Essential Readings in Light Metals: Aluminum Reduction Technology.
Edited by Geoff Bearne, Marc Dupuis and Gary Tarcy.

3. DESIGN

The story of the evolution of aluminum reduction technology over the last 50 years is interesting. It has been a period of scale up and consolidation. The latest generation of reduction cells are perhaps five or six times bigger that they were in the 1960s and while variants have been developed by several different companies, they are all side-by-side prebake anode, multiple riser, point feed technologies. Significant advancements in materials and the understanding of thermal, electrical, and magnetic behavior of the cells have underpinned the productivity increases as well as improvements in energy efficiency and environmental performance.

However, the lines of aluminum reduction cells (generally referred to as potrooms) have long lives because of their relatively high capital cost and low operating cost, so a wide range of new and old technologies still operate today, including some Söderberg continuous anode varieties. The lives of older plants have been greatly extended by continuous improvement and one of the success stories of the industry is how it has been able to greatly exceed the original design capacities of installed technologies for relatively low cost.

Papers in the design section describe the development of new reduction cell technologies as well as the modernization of existing ones. They include retrospectives, accounts of successful trials, and "announcements" of new technologies that have had significant impacts on the industry. A few papers describe the development of selected reduction technology components, such as slotted anodes and shell cooling fins.

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DEVELOPMENT OF LARGE PREBAKED ANODE CELLS BY ALCOA

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The development history, design features and current results from Alcoa's large prebaked anode cell designs; P-155, P-225 and A-697 are described. The P-155 and P-225 designs produced in the sixties optimized return on capital for the U. S. costs of that period. The redesign of P-155, designated A-697 adjusts this optimum to the costs of seventies. Redesign of the P-225 is underway.

The purpose of this discussion is to acquaint you with some of the history, techniques used, and results obtained in the development of large prebaked Hall Process smelting cells by Alcoa during the past 20 years or so. (Figure I, Second Generation Hall Cell)

The early prebaked anode Hall cells developed from about 10 kA to 50 kA by 1935 and to 100 kA in the 1950's. Almost all of this development was on a trial and error basis accomplished by scaling up the physical size of previous cells. Within Alcoa most of the cells were center worked and placed side by side in the potroom building. As the size and current inputs of these cells increased, the fundamentals of magnetic effects and thermal balance were recognized; but sophisticated techniques for studying those problems were not available. As the cell amperage approached 100 kA the significance of these effects prompted development of measurement and analytical techniques to study heat flows and magnetic effects.

In the 1950's most of Alcoa's cell development was concentrated in a smelting development laboratory at the Tennessee Operations designated Potline B. Here full size prototype cells were operated, studied, and evaluated under wide ranges of operating techniques and power inputs. In this development laboratory much data relative to heat losses, voltage losses, and magnetic effects were collected and laboriously analyzed using mostly manual methods. Equipment to measure heat flows was developed at our Technical Center. The development by Alcoa of heat flow transducers in both permanent and portable versions has been previously reported in the literature(1). From studies of heat losses and magnetically induced metal and bath flows, there has been demonstrated several types of interactions. Some of this work has been described R.F. Robl in a 1978 paper(2). A key factor in solving the magnetic problems was the construction of scale models of proposed cell designs. These were very accurately scaled at 1/16 size and included appropriate magnetic and non-magnetic components. With these models the effects of many changes in bus configuration and placement of shielding could be evaluated quickly and at less cost. Verification of data gathered in this manner could then be made by measurements in full size cells. In turn, the appropriate empirical factors were then entered into the computer equations developed later.

Today several computer models are used in cell design and operating analysis. They include a one dimensional equilibrium model and a three dimensional finite element heat and current flow model. An additional one dimensional, dynamic model has more recently been used to predict relative operating and economic results for varying power inputs and cell operating conditions. This has been useful in optimizing cell performance.

