STUDY OF LITHIUM DOPED SOLAR CELLS

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FIRST QUARTERLY REPORT

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First Quarterly Report

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ABSTRACT

During the first quarter, work concentrated on various methods for introducing lithium into solar cells, and on the solar cell properties resulting from the lithium distribution left after several different diffusion schedules.

Three cell shipments, each of sixty (60) cells, were delivered to JPL for testing. The spread of the cell photovoltaic output, and typical lithium distributions for each shipment, are included.

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1.0 INTRODUCTION

This program is intended to determine the properties of silicon solar cells doped with lithium. These properties depend mainly on the distribution of lithium in the cell, and also on the starting silicon. The properties of interest are the photovoltaic output before particle irradiation, and also following irradiation. Process parameters to be most studied are those giving optimum post irradiation recovery at near-room temperatures, and good cell stability under conditions similar to those expected when operating in space.

Six hundred cells with controlled variation of process parameters are scheduled to be delivered to JPL during the contract year.

Because cells made from crucible grown silicon recover more slowly than those using oxygen lean silicon, the first two cell shipments for irradiation testing used crucible grown silicon, to allow the longest period for observation during the contract period.

2.0 TECHNICAL DISCUSSION

2.1 LITHIUM INTRODUCTION METHODS

Earlier work had mainly used painted-on suspensions of lithium metal in oil, or vacuum evaporation of lithium. The paint-on method is straightforward but has disadvantages in control of the amount and the coverage of the lithium. The evaporated lithium films should allow closer control of the amount and location of lithium, but the deposited lithium did not always remain on the cell surface; in addition, the lithium vapor tended to leak to the front cell surface.

Besides seeking improvements in the above methods, trials were made of two other possible ways for introducing lithium. Both methods transported lithium vapor at fairly high gas pressures.

The first vapor method used a flowing inert gas stream in a furnace tube, which also contained a heated source of metallic lithium. The practical problems were severe and included difficulty in providing a suitable container for the heated lithium, and in finding a shield to protect the furnace tube from attack by hot lithium vapor. There was also more chance of unsafe operating conditions and uneven lithium distributions across the silicon surface caused by

2.1 Lithium Introduction Methods (continued)

gas flow patterns, or by a dependence of the lithium reaction on the surface finish of the silicon.

Despite these formidable problems, this method is still under study. Using this method, lithium was introduced through the diffused boron layer, although the resultant cell properties were poor because of localized punch-through by lithium clusters or from contact degradation. The method is still being considered as a means of back surface introduction, to see if controllable lower surface concentrations (in the range 10^{15} to 10^{17} lithium atoms per cm^3) can be achieved.

The second vapor method used thermal evaporation at relatively high gas pressures (50 microns Hg). Again the problems were mainly from gas flow patterns, which gave uneven lithium distribution. To date the most reliable method has been found to be the paint-on method, and this was used to fabricate the first three shipments. However, work continues to improve both the thermal evaporation method, and the flowing gas vapor method.

2.2 LITHIUM DIFFUSION STUDIES

The best diffusion method to date has been to heat the silicon coated with lithium in a furnace tube held at the diffusion temperature with an inert gas flowing through the tube.

A comparison of argon and nitrogen as inert gas in the furnace tube showed that the greater reaction of lithium with silicon under argon did not increase the surface concentration or penetration of lithium, but increased the brittleness of the silicon and gave greater breakage. Therefore nitrogen was used for most tests.

A further trial involving deposition of a cover layer of silicon monoxide immediately after lithium evaporation, and heating the cells directly in the evaporator did not increase the lithium concentration.

Several different combinations of diffusion temperature and time were studied. These included 450°C for 40 minutes, 450°C for 5 minutes, both followed by removal of excess lithium and various redistribution times (up to 80 minutes) at 450°C. Also tests were run at 425°C for 90 minutes, followed by redistribution times up to 120 minutes, and also

2.2 Lithium Diffusion Studies (continued)

350°C for 30 minutes. Correlation of the cell performance and the resultant lithium distribution has increased understanding of the processes involved.

