

# **Molted Carbonate Fuel Cell Product Design and Improvement - 4th Quarter, 1995**

**Quarterly Report  
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### **Statement of Cooperative Agreement Objectives**

The primary objective of this effort is to establish, by 1998, the commercial readiness of MW-class IMHEX<sup>®</sup> MCFC power plants for distributed generation, cogeneration, and compressor station applications. Commercial readiness will require an advanced IMHEX<sup>®</sup> technology base, lower-cost manufacturing processes, verified balance-of-plant components, proven packaging and assembly approaches, demonstrated prototype power plants, finalized manufacturing and market distribution plans and a committed commercialization team. The M-C Power Team's supporting objectives are:

- ▶ To finalize product definition, complete detailed product design, identify and evaluate balance-of-plant components, and generate power plant manufacturing and market distribution plans which will result in successful transition from development into commercial market entry;
- ▶ To develop and optimize fuel cell component manufacturing processes and power plant assembly and packaging methodologies which will provide a market-responsive MW-class power plant in low production volumes appropriate for the initial stages of commercialization;
- ▶ To advance and improve the IMHEX<sup>®</sup> stack technology, balance-of-plant components, and power plant integration which will provide the technology basis for a reliable, cost-effective MW-class product;
- ▶ To demonstrate and verify the reliability, performance, and cost-effectiveness of these technologies in a prototype IMHEX<sup>®</sup> fuel cell power plant which will establish the marketplace confidence needed for successful entry into the commercial market; and
- ▶ To establish the necessary infrastructure and strategic alliances with vendors/suppliers to support market entry and commercialization.

The work to be performed by M-C Power and the subcontractors is divided into the six tasks listed below. The objectives for each task, along with a brief update, where appropriate, is shown on the following pages, which constitutes this technical report. A breakdown of the subtasks is included in this report.

<b>Task 1:</b>	<b>Product Definition and Planning</b>
<b>Task 2:</b>	<b>System Design and Analysis</b>
<b>Task 3:</b>	<b>Manufacturing Process Development</b>
<b>Task 4:</b>	<b>Packaging and Assembly</b>
<b>Task 5:</b>	<b>Test Facility Development</b>
<b>Task 6:</b>	<b>Technology Development, Improvement, and Verification</b>



**Summary of Work Accomplished During the Reporting Period By Task (7/1/95 - 9/30/95)**

**TASK 1 PRODUCT DEFINITION AND PLANNING**

**Objective:** The objectives of this task are to provide the product definition and plans necessary to ensure that the MW-class power plant developed and verified during this activity is responsive to the marketplace needs and conforms to M-C Power's existing Commercialization Plan and to prepare a report to satisfy the requirements of the National Environmental Policy Act.

**Subtask 1.1 Identify Requirements**

**Objective:** The contractor shall update existing product requirements based on marketplace input and document the requirements of a MW-class market-responsive MCFC power plant through market surveys, product option evaluations, and analysis of applicable codes and regulations. The contractor shall prepare a market analysis report that identifies product requirements, analyzes the survey results, and identifies applicable codes and regulations.

**Subtask 1.1.1 Market Surveys**

**Objective:** Bechtel will assist M-C Power to conduct a market survey. In this survey, potential users of the fuel cell unit in different business segments and different regions will be contacted to obtain pertinent information about current utility usage, needs and costs.

**Status:** *M-C Power is working with ACCT's (Alliance to Commercialize Carbonate Technology) marketing committee to develop this marketing survey. A request for quotation has been developed and issued for a market study.*

**Subtask 1.1.2 Analyze Market Surveys, Codes and Regulations**

**Objective:** Bechtel will assist M-C Power to analyze the data collected in Task 1.1.1 to identify the business segments and regions which have the highest market potential and to estimate this potential market size.

**Status:** *This task is dependent on the completion of task 1.1.1 above.*

**Subtask 1.1.3 Generate Product Requirements Document**

**Objective:** Bechtel will assist M-C Power to summarize the analysis conducted in tasks 1.1.1 and 1.1.2 into a cohesive document. A final document will be issued by incorporating the comments received.

**Status:** *This task is dependent on the completion of tasks 1.1.1 and 1.1.2 above.*

**Subtask 1.2 Generate Product Definitions**

**Objective:** The contractor shall generate product options based on market requirements and technical feasibility, select a market entry product approach based on its cost-effectiveness and market responsiveness, and prepare a product description document.

**Subtask 1.2.1 Product Options**

**Objective:** For the fuel cell unit to be a viable commercial product for on-site and distributed power generation, it has to compete with purchased power from grid, reciprocal engines and small gas turbines. Bechtel will determine the acceptable cost range for the fuel cell unit by conducting an economic comparison with the competing power supply and generation options.

**Status:** *Bechtel is currently conducting a product option trade-off study for this task. Bechtel will issue a report summarizing their results on these studies. The final product definition is also dependent on the results of subtask 1.1.*

**Subtask 1.2.2 Product Option**

**Objective:** Based on the market analysis done in task 1.2.1, Bechtel will define the commercial unit in terms of the following items:

- ▶ Power generation capacity of the unit
- ▶ Desired steam, hot water and hot gas production rates and delivery pressures and temperatures
- ▶ Acceptable thermal efficiencies
- ▶ Acceptable capacity rating with ambient temperature
- ▶ Acceptable turndown ratio
- ▶ Acceptable load following capability
- ▶ Minimum thermal cycling capability
- ▶ Minimum availability required for the unit
- ▶ Noise and emission limits
- ▶ Applicable codes and standards
- ▶ Maximum plot area allowed
- ▶ Acceptable cost range of the unit

Bechtel will issue a report which summarizes the economic comparison conducted in task 1.2.1 and the product definition in task 1.2.2.

**Status:** *Bechtel is investigating alternate power plant options, which will help define the commercial unit.*

**Subtask 1.4 Commercialization Plans**

**Objective:** M-C Power will develop a commercialization business plan which addresses those steps taken to develop/obtain the competencies (packaging, distribution, sales and services) to commercialize the MCFC technology based on the market surveys and product definition work completed in previous tasks.

**Subtask 1.4.7 Product Environmental Plan**

**Objective:** Environmental compliance regulations of representative locations within the U.S.A. regarding the operation of IMHEX® fuel cell power plants and their fabrication and decommissioning will be assessed. A plan will be developed to address requirements of the

conceptual manufacturing facility, including the recycling of decommissioned stacks and expended components.

*Status: This subtask is complete.*

**Subtask 1.4.9 Product Cost Reduction Plan**

**Objective:** M-C Power will develop a cost reduction cost benefit analysis showing the steps required to achieve user performance and cost requirements.

*Status: Bechtel is working on alternate power plant designs. The costs of implementing these designs are being compared with current designs. Once designs are finalized, associated costs can be tabulated.*

**Subtask 1.5 Task Management & Reporting**

**Objective:** M-C Power and its contractors will perform general management efforts, prepare required financial, schedule and management reports as required. Also, work necessary to keep management information up to date will be performed.

*Status: Monthly and quarterly reports have been submitted to the DOE for the PDI cooperative agreement as specified within the agreement. Also, M-C Power prepares and submits a weekly report to D. Hooie, of the DOE, which provides additional information on the PDI project, where appropriate.*

**TASK 2 SYSTEM DESIGN AND ANALYSIS**

**Objective:** The objective of this task is to conduct a system optimization study to evaluate various process options for maximizing plant performance and minimizing plant cost of the commercial unit. Based on the selected operating parameters and plant configuration, a preliminary design and cost estimate will be prepared to analyze the overall plant performance and economics.

**Subtask 2.1 System Optimization**

**Subtask 2.1.1 Power Plant Baseline Design**

**Objective:** Bechtel will use the design and cost estimate in a recently completed GRI fuel cell balance of plant (BOP) cost analysis study as the baseline system against which trade-off studies will be performed.

*Status: Trade-Off studies are in progress.*

**Subtask 2.1.2 Power Plant Performance Trade-Off Studies**

**Objective:** Bechtel will perform several trade-off studies to determine the optimum operating parameters and process configuration for the commercial unit. A single variable will be changed at a time to identify its impacts on the plant performance and cost. Any efficiency

improvement will be weighed against the increase in plant complexity, cost and physical dimensions. The trade-off studies to be conducted are listed below:

- ▶ Current Density Optimization
- ▶ Pressure Optimization
- ▶ Optimum Combustion Temperature in the Reformer
- ▶ Adding Shift Catalyst to the Reformer

**Status:** *M-C Power is currently working with Bechtel to provide input for these trade-off studies.*

**Subtask 2.2**     **Generate Preliminary Design**

**Objective:** Based on the process configuration selected in task 2.1, Bechtel will prepare a preliminary design for the commercial unit. Bechtel will confirm, jointly with DOE and M-C Power, the design basis to be used. The basis of the design will follow the product definitions established in task 1.

**Subtask 2.2.1**     **Power Plant Process Design**

**Objective:** In this task, Bechtel will first prepare a detailed process flow diagram and develop the heat and material balance over a wide range of operation including the normal operation, startup, and shutdown.

Bechtel will then size the equipment, including those items required for startup and shutdown. The equipment specification will contain sufficient details for suppliers to estimate the costs and develop preliminary sketches of the equipment dimensions.

**Status:** *M-C Power is currently working with Bechtel to develop alternate power plant designs.*

**Subtask 2.2.2**     **Power Plant System Engineering**

**Objective:** In this task, Bechtel, with support from Stewart & Stevenson (or others), will specify the piping, valves, insulation, structural steel, instruments, control, and electrical requirements for the commercial unit. Bechtel and Stewart & Stevenson will also develop a layout.

**Status:** *Depends on the specific alternate design chosen in subtask 2.2.1.*

**Subtask 2.3**     **Generate Preliminary Cost Estimate**

**Subtask 2.3.1**     **Power Plant Capital Cost Estimate**

**Objective:** In this task, Bechtel will prepare jointly with Stewart & Stevenson (or others), a capital cost estimate for the commercial unit.

**Status:** *Price information is being gathered as plant alternatives are being investigated.*

**Subtask 2.3.2**     **Power Plant Operating Cost Estimate**

**Objective:** Bechtel will, jointly with M-C Power, estimate the operating labor and establish the

maintenance schedule, labor, and materials requirements for the commercial unit. The maintenance requirements will be extrapolated from plants with similar service severity and operating environment. The chemicals and catalysts consumption will be calculated. M-C Power will project the cell life as to determine the stack replacement cost.

**Status:** *Some background cost information is available from experience. A more definite cost estimate will be prepared when the power plant design is finished.*

**Subtask 2.3.3 Power Plant Economic Analysis**

**Objective:** Based on the capital and operating costs developed, Bechtel will conduct an economic analysis to determine the cost of electricity. This analysis will follow the methodology established in EPRI's Technical Assessment Guide (TAG).

**Status:** *Depends on the completion of subtasks 2.3.1 and 2.3.2.*

**Subtask 2.4 Performance Analysis**

**Subtask 2.4.1 Power Plant Design Performance**

**Objective:** Based on the design conducted in subtask 2.2, Bechtel will calculate and summarize the plant performance of the market entry unit at the rated capacity.

**Status:** *Depends on the completion of subtask 2.2.*

**Subtask 2.4.2 Power Plant Off-Design Performance**

**Objective:** The off-design performance to be evaluated for the market entry unit include:

- ▶ The minimum turndown ratio
- ▶ Part load efficiency
- ▶ Capacity rating as a function of ambient temperature

**Status:** *Depends on the completion of subtask 2.2.*

**TASK 3 MANUFACTURING PROCESS DEVELOPMENT**

**Objective:** The objectives of this task are to reduce stack costs and improve quality by optimizing existing cell and stack manufacturing processing, assessing and implementing in-house processing of separator plates, implementing advanced, high-speed low-cost cell manufacturing processes, and to design a conceptual stack manufacturing factory.

**Subtask 3.1 Cell Component Manufacturing Process Simulation**

**Objective:** Active component manufacturing processes will be optimized through the use of simulations, modeling, and testing and implemented to reduce cost, increase through-put, and improve quality of the baseline manufacturing processes.

**Subtask 3.1.1 Computerized Cell Component Manufacturing Process Simulation**

**Objective:** Discreet system simulation programs and analytical modeling programs for the evaluation of statistical variability within the linked manufacturing processes will be evaluated. When this information is combined with the normal manufacturing process routings, the analysis will project manufacturing throughput and will allow for the study of capacity and labor costs in a realistic environment.

Capital equipment utilization will be examined to determine the effect on product cost and quantity. These studies will lead to a definition of future equipment and staffing needs and provide a basis for a conceptual factory design.

**Status:** *M-C Power continues to develop a computerized process simulation that will be used to analyze the current manufacturing process as well as optimize this process.*

**Subtask 3.1.2 Analyze Cell Component Manufacturing Process**

**Objective:** The object of this task is to conduct a detailed evaluation of the current manufacturing processes so that areas for improvement can be selected and prioritized. Statistical methods will be used to determine key process parameters, to assess control philosophies, and to reduce active component variation. Design of Experiment Techniques and Statistical Process Control will be used as the basis for improving the manufacturing process.

**Status:** *M-C Power is also investigating ways to automate the current manufacturing processes in order to reduce the overall cost per kW for the fuel cell stack.*

**Subtask 3.1.3 Optimize Current Cell Component Manufacturing Process**

**Objective:** Based on the analysis and simulation of Task 3.1.1 and 3.1.2, on-line control and process improvements will be selected which optimize yields while maximizing throughput without impacting quality. The optimization of the process will focus on problem definition and solving, evaluating options, statistical testing, updating control documentation, and selecting process improvements which can be implemented to enhance baseline production facilities without impacting delivery schedules or quality.

**Status:** *Depends on the completion of subtasks 3.1.1 and 3.1.2.*

**Subtask 3.1.4 Automate Current Cell Component Manufacturing**

**Objective:** Optimization and automation of the current manufacturing processes which improve cost, quality, production rate, and safety in active cell component production will be implemented. This includes decreasing direct labor costs, combining tasks, installing process instrumentation and controls, improving handling systems, and adopting on-line quality controls.

**Status:** *Depends on the results of subtask 3.1.2.*

**Subtask 3.1.5 Maintain Manufacturing Equipment**

**Objective:** The manufacturing facility will be maintained according to a regularly scheduled maintenance program has been developed and will be followed to ensure proper and reliable operation.

Design, procurement, and refurbishing of the sintering furnace and other key manufacturing equipment will be accomplished under this task. Cost covers labor, services, materials and subcontractor labor.

**Status:** *M-C Power is working with the sintering furnace manufacturer and a local contractor to complete the sintering furnace upgrade. The furnace has been dismantled and all of the retrofit work is in progress with a scheduled completion date of January 31, 1996. Furnace start-up and testing will occur during the first few weeks of February, 1996.*

**Subtask 3.2** **Cell Stack Hardware Manufacturing**

**Objective:** Existing plate processing and fabrication techniques will be evaluated. Appropriate technologies and equipment will be implemented and brought in-house to improve quality control and reduce cost.

**Subtask 3.2.1.1** **Improved Plate Manufacturing Process**

**Objective:** Advanced, cost-effective manufacturing processes for plate hardware to reduce cost and improve quality will be evaluated. Four steps have been identified: forming, trimming, joining, and aluminizing.

**Status:** *M-C Power is reviewing and investigating the four (4) steps listed above for alternate, more cost effective processes.*

**Subtask 3.2.1.4** **Verify Improved Plate Manufacturing Techniques**

**Objective:** Plates and sections of plates will be tested in out-of-cell and in-cell tests to verify dimensional quality and operational performance. Improvements will be selected which can be implemented and will reduce fabrication cost.

**Status:** *Depends on the completion of subtask 3.2.1.1.*

**Subtask 3.2.2** **Implement Improved Plate Manufacturing Phase I Processes**

**Objective:** Improved plate designs will be combined with selected advanced plate fabrication techniques and implemented in order to reduce costs. Successful evaluations of advanced plate processing techniques and material suppliers will result in a formal recommendation to adopt and implement these new process technologies or fabricators.

**Status:** *Depends on the findings found in subtask 3.2.1.1.*

**Subtask 3.3** **Develop Advanced Manufacturing Processes (Cell/Stack Components)**

**Objective:** The market entry product potentially requires advancements in the baseline manufacturing processes currently being utilized and optimized. Optimizations being implemented are

projected to reduce stack costs to below \$4,000/kW in low production volumes. To achieve the \$430/kW cost target for market entry, advanced processes and designs need to be evaluated and qualified. The objective of this task is to identify, evaluate, and qualify potential advanced processes.

**Subtask 3.3.1.1**

**Identify Advanced AC Candidate Manufacturing Processes**

**Objective:**

Processes will be identified and qualified at subscale levels for the rapid, low-cost fabrication of electrodes, electrolyte, matrix tapes, and separator plates. Advanced manufacturing techniques will be evaluated for achieving high-rate, durable manufacturing processes. The goal is to achieve an order of magnitude increase in throughput with no adverse impact on quality or performance.

**Status:**

*Advanced manufacturing techniques are currently being investigated.*

**Subtask 3.3.1.3**

**Procure Advanced AC Candidate Manufacturing Equipment - Phase I**

**Objective:**

After identification and evaluation of improved processes subscale equipment will be procured for verification trials. Evaluation and qualification of new equipment in these processes at sub-scale sizes will be conducted to verify process acceptability and cost-effectiveness prior to full scale implementation. A thorough costing analysis will be conducted prior to the adoption of advanced manufacturing processes to ensure the viability of the selected option.

**Status:**

*Depends on the completion of subtask 3.3.1.1.*

**Subtask 3.4**

**Manufacturing Process Scale Up**

**Objective:**

Manufacturing system simulations will be used to define scale-up goals and achievable targets for the advanced processes qualified and selected in Task 3.3.

**Status:**

*Depends on the completion of subtask 3.3.1.1.*

**Subtask 3.4.2**

**Implement Advanced Manufacturing Process Scale Up Phase I**

**Objective:**

Full-scale equipment for advanced processes which can be cost-effectively scaled up and implemented into existing facilities will be procured and installed. Advanced equipment will be shaken down, tested, and used for component production to verify cost savings in low production volumes. Advanced component technologies developed under subtask 6.1 will be evaluated in commercial-scale stack hardware under this or parallel programs.