Due to Alcoa's relatively low cost power base, most of the developmental effort in the 1960's concentrated on high cell productivity and low capital investment. This thrust is in sharp contrast to producers on other continents where power availability and cost had put strong pressure for lower current densities and resulting lower power

(1) W. E. Haupin, J. W. Luffy - 106th AIME Annual Meeting, 1977.

(2) R. F. Robl - 107th AIME Annual Meeting, 1978.

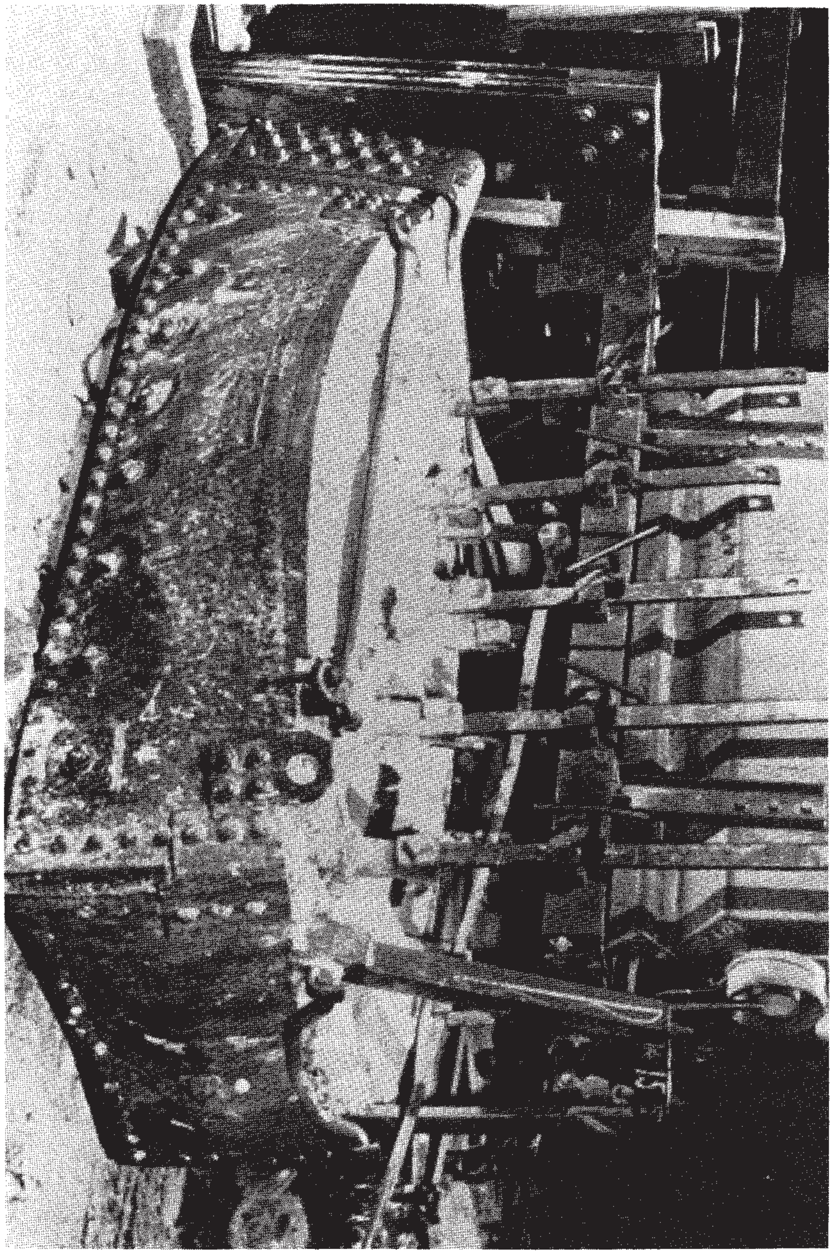

FIGURE I - SECOND GENERATION HALL CELL

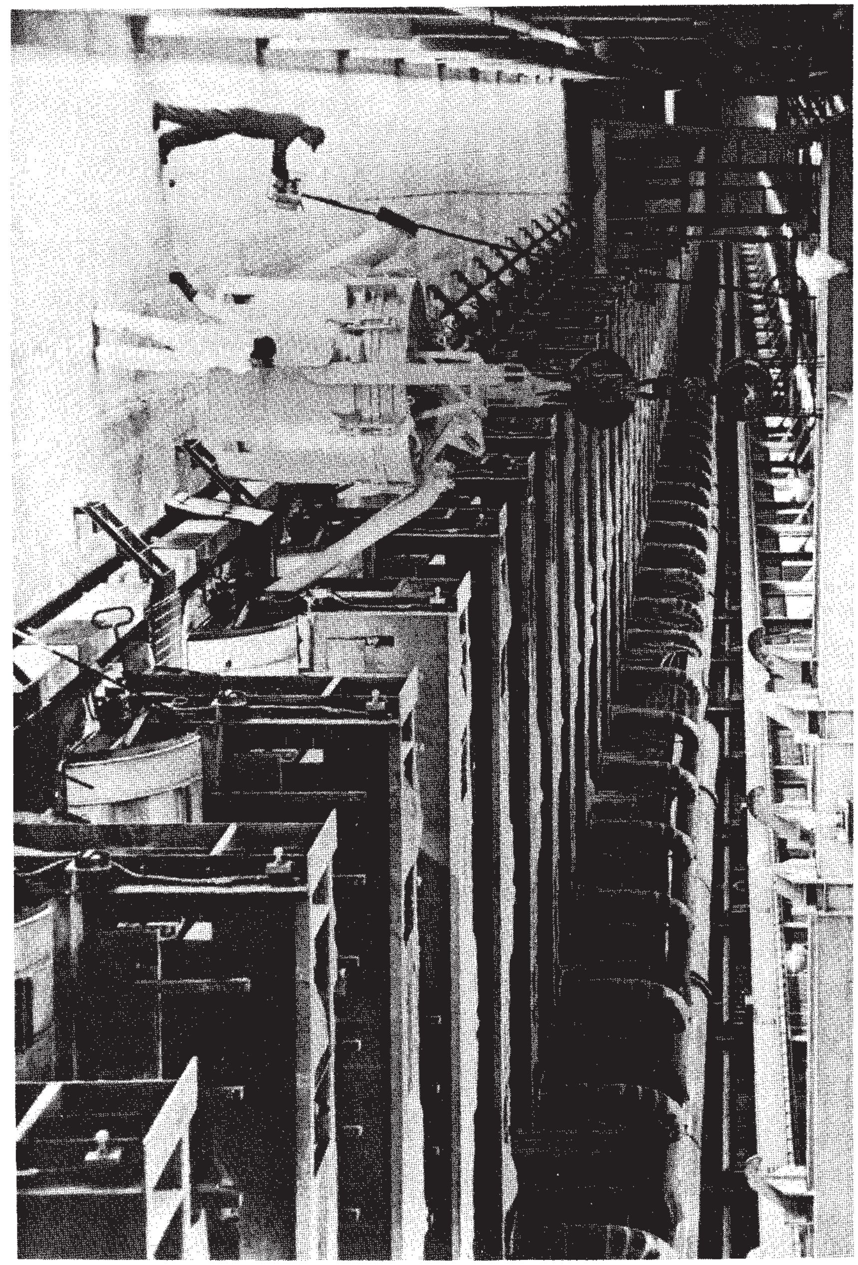

FIGURE II - P-155 POTLINE AT BADIN

consumptions. Alcoa's basic approach during this period led to cell designs of increased amperages and at anode current densities generally above .80 A/cm^2 and as high as .90 A/cm^2. Two basic schemes were pursued on cells at amperages in excess of 150 kA.

