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## NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM, AN UPDATE

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### ABSTRACT

The major objective of the NASA Aerospace Flight Battery Systems Program is to provide NASA with the policy and posture to increase and ensure the safety, performance and reliability of batteries for space power systems. The program was initiated in 1985 to address battery problems experienced by NASA and other space battery users over the previous ten years. The original program plan was approved in May of 1986 and modified in 1990 to reflect changes in the agency's approach to battery related problems that are affecting flight programs. The NASA Battery Workshop is supported by the NASA Aerospace Flight Battery Systems Program. The main objective of the discussions at this workshop is to aid in defining the direction which the agency should head with respect to aerospace battery issues.

Presently, primary attention in the Battery Program is being devoted to issues revolving around the future availability of nickel-cadmium batteries as a result of the proposed OSHA standards with respect to allowable cadmium levels in the workplace. The decision of whether or not to pursue the development of an advanced nickel-cadmium cell design and the qualification of vendors to produce cells for flight programs hinges on the impact of the OSHA ruling. As part of a unified Battery Program, the evaluation of a nickel-hydrogen cell design options 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 addressed 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 1) increasing the fundamental understanding of primary and secondary cells; 2) providing for improved cell/battery manufacturing process control, specifically in the nickel-cadmium area; 3) addressing and investigating the establishment of a NASA standard nickel-hydrogen cell design; 4) establishing specifications, design and

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operational guidelines for both primary and secondary cells and batteries; 5) providing training relating to the above areas; and 6) opening and maintaining communication lines within NASA and the aerospace 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 and Mission Quality. In July of this year Mr. Shahid Habib was named as the Headquarters, Code Q program manager, replacing Mr. Frank Manning. The original organization of the tasks in the program plan, the initiation of the plan and annual status updates have been previously reported in references 1 through 5.

The major issue facing the agency today revolves around the future of Ni-Cd technology and the potential impact of the proposed OSHA standards on future Ni-Cd cell production, both in terms of cost and the willingness and ability of the manufacturers to meet the new standards. The goals and objectives of the NASA Aerospace Flight Battery Systems Program are reevaluated periodically to address such concerns in a timely manner. The overall plan, the specific modifications, and the status of the tasks 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. The NASA Aerospace Flight Battery Systems Program is organized under four major tasks: Program Management, Battery Systems Technology, Secondary Battery Technology, and Primary Battery Technology.

### Program Management

The NASA Lewis Research Center is responsible for the management of this program. The NASA Lewis Research Center Program Manager provides continuing coordination with all the NASA centers, Jet Propulsion Laboratory (JPL), NASA Headquarters and the NASA Aerospace Flight Battery Systems Steering Committee. The NASA Aerospace Flight Battery Systems Steering Committee provides advice on battery issues. The Committee is chaired by the Office of Safety and Mission Quality, membership is comprised of one representative from each of the NASA centers and one representative from Aerospace Corporation, representing the Air Force. The Lewis Research Center Program Manager has full responsibility for technical management, cost and scheduling of the program.

### Battery Systems Technology

The Battery Systems Technology Task addresses 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, space power system design, integration, and checkout.

The Goddard Space Flight Center (GSFC) is in the process of developing a NASA Handbook for Nickel-Hydrogen Batteries. Mr. Jim Dunlop has been hired as a consultant to aid in the development of the Ni-H<sub>2</sub> handbook. The handbook is in the final phases of the review process. The NASA Handbook for Nickel-Hydrogen Batteries will address the following subjects: 1) Nickel-Hydrogen Cell Design, 2) Aerospace Applications of Nickel-Hydrogen Batteries, 3) Nickel-Hydrogen Battery Design, 4) Advanced Battery Design Concepts, 5) Performance of Nickel-Hydrogen Batteries 6) Battery Procurement, 7) Standard Test Procedures for NASA, 8) Storage and Handling, and 9) Safety.

