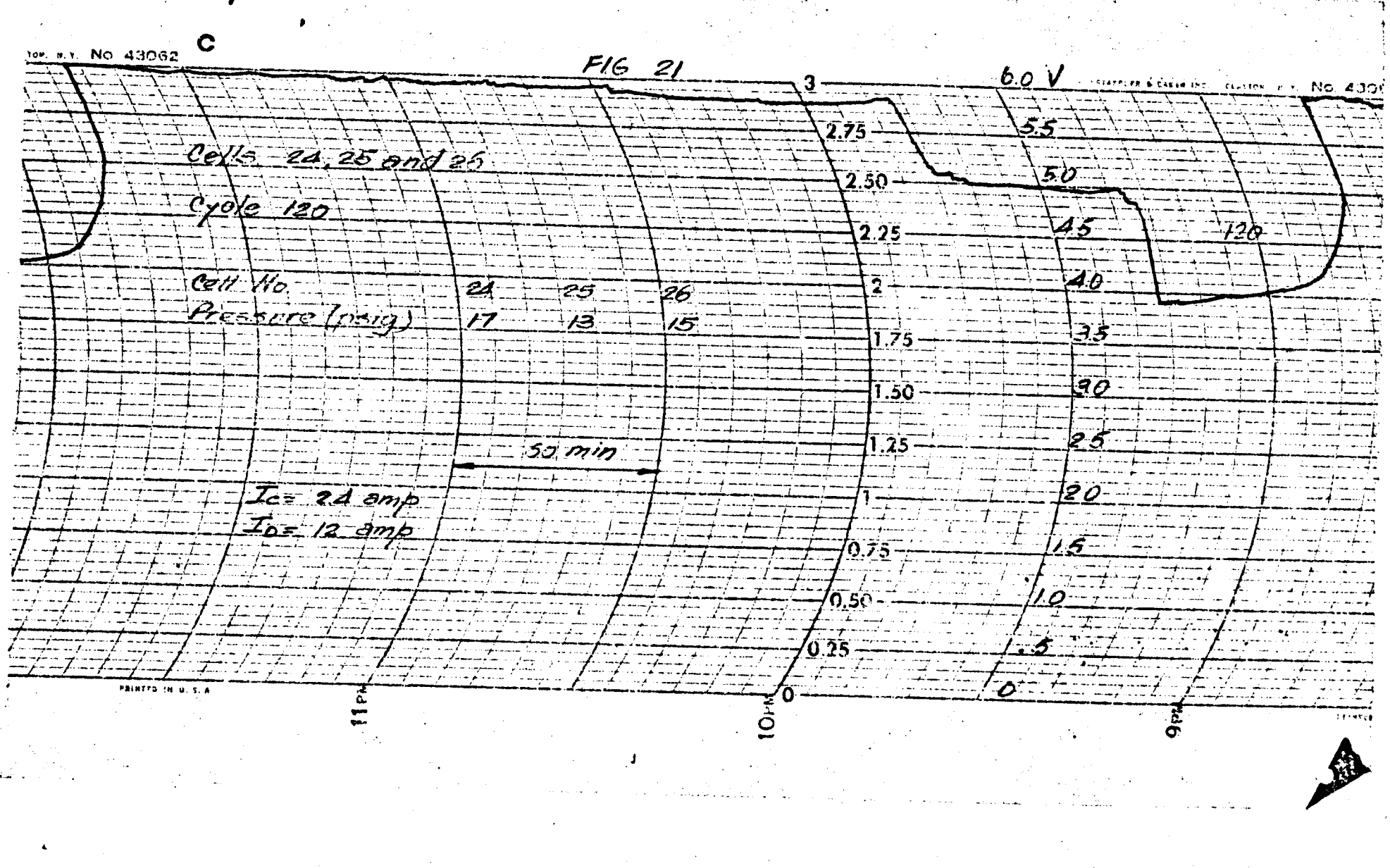

No. 13091 C
FIG 16
No. 13091 C
Cells 24, 25 and 26
Cycle 20
Cell No
Pressure (psig)
24
13
25
14
26
15
I_{ch} 2.4 amp
I_{ex} 12 amp
15min
20
6 V
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0


No. 4300L C
FIG 17
Cells 24, 25, 26
Cycle 40
Cell No : 24 25 26
Pressure (psig) : 17 15 16
I_c = 2.4 amp
I_D = 12 amp
15min
40
No. 4301 C