**Status:**

*Depends on the completion of previous subtasks.*

**Subtask 3.5**

**Cost Reduction**

**Objective:**

The contractor shall evaluate and implement stack cost reduction technologies including recycling of materials, recovery of processed raw materials and recycling, implementing advanced component technologies, and verifying advanced plate engineering designs and concepts.

**Subtask 3.5.2**

**Develop Advanced Plate Design**

**Objective:**

Advanced design and cell package concepts have the greatest potential for decreasing the cost of the IMHEX® stack. Modified and innovative plate concepts that illustrate the potential for order-of-magnitude cost reductions (such as one piece plate design) will be evaluated. Engineering drawings will be prepared and implemented in commercial-scale



hardware if appropriate. These concepts may first be implemented in sub-scale tests if the costs and risks of commercial-scale hardware implementation are inappropriate.

**Status:** *M-C Power is developing a "Mod-4" plate, which will incorporate several design improvements to the current plate design. "Mod-4" plate design work is on hold pending budget resolution.*

**Subtask 3.5.2.1**      **Identify Advanced Plate Manufacturing Candidate Processes**

**Objective:** Under the Product Development Test Program, M-C Power developed an advanced separator plate design, MOD 4. A prototype trial to define pressing, welding, cutting, and aluminizing parameters was also made.

Under this task, design modifications will be incorporated to address the deficiencies noted above. Finally, tests to quantify clamping force distribution and improvement made to the plate will be conducted. A second prototype run (50 plates) will be made in accordance with the revised design specifications. Once completed, the prototype run will be used to conduct an advanced full area stack test (AS-1).

**Status:** *"Mod-4" plate design work is on hold pending budget resolution.*

**Subtask 3.5.3**      **Verify Advanced Component Cost Savings**

**Objective:** Advanced component technologies developed and verified in bench-scale hardware under subtask 6.1 which have the potential to provide cost savings (either capital cost or operating cost) to the product will be transferred and scaled up to production in commercial-scale manufacturing equipment. Advanced component technologies will be evaluated in sub-scale stacks to verify performance, durability, manufacturability, and cost.

**Status:** *M-C Power will calculate the cost savings on using advanced component technologies, once these technologies are perfected and successfully tested in bench scale tests.*

**Subtask 3.5.3.1**      **Select Advanced Component Materials and Processes**

**Objective:** Under this task, scale up of the stabilized Ni cathode and the LiNa electrolyte will continue. M-C Power has developed, under the PDT program, the know-how required for tape casting the stabilized Ni cathode and the LiNa electrolyte. Scale up to full area size components will be made under this subtask. Additionally, the sintering parameters of the stabilized Ni cathode will be characterized. Once the scale-up is completed enough, components to conduct a full area stack test (AS-1) will be manufactured.

**Status:** *M-C Power is continuing to experiment and test advanced components.*

**Subtask 3.5.3.2**      **Define and Use 100cm<sup>2</sup> and 1000cm<sup>2</sup> Processes**

**Objective:** The allocation provided under this subtask covers labor, materials and services needed to conduct bench scale test(s) in support of advanced development, manufacturing scale up or other technical issues needed by the program.

**Status:**      *Li/Na Electrolyte*

*A production lot of Li/Na electrolyte powder was received. Samples were collected for chemical analysis and physical characterization of the powder were*

*initiated. Incoming raw material quality assurance will be completed next quarter.*

**Stabilized Cathodes**

*X-Ray diffraction work was completed and the stabilized cathode powder is considered acceptable for use.*

*Work was initiated by M-C Power to determine the monitoring equipment necessary to track the sintering of the stabilized cathodes. Sintering development work will begin during the second quarter of 1996.*

**Low Cr Anodes**

*The Scanning electron microscopy (SEM) analysis results for the low Cr anodes sintered at a vendor were received and look promising.*

**Subtask 3.6**    **Quality Assurance/Quality Control**

**Objective:** M-C Power has chosen to follow the American National Standard/American Society for Quality Control (ANSI/ASQC) Q91-1987 quality standard, a technical equivalent of the International Standards Organization (ISO) 9001 standard, ("Quality Systems - Model for Quality Assurance in Design/Development, Production, Installation, and Servicing"). The Q91 standard provides requirements for quality program development and maintenance, while allowing the flexibility to meet the specific needs of M-C Power. ISO registration is planned.

**Subtask 3.6.1**    **Outline QA/OC Program Requirements**

**Objective:** Quantitative goals such that progress can be objectively assessed will be developed.

**Status:**        *Inactive during this reporting period.*

**Subtask 3.6.3**    **Update QA/OC Procedures and Methods**

**Objective:** Existing QA/QC procedures will be reviewed and revised to cover improvements made under previous DOE contracts. A primary focus of these procedures will be the planning and control of processes rather than inspection and remedial action. The revised procedures will then be integrated into M-C Power Quality Assurance Manual.

**Status:**        *Inactive during this reporting period.*

**Subtask 3.7**    **Analytical Testing**

**Objective:** Improvement and upgrading of analytical capabilities has been ongoing at M-C Power and investigation into new or improved analytical methods to meet the increasing analytical needs in a cost-effective and timely way has been a priority and will be addressed in a systematic approach.

**Subtask 3.7.1**    **Identify QA/OC Analytical Equipment Requirements**

**Objective:** Future analytical needs will be assessed. The need for specific tests will be evaluated and the adequacy of analytical testing in providing useful data will be confirmed.

**Status:**        *Inactive during this reporting period.*

**Subtask 3.7.6**    **QA/OC Equipment Maintenance**

**Objective:** The manufacturing facility will be maintained according to a regularly scheduled maintenance program has been developed and will be followed to ensure proper and reliable operation.

**Status:** *Regular maintenance done on existing QA/QC equipment.*

**TASK 4** **PACKAGING AND ASSEMBLY**

**Objective:** The objectives of this task are to improve and verify efficient and low-cost packaging and assembly methodology for the BOP and the stack module and to design a conceptual power plant factory.

**Status:** *M-C Power does not anticipate completing or spending any money on task 4 activities in budget period 1. Therefore, these tasks are not shown in this report.*

**TASK 5** **TEST FACILITIES**

**Objective:** The objective of this task is to provide the facilities necessary to support cell technology and stack verification and power plant distribution. The facilities will consist of new facilities and upgraded existing facilities.

**Subtask 5.1.1** **Develop 50/250kW Pressurized Test Facility**

**Objective:** Initial efforts to define and develop a pressurized 250 kW test facility to verify MCFC stack endurance in a plant configuration which could also simultaneously operate 50 kW pressurized stack tests are planned for the first budget period.

**Status:** *The Unocal facility is being investigated for this facility.*

**Subtask 5.1.2** **Maintain 20kW Atmospheric Test Facility**

**Objective:** The existing DOE owned 20-kW atmospheric test facility is capable of testing commercial-area (1 m<sup>2</sup>) stacks. The facility will be maintained to ensure safe and reliable operation. Testing will be performed under subtask 6.4.

**Status:** *Inactive during this reporting period.*

**Subtask 5.1.3** **Maintain Acceptance Test Facility (ATF)**

**Objective:** The ATF is a DOE-owned facility was built under DOE Contract No. DE-AC21-90MC27394 for conditioning and acceptance testing of 50-kW and 250-kW MCFC stacks. The ATF will be maintained to ensure safe and reliable operation.

**Status:** *General maintenance and improvements are being done to the ATF for future fuel cell stack conditioning needs. The majority of all maintenance and improvements have been implemented. All the repairs should be completed during the first quarter of 1996. M-C Power is working with the ATF equipment skid manufacturer to implement the remaining completion items.*

**Subtask 5.1.4** **Develop Pressurized Bench-Scale Facility**

**Objective:** Several 100 cm<sup>2</sup> test stands and one 1000 cm<sup>2</sup> stand will be designed, procured, and installed to support MCFC technology development. The test stands will be capable of simulating system operating conditions at elevated pressure. These stands will be used to generate

performance data to assist in projecting the impact of improved cell technology on system performance.

**Status:** *Three (3) tests have been started this year under the PDI program. Updates on these tests are shown below.*

**100 cm<sup>2</sup> Cell Test M0195003**

*This cell test includes the first Li/Na electrolyte tested at M-C Power and a lower cost version of the stabilized cathode. Cell M0195003 has completed approximately 5160 hours of pressurized operation, as of December 29, 1996. The steady state performance at 60% fuel utilization, system gases and 3 atm. remains relatively steady at 762 mV at 160 mA/cm<sup>2</sup>. A lifograph of this cell test is attached for reference.*

**100 cm<sup>2</sup> Cell Test M0195004**

*This cell test was terminated after completing 2470 test hours after completing all planned tests. The purpose of this test was to measure the effect of the ATF and power plant start-up procedures on cell performance.*

**Subtask 5.2.1 Review and Update 250-kW Facility**

**Objective:** Under the PRDA program, M-C Power constructed and operated a 250 kW facility. The facility is located at the Unocal Fred L. Hartley Research Center, Brea, CA. The facility, after significant efforts, was commissioned and successfully operated very briefly. As a result of this effort, the start-up team (Bechtel, M-C Power, Stewart & Stevenson, and Unocal) believes that this facility represents the best chance of achieving timely testing of full-area, full-eight stacks - 250 kW class - in a cost effective way.

**Status:** *M-C Power has shut down the Unocal 250kW stack and completed a thorough investigation and evaluation of the stack at M-C Power's headquarters. A detailed report of the findings and recommendations for future stacks has been prepared and issued internally. Alternatives are being investigated regarding the use of the Unocal facility as a test site.*

**TASK 6 TECHNOLOGY DEVELOPMENT, IMPROVEMENT AND VERIFICATION**

**Objective:** The overall objective of this task is to provide the cell, stack, and BOP component technology developments, improvements and verifications and to provide the power plant product verification to bring a multi-fueled, integrated, simple, low-cost, modular, market-responsive IMHEX<sup>®</sup> molten carbonate fuel cell power plant to the marketplace. This task includes design, fabrication, construction, testing, and analysis of a MW-class (nominal 1 MW) power plant demonstration.

**Subtask 6.1 Cell Package**

**Objective:** The contractor shall improve cell package cost, performance, stability, and durability using evolutionary approaches with existing technology and innovative approaches to achieve breakthroughs. Materials, geometrics, and microstructures will be addressed. Out-of-cell, single-cell, and subscale stack tests will be used to verify and implement improvements. The contractor shall address cathode dissolution and performance, cell sealing, thermal cycling, cell package simplification, cost reduction, and component strengthening.

**Subtask 6.1.1 Active Component Unit Improvement**

**Subtask 6.1.1.1**

**Active Area Component Improvements**

**Objective:**

To complete development and verification of "Second generation" active components. IGT to document results and transfer data to M-C Power Corporation.

**Status:**

*Effort concentrated on alternate cathode development at Argonne National Laboratory. Subtask 6.1.1.1.5 has more details on this topic.*

**Subtask 6.1.1.1.1**

**Improved Cathode Performance**

**Objective:**

Contractor (IGT) shall continue efforts to improve cathode performance and endurance, including creep resistance and microstructure. Contractor (IGT) shall document the effect of  $\text{CaCO}_3$  addition to the cathode on cathode microstructure and wetting properties, primarily with Li/Na electrolytes. Contractor (IGT) shall document results with both physical mix and solid solution stabilized cathodes, clearly indicating any test conditions or post-test analyses which could confuse the conclusions.

Contractor (IGT) shall use the existing cathode microstructure and performance model to guide this effort.

**Status:**

*This subtask is complete.*

**Subtask 6.1.1.1.2**

**Alternate Electrolyte**

**Objective:**

Contractor (IGT) shall review the need for pre-wetted (with Carbonate) matrix when fiber reinforcement is used using out-of-cell tests. Contractor (IGT) shall continue evaluation of alternate electrolytes, specifically the Li/Na/K/Ca system. Contractor (IGT) shall document ionic conductivity, liquids temperature, wetting properties, cathode dissolution, and cell corrosion as a function of melt composition through literature survey updates and cell testing results. Cell testing at the  $100 \text{ cm}^2$  level will be conducted under Task 6.1.1.4.1 with post-test analysis conducted under this Task.

Contractor (IGT) shall continue operation of cell IGT-BSTC-66-93-4 and perform post-test analysis of cell IGT-66-94-1.

**Status:**

*This subtask is complete.*

**Subtask 6.1.1.1.3**

**Strengthened Anode Fabrication**

**Objective:**

Contractor (IGT) shall provide a detailed written summary and oral presentation of the status of Ni-Al anode fabrication techniques, creep data, and cell test results. Contractor (IGT) shall critically compare competing techniques on a technical basis and relative to MAUS testing performed under a previous GRI program. Contractor (IGT) shall report on results using a Ni-CrOx anode.

Contractor (IGT) shall support M-C Power's evaluation of anodes made from pre-alloyed Ni-Al powders for compatibility with MCFC requirements. Such support will consist of participation in analysis of powder morphology and pre-test and post-test anode characterizations as well as definition of processing (sintering) conditions.

**Status:**

*This subtask is complete.*

**Subtask 6.1.1.1.4**

**Cathode Dissolution**

**Objective:**

Contractor (IGT) shall quantify the effect on cell performance and cathode dissolution of stabilizer addition to the electrolyte through cell testing under Task 6.1.1.4.1. Contractor (IGT) shall identify cost-effective approaches to the stabilizer addition to the electrolyte and establish electrolyte taping procedures. Contractor (IGT) shall use Li/Na as the bulk electrolyte.

**Status:**

*Ongoing cell testing under Sub Task 6.1.1.4 will provide data for analysis under this subtask.*

**Subtask 6.1.1.1.5**

**Alternate Cathode Material**

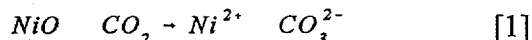
**Objective:**

Contractor (IGT) shall procure samples of alternate cathodes from Argonne National Laboratory and, if possible from ECN in the Netherlands. Contractor (IGT) shall perform the necessary characterizations to ensure proper matching of cathode, anode, and matrix. Contractor (IGT) shall perform parallel cell tests under Task 6.1.1.4 to compare Ni cathodes and stabilizing agent in the electrolyte, ANL's cathode, ECN's cathode, and stabilized Ni cathodes. Contractor (IGT) shall perform post-test analysis for these tests and report the results in a Topical Report.

In addition to the work being performed by IGT, Argonne National Laboratory will perform work related to cathode dissolution.

**Status:**

*Argonne National Laboratory is developing advanced cathodes for pressurized operation of the molten carbonate fuel cell (MCFC). The present cathode, lithiated nickel oxide, tends to transport to the anode of the MCFC where it is deposited as metallic nickel. The rate of transport increases with increasing CO<sub>2</sub> pressure due to an increased solubility of nickel oxide (NiO) in the molten carbonate electrolyte via the reaction:*



*Although a life of 40,000 hours is projected for MCFCs operated at 1 atm and a low CO<sub>2</sub> partial pressure (about 0.1 atm), transport of nickel to the anode at a higher pressure (e.g., 3 atm) and a high CO<sub>2</sub> partial pressure (e.g., about 0.3 atm) is thought to be too high for an acceptable life. This transport is expected to lead eventually to poor MCFC performance and/or shorting.*

*The advanced cathodes currently being developed at Argonne National Laboratory are lithium ferrate (LiFeO<sub>2</sub>) and lithium cobaltate (LiCoO<sub>2</sub>). Their transport to the anode is expected to be lower than that of NiO. The transport of LiFeO<sub>2</sub> is thought to be zero because Fe<sup>2+</sup> is not reduced at the anode. Although Co<sup>2+</sup> is reduced to metallic cobalt at the anode by a reaction similar to reaction [1], the LiCoO<sub>2</sub> cathode has a lower rate of transport than NiO because of a significantly lower solubility in the MCFC electrolyte (more than a factor of ten lower than NiO).*

*The LiFeO<sub>2</sub> cathode, because of its high resistivity (about 300 ohm-cm), cannot be employed as a direct substitute for the lithiated NiO cathode, which has a resistivity of about 0.1 ohm-cm. Instead, dopants are required to improve the*

resistivity of the  $\text{LiFeO}_2$  cathode to an acceptable level (about 1 ohm-cm); development of an appropriate combination of dopants was the focus of much of prior work at ANL. The  $\text{LiCoO}_2$  cathode, which has a resistivity of about 1 ohm-cm without being doped, is being developed as a direct substitute for the lithiated  $\text{NiO}$  cathode.

Recent studies of the  $\text{LiFeO}_2$ - $\text{LiCoO}_2$ - $\text{NiO}$  phase diagram are presented. These studies are being conducted to aid in optimizing the composition of the doubly doped  $\text{LiFeO}_2$  cathode. Conductivity data from selected solid solutions are presented.

#### PHASE DIAGRAM STUDIES

The solubilities of  $\text{NiO}$  and  $\text{LiCoO}_2$  in  $\text{LiFeO}_2$  are being measured to aid in optimizing the doubly doped  $\text{LiFeO}_2$  cathode composition. Last quarter, some results from compositions along the  $\text{NiO}$ - $\text{LiFeO}_2$  join were presented. These data indicate that a continuous solid solution exists along the  $\text{NiO}$ - $\text{LiFeO}_2$  join. We repeated the conductivity experiments on better-quality pellets and extended the measurements to include the effect of  $\text{CO}_2$  partial pressure on resistivity. The resistivity data (in 57:43  $\text{CO}_2$ : $\text{O}_2$ ) collected at 650°C are given in Table 1.

Table 1. Resistivity of  $\text{NiO}$ - $\text{LiFeO}_2$  Solid Solutions

Mole fraction $\text{NiO}$	Resistivity at 650°C, ohm-cm
0.03	99.3
0.06	101.8
0.25	41.1
0.5	10.9
0.875	1.08

As expected, the resistivity of the solid solution decreases with  $\text{NiO}$  concentration. All resistivity data are given in Fig. 1; from the figure, some change in resistivity is seen with change in the  $\text{CO}_2$ : $\text{O}_2$  ratio. These changes have been reported for other materials in the  $\text{LiFeO}_2$ - $\text{LiCoO}_2$ - $\text{NiO}$  system.