As a part of the Handbook Development Task of the Battery Program, GSFC is also preparing a Handbook for the Handling and Storage of Aerospace Nickel-Cadmium Batteries. This handbook is not intended to duplicate the information covered in NASA reference Publication 1052, Sealed-Cell Nickel-Cadmium Battery Applications Manual. The purpose of this handbook is to update the handling procedures and practices for working with nickel-cadmium batteries. The Handbook covers changes in guidelines resulting from improvements in design, manufacturing, and testing of nickel-cadmium cells and batteries. The heritage of many GSFC flight Ni-Cd battery developments over the past three decades is covered in the handbook. This handbook specifically covers the following 1) Background, 2) Nickel-Cadmium Cell Primer, 3) The Environment and Nickel-Cadmium Batteries, 4) Battery Handling and Storage Guidelines and 5) Nickel-Cadmium Cell Design and Evolution (from 1960-1989).

The handbooks are intended to serve as the basis for a training plan, at the engineer and technician levels, that will ensure that personnel involved with the test and operations of batteries and their related power systems are fully qualified to implement safe and proper operational procedures including storage practices. The Kennedy Space Center (KSC) has responsibility for this task. A subcommittee consisting of engineers who have direct flight battery expertise has been formed at KSC. The subcommittee is in the process of assessing battery training requirements first at KSC then within the agency. Safety and handling procedures used by individual projects are being assembled. Presently, safety and handling procedures have been mission specific. This task will attempt to develop an integrated plan to be used agency wide.

The Battery Data Base subtask addresses a NASA Battery System Data Base Environment to serve the NASA battery community for the dissemination of technical notes, policy documentation and test data. Efforts are 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 battery data base will serve as an integrated repository of knowledge gained from manufacturing, ground testing, and flight experience. The goal is to 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. Data base capabilities in the following areas will be established: bulletin boards, a documentation library, test data archives, and battery models. In the past few months, responsibility for the implementation of this subtask has been transferred from Ames-Dryden Flight Research Facility to the Lewis Research Center.

The majority of the NASA cell test data base resides at the Naval Weapons Support Center, Crane, IN. Efforts are underway to organize and structure the Crane test data so that it will be easily accessible within the data base. As part of this subtask, Crane has updated NASA pack history files dating back to 1975, provided pack record structure information, and converted data tapes to a useable format for all NASA tests dating back to 1981. This initial data is presently accessible through direct interactions with Crane. A plan to establish on-line capabilities for data access through Crane is being pursued.

The NASA Battery Workshop comes under the sponsorship of the NASA Aerospace Battery Systems Program. The Marshall Space Flight Center hosted the Workshop in December 1990 and is the sponsor of this year's workshop as well. NASA Conference Publication 3119, *The 1990 NASA Aerospace Battery Workshop*, (ref. 6) summarizes the proceedings of last year's workshop. The workshop serves as a forum for open communication of battery related activities between industry and government. The panel discussion sessions covering the Cadmium Issue and Current Nickel-Hydrogen Cell Designs should provide valuable input into NASA programs.

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 potential loss of nickel-cadmium cell suppliers and the development of nickel-metal hydride technology as a potential replacement technology are of prime importance in addressing NASA's future secondary battery requirements.

### Secondary Battery Technology

The Secondary Battery Technology Task was established to improve the performance, quality, safety, and reliability of secondary battery systems. This task presently focuses on the nickel-cadmium and nickel-hydrogen systems which encompass the majority of NASA's present and planned secondary battery applications. Again, the issues being raised with respect to the proposed OSHA cadmium ruling and its potential impact will have an effect on the direction of the Battery Program with respect to secondary technologies.

Nickel-cadmium batteries provide the storage capability for the majority of NASA's missions. As a result, the future of nickel-cadmium manufacturing and the availability of nickel-cadmium cells are of major concern to the agency. NASA is in the process of evaluating the impact of the cadmium ruling and the direction required to ensure that future missions will have the needed storage systems. This involves decisions with respect to nickel-cadmium and nickel-metal-hydride technologies. NASA had developed a recovery plan to address the nickel-cadmium cell quality and reliability problems that surfaced in the late 1980's. Near-term and far-term options for the resolution of the life and reliability problems with the current design nickel-cadmium cells were formulated and are being implemented. The near-term approach is aimed at the re-establishment of a qualified NASA Standard Nickel-Cadmium Cell. The far-term solution involves the establishment of an Advanced Nickel-Cadmium NASA Standard Cell design which would incorporate electrochemically impregnated plates and non-nylon separators. The procurement to implement the far-term solution has not been initiated, pending a determination of the future of nickel-cadmium batteries. The need for a program addressing nickel-metal-

hydride development is also being evaluated.