2.3 LITHIUM CONCENTRATION PROFILES

These were determined by direct probing of the lithium-diffused slices or completed cells. Section 2.4 shows typical examples. In general, the profiles obtained for most diffusion cycles were not uniform. Also, in most cases, during redistribution there was a decrease in the lithium concentration near the back surface of the cell, and this loss of lithium was more severe for higher redistribution temperatures. This back surface slump in lithium concentration was not reduced when either a titanium-silver or silicon monoxide layer covered the lithium during redistribution. However the average concentration of lithium in cells redistributed with these coatings was slightly higher, warranting further studies. The amount of lithium deposited during a tack-on diffusion far exceeded that found after most of the redistribution schedules used. Even so, sufficient lithium was generally available in the cell, to provide V_{OC} values up to 580 to 600 millivolts when crucible grown silicon was used. As found earlier, the I_{SC} values were determined mainly by the lithium concentration near the front surface of the cell, I_{SC} being lower for higher lithium concentrations.

Cells were formed after a typical tack-on diffusion, and redistribution cycles were applied to the completed cells. The resulting cell characteristics generally resembled those obtained when cells were made from slices redistributed with the same schedule. However, the cells undergoing redistribution showed serious increase in series resistance for longer redistribution times, indicating interaction at the silicon-metal interface.

2.4 OTHER TOPICS

Some cells were made using chemically or mechanically polished slices. No advantage in cell performance was obtained, although cells with polished surfaces will be kept for study of the lithium-boron interaction. Minor changes in silicon monoxide coating procedure gave slightly improved cell performance.

Attempts to apply lithium by DC sputtering were not promising. Some array interconnection tests showed that the present titanium-silver contacts were not as reliable as those used on N/P cells. Other contact metals, including

2.4 Other Topics - (continued)

aluminum or gold-nickel are being studied.

2.5 CELL SHIPMENT DETAILS

Three cell shipments were made, each of sixty (60) cells.

The details are as follows:

First Shipment:

Cell Numbers - CRL-1 through CRL-60

Silicon - Crucible-grown, 111 orientation, arsenic-doped, resistivity approximately 30 ohm-cm.

Lithium Diffusion - Paint-on, 450°C for 5 minutes, followed by redistribution at 450°C for 40 minutes.

Cell Properties - (AMO, 140 mW/cm^2, cell temperature 28°C)

I_{sc} range	64 to 74 mA
V_{oc} range	595 to 610 mV
I_{475} range	60 to 68 mA

Figure 1 shows the I_{475} values for the 80 starting slices. The number of cells in successive 2 mA ranges of I_{475} is plotted; also indicated is the cumulative percentage of the lot.

Lithium Distribution - Figure 2 shows the lithium distribution measured on a cell typical of those sent in the first shipment.

Second Shipment:

Cell Numbers - C2-1 through C2-60

Silicon - Crucible-grown, 111 orientation, arsenic-doped, resistivity approximately 5 ohm-cm.

Lithium Diffusion - Paint-on 425°C for 90 minutes, followed by redistribution at 425°C for 120 minutes.

Cell Properties (AMO, 140 mW/cm^2, cell temperature 28°C)

