ABSTRACT
As the NASA Aerospace Flight Battery Systems Program enters into its second funded year, the Program Plan is being modified to reflect the current status of battery needs for NASA. These needs focus upon the end objective of producing higher performance and higher reliability cells and batteries. Battery related problems are being brought forward by the NASA battery community for continual review and resolution, using the NASA Aerospace Flight Battery Systems Steering Committee as the means to review and determine battery policy. Top attention in the Battery Program is being devoted to an advanced nickel-cadmium cell design and the establishment of a semi-dedicated line for the production of an advanced nickel-cadmium cell. As part of a unified Battery Program, the development of a nickel-hydrogen standard and primary cell issues are also being pursued to provide high performance NASA Standards and space qualified state-of-the-art primary cells. The resolution of issues is being worked with the full participation of the aerospace battery community.

INTRODUCTION
The NASA Aerospace Flight Battery Systems Program represents a unified NASA wide effort with the objective of providing NASA with the policy and posture which will increase the safety, performance, and reliability of space power systems. The program consists of three major technical tasks designed to accomplish this objective. These are: Battery Systems Technology, Secondary Battery Technology, and Primary Battery Technology. The approach to achieving the program objectives involves increasing the fundamental understanding of primary and secondary cells; providing for improved nickel-cadmium manufacturing process control; providing for the establishment of a NASA standard nickel-hydrogen cell design; establishing specifications, design and operational guidelines for both primary and secondary cells and batteries; providing training relating to the above areas; and opening and maintaining communication lines within NASA and the aerospace battery community.

The NASA Lewis Research Center (LeRC) has the overall responsibility for management of the program. Dr. Patricia O'Donnell of the Lewis Research Center is the program manager. The majority of the NASA centers are involved in the execution of specific tasks within the program. The overall objectives, guidelines and funding are provided by NASA Headquarters through Code Q, the Office of Safety, Reliability, Maintainability and Quality Assurance. The NASA Battery Steering Committee provides guidance by overseeing the activities, reviewing the ongoing programs and making recommendations concerning future areas of concern. The NASA Battery Steering Committee is comprised of one member from each of the NASA centers and a member from Aerospace Corporation, representing the Air Force. The original organization of the tasks in the program plan, the initiation of the plan and status during the first year of funding have been previously discussed in references 1 through 3 respectively.

Over the past year NASA senior management has become increasingly aware of the seriousness of the situation that has developed with regard to the quality and reliability of nickel-cadmium secondary cells as the number and frequency of ground test failures has increased. As a result, additional funding has been granted to resolve the current nickel-cadmium problems that NASA has been encountering and to initiate improved checks and balances for ensuring cell and battery quality. This has resulted in an overall restructuring of the NASA Aerospace Battery Systems Program Plan to address the issues at hand. The overall plan and the specific modifications will be addressed in this paper.

PROGRAM PLAN OVERVIEW - TASK STATUS
This program is designed to enhance the safety, reliability, and performance of NASA's aerospace primary and secondary batteries as well as battery power systems. It is also intended to bring NASA up to state-of-the-art with current battery technology. The program is organized under

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four major tasks: Program Management, Battery Systems Technology, Secondary Battery Technology, and Primary Battery Technology, details of which are discussed below.

Program Management

The objective of this task is provide comprehensive nickel-cadmium with all the NASA centers, Jet Propulsion Laboratory (JPL), NASA Headquarters and the Battery Steering Committee. Program management is provided by the Lewis Research Center, which has full responsibility for technical management, cost and scheduling of the program.

Battery Systems Technology

The Battery Systems Technology Task addresses the need to deal with the overall systems aspects associated with the integration of cells into batteries and batteries into power systems. The objective is to improve the reliability of energy storage, power system design, integration, and checkout.

Goddard Space Flight Center (GSFC) is in the process of developing a NASA Battery Systems Handbook that will define good, consistent design, integration and checkout practices to be applied across all NASA programs. Secondary nickel-cadmium and nickel-hydrogen systems will be emphasized. A draft of the handbook is expected by the end of this fiscal year. The handbook will serve as the basis for a training program, under Goddard’s guidance, that will ensure that personnel at both the engineer and technician levels, involved with the design, test, integration, and operation of batteries and their related power systems are fully trained and qualified for safe and proper operational procedures.

