Molten Carbonate Fuel Cell Product Design & Improvement - 2nd Quarter, 1996

**Quarterly Report
April 1 - June 30, 1996**

Work Performed Under Contract No.: DE-FC21-95MC30133

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

By
M-C Power Corporation
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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[®] MCFC power plants for distributed generation, cogeneration, and compressor station applications. Commercial readiness will require an advanced IMHEX[®] 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[®] 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[®] 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.

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

Summary of Work Accomplished During the Reporting Period By Task (4/1/96 - 6/30/96)

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.

Status: Analyze Market Surveys, Codes and Regulations

M-C Power has placed a subcontract with the Alliance to Commercial Carbonate Technology (ACCT) to do a study for the early adopters program. This study is currently ongoing. Questions are being issued to a variety of industries, such as small commercial customers, large customers, etc., to develop an overall profile of the type of companies that will be potential customers of the first fuel cells produced.

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.

Status: Product Marketing Efforts

M-C Power is working with a consultant who has conducted a literature search which will be used to develop a matrix for various market segments to determine what each segment's technical requirements are with respect to fuel cell capabilities. The consultant is investigating the commercial co-generation, industrial co-generation, utility distributed generation and other fuel cell opportunity markets. The consultant expects to complete the first of four (4) tasks during the third quarter of 1996.

Subtask 1.3 **Product Goals**

Objective: M-C Power will develop product goals that will be used to measure the progress and success of specific development activities and to redirect the development efforts as appropriate. Specifically, M-C Power will develop performance goals, life goals, and cost goals.

Status: *M-C Power is developing an overall business plan for the commercialization of fuel cells, based on the current information available.*

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 service) to commercialize the MCFC technology based on the market surveys and product definition work completed in previous tasks.

Status: *This subtask is complete.*

Subtask 1.5 **Task Management & Reporting**

Objective: M-C Power and its contractors will perform general management as well as 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.*

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 **Power Plant System Optimization**

Objective: To meet performance and cost targets for market-entry fuel cell power plants. The current design will be technically optimized through trade off studies and then analyzed and optimized to reduce material, labor, equipment, site installation, and operating costs.

Status: *This subtask is complete. Detailed design is being performed under Task 2.2.*

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.

Status: *Power Plant Process Design*

Bechtel is continuing work on the process trade-off study which included an assessment of the impact on the overall system performance and cost due to changes in the following items:

1. *Intercooler inlet temperature*
2. *Current density*
3. *Reforming temperature*

4. Cathode recycle adduction
5. Operating pressure
6. Various 1 atmosphere schemes

Power Plant System Engineering

Bechtel verified that the new stack simulation model does automatically adjust the user input anode feed to meet water shift equilibrium at the input temperature. Bechtel is integrating its heat and material balance calculations with the new fuel cell stack simulation program.

Because of the higher air and cathode inlet temperature requirement, the original base case scheme is no longer valid. The makeup air compressor cannot be driven by cathode exhaust because the exhaust must preheat the makeup air prior to power recovery. Bechtel is reviewing a new scheme proposed by M-C Power. The new scheme employs a new intercooler feed/efficient exchanger to raise the intercooler inlet temperature. Higher overall efficiency is achieved by not having to cool the cathode exhaust prior to the expander.

Subtask 2.3 Detailed Cost Estimate

Objective: In this task, a detailed capital and operating cost estimate will be generated based on the design developed in Subtask 2.2.

Status: *The completion of this subtask is dependent on the finalization of the design work being done in Task 2.2.*

Subtask 2.4 Performance Analysis

Objective: The power plant performance will be simulated and evaluated for a range of operating states and conditions. Reliability, availability, maintainability, and safety will be assessed.

Status: Power Plant Dynamic Simulations
Inactive during this reporting period.

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.

Status: Computerized Cell Component Manufacturing Process Simulation

With the growing complexity of integrated manufacturing systems and the ever-rising price capital equipment, the M-C Power team decided to simulate projects before investing in capital equipment for full-scale production.

Simulation is a process of building a computer based model of an operation and exercising the model to determine how the system will perform under varying conditions. A model is constructed using the description of a system's physical components and the logic of its operations. This model is used as a laboratory for conducting experiments that predict how the system will operate under various scenarios. Because complex operational problems can be addressed in a simulation project without incurring the cost of actual system experimentation, simulation provides cost effective analyses.

M-C Power has been successful in modelling a factory with 1 line - 1 shift capacity and a simulated run of 1 year that produces up to 20 MW production.

The simulation software systems can be used to do the following tasks:

- 1. Design and evaluate a new production facility.*
- 2. Evaluate alternative production line designs.*
- 3. Design and evaluate new equipment options.*
- 4. Evaluate the effect of manufacturing new products.*
- 5. Evaluate proposed control strategies.*
- 6. Evaluate whether or not a system will meet production objectives*

Specifically, the simulation can help answer the following types of questions:

- 1. Determine the resources necessary to achieve a specified future capacity.*
- 2. Identify the optimum personnel staff while transitioning from a R&D - based to full production - based facility.*
- 3. Generate cost analysis reports to help understand transitioning costs and other costs to meet business goals.*
- 4. Determine the optimum capital expenditure required to begin low-scale production.*

Automate Current Cell Component Manufacturing

M-C Power is in the process of completing a major rebuild and upgrade of the sintering furnace. During the past quarter, M-C Power has been working with the furnace vendor to install new regulators, temperature transmitters and controllers and gas line heaters. Troubleshooting work and repair of control wiring and other programming issues is complete. The furnace rebuild is approximately 98% complete. Heat up and test of the furnace is expected to start in July, 1996.

Manufacturing Equipment

During the past quarter M-C Power has recalibrated the viscometer, completed repairs

to the Q-mill, installed tape caster anti-static brushes, repaired the dryroom cranes and completed air bearing cart maintenance in preparation for stack transportation from the Acceptance Test Facility (ATF). All these activities were done as part of the maintenance of the manufacturing equipment.

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.

Status: *This subtask is ongoing.*

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.

Status: *Develop Advanced Manufacturing Processes*
M-C Power is currently investigating powders with different particle morphology so that sprayed electrodes will have the desired microstructures.

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: *This subtask is ongoing. Various scenarios are being investigated on M-C Power's computer model described under Task 3.1.*

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.

Status: *Component Scale Up To Full Area*
After learning that one of the critical matrix tape casting formulation ingredients currently in use had been discontinued by the manufacturer, vendors were contacted to identify alternate or similar products that are compatible with M-C Power's matrix formulation. Samples of candidate replacements for this dispersant were received and casting trials were completed. Two alternate dispersants were identified, which yield the same matrix viscosity, porosity, and porosimetry. Although additional dispersants will be

evaluated for possible cost reductions, this product meets our matrix requirements and may be used for future manufacturing runs.

Tape casting formulations for initial full-area advanced anode and cathode casts have been scaled-up to 10 gallons from those used to produce 100 cm² samples. Viscosity targets, casting speeds, and drying profiles are now being addressed. M-C Power began compiling an outline of the casting, sintering, and data collection procedures to be implemented during the scale-up activities. Scale up activities are scheduled for August of 1996 for the following components.

Water-based tape casting trials of the first-version stabilized cathode were initiated this month. The water-based casting system yields an acceptable cast porosity and two of these tapes were sintered. Sintered parts were very fragile, exhibiting little or no sintering at the maximum temperature of furnace. The powdery-white surface of these sintered water-based tapes suggest the stabilizing agent is being pulled to the surface during drying in the tape caster. This effort has been discontinued.

The type and concentration of organic compounds contained in the solvent-based stabilized cathode tapes have been documented. Thermogravimetric analyses (TGA) and Material Safety Data Sheets (MSDS) sheets were included. This information will be used to verify that permitting is in-place for removal of these organics in the sintering furnace, and identification of the preheat section atmosphere, such that complete binder removal is achieved.

Low chrome anodes were sintered at varying heat profiles. Samples were submitted for Hg porosimetry to evaluate the effects of the sintering profile on the pre-test electrode porosity and porosimetry.

Separator Plate Materials

Several separator plate materials were tested for the oxidation characteristics by heating in air at 650°C for an extended length of time.

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.

Status: Definition of Quality Program Requirements

This subtask is complete. Quality program development has continued as discussed below.

Development of Quality Implementation Plan

This subtask is complete. Quality program development continues as discussed below.