The first scheme resulted in the Alcoa design known today as the P-155. This pot was initially designed with a cathode insulation for operation at a nominal 155 kA. The prime emphasis was on a cathode bus system that would achieve a balanced current flow and stable magnetic pattern. Accomplishing the desired results required cathode bus of graduated sizes to promote appropriate current flow patterns. To this prototype installation was added an automatic, pneumatically operated alumina feeder developed at Alcoa's equipment development division. Automatic power input adjustment was accomplished by computer control. A tight hooding system was designed to promote effective fume capture. The cell was equipped with a dual volume draft system to promote better capture of fumes during anode changing and tapping when some hood removal is required. An overview of this cell is shown in Figure II.

This cell was judged to be an unqualified success, and the first commercial installations were made in Point Henry, Australia (1963) and in Badin, North Carolina (1964).

Initially, these installations were operated at the prototype current loading of 155 kA. Pressures for increased production and labor productivity prompted further studies of cathode insulation and bath chemistry at our research facilities. From these efforts have come current day operations at 170 kA. The capabilities of this design are indicated in Figure III.

FIGURE III - ALCOA P-155 DESIGN AND OPERATING DATA

	Design	Actual Performance*
Amperes	165-170,000	171,200
Volts/Pot	4.5 - 4.6	4.6
Anode Current Density (A/cm^2)	0.81 - 0.83	0.84
Production (kg/Pot Day)	1200 - 1235	1276
Power Consumption (kWh/kg)	14.88 - 14.99	14.85
Current Efficiency (%)	90	92.4
Gross Carbon	.600	.561
Net Carbon	.450	.441

*Badin (North Carolina) 1978 year

As can be noted from the performance data, the power consumption - although good - is not as good as that being achieved in newer, low current density designs. The excellent productivity and low capital investment per annual ton of production still make this cell economically attractive in many locations. Today there are seven of these potlines in operation and three under construction.

The second scheme of cell development has come to be known as the Alcoa P-225 cell design. This cell was developed for a high degree of automation and production and reasonable power consumption. This cell was also developed in our Potline B for operation at a nominal 225 kA. A rather intricate cathode bus arrangement was required to control the potentially severe magnetic effects encountered at this high current. A second significant departure from conventional cells was the independent elevation adjustment of the 16 pairs of anodes which are computer controlled. Those of you who have operated prebaked anode pots and periodically encountered problems with loss of anodes due to overloading (we call these burnoffs) can appreciate the potential for better control available with this ability to monitor and control anode currents. This improvement required 14 years of effort in Potline B and three generations of pot designs to accomplish. Successful implementation has required the con-current development of today's very fast computers to process the enormous volume of data and make outputs. We have learned by experience what many operating personnel have always suspected--control of anodes with insufficient data can aggravate instability, can chase metal motion around the pot and make pot voltage control more difficult. Using six Mod Comp II computers (3 control--3 backup) in our large new Massena potline, we are now able to handle the magnetics of 230 kA as well as we handle those of 170kA. This achievement in an operating potline is believed to be unmatched anywhere in the world.

Is this degree of control necessary? I believe it is, although I admit the question has not been resolved in Alcoa, because we have no block control pots operating at this amperage. It is necessary, in my opinion, because the unavoidable disturbances in current distribution caused by anode setting, tapping and cold bath additions are much greater with today's large anodes and high amperages. When an anode pair is replaced in the P-225, for instance, 15,000 amperes have to be redistributed. These transient effects should make the deep metal pool--profile setting approach used by some producers untenable at these amperages. Perhaps, you gain some indication of the problem when I tell you forty (40) pair moves are made at Massena per pot per day.

Other features include a tight hooding system with dual volume draft, automatic alumina feeders, an air conveying system for alumina delivery to the pots, and obviously the job of raising anode bridges is eliminated. An overview of the cell is shown in Figure IV.

The performance of this cell has been good. As can be seen from the performance data in Figure V.