In order to support flight programs and address NASA's future needs with respect to nickel-cadmium cells, GSFC is responsible for a subtask that involves the evaluation of SAFT cells and Hughes "advanced" Ni-Cd. A number of cells has been provided by SAFT for evaluation by NASA. 20 and 24 AH cells are currently on test. Tests have been in progress for greater than two years. Testing is being conducted at 40% DOD and 0 and 20°C. The data accumulated to date shows performance of the SAFT cells to be comparable to that of the NASA Standard cells used for LANDSAT. Sixty advanced design Ni-Cd cells have been purchased from Hughes. Six, five to eight cell test packs of advanced design cells and an additional eight cell pack of 'super' Ni-Cd cells are currently undergoing stress testing at 20 or 30°C and 40% DOD at Crane. An additional pack of advanced Ni-Cd cells with Z/PS or Z/PBI separators is being evaluated under a GEO regime. The advanced design cells do not contain the electrolyte additive used in the 'super' Ni-Cd cells. To date, the cells have accumulated >8000-10000 cycles. A summary of the status of these tests appears in reference 6.

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 alternate separators, and varied electrolyte levels. Modified cells will be constructed and tested to evaluate the effectiveness of the component changes. The composite Task Force Group on Near Term Nickel-Cadmium Cell Design has made recommendations regarding the selected parameters and levels to be evaluated. Plans are to initially evaluate the effects of nickel attack level, positive plate loading and negative plate loading in a statistically designed experiment. The first cell order has been placed, plaque production is scheduled to begin in mid November.

NASA, through the Goddard Space Flight Center, is also in the process of revising the NASA Specification for Manufacturing and Performance Requirements of NASA Standard Aerospace Nickel-Cadmium Cells, NHB 8073.1. The NHB was originally written to update the existing specification to correlate with the current NASA Standard Nickel-Cadmium Cell Manufacturing Control Documents at Gates Aerospace Batteries. The NHB is presently being revised to do the following: 1) strengthen the technical contents and requirements of the document; 2) incorporate performance assurance requirements and thereby improve the quality of the cells produced; and 3) incorporate comments received from Gates Aerospace Batteries on the present version of NHB 8073.1.

The approach for the long-term resolution of the nickel-cadmium problems involves the definition and development of a NASA standard advanced nickel-cadmium cell for NASA Secondary battery applications. It is to be accomplished by developing detailed, rigid specifications and sponsoring the development of manufacturing, testing and inspection processes by both government and contractor agencies. The present approach is to procure cells, from any qualified bidders, built to the rigid specifications required to ensure the quality and reliability of the cells. The cells will be tested and vendors qualified. The advanced design requires electrochemically impregnated plates and a separator capable of sustained operation at 30°C. Goddard Space Flight Center has responsibility for the management of this subtask. As

mentioned previously, the initiation of the procurement has not been implemented pending a decision with respect to the future manufacture of nickel-cadmium cells.

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 and reliability of flight lot cells without extensive life testing and to predict the performance of a battery from a set of spacecraft operating conditions. 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 the 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 model, simulating the charge and discharge has been developed. The Phase II model is presently undergoing verification. The model predictions match actual test data through much of the cycle life. The Phase II model is presently undergoing modifications to incorporate proton diffusion and a more rigorous treatment of the active material conductivity as improvements to modelling the response at the positive electrode that were identified during work on a Ni-H<sub>2</sub> electrochemical model at Texas A&M. 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 1992. Additional information on the status of this effort is available in references 7-15.