Development of QA/QC Procedures and Methods

Quality procedure development and documentation has proceeded and numerous operating procedures were developed and implemented for quality assurance, testing, and analytical functions. A comprehensive list of the procedures developed to date is included as Appendix "A". A primary intent of these procedures has been to standardize those activities in which several individuals and groups may be involved. Training in the use of these procedures was performed for some of the more complex technical procedures, such as the operation of the stack gas analytical system and the coordinate measurement machine.

During this quarter, procedural plans and drafts were documented for QA procedures pertaining to incoming material inspection and testing, inspection and test status, indication of test status, product release status, control of nonconforming material, review of nonconforming material, request for deviations and waivers, and the rework of nonconforming material. These procedures address not only the need to control nonconformances and prevent their inadvertent use, but also to ensure that identified causes of nonconformances relating to design, process capability, and process control are resolved to prevent reoccurrences.

Continuing work under this task will focus on ISO sections relating to design verification and control to ensure that the functional needs of the stack are adequately reflected in the specifications for subassemblies and individual components.

Implement QA/QC Procedures and Methods

No activity during this quarter.

Maintain QA/QC Procedures and Methods

No activity during this quarter.

QA Product Audit

Based on lessons learned from the PDT-1 stack components and the overall separator stack fit-up testing, new measurement methods were developed for assessment of theseparator plate subcomponents. This approach prioritizes the total thickness of the subassemblies in the various plate zones, rather than the specific dimensions of the formed features. Assessment of parts from this perspective has correlated better than previously-used methods with the observations from mock assemblie, and is thus a better predictor of the true functional performance of the stack.

The foregoing approach required changes in existing methods for plate measurement. Manual methods were implemented for the on-site quality control measurements performed for the PDI-1 separator plates during forming. Work is ongoing to update the

coordinate measurement machine (CMM) methods to allow plate measurements with appropriate referencing to allow the assessment of component thicknesses. Trials have begun in the development of a vacuum fixture for the plates to replace the mechanical clamping previously used. In addition to improving the reliability of the data, it is hoped that such a method will decrease the time required for plate measurement.

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.

Identification of Analytical Requirements

No activity during the second quarter.

Perform Cost/Benefit Analysis

No activity during second quarter.

Generate Recommendations Document

No activity during second quarter.

Procure Equipment

No activity during second quarter.

QA/QC Equipment Maintenance

This task includes the repair and routine maintenance of Government-owned equipment, such as the coordinate measuring machine (CMM) and stack gas analyzers. Activities performed under this task included several repairs and parts replacement for the gas chromatographs used for stack gas analyses and the stocking of critical spare parts to minimize downtime during stack testing operations.

In the course of the PDT-1 stack test, both gas chromatographs experienced detector problems, ultimately requiring rebuilding and recalibration. Replacement parts were received and installed without a major impact on analyzer availability. It is believed that the failure was due to an interrupted carrier gas flow to the analyzers at some point prior to the beginning of the test. Procedural changes and possible flow controls may be implemented prior to the PDI-1 test to prevent loss of carrier flow.

Develop Methods and Implement

No activity during second quarter.

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.

Subtask 4.1 Packaging Methodology Improvements

Objective: The packaging of the fuel cell stack and the balance of plant has a significant impact on the size, weight, cost, and heat loss. Mechanical integration will reduce cost and increase efficiency by reducing heat losses.

Status: *Inactive this reporting period.*

Subtask 4.2 Packaging Methodology Verification

Objective: A scale model will be produced to verify the configuration and the packaging method prior to manufacturing. The performance of advanced gas distribution manifolds will be verified through simulated tests to check that the proper flow distribution is attained.

Status: *Inactive this reporting period.*

Subtask 4.3 Assembly Methodology Improvements

Objective: Assembly methods for the BOP equipment and the fuel cell power module will be improved. Predictability studies will be conducted during the specification and design phase. Design parameters affecting material selection, fit-up, and tolerances will be verified. The cost effectiveness of automated welding will be assessed. Production tooling will be developed and cost effective acceptance testing for various components and the system prior to shipment will be determined.

Status: *Eight mockups were built to assess the fit-up specification for full-area stacks using pressure sensitive film and sheets of strain gauges. The final mockup (#8) employed actual active components with the pressure sensitive film and strain gauges in the top 25 cells. Both external and internal sealing were demonstrated. Therefore, the stack was qualified and transported to the ATF for conditioning and commissioning.*

Subtask 4.4 Assembly Methodology Verification

Objective: Stack assembly methodology will be verified through a trial assembly and fit-up on the proposed automatic cell stacking machine. A three-dimensional computer model of the BOP mechanical skid, fuel cell power module, and the electrical module will be generated to verify the assembly approaches for the construction of the MW-class power plant.

Status: *Inactive this reporting period.*

Subtask 4.5 Conceptual Assembly Factory Design

Objective: A conceptual design of a packaging and assembly plant will be developed based on the production level and product definitions necessary to meet market requirements.

Status: *Inactive this reporting period.*

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 Cell & Subscale Stack Test Facilities

Objective: Cell and stack test facilities are required for verification of cell component performance and durability and confirmation of cell and stack designs.

Status: Maintain 20kW Atmospheric Test Facility
Inactive this reporting period.

Maintain Acceptance Test Facility (ATF)

Modifications to the enclosure furnace top to allow installation of two additional (four total) furnace profile thermocouple assemblies was completed. Each profile thermocouple contains several thermocouple temperature measuring junctions. These thermocouples were used to obtain additional manual temperature data if necessary, during critical stack conditioning operations, such as electrolyte melting during stack conditioning. Work on installation and calibration of the stack shrinkage string potentiometer was completed. Calibration of all test facility instrumentation was completed in preparation for facility operation.

ATF equipment start up and control operator exercises were completed this quarter in preparation of the PDT-1 stack conditioning operation. ATF operating manual was developed and used for general information, training exercises, and extended hot operation.

During this quarter, PDT-1 stack conditioning, binder removal, load, and stack cool down operations were completed. After switching to process gas compositions with higher anode H_2 and CO_2 gas concentrations to begin stack load testing, a leak on the anode heater outlet piping was detected. All accessible flange joints were inspected and repaired, as necessary. Two test facility equipment failures were experienced this month during 976 hours of test facility operations. The first was the failure of the cathode heater power controller cooling fans. A temporary compressed air line was installed to cool the power controller to continue heater operation. The second failure was a bearing in the anode recycle blower. The blower remained operable until the end of the test.

Develop Pressurized Bench-Scale Facility

Meeting minutes were completed and issued. Several tests have been started this year. Updates on these tests are shown below.

Subtask 5.2

Stack Module Verification Facility

Objective: The existing 250-kW partially integrated facility at Unocal will be used to test an additional 250- kW stack under this program.

Status:

Review and Update 250-kW Facility
Inactive during this reporting period.

Subtask 5.3

Power Plant Shipping Design

Objective: Building upon the experience of Unocal and SDG&E, this task will concentrate on identifying and quantifying the shock and vibration limits so that means of transportation can be devised.

Status:

Inactive during this reporting period.

Subtask 5.4

Upgrade Unocal Facility to 500-kW

Objective: This task is involved with the modifications required to the Unocal power plant to accept future stacks up to 500-kW in size.

Status:

Inactive during this reporting period.

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[®] 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.

Status: Active Component Improvement

Improved Cathode Performance

According to IGT's cathode performance model, only 1/8 of the available cathode surface area is participating in the electrochemical reaction. Up to 40 mV can be gained by increasing the active cathode surface area. In fact, in 1993, cell performance at 1 atm with reference gases at 160 mA/cm² improved by at least 20 mV when the Ni loading of the cathode was increased from 20 to 30%. Additionally, the better performance of the stabilized Ni cathode over the stabilizer-free cathode may have been due to its higher Ni loading, which is about 30% compared to 20% for the latter.

Gas transport, especially at elevated pressure, can be improved and cathode performance can be increased by less tortuous gas paths in the porous cathode. It is predicted that up to 15 mV can be gained if the cathode pore tortuosity were reduced.

A low-tortuosity cathode has been assembled in a bench-scale cell to evaluate the effectiveness of reduced tortuosity for increasing cell performance. The cell, Cell PDI-13, has been in operation for 164 hours. Its potential at 160 mA/cm² with reference gases is 797 mV and is still improving. The electrode polarization of Cell PDI-13 the lowest observed under the described operating conditions. Further details of this test are presented below. A repeat of this test is planned.

Another approach to improving cathode performance is to increase the conductivity of the cathode by increasing the lithiation of the cathode. Although a higher cathode lithiation may just be transitory and will eventually equilibrate to the normal 2-3 atom percent, enhancing cathode performance at the early stage of cell operation can stabilize the cell sooner than the normally observed 200 hours. To verify increased lithiation, three experiments were performed in which cathodes were lithiated and impregnated out-of-cell between a matrix and a perforated stainless steel assembly simulating the cathode environment during start-up in a cell.