I475 Distribution for Cells Fabricated For First JPL Shipment

Figure 1

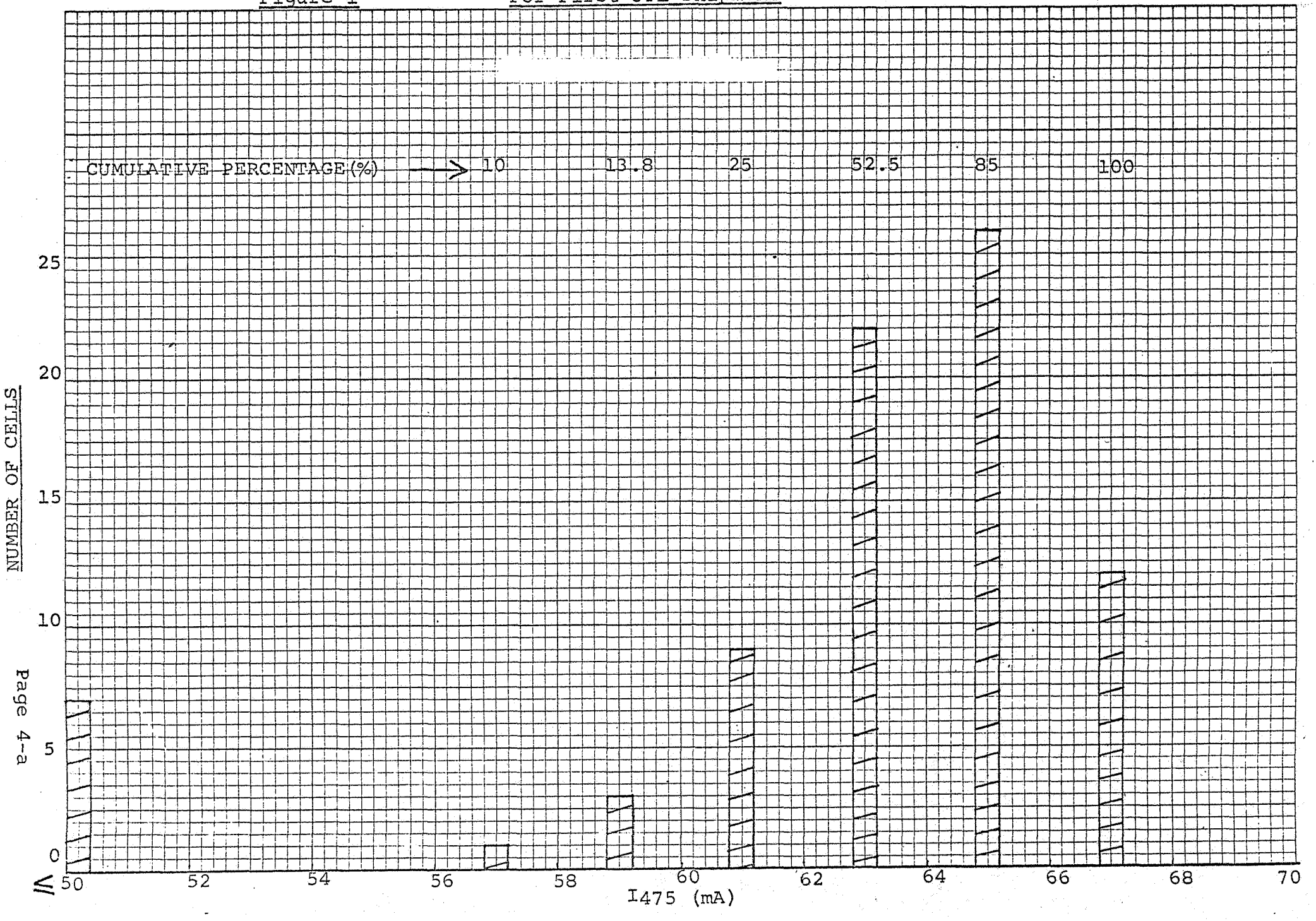
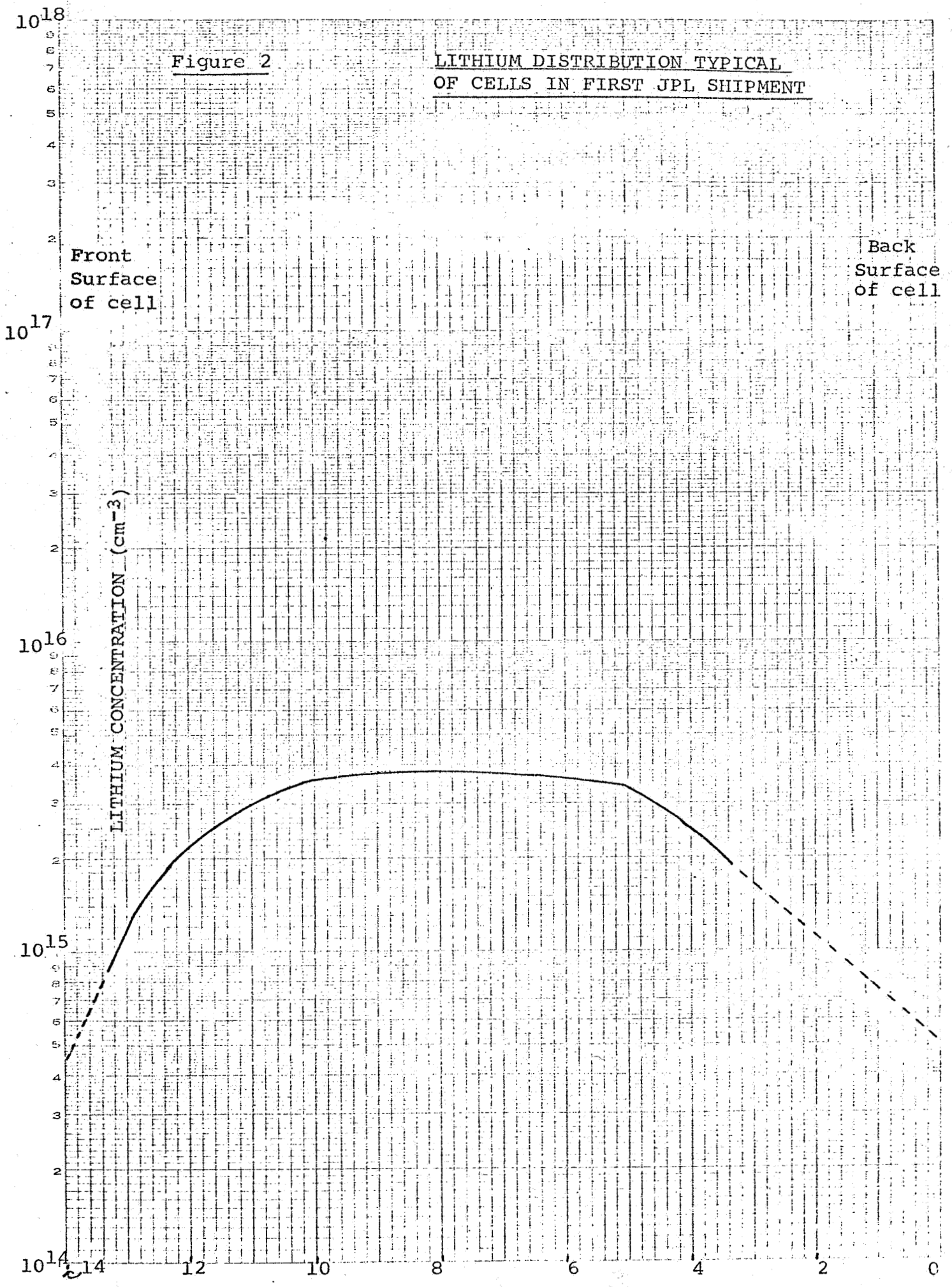