The major goal of the Nickel-Hydrogen Technology subtask is to evaluate design features for incorporation into nickel-hydrogen cells for NASA missions. 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 consistent production of 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, technology development 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. Preliminary results of the testing of cells with varied KOH concentration support the accelerated boiler plate tests run previously. The three cells containing 31% KOH failed at cycles 3729, 4165, and 11,355. One of the cells with 26% KOH failed at cycle 15,314, the remaining cells have accumulated >17,000, 80% DOD LEO cycles at 10° C, and continue on test. DPA's have been performed on the failed cells. The testing of the advanced design specifically involves evaluating the effect of the catalyzed-wall wick on cell life and performance. These cells are being cycled at 60% DOD and 10°C in a LEO regime. The cells with the catalyzed wall wick have accumulated >14,000 LEO cycles with no cell failures. One of the cells without the catalyst on the wall failed at cycle 9,588, the two remaining cells continue to cycle and have accumulated >14,000 cycles. Details on the status of these evaluations can be found in references 16 and 17. Flight cells evaluating potential replacements for the asbestos separators presently used in nickel-hydrogen cells have been delivered and are scheduled to begin characterization testing in November of this year. Battery program funds support cycle testing of the above groups of cells and the performance of

destructive physical analyses as the cells fail. Cells have also been ordered to evaluate the effects of impregnation method and cell design on performance and cycle life. This subtask involves close coordination with Hubble Space Telescope and Space Station Freedom, missions which are using or will use nickel-hydrogen batteries for energy storage.

A subtask which involves the implementation of a program of independent 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 independent checks and balances include the following: 1) test facility upgrades; 2) support of task force activities to investigate specific problem areas; 3) the establishment of an independent DPA facility to perform routine diagnostic component testing; 4) the investigation of impedance as a diagnostic tool for predicting cell performance, life and quality; and 5) the development of advanced NDE methods for nickel-hydrogen cell cases.

The expansion and upgrading of test facilities at JPL and the GSFC, planned as part of the independent checks and balances sub task, will provide increased capability within NASA for the testing and mission simulation testing of cells and batteries for future NASA missions. JPL has built ten test stands capable of performing parametric characterization and mission simulation type testing. Upgrades to GSFC test facilities have been supported as well. Goddard is designing stands capable of testing nickel-cadmium and nickel-hydrogen cells. These test racks will have the added advantage of being transportable to the launch site for on-site, pre-launch testing or conditioning.

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 sub task. These include the Crane Data Evaluation Task Force, the effort for the Establishment of Standard DPA Procedures, and the Separator Test Procedures Task.

The Crane Data Evaluation Task Force group 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 was expanded to include the identification of a meaningful test matrix for the testing and evaluation of cells for LEO and GEO applications. JPL contracted with MRJ to perform this work. Reports by MRJ and JPL, discussing the evaluation of the procedures used in testing nickel-cadmium cells have been issued (ref 19, 20). The recommendations will be evaluated and new test procedures established.

The Marshall Space Flight Center has the responsibility for developing and establishing NASA standards for the performance of destructive physical analyses. Current DPA procedures used in the industry are being evaluated in an effort to identify a standard procedure for the agency. Plans are to implement an approved procedure 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 DPA's and routine diagnostic tests for secondary cells. The Marshall Space Flight Center is organizing efforts relating to the establishment of the independent DPA facility.

A task force group was formed to evaluate the present separator test procedures used to screen and evaluate separator uniformity and quality for use in nickel-cadmium cells. The Lewis Research Center is involved in defining improved tests that will more closely evaluate separator characteristics as related to the actual cell environment. A support service contractor has been hired to perform this subtask. Procedures will be made available as they are developed.

As part of an effort to understand and define the component properties that lead to reliable, high performance cells JPL performed a task comparing properties of plates produced in the 1970's when cells were relatively problem free to those of plates made more recently. Preliminary evaluation of materials made in 1978 and 1985 showed no major differences in physical characteristics. This sub task provided valuable input for the modelling effort. References 21 and 22 summarize the work performed to date under this subtask.

The use of impedance spectroscopy as an interpretive tool for predicting cell performance, life, and quality is being investigated. The Lewis Research Center is responsible for this effort. To date Ni-Cd, Ni-H<sub>2</sub>, and Li-SO<sub>2</sub> cells have been evaluated. Cells of the same chemistry exhibit characteristic impedance spectra that relate to manufacturer. It remains to be seen if these characteristics correlate with life and performance. The status of the efforts in this area has been reported in references 23-29.

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 Langley Research Center is responsible for investigating advanced NDE techniques for flaw definition and flaw growth in nickel-hydrogen cell cases. X-Ray residual stress characterization, Bragg diffraction, Shearography and Thermoelectricity are being investigated. This subtask involves close coordination with related activities being conducted by the Space Station Freedom Program Office.