Post-test observations were essentially the same for all three studies. The matrix and cathode both expanded slightly, the cathode more than the matrix. The cathode was very dark gray, indicating oxidation.

The cathode was washed and submitted for chemical analysis. The results are summarized in Table 1. The normal lithiation for in-situ oxidized cathodes is between 2-3 atom per cent Li. Cathodes with increased lithiation will be tested in 3-cm² cells to determine if initial cell performance is enhanced.

Cathode Dissolution

Post test analysis of Cells PDI-5 and PDI-6 components was completed. Both cells were operated at 3 atm with system fuel and a market entry oxidant (MEO) at 250 mA/cm². Cell PDI-5 was operated for about 3500 hours and had a peak performance of 740 mV. However, it had a high decay rate due to carbonate loss by creepage through the aluminized surface of the anode flange. There were also severe corrosion flakes on both sides of the cathode current collector and deposits of the cathode stabilizing agent were evident at the holes of the anode current collector along the fuel inlet.

Table 1 Results of Cathode Lithiation Experiments

Experiment No.		Li : Ni Atomic Ratio
Study A		2.2 : 97.8
Study B		10.2 : 89.8
Study C		11.4 : 88.6
Control		Not yet available

Cell PDI-6 flanges were not aluminized and cell operation was conducted at 700°C. It also had a high decay rate due to its high operating temperature and was terminated after a total test time of 2352 hours. It had worse corrosion than Cell PDI-5 and its matrix was crumbly and appeared dry.

It is pre-mature to interpret the cathode dissolution data for Cells PDI-5 and PDI-6 because they are first of their kinds, Cell PDI-5 being the first operated with MEO at 650°C and Cell PDI-6 being the first with MEO at 700°C.

Alternative Cathode Material

A review of available cathode dissolution data was made and indications are that Li/Na electrolyte provides the lowest acidity for cathode dissolution and that, after 40,000 hours, the amount of Ni in the matrix is projected to be less than 5 volume percent of the matrix which is unlikely to cause matrix shorting. An accelerated bench-scale test for cathode dissolution under noble oxidant is being operated to determine the threshold for the amount of Ni in the matrix that can short the cell. Our assessment for cathode dissolution with NiO based cathode will be updated as data become available.

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. Although a life of 40,000 hours is projected for MCFCs operated at 1 atm and a low CO₂ partial pressure, the transport of nickel to the anode at a higher pressure and a high CO₂

partial pressure has not been verified.

Alternative cathodes based on lithium ferrate (LiFeO_2) and lithium cobaltate (LiCoO_2) are less soluble. However, the LiFeO_2 cathode, because of its high resistivity cannot be employed as a direct substitute for the lithiated NiO cathode. Instead, dopants are required to improve the resistivity of the LiFeO_2 cathode to an acceptable level. Development of an appropriate combination of dopants was the focus prior work.

Resistivity results from selected solid solutions in the LiFeO_2 - LiCoO_2 - NiO system were reported last quarter. One composition (Material 1) was found which has a resistivity close to that of LiCoO_2 .

In this quarterly report, data from are presented an MCFC cell test using Material 1. We also present some phase diagram and resistivity data from new solid-solution cathode materials based on LiFeO_2 are also presented.

A 5 X 5-cm MCFC test is in progress using Material 1. The oxidant consists of 60 - 70% O_2 and 30 - 40% CO_2 . The electrolyte is a $(70\text{Li},30\text{K})_2\text{CO}_3$ tile. As shown in Figure 1, there was an initial conditioning period which lasted about 400 h. After that time, the cell potential was constant at 0.86 V at 160 mA/cm^2 (cf. $\text{Ni}(\text{Li})\text{O}$, ~ 0.9 - 0.91 V). The cell continues to operate with a stable potential and will continue to operate until 2000 h have elapsed or cell failure.

FIGURE 1
Potential vs. Time Plot For MCFC Using Material 1

During the cell test, cell polarization curves were taken. Three of these are given in Figure 2. They show, that after the initial conditioning period, the cell resistance was essentially unchanged.

Cell area-specific resistance data (ASR) show the expected trend (see Figure 3). There is an minimum in ASR value at about CO_2 mole fraction of 0.2 - 0.3.

FIGURE 2
 Cell Polarization Curve For MCFC Using Material 1

FIGURE 3
 ASR vs Mole Fraction Carbon Dioxide For Material 1

In previous, doubly-doped compositions, Co migration from the cathode was observed. A post-test examination of the cell at the end of the experiment will be performed to ascertain the extent of Co migration, hence chemical stability, of Material 1.

If, as expected, the cell continues to operate for 2000 h, an attempt will be made to improve cathode performance. The parameters for this study are loading density (mg/cm²) and overall cathode microstructure.

New Materials

Other solid solutions based on LiFeO_2 are being evaluated in case Co migration persists in the current doubly-doped, single-phase composition. We are characterizing compositions in the $\text{LiFeO}_2\text{-MgO}$, $\text{LiFeO}_2\text{-MgO-NiO}$ and $\text{LiFeO}_2\text{-MgO-CoO}$ systems by X-ray diffraction and resistivity measurements.

Alternate Cell Package Development

Alternative Cell Package Design and Development

Results from 2-cell bench-scale stack tests indicate that high parasitic currents develop when the anodes of the cells are extended to the outside edge of the wet seal and to the manifold side of the oxidant manifold wet seal. These parasitic currents result from the outside perimeter of the anode behaving like a cathode in the presence of oxygen. A short circuit develops across the wet seal with electrons and ions flowing through the anode. Additional fuel is consumed by this short circuit and the performance of the cell is lowered proportionally. The short circuit should be prevented if the outer edge of the anode can be made to behave as an electronic insulator. Three approaches were evaluated: 1) fabricate the anode from Ni+5%Al which becomes a high resistance material when oxidized, 2) fill the outer edge of the anode with aluminum paint which oxidizes to Al_2O_3 when exposed to the oxidizing atmosphere at the outer perimeter of the wet seal, and 3) use a $LiAlO_2$ caulk around the outer edge of the anode.

Each of these three approaches has been tested in a 3-cm² lab-scale cell. The first approach did not work. The Ni+5%Al material still exhibited significant electronic conductivity when oxidized. The second approach gave satisfactory results in a lab-scale cell. However, when the outer edge of the anodes in a 2-cell bench-scale stack were filled with aluminum paint and the anodes extended to the outer edge of the wet seal, a significant parasitic current still developed. The third approach was tried in bench-scale Cell IGT-BS-TC-42-96-2 and gave satisfactory results. However, this cell also used laminated pre-conditioned components.

The limited results obtained using a $LiAlO_2$ caulk to protect the outer edge of the anode are promising and it is recommended that this approach be further investigated.

Advanced Cell Package Fabrication

The functionality of an out-of-cell pre-conditioned laminate consisting of cathode current collector, cathode, and matrix was demonstrated by testing in a bench scale cell. The only other components provided to the cell were the anode and the anode current collector. The cell had a good OCV and wet seal efficiency and the gas crossover was low. The cell stabilized at a performance of 785-790 mV at 160 mA/cm² without decay. Furthermore, it was thermally cycled twice to 100° C and it regained its performance level after each thermal cycle.

However, laminated components are not without issues. In fuel cells in which components reach to the outer cell edge, rather than only to the inside edge of the wet seal, they are exposed to gases or environments that can break them down, reducing long-term stability. The development of parasitic currents in the wet seal area must also be prevented as discussed above.

A method for laminating the anode to the cathode/matrix was evaluated. This type of laminate was tested in Cell IGT-BS-TC-42-96-2, which showed a performance of approximately 734 mV at 160 mA/cm² prior to thermal cycling. The OCV of 1044 closely matched the theoretical value of 1043 and the anode and cathode wet seal efficiencies were good (98 and 100%, respectively), suggesting good gas sealing and anode edge protection. Post-test disassembly showed that the caulk effectively protected the anode,

which was virtually unoxidized. The disadvantage of this method lies in the difficulty of making the caulk the same height as the anode, causing poor component contact and high cell resistance as was initially seen in the above cell. Cell resistance was decreased from 48 mOhms to 4.4 mOhms by incrementally increasing the holding force from 15 to 35 psi. The cell did not thermal cycle well. Performance decreased about 25 mV after cooling to 100°C, then ramping back to 650°C due to a net increase in polarization.

