Battery Energy Storage Test (BEST) Facility: Second Progress Report

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BATTERY ENERGY STORAGE TEST FACILITY

ABSTRACT

The Battery Energy Storage Test (BEST) Facility will be a national center for testing and evaluating battery energy storage systems, including associated electrical conversion equipment developed for use on electric power grids. The project is funded jointly by the U.S. Department of Energy (DOE), the Electric Power Research Institute (EPRI), and Public Service Electric and Gas Company (PSE&G).

The BEST Facility program consists of four phases: Design, Construction, Testing and Acceptance, and Operation. This interim progress report covers a middle period (July 1978 to December 1979) in construction of the facility, in procurement of major items of operating equipment, in developing plans for testing and acceptance of the facility prior to its use, and also in developing the plans for testing of advanced batteries during the subsequent operating life of the facility. Approximately two years' work preceded this interval, and one year remins to completion and acceptance by the three cosponsors. The building is now 90% complete. The power conversion system was completed by Garrett and successfully factory tested at the end of the year. The station lead acid battery modules were built by C&D Batteries Division and the factory tests completed. The station computer (monitor and control system) hardware was completed and software programming was begun by Honeywell Process Control Division.

A startup and acceptance test manual was drafted and final revisions are in process to Volume 1 for the requirements. Work was started on Volumes 2 and 3 for the procedures and supporting documentation. These three volumes will encompass the four-phase test program: factory testing, construction verification testing, operational testing, and acceptance testing.

A Developers Users Group was convened several times, for the purpose of advising on the nature of the test programs and on compiling a Test

Programs Guidelines document. Detail planning was also well along for test data processing equipment and procedures. A demonstration of some online computer procedures was given at the annual review meeting, using simulated battery performance data in a data base management system.

Planning for the installation of a zinc chloride battery in 1981 in the second test bay was begun in cooperation with the developer, Energy Development Associates.

PERSPECTIVE

PROJECT DESCRIPTION

The Battery Energy Storage Test (BEST) Facility is to be a national center for testing and evaluating advanced battery energy storage systems currently under development for utility energy storage applications. Associated ac/dc power conversion equipment will be included. Project scope of RP255-2 includes preliminary and final design, construction and shakedown of the baseline facility, and development of criteria and methods for subsequent operation.

The BEST Facility will have provisions for simultaneously testing three or more batteries of nominal 1- to 10-MWh capacity--sufficient to permit meaningful evaluation of technologies while keeping test facility and prototype battery costs as low as possible.

PROJECT OBJECTIVE

The basic objective in constructing the BEST Facility is to provide the necessary means for independent testing to verify battery system characteristics and performance. Most significant will be the evaluation in a utility environment. This is an important step for each advanced system after its development to a prototype production stage. Programs with contract support from EPRI and the Department of Energy (DOE) include the aqueous systems: zinc chloride, zinc bromide, and advanced lead acid; and the high-temperature systems: sodium sulfur and lithium metal sulfide.

The ultimate value of the BEST Facility project will be a substantial reduction of the technical, financial, and safety risks associated with commercializing battery systems for utility energy storage. This will help protect utility, industry, and government investments, which are likely to reach several hundred million dollars over the next 5-10 years.

PROJECT RESULTS

This is the second report of progress on the actual construction of the BEST Facility, covering the middle 18 months of the 4-year contract. After the facility is completed in 1980, approximately 10 months later than the original schedule anticipated, there will be a final report.

As of December 1979, the facility structure was 90% complete and equipment installation was beginning. Factory tests on the power conversion equipment and the station battery were completed successfully. The monitor and control system computer hardware was completed and tested by Honeywell, but there will be about a 6-month delay in delivery of the software due to unforeseen programming complexities.

The preoperation tasks are about 50% completed. This work includes simulating and analyzing test data, planning operating and maintenance procedures, and developing manuals for performing the facility acceptance tests.

Overall work is progressing satisfactorily on a revised schedule that anticipates acceptance testing to be completed before December 1980. Public Service Electric and Gas Company is providing excellent initiative and strong management direction in fulfilling contract objectives and meeting task requirements. The contract was supplemented during 1979 to provide for completion of the second test bay and installation of the zinc chloride battery system in 1981.

The BEST Facility project is also proving to be of immediate value in that it has become the main focus of potential users, developers, and funding agencies for discussing the issues surrounding the development and future use of batteries, thus accelerating the commercialization of battery storage systems for application to utility energy storage.

A previous report, covering progress from March 1976 through June 1978, was issued February 1979 as EPRI Interim Report EM-1005 (RP225-2) and DOE contract EY-76-C-02-2857.

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ILLUSTRATIONS

EXECUTIVE SUMMARY

This interim report describes construction progress, test program development, and design modifications occurring between July 1978 and December 1979.

The BEST Facility program consists of four phases: Design, Construction, Testing and Acceptance, and Operation. This report includes key milestone dates, a description of activities for the first three phases, including those associated with the future implementation of the second test bay, and a description of interaction between the BEST Facility project and the advanced battery development program. A previous report, covering progress from March 1976 through June 1978, was issued February 1979, as EPRI EM-1005, Project 225-2, and DOE contract EY-76-C-02-2857.

The building contains three battery test bays, space for three AC/DC power conversion systems, switchgear, instruments, and control systems. Some 13 kV switchgear, power factor correction capacitors and auxiliary power transformers are located outdoors. Provision is also made to construct concrete pads for outside tests. Supervisory control and monitoring of systems in test is accomplished through a computerized process control system based on commercial operation concepts employed by PSE&G for generating plant control and for central load dispatch. Operating control systems will be supplied by the battery developers. Additional hardwired systems are provided for safety, environmental protection, and control. A remote data access system will make stored test data in tabular or graphic form available to authorized data users at remote locations. Three test services, developmental testing, prototype testing, and demonstration testing are to be offered.

Activities during this period included:

- Building construction
- Procurement and fabrication of equipment for the baseline facility
- Preparation of test programs
- Preparation of data analysis and acceptance test procedures
- Preparation and execution of a contract modification for implementation of the second test bay

At the end of 1979, the building structure was better than 90% complete and installation of HVAC equipment and motor control centers had started. Subcontracts for major equipment were nearing completion, all parts of the power conversion equipment had been built and assembled, and factory testing was completed in December. Also completed were factory tests on the facility shakedown battery. Shipment of the converter and battery is scheduled for early 1980. All hardware for the facility control computer is complete; software implementation will continue into 1980.

Substantial progress was made in the development of three test services to be provided to battery and converter developers: development testing, prototype testing, and demonstration testing. Guidelines for testing of battery energy storage systems at the BEST Facility are scheduled for completion in April 1980.

Test data processing implementation plans evolved during the year from tape storage and commercial time-sharing services to disc storage and processing on a dedicated minicomputer; procurement of components for this system is underway. Volume I of a comprehensive set of testing and acceptance test procedures was finalized; work on Volumes II and III has started and will continue into 1980.

A contract modification for implementation of the second test bay for testing of a 5 MWh zinc-chlorine battery was executed, and design work has started. Numerous national and international inquiries were received indicating the great interest in the project and in the work in progress. Under the present schedule, work activities will lead to baseline facility acceptance in late 1980 and testing of advanced batteries in mid-1981.

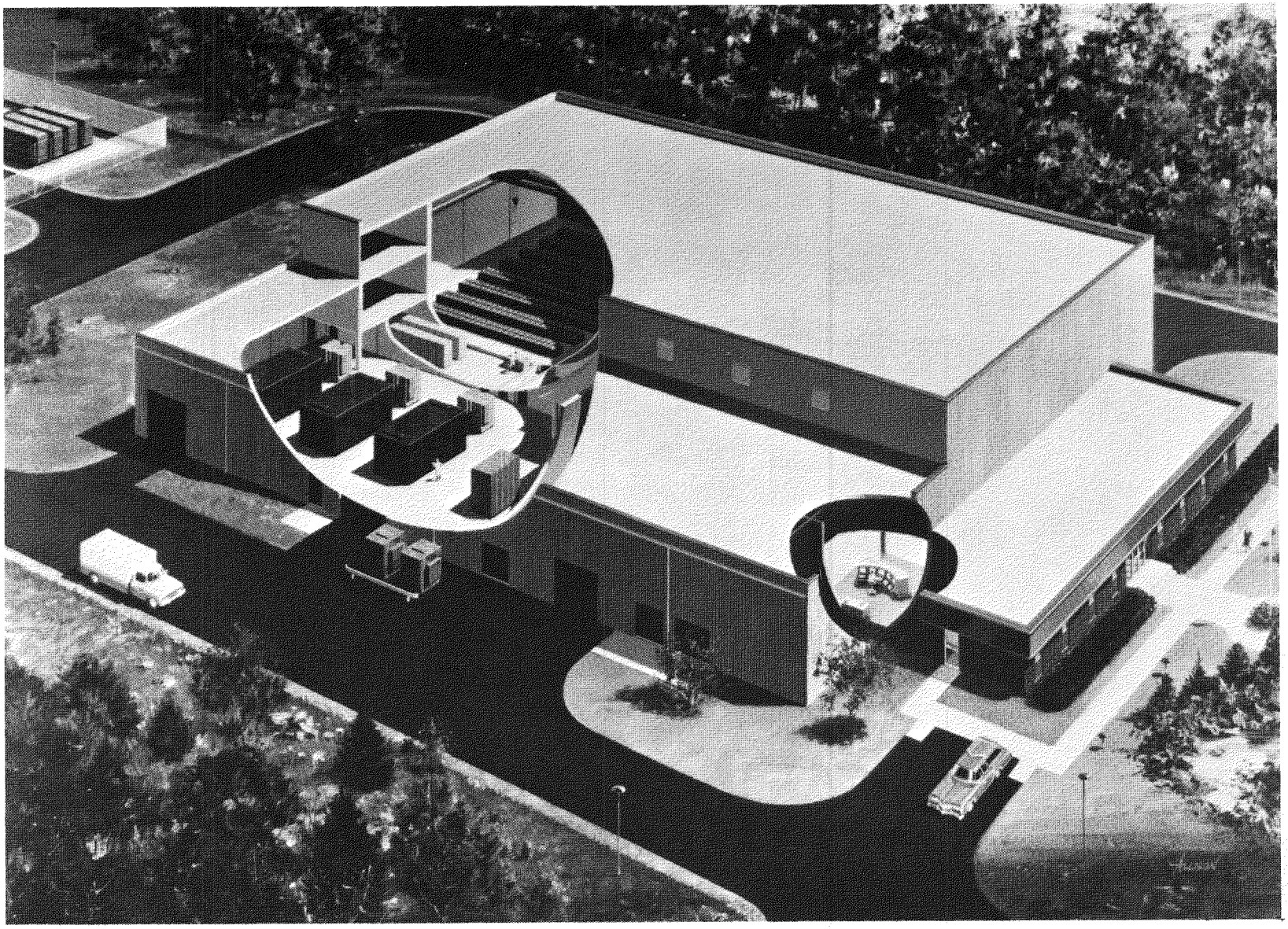


Figure S-1. BEST Facility, Artist's Conception.