### 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 in the primary battery area.

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 National Space Transportation System 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. Lithium D-Cell, and Zn-O<sub>2</sub> cell development are part of the primary battery efforts. Subtasks are underway which are designed to optimize these systems and make them safer for use.

JSC contracted with Yardney Technical Products to investigate the development of internal/external short circuit protection for lithium cells. The objective of this subtask was to develop a positive control for both internal and external short circuits in lithium cells. The control is activated by temperature, shutting the cells down from the heat generated by shorts. The protective coating developed under this contract was so thick (~25 mils) that the capacity was reduced by 50% and the rate capability was also substantially reduced. Yardney Technical Products is pursuing additional development of the film as part of an internal IR&D effort.

Lithium D-Cell development encompasses the development of an optimized lithium D-cell, or a family of D-cells, that can serve as a building block for the for the varied applications now flying and those to be flown in the near future. The goal is to develop cells capable of meeting relatively high rate requirements while being as tolerant as possible to electrical and thermal abuse. The candidates for evaluation and selection are the JSC Li-BCX, the JPL high rate LiSOCl<sub>2</sub>, and the Wilson Greatbatch, Ltd. Li-CSC.

The NASA Aerospace Flight Battery Systems Program also supports the development of a pair of Zn-O<sub>2</sub> cells: a high capacity cell of 150-200 AH at rates of 25-100 hours and smaller capacity 9-12 AH cell to be operated at higher rates of 3-12 hours.

## 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 with 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 future of the secondary nickel-cadmium cells is presently the top priority of the program. In addition, continuing efforts in the nickel-hydrogen and primary battery areas are aimed at preventing the problems in these areas.

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# **CONCEPTUAL DOCUMENTATION ANALYSIS**

**By: Carolyn Ausborn**

**INNOVATIVE KNOWLEDGE ENGINEERING**



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**CONCEPTUAL DOCUMENTATION**  
**ANALYSIS : INTRODUCTION**

- **Knowledge Management**
- **Preserve Corporate Asset -----> Knowledge**
- **Spur Technology Forward**

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## **CONCEPTUAL DOCUMENTATION ANALYSIS**

- Importance of "GOOD" Documentation
- WORDMAP: Documentation Analysis Tool
- Battery Technology Example

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**IMPORTANCE OF "GOOD"**  
**DOCUMENTATION**

- **Customer Correspondence**
- **Customer Relations**
- **Contracts Renewed / Won**
- **Departmental Records**
- **Knowledge Representation**

**INNOVATIVE KNOWLEDGE ENGINEERING**



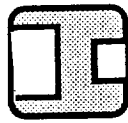
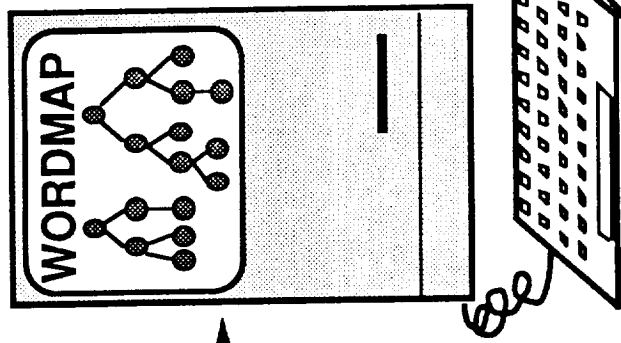


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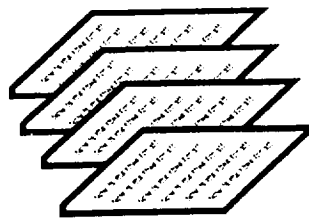
# WORDMAP: Document Analysis Tool

KNOWLEDGE PROBE  
OUTPUT (CLIENT)

- MOST SPECIFIC LEVEL
- LESS SPECIFIC LEVEL
- LESS GENERAL LEVEL
- MOST GENERAL LEVEL



(ANY TEXT FILE)



Documentation

INNOVATIVE KNOWLEDGE ENGINEERING



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## **WORDMAP: Document Analysis Tool**