Optimize Cell

The objective of this subtask is to apply the approaches identified in the Limits of Performance topical report, of May 1995, to study ways to achieve maximum performance.

Decrease Cathode Tortuosity

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 indicate that two ways to improve cathode performance would be to increase the surface area for the electrochemical reaction and to decrease cathode tortuosity. The tortuosity issue will be addressed by attempting to increase the proportion of vertical pores in the cathode. This decrease in tortuosity will shorten the path length for the ionic and electrical currents moving through the chain of agglomerate particles in the electrode and will shorten the path length for the oxidant gases moving through the vertical pores. The result should be a decrease in ohmic resistance and in mass transfer polarization.

Cell 4-MOLS. This 3 cm² cell was started with a low tortuosity cathode. The cell was terminated after 2016 hours of operation. At termination, the cell generated a potential of 915 mV at 160 mA/cm² with 37 and 52 mV anode and cathode polarization, respectively, and 51 mV IR-drop. Cell 4-MOLS showed 45 mV IR-drop at its lowest point. By comparison, Cell SPM-T92, which had a Li/Na electrolyte and, therefore, low IR-drop, showed 39 mV at the lowest point. The lifegraph of Cell 4-MOLS is shown in Figure 4.

Tapes of low-porosity cathodes were prepared during the period. Two types of samples were prepared; one used Ni expanded metal as a reinforcing material and the other did not. Both samples were sintered and submitted for SEM analysis to determine the extent to which the pores and agglomerate chains are oriented.

A cathode which was prepared in the same manner as the cathode in Cell 4-MOLS was examined by SEM. It showed a graded porosity with the bottom being more compacted and more uniform than the top. The 4-MOLS cathode, which was identical to this electrode, exhibited significantly lower polarization and internal resistance than a standard cathode prepared from the same starting materials. By contrast, an electrode that was prepared by a modified procedure appears rough on both surfaces and has a uniform porosity from top to bottom. It is not possible to distinguish any pore orientation in either of these electrodes. However, when these electrodes are compared with a standard electrode, the new process appears to have had a significant impact on the electrode morphology. The nickel agglomerates are more compact and the pores larger and better interconnected in the electrode prepared by the new process.

Cathode Depolarization

A method for substantially lowering cathode polarization was discussed in the last

quarterly report. Several cells with Li/K electrolytes have been depolarized using the method and results indicate that the cathode performance improves substantially as the

FIGURE 4
Lifegraph of Cell 4-MOLS

result of a drop in cathode polarization. Cells 2-MOLS and 5-PALS, terminated last October, showed low cathode polarization and stable performance after the cathode was subjected to the depolarizing process.

The effect of the depolarizing process in a cell with Li/K electrolyte was studied in Cell SPM-T86 and the results indicated that the depolarizing process substantially lowers cathode polarization and that the cell becomes less sensitive to changes in the operating temperature and large gains in cell potential are seen. The effect of the depolarizing process in a cell with a Li/Na electrolyte in a cell having a stabilized Ni cathode and a Ni-3Cr anode was studied in Cell SPM-T89 where the results, discussed in the last quarterly report, indicated that the cathode depolarizing process results in 8 to 10 mV gain in cell performance due to lower cathode polarization only if the temperature is 650° C or higher and losses are seen when the temperature is below approximately 615 to 620° C, because the Li/Na electrolyte with the stabilized cathode is more sensitive to operating temperature than the Li/K.

Cells SPM-T92 and SPM-T93 discussed below were started during this quarter with similar components to those of Cell SPM-T89 but without cathode stabilization.

Cell SPM-T92 was started with a Ni-3Cr anode, an unstabilized Ni cathode, and Li/Na electrolyte for comparison with Cell SPM-T89. Polarization curves, between 575° C and 675° C in 25° C increments with one additional at 588° C, before and after depolarizing the cathode, were obtained between 288 and 384 hours of operation. Cell SPM-T92 was depolarized again prior to termination at 888 hours of operation. The lifegraph is shown in Figure 5.

The steady state performance before the depolarization was 910 mV at 160 mA/cm², with 35 mV anode polarization, 67 mV cathode polarization, and 40 mV IR-drop. The steady state performance after the depolarization was 940 mV cell potential with 33 mV anode polarization, 40 mV cathode polarization, and 40 mV IR-drop. The results at 160 and 240 mA/cm² are presented in Figure 6. The results of the depolarization process show that, at 650° C, the cell potential improved 31 mV at 160 mA/cm² and 49 mV at 240 mA/cm². At 575° C, the cell potential improved 75 mV at 160 mA/cm² and 107 mV at 240 mA/cm² and the cell is less sensitive to changes in the operating temperature. These results are seen in the figure and are comparable to the results reported earlier for the Li/K electrolyte, where, at 650° C, the cell potential improved 24 mV at 160 mA/cm² and 41 mV at 240 mA/cm² and, at 575° C, the cell potential improved 78 mV at 160 mA/cm² and 105 mV at 240 mA/cm². A second depolarization at 650 hours produced no further improvement.

Cell SPM-T93 was started with the same type of components as Cell SPM-T92 to study the reproducibility of the depolarizing process in a cell with Li/Na electrolyte without the cathode stabilizing agent. The cell reached a steady state potential of 936 mV at 160 mA/cm² after 288 hours with 32 mV anode polarization, 51 mV cathode polarization, and 32 mV IR-drop. At this point, an attempt was made to generate the polarization curves between 575° C and 675° C prior to the depolarization process, as done before. The cell, however, could not hold loads higher than 80 mA/cm² at 575° C and 588° C despite the

excellent performance at 650°C, because the cathode polarization was unstable and increased rapidly if left at 160 mA/cm² and higher loads.

FIGURE 5
Lifegraph of Cell SPM-T92

FIGURE 6
Change In Cell Potential With Temperature At 160 mA/cm²
And 240 mA/cm² Before And After Depolarizing The Cathode of Cell SPM-T92

Therefore, the cell temperature was raised back to 650°C and the procedure was modified by taking the polarization curves at 25°C decreasing temperature intervals with one additional at 588°C, then increasing the temperature to 650 and 675°C and down to 650°C. This way, the cell held better load at 588°C but still could not hold 240 mA/cm² at 575°C. The cell was then depolarized at 336 hours. After the depolarization process, the cell showed no net change in performance. The depolarization process was then repeated. This resulted in a 23 mV loss in cell potential due to higher cathode polarization and higher cathode IR-drop.

To check if changes in the wetting properties of the electrolyte is causing cathode flooding, the anode was subjected to a heavy discharge. If the cathode is becoming flooded after the depolarizing process due to changes in the wetting properties, the anode oxidation caused by the heavy discharge would increase its wicking properties temporarily and the cathode would become drier resulting in lower cathode polarization. The heavy discharge resulted in a temporary 17 mV cell potential improvement due mainly to lower cathode polarization. This is strong evidence that the cathode was flooded. Cell SPM-T93 began life exhibiting extremely high performance. At 288 hours, Cell SPM-T93 was operating at a potential 26 mV above the identical Cell SPM-T92 at the same point in its life.

The depolarization process works well with cathodes in cells using Li/K electrolyte and in cells using Li/Na electrolyte that do not contain the cathode stabilizing agent. Evidence points to differences in wettability as the cause for the difference. Electrodes that have good wettability may not benefit.

Corrosion

Samples of a homogeneous alloy which has the potential for elimination of the nickel coating on the anode side of the separator plate have been received from a vendor. The performance of this material is being evaluated in three separate series of tests: 1) separate samples are being subjected to carbonate attack in fuel and oxidant environments, 2) the electrical conductivity of the material is being measured as a function of time and in the presence of carbonate in a dual atmosphere test cell, and 3) anode and cathode current collectors were fabricated from the material and are being used in a 3-cm² lab-scale cell to monitor the electrical performance, corrosion resistance, and deformation resistance under actual operating conditions. During the period, the fuel and oxidant corrosion tests and the conductivity test of the alloy were performed. The 3-cm² cell test is still under test.

This period two corrosion tests were started, one under fuel and one under oxidant. The tests were terminated after 1000 hours to obtain SEM analysis. Three distinct surface layers form in the metal samples under these conditions; a dry oxide corrosion layer, a thin electrolyte film corrosion layer, and a thick electrolyte blanket corrosion layer. The corrosion tests were completed and the samples retrieved for analysis.