The Battery Problem Reporting System subtask was established to provide a problem data base from battery and cell operations both in the field and in flight. The original approach to providing the required data base was to incorporate the development of a Battery Problem Reporting Task within the existing, Johnson Space Center (JSC), Problem Reporting and Corrective Action (PRACA) System which is presently used to address design, manufacturing and operational deficiencies in National Space Transportation System (NSTS) hardware. The existing PRACA system did not fully cover the requirements of this task and has been abandoned. Effective reporting systems were underway to develop a battery specific data base that would provide access to operational cycle test data in addition to a problem reporting system. The goal is permit all NASA centers to input and retrieve pertinent information, and to facilitate the issuance of rapid alerts when potential problems and/or trends have been identified. Ames Dryden Flight Research Facility has assumed responsibility for implementation of this subtask.

The NASA Goddard Battery Workshop comes under the sponsorship of the NASA Aerospace Battery Systems Program Plan. The workshop serves as a forum for open communication of battery related activities between industry and government. The next workshop is scheduled to be held in the spring of 1990 and every other year thereafter.

The future requirements and applications for both primary and secondary battery systems are continuously monitored as part of Battery Systems Task. The Lewis Research Center has responsibility for this subtask. The preliminary findings have been summarized and distributed among the NASA Battery Systems Steering Committee Members. Future reports will be issued as required.

Secondary Battery Technology

The re-establishment of a qualified Standard Nickel-Cadmium Cell is the major concern of this task. Recent test data from the Crane life cycle testing has revealed serious ongoing life problems with current nickel-cadmium cells. The Secondary Battery Technology Task has been initiated to evaluate near-term options for the resolution of life problems with current design nickel-cadmium cells. This involves the evaluation of SAFT cells and Hughes ‘super’ Ni-Cd cells as possible replacements for the current NASA Standard cells produced by Gates Aerospace Batteries. A number of cells has been evaluated by NASA. 20, 24 and 40 AH cells are currently on test. Sixty advanced design Ni-Cd cells have been purchased from Hughes and are currently undergoing characterization testing at Crane. Stress testing is planned for both sets of cells. The Goddard Space Flight Center is responsible for the procurement and testing of the above cells. Modifications to the present Gates cells are also being investigated as a part of the near-term solution. An interactive contract with Gates, under the management of the Lewis Research Center, has been initiated that would allow variations in the porosity, nickel attack level, and the loading level of the positive electrodes as well as the incorporation of modified separators, and varied electrolyte levels. Modified cells will be constructed and tested to evaluate the effectiveness of the component changes.

Funding has been approved for the proposed long-term resolution which involves the identification of an advanced nickel-cadmium cell design and the establishment of a semi-
dedicated line for the production of the advanced design cell. A "Procurement Evaluation for the Production of Ni-Cd Cells" was conducted by Goddard Space Flight Center and the recommendations of that study are to be implemented under this subtask. Goddard Space Flight Center has responsibility for the management of this subtask.

The Jet Propulsion Laboratory is responsible for the Applied Nickel-Cadmium Technology subtask. This subtask involves the development of an electrochemical model of the nickel-cadmium system that involves physical, chemical, and electrochemical studies at the component and cell levels. The model will be used to develop an accelerated test which can be used to determine the quality of flight lot cells without extensive life testing. Phase I of the model, which involves using a table lookup approach for determining cell performance, has been implemented and is available for distribution through COSMIC. Phase II of model involves the replacement of the table lookup approach used in Phase I with a one dimensional electrochemical model being developed under a contract with Texas A&M. The Phase II model is scheduled to be complete in September of 1990. The third and final phase of the model involves the expansion to a two dimensional model and the incorporation of factors to predict performance degradation. The Phase III model is scheduled to be complete in May of 1992.

Steps are underway to evaluate the critical aspects of nickel-hydrogen technology in order to prevent a situation similar to that presently being experienced with nickel-cadmium cells and to ensure the production of consistent, quality cells. The Lewis Research Center has responsibility for the Nickel-Hydrogen Technology subtask. It involves coordination of Code R, Office of Aeronautics and Space Technology, efforts and Code Q support for the verification and qualification of technology advances identified through the Code R program. Currently the effects of the NASA advanced design features and the effects of 26% vs 31% KOH are being evaluated in flight cells being tested at Crane. Flight cells are also being built which will evaluate potential replacements for the asbestos separators presently used in nickel-hydrogen cells. The goal of this subtask is to recommend the design features of a NASA Standard Nickel-Hydrogen cell. It involves close coordination with Hubble Space Telescope and Space Station Freedom, missions which plan to use nickel-hydrogen batteries for energy storage.