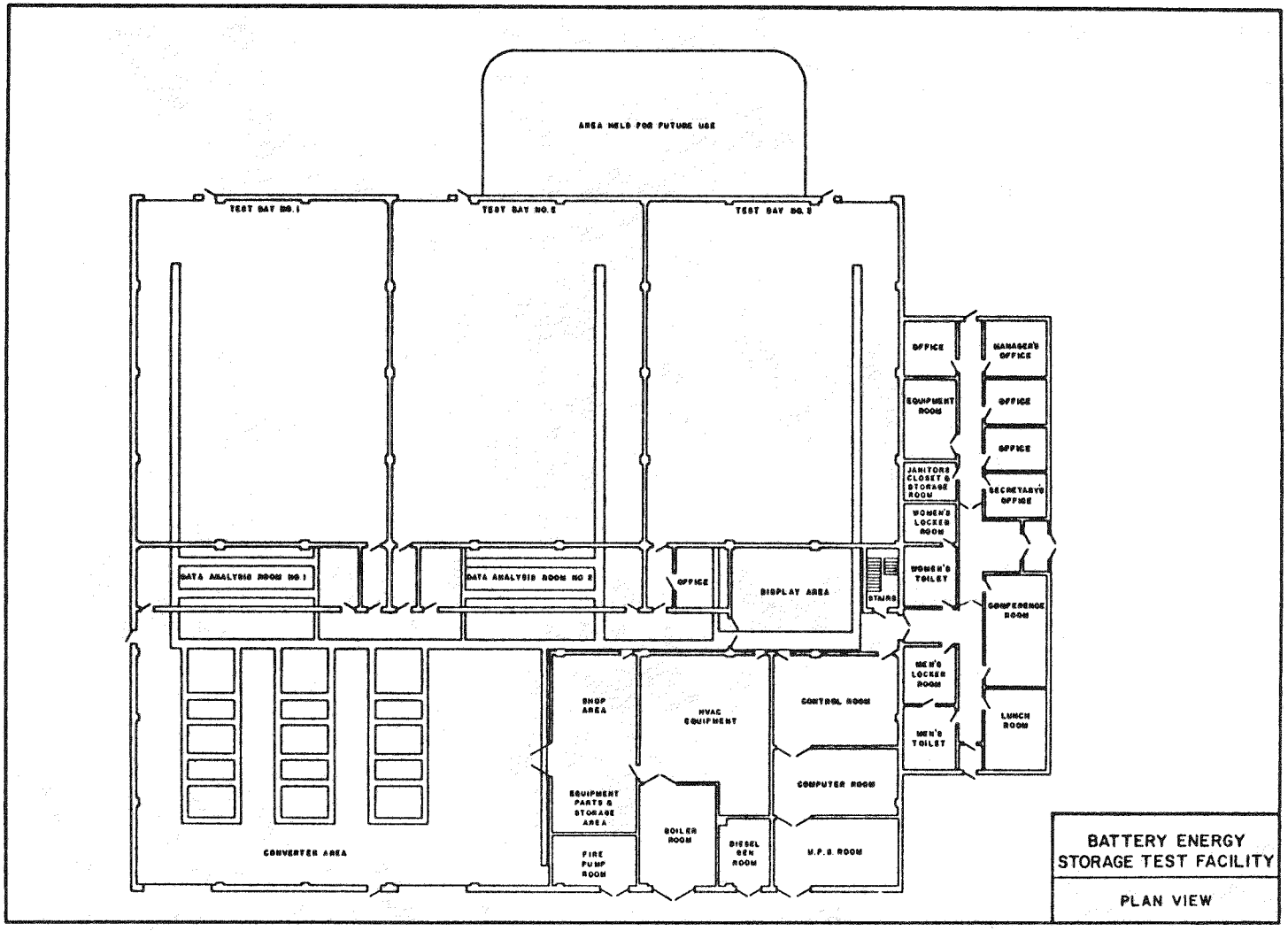
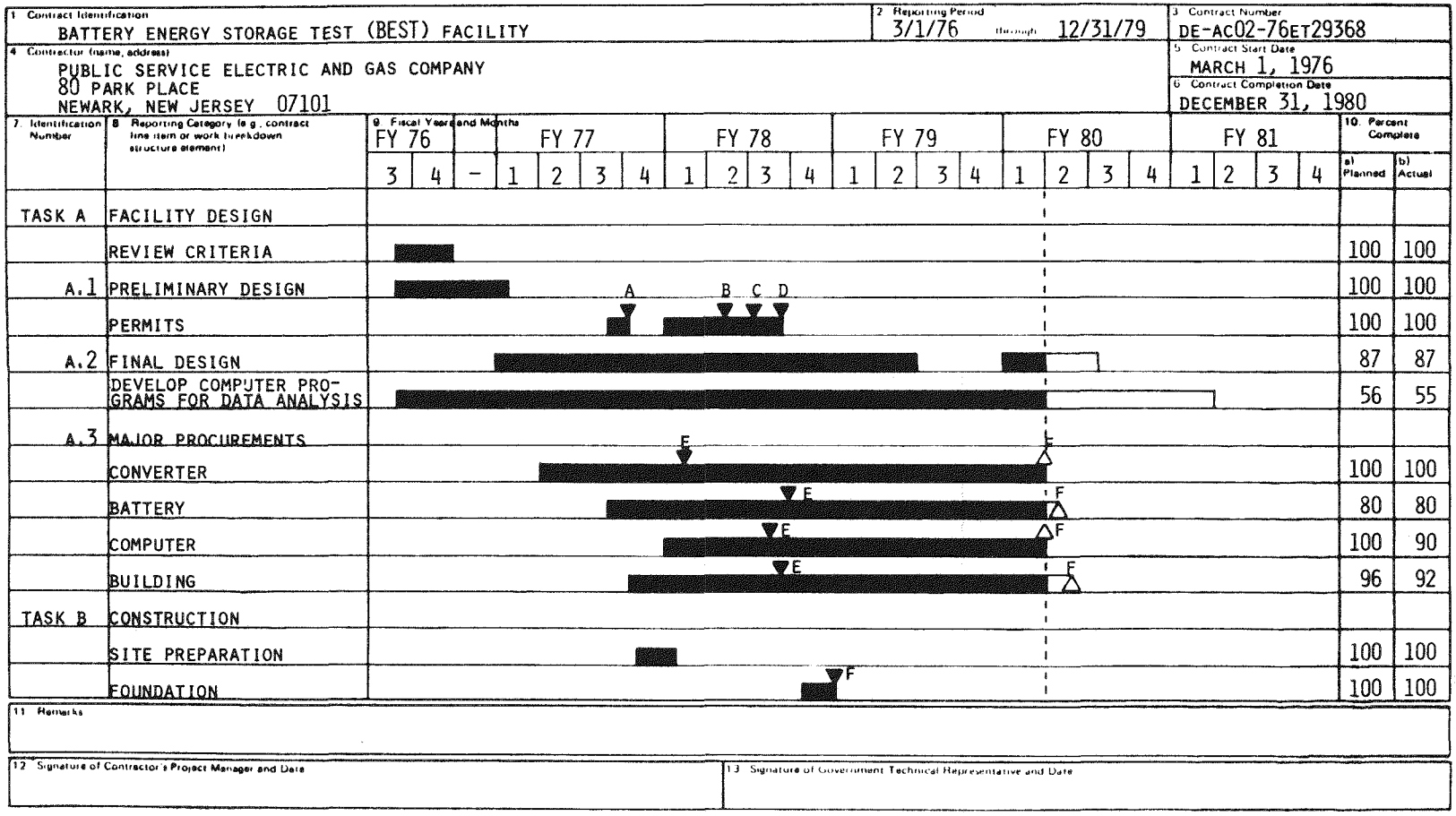
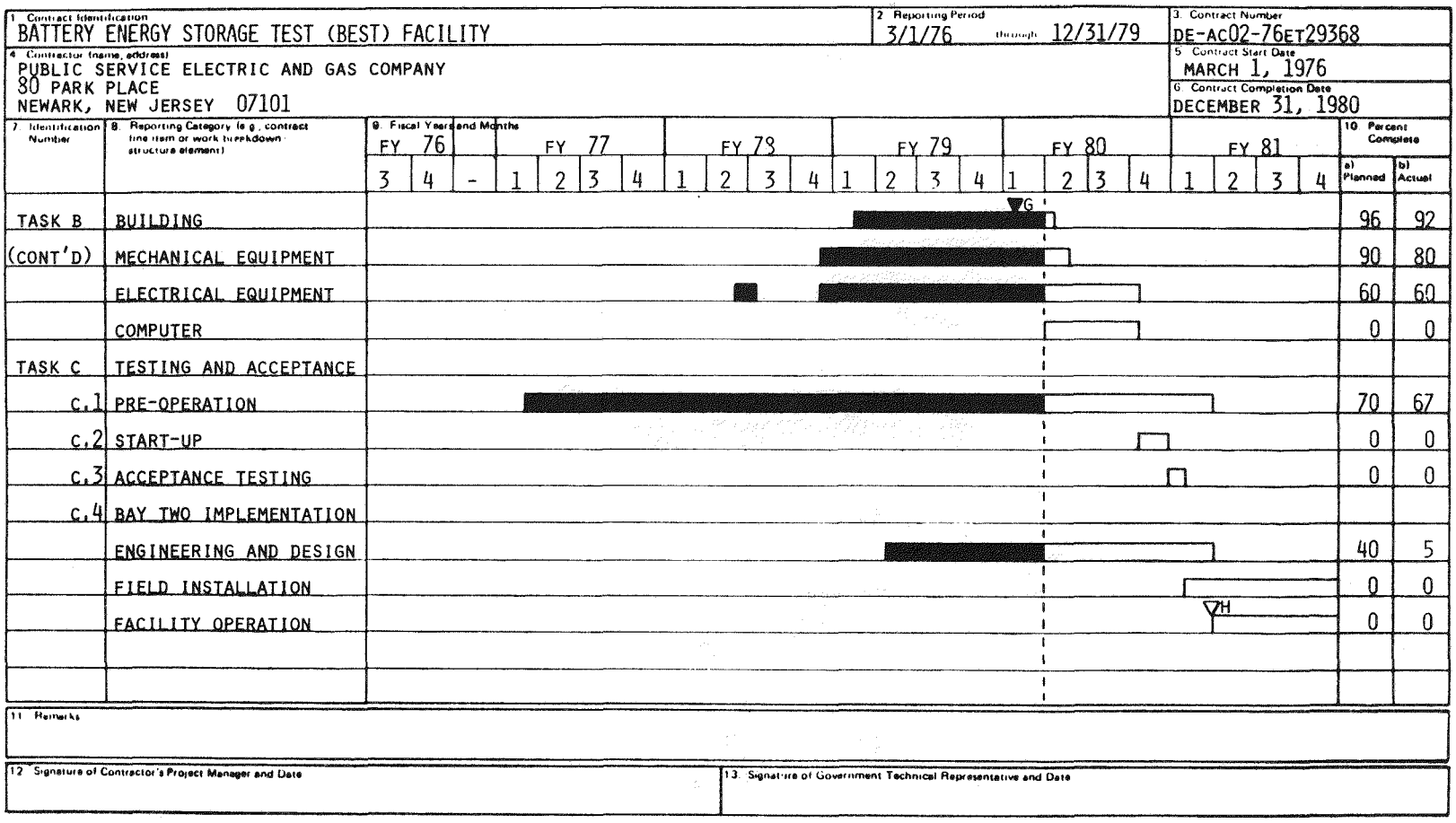


Figure S-2. BEST Facility, Plan View.



NOTES:
A SITE PLAN APPROVAL
B STATE ISSUES PLAN RELEASE, TOWNSHIP ISSUES BUILDING PERMIT
C STATE WITHDRAWS PLAN RELEASE
D STATE REISSUES PLAN RELEASE
E CONTRACT AWARD DATE
F DELIVERY OR COMPLETION DATE
G BUILDING WEATHERTIGHT
H OPERATION USING FACILITY SHAKEDOWN BATTERY

Figure S-3. Milestone Schedule and Status Report.



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G BUILDING WEATHERTIGHT
H OPERATION USING FACILITY SHAKEDOWN BATTERY

Figure S-3. Milestone Schedule and Status Report (continued).

SECTION 1

CONSTRUCTION

Construction of the BEST Facility commenced with the award of a contract for site preparation in June of 1977. Construction progress between June of 1977 and July 1, 1978 has been reported in Battery Energy Storage Test (BEST) Facility First Progress Report. The first progress report described the major efforts during that period as finalization of basic design, obtaining of permits, completion of site preparation and mobilization for construction. On July 28, 1978 building construction started. Figures 1-1 through 1-6 provide a pictorial progress report of the period July, 1978, through December, 1979. Key events during this period are shown in the Key Event Chronology (Appendix A-1). As the structure nears completion, emphasis is shifting to equipment installation and component and subsystem testing. Construction completion is scheduled for October of 1980 and the first advanced battery test program will begin in mid-1981.

Branciforte Builders Inc. of New Brunswick, New Jersey, is the contractor for building erection and HVAC system installation. Excavation and forming of footings and foundations was completed by the end of October, 1978. Also completed at that time was all subgrade work including conduits, plumbing, and grade beams. During December, 1978, building steel arrived on site and was erected within six weeks, however the first three months of 1979 included significant periods of inclement weather preventing the next construction phase of masonry work to proceed. By April of 1979 work was again in full swing with the concrete roof planks being installed and concrete block and brick work in progress. During July and August the installation of roofing material, HVAC equipment, roll-up doors, plastering, and fire proofing paralleled the masonry work, and in the fall of 1979 the interior masonry including the converter area and floor of Test Bay No. 1 was completed. Work also proceeded under separate subcontract on the HVAC controls system.

S.M. Electric Co. was awarded the equipment installation subcontract in July of 1979 and has started installation of the slabs for the converter transformer, power factor correction module, outdoor switchgear, and motor control centers. Emphasis will now be on providing building heat to permit construction and equipment installation to proceed in all areas of the building during the winter months.