One conductivity-test with the alloy was operated for 1000 hours. The conductivity test was started using a standard 3 cm² test stand. The cell uses a standard Ni/Cr anode with a Ni current collector on one side and a standard NiO cathode with a stainless steel current collector on the other with a disk of the alloy separating the two electrodes. This disk occupies the place usually occupied by the electrolyte matrix. In the strictest sense, these electrodes cannot be described as anode and cathode because no electrochemistry

is taking place in the cell. The electrical current carried through the cell is entirely electronic.

Both electrodes were prefilled with carbonate. The specimen was under a dual atmosphere of fuel and oxidant. The test was run for 1000 hours and then disassembled to obtain SEM analysis of the corrosion layer. Results will be compared with previous 1000 hour conductivity tests of 316L and 310S stainless steels and with the results of the corrosion tests and cell test.

Figure 7 is a plot of the IR drop in mV across the conductivity cell for 1000 mA and represents the IR drop through the entire (Ni current collector/Ni3Cr anode/alloy separator/NiO electrode/316L current collector) assembly. As a comparison, the IR drops for an earlier version of the alloy (C-14) and for a 316L stainless steel separator (C-9) are shown for similar conductivity tests. The C-14 and C-9 cells, however, used carbonate-containing NiO electrodes on the oxidant side but dry Ni-10Cr electrodes on the fuel side whereas the C-16 sample used carbonate-containing electrodes on both sides. Using this data to estimate the electronic contribution to the total IR drop for a stack operating at 160 mA/cm² projects relative electronic resistances drops of 52 mV for C-16, 19 mV for C-14, and 12 mV for C-9 per cell at 1000 hours.

It is not known if the presence of carbonate in the Ni-10Cr electrode is causing the large difference between the two versions of the alloy or whether it is inherent in the alloy compositions. Because of the importance of this result, the experiment will be repeated. Also, results will be available within a few weeks from the 3 cm² cell test, discussed below, using the alloy as current collectors.

Perforated sheet metal anode and cathode current collectors were prepared from the alloy and a 3-cm² cell (Cell SPM-T95) using these current collectors was started. The electrical resistance of the anode/anode current collector assembly and the cathode/cathode current collector assemblies will be monitored for 1000 hours and compared to the resistance of their Ni and 316L counterparts. Differences will be due to differences in the behavior of the oxide layer forming at the electrode/current collector interface. At the completion of the tests, the current collectors will be combined with the samples from the corrosion and conductivity tests and analyzed by SEM and EDX to evaluate the rate of corrosion and the tendency of the oxide layers to spall during cool down. The flatness of the current collectors will also provide a qualitative measure of the tendency of the alloy to deform at operating temperature.

Cell SPM-T95, with anode and cathode current collectors made from the alloy, standard electrodes, and Li/K electrolyte has operated 216 hours and shows 853 mV cell potential at 160 mA/cm² with 46 mV anode polarization, 58 mV cathode polarization, and 87 mV total IR-drop. The anode and the cathode IR-drops are 47 mV and 40 mV, respectively. The total IR-drop is approximately 35 mV higher than that shown with Ni anode current collector and 316 SS cathode current collector. The performance is shown in Figure 8.

FIGURE 7
Conductivity Test C-16, C-14, And C-9

FIGURE 8
Lifegraph Of Cell SPM-T95

Verification Testing

Bench-Scale Testing

The performance behavior of bench scale cells operated at 3 atm was reviewed and a number of key performance and endurance issues were identified.

- *700° C cell operation is detrimental to cell endurance.*
- *Under system oxidant, Li/Na has low acidity. When a cathode stabilizing agent was added to it, the cathode dissolution increased, suggesting that the dissolution mechanism may have changed from acidic to basic in which dissolved species have a faster transport rate.*

Based on the above findings, a number of cell tests have been planned and have either been started or are under preparation. The tests are summarized in Table 2 and are individually discussed below. An overall summary of the cell tests conducted to date is presented in Table 3. The performance of the cells that are in operation is summarized in Table 4.

Cell IGT-BS-TC-42-96-3

The purpose of this cell is to accelerate the rate of cathode dissolution and Ni deposition in the matrix by the use of noble oxidant of $67\text{CO}_2/33\text{O}_2$ with system fuel at 3 atm. The $p\text{CO}_2$ of the noble oxidant at 3 atm is 1.5 atm and is 6.25 times that of the system oxidant which is only about 0.24 atm. Because the rate of Ni transported to the matrix is a function of $p\text{CO}_2$, the time to short the matrix under the system oxidant is expected to be 6.25 times higher than under the noble oxidant. Thus, if matrix shorting under noble oxidant for Cell IGT-BS-TC-42-96-3 occurs after 6,400 hours, then an endurance of 40,000 hours against cathode dissolution can be expected under system oxidant.

The cell has been in operation for 1344 hours, of which about 1000 hours has been at 3 atm. The cell peaked at 915 mV at 160 mA/cm² at 3 atm with a resistance of only 2.0 mOhms. The cell performance was checked on reference oxidant at about 950 hours of operation and showed a potential of 830 mV. It resumed 915 mV potential after switching back to the noble oxidant. At about 1100 hours of operation, the cell was operated on system oxidant for comparison with other cells. It showed a potential of 787 mV which is about 20 mV higher than the best performance of 765 mV previously achieved with the system oxidant at 160 mA/cm². However, when the noble oxidant was re-introduced, the cell failed to regain its 915 mV original cell performance, showing just 892 mV. There was a significant increase in cell resistance after switching back to noble oxidant from system oxidant although the electrode polarization decreased. This symptom is similar to that observed for Cell IGT-42-96-4. Because this cell is being operated for evaluation of cathode dissolution, it will be operated for at least 2,000 hours at pressure.

The cell performance as a function of time and pressure is shown in Figure 9. The cell performance had remained stable at the 912-914 mV level up to 1152 hours of operation. The abrupt decrease in the cell performance could be due to a re-distribution of carbonate in the cell packaging with the different gases. The current cell performance is approximately 892 mV and appears to be improving slowly. The anode and cathode wet seal efficiencies are 98% and 97%, respectively. To date, the cell has operated for 1344 hours and will continue its operation next month.

FIGURE 9
 Life Plot Of Cell IGT-BS-TC-42-96-3

Cell PDI-8

The purpose of this test is to determine the performance characteristics of a cell operating at 3 atm pressure of 250 mA/cm² with system fuel and a market entry oxidant (MEO). The cell start-up occurred with the gas type SF/MEO and the process gas flows were set for 75% U_i F and 40%U_iO at 250 mA/cm². Operation of Cell IGT-PDI-8 continued this quarter at 3 atm and a current density of 250 mA/cm². The cell performance as a function of time and pressure is shown in Figure 10.

Since last month the cell potential at 3 atm and a current density of 250 mA/cm² decreased from 711 to 701 mV due to increases in IR and polarization. The fuel utilization was decreased from 75% to 60% at 4176 hours of operation to compensate for the low anode wet seal efficiency of 80%. Also, anode over cathode overpressure runs were conducted to investigate the nitrogen gas crossover situation. The results clearly indicate that the crossover is occurring from the oxidant to the fuel compartment through a crack in the matrix, and the anode wet seal efficiency decrease with time is due to an external leak on the wet seal. This will be verified during the cell disassembly after shut down.

The cell decay rates are approximately 5 mV/1000 hours from 672 to 4152 hours of operation and 80 mV/1000 hours from 4176 to 4704 hours. In view of the poor performance, low anode wet seal efficiency, and high nitrogen crossover, Cell PDI-8 was terminated after 4704 hours (4053 hours at 3 atm and a current density of 250 mA/cm²). The post-test disassembly observations will be presented next month.

FIGURE 10
 Life Plot Of Cell IGT-PDI-8

Cell IGT-PDI-9

The purpose of this cell test is to determine the performance of a cell operating at 3 atm pressure and 250 mA/cm² with system fuel and a market entry oxidant (MEO). The gas flows were set for a fuel utilization of 75% and an oxidant utilization of 40% at 250 mA/cm².

Cell PDI-9 has just been started and has been at 3 atm for less than 100 hrs. Its performance before and after pressurization has not been good because of high electrode polarization. At 3 atm, the cell potential of 675 mV is 65 mV lower than that of Cell PDI-5 which was operated under the same conditions.