Figure 2

LITHIUM DISTRIBUTION TYPICAL OF CELLS IN FIRST JPL SHIPMENT



I_{sc} range 65.5 to 73.5 mA

V_{oc} range 575 to 600 mV

I_{475} range 58 to 69.5 mA

Figure 3 shows the I_{475} distribution for the 100 starting slices, plotted like Figure 1.

Lithium Distribution - Figure 4 shows a measured lithium distribution typical of the cells in the second shipment.

Third Shipment:

These cells were made to allow various redistribution cycles to be applied to the cell before or after irradiation. Thus the cell values given are those after the lithium "tack-on" only.

Cell Numbers - C3-1 through C3-61

Silicon - Float-zone refined, 111 orientation, phosphorus doped, resistivity approximately 65 ohm-cm.

Lithium Diffusion - For C3-1 through C3-32
Paint-on, diffused 350°C for 30 minutes
For C3-33 through C3-61
Paint-on, diffused 425°C for 5 minutes

For these short cycles, the slices were introduced into a hot zone at the indicated temperature, and left for the times shown. This resulted in an average diffusion temperature less than that shown; this was especially the case for the 425°C diffusion. Figure 6 shows this effect. The ratio in penetration distance for equivalent concentrations is approximately 3.5 instead of the theoretical value of 1.4.