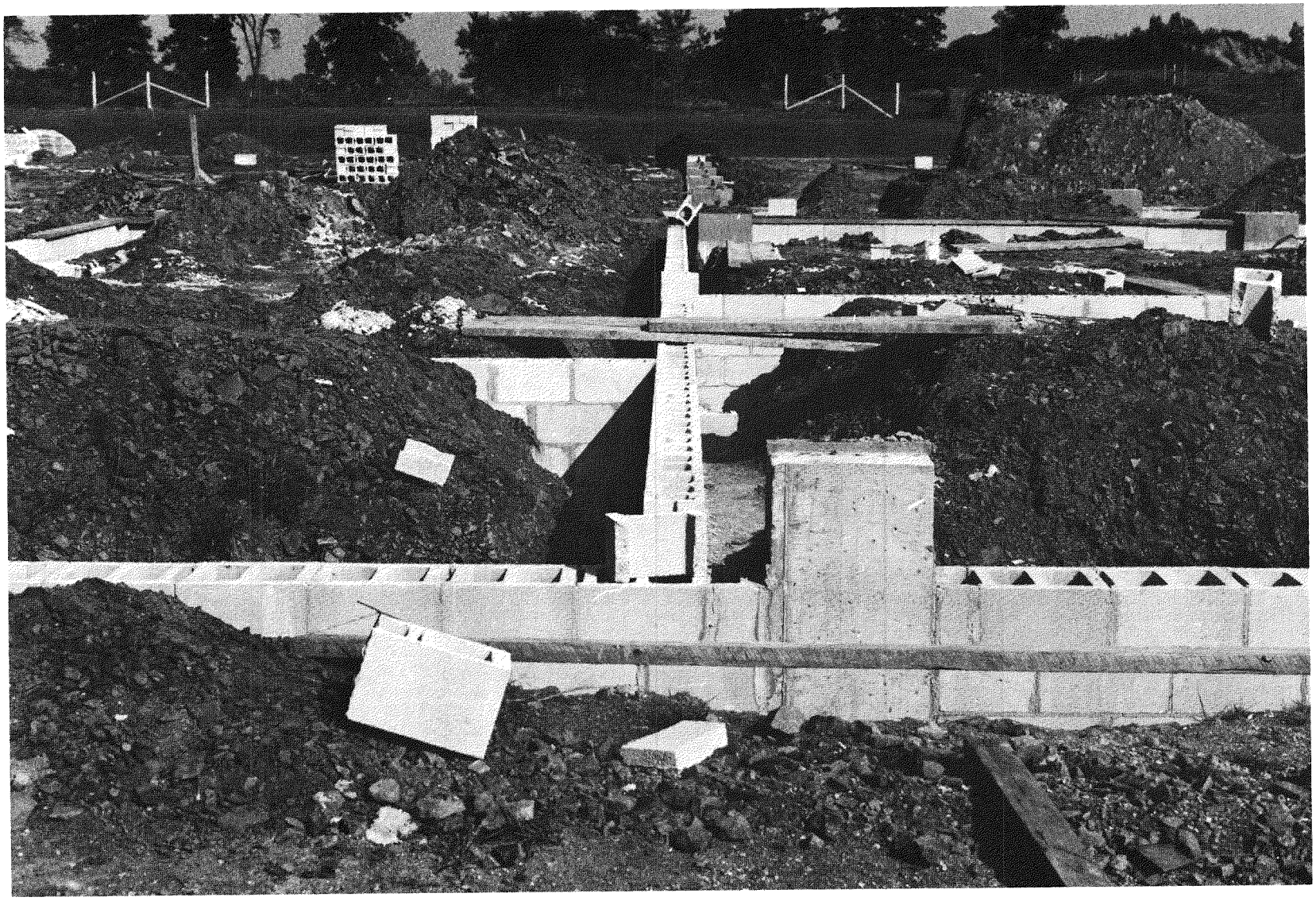

Figure 1-1. BEST Facility 10/3/78
Looking North Along Column Line 4

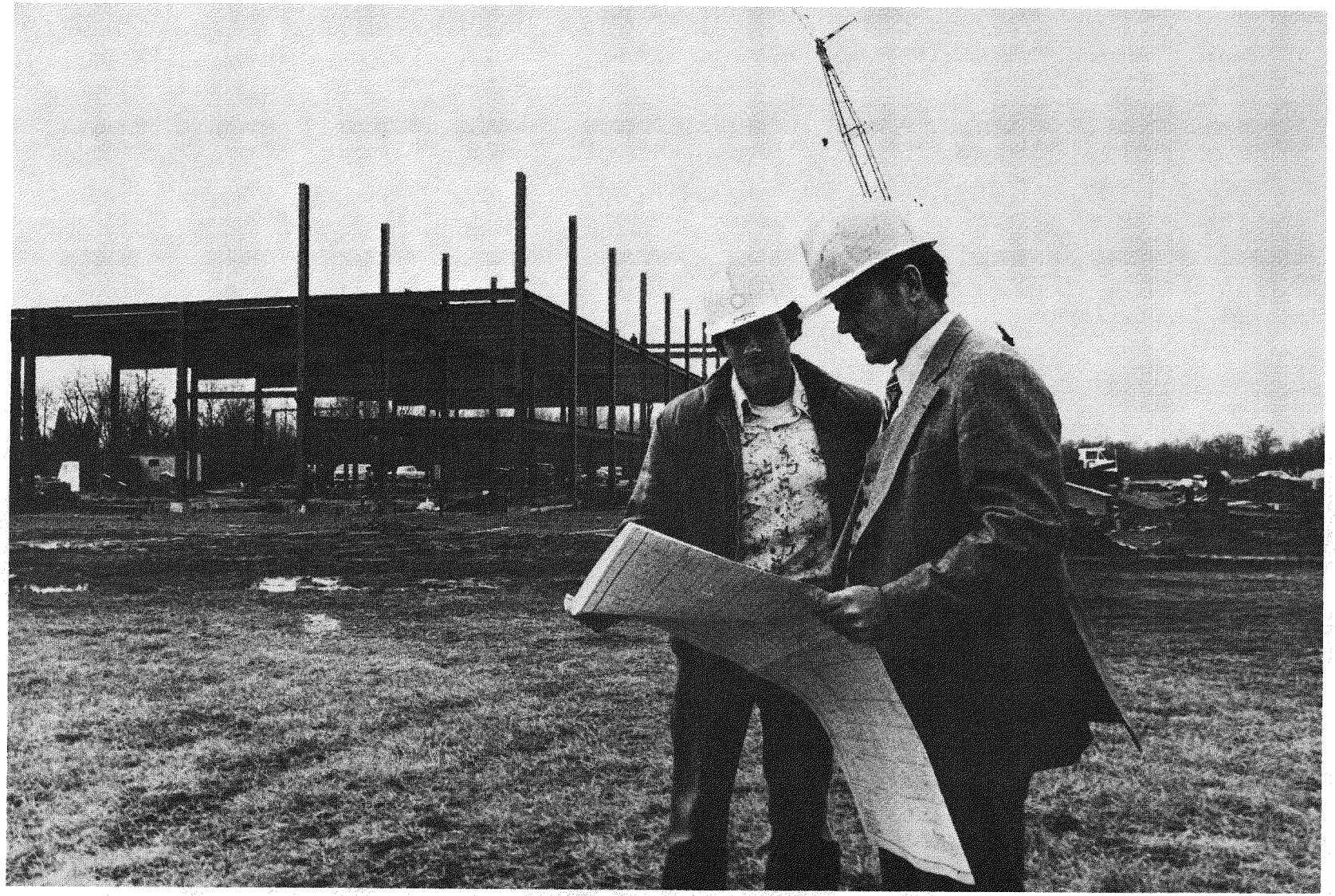

Figure 1-2. BEST Facility 12/7/78
Steel Erection in Progress

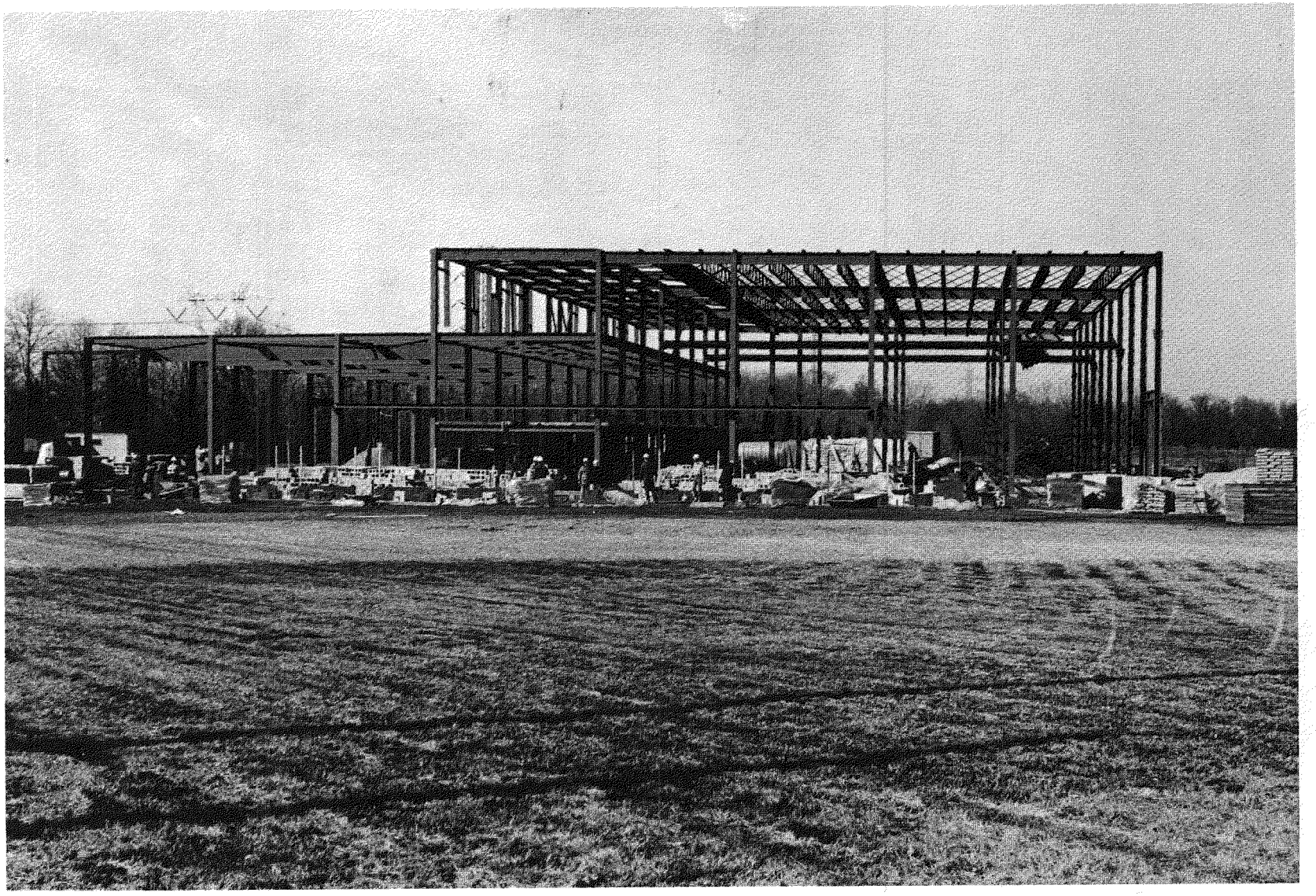

Figure 1-3. BEST Facility 3/13/79
Looking West

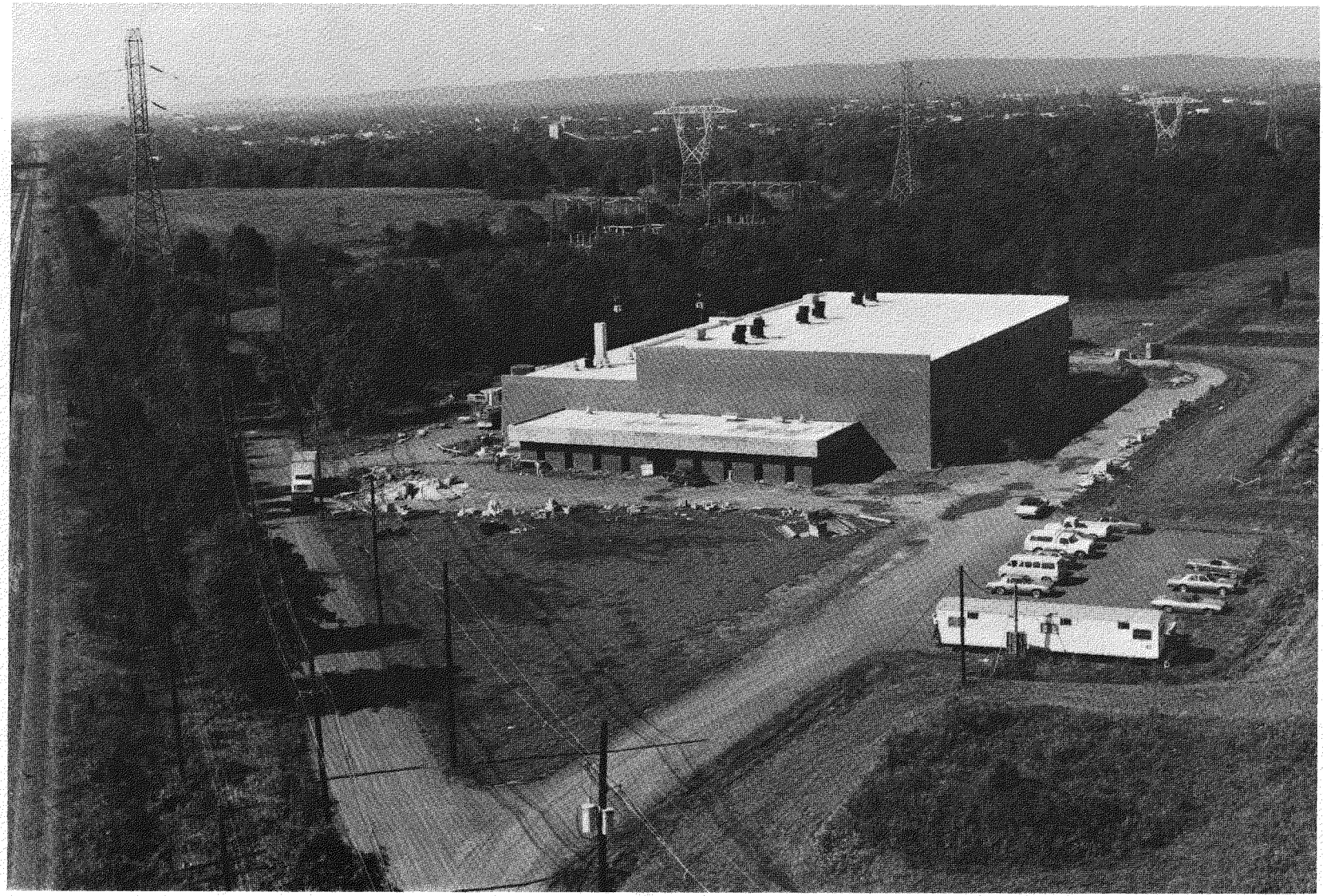

Figure 1-4. BEST Facility 9/17/79
Aerial Photo

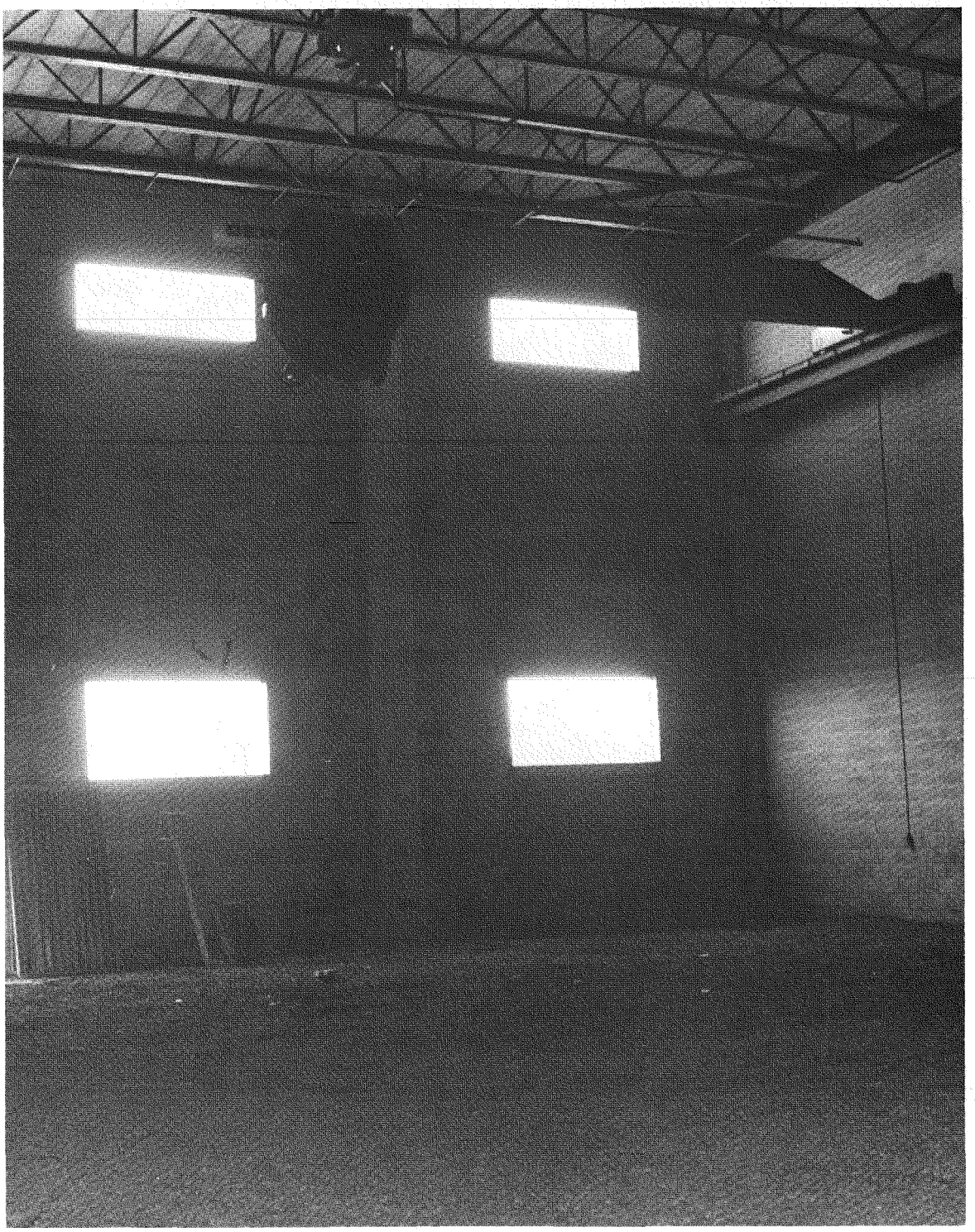

Figure 1-5. BEST Facility 11/15/79
Test Bay Number Two

Figure 1-6. BEST Facility 11/15/79
Converter Area

SECTION 2

BATTERY TESTING PROGRAMS

Overview

Test program development and progress made through August, 1978, were reported in the first progress report. A more recent description appears in the paper BEST Facility: Test Programs and Data Processing - An Update presented at the 14th IECEC Meeting, August, 1979, included as Appendix F of this report. Activities and progress since September, 1978, are described below. Briefly, this task will result in development of test program guidelines for battery system testing at the BEST Facility in coordination with other contractors and advisory groups.

Test program development under the baseline implementation phase is to be embodied in a document Guidelines for Testing at the BEST Facility. The guidelines will address test program requirements which are to apply to all of the battery energy storage systems tested. Detailed and individual test plans will be drafted by equipment developers in conformance with the guidelines. Battery and converter developers and the BEST Facility staff will then cooperate in the preparation of detailed test procedures.

Background

A Test Program Guidelines Working Paper was submitted to the Testing Methodology Group (TMG) for review in September, 1978. Topics in this working paper are listed in the first progress report. The guidelines working paper included a proposal, prompted by equipment developers' inquiries, that three test services be offered: development, prototype, and demonstration testing. These test programs are described in Appendix F; an update appears later in this section. PSE&G recommended

formation of a BEST Facility Developer Users Group consisting of battery systems developers to advise PSE&G on testing guidelines during the baseline facility implementation phase and on operating procedures during facility operation. The Testing Methodology Group meeting in September, 1978, reviewed the working paper and endorsed the concepts of three test services and of the Developer Users Group. The TMG suggested that the Developer Users Group also be opened to developers of power conversion equipment and that a 'menu' of allowable utility applications tests be developed with utility advice as an addendum to the guidelines. This procedure can incorporate utility needs while accommodating differences between the technologies tested. The utility advice in developing a 'menu' of utility applications tests will be obtained from a utility users group. EPRI laid plans shortly after the TMG meeting to form such an advisory group consisting of utility representatives interested in energy storage. The guidelines working paper was subsequently revised to reflect TMG comments and an appendix added definition of the information which might be supplied by a utility users group. Development of three test services and formation of a Developer Users Group were approved by the BEST Facility Planning Group in November, 1978.

BEST Facility Developer Users Group

A charter for the Developer Users Group (DUG), Appendix D of this report, and the revised guidelines working paper were reviewed by project management in February, 1979. Both documents were sent to equipment developers on March 7, together with an invitation to attend an initial meeting of the DUG in April, 1979.

The DUG held four meetings in 1979 with the objectives of organization and review of the test program guidelines topics presented in the guidelines working paper. Participants in these meetings included representatives of lead-acid and advanced battery technologies and converter developers. The first meeting of the group, in April of 1979 served to acquaint participants with the status of the BEST Facility Project, to review the purpose and issues of the test program guidelines, and to organize the group to facilitate the attainment of the goals identified in the charter.

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ARGONNE NATIONAL LABORATORY

BROWN BOVERI & CIE

C & D BATTERIES DIVISION

DOW CHEMICAL

EAGLE PICHER INDUSTRIES INC.

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HOOKER CHEMICAL CORPORATION

PUBLIC SERVICE ELECTRIC AND GAS COMPANY

ROCKWELL INTERNATIONAL CORPORATION

UNITED TECHNOLOGIES CORPORATION

WESTINGHOUSE ELECTRIC CORPORATION

Figure 2-1 BEST Facility Developer Users Group Participating Organizations

Organizational activities of the group resulted in election of a chairman and secretary and the formation of a steering committee to prepare future agendas. The steering committee divided the test program guidelines topics into four groups:

- Test Services
- Test Program
- Data Management, Processing, Recording, Operation, Monitoring and Control
- Pre-qualification, Safety, Installation, Maintenance