The cell performance as a function of time and pressure is shown in Figure 11. The cell performance at 250 mA/cm² increased from 586 mV to 631 mV due to decreases in IR (5 mV) and polarization (40 mV). The OCV at 1 atm was 1019 mV, 2 mV lower than the theoretical value of 1021 mV. The cell was then pressurized to 3 atm with the gas type SF/MEO. The cell performance at these conditions and 250 mA/cm² (75% U_F and 40% U_O) was 675 mV. The observed performance improvement of 44 mV from 1 to 3 atm (631 mV to 675 mV) is 16 mV lower than that predicted by the PSI model. The average OCV of 1045 mV at 3 atm is 4 mV higher than the theoretical value of 1041 mV. The anode and cathode wet seal efficiencies are 99% and 100%, respectively, with a nitrogen crossover of 1.5%. If there is no further improvement in Cell PDI-9, it will be terminated next month.

FIGURE 11
 Life Plot of Cell IGT-PDI-98

Cell IGT-PDI-10

The purpose of this cell test is to determine the performance of a cell operating at 3 atm pressure and 250 mA/cm² with the gas type SF/MEO. Startup for Cell PDI-10 occurred with the heatup schedule specified for the 250-kW Stack PDT-1. The flows for the gas type SF/MEO (set for 75% U₂F and 40% U₂O @ 250 mA/cm²) were initiated after the cell attained 650° C.

The cell is being conditioned first at 650° C and 1 atm. The plan was to operate it 1 atm at 700° C if it shows good performance at 650° C. At 650° C, the cell performance is only 588 mV after 312 hours. The resistance is very high, 7 mOhms, and it will be determined from post test analysis if the high resistance is related to the startup procedure. Because the cell is unlikely to reach an acceptable performance of at least 650 mV at 1 atm and 650° C, it will be terminated.

The current performance (312 hours) of Cell PDI-10 is approximately 61 mV low, possibly due to the impact of the long heatup schedule employed for this cell test. The wet seal efficiencies are 98% and 100%, respectively, and the nitrogen gas crossover is negligible (approximately 0.1%). At present, the effect of long heatup time on the bench-scale cell performance is not completely understood. Additional cells will be operated using the long startup schedule.

Cell IGT-BS-TC-42-96-4

The purpose of this test is to determine the baseline performance and cathode dissolution rate of a Li/Na cell operating under system conditions (gas type SF/SO) at 3 atm pressure without addition of the stabilizing agent to the cathode or electrolyte. This dissolution rate will then be compared to that previously obtained from a cell assembled and operated with a stabilized Ni cathode and Li/Na electrolyte.

After being at 3 atm for about 750 hours, the cell potential with 75% fuel and 50% oxidant utilizations is 732 mV. This is 20 mV lower than the peak of 752 mV and 33 mV lower than the highest potential ever achieved under these operating conditions (Cell IGT-BS-TC-66-94-1 peaked at 765 mV). The cell performance as a function of time and pressure is shown in Figure 12. Since last month the cell performance 160 mA/cm² (75% U₂F and 40% U₂O) decreased from 754 mV to 732 mV due to an increase in IR. The current cell performance of 732 mV is the same as that obtained for Cell PDI-2 operated under similar conditions. Cell PDI-2 was assembled with similar components as IGT-BS-TC-42-96-4 except the Li/Na electrolyte had the stabilizing agent added to it. The anode and cathode wet seal efficiencies are 96% and 100%, respectively, with a low nitrogen crossover of 0.2%. To date, the cell has operated for 1320 hours with a decay rate of 31 mV/1000 hour from 672 to 1320 hours of operation.

Cell PDI-13

The purpose of this test is to evaluate the performance of a low-tortuosity Ni cathode. The performance graph for Cell PDI-13 is shown in Figure 13. The cell performance at 160 mA/cm² increased from 715 to 797 mV due to decreases in IR (7 mV) and polarization (75 mV). This current performance of 797 mV is 28 mV higher than the best stabilized Ni cathode ever tested (Cell BS-TC-66-93-4) under similar conditions. The cell OCV of 1041 mV matched the theoretical value of 1043 mV. The average cell resistance of 4.2 mOhms is approximately 1.2 mOhms greater than that expected for cells assembled with Li/Na electrolyte (approximately 3 mOhms). Instrumentation is suspected as the cause for the high IR. The anode and cathode wet seal efficiencies are 100% and 98%, respectively, and the nitrogen crossover is approximately 0.7%. To date the cell has operated for 164 hours and will continue its operation next month.

FIGURE 12
 Life Plot of Cell IGT-BS-TC-42-96-4

FIGURE 13
LIFE PLOT OF CELL IGT-PDI-13

Table 2 PLANNED AND ONGOING CELL TESTS

Cell ID	Test Purpose	Special Components and Test Conditions	Status and Performance
IGT-BS-TC-42-96-3	Accelerate Ni shorting of matrix by using noble oxidant	Standard components, Li/Na, stabilizer-free cell package. Noble oxidant with system fuel at 3 atm and 160 mA/cm ² .	1300 hours total test time, 1000 hours at 3 atm. Peak 915 mV at 160 mA/cm ² at 3 atm, fell to 892 mV after system oxidant for 2 hours. IR had increased to 5 mOhms.
IGT-BS-TC-42-96-4	Baseline performance and endurance for stabilizer-free cell package with Li/Na at 3 atm with system gases at 160 mA/cm ² .	Standard components, Li/Na, stabilizer-free cell package. System gases at 3 atm and 160 mA/cm ² .	1300 hours total test time, 750 hours at 3 atm. Performance has dropped to 732 mV at 160 mA/cm ² , 3 atm due to high iR.
PDI-8	Baseline performance and endurance with SF/MEO gases at 3 atm at 250 mA/cm ² .	Low-cost matrix process with stabilizer added to electrolyte. Both cathode and cathode current collector to the edge.	4,600 hours total test time, 3900 hours at 3 atm. Peak 738 mV at 250 mA/cm ² . Decayed to 703 mV due to loss of anode wet seal.
PDI-9	Repeat PDI-8 but without stabilizer in the electrolyte.	Standard matrix. Stabilizer-free Li/Na. Cathode to the edge.	Only 675 mV at 3 atm. Low performance due to high electrode polarization.
PDI-10	Baseline performance and endurance at 700°C for stabilizer-free Li/Na cell package with SF/MEO gases at 3 atm and 250 mA/cm ² .	Standard matrix. Stabilizer-free Li/Na.	Underwent heat-up simulating stack procedure. At 650°C and 1 atm, performance at 250 mA/cm ² is only 588 mV. Low potential is due to high iR.
PDI-12	Baseline performance and endurance at 625°C for stabilizer-free Li/Na cell package with SF/MEO gases at 3 atm and 250 mA/cm ² .	Standard matrix. Stabilizer-free Li/Na.	To be started.
PDI-13	Low-tortuosity Ni cathode.	Low-tortuosity Ni cathode. Stabilizer-free Li/Na.	Just started
To be Named	Low-tortuosity Ni cathode.	Low-tortuosity Ni cathode. Stabilizer-free Li/Na.	Components being prepared.

Cell IGT-BS-TC-42-96-2

Cell IGT-BS-TC-42-96-2 was assembled with an out-of-cell pre-conditioned cathode/matrix/carbonate/anode laminate and the cathode current collector both extended to the wet seal. The anode current collector was placed within the flange. The anode was protected by LiAlO_2 around the perimeter. The purpose of this test was to evaluate the performance of the out-of-cell laminated cell package fabricated with the Li/Na electrolyte. The cell performance at 1 atm and 160 mA/cm^2 increased from 410 mV to 734 mV due to decreases in IR (290 mV) and polarization (34 mV). The OCV of 1044 mV matched the theoretical value of 1043 mV. The anode and cathode wet seal efficiencies were 98% and 100%, respectively, and the nitrogen crossover was initially high at 2% and decreased to 1.0%.

The most important aspect of this test is that the cell attained the correct open circuit voltage (OCV) with the anode extended to the edge indicating that no internal parasitic currents existed in the cell. This was confirmed by GC analyses conducted on the fuel outlet at OCV conditions. These preliminary results demonstrated that the LiAlO_2 is capable of protecting the extended anode from the ambient air (oxidizing environment) surrounding the cell. The cell was thermal cycled at 984 hours. The cell performance decreased by about 25 mV after the thermal cycle due to an increase in polarization. Both the anode and cathode wet seal efficiencies were 100% and the nitrogen crossover decreased from 1.0 to 0.5%. Also, GC analyses conducted on the fuel outlet at OCV conditions after the thermal cycle did not indicate the existence of internal parasitic currents in the cell. Although the cell did not regain the original performance after the thermal cycle, the LiAlO_2 demonstrated the capability of protecting the extended anode from the ambient air surrounding the cell. In view of the low performance, Cell IGT-BS-TC-42-96-2 was terminated after 1152 hours of operation.