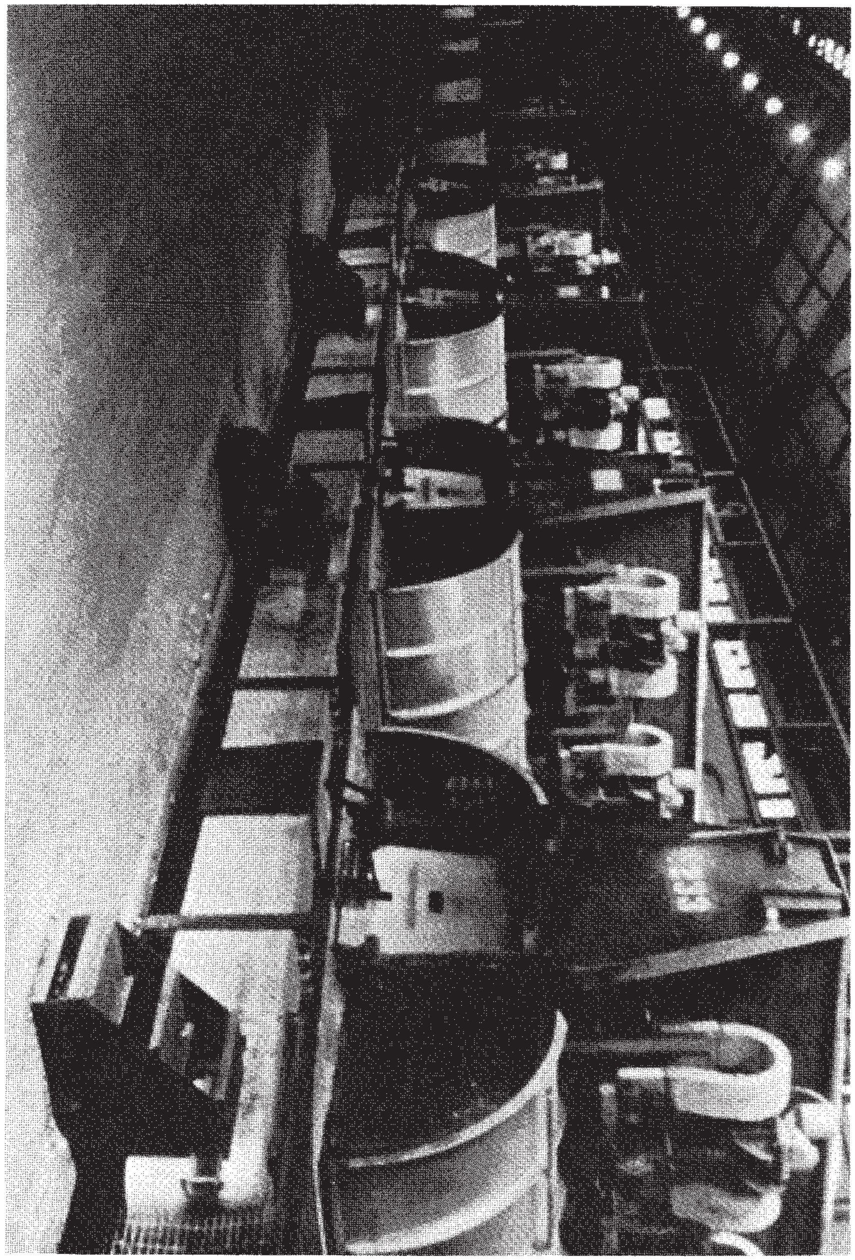

FIGURE IV - P-225 POTLINE AT MASSENA

FIGURE V - ALCOA P-225 DESIGN AND OPERATING DATA

	Design	Actual Performance*
Amperes	225,000	231,200
Volts/Pot	4.5	4.6
Anode Current Density (A/cm^2)	0.87	0.89
Production (kg/Pot Day)	1620	1698
Power Consumption (kWh/kg)	14.9	15.07
Current Efficiency (%)	89.4	91.0
Gross Carbon	.595	.581
Net Carbon	.450	.453

*Massena (New York) 1978 year

This cell design operates at comparable efficiences to the P-155, but requires the lowest labor per unit of production of any of the Alcoa cell designs. Please note that this Massena data is at higher current density.