Each topic was organized to represent the agenda for a separate meeting, resulting in a complete review of guidelines topics in four meetings, of which three have been convened. An annotated questionnaire was provided by PSE&G prior to each meeting as a vehicle for defining discussion issues. These meetings have substantially modified and expanded the concepts initially presented in the working paper and also provided valuable communication between battery and power conditioning system developers. Following a fourth meeting in January, 1980, and subsequent review of a draft guidelines document, submission of a test program guidelines document to DOE/EPRI is planned for April, 1980. The following subsection of this report will describe the significant concepts of the test program guidelines which have been developed with the aid of the DUG.

Test Program Guidelines

The three DUG meetings held during 1979 for the purpose of reviewing test program guidelines had significant results in aiding PSE&G in refining and modifying the concepts presented in the guidelines working paper. Concepts refined or modified as a result of DUG advice include the definition of test services, the standard test schedule for prototype testing, and the definition of equipment interfaces.

The meeting on test services led the BEST Facility staff to reconsider the test service definitions in two areas. The result is shown in Figure 2-2. The working paper proposed that the size of a battery for development testing be limited to a minimum of 500 KWh. A number of the developers felt that removal of this limitation was important because they were limited by their in-house test facilities to the 50-

THREE TEST SERVICES

	DEVELOPMENT TESTING	PROTOTYPE	MINI-DEMONSTRATION
OBJECTIVES	VERIFY SYSTEM DESIGN CONCEPTS IN A UTILITY ENVIRONMENT	ASSESS PERFORMANCE IN UTILITY ENVIRONMENT	REALISTIC FIELD OPERATING EXPERIENCE; SHOWCASE
HARDWARE	PRE-PROTOTYPE	PROTOTYPE COMMERCIAL: 5 TO 10 MWH	COMMERCIAL: 5 TO 10 MWH
INSTRUMENTATION	SPECIAL PURPOSE	CAREFUL MONITORING	COMMERCIAL LEVEL + ADDITIONAL AS REQUIRED
TESTING	DEVELOPER DEVISED PROCEDURES	UTILITY-ORIENTED EVALUATIVE TESTING	SIMULATED (?) COMMERCIAL OPERATION
REPORT DISSEMINATION	SAME BASIS AS SUPPORTED IN-HOUSE TESTING	DEVELOPER TO ADVISE ON APPROPRIATE LEVEL OF PUBLICITY	MAXIMUM EXPOSURE

Figure 2-2. BEST Facility Test Services

100 KWh range. Normal scale-up and development programs would probably call for development testing of a battery in the 100-500 KWh range. This size agreed with recommendations of the Facility Batteries Groups (FBG) (Recommended Criteria for BEST Facility Batteries revised in June, 1979), which states:

> "The concept of developmental testing has been established to allow the developer to test his battery (nominally 500 KWh-1 MWh) to assess characteristics that are not possible or cost-effective to evaluate in the laboratory. Battery sizes of less than 500 KWh are acceptable to test as long as the developer can demonstrate the technical and financial logic of testing the battery at the BEST Facility as opposed to alternate test facilities (such as the developer's laboratory or NBTL). The only criteria the FBG recommends for developmental testing are (1) an acceptable safety/environmental impact statement and (2) the testing is a logical step in the overall RD&D program."

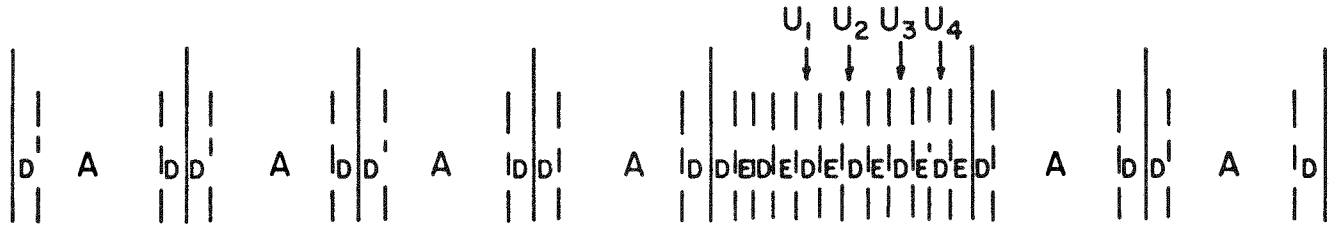
This recommendation was found acceptable to those developers that had expressed concern and was adopted.

The DUG also raised a question concerning the type of test program which should be conducted during the test service labelled mini-demonstration. A utility-driven program would place a battery energy storage system in the mini-demonstrating testing service at the disposal of the PSE&G load dispatcher to operate as required for efficient utility system operation. A program-driven test program would involve performing a pre-determined sequence of cycles typical of a variety of utility operations, as in prototype testing. The DUG favors a utility-driven program. Further advice on this issue will be sought from the utility user's group.

DUG discussions of test schedule resulted in modifying the originally proposed schedule for prototype testing, as shown in Figure 2-3. This program-driven schedule consists of a total of 300 cycles composed of six 40-cycle applications groups and a 60-cycle staged utility group. The applications groups are made up of an established sequence of applications tests. Each applications test contains five charge/discharge

CYCLES	0	20	40	60	80	100	120	140	160	180	200	220	240	260	280	300
MONTHS	0	2	3	4	5	6	7	8	9			14	15	16	17	18

PROPOSED TEST SCHEDULE



A = APPLICATIONS GROUP
D = DESIGN CYCLE TEST
E = EVALUATION TEST

STAGED UTILITY CONDITIONS GROUP

U_1 = 1 MONTH IDLE STAND

U_{2-4} = RATED PERFORMANCE LIMITS, TRANSIENTS, STAGED FAULTS, CREDIBLE ACCIDENTS

Figure 2-3. BEST Facility Prototype Test Schedule

cycles with appropriate "idle" durations to represent a possible utility operating sequence. The DUG has asked the utility user's group to recommend a menu of applications cycles and designate those which should be mandatory for every battery energy storage system and those which should be optional. The staged utility conditions group commences with a sequence of cycles which serve as "control" or "baseline" cycles followed by a number of tests which simulate, in a controlled manner, conditions which battery energy storage systems can expect to experience in utility installations. These conditions include electrical faults, transients, and extended periods of "idle". The DUG endorsed a recommendation that previously proposed "credible accident tests" be eliminated. These tests which verify operation of protective control systems will be performed during the startup, verification, and acceptance period which now precedes commencement of the 300 cycle test program.