100 cm^2 Cell IM9503

Post-test chemical analysis was completed for Cell IM9503. The purpose of this test was to determine the baseline operating characteristics of a lower cost matrix. The test was terminated after attaining the endurance requirements for the test. After 2281 hours of operation at 3 atm and systems conditions, the cell performance was steady at 762 mV at 60% U_{fuel} . Examination of the pre- and post-test matrix porosimetries show little change after >2000 hours of pressurized operation.

Cell MCP IM9601

The purpose of this test is to determine the baseline performance and endurance for a Ni+LaI anode and a stabilized Ni cathode operated at 3 atm pressure with system gases (gas type SF/SO) using the Li/Na electrolyte. This test is a repeat of Cell IM9502 operated for approximately 740 hours at 3 atm and 160 mA/cm^2 under system conditions with Li/Na electrolyte.

Operation of Cell IM9601 continued this quarter at 3 atm and 160 mA/cm^2 . The cell performance as a function of time and pressure is shown in Figure 14 for the gas type (SF/RO and SF/SO). The cell was set to operate at 60% fuel utilization and 50% oxidant utilization for the gas type SF/RO and for the gas type SF/SO at 60% fuel utilization and 40% oxidant utilization at 160 mA/cm^2 . The cell potential at 3 atm and 160 mA/cm^2 on SF/SO was stable at the 747 to 750 mV level up to 2210 hours of operation. After this, the voltage was erratic and the cell could not be loaded. The anode and cathode wet seal efficiencies were 92% and 100%, respectively, with a nitrogen crossover of 1.6%. In view

of the cell loading problem Cell IM9601 was terminated after 2328 hours of operation. After the shutdown, an inspection of the test stand revealed that the electronic load device on the stand shorted out the leads employed for loading the cell. Post-test disassembly observations of Cell IM9601 will be presented next month.

Cell IM9602

The purpose of Cell IM9602 was to determine the baseline performance and endurance of a lower cost advanced component cell package operated at pressurized (3 atm) systems conditions using electrolyte prepared by a low-cost process. The cell was assembled with a Ni+3Cr anode and a stabilized Ni cathode.

Cell disassembly revealed that the carbonate had completely melted and wicked into the active area components. Poor component contact and significant corrosion of the cathode current collector may have caused the high internal resistance. Samples of the active components were submitted for post-test chemical analysis and porosimetry.

Cell IM9602 had a high initial IR of 28 mOhms which decreased to 21 mOhms during 264 hours of operation. Due to the high IR the cell could not be loaded beyond 40 mA/cm² and still maintain a cell voltage above 600 mV. The cell temperature was increased from 650° C to 720° C, held for two days, and decreased back to the normal operating temperature of 650° C. The cell clamping force was also increased from 25 to 30 psi in an attempt to decrease IR. Both these actions did not affect the cell IR or performance. The anode and cathode wet seal efficiencies were 96% and 95%, respectively, and the nitrogen gas crossover was approximately 4.2%. In view of the poor performance Cell IM9602 was terminated after 456 hours of ambient pressure operation.

Cells IGT-BS-TC-42-96-3, IGT-BS-TC-42-96-4, PDI-9, PDI-10 and PDI-13 will continue operation next month. Another cell test will be assembled and operated at 3 atm pressure, 250 mA/cm² under market entry system conditions (SF/MEO) and 625° C to determine the effect of the lower temperature on the performance and endurance.

100 cm² Cell IM9603

The purpose of Cell IM9603 is to provide baseline performance and endurance data for an advanced component cell package containing a lower cost stabilized cathode and the Li/Na electrolyte system. The active area components were manufactured and a pre-test report was completed. Cell startup is scheduled for next month.

100 cm² Cell IM9604

Lab-scale manufacturing trials were completed for the active area components of Cell IM9604. Except for a lower cost stabilized cathode, the active area components will be the same as those tested in M0195003.

100 cm² Cell M0195003

Cell test M0195003 completed 9548 hours of operation as of 6/29/96 and continues steady operation at 764 mV at 160 mA/cm² and 60% $U_{t_{fuel}}$ on system gases pressurized to 3 atm as shown in Figure 15. This test includes the first Li/Na electrolyte tested at M-C Power and a lower cost version of the stabilized cathode. This test will reach one year of operation at pressurized systems conditions on July 8, 1996.

FIGURE 14
 TEST NO. IM9601

FIGURE 15
 CELL M0195003
 Cell Operating Performance

100 cm² Cell M0196001

Cell M0196001 was used to evaluate an advanced subscale cell conditioning procedure and acquire benchmark fuel cell performance levels for ATF and power plant operating conditions. Tests included clamping force release tests and hot hold verification testing using a proposed "safe" gas composition. Disassembly, measurement, and visual observations of the cell interior and active area components will occur next month pending completion of the current ATF operations.

100 cm² Cell M0196002

Cell M0196002 is being used to evaluate an ATF cell conditioning schedule and provide benchmark performance data under ATF operating conditions. The cell completed 498 hours as of 6/27/96, at 1 atm with ATF-F1 and ATF-O2 gas compositions. The cell had been loaded to 6 A but, due to a decrease in performance, the load was lowered to 2 A to allow for cell recovery. At a load of 2 A, the cell performance decreased from 930 mV over a four day period. The reason for the decay is not clear at this time. Next month, the cell internal resistance will be evaluated and the clamping force increased to try to improve the cell performance.

Table 3 OVERALL SUMMARY OF BENCH-SCALE CELL TESTS CONDUCTED TO DATE IN TASK 6.1.1.4. - Continued				
Cell No.	Purpose	Status	Duration Hours	Conclusion
IGT-PDI-1	Determine performance of Li/Na at 3 atm system conditions.	Terminated	2352	Performance comparable to previously operated cells assembled with similar components.
IGT-PDI-2	Determine cell performance with stabilizer in Li/Na electrolyte at 3 atm 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 pre-conditioned laminate with Li/Na electrolyte.	Terminated	504	Cell did not perform well due to high IR.
IGT-BS-TC-42-95-6	Determine effect of opposing gas on exposed cathode in the fuel manifolds.	Terminated	309	Re-evaluate the method of electrode edge protection.
MCP-IM9502	Determine performance of Ni+3Al anode at 3 atm system conditions using Li/Na.	Terminated	1100	Cell did not perform well due to a high decay rate (55 mV/1000 hours).
MCP-IM9503	Evaluate operating characteristics of a low-cost matrix formulation.	Terminated	2376	Cell performance is comparable to the SOA cells assembled with prewetted matrices.
MCP-IM9504	Determine endurance characteristics of Li/Na at 3 atm and system conditions.	Terminated	792	Cell test terminated due to poor performance.
IGT-BS-TC-42-96-1	Determine effect of opposing gas on exposed anode in oxidant manifolds.	Terminated	288	Re-evaluate method of electrode edge protection. The Al paint employed for anode edge protection did not work well.
IGT-PDI-5	Determine cell performance at 3 atm, 250 mA/cm ² with Li/Na market entry oxidant	Terminated	3480	Cell did not perform well due to carbonate losses
IGT-PDI-6	Determine performance of a pre-conditioned cathode/matrix/anode laminate and CCC both extended to the edge. Evaluate LiAlO ₂ for protection.	Terminated	2376	Corrosion of CCC and carbonate losses due to high operating temperature (700°C).
IGT-BS-TC-42-96-2	Determine baseline performance and life of lower cost cell package at 3 atm system conditions.	Terminated	1152	Cell did not perform well due to high IR and did not thermal cycle well. LiAlO ₂ provided a good protection for the extended anode to the edge with no parasitic currents.
IM9602	Determine baseline performance and life of lower cost cell package at 3 atm system conditions.	Terminated	432	Cell did not perform well due to high IR.

Table 4 PERFORMANCE SUMMARY OF THE BENCH-SCALE CELLS THAT ARE IN OPERATION

Cell No.	Hours of Operation	Cell Data (mV)				Wet Seal Efficiency, %		N ₂ Crossover %
		OCV	Performance	IR	Polarization	Anode	Cathode	
PDI-13	164	1041 ^a	797 ^a	68 ^a	176 ^a	100	98	0.7
IGT-BS-TC-42-96-3	1344	1113 ^b	892 ^b	83 ^b	138 ^b	98	97	-
IGT-BS-TC-42-96-4	1320	1000 ^c	732 ^c	64 ^c	204 ^c	96	100	0.2
PDI-8	4728	1026 ^d	701 ^d	80 ^d	245 ^d	85	100	5.3
PDI-9	528	1041 ^e	675 ^e	92 ^e	274 ^e	99	100	1.5
PDI-10	312	1023 ^f	588 ^f	172 ^f	263 ^f	99	100	0.1
IM9601	2328	1020 ^g	748 ^g	50 ^g	222 ^g	92	100	1.6

^aAt 160 mA/cm², 75%U_iF and 50% U_iO @ 1 atm on RF/RO.