X-ray diffraction data from compositions along the  $\text{LiCoO}_2$ - $\text{LiFeO}_2$  join show that there are two regions of homogeneity. Typical X-ray diffraction results are given in Fig. 2. Here, peaks of interest from  $\text{LiCoO}_2$  and  $\text{LiFeO}_2$  are indicated by circles and triangles, respectively. Data from a series of compositions are plotted as the percent  $\text{LiCoO}_2$  peak intensity versus  $\text{LiCoO}_2$  concentration (see Fig. 3). Here, the percent  $\text{LiCoO}_2$  peak intensity is defined as

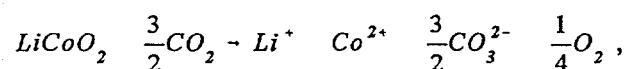
$$\% \text{LiCoO}_2 \text{ peak intensity} = \frac{I_{\text{LiCoO}_2}}{I_{\text{LiCoO}_2} + I_{\text{LiFeO}_2}} \times 100\%$$

where  $I_{\text{LiCoO}_2}$  and  $I_{\text{LiFeO}_2}$  are the peak intensities from  $\text{LiCoO}_2$  and  $\text{LiFeO}_2$ ,

respectively. At low (0 to about 6 m/o)  $\text{LiCoO}_2$  concentrations, no peaks due to excess  $\text{LiCoO}_2$  were seen. At high (85 to 100 m/o)  $\text{LiCoO}_2$  concentrations, no peaks due to excess  $\text{LiFeO}_2$  were seen. Diffraction peaks due to free end-member oxides were clearly seen at the intermediate compositions.

Similarly, two regions of homogeneity were seen along the  $\text{NiO-LiCoO}_2$  join. At low (0 to about 15 m/o)  $\text{LiCoO}_2$  concentrations, no peaks due to excess  $\text{LiCoO}_2$  were seen; at high  $\text{LiCoO}_2$  concentrations (95-100 m/o), no peaks due to excess  $\text{NiO}$  were seen.

All phase compositional data are plotted in the form of a phase diagram (see Fig. 4). We have drawn proposed solid solution boundaries for the ternary  $\text{LiFeO}_2\text{-LiCoO}_2\text{-NiO}$  system in Fig. 4 based on our results. Interestingly, the doubly-doped  $\text{LiFeO}_2$  compositions which were tested in  $5 \times 5\text{-cm}$  cell tests lie outside the proposed boundaries. This, in part, may explain the high Co-migration from doubly-doped cathodes which was reported earlier. The observed Co migration may also be exacerbated by the dissolution reaction,



acting on the free  $\text{LiCoO}_2$

Two new compositions are being prepared (in m/o): 74  $\text{LiFeO}_2$ , 20  $\text{NiO}$ , 6  $\text{LiCoO}_2$ ; and 70  $\text{LiFeO}_2$ , 25  $\text{NiO}$ , 5  $\text{LiCoO}_2$ . These compositions will further refine the solid solution limits in the ternary. If they are indeed solid solutions, they will be tested in  $5 \times 5\text{-cm}$  cells. These results will be discussed next quarter.

#### MCFC TESTS

The effects of porosity in  $25\text{-cm}^2$   $\text{LiCoO}_2$  cathodes are being investigated. The porosity is altered by changing the fibers-to-fines ratio in the cathode. (The fibers are made by spraying a suspension of powder in organic binders and subsequently firing them). We reported last quarter that the 3:1 fibers-to-fines ratio appears to be slightly better than the 2:1 ratio. A cathode consisting of a 4:1 ratio of fibers to fines was tested this quarter. The performance of the 4:1 ratio was comparable to that of the 2:1 ratio. Thus, the 3:1 seems near the optimum ratio of fibers-to-fines.

#### **Subtask 6.1.1.2**

##### **Objective:**

#### Alternate Cell Package Development

To simplify cell and stack fabrication, assembly, and conditioning through modified cell package and component design, integrated manufacturing, and out-of-cell conditioning.

#### **Subtask 6.1.1.2.1**

##### **Objective:**

#### Alternative Cell Package Design & Development

Contractor (IGT) shall continue development and evaluation of cell package designs which involve elimination of electrode ledges to reduce differences in stiffness between the wet seal and active areas of the cell. Contractor (IGT) shall quantify the effect of direct contact of electrodes with the opposing gas (i.e., anode and oxidant, cathode and fuel). Contractor (IGT) shall evaluate cell sealing approaches including a matrix "gasket", electrode densification (coining), and "welding" of electrode and/or current collector to the plate. Contractor (IGT) shall conduct verification testing in  $100\text{ cm}^2$  under Task 6.1.1.4.2 with appropriate atmospheres and pressure differentials.



Contractor (IGT) shall design and construct out-of-cell screening tests for edge sealing evaluation.

**Status:**

*Approach: Extending the anode to the outside edge of the wet seal and to the inside edge of the oxidant manifold requires that the exposed edge of the anode be rendered electrochemically inert to prevent the formation of parasitic cells in those areas. These parasitic cells will decrease the cell OCV. The feasibility of rendering the parasitic cells inactive can be tested economically using 3 cm<sup>2</sup> as a screening tool. An anode, treated in such a way to make it inert when exposed to the oxidant, is used as a cathode in a standard 3 cm<sup>2</sup> cell assembly. For the approach to work, the 3 cm<sup>2</sup> cell must show a very high cathode polarization, a very high cathode resistance or both, essentially making it a non-working cathode. If the cathode polarization, the cathode resistance, or both, are high enough, very little current will flow under normal operating conditions, in which case we can say that the expected parasitic current in an actual cell will be very low or negligible and the type of anode and its protection will work well extended to the outer edge of the cell. Cells SPM-T87 and SPM-T88 were started during the quarter to evaluate aluminum for this purpose.*

Cell SPM-T87. This cell was started with green Ni-3Al tapes as both anode and cathode and with the cathode also having Al paint on both faces. Although, as expected, the cell showed very high cathode polarization and high cathode resistance, they were not high enough. At the normal operating cell potential of 880 to 900 mV, a current density of 40 mA/cm<sup>2</sup> could be obtained, suggesting that a Ni-3Al green tape anode extended to the outer edge of the cell and with Al paint protection at the outer edge and at the manifolds, would show low OCV due to a high parasitic current at the outer edge and at the oxidant manifolds.

Cell SPM-T88. This cell was started with a sintered Ni-3Al anode and a sintered Ni-3Al cathode painted with Al paint on both sides. Cell SPM-T88 was operated 120 hours and showed only a 1 mA/cm<sup>2</sup> current density at the normal operating cell potential of 890 to 900 mV and the cell resistance was approximately 450 times higher than normal. This indicates that a bench scale cell with this type of Ni-3Al anode extended to the edge and protected with Al-paint at the outside edge and at the manifold areas would show negligible short circuit current and normal performance can be expected. On termination, the Al-coated cathode separated cleanly from the matrix and the cathode current collector and it looked metallic on the two faces and dark gray to black in the middle. The room temperature electrical conductivity of the two faces and the middle was measured. The room temperature resistance was infinite in one side and 2 to 3 megohms in the other. The middle showed 10 to 12 k-ohms.

The results of cell SPM-T88 indicate that it might be possible to extend the anode to the outer edge of the cell, if the anode is Ni-3Al and well protected with aluminum paint at the outside edge and the manifold areas. Clearly the anode material should be stable, not only under the normal anode conditions but under the oxidizing condition at the edge. This eliminates Cr-containing anodes as a possible material because Cr forms soluble lithium chromate under oxidizing conditions.

On the other hand, aluminum-containing anodes, for example the Ni-3Al of Cell SPM-T88, will form insoluble Al<sub>2</sub>O<sub>3</sub> or LiAlO<sub>2</sub>. Ni-3Al anodes, however, have not been fully developed and tested in bench scale cells.

**Subtask 6.1.1.2.2**

**Advanced Cell Package Fabrication**

**Objective:**

Contractor (IGT) shall, under the IHI program, define and evaluate approaches and techniques for laminating active cell components during initial manufacture. Contractor (IGT) shall address cutting and handling of "green" laminates.

Contractor (IGT) shall process "green" laminates into cell packages and conduct verification testing in 100 cm<sup>2</sup> single cells under this Task.

**Status:**

*A topical report is being prepared.*

**Subtask 6.1.1.2.3**

**Out of Cell Component Preconditioning**

**Objective:**

Contractor (IGT) shall, under the IHI program, define and evaluate techniques for out-of-cell conditioning of the laminated cell packages prepared under Task 6.1.1.2.2. Contractor (IGT) shall demonstrate the performance in 100 cm<sup>2</sup> under this Task. Contractor (IGT) shall address cutting of conditioned laminates using techniques amenable to mass production at commercial scale.

**Status:**

*A topical report on cell package lamination and out-of-cell conditioning is being prepared.*

**IGT-BS-TC-42-95-5Cell**

*Cell IGT-BS-TC-42-95-5 was assembled with the first version laminate and the cathode current collector both extended to the wet seal. The only other active component provided was a Ni+5Cr anode which was placed within the housing along with a perforated nickel current collector. The purpose of this test was to evaluate the performance of the out-of-cell preconditioned laminated package fabricated with the Li/Na electrolyte. The reference fuel and oxidant gas flows were set for 75% fuel and 50% oxidant utilizations at 160 mA/cm<sup>2</sup>. The cell performance at 160 mA/cm<sup>2</sup> was initially 532 mV and decreased to 465 mV with time due to an increase in polarization. The cell could not be loaded to 160 mA/cm<sup>2</sup> until 264 hours of operation due to high IR. The cell resistance was initially high at 86 mohms and decreased to 6 mohms with time due to an incremental increase in clamping force. The OCV of 1046 mV was 3 mV higher than the theoretical value of 1043 mV. The anode and cathode wet seal efficiencies were 100% and 99%, respectively, and the nitrogen crossover was very low at 0.3%. In view of the poor cell performance the cell test was terminated after 504 hours of operation.*

*Post test examination of the components showed strongly bonded active components except between the cathode and the cathode current collector. The cathode current collector seemed to be in contact with the cathode at the central region only. This could be the cause of the high cell IR. It should be noted that the perforated stainless steel plate supporting the cathode side of the laminate during pre-conditioning was used as the cathode current collector for this cell. During handling, the perforated plate detached from the cathode and peeled away some cathode material with it. When the plate was placed back on the cathode, the plate may not have perfectly fit within its original footprint thus creating uneven contacts.*

**Subtask 6.1.1.3**

**Corrosion, Modeling and Performance**

**Objective:**

To test separator plate materials in bench-scale fuel cells. To maintain and upgrade the Cathode Performance Model. To increase and optimize the active cell package

performance.

**Subtask 6.1.1.3.1**

**Corrosion**

**Objective:**

Contractor (IGT) shall analyze post-test separator plate materials from 100 cm<sup>2</sup> cells operated under Task 6.1.1.4. Contractor (IGT) shall supply post-test metallographic analysis and cell operating data to M-C Power.

**Status:**

*Samples of a metal with the potential for service are being investigated. No significant progress to report on this subtask during this reporting period.*

**Subtask 6.1.1.3.3**

**Performance**

**Objective:**

Contractor (IGT) shall continue efforts to improve MCFC performance including stability.

**Subtask 6.1.1.3.3.1**

**Define Baseline Cell Package**

**Objective:**

Contractor (IGT) shall define the Baseline Cell Package and propose improvements within 30 days of contract execution. The definition shall include raw materials, processing procedures, component dimensions, startup procedures, and typical performance and stability.

**Status:**

*This subtask was completed..*

**Subtask 6.1.1.3.3.2**

**Define Initial Advanced Cell Package**

**Objective:**

Contractor (IGT) shall define an initial Advanced Cell Package using Li/Na electrolyte, NiAl anode, and cathode stabilization (either by CaCO<sub>3</sub> in the electrolyte or the cathode) based on data obtained in prior programs. Contractor (IGT) shall perform cell tests of the advanced cell package under subtask 6.1.1.4 and use the results to modify and improve the Advanced Cell Package. Post-test analysis will be conducted under this subtask.

**Status:**

*This subtask was completed..*

**Subtask 6.1.1.3.3.3**

**Define Performance Limits**

**Objective:**

Contractor (IGT) shall estimate the limits of performance (current density, voltage) at present systems conditions and propose ways to achieve the limit, emphasizing cell components. Contractor (IGT) shall propose approaches to double the current density.

**Status:**

*Efforts are being made to increase the active cathode surface area. One method is to use high surface area Ni. To provide large pores for efficient gas transport, the high surface area powder will be formulated in such a way that it forms a foamed structure. Initial attempts at making the foamed structure have been encouraging. Pore size distribution of the preliminary porous structure shows pores for efficient gas transport. The process is now being scaled up to prepare 100 cm<sup>2</sup> size cathode cell testing. Powders for the 100 cm<sup>2</sup> cathodes have been prepared.*

**Subtask 6.1.1.3.3.4**

**Optimize Cell**

**Objective:**

Contractor (IGT) shall fabricate components based on the finding of Task 6.1.1.3.3.3 for testing in 100 cm<sup>2</sup> cells under subtask 6.1.1.4.

**Status:**

**Decrease Cathode Tortuosity**

*Approach: Computer modeling was used to study the effects of the BET surface area, thickness, electrolyte filling, and tortuosity on the performance of the cathode. The results indicated that two ways to improve the cathode performance would be to increase the surface used for the electrochemical reaction and to decrease cathode tortuosity. For this purpose we are attempting to align the pores perpendicular to the plane of the electrode. This will decrease tortuosity, shortening the path length for the ionic and electrical current transport in the cathode resulting in improved cathode performance. A good structure was obtained and Cell 2-MOLS was assembled.*

*During the period, Cell 2-MOLS was terminated and Cell 3-MOLS was started and terminated. Cell 2-MOLS had been started in September. Cell 3-MOLS had the same type of components as Cell 1-MOLS and was started to check the reproducibility. Also during the period, two samples of Ni cathode were prepared for SEM analysis. Both tapes were made from the same Ni slurry and sintered the same way but only one had aligned pores.*

#### Cell 2-MOLS.

*This cell began life exhibiting poor performance. It used a cathode with aligned pores that was sintered before cell assembly. The cathode tape had many void-like cavities caused by trapped bubbles of air during taping.*

*Cell 2-MOLS reached a peak potential of 940 mV at 160mA/cm<sup>2</sup>, with 25 and 42 mV anode and cathode polarization and 49 mV IR-drop. At termination the cell potential, anode and cathode polarization and IR-drop at 160mA/cm<sup>2</sup> were 921 mV, 35 mV, 45 mV, and 57 mV, respectively. The small 19 mV decay was caused by increases in the anode polarization and IR-drop. As seen in Figure 6.1.1.3.3.4.1, the cathode polarization was stable at 42 to 48 mV. The cathode polarization (45 mV) and the cathode IR (40 mV) are somewhat high, compared to that obtained in Cell 1-MOLS, possibly due to the voids caused by the trapped air during the taping.*

#### Cell 3-MOLS.

*This cell was started and terminated during the period. The test had similar components to those used in Cell 1-MOLS and was started to study the reproducibility of the green tape cathode. Cell 3-MOLS reached 930 mV potential at 160mA/cm<sup>2</sup>, with 36 and 50 mV anode and cathode polarization and 42 mV IR-drop, but decay was fast. The cell developed problems with the reference electrodes and carbonate was added to the reference electrode pockets, which possibly resulted in cathode flooding. This was diagnosed by adding carbonate, which caused a 20 mV increase in the cathode polarization.*

*The results obtained with these tapes indicate that the electrodes made by this technique have decreased the cell IR-drop and improved carbonate distribution. Further testing is required to fully assess the benefits of the technique.*

#### Thin Anode

*The approach being developed is to substantially reduce the thickness of the anode and anode current collector without sacrificing performance. The anode is prepared by applying slurry onto a green lithium aluminate tape thus avoiding the cost of sintering the anode.*

### Cell 5-PALS.

*This 3 cm<sup>2</sup> cell was started in September with a Ni-3Al anode, a Ni expanded metal anode current collector backed by a 3-rib separator section, a Gould Ni cathode, reinforced matrix, and standard Li/K electrolyte. The cell reached 883 mV at 160 mA/cm<sup>2</sup> after 72 hours of operation, with 38 mV anode polarization and 61 mV IR-drop. This performance was below average.*

*Cell 5-PALS was terminated during October. This cell suffered through a failure of the oxidant supply at 350 hours but recovered most of its performance within 100 hours. The cell demonstrated that achieving and maintaining high cell potential is possible with anodes. However, a slight deformation of the anode was observed.*

### Cathode Depolarization.

*Approach: Work performed in September, led to the discovery of a method for substantially lowering cathode polarization. Several cells have been depolarized and results indicate that the cathode performance of lab-scale cells improves substantially as the result of a drop in cathode polarization. Cells 2-MOLS and 5-PALS, terminated during October, showed low cathode polarization and stable performance after the cathode was subjected to the depolarizing process. Cell SPM-T85, also subjected to the cathode depolarizing process, was terminated after 2000 hours of operation. Cell SPM-T86 was started with the same type of components as SPM-T85 to study the changes in cell performance with temperature before and after the depolarizing process. One test conducted using a bench-scale cell, however, did not show a performance improvement.*

*Cell SPM-T85: This cell was started during September with standard components with the purpose of verifying the reproducibility of the cathode depolarization process in a cell with standard components. At steady state the cell potential was 918 mV at 160 mA/cm<sup>2</sup>, with 38 mV anode and 47 mV cathode polarization and 51 mV IR-drop. This performance is above the average of approximately 900 mV. As in previous cases, lower cathode polarization was the main cause of the performance gain.*