DUG considerations of control and operation included a discussion of interfaces between the developer-supplied battery system controller and the Facility Monitor and Control System (FMCS). Concepts presented to the DUG in the guidelines working paper and further during the annual project review meeting followed the original concepts of the Bechtel Design Report[3] and were described in the first progress report. An exerpt from the notes to the questionnaire for this meeting and Figure 2-4, presented at the annual project review meeting in October, 1979, illustrating the concepts set forth for discussion is included at the end of this section for reference.

As a result of discussions on the above topic, the following recommendations were received: It was recognized that it was advantageous for BEST Facility power conversion systems to interface with the (battery) site controller through the FMCS, with the FMCS acting as a passive link, presenting a single standard interface to the site controller. However, if a developer chooses to bring a complete battery/converter system to the BEST Facility, the control interface should be directly from the site controller to the converter.

Control Interfaces Concepts

An exerpt from a questionnaire sent to developers for the November 1 DUG meeting illustrates the BEST Facility control interface concepts:

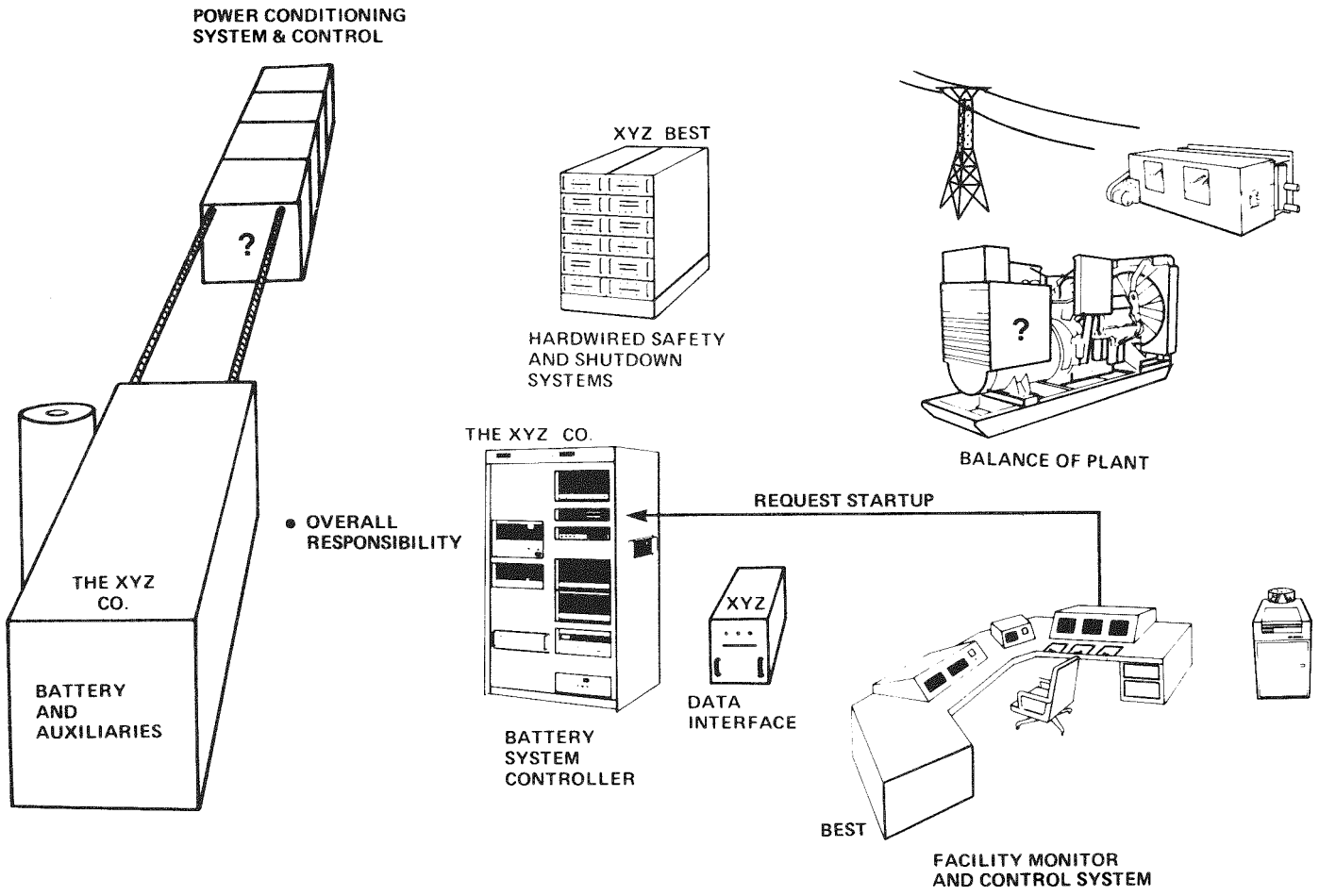


Figure 2-4. BEST Facility Battery Energy Storage Test Components

"How should developer's equipment be integrated with BEST Facility equipment for control purposes in each of the test services?". The following information was supplied with the questionnaire to aid participants in understanding BEST Facility design concepts: (Ref. pp. 37-41 of the working paper).

"The current working concept is that the BEST Facility control computer (Facility Monitor and Control System, FMCS) will emulate a utility load dispatcher during prototype and demonstration testing. Whether, in fact, demonstration testing would be driven by the FMCS or by the PSE&G load dispatcher with the FMCS as a passive link is at this time undecided. A description of control system components and their functions appears below:

Battery: The battery developer is expected to supply both a battery and a site controller with a control interface and a data interface to the FMCS. (Interfaces presently available to the FMCS are serial RS-232C and IBM 2780.)

Converter: The converter developer will supply a converter controller with RS-232C control interface.

Site Controller: Supplied by the battery developer, it starts up, functionally controls and monitors the battery, converter, and battery auxiliaries. In addition, in demonstration testing, the site controller interfaces to all on-site systems and starts these up. The site controller provides control logic for soft shutdown* of the systems.

FMCS: The FMCS starts up and controls BEST Facility systems in prototype testing. It emulates a power system load dispatcher and transmits functional requirements to the site controller. The FMCS provides backup (more permissive) logic for initiating soft shutdown through the site controller and for initiating hard shutdown through the hardwired safety and shutdown systems.

*A soft shutdown is defined as a shutdown sequence controlled by intelligent devices, e.g., computers. Hard shutdown is defined as a shutdown achieved by operation of hardwired relay-type and other electromechanical devices.

Hardwired Safety and Shutdown Systems: These include electromechanically activated systems and passive logic provided by the BEST Facility and the developer for their respective systems and integrated for correct sequence of operation. Hardwired systems logic is more permissive in initiating shutdown than the soft shutdown logic systems resident in the site controller or FMCS."

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SECTION 3

FACILITY DESIGN AND IMPLEMENTATION

Overview

Virtually all primary hardware design activities are complete as of the date of this report. Computer software design remains an on-going activity. A secondary design activity has been necessitated by an approach which was taken in 1978 to shorten the original projected schedule. The initial schedule developed after the preliminary engineering was not acceptable to DOE and EPRI. The procedure adopted at that time to shorten the schedule was to parallel certain activities in the procurement and construction process. This approach essentially consisted of delivering equipment to the facility in stages. Due to the long lead-time of major equipment, this approach required that the building be designed with typical and/or 'black box' considerations for major equipment. When the equipment is shipped, detailed shop drawings obtained from the various vendors are used to make the design drawings equipment-specific. This secondary design activity is now in progress.

Progress during the past year is described in detail below and includes construction of the first power conditioning system, manufacture of the facility shakedown battery, hardware and software development for the facility monitor and control system, implementation and planning for test data analysis, and completion of Volume 1 of the Startup and Acceptance Test Procedure Manual.

Power Conditioning System

Manufacture of the first BEST Facility Power Conditioning System (PCS) was completed in October of 1979. Factory testing was completed during December, 1979. One-half of the completed system (less major magnetics) is shown in Figure 3-1, which also shows one bridge-module in its pull-out position, a provision for ease of servicing. Figure 3-2 shows

Figure 3-1. Portion of First BEST Facility Power Conversion System

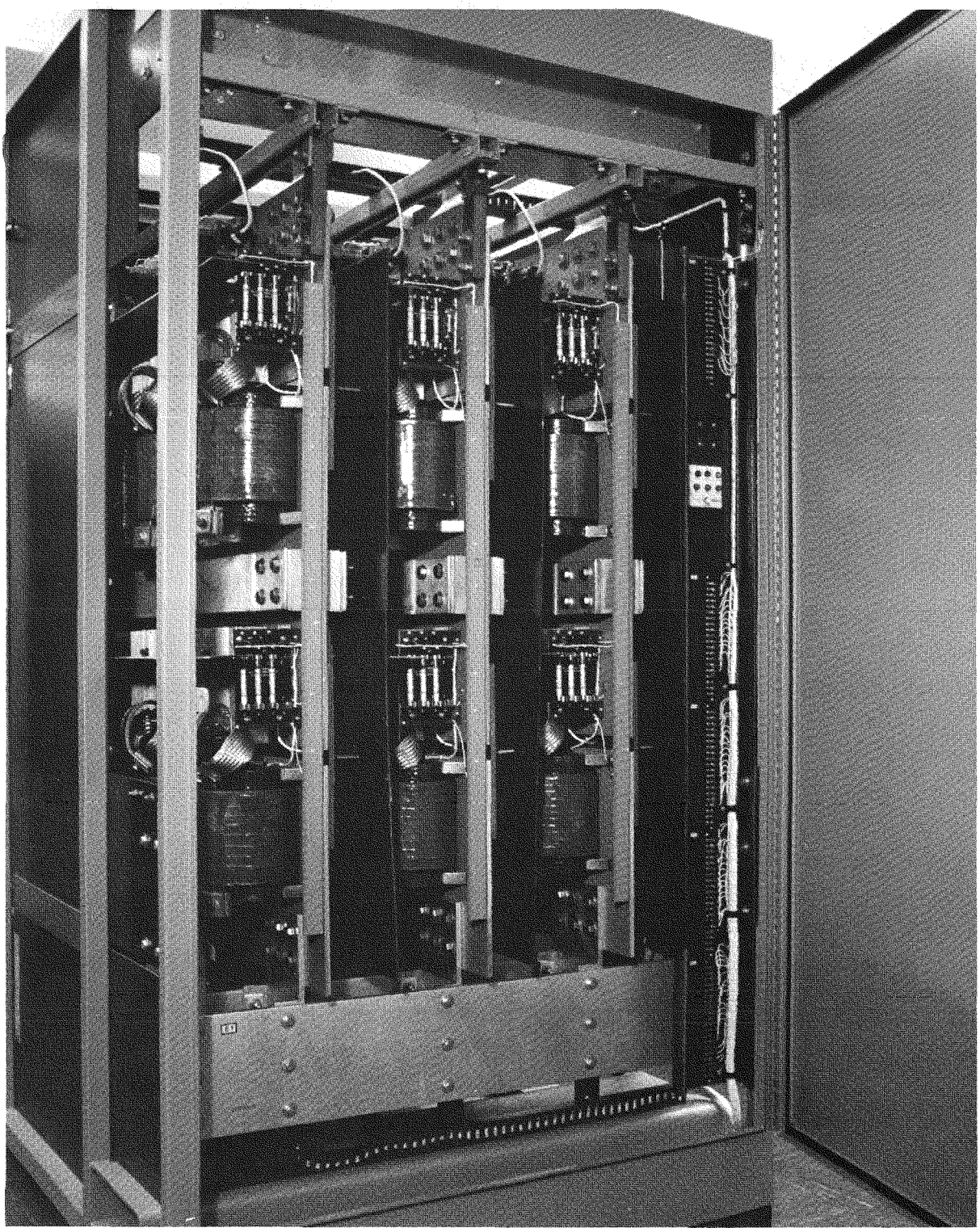

Figure 3-2. Power Conversion System Bridges

a closeup of one cabinet containing three bridge modules. Design characteristics of the PCS were described in the first progress report, while design of the control interface was completed during this reporting period. Response to step changes in setpoint is designed to be overdamped. The response time of the internal controls is less than one second; the response of the FMCS/PCS digital interface may add an additional four seconds.

Power Conditioning System Simulation

A parallel activity in 1979 was the implementation and operation of a power conditioning system simulation. This simulation will be available for use in exploring interfaces to those advanced battery systems. The simulation is implemented in the form of a digital computer code operating on a Hewlett-Packard 9825 calculator with XY plotter and augmented storage. Future power conditioning system users will have access to this code.

The purposes of the simulation now being performed by Garrett AiResearch Manufacturing Company of California are two-fold: The simulation is intended to check performance prior to actual field testing to assure that all design conditions have been met, and to serve as a tool for further design work and/or understanding of the interaction of battery and power conditioning system. To achieve this purpose, the power conditioning system is simulated in detail to obtain overall input and output characteristics. The simulation is coupled to a simplified representation of the utility system and battery. (The representation of the power conditioning system was not intended to cover all design aspects of the system, other engineering studies were required to develop the ratings of actual hardware components.) An advantage to the digital technique is the ability to reproduce time constants and responses lying outside the capabilities of available analogue components. For convenience, the simulation has been written in two versions. One of these is appropriate for most normal operating conditions, while the second is needed for very fast electrical transients, such as lightning strokes.