^bAt 160 mA/cm², 75% U_iF and 40% U_iO @ 3 atm on SF/NO.

^cAt 160 mA/cm², 75% U_iF and 40% U_iO @ 3 atm on SF/SO.

^dAt 250 mA/cm², 60% U_iF and 40% U_iO @ 3 atm on SF/MEO.

^eAt 250 mA/cm², 75% U_iF and 40% U_iO @ 3 atm on SF/MEO.

^fAt 250 mA/cm², 75% U_iF and 40% U_iO @ 1 atm on SF/MEO.

^gAt 160 mA/cm², 60% U_iF, and 40% U_iO @ 3 atm on SF/SO.

Subtask 6.3 **Balance of Plant Component Development**

Objective: In this task, Bechtel's second 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 negotiations 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.

In the second year, the effort described above will be carried out for the power conditioner, reformer with catalytic combustor, turbo machinery, and the HRSG unit, which are all BOP components.

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.

Status: **PDI-1 Fabricate, Engineering Efforts**

A drawing review meeting for the separator plates and the intermediate plates was conducted. The separator plate drawings were revised first due to a scheduled trip to the stamping vendor to press the plates. The PDI-1 intermediate plate drawings have been put on hold pending the lessons learned from the fabrication of the PDT-1 intermediate plates.

The PDI-1 top clamp plate drawing and the load plate drawing have been released to the Operations Department for fabrication.

M-C Power issued thirteen (13) drawings for the fabricated plenum review. The plates and rails have been pressed. The plates The drawings were revised and have gone through the drawing approval procedures. The thirteen (13) Revision 0 drawings of the fabricated PDI-1 plenum were duplicated and released for fabrication.

M-C Power started the preliminary design for the PDI-1 shipping container. The base of the shipping container will be the steel frame that the Unocal stack was returned on. Trimming and welding are scheduled for July.

Work on the plenum, separator and main rail plates progressed.

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

Objective: The major purpose of this demonstration 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 power plant at a customer site.

Status: **1 MW Stack Design**

The design of the 1 MW anode end plate assembly was initiated based on the Bechtel report titled "Final Report, Fuel Cell Balance of Plant Cost Analysis" which incorporates the intercooler plate design for manifolding. The initial conceptual design involves a cast anode end plate with integral stiffening ribs. The design has not yet been evaluated

using finite element analysis (FEA), but will be used as the starting point for the 1 MW anode end plate. As a follow-up, M-C Power began gathering information for the FEA software package that M-C Power should purchase to evaluate the AEP design.

The evaluation of the major alternative systems of the 1 MW plate design has been completed and issued for comment.

Subtask 6.6 **Update Commercialization Plan**

Objective: The commercialization plan will be updated based on the results of the MW-class demonstration.

Status: *Inactive during this reporting period.*

APPENDIX A: ISO 9001 Quality Assurance Procedures

1	<u>Management Responsibility</u> Quality Policy Maintenance Responsibilities for Quality Quality Program Management	11	<u>Inspection, Measuring, and Test Equipment</u> Approved Gauge Specifications Gauge Calibration and Certification
2	<u>Quality System</u> Performance of Quality System Reviews Quality System Documentation Requirements Development of Quality Plans	12	<u>Inspection and Test Status</u> Inspection and Test Status Indication of Test Status Product Release Status
3	<u>Contract Review</u> Performance of Contract Reviews	13	<u>Control of Nonconforming Product</u> Control of Nonconforming Material Review & Disposition of Nonconforming Material Request for Deviation or Waiver Rework Material Request for Material Review Conditional Release of Nonconforming Product Rework of Nonconforming Product Product Recall
4	<u>Design Control</u> Identification of Developmental Issues Design Release Status Planning of Design and Development Activities Technical Interfaces for Design Reviews Development of Design Input Requirements Development of Design Output Requirements Performance of Design Reviews Design Verification Design Validation Control of Design Changes	14	<u>Corrective Action</u> Requests for Corrective Actions Investigation of Nonconformances Corrective Action Implementation and Review Supplier Corrective Actions Preventative Action Requirements
5	<u>Document Control</u> Requirements for Controlled Documents Quality Manual Maintenance Quality Procedure Development & Approval Operating Procedure Development & Approval Drawing Approval	15	<u>Handling, Storage, Packaging, and Delivery</u> Specification of Handling & Storage Requirements Development of Handling and Storage Procedures Storage of Perishable Materials Special Handling Requirements
6	<u>Purchasing</u> Quality Specifications for Purchased Products Vendor Certification and Selection Assessment of Subcontractors Verification of Purchased Product Vendor Product Certification	16	<u>Quality Records</u> Required Quality Records Quality Record Maintenance and Retention
8	<u>Product Identification and Traceability</u> Material Identification Material and Component Traceability Material Transfer	17	<u>Internal Quality Audits</u> Internal Quality Audit Preparation and Planning Internal Quality Audit Performance Internal Quality Audit Reporting Internal Quality Audit Corrective Action & Review
9	<u>Process Control</u> Process Development & Capability Assessment Process Control Requirements Certification of Manufacturing Processes Temporary Process Deviations Production Hold Experimental/Developmental Processes	18	<u>Training</u> Employee Orientation Requirements for Quality Training Requirements for Technical Training Certification Requirements
10	<u>Inspection and Testing</u> Incoming Material Inspection and Testing Measurement Terminology Measurement Test Units Acceptance Sampling & Material Certification In-process Inspection and Testing Final Inspection and Testing Requirements for Lot Certifications Performance Testing Requirements Inspection and Test Records	19	<u>Servicing</u>
		20	<u>Statistical Techniques</u> Application of Statistical Techniques Test Method Certification Data Assessment and Control Development of Sampling Plans Use of Control Charts

APPENDIX B: QA and Analytical Procedures

Test and Measurement Procedures

Main Rail Measurements
Separator Plate Rib Measurements
Separator Plate Dimple Measurements
Separator Plate Flatness Measurements
Bipolar Plate Total Wet Seal Measurements
Tapped Hole Qualification
Bipolar Plate & Half Cell Visual Inspection
Modified Total Wet Seal Measurements
Nickel Testing
Bipolar Plate Total Step
Dimple Amplitude Measurements
Feed Channel Measurements
Rib Amplitude Measurements
CMM Program List
CMM Data Transfer / Conversion
CMM Start-Up
CMM Preventive Maintenance
CMM Probe Tip Calibration
CMM Main Rail Measurements
CMM Bipolar Plate Measurements
CMM Bipolar Plate Rail Profile Measurements
CMM Bipolar Plate Planform Measurement
Electrode Data Conversion Procedure
CMM Text File Conversion Procedure

QA Laboratory Operating Procedures

Microscope Reticle Measurement
Grinding of Stainless Steel Plate Samples
Sample Preparation of Anode XRD Sample
Preparing a 3" Cold Mount
Carbonate Apparatus
Electrode Carbonate Washing
Microwave Digestion
Mercury Porosimetry
Cold Mounting of Anode XRD Sample
Tape Caster Waste Water Analysis
Grinding of Stainless Steel Plate Samples
Preparing a Hot Mount

Stack Gas Analytical System Operating Procedures

System Layout
System Flow Schematics
Independent System Operation
Operating Program Overview
Data Transmission Schematic
Chromatograph Manual Operation
Chromatograph Supplemental Ports
Dew point Analyzer Strip Chart
Dew Point Digital Output
Initiating Operating Program
Initiating Send report Option
Chromatograph Start-Up Procedure
Chromatograph Calibration

Chromatograph Support Gases
Total Hydrocarbon Analyzer Start-Up Procedure
Total Hydrocarbon Analyzer Calibration
Total Hydrocarbon Analyzer Support Gases
Chromatograph Integrator Start-Up
Resetting Integrator
Integrator Input Level Adjustment
Integrator Threshold Evaluation
Analytical System Start-Up
Analytical System Shut-Down
Desiccant Cartridge Replacement
Balancing Dew Point Sensor Optics
System Leak Check
Support Gas Cylinder Replacement

Description of Attachments

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

Thomas G. Benjamin 9/13/96
T. G. Benjamin, PDI Project Manager - Date

DOE Reviewing Representative