*Figure 6.1.1.3.3.4.5 is the lifograph of Cell SPM-T85. The depolarizing process was done at 288 hours, again at 1272 hours, and finally before termination at 1872 hours. The cell improved only 7 mV with the second depolarizing process. As can be seen in the figure, after 1848 hours the cell shows a small (16 mV) decay in performance from the peak 940 mV cell potential obtained after the first time it was depolarized due to an increase in the IR-drop. At this point we added 12 mg of carbonate to check if the decay was due to carbonate losses; the cell improved only 4 mV with the addition. At 1872 hours we depolarized the cell for the last time and the cell performance improved another 8 mV. At termination, the test was showing 935 mV cell potential and the IR-drop had increased approximately 10 mV. This test demonstrates that the cathode modification caused by the depolarizing process is permanent.*

*Cell SPM-T86: In October the change in the cell potential with temperature was studied in the range of 575° to 675°C, after the depolarizing process was performed in Cell SPM-T85. Comparison of these results with previous tests conducted several years ago using cells that were not subjected to the cathode depolarizing process indicate that the depolarization lowers the sensitivity to temperature, especially at*

*temperatures below 625°C. Unfortunately, it is difficult to make comparisons using different cells. Therefore, Cell SPM-T86, with the same type of components as SPM-T85, was started in November to measure the impact of temperature on performance before and after the depolarizing process using the same components.*

*The performance of Cell SPM-T86 is presented in Figure 6.1.1.3.3.4.6. Polarization curves between 575°C and 675°C prior to depolarizing the cathode were obtained when the cell reached steady state, after 288 hours of operation. The cathode was depolarized at 480 hours and the polarization curves between 575°C to 675°C after the depolarizing process was generated.*

*The results indicate that the largest impact of the depolarizing process on the cell performance is seen at 575°C. The changes in cell potential, cathode polarization, and IR-drop with the temperature before and after the depolarization are seen in Figures 6.1.1.3.3.4.7 to 6.1.1.3.3.4.9 and summarized in Table 6.1.1.3.3.4.1.*

*At 575°C and 160 mA/cm<sup>2</sup> the cell potential after the depolarizing process is 78 mV higher than what it was prior to the depolarizing process. Of the 78 mV gain, 62 mV are due to lower cathode polarization, 6 mV due to lower anode polarization, and 10 mV due to lower IR-drop. At 575°C and 240 mA/cm<sup>2</sup> the cell potential after the depolarizing process is 105 mV higher than what it was prior to the depolarizing process, of which 80 mV are due to lower cathode polarization, 10 mV due to lower anode polarization, and 15 mV due to lower IR-drop.*

*At 675°C the cell potential improves 19 mV at 160 mA/cm<sup>2</sup> and 29 mV at 240 mA/cm<sup>2</sup> after depolarizing of which 17 mV at 160 mA/cm<sup>2</sup> and 26 mV at 240 mA/cm<sup>2</sup> are due to lower cathode polarization. An Arrhenius plot, a plot of the log of the cathode polarization vs the reciprocal of the absolute temperature is presented in Figure 6.1.1.3.3.4.10. As seen in Figure 6.1.1.3.3.4.10, the change in log of the cathode polarization with the reciprocal temperature changes from linear before the depolarization process to non-linear after. We are not sure what this change implies, but it might indicate that the reaction mechanism has changed to a composite one and that some type of physical change has taken place in the cathode.*

*The changes in performance with the depolarizing process have been observed in lab-scale cells with Li/K electrolyte. These gains in cell performance suggest that it might be possible to lower the operating stack temperature to 625°C and still obtain higher cell performance. Because the highest performance improvement is seen at 575°C, the current density of the stack, and therefore the temperature distribution, can be expected to be more uniform with lower maximum temperature. The depolarizing process was attempted in a bench-scale cell with a Li/Na electrolyte but no gains were seen. Bench-scale cell PDI-1 was first depolarized while under system gases at 3 atmospheres and the cell performance dropped to 580 mV from 730 mV. The same cell was again depolarized before termination but under reference gases at 1 atmosphere with no gains or losses. It is not known whether the differences in lab-scale and bench-scale tests is the result of different electrolyte compositions or different electrode structures. Currently we are preparing to start one 3 cm<sup>2</sup> cell with a Li/Na electrolyte to study the depolarizing process. The components of Cells SPM-T85 and -T86 also will be analyzed.*

#### Subtask 6.1.1.4

##### Objective:

##### Verification Testing

To provide cell testing support for subtasks 6.1.1.1, 6.1.1.2, and 6.1.1.3 and for M-C Power.

Contractor (IGT) shall conduct 100 cm<sup>2</sup> single-cell tests in support of the other tasks in this program. Contractor (IGT) shall install and commission four pressurized 100 cm<sup>2</sup> single cell test facilities.

##### Status:

##### Bench-Scale Testing

*An overall summary of the cell tests conducted to date in this task is presented in Table 6.1.1.4.1. The performance of the cells that are in operation is summarized in Table 6.1.1.4.2. These tables are located on pages 35 and 36, respectively.*

##### Cell IGT-BS-TC-66-93-4

*Cell IGT-BS-TC-66-93-4 was started in January 1994 under DOE Contract DE-AC21-90MC27394 to verify the excellent performance of Cell IGT-BS-TC-66-93-3 which employed a Li/Na electrolyte with a stabilized cathode.*

*Cell IGT-BS-TC-66-93-4 was temporarily shut down after ~ 6000 hours of operation due to IGT's relocation to Des Plaines. Prior to termination the cell performance, IR, and polarization at 160 mA/cm<sup>2</sup> were 784 mV, 45 mV, and 214 mV, respectively. The OCV of 1044 mV closely matched the theoretical value of 1043 mV. The anode and cathode wet seal efficiencies were 97% and 99%, respectively, with negligible (0.2%) nitrogen gas crossover. The cell was clamped, stored at room temperature in a dry box for ~ 650 hours (27 days) and restarted on September 14, 1994 at IGT's Energy Development Center (EDC).*

*The performance graph of Cell IGT-BS-TC-66-93-4 is shown in Figure 6.1.1.4.1 before and after the thermal cycle. The results indicate that during the last 700 hours of cell operation the performance at 160 mA/cm<sup>2</sup> decreased from 719 mV to 716 mV due to an increase in polarization. The anode and cathode wet seal efficiencies are 83% and 99%, respectively. Also, during this period, the open circuit voltage (OCV) was stable and the nitrogen crossover increased from 6.7 to 7.3%. Nitrogen crossover of this magnitude could account for the observed low open circuit voltage. The OCV decay rate was determined to be 4 mV/1000 hours from 7778 (after restart) to 16850 hours of operation. This decay is attributed to the increase of nitrogen gas crossover from 1.2 (after restart) to 7.3% with time.*

*During the 16850 hours of operation the cell decay rate was 2 mV/1000 hours from 7778 (after restart) to 16850 hours of operation. Operation of Cell IGT-BS-TC-66-93-4 was terminated on December 11, 1995 after 16850 hours of operation (~ two years). During this period this single cell generated more than 200 kW-hours of power.*

*Post-test disassembly of Cell IGT-BS-TC-66-93-4 revealed that the exterior of the cathode flange was clean without any sign of severe corrosion or salt deposition. The exterior of the anode flange which was on top, however, had shiny white crystalline deposits all throughout the fuel outlet side. There was no protection made for the cathode wet seal. Yet, the cathode wet seal was clean and metallic. The anode wet seal was protected with a 2-mil aluminum foil. The matrix was strongly bonded to*

*this side of the wet seal and corrosion of the base metal under it was minimal. The cathode current collector spalled and the scale fell off into the gas channels but the severity was comparable to those of shorter term (2000 to 5000 hours) cell tests. The gas channels of the cathode flange also exhibited signs of spalling. All the scale from the cathode current collector and gas channels was collected and will be analyzed for carbonate inventory. The anode current collector was metallic on both sides.*

*The active components were entirely and strongly bonded together, a sign of good fit-up and uniform clamping force distribution. The anode was able to be separated from the matrix. It was fairly metallic and light grey in color. It had a few tiny lumps near the center on the matrix side. On the gas side, these lumps correspond to balls of salt deposits in the holes of the anode current collector. The salt may be from the stabilized Ni cathode.*

*Cell IGT-BS-TC-66-93-4 was terminated and transported from IGT's State Street facility to EDC after 6000 hours of operation. After re-start at EDC, the cell IR and polarization were higher than the respective values before the thermal cycle. The post-test cathode current collector was slightly bowed up at the center. It has been our experience that IR is generally high if the cathode current collector is bowed after the test. It is conceivable that the bowing might have occurred during the second heat-up.*

*Post test analysis will be performed during the next reporting period.*

#### Cell IGT-PDI-1

*The purpose of this cell test is to evaluate the baseline characteristics of the Li/Na/ electrolyte at 1 and 3 atm pressures with system gases. The cell startup occurred with system gases and system conditions were maintained from the beginning of the test without a stabilizing period on reference gases.*

*Cell IGT-PDI-1 operated for 2352 hours and was terminated after achieving its test goal of 2000 hours of operation under system conditions. The cell operated for 480 hours at 1 atm and under system conditions. The cell performance at 160 mA/cm<sup>2</sup> (75% U<sub>2</sub>F and 40% U<sub>2</sub>O) under these conditions increased from 660 mV to 708 mV due to a decrease in IR (32 mV) and polarization (16 mV).*

*The cell was then pressurized to 3 atm under system conditions. The cell performance at these conditions and 160 mA/cm<sup>2</sup> increased from 732 mV to 745 mV due to a decrease in polarization. The observed performance improvement of 37 mV from 1 to 3 atm was ~ 33% lower than that predicted by the PSI model. The cell performance then decreased from 745 mV to 733 mV with time due to an increase in IR and polarization. The overall cell decay rate was ~ 11 mV/1000 hours from 480 to 2352 hours of operation at 3 atm. Also, before termination, two cathode depolarization tests were conducted on Cell IGT-PDI-1 to verify the performance gain of 20 mV obtained in a lab scale (3 cm<sup>2</sup>) cell. After the first test, the cell lost 14 mV (730 mV to 716 mV) and slowly regained the potential of 731 mV. The second cathode depolarization test conducted resulted in a performance loss of 185 mV (744 mV to 559 mV). These two test results indicate that the cathode polarization did not work in this 100 cm<sup>2</sup> bench-scale and could not confirm the performance gain (20 mV) experienced in the 3 cm<sup>2</sup> lab scale cell.*



*Post test cell disassembly showed that the porous components were strongly bonded together suggesting good component contacts during operation. The anode was black and oxidized, a possible reason for poor performance. Carbonate crystals deposited around the gas flow tube fittings and on the bottom of the anode flange suggest carbonate creepage. A sample of active components were obtained from the central region of cell active area for carbonate analysis.*

#### Cell IGT-PDI-2

*The purpose of this cell test is to establish the baseline characteristics of a cell having a cathode stabilizing agent added to the electrolyte at 1 and 3 atm pressures under system conditions. The cell start-up occurred with system gases and system conditions were maintained from the beginning of the test.*

*Cell IGT-PDI-2 operated for 2352 hours and was terminated after achieving its test goal of 2000 hours of operation under system conditions. The cell operated for 432 hours at 1 atm and under system conditions. The cell performance under these conditions and at 160 mA/cm<sup>2</sup> (75% U<sub>F</sub> and 40% U<sub>O</sub>) increased from 633 mV to 684 mV due to a decrease in IR (39 mV) and polarization (12 mV).*

*The cell was then pressurized to 3 atm under system conditions at about 432 hours of operation. The cell performance under these conditions and at 160 mA/cm<sup>2</sup> was ~ 755 mV. The observed performance improvement of 71 mV from 1 to 3 atm was ~ 29% higher than that predicted by the PSI model. The performance then decreased slowly from 755 mV to 730 mV with time due to an increase in cell polarization. The overall cell decay rate was determined to be ~ 15 mV/1000 hours from 430 hours to 2352 hours of operation at 3 atm.*

*Upon cell disassembly, the components looked normal. There were salt deposits on the gas side of the anode. From the looks of the post test components, it is difficult to tell the cause of poor performance of this cell. Samples of porous components from the central region of the cell have been obtained. They will be analyzed for carbonate inventory to determine the carbonate distribution among the components.*

#### Cell IGT-BS-TC-42-95-4

*A special 6" x 6" 2-cell stack hardware was designed and fabricated to test electrodes to the edge. The purpose of this subtask is to determine the effects of the gas atmosphere on electrodes exposed to opposing gases; that is, the effect of the oxidant air on the anode and of the fuel on the cathode. Two cell tests were conducted this quarter to determine the effects of opposing gas atmospheres on electrodes extended to the edge.*

*The purpose of this two cell (6" x 6") stack test was to determine any deleterious effects of the gas atmospheres on the electrodes exposed to opposing gases in the manifolds and peripheral edges during cell operation. This cell test was basically a repeat of Cell IGT-BS-TC-42-95-3 with the following exceptions.*

- 1. Electrodes were protected by wrapping with a thicker, 2 mil aluminum foil (0.25" overlap) instead of the 1 mil foil employed for Cell IGT-BS-TC-42-95-3.*
- 2. For the anode and cathode, both the periphery and the edges exposed to all the four*

*manifolds (two fuel and two oxidant) were protected with the aluminum foil.*

*The results indicated that the initial OCV for the stack was within 165 mV of the theoretical value of 2086 mV and thereafter the OCV and performance of the stack, Cell 1 and Cell 2 gradually decreased with time. The drop in OCV and performance was primarily due to the existence of parasitic currents between the cell active area, gas manifolds, and the cell peripheral edges. Gas analyses obtained on the fuel outlet at OCV confirmed the existence of these parasitic currents. The results also indicated that the magnitude of these parasitic currents was high at 74 mA/cm<sup>2</sup> initially but dropped to 41 mA/cm<sup>2</sup> in about 43 hours of operation. The magnitude of these currents then increased slowly from 41 mA/cm<sup>2</sup> to 51 mA/cm<sup>2</sup> with time and stabilized at 49 mA/cm<sup>2</sup>. In view of the OCV and performance decay with time, Cell IGT-BS-TC-42-95-4 was terminated after 382 hours of operation. The performance data of Cell IGT-BS-TC-42-95-4 showed that even the 2 mil thick aluminum foil did not effectively protect the edges and alternatives have to be found.*

#### Cell IGT-BS-TC-42-95-6

*In an attempt to systematically determine the deleterious effects of the opposing gas atmospheres on the electrodes, another 6" x 6" cell test, IGT-BS-TC-42-95-6 was assembled and started in November, 1995.*

*The purpose of this two cell (6" x 6") stack test is to determine the deleterious effect of the gas atmosphere on the exposed cathode in the fuel manifolds. In this test, only the cathode was extended to the edge and all other components, i.e. anode, and both current collectors were housed inside the cell.*

*The normal bench-scale startup schedule was employed for this test and the reference fuel (75H<sub>2</sub>/25CO<sub>2</sub>) and oxidant (70Air/30CO<sub>2</sub>) gas flows were set for 75%U<sub>F</sub> and 50%U<sub>O</sub> at 160 mA/cm<sup>2</sup> based on 50 cm<sup>2</sup> active area.*

*The performance of the stack, Cell 1 and, (bottom), Cell 2 (top) at 160 mA/cm<sup>2</sup> and as a function of time is shown in Figures 6.1.1.4.2.1 and 6.1.1.4.2.2. The results indicate that the initial OCV for the stack was within 25 mV of the theoretical value of 2086 mV and thereafter the OCV and the performance of the stack gradually decreased with time. Also, the initial performance of Cell 1 and Cell 2 at a current density of 160 mA/cm<sup>2</sup> was 743 mV and 719 mV, respectively. The gas analysis conducted on the fuel outlet at OCV initially indicated the existence of a parasitic current of 16 mA/cm<sup>2</sup>.*

*Since last month the performance of Cells 1 and 2 decreased from 743 mV and 719 mV to 717 mV and 564 mV, respectively, due to an increase in polarization. Also, Cell 2 could not sustain a current density of 160 mA/cm<sup>2</sup>. The magnitude of the parasitic current determined by the gas analysis conducted on the fuel outlet at OCV remained stable at the 16 to 18 mA/cm<sup>2</sup> level. The anode and cathode wet seal efficiencies are 100% and 98%, respectively, and the nitrogen crossover varied from 1.2-1.9%. In view of the poor performance of Cell 2, the test was terminated after 309 hours of operation. Post-test disassembly indicated that the poor performance of Cell 2 was due to anode oxidation.*

*Upon post test disassembly, the active components showed good adherence with each*

*other. The cathodes looked normal but, for Cell 2, the poor performing cell, there was an oxidation pattern on the anode. It was dark at the hole area of the current collector and metallic at the covered area, suggesting a reaction by an oxidizing gas. It was further observed that in the area between the oxidant blocker and the active area the anode side of the matrix was brown suggesting oxidant leakage through the blocker into the anode side. The poor performance of Cell 2 was due to anode oxidation.*

#### Cell IGT-PDI-5

*The purpose of this cell test is to establish the performance characteristics of a cell operating at 3 atm pressure and 250 mA/cm<sup>2</sup> with system fuel and a market entry oxidant (MEO) specified by M-C Power. Operation of Cell IGT-PDI-5 continued this month at 3 atm and 250 mA/cm<sup>2</sup> with the system fuel and MEO. The cell performance as a function of time and pressure is shown in Figure 6.1.1.4.3.1. The data indicate that since last month the cell performance at a current density of 250 mA/cm<sup>2</sup>, 75% U<sub>F</sub>, and 40% U<sub>O</sub> is stable at 740 mV. The anode and cathode wet seal efficiencies are 97% and 100%, respectively, and the nitrogen gas crossover is low at 0.6%. To date, the cell has operated for 1632 hours and will continue its operation next month.*