The cases that will be studied with the simulation are as follows:

1. Step change in control reference input for each mode of operation.

2. Transition from each mode of operation to other modes of operation.
3. Switching of power factor correction capacitors for each mode of operation.
4. Step change in utility system phase angle during discharge operation.
5. Small variations in load to simulate load-following.
6. Sustained changes in AC voltage in each mode of operation.
7. AC voltage dip and rise in each mode of operation.
8. Commutation failure for each mode of operation.
9. The operation of each protective device for a fault on the utility system and within the power conditioning system itself.
10. Lightning stroke to the AC terminals (program modification required).
11. End-of-discharge operation at lowest currents.
12. Operation in back-to-back mode, with half of the equipment operating as an inverter and the other half as a rectifier to simulate field testing.

These cases are intended to show the transient and steady-state voltage and currents on the AC and DC sides of the power conditioning system. Variation in parameters used to represent the power conditioning system and the battery system will then describe the expected interaction between systems.

An interesting phenomenon which surfaced during the simulation development is the interaction of the time constant of the power conditioning system and that of the battery. According to classical control theory, the time constant of the PCS must be twice that of the battery system to assure stable operation; but battery time constants will change depending upon the state of the charge of the battery and the type of battery to be tested, and detailed information on advanced battery equivalent circuits was not available. However, assumptions concerning a zinc-chlorine battery indicated that its time constant at the end of discharge would be similar to the back-to-back PCS operational time constant, e.g., the limiting case of a high inductance, low resistance battery. Therefore, the back-to-back operation became a design limiting condition. Adoption of this limiting conditions results in a power conditioning system overall response time of less than four

seconds, which will be stable for all types of batteries that could conceivably be brought into the BEST Facility.

Facility Shakedown Battery

Functional requirements, selection, and award of a subcontract for the BEST Facility shakedown battery were reported in the first progress report. The subcontract for the battery was awarded to C & D Batteries Division of Eltra Corporation. The battery proposed by C & D and accepted by PSE&G calls for a deep-cycling, calcium-grid, lead-acid battery with hydrogen recombiners. Six cells will be packaged together to form a module. Modules will be assembled into four strings of a maximum 250V-rating, resulting in a battery capacity of 1.8 MWh at the 10-hour discharge rate, with a nominal power output capability of 625 KW.

During 1979 the subcontractor proceeded with production of the battery and started factory tests on completed modules in November. Factory tests were completed in December; shipment of battery modules will commence in early 1980.

Facility Monitor and Control Systems

The basic design approach to facility control was to simulate commercial operation of load-leveling batteries with provisions for maximum safety and data-logging capability. The selection of a computer-based control system and the basic requirements were reported in the first progress report. Progress since July of 1978 includes the manufacture of system hardware, software development, and re-design of the control room console.

During the past year, the following peripheral equipment for the FMCS was tested and delivered either to the BEST Facility or to storage for delivery at a later date:

- Uninterruptible Power Supply (UPS)
- Control Room Annunciator System
- Closed Circuit Television System (CCTV)

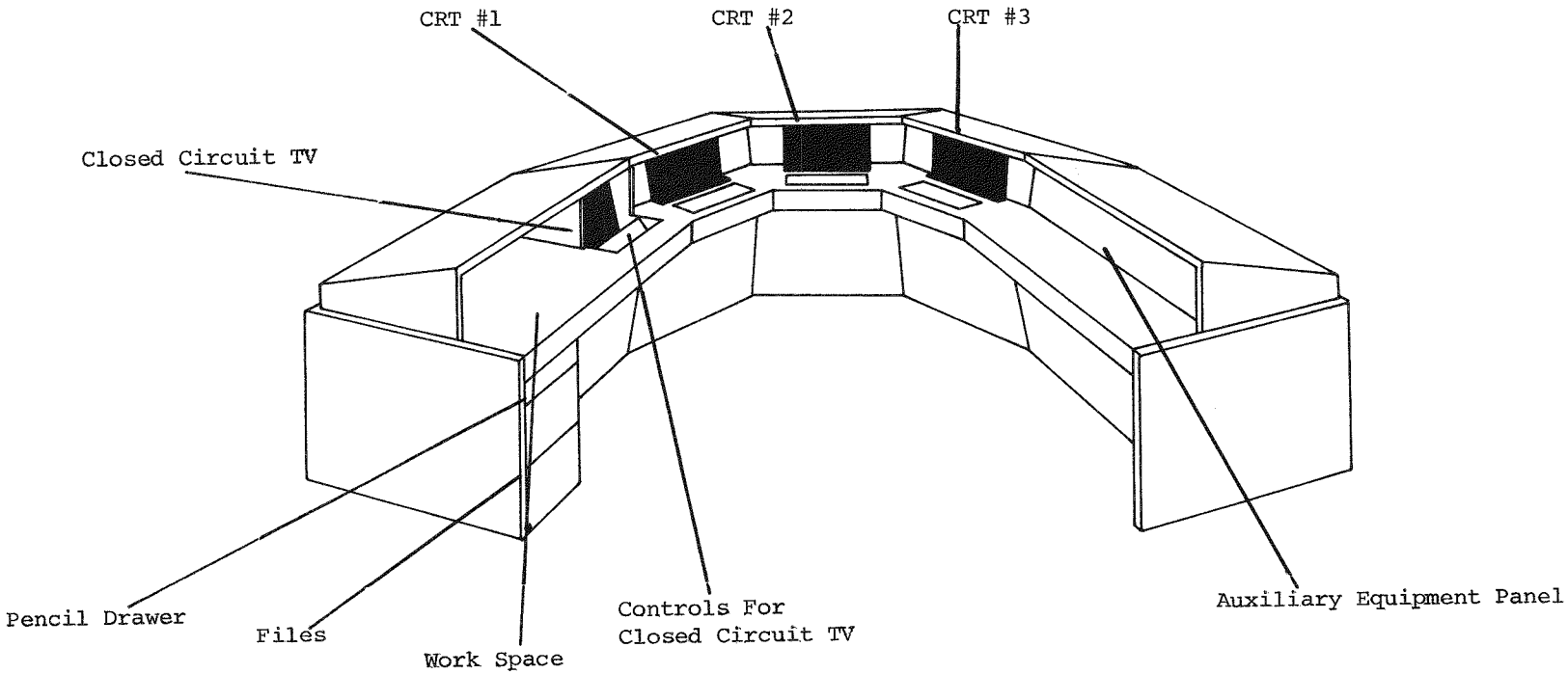

Figure 3-3. BEST Facility Operator's Console

Progress has been achieved on the hardware and software of the Honeywell model 4500 process computer. PSE&G approved the hardware configuration and issued a change-order to include additional equipment to improve reliability and to facilitate installation of a redundant Central Processing Unit (CPU) in the future. Work has progressed on system software by defining the system data base, design of system drawings, and development of functional descriptions for control programs and special logs.

A Human Factors Engineering Review of the control console identified several potential visibility problems caused by the layout and configuration of the console. A re-design of the console was initiated, with the manufacture of the new console scheduled to coincide with completion of the system.

Prefabricated cables to connect the battery to the computer system are the last pieces of equipment to be purchased. The installation and initial checkout of the system is currently scheduled to mesh with the completion of the baseline facility and completion of software development.

Data Analysis and Data Analysis Programs

The objectives of the data analysis program task were described in the first progress report, together with progress made through June, 1978. Current functional designs are described in the paper, The BEST Facility: Test Programs and Data Processing - An Update presented at the 14th IECEC Conference, August, 1979, (Appendix F). The functional design concept envisages a data base (raw test data, data characterization, and a computerized test log) to be accessed by authorized data users at their home locations on graphics terminal equipment, Figure 3-4. An offline computer which provides access to test data will be available to the user for data processing. The user can also transfer data as computer media. A draft functional description was reviewed by the Testing Methodology Group; the design was received favorably. This functional description was sent to the battery developers in November, 1978. Comments received were of a technical nature and were answered individually in early 1979.

A first implementation plan, as conceived in September, 1979, called for data residence and processing to be placed with a commercial time-

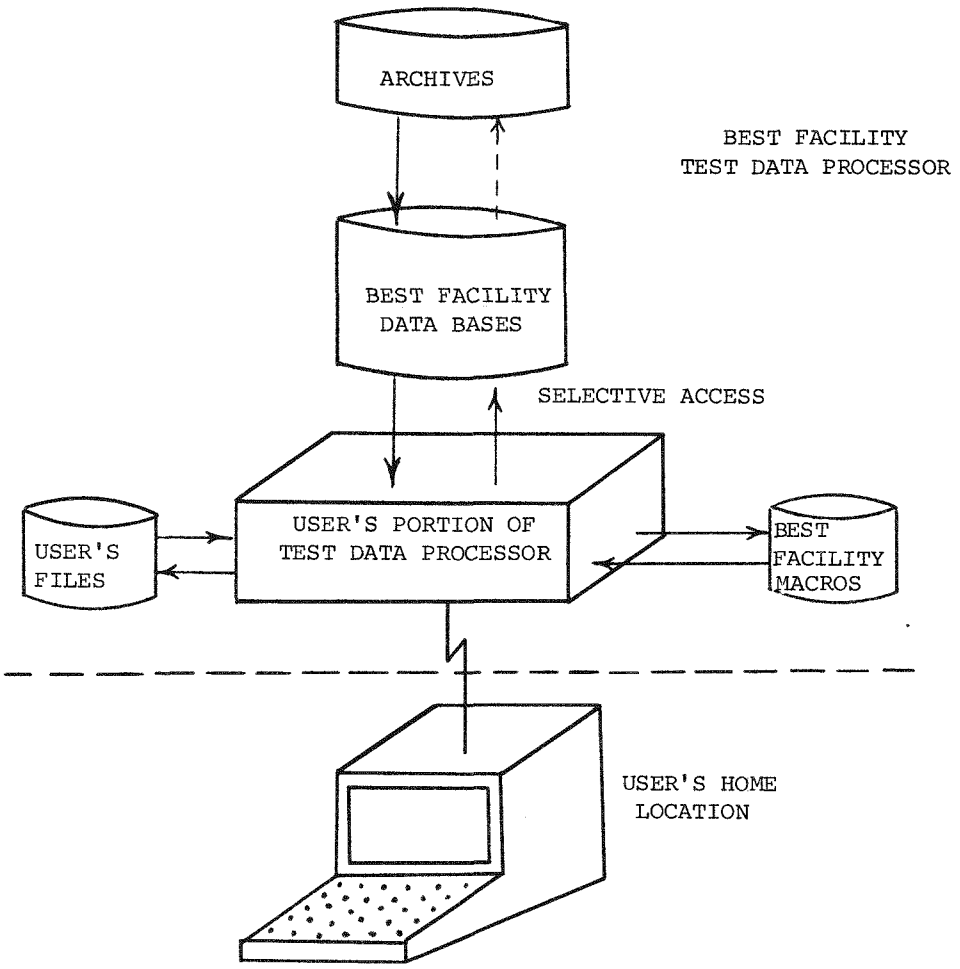

Figure 3-4. BEST Facility Data User's Personal Computer System

sharing service, with much of the less recent data stored on tape.

In January 1979, technical comments by EPRI and follow-up evaluation by PSE&G staff modified the original concept: large disc-pack storage in connection with a dedicated mini-computer could economically store all of the data for on-line access, resulting in a higher grade of service and a simplification of the data retrieval software. EPRI also invited PSE&G to view a demonstration of a candidate data management system, the Relational Management Information System (RIMS), created for EPRI Fuel Rod Mechanical Modeling Project (RP971-1). This software system, operating on large disc storage bases resident on a PRIME Corporation mini-computer, appeared to meet virtually all of the functional requirements of the BEST Facility system for storage, retrieval, graphics display, report writing, ad-hoc inquiry, and flexible user inquiry. Subsequently, PSE&G began a detailed investigation of technical alternatives in the spring of 1979. The RIMS System was compared to 10 commercial data base management systems, and discussions were held with commercial time-sharing services. Data Pro and other sources, including in-house data processing consultants were also employed to investigate total cost of leasing and operation of a dedicated mini-computer. A use-model based on a reasonable schedule for battery testing was used for cost evaluation. Following fact-gathering and analysis, the following conclusions were reached:

1) The BEST Facility should store all data on disc during the lifetime of a test program and of active analysis following testing.
2) RIMS was rated most suitable for BEST Facility use among the data base management systems examined.
3) Implementation of the BEST Facility data processing systems on a dedicated computer could save several hundred thousand dollars over the initial six years of operation, as compared to the use of a commercial time-sharing device.
4) Currently, two PRIME mini-computers are being procured for other PSE&G departments. Parasite operation on a PSE&G-owned computer for software development and acceptance testing would allow deferment of purchase of a dedicated computer until the availability of advanced batteries became more firmly known.

These conclusions, and the actions implied, were approved by project managers in May, 1979. PSE&G agreed to furnish use of a PRIME 550 com-

puter for software development and baseline facility acceptance testing, providing the BEST Facility Project would supply a disc-drive, required add-on memory and communications. EPRI made the RIMS software package available for BEST Facility use in June, 1979, and a plan for implementation was drawn up.