No. 43091 C
FIG 18
No. 43091 C
V
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Cells 24, 25 and 26
Cycle 60
Cell No
Pressure (psig)
24
17
25
15
26
16
15 min
60
I_C = 24 amp
I_D = 12 amp
10 PM
9 PM
8 PM


No. 43091 C
FIG 19
Coils 24, 25, 26
Cycle 80
Coil No
Pressure
24
25
26
15
16
17
I_C = 24 amp
I_D = 12 amp
15 min
6 V
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
9 AM
No. 43091
80


C
FIG 23
6.0 V
No. 4306
Cells 24, 25 and 26
Cycle 100
Cell No
Pressure (psig)
24
25
26
18
14
16
30 min
I_c = 24 amp
I_d = 12 amp
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
100
5PM
4PM
3PM


C
FIG 21
6.0 V
No. 43062
Cells 24, 25 and 26
Cycle 120
Cell No.
Pressure (psig)
24
25
26
17
13
15
50 min
Ic = 24 amp
Id = 12 amp
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
120
11PM
10PM
9PM
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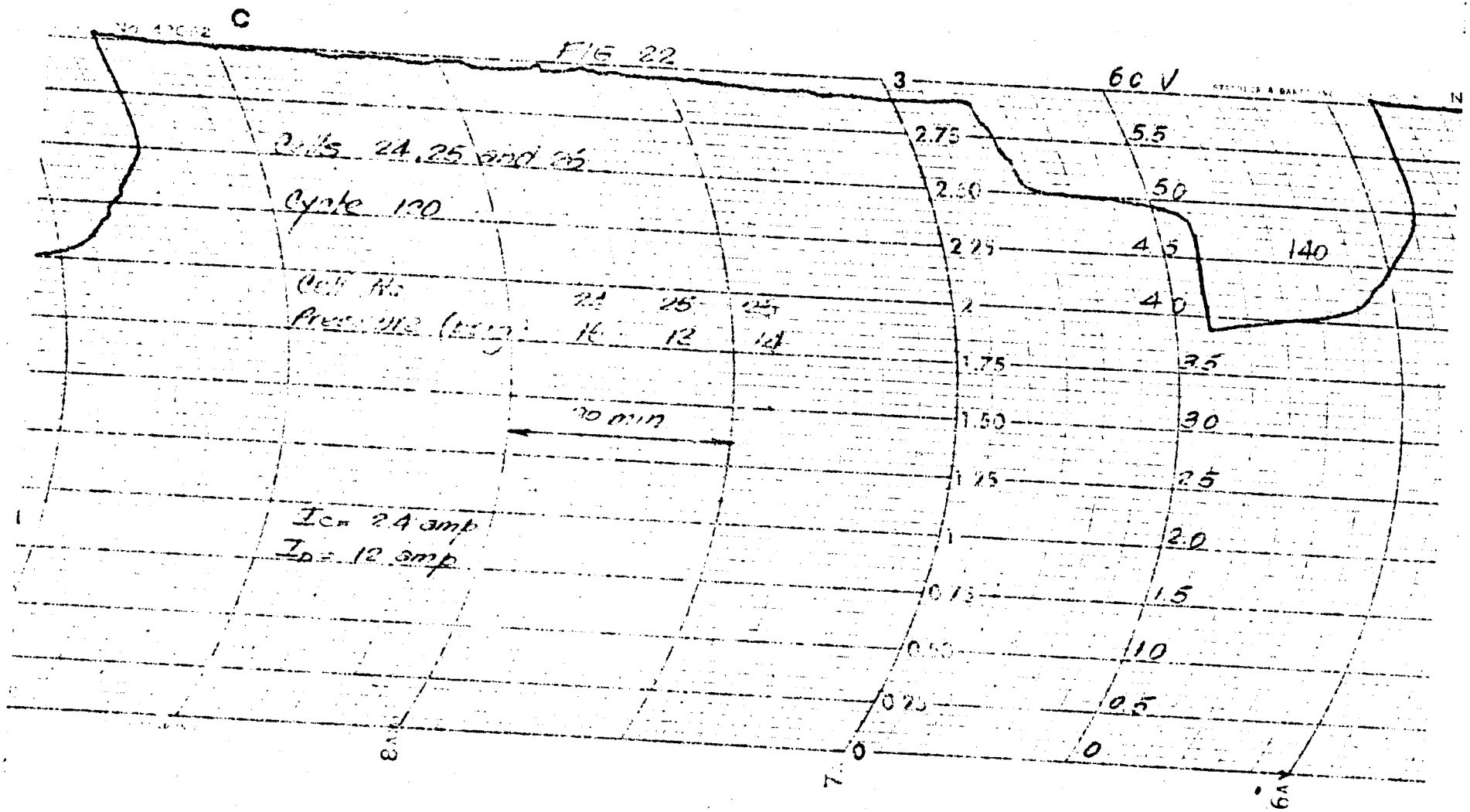
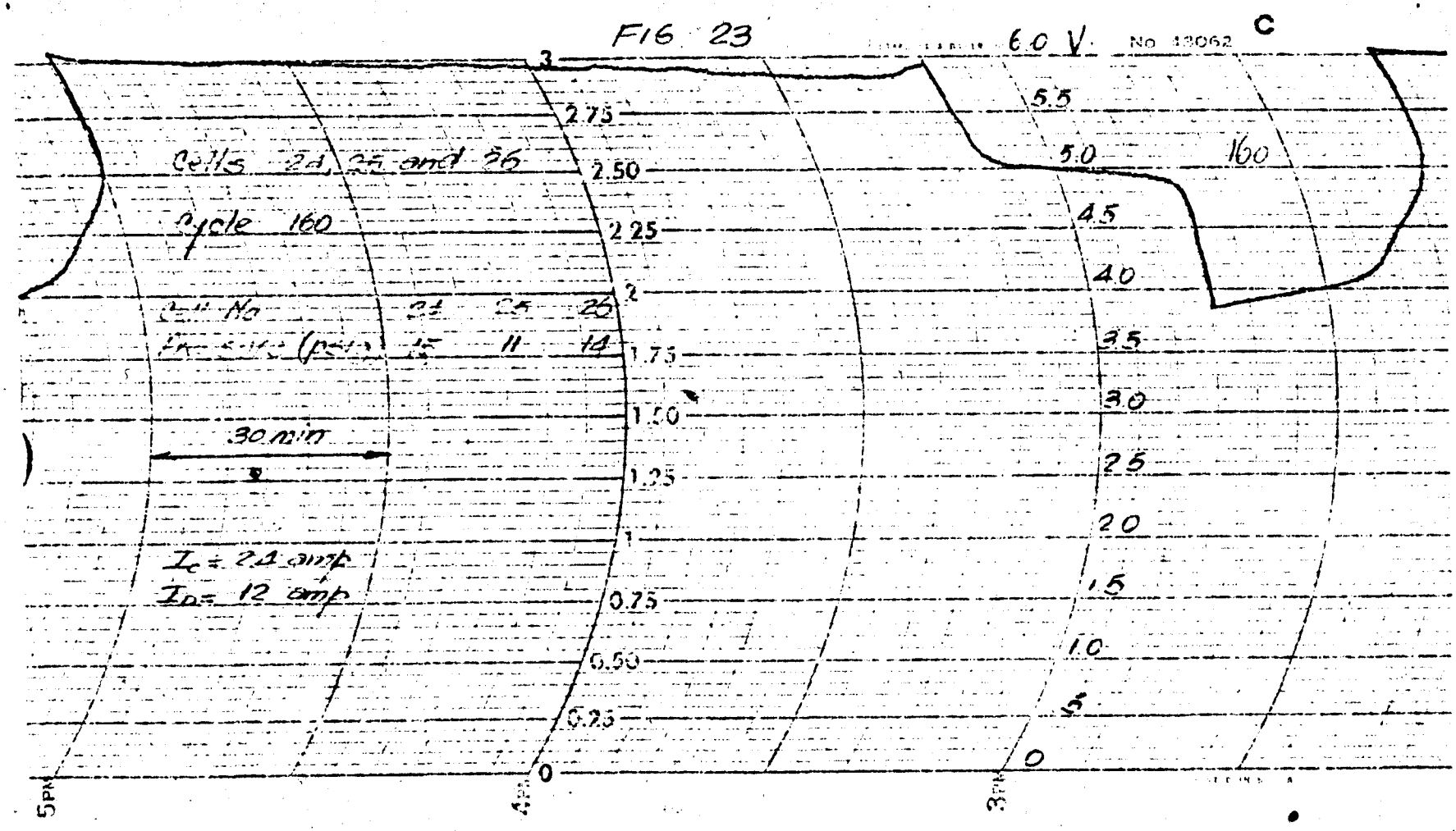
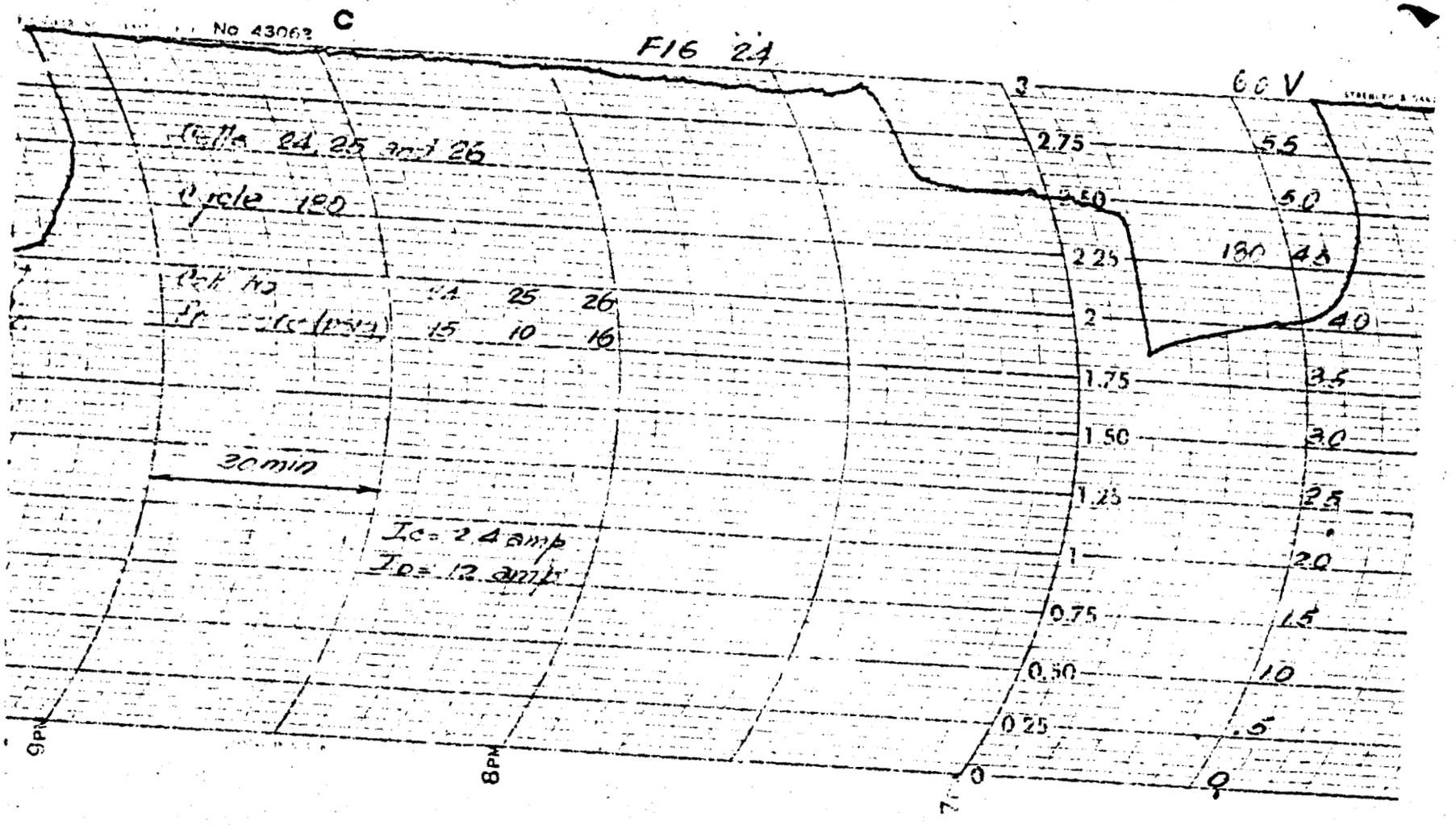

C
FIG 22
3
60 V
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
140
Cells 24, 25 and 26
Cycle 120
Cell No
Pressure (psig)
24
25
26
K
12
14
30 min
Ic = 24 amp
Ip = 12 amp

FIG 23


60 V
No 13062
C
Cells 24, 25 and 26
Cycle 160
Cell No 24 25 26
30 min
I_c = 24 amp
I_D = 12 amp
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
160
5PM
4PM
3PM


No 43062
C
FIG 24
Cells 24, 25 and 26
Cycle 180
Cell No 24 25 26
Ic (amps) 15 10 16
30 min
Ic = 2.4 amp
Io = 12 amp
9PM
8PM
7PM
3
2.75
2.50
2.25
2
1.75
1.50
1.25
1
0.75
0.50
0.25
0
Q
C C V
55
50
180 45
40
35
30
25
20
15
10
5
0