#### Cell IGT-PDI-6

*The purpose of this test is to determine the performance characteristics of a cell operating at 3 atm and 250 mA/cm<sup>2</sup> with system fuel and a market entry oxidant (MEO). The cell performance as a function of time at 1 atm pressure is shown in Figure 6.1.1.4.3.2. The data indicate that the cell performance at 250 mA/cm<sup>2</sup> increased from 599 mV to 666 mV due to a decrease in IR (24 mV) and polarization (43 mV). The average cell OCV is 1018 mV, 3 mV lower than the theoretical value of 1021 mV. For Cell PDI-6 the performance at 160 mA/cm<sup>2</sup>, 75% U<sub>F</sub> and 40% U<sub>O</sub> was ~ 758 mV for the gas type SF/MEO. The anode and cathode wet seal efficiencies are 100% each and the nitrogen crossover is ~ 1.1%. To date the cell has operated for 480 hours and it will be pressurized to 3 atm next month.*

#### Cell PDI-8

*The purpose of this cell test is to determine the performance characteristics of a cell operating at 3 atm pressure and at 250 mA/cm<sup>2</sup> with system fuel and a market entry oxidant (MEO). The cell performance as a function of time at 1 atm pressure is shown in Figure 6.1.1.4.3.3. The data indicate that the cell performance at 250 mA/cm<sup>2</sup> increased from 620 mV to 659 mV due to a decrease in polarization. The average cell OCV is 1019 mV, 2 mV lower than the theoretical value of 1021 mV. The anode and cathode wet seal efficiencies are 100% and 97%, respectively, and the nitrogen crossover is ~ 0.9%. To date the cell has operated from 480 hours and will be pressurized to 3 atm next month. The cell performance as a function of pressure will be reported next month.*

#### Cell IM9502

*The purpose of Cell IM9502 is to determine the baseline operating characteristics of an M-C Power Ni+3Al anode operated at 3 atm pressure and under system conditions using the Li/Na electrolyte for 2000 hours. Cell IM9502 operated for 1100 hours and was terminated due to performance decay (34 mV) at 3 atm and under system conditions. The cell was set to operate at 60% fuel utilization and 40% oxidant*

*utilization at 160 mA/cm<sup>2</sup> under system conditions. The cell performance at 3 atm and 160 mA/cm<sup>2</sup> under system conditions slowly decreased with time from 752 mV to 718 mV due to increases in IR (18 mV) and polarization (16 mV). The cell performance at 160 mA/cm<sup>2</sup>, 3 atm, 75% U<sub>F</sub>, and 40% U<sub>O</sub> also decreased from 725 mV to 692 mV.*

#### Cell IM9503

*Cell IM9503 is a repeat of test IM9501 which was operated to characterize the performance of a low cost electrolyte matrix concept as a function of time (2000 hours) at 3 atm pressure and under system conditions. Cell IM9503 operated for 2000 hours at 3 atm, 60% U<sub>F</sub>, 40% U<sub>O</sub> with a stable performance of 760 mV at 160 mA/cm<sup>2</sup> under system conditions. The cell performance at a current density of 160 mA/cm<sup>2</sup>, 75% U<sub>F</sub> and 40% U<sub>O</sub> was determined to be 743 mV. The cell test was terminated after achieving its test goal of 2000 hours of operation at 3 atm under system conditions.*

#### Cell IM9506

*The purpose of Cell IM9506 is to determine the operating characteristics of a thinner cell package of a stabilized cathode and Li/Na electrolyte operated at 3 atm pressure and under system conditions for 2000 hours. In this cell package the anode and matrix thicknesses are half that currently utilized for the 250 kW stacks.*

*From the start, Cell IM9506 had a very low OCV of 790 mV compared to the theoretical value of 1043 mV. The OCV did not improve after 72 hours of operation. The anode and cathode wet seal efficiencies were 97% and 80%, respectively. The cell was cooled down and inspected for any obvious avenues for short circuits to explain the low OCV of 790 mV. No shorts were found in the system and the test was aborted after 72 hours of ambient operation.*

**Table 6.1.1.4.1. OVERALL SUMMARY OF BENCH-SCALE CELL TESTS  
 CONDUCTED TO DATE IN TASK 6.1.1.4.**

Cell No.	Purpose	Status	Hours of Operation	Conclusion
IGT-BS-TC-66-93-4	Determine cell performance by substituting the SOA Li/K electrolyte with Li/Na electrolyte at ambient pressure using reference gasses.	Terminated	16850	Longest operating Li/Na cell ever operated at the continuous load of 160 mW/cm <sup>2</sup> . Demonstrated excellent endurance.
IGT-BS-TC-66-94-1	Determine performance characteristics of Li/Na electrolyte at system conditions.	Terminated	6908	No evidence of Ni-shorting.
CVC-BS-TC-94-1	Evaluate the performance of an out-of-cell preconditioned cell package.	Terminated	762	Successful demonstration of the out-of-cell preconditioned laminated cell package concept.
CVC-BS-TC-94-6	Same as for Cell CVC-BS-TC-94-1	Terminated	1558	Cell did not perform well due to high IR. Warpage is a problem with the second version laminate using a sintered cathode.
IGT-BS-TC-42-95-2	To test electrodes to edge and determine the effects of opposing gas atmospheres on the electrodes in the manifold areas.	Terminated	189	Results confirm that the edges of the electrodes have to be protected.
IGT-BS-TC-42-95-3	To test electrodes to edge and determine the effects of opposing gas atmospheres on the electrodes in the manifold areas.	Terminated	187	Re-evaluate the method of electrode edge protection.
IGT-BS-TC-42-95-1	Evaluate the performance of a pre-conditioned laminate with Li/Na electrolyte.	Terminated	2161	Successful demonstration of the laminate with Li/Na electrolyte
MCP-IM9501	Evaluate the operating characteristics of a matrix cast without pre-wetting with carbonate	Terminated	266	Poor cell performance due to electrode switch during assembly.
MCP-IM9505	To determine the performance of a cell package taken from the active area of the UNOCAL 250 cell stack	Terminated	187	Cell did not perform well due to high IR.
MCP-IM9506	To determine the performance of a thinner cell package using a stabilized cathode and a Li/Na electrolyte.	Terminated	72	Cell terminated due to a very low OCV of 790 mV.
IGT-BS-TC-42-95-4	To test electrodes to edge and determine the effect of opposing gas atmospheres on the electrodes.	Terminated	382	Re-evaluate the method of electrode edge protections.
IGT-PDI-1	Determine the performance characteristics of the Li/Na electrolyte under pressurized operation, 3 atm, using system gasses.	Terminated	2352	Performance comparable to previously operated cells assembled with similar components.

**Table 6.1.1.4.1. OVERALL SUMMARY OF BENCH-SCALE CELL TESTS  
CONDUCTED TO DATE IN TASK 6.1.1.4.**

IGT-PDI-2	Determine the cell performance having a stabilizing agent added to the Li/Na electrolyte at 3 atm under system conditions.	Terminated	2352	Matching cell performance data is not available for a direct comparison.
IGT-BS-TC-42-95-5	Evaluate the performance of a preconditioned laminate with Li/Na.	Terminated	504	Cell did not perform well due to high IR.
IGT-BS-TC-42-95-6	To determine the effect of opposing gas atmosphere on the exposed cathode.	Terminated	309	Re-evaluate the method of electrode edge protections.
MCP-IM9502	To determine the performance of Ni+3Al anode operated at 3 atm and system conditions using Li/Na.	Terminated	1100	Cell did not perform well due to a high decay rate (55mV/1000 hrs.).
MCP-IM9503	To evaluate an alternative concept for electrolyte loading.	Terminated	2376	The cell performance is comparable to the SOA cells.

**Table 6.1.1.4.2. PERFORMANCE SUMMARY OF THE BENCH-SCALE CELLS THAT  
ARE IN OPERATION**

Cell No.	Hrs. of Op.	OCV	Cell Data (mV)			Wet Seal Efficiency, %		
			Perform. *	IR*	Polarization *	Anode	Cathode	N <sub>2</sub> Crossover %
IGT-PDI-5	1632	1054	740	65	249	97	100	0.6
IGT-PDI-6	480	1018	666	62	290	100	100	1.1
IGT-PDI-8	480	1019	659	100	260	100	97	0.9

\* At a current density of 250 mA/cm<sup>2</sup>.

+ Under system conditions, 75%U<sub>F</sub> and 40% U<sub>O</sub>.

Subtask 6.2.1 Buss Bar Material Selection

**Objective:** Designs will be developed and materials selected to connect the stacks in series, to minimize resistance and to minimize the complexity of vessel penetration.

**Status:** *Preliminary investigation work is ongoing to support this activity.*

**Subtask 6.3** **Balance of Plant Component Development**

**Objective:** In this task, Bechtel's first year activities are as following:

- Screen and select the major BOP component developers
- Define the overall development program, scope of work, and budget with each developer
- Conduct contract negotiation with each developer
- Coordinate the technical support from the developers for the trade-off studies and the preliminary design and cost estimate in Task 2

**Status:** *Bechtel has been contacting and working with several vendors on this subtask.*

**Subtask 6.4** **Full-Area Stack Tests**

**Objective:** Commercial-area stack tests are used to verify improvements in the design, fabrication, and performance of full-area components and processes and to verify operational advancements in the technology.

**Subtask 6.4.1** **Fabricate and Operate 20kW Non Pressurized Stacks**

**Objective:** Two commercial-area short stacks (20-kW) will be fabricated and operated at atmospheric pressure to verify new separator plate concepts, advanced component technologies, manufacturing scale-up, modified stack start-up and operating procedures, and commercial stack fixturing.

**Subtask 6.4.1.1** **Stack AS-1 (20kW) Fabricate and Operate**

**Objective:** Stack AS-1 will be used to qualify the baseline cell package. Preliminary work effort will be performed during the first budget period; however, fabrication and testing will occur in a later budget period.

**Status:** *No significant progress to report on this subtask during this reporting period.*

**Subtask 6.4.4** **Stack Failure Mode Verification**

**Objective:** M-C Power, under the Product Development Test Program, completed a highly successful full-area, short-height Stack Test - MCP-7. Under this subtask, an allocation is provided to continue stack operations. The purpose of the continuing stack operations is to validate, if necessary, the Unocal failure mode. M-C Power believes that confirming the failure mode in a full-area stack is necessary to develop customer confidence.

**Status:** *M-C Power did continue the stack test to collect additional data. The test has since been shut down.*

**Subtask 6.5** **MW-Class Power Plant Demonstration**

**Objective:** The major purpose of this demonstration unit is to verify commercial readiness of M-C Power's IMHEX® fuel cell power plant by demonstrating the characteristics, performance, and operability of a prototype market-entry unit at a customer site.

**Status:** *Inactive during this reporting period.*

**Subtask 6.5.3.2.2**

**Manufacture 1 MW Electrolyte Matrix Tapes**

**Objective:**

Repeat components will be fabricated for the power plant. Some initial production techniques will be tested prior to full production.

**Status:** *No significant progress to report on this subtask during this reporting period.*

**Description of Attachments**

★ U.S. Department of Energy, Morgantown Energy Technology Center, Contract Report Transmittal Checklist

*Thomas G Benjamin 1/30/96*  
T. G. Benjamin, PDI Project Manager - Date

\_\_\_\_\_  
DOE Reviewing Representative



## Figures

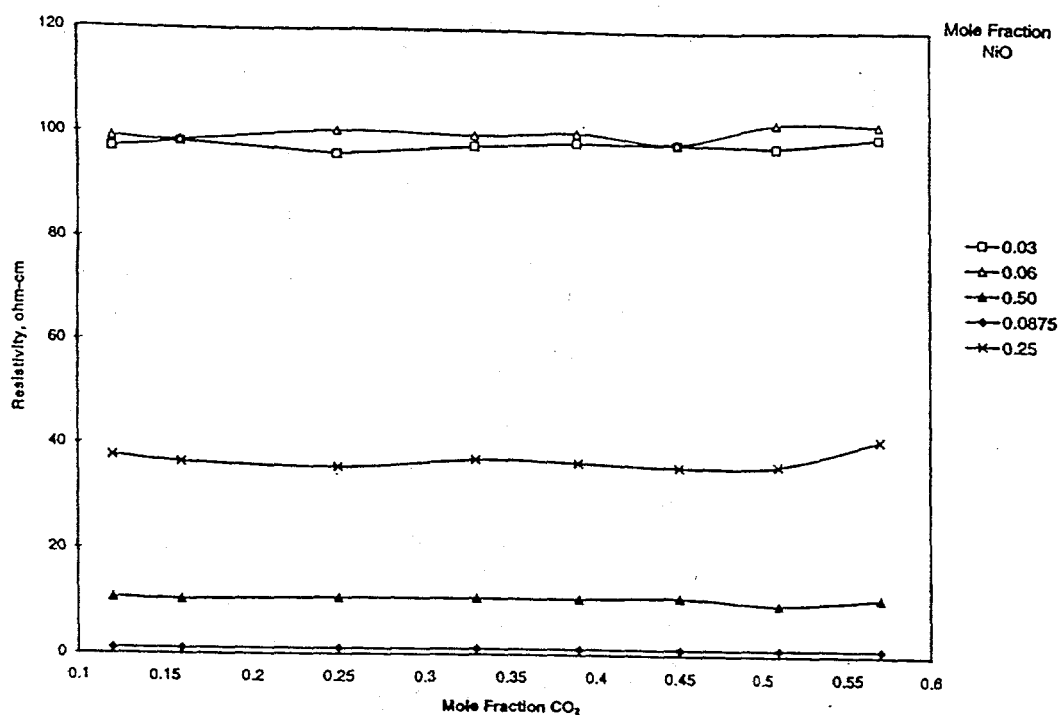


Fig. 1. Resistivity of  $\text{LiFeO}_2\text{-NiO}$  solid solutions as a function of mole fraction  $\text{CO}_2$ .

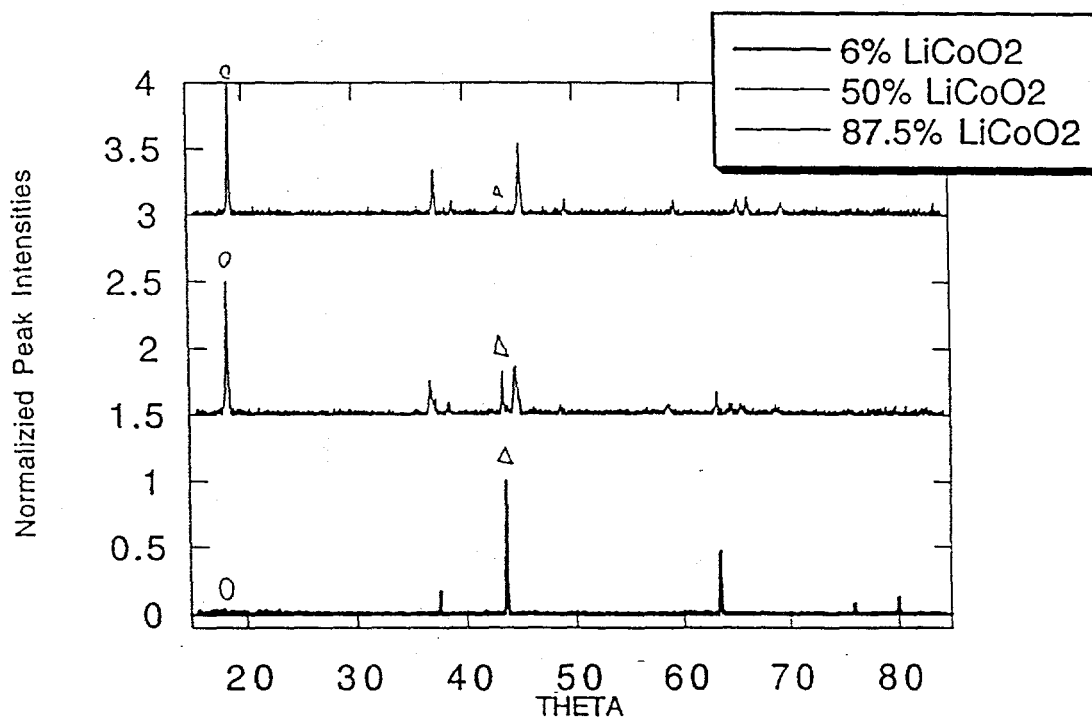


Fig. 2. X-ray diffraction patterns of  $\text{LiCoO}_2\text{-LiFeO}_2$  solid solutions. The circles indicate  $\text{LiCoO}_2$  and the triangles,  $\text{LiFeO}_2$ .