The following work has been completed since July, 1979:

- A program to train personnel in the use of PRIME and RIMS Systems was initiated. A PRIME computer in Mountainside, New Jersey, (sales computer) is presently being used for software development, a service to which PSE&G is entitled as a customer.
- A simple test-data generator was used to create simulated battery testing data bases for use in developing information concerning retrieval and other properties of the RIMS System. Science Applications Inc. (SAI) was contacted for discussion of RIMS enhancements which may be needed.
- A backup and recovery system was implemented and tested; it is currently in use.
- A software standards manual was written for project use.
- Specification of the BEST Facility baseline lead-acid data base for acceptance testing was started and is near completion.
- A draft specification of format for data to be transmitted from the Facility Monitor and Control System to off-line data processing has been written.
- A list of equipment required to supplement operation on the PSE&G PRIME 550 computer was prepared. An RFQ for this equipment has been drafted and issued. This equipment will be needed when operation is transferred from the PRIME sales computer to PSE&G-owned computers.
- A simulation of the operation of a 96-cell string of lead-acid batteries was programmed and run, resulting in a more sophisticated trial data base for development and testing of applications progress.
- The capabilities of the RIMS System were demonstrated using this data base at the October 31, 1979 Annual BEST Facility Project Review Meeting. Figure 3-5 shows a RIMS-produced plot produced during this demonstration. The command which produced this plot was: "PLOT PBS X ET Y TC(43) FOR LCN LE 40 TOP 'CELL 43, CYCLES 37-40'"

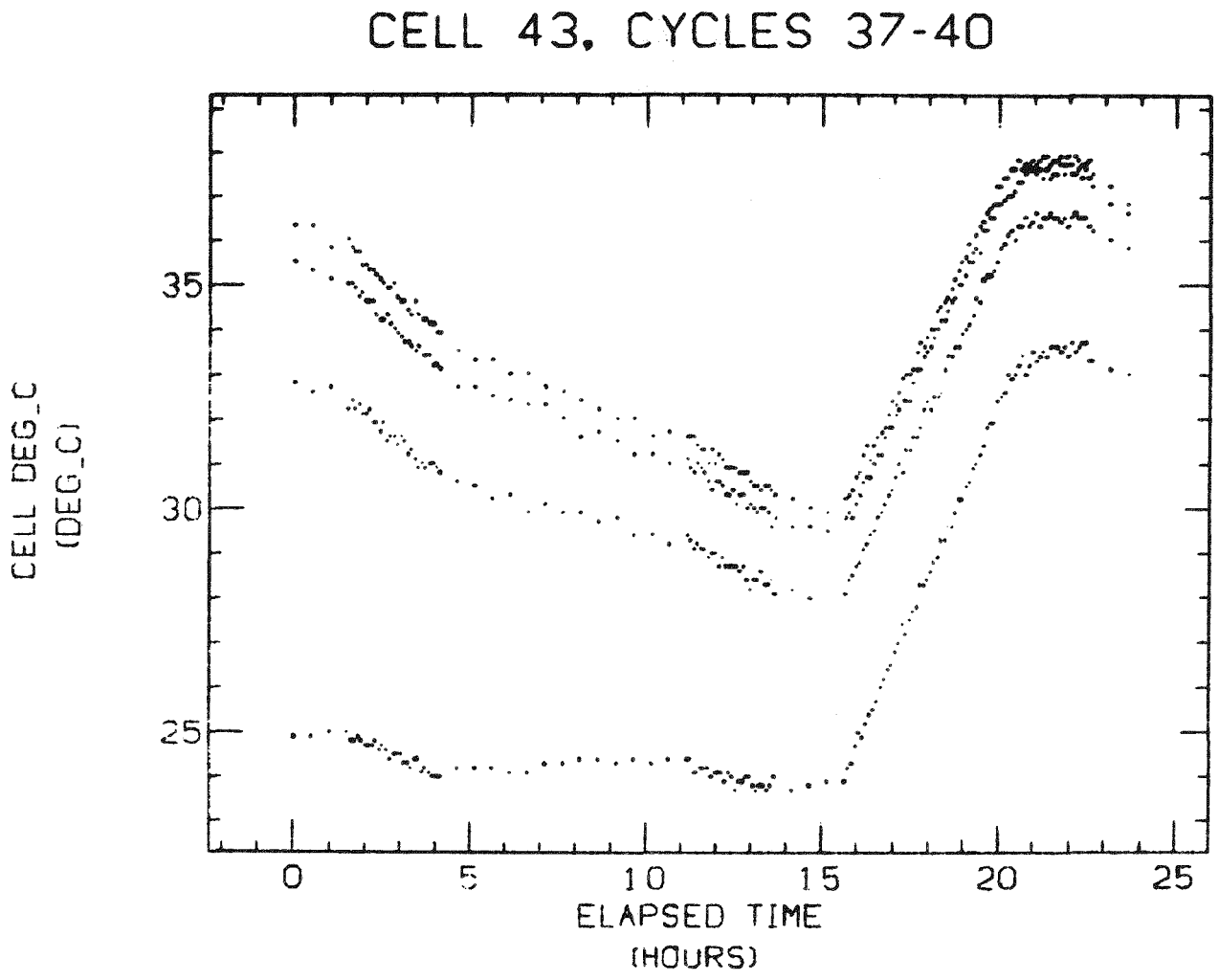

Figure 3-5. Figure Produced by RIMS System Based on Lead-Acid Battery Simulation

Completion of the implementation phase is anticipated by mid-1980. Software will be tested initially by simulation and then further tested and demonstrated in use during BEST Facility acceptance testing. User and technical documentation will be provided.

Startup and Acceptance Testing

The first progress report described the component subsystem and facility acceptance tests to be performed to verify that BEST Facility equipment and systems meet functional requirements. Also described in the first progress report was the commencement of preparation of an acceptance test manual. Between September, 1978, and December, 1979, Volume I of the BEST Facility Startup and Acceptance Test Procedure Manual was completed. This volume describes the administrative and technical requirements of the acceptance test program described below. Work has also started on Volumes II and III which contain detailed procedures and support documents. A table of contents for Volume I is shown in Appendix E.

The acceptance test program is divided into four phases:

Phase I	-	Factory Testing
Phase II	-	Construction Verification Testing
Phase III	-	Operational Testing
Phase IV	-	Acceptance Testing

These four levels of testing are designed to verify each of the four levels of design documentation shown in Figure 3-6.

Factory testing is performed by the vendor prior to shipment of equipment to the BEST Facility. These tests were specified in the original RFQ's. Factory tests on major equipment are witnessed by PSE&G.

Construction verification testing shall be performed on individual components and subsystems after installation at the BEST Facility. These tests are performed to insure that the proper construction and installation procedures and methods have been used. Construction verification tests include:

a) Physical inspections

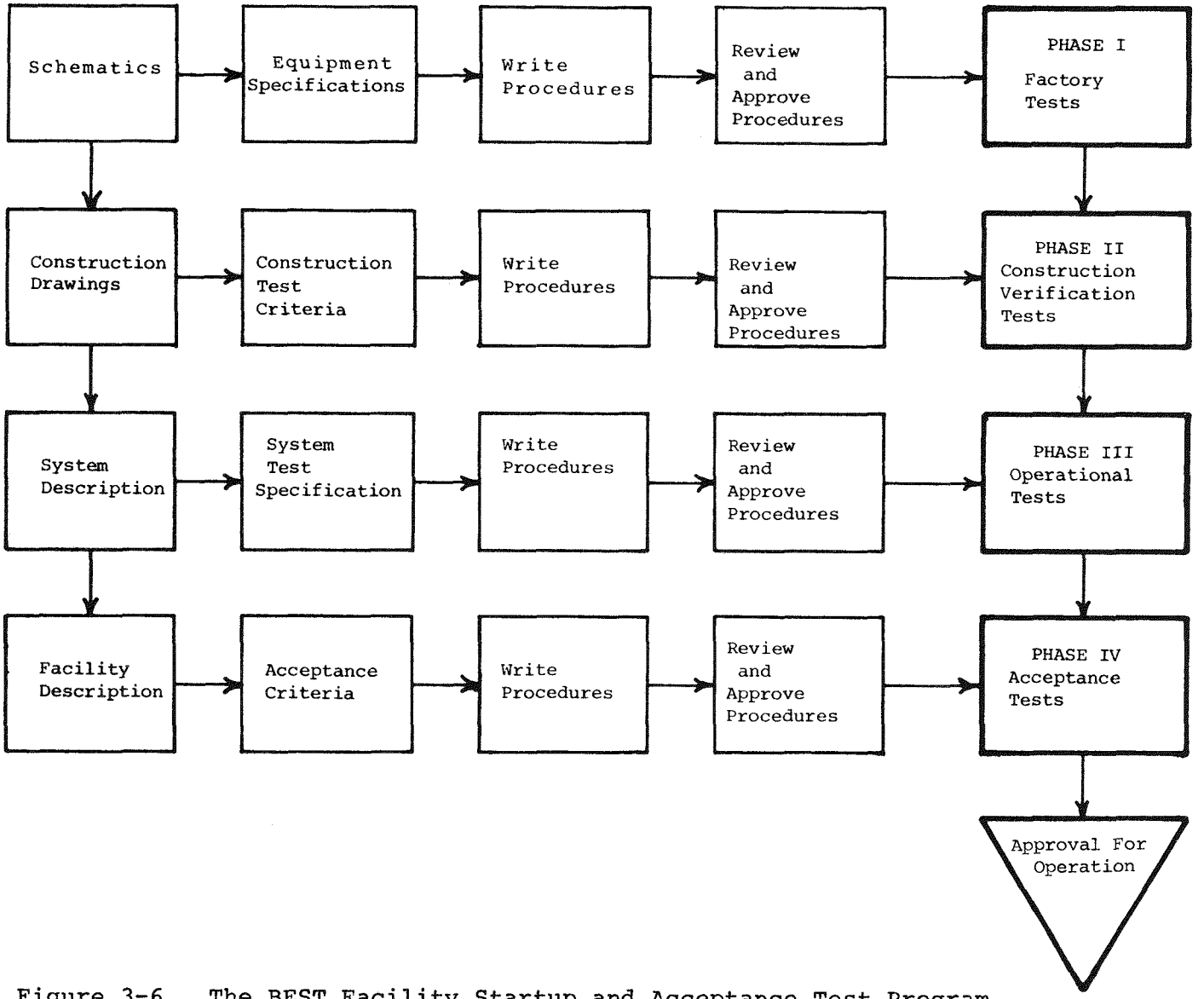

Figure 3-6. The BEST Facility Startup and Acceptance Test Program

b) Calibration of instrumentation, safety, and protection equipment
c) Component and subsystem performance checkout
d) Safety and protection feature checks

Operational tests will be performed on completed systems to verify that the functional operation meets the design intent. Operational tests include:

a) Integrated subsystem checkout and manual operation
b) Use of the facility monitor and control system to operate and monitor system functions
c) Use of the lead-acid battery to provide operating conditions necessary for a thorough verification of the facility systems
d) Use of the power conditioning systems
e) Use of other required auxiliary systems

Acceptance testing will be performed as a final step in the test program to demonstrate to project sponsors that the facility meets design intent. The acceptance test period includes:

a) Facility operation using automatic control
b) Verification of system performance in accordance with pre-determined acceptance criteria and design requirements
c) Identification and correction of items which do not conform to specifications or design intent

The BEST Facility will not commence test programs on advanced batteries until the startup and acceptance program of the baseline facility has been completed.

EPRI Support Program

EPRI and PSE&G contributed to establishment of a BEST Facility support program with the objective of obtaining operating experience on a small scale prior to the start of facility acceptance testing. The program consists of cycling cells resembling those used in the BEST Facility shakedown battery in cycles resembling acceptance test cycling. The eight cells, provided by PSE&G and manufactured by C & D Battery Co., are packaged into two modules of four cells each constructed to simulate one-third of a BEST Facility module at about 70%

physical scale in each dimension and 25% of ampere-hour capacity. The cells are instrumented for current, voltage, and temperature measurements and will be cycled under automatic control and with automatic data acquisition using techniques resembling those to be used at the BEST Facility. Testing is being performed for EPRI by Lockheed Missile Corporation to PSE&G specifications. Objectives of the program in support of the BEST Facility include:

- To gain operating experience
- To obtain battery performance information
- To establish a data base for development of data analysis programs

Progress in 1979 includes:

- Procurement and delivery of the battery modules to Lockheed
- Procurement and installation of automatic cycling and data acquisition equipment by Lockheed
- Shakedown of the apparatus
- Startup of testing

Testing completion is expected in the first half of 1980.

SECTION 4

SECOND TEST BAY IMPLEMENTATION FOR THE EDA ZINC-CHLORINE BATTERY

Contract Approval

On February 7, 1979 PSE&G submitted a proposal to DOE and EPRI for contract modification to implement test bay no. 2 for a prototype test program for Energy Development Associates' (EDA) zinc-chlorine battery, the first advanced battery to be tested at the BEST Facility. Prior to February 7, a number of technical coordination meetings had been held with EDA to prepare available technical, cost and schedule information for the proposal. Additional technical coordination meetings were held after the proposal was submitted to exchange design information in preparation for the formal commencement of work upon receipt of a contract. Effective October 1, 1979 PSE&G received a contract modification to implement test bay no.2 for the zinc-chlorine battery.

Coordination Procedure

To bring a battery to test at the BEST Facility, the battery developer and PSE&G must coordinate their efforts to insure hardware, software, and schedule compatibility. A general plan for coordination between developers and PSE&G appeared in Section 5 of the first progress report. A program coordination procedure between Energy Development Associates and the BEST Facility was developed. The method of coordination provided by this procedure is as follows:

"A working group consisting of representatives of the BEST Facility and EDA shall meet as required to consider areas that require coordination. When mutual agreement is reached by the working group, a recommendation shall be submitted to the PSE&G program manager and his counterpart of EDA. The managers shall meet as required to act on such recommendations. Agreement by both managers is necessary for a recommendation to be implemented. Issues which cannot be resolved to the satisfaction

of both shall be returned to the working group for revision. Substantial disagreements which cannot be solved by the working group and the managers shall be submitted to the DOE/EPRI project managers for resolution."

This procedure was implemented and personnel in each organization were assigned to the working group.