The first commercial installation of these cells was at Alcoa's Tennessee Operations in 1969. Today, three potlines utilize this cell type and operate in excess of 230 kA. The largest potline is located in Massena (New York) and has an annual production of just over 130,000 short tons.

With the increasing cost of power in the United States in the early 1970's came a concern within Alcoa for development of lower power consumption Hall cell designs. Other worldwide producers long exposed to high cost power had already moved into lower current density cell designs. Alcoa's first major effort resulted in the cell now designated Alcoa 697. As can be seen from the picture Figure VI, this cell is similar to the P-155 design but larger.

Development of this cell was not accomplished in a laboratory, but in an existing plant potline at Badin (North Carolina) Works. This radical departure from past practice resulted in the installation of two prototype pots in the space previously occupied by three conventional P-155 pots. To provide for flexibility in evaluation of these prototypes, a boost rectifier system was installed to permit operation as high as 200 kA.

Significant improvements to previous designs included a newly-designed hooding system with latching devices to insure the highest possible fume capture. This pot is equipped with automatic alumina feeders and pneumatic alumina delivery system.

The prototype pots were put into operation in May, 1977, and continue to be operated. The degree of success achieved in the initial installations was attributable in part to the computer modeling used to determine cathode bus sizing, potlining insulation, and magnetic patterns. The predicted stability of the metal pool at depths of only 10-12cm has been verified by measurements made in the pots. Flow vectors are below 0.1 meter/sec and the pool is flat within nominally $\pm$ 6mm.