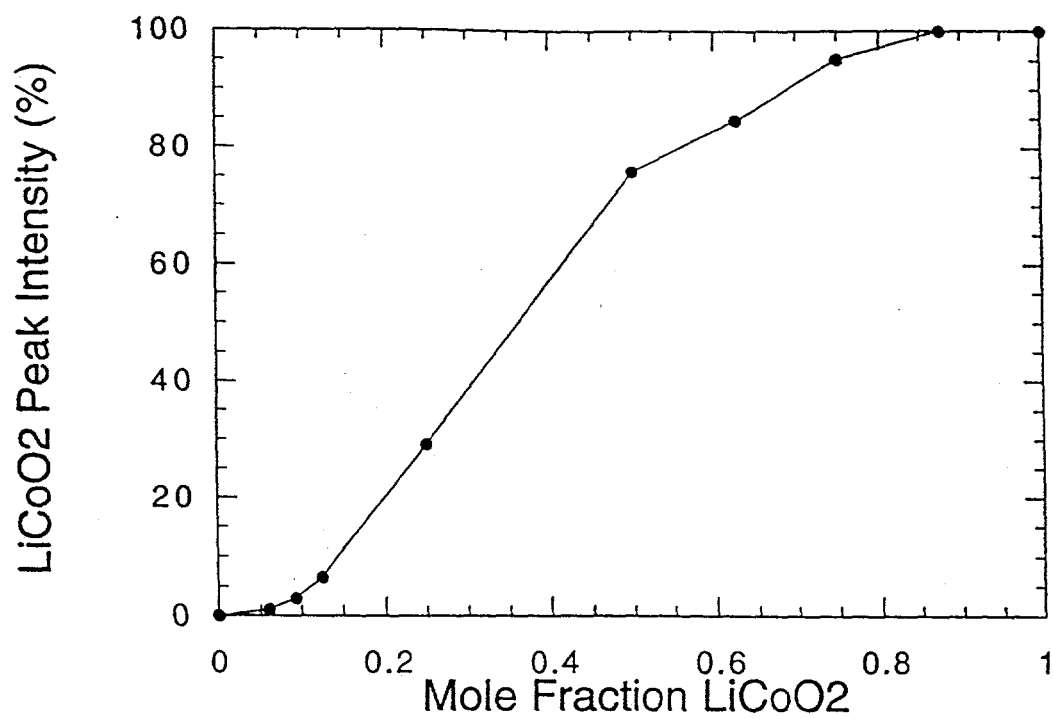


Fig. 3.  $\text{LiCoO}_2$  peak intensity as a function of mole fraction  $\text{LiCoO}_2$  in  $\text{LiCoO}_2$ - $\text{LiFeO}_2$  solid solutions

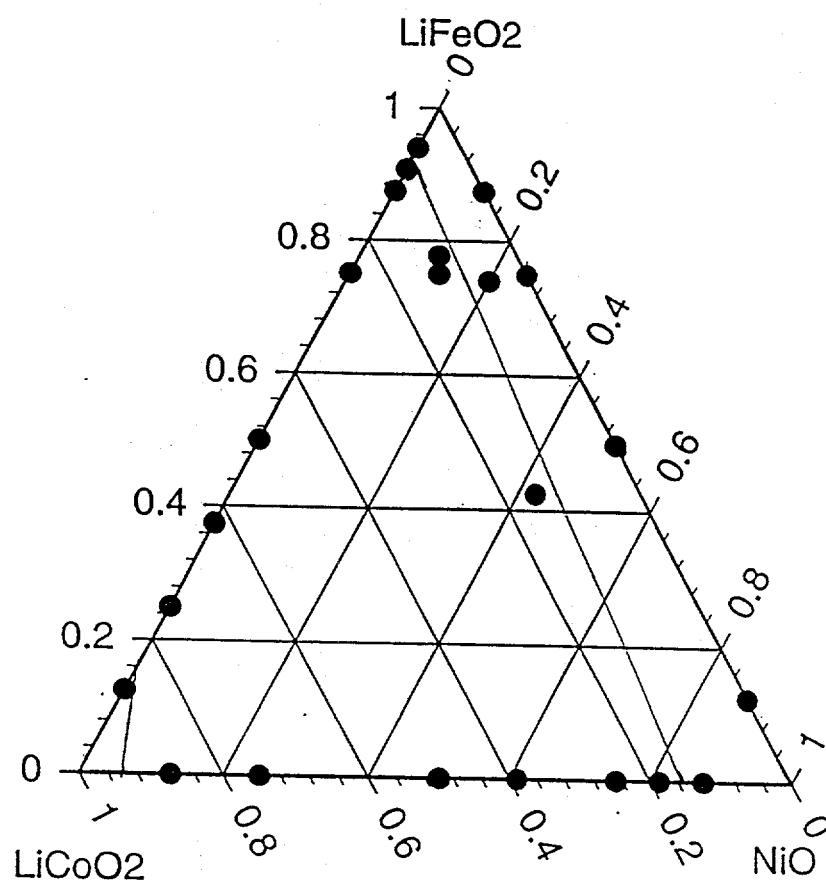


Fig. 4. Proposed ternary phase diagram for the  $\text{LiFeO}_2$ - $\text{LiCoO}_2$ - $\text{NiO}$  system