Cell Properties (AMO, 140 mW/cm^2, cell temperature 28°C)

C3-1 to C3-32

I_{sc} range 65.5 to 76 mA
V_{oc} range 525 to 565 mV
I_{450} range 50 to 67 mA

I475 Distribution for Cells fabricated

Figure 3 For Second JPL Shipment

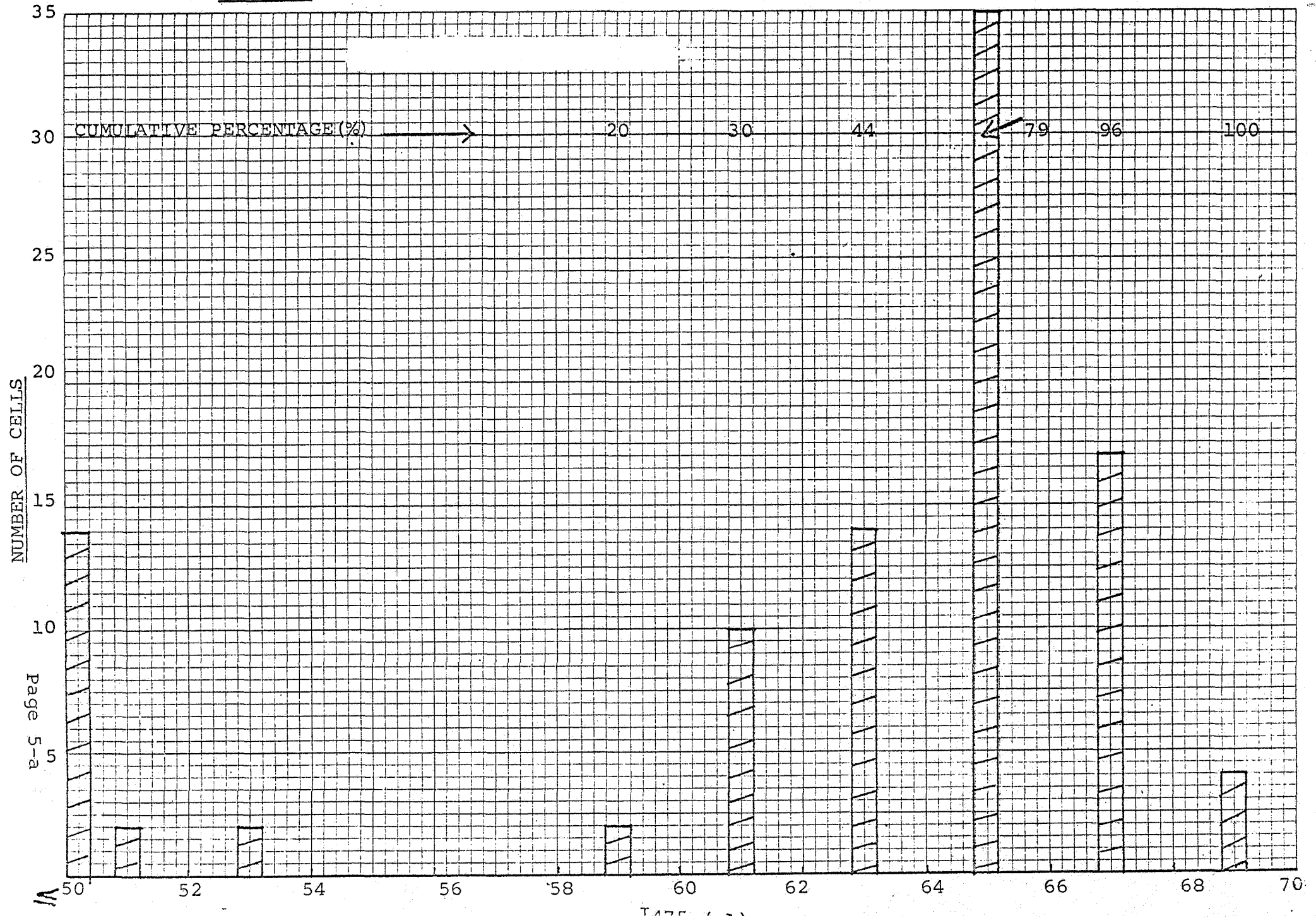
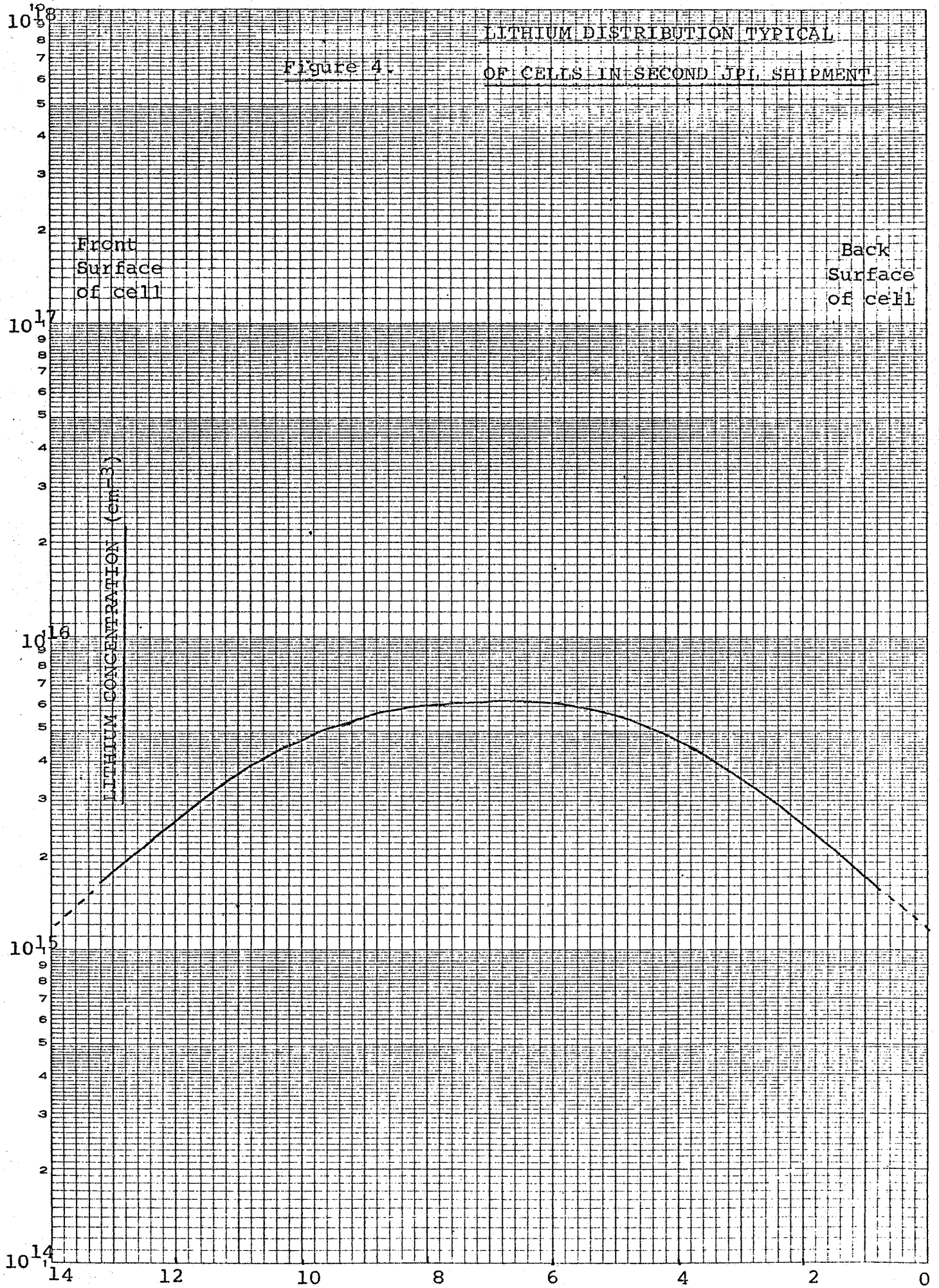