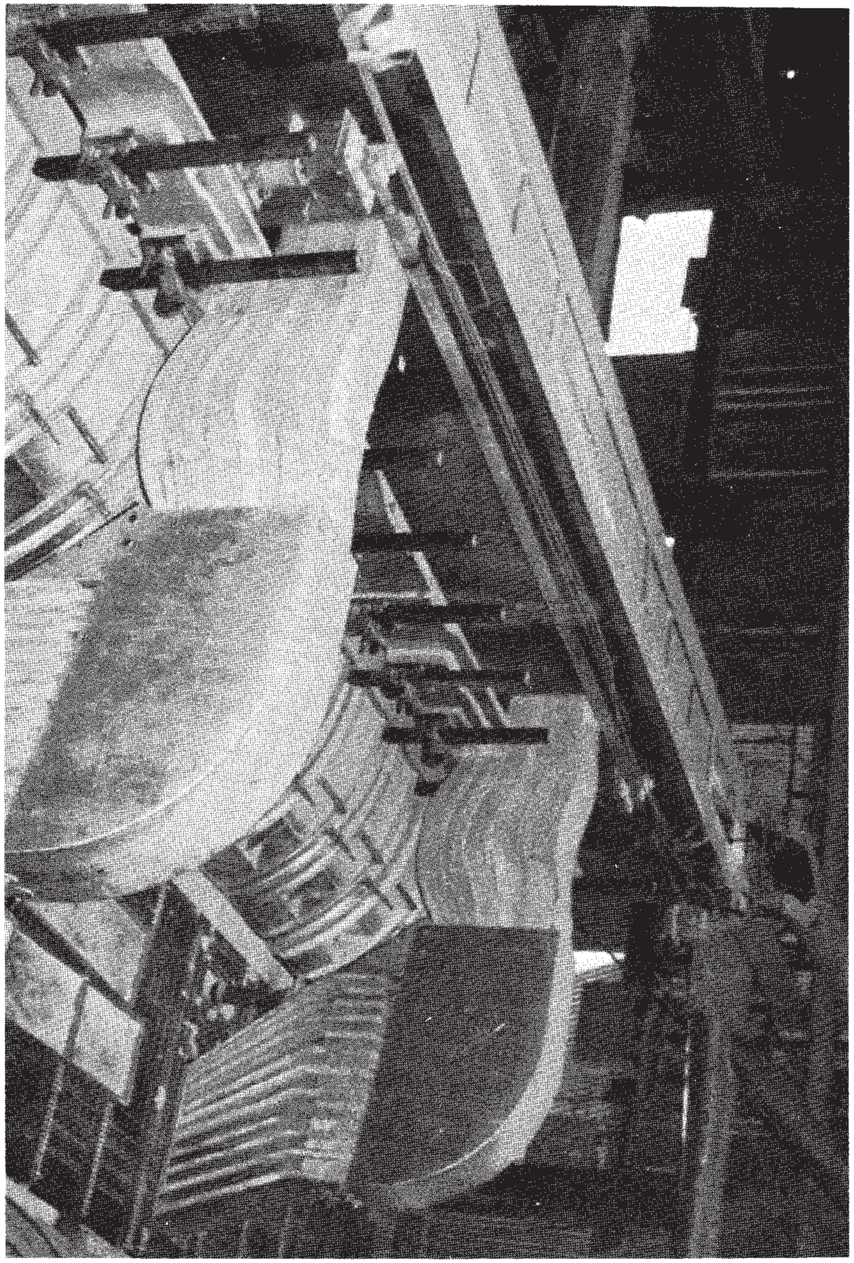

FIGURE VI- ALCOA 697 POT AT BADIN

In 1978 an aluminum producer made the decision to install the Alcoa 697 cell design in a plant in the United States. At this point, the operation of the Alcoa 697 prototypes was analyzed to select the optimum current input level and power consumption level needed. A decision was made to select operation at 180 kA which balances production with excellent power consumption. Shown in Figure VII are the results of these cells at various power input levels.

FIGURE VII - ALCOA 697 DESIGN AND OPERATING DATA

		Actual Performance*			
	Design	170 kA	180 kA	190 kA	Average Total Data**
Amperes	180,000	170,594	180,192	189,667	181,209
Volts/Pot	4.2	4.13	4.17	4.20	4.18
Anode Current Density (A/cm^2)	.72	.68	.72	.76	.73
Production (kg/Pot Day)	1350	1302	1369	1402	1366
Power Consumption (kWh/kg)	13.5	12.96	13.20	13.62	13.31
Current Efficiency (%)	93	94.6	94.1	91.6	93.5
Pot Days Operated	-	122	296	218	1322
Gross Carbon	.600	NA	NA	NA	NA
Net Carbon	.450	NA	NA	NA	NA

*2 test cells at Badin (North Carolina) Works
** From May, 1977, to April, 1979
Including transitional periods between set points.

In discussions with the client for the Alcoa 697 cell design, a number of refinements and operating changes were made to evaluate their effect on pot operation and efficiency. One notable change resulted from these evaluations. With the significant ledging encountered in low current density operation, some problems were encountered in changing corner anodes. To alleviate this problem, the end potlining insulation was restudied and revised to provide a more workable ledge profile. In February of this year one of the prototypes was cut out and the revised potlining installed. To date the revised potlining has been operating with excellent results and the desired ledge profile has been achieved.

A comparable redesign for lower current density operation has just been completed for the P-225 design. This, the largest Alcoa cell ever operated, now has two prototypes operating in the existing P-225 potline in Massena. Very preliminary results indicate a successful new cell design comparable to the Alcoa 697 but operating in excess of 230 kA.

Alcoa's experience with the development of new cell designs installed in operating plants has been judged successful. It is believed that the sophisticated design techniques and computer modeling available today have made possible quite accurate predictions of cell design and operating results. Thus, the older, more laborious methods used in the original Potline B development laboratory have given way to the in-plant development used in the Alcoa 697 cell design and the other similar developments currently underway.