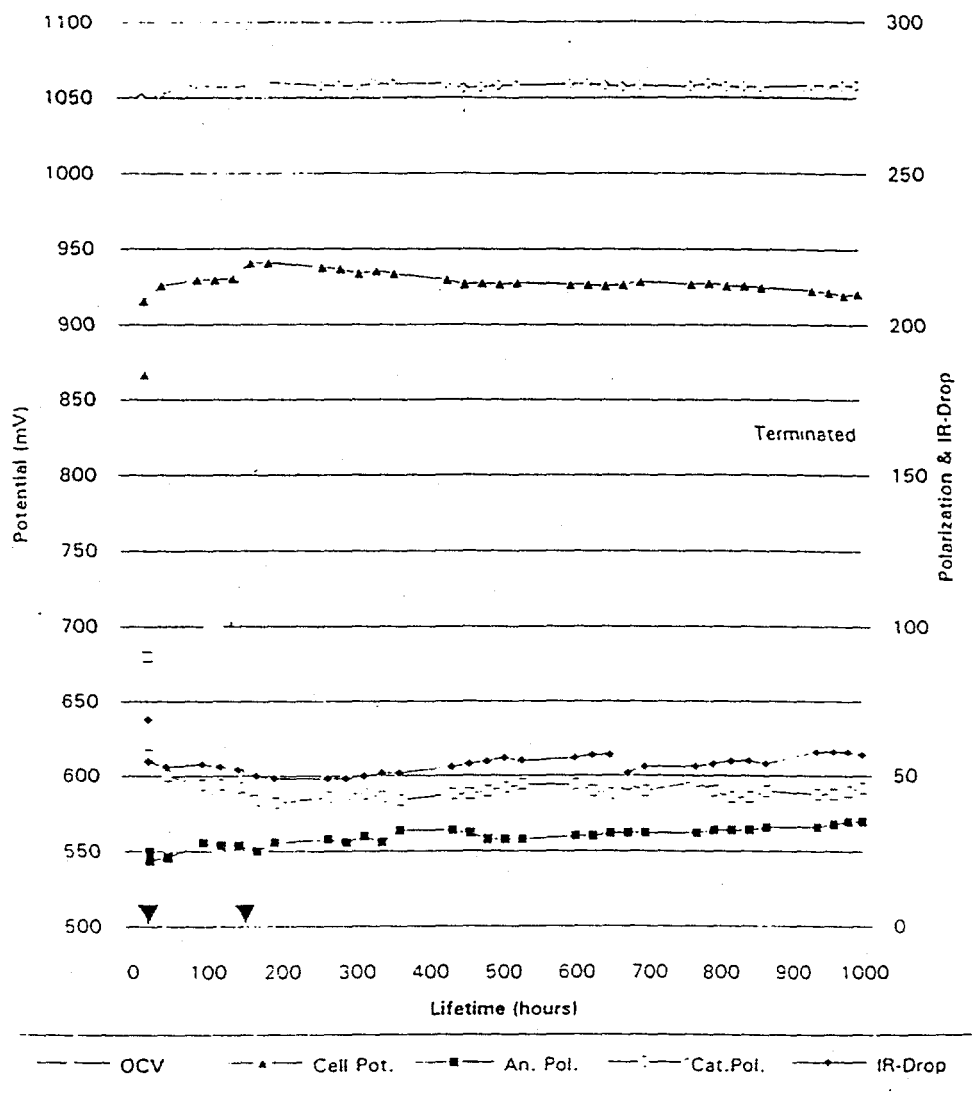


Figure 6.1.1.3.3.4.1. LIFEGRAPH OF CELL 2-MOLS

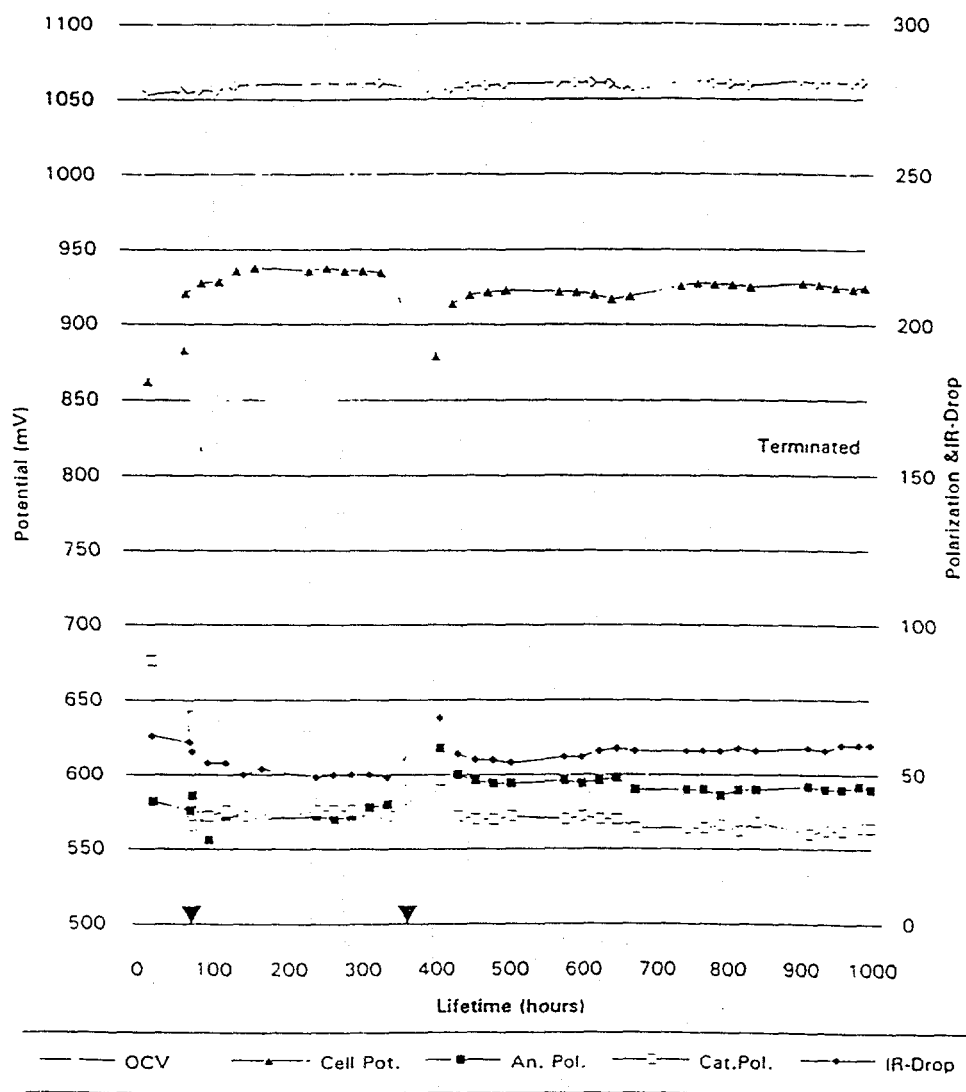


Figure 6.1.1.3.3.4.5. LIFEGRAPH OF CELL 5-PALS

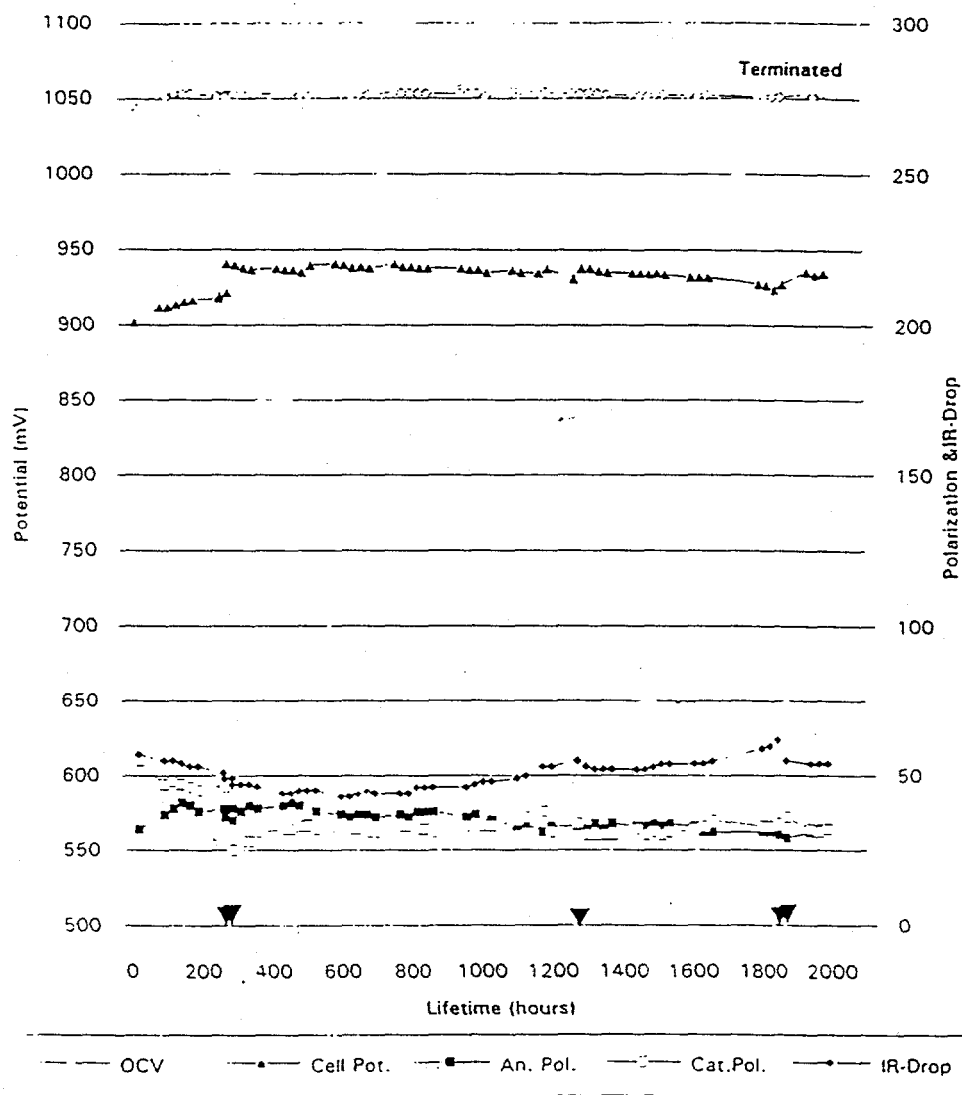


Figure 6.1.1.3.3.4.5. LIFEGRAPH OF CELL SPM-T85

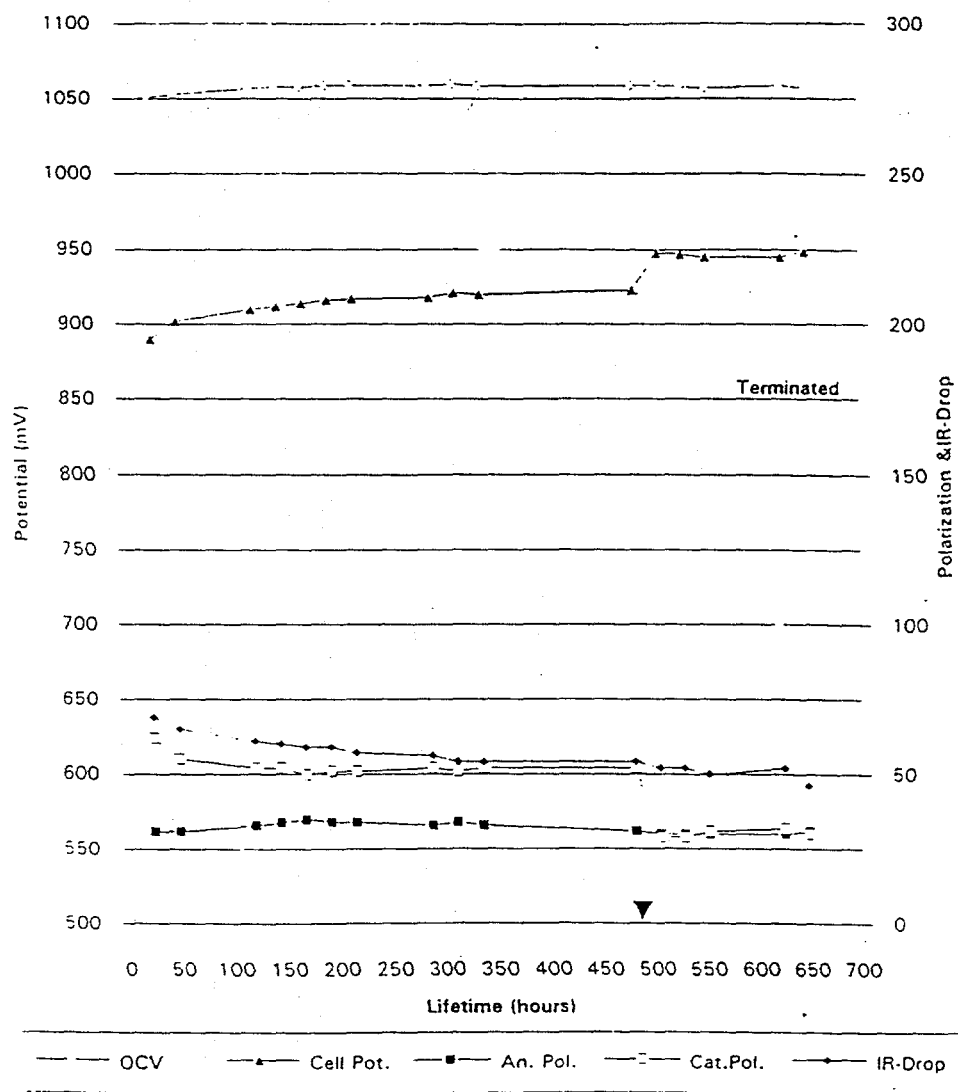


Figure 6.1.1.3.3.4.6. LIFEGRAPH OF CELL SPM-T86



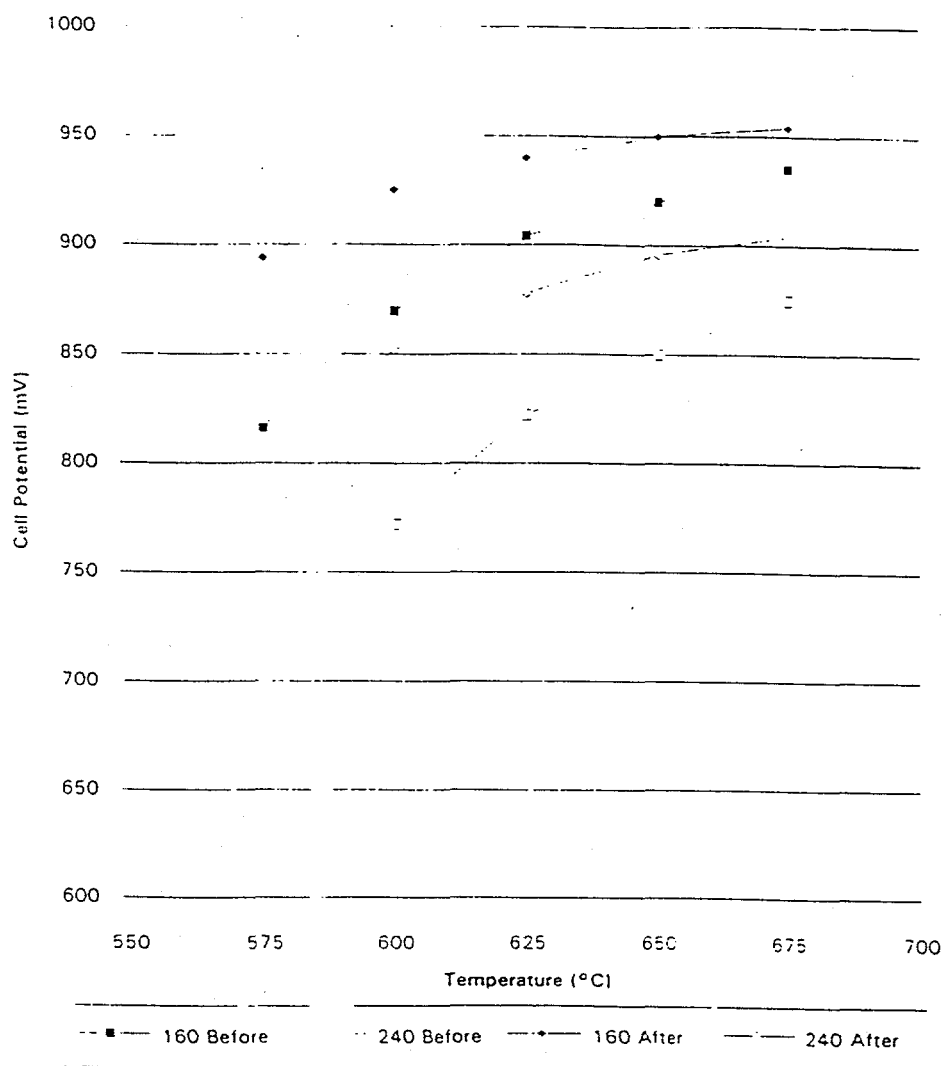


Figure 6.1.1.3.3.4.7. CHANGE IN CELL POTENTIAL WITH TEMPERATURE  
AT 160 mA/cm<sup>2</sup> AND 240 mA/cm<sup>2</sup> BEFORE AND  
AFTER DEPOLARIZING THE CATHODE

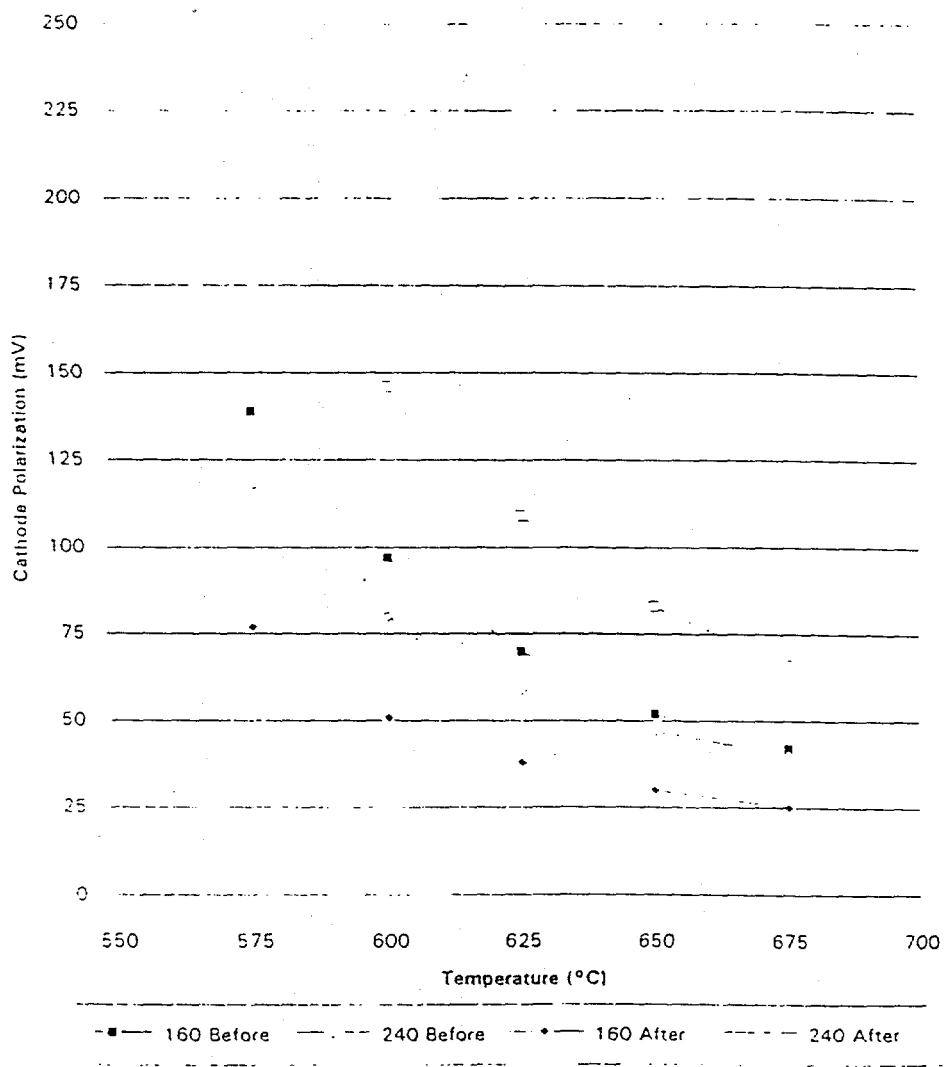


Figure 6.1.1.3.3.4.8. CHANGE IN THE CATHODE POLARIZATION WITH TEMPERATURE AT 160 mA/cm<sup>2</sup> AND 240 mA/cm<sup>2</sup> BEFORE AND AFTER DEPOLARIZING THE CATHODE

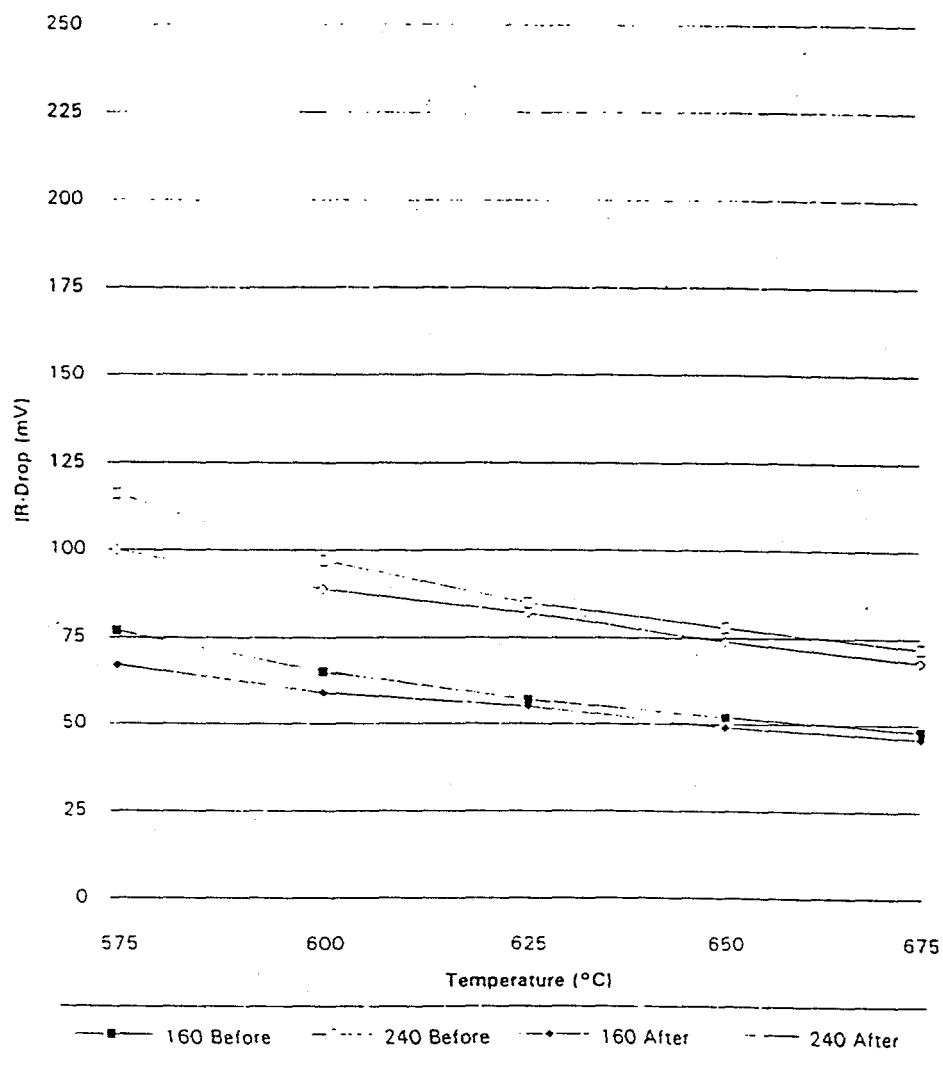


Figure 6.1.1.3.3.4.9. CELL IR-DROP VS TEMPERATURE AT 160 mA/cm<sup>2</sup> BEFORE AND AFTER DEPOLARIZING THE CATHODE

**Table 6.1.1.3.3.4.1. CHANGES IN CELL PERFORMANCE  
WITH TEMPERATURE BEFORE AND AFTER  
DEPOLARIZING THE CATHODE IN  
CELL SPM-T86**

Before Depolarizing (mV)						
Temp.	Cell Pot.	Polarization		Cell Pot.	Polarization	
°C	160 mA/cm <sup>2</sup>			240 mA/cm <sup>2</sup>		
	AC	AR	CR	AC	AR	CR
575	816	40	139	700	59	199
600	870	36	97	772	53	146
625	904	33	70	822	49	109
650	923	32	53	853	46	83
675	935	29	42	875	42	66

After Depolarizing (mV)						
Temp.	Cell Pot.	Polarization		Cell Pot.	Polarization	
°C	160 mA/cm <sup>2</sup>			240 mA/cm <sup>2</sup>		
	AC	AR	CR	AC	AR	CR
575	894	34	77	805	49	118
600	925	33	51	852	47	80
625	940	32	38	878	44	59
650	949	29	30	895	42	47
675	954	27	25	904	41	40

IR-Drop Before Depolarizing						
Temp.	160 mA/cm <sup>2</sup>			240 mA/cm <sup>2</sup>		
°C	AC	AR	CR	AC	AR	CR
575	77	34	44	116	51	65
600	65	29	37	97	43	54
625	57	25	31	85	38	47
650	52	22	30	78	33	45
675	48	19	29	72	29	43

IR-Drop After Depolarizing						
Temp.	160 mA/cm <sup>2</sup>			240 mA/cm <sup>2</sup>		
°C	AC	AR	CR	AC	AR	CR
575	67	27	40	100	41	59
600	59	23	36	89	35	54
625	55	21	33	82	32	50
650	49	19	30	74	29	46
675	46	18	28	68	26	42