Figure 4. LITHIUM DISTRIBUTION TYPICAL OF CELLS IN SECOND JPL SHIPMENT



2.5 Cell Shipments - (continued)

C3-33 to C3-61

I_{sc} range 67.5 to 74.5 mA

V_{oc} range 525 to 560 mV

I450 range 49 to 61 mA

Figure 5 shows the I450 distribution, for the shipped cells only, in the two groups.

Lithium Distribution - Figure 6 shows the measured lithium distribution typical of the cells in each group in this shipment.

3.0 CONCLUSIONS

The difficulty in finding an optimum method for introducing lithium indicates the need for continued concentrated effort to find improved methods. The lithium distribution in the cells was not uniform, and more understanding is required of the effects of different diffusion cycles and conditions.

Despite these comments, the first three shipments comprised farily well controlled groups of cells showing good output.

4.0 RECOMMENDATIONS

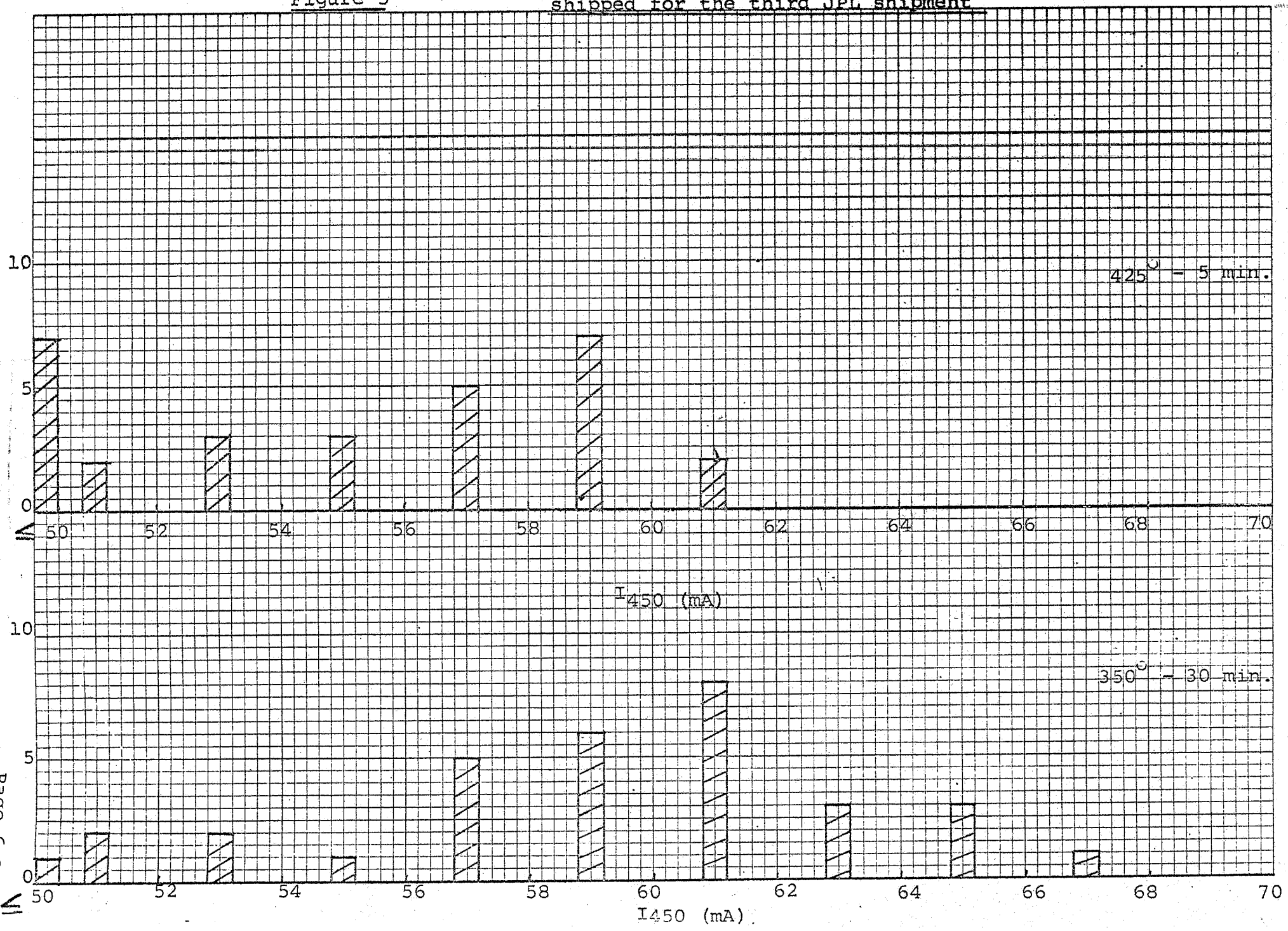
For the next quarter, effort will be continued on lithium introduction methods, and to understand the behavior of lithium after various diffusion cycles.