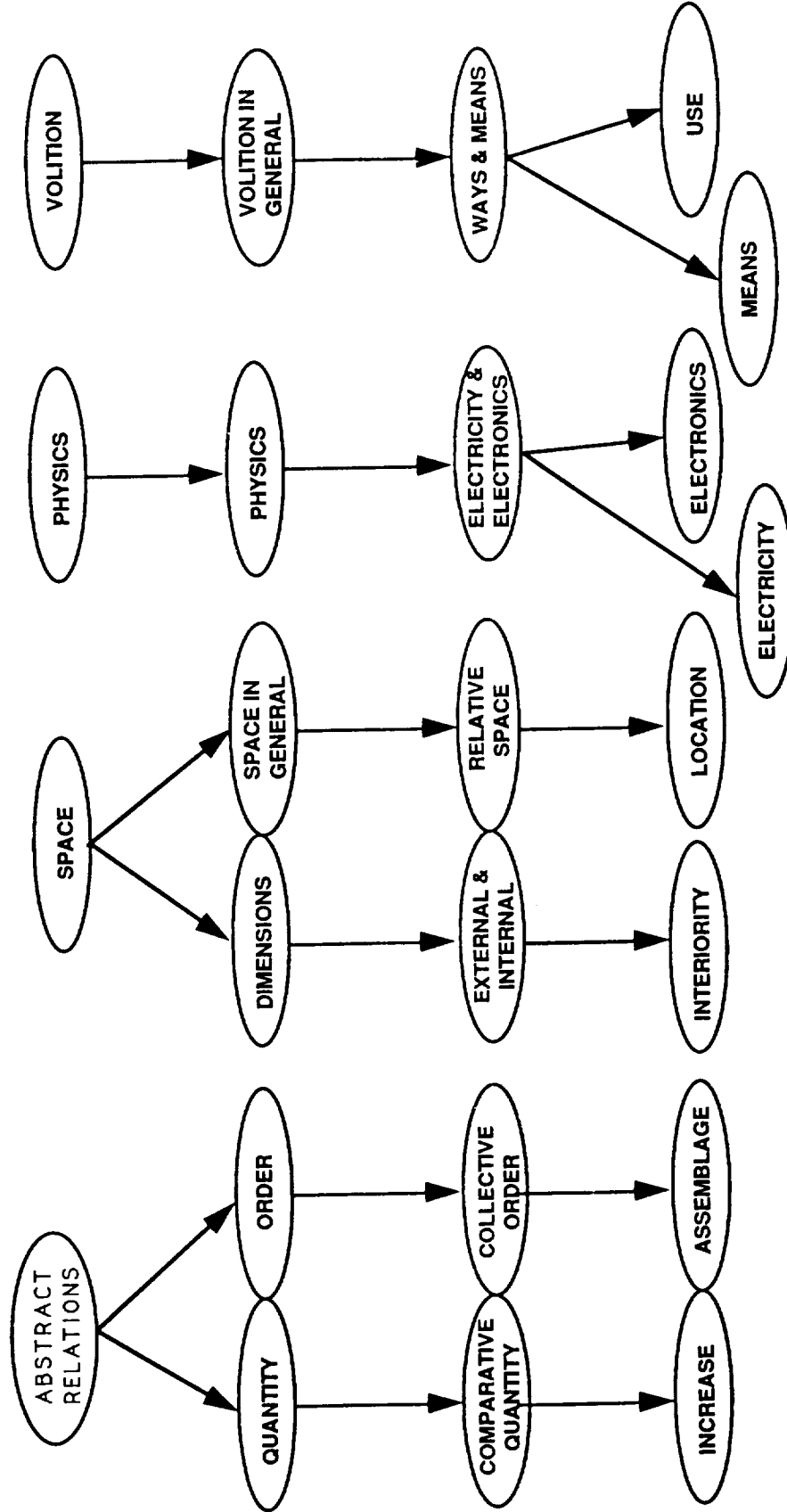
- **Natural Language Processing Technology**
- **Only Limitation : Spelling**  
**Minimum of Two Words**
- **No Syntax / Grammar Parsing**
- **Produces List of Concepts Represented**

**INNOVATIVE KNOWLEDGE ENGINEERING**



AUSBORN & BREWER, INC.

## Battery Technology Example



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