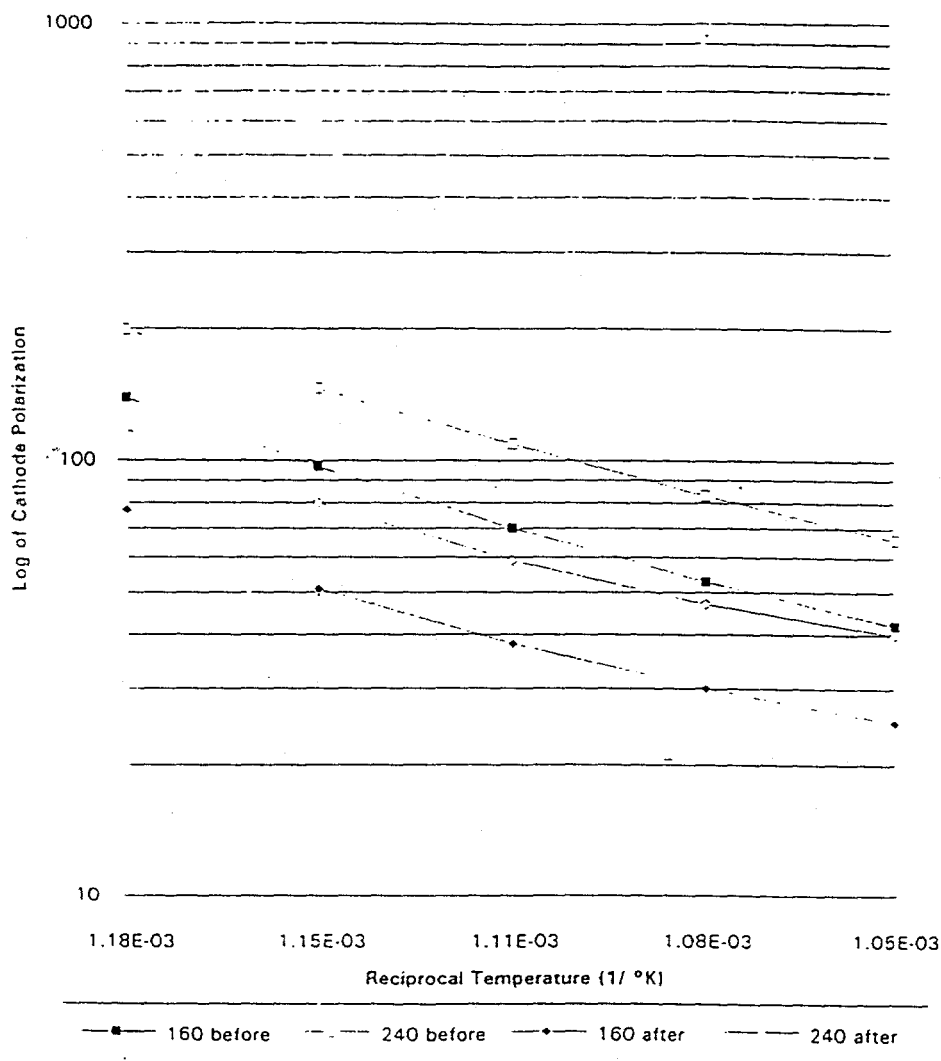


Figure 6.1.1.3.3.4.10. LOG OF CATHODE POLARIZATION VS  
RECIPROCAL TEMPERATURE BEFORE AND  
AFTER DEPOLARIZATION

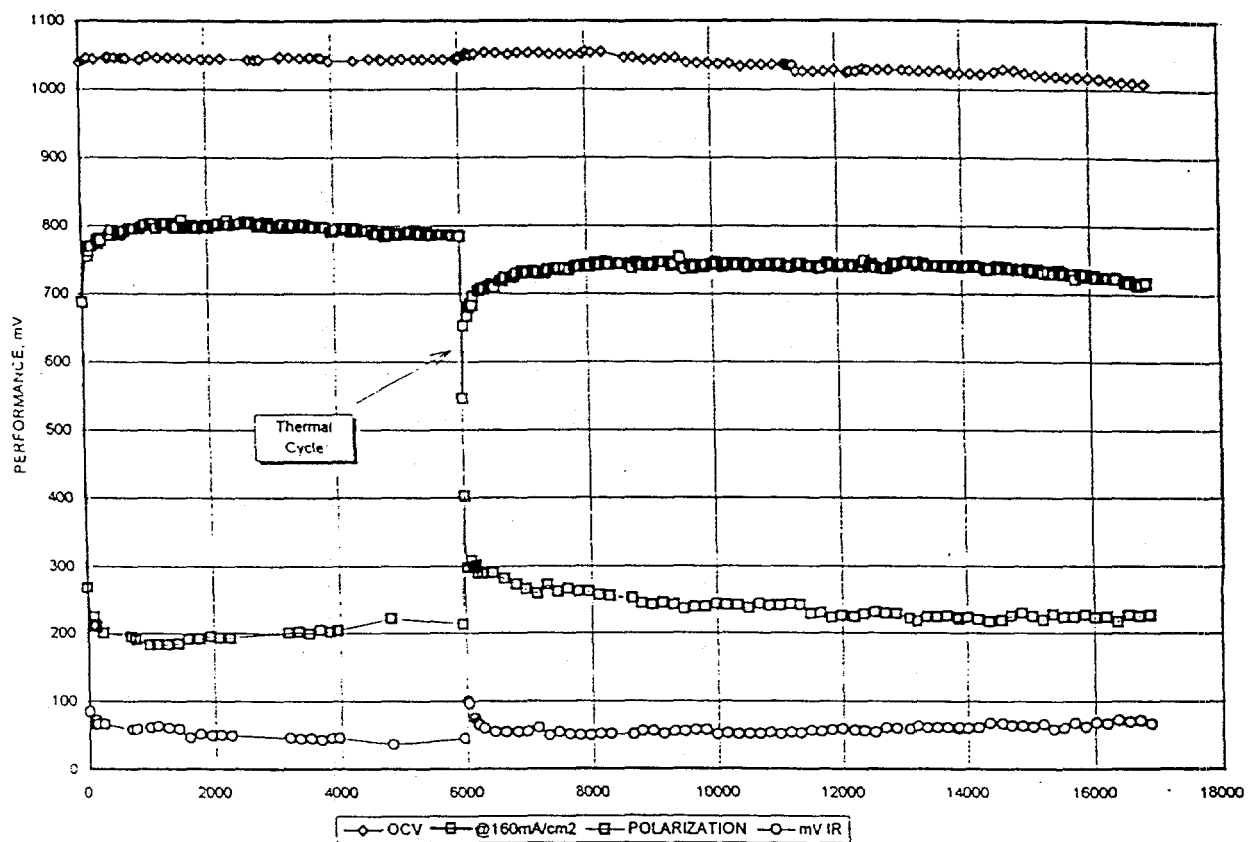


Figure 6.1.1.4.1. LIFE PLOT OF CELL IGT-BS-TC-66-93-4

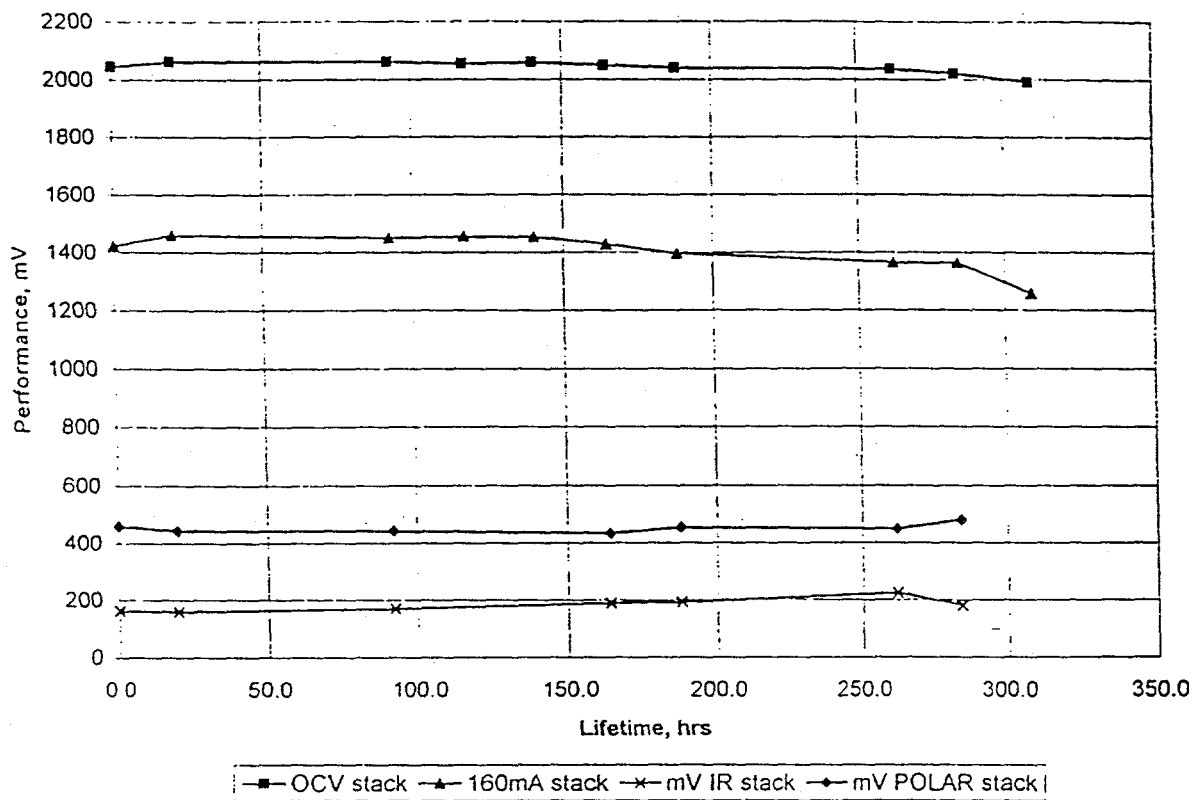


Figure 6.1.1.4.2.1. STACK PERFORMANCE AS A FUNCTION OF TIME  
FOR CELL TEST IGT-BS-TC-42-95-6

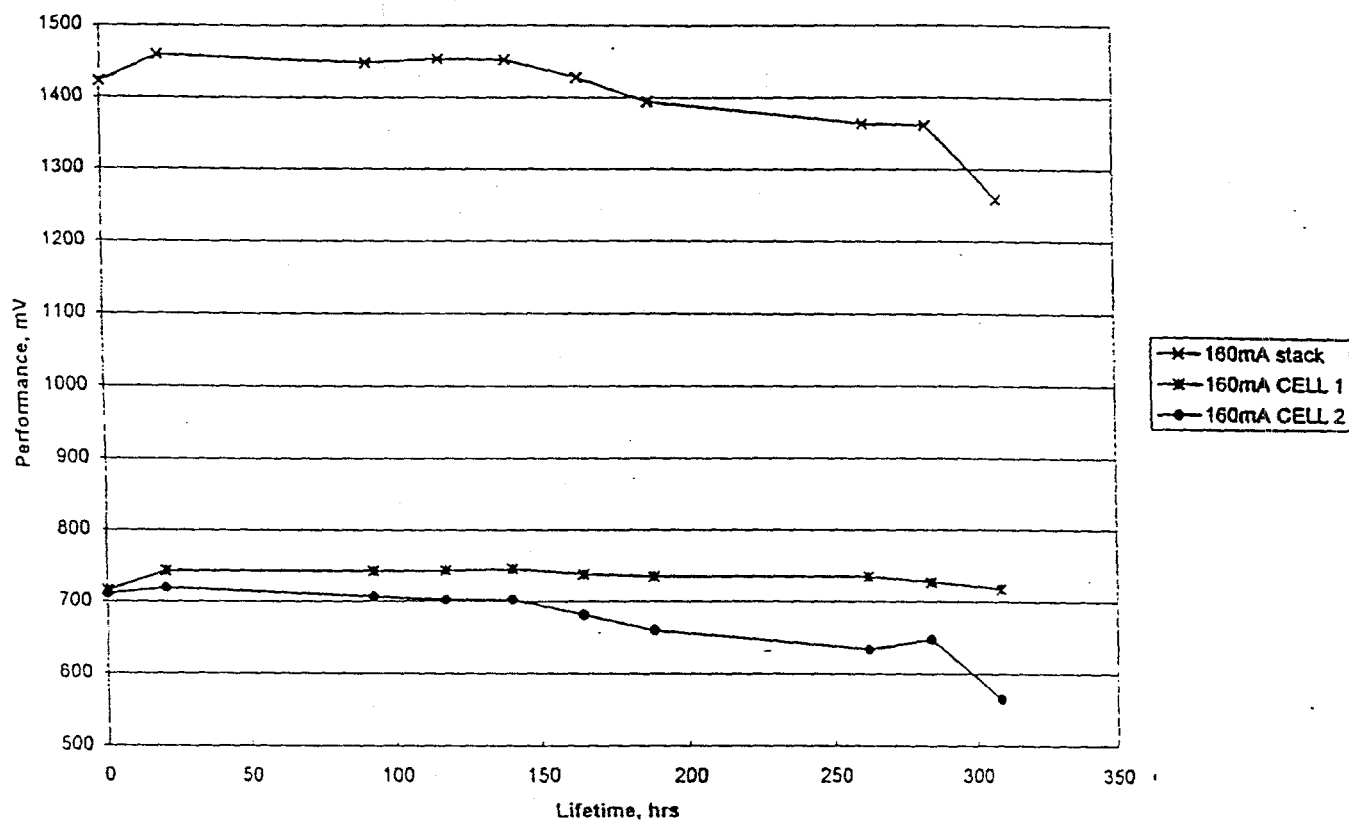


Figure 6.1.1.4.2.2. PERFORMANCE OF CELLS 1 AND 2 FOR CELL TEST IGT-BS-TC-42-95-6



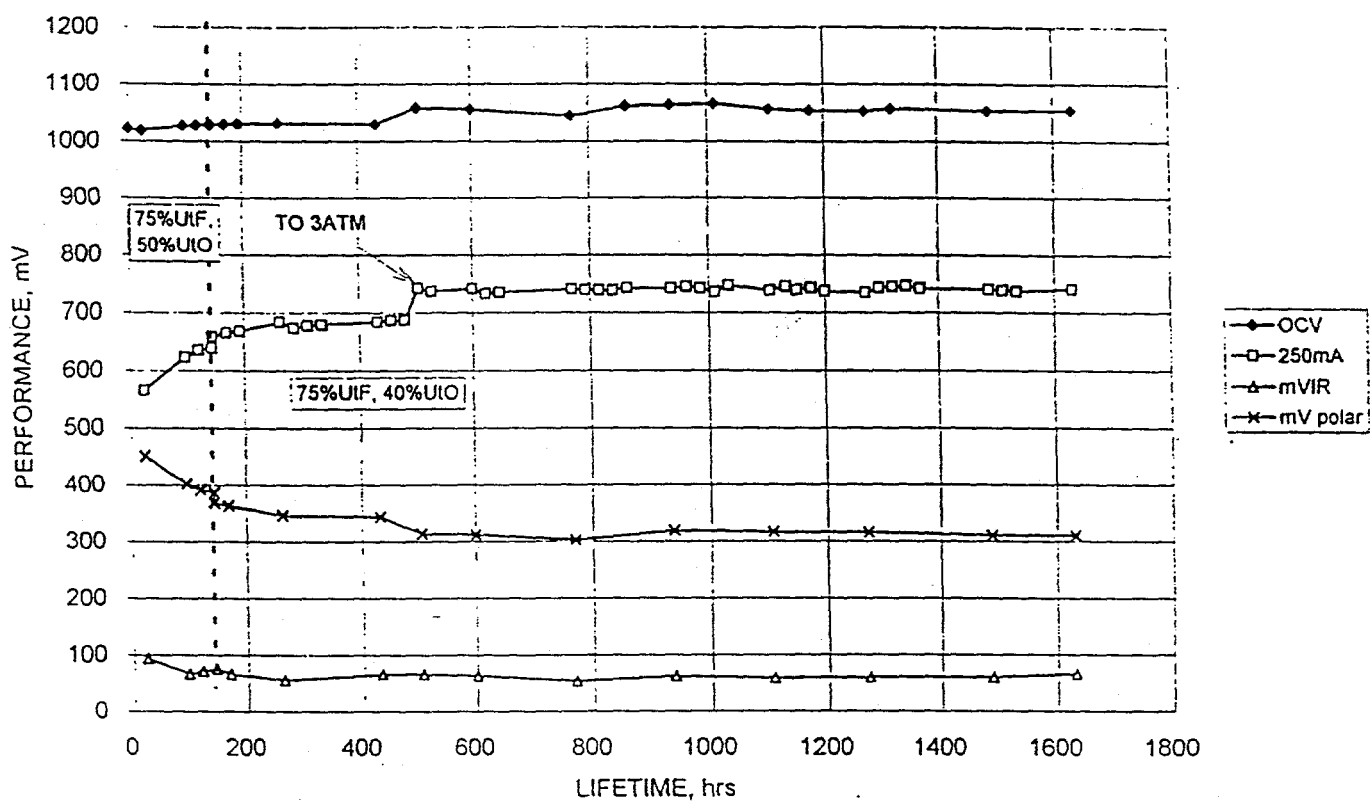


Figure 6.1.1.4.3.1. LIFE PLOT OF CELL IGT-PDI-5

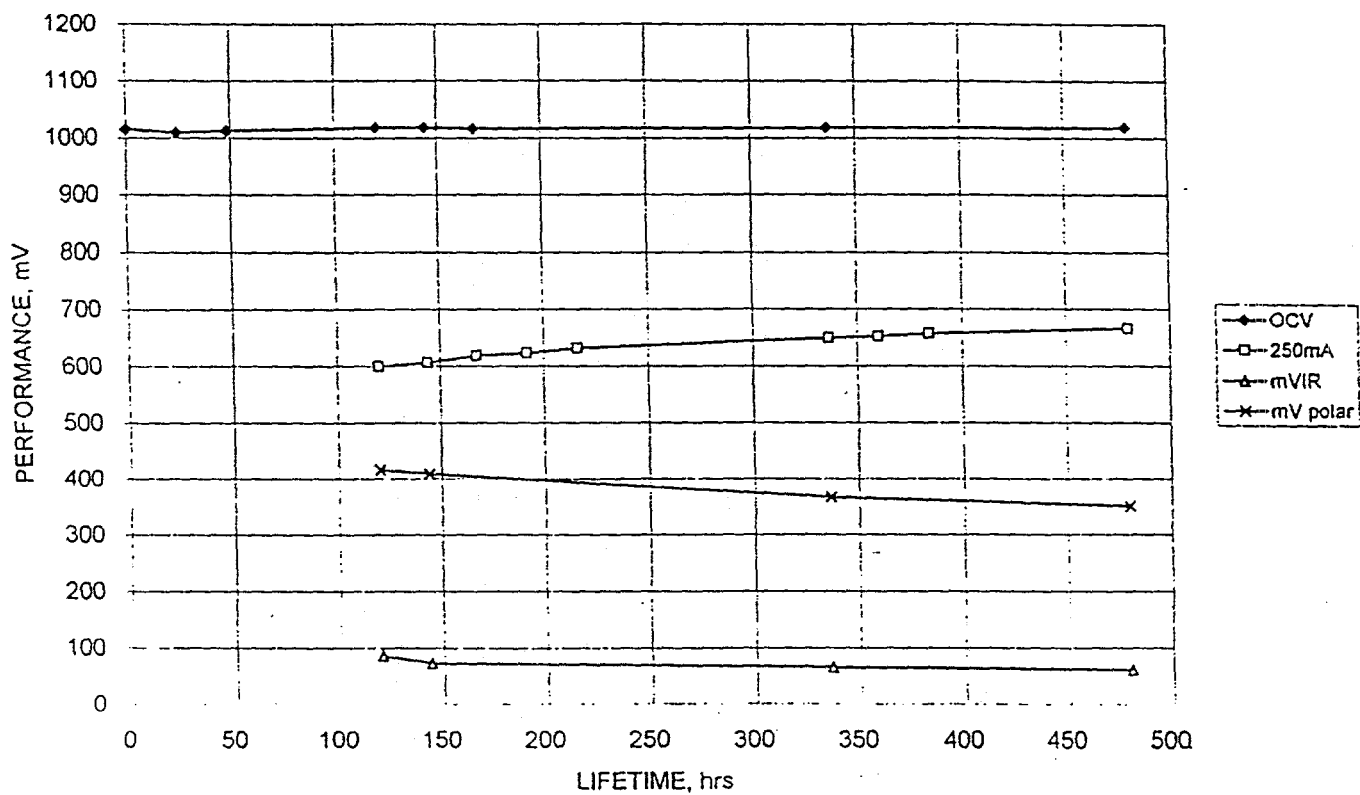


Figure 6.1.1.4.3.2. LIFE PLOT OF CELL IGT-PDI-6

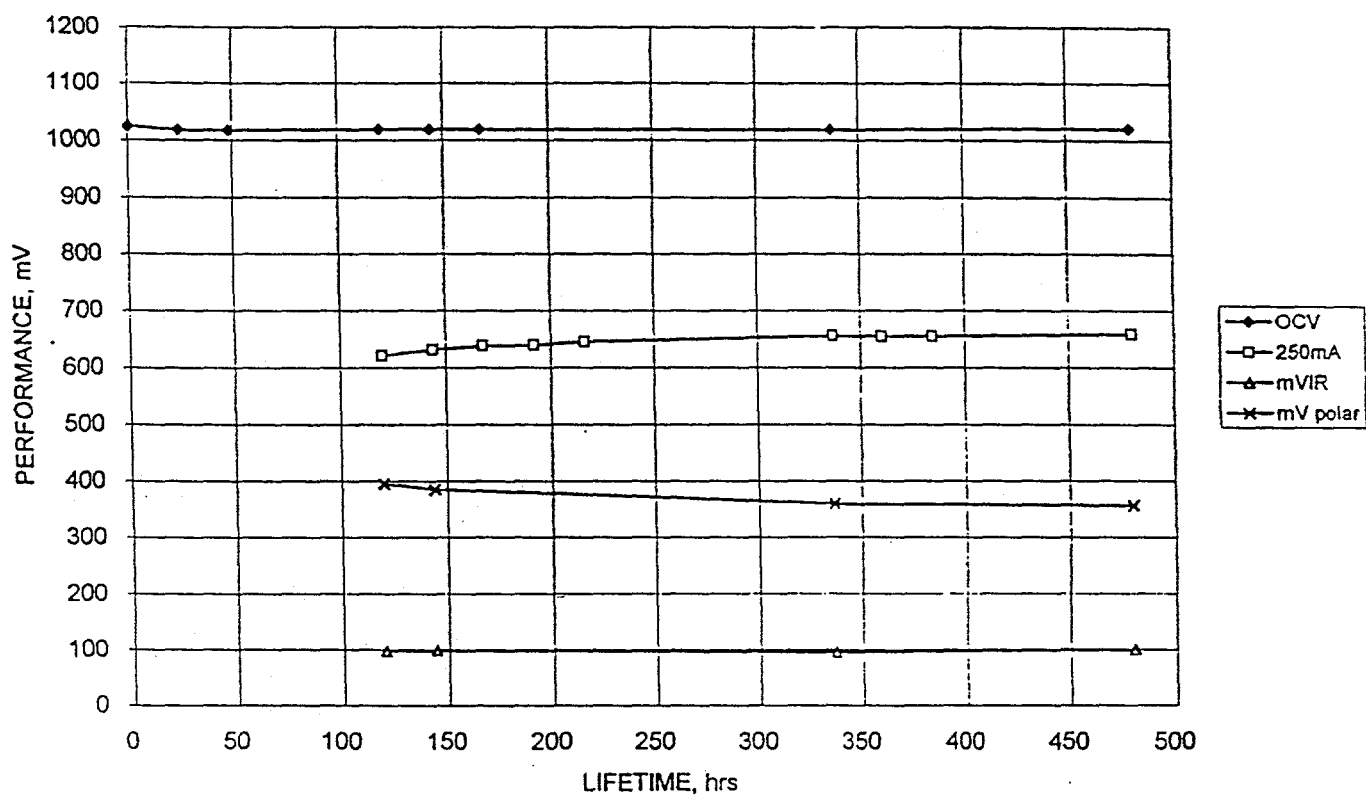


Figure 6.1.1.4.3.3. LIFE PLOT OF CELL IGT-PDI-8