A subtask which involves the implementation of a program of increased checks and balances was added to the Secondary Battery Technology Task in response to the current nickel-cadmium situation. The increased checks and balances are aimed at identifying potential problem areas in a timely manner so that appropriate actions can be taken to correct the problems with minimal impact.

The expansion and upgrading of test facilities at JPL and Goddard is planned as a part of this effort. This will provide increased capability within NASA for the non-routine testing and mission simulation of cells and batteries for future NASA missions.

Several of the task force activities initiated at the Nickel-Cadmium Mini-Workshop held at the NASA Marshall Space Flight Center (MSFC) in June of 1988 are continuing as a part of the increased checks and balances effort. These include the Crane Data Evaluation effort, the Quality Oversight Task and the effort for the Establishment of Standard DPA Procedures. The Crane Data Evaluation task force determined that the present data base of Crane data is not useful for the determination of product consistency or statistical relationships. The task force role has been expanded to include the identification of a meaningful test matrix for the testing and evaluation of cells for LEO and GEO applications. JPL has responsibility of organizing this activity. As part of the Quality Oversight Task, efforts are presently underway at GSFC to incorporate NASA Performance Assurance Requirements and an accompanying letter of delegation into a revised version of the NASA Standard Cell Specification NHB 8073.1. The Task Force Group that investigated the establishment of industry-government wide standards for the performance of destructive physical analyses is being asked to recommend a uniform DPA procedure for Ni-Cd Cells. The procedure will become the NASA Standard DPA Procedures and be implemented at the independent DPA facility that is being established as part of this subtask. Here the objective is to establish an independent facility for the performance of DPAs and routine diagnostic tests for secondary cells. The Marshall Space Flight Center is organizing efforts relating to the establishment of an independent DPA facility.

As part of an effort to understand and define the component properties that lead to reliable, high performance cells JPL is performing a task that involves comparing properties of plates produced in the 1970's when cells were relatively problem free to those of plates made more recently.

Efforts are underway to investigate the use of impedance spectroscopy as an interpretive tool for predicting cell performance and quality. The Lewis Research Center is
responsible for this effort.

The mechanical aspects of nickel-hydrogen case integrity and non-destructive evaluation of the cell closure welds are of particular concern for determining flight worthiness of nickel-hydrogen cells. As a part of this program the Lewis Research Center is responsible for investigating advanced NDE techniques for flaw definition and flaw growth in nickel-hydrogen cell cases. This subtask involves close coordination with similar efforts being conducted by Space Station Freedom and Hubble Space Telescope Program Offices.

Primary Battery Technology

The objective of the Primary Battery Technology Task is to improve the performance, reliability and safety of primary battery systems. The major thrust of this effort is to reduce the number of different cell chemistries now used by identifying and qualifying high performance NASA Standard Primary Cells. The Johnson Space Center has primary responsibility for work performed under this task.

A Primary Battery Design and Safety Handbook has been prepared and is expected to be published in the near future. It is intended that the handbook provide NSTS users with the necessary guidelines, standard testing procedures and requirements to ensure mission success.

An excess of a dozen different cell chemistries are presently used by NASA to provide the power requirements for primary battery applications. Many of the cells and batteries used are commercially available off-the-shelf items. As a result, NASA has no control over the manufacturing processes used to produce these cells. Therefore, NASA, through JSC, is in the process of setting up a logistics source of primary cells that will have been previously screened and qualified. This will help to ensure the cell/battery quality and result in greater system reliability.

Studies have been conducted in order to minimize the number of cell chemistries which would represent an overall optimum for all NASA missions. The high rate LiSOCl2-D-Cell, developed by JPL, Li-BCX, and Zn-O2 systems have been identified as the most promising to cover all of NASA's primary cell requirements. Subtasks are underway which are designed to optimize these systems and make them safer for use.

CONCLUDING REMARKS

The NASA Aerospace Flight Battery Systems Program provides for a balanced cell, battery and systems program which includes primary and secondary battery activities in support of NASA's flight programs. It has provided for increased communication within the agency and within the battery industry as well. The program addresses flight battery and related flight power system activities which are essential for ensuring safe and reliable performance. The plan has responded to the recent problems with the nickel-cadmium system and has been modified over the past year to concentrate on the resolution of the nickel-cadmium problems. In addition, continuing efforts in the nickel-hydrogen and primary battery areas are aimed at preventing the recurrence of the similar problems in these areas.

REFERENCES