5.0 NEW TECHNOLOGY

None

Figure 5

I450 Distribution for the cells shipped for the third JPL shipment



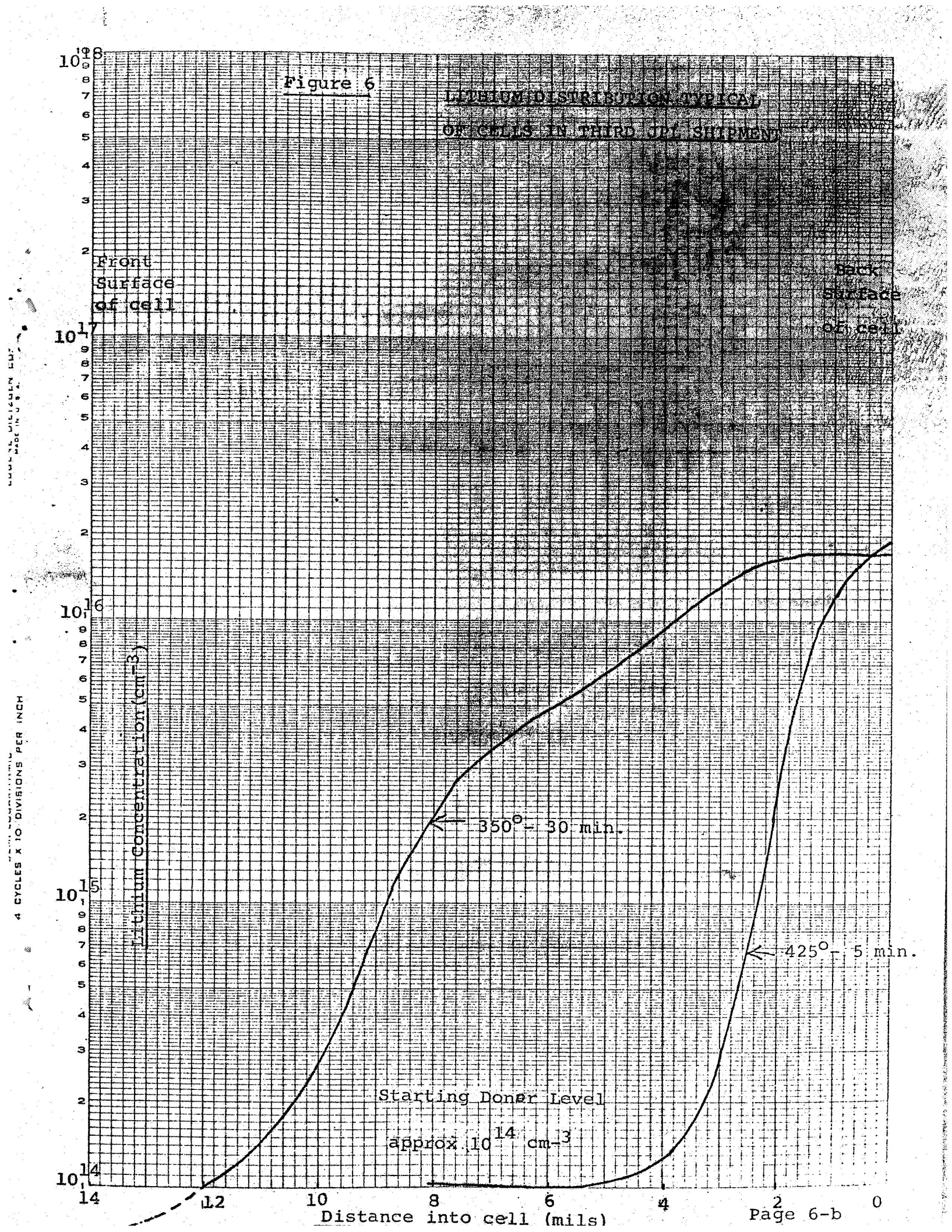


Figure 6
LITHIUM DISTRIBUTION TYPICAL OF CELLS IN THIRD JPL SHIPMENT
Front Surface of cell
Back Surface of cell
Lithium Concentration (cm⁻³)
350° - 30 min.
425° - 5 min.
Starting Donor Level
approx 10¹⁴ cm⁻³
Distance into cell (mils)
4 CYCLES X 10 DIVISIONS PER INCH