Progress

On October 24, 1979 a meeting was held with EDA to coordinate the engineering and scheduling details necessary for implementation of the second test bay. This meeting included an exchange of design drawings, identification of interfaces requiring detailed investigation, review of EDA and PSE&G schedules, and review and agreement on the previously described procedure for program coordination between EDA and PSE&G. Interfaces requiring detailed investigation were listed together with tasks necessary to complete the engineering of these systems, the responsibilities for completion, and constraints on performing these tasks. A review of proposed EDA and PSE&G schedules identified the need for a joint schedule and a significant shortening of the PSE&G procurement and installation durations.

The next meeting was held on December 14, 1979 at EDA in Madison Heights, Michigan. The purpose of this meeting was to exchange specific design information resulting from completion of the tasks assigned during the October meeting. Examples of the accomplishments during this meeting included:

- Resolution of responsibility for designing, purchase, and installation of systems and equipment necessary
- Establishment of design milestones
- Identification of specific operating modes and short-circuit characteristics of the EDA battery
- Interface requirements with the FMCS including sensors and data link specifications
- Maintenance and safety requirements of the EDA battery

A number of unresolved issues were identified during the December 14, meeting and commitments were made for timely resolution. In addition, plans were established for coordination to proceed between the responsible individuals in each organization.

Plans

The coordination with EDA will continue with meetings held as required to exchange information necessary to complete individual design responsibilities and plans for delivery of the zinc-chlorine battery to commence before the end of 1980. The problems foreseen by PSE&G to meet this schedule involves the design, purchase, and delivery of the DC bus and switchgear to connect the zinc-chlorine battery to the converter, and additional computer equipment necessary for the facility monitor and control system. Both the DC bus and the computer equipment will require a one-year lead time for delivery. Future work at PSE&G will include efforts to reduce this delivery time. In the event that these times cannot be reduced, a six-month delay in commencement of the EDA test program is to be anticipated.

SECTION 5

COORDINATION ACTIVITIES WITH DEVELOPERS

Technical coordination meetings with advanced battery developers were held for the purpose of exchange of design and schedule information. The scheduling of these meetings has been flexible and of necessity linked to the developer's progress. A summary of meetings with battery developers is detailed below.

Argonne National Laboratories

On June 20 and 21, 1979 PSE&G representatives attended the ANL Annual Review Meeting at the Argonne Laboratories in Chicago. The purpose of attending the meeting was to become familiar with the lithium-metal-sulfide battery system in order to develop the balance of plant systems and cost under contract to DOE.

Brown Boveri Corporation

On May 17-18, 1979 representatives of BBC from West Germany met with members of the BEST Facility team. A discussion of the program's status included requirements for battery instrumentation, development of methods for analyzing battery performance data and application of load-leveling batteries to utility systems.

Developer Users Group

A meeting on April 23-24, 1979 served to determine methods of selecting a chairman and secretary, determining topics for future meetings and their frequency. A meeting on August 8, 1979 was convened for the purpose of reviewing the subject of test services as described in the Guidelines For BEST Facility Battery Testing Programs: A Working Paper.

A meeting on September 20, 1979 addressed the subject of test programs, in general, while the subsequent meeting of November 1, 1979 addressed more specific test program issues such as: control, monitoring, operation, data recording, processing, management, and distribution.

Energy Development Associates

On November 30, 1978 a meeting was arranged for the express purpose of determining coordination procedures that would ensure effective communications between PSE&G and EDA. At the meeting on March 23, 1979 a preliminary description of design assumptions and interface requirements prepared by PSE&G for the installation of the EDA zinc-chlorine battery system at the BEST Facility was presented.

A review of the DOE/EPRI/EDA BEST Battery Program was presented on May 1-3, 1979. A coordination meeting on July 10-11, 1979 resulted in supplemental information on charging and discharging operations. The September 18, 1979 meeting served to apprise PSE&G of the latest design information from EDA, thus enabling a more accurate estimate of second bay implementation cost. The main objective of the October 24, 1979 meeting was to review and resolve the differences between the PSE&G schedule for implementation of test bay no. 2 at the BEST Facility and the EDA schedule for installation of the zinc-chlorine battery system. The December 14, 1979 meeting was concerned with the technical detail on implementation of the second bay. Main topics were EDA's response to a list of assumptions and questions by PSE&G and the coordination of the implementation schedule between EDA and PSE&G.

Ford

Coordination with Ford on their load-leveling battery has continued. Representatives of PSE&G attended the DOE-Ford Annual Sodium-Sulfur Battery Review on November 1, 1978. A visit to Ford Aeroneutronics Division was made in January, 1979 to observe progress and to assess instrumentation and installation requirements.

General Electric Company

The GE Sodium-Sulfur Battery Program Review was attended on May 16, 1979. Main items of interest included development, testing, system design and proposed future programs.

SECTION 6

PROGRAM MANAGEMENT ORGANIZATION

This section updates detailed information appearing in the first progress report. An updated Prime Contractor Program Management Organization is shown in Figure 6-1. The offices of BEST Facility program Manager and facility manager for the operation phase are now merged in Al Pivec, who assumed this responsibility from Peter Lewis in September, 1979. The position of design and construction team leader was assumed by John Abraham in November, 1979. Mr. Abraham had previously been sponsor engineer. The BEST Facility Developer Users Group (Section 2 and Appendix D), comprised principally of battery systems equipment developers, was formed in April, 1979 and is expected to continue its activities during operation.

The functional description of the BEST Facility project management organization and the relationship of the prime contractor to DOE-EPRI project management is depicted in Figure 6-2. This organization is structured to enable participation by a wide-ranging group of people and the BEST Facility Planning Group who provide the overall guidance and direction for the project.

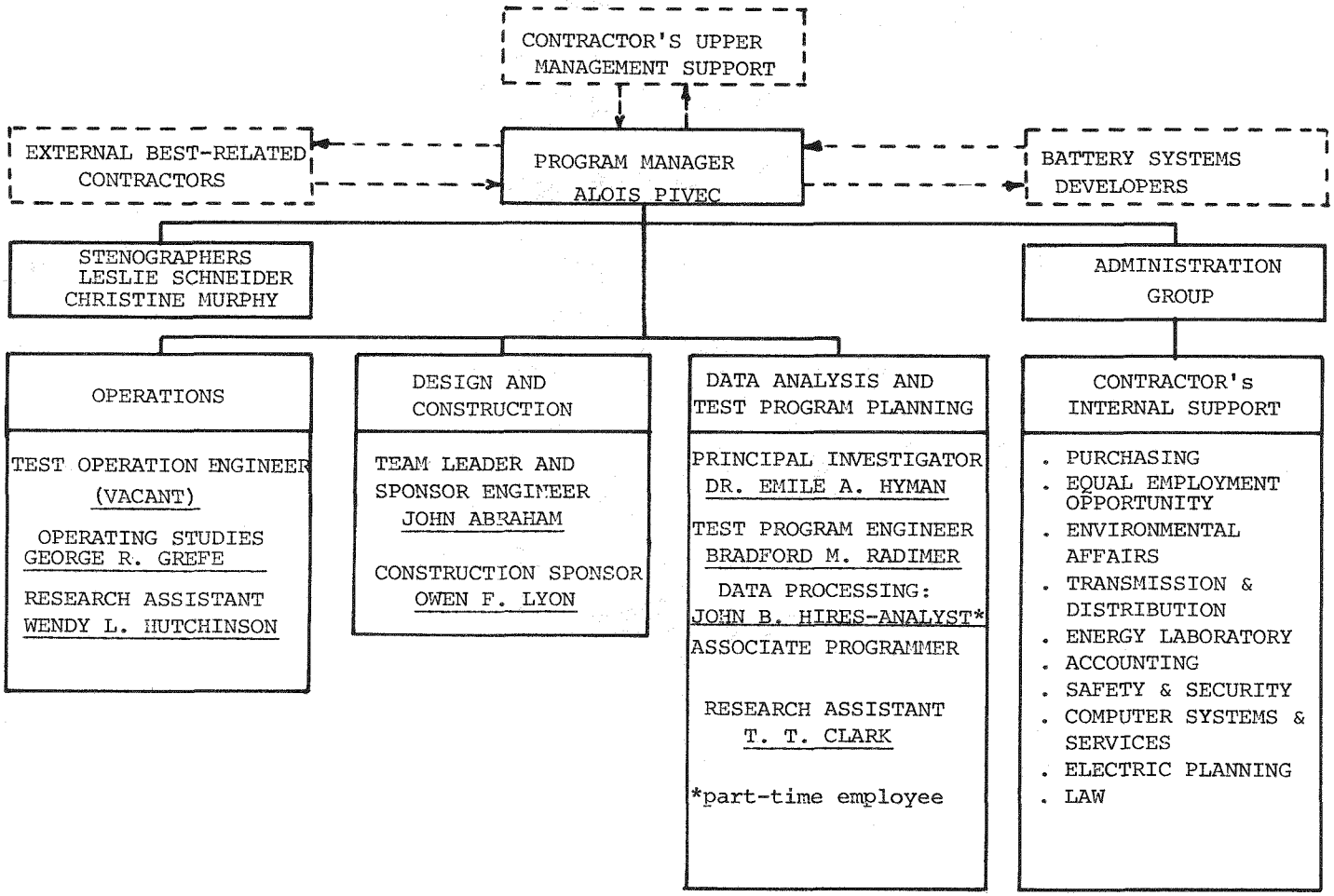

Figure 6-1. Prime Contractor Program Management Organization

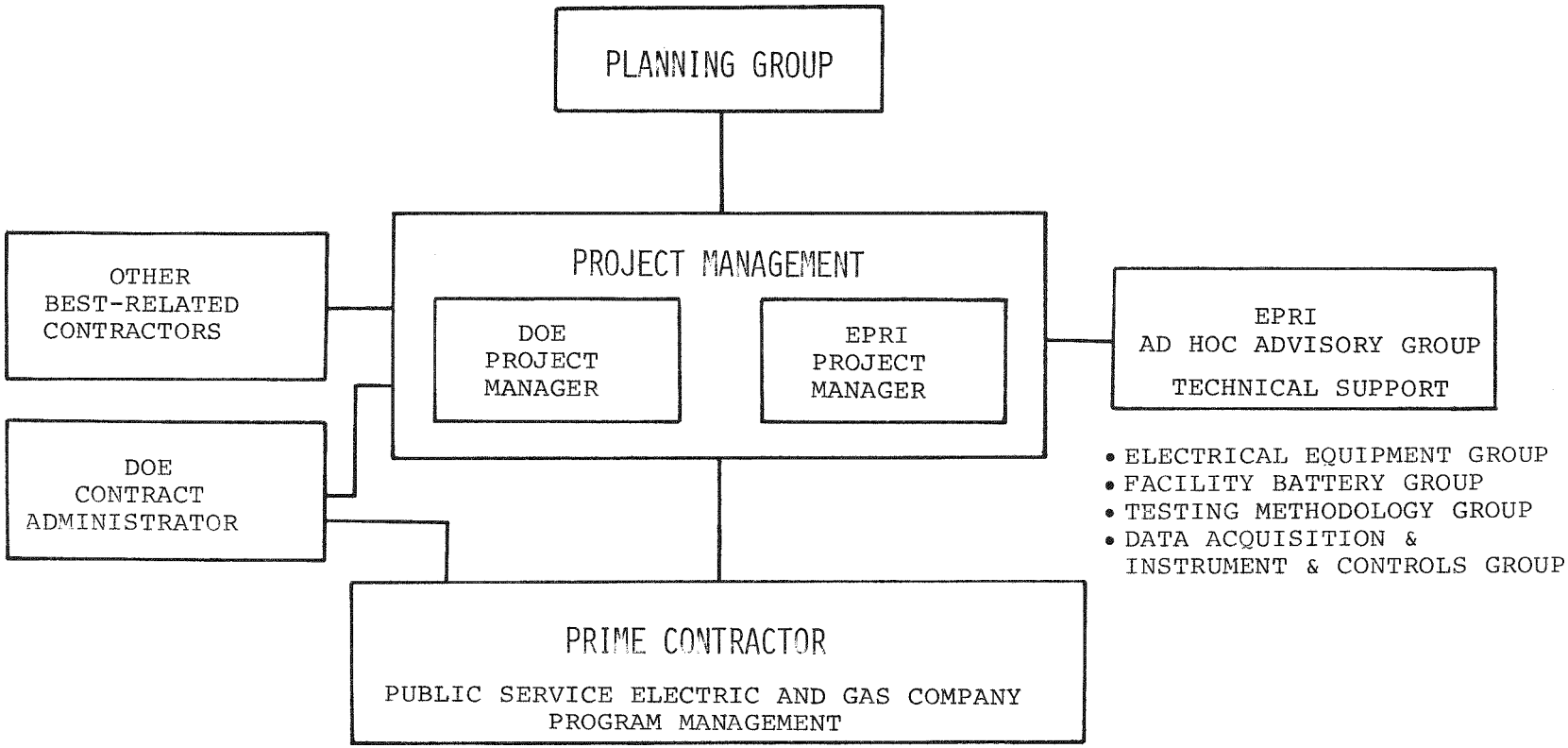

Figure 6-2. BEST Facility Management Organization.

APPENDIX A-1

KEY EVENT CHRONOLOGY

EVENT	DATE
Energy Research and Development Administration (ERDA) issues request for proposals (RFQ No. E(11-1)-p-76-003) for "Design, Construction, Testing and Acceptance, and Operation of the BEST Facility".	9/29/75
ERDA notifies PSE&G that it has competitively been selected as BEST Facility prime contractor.	1/14/76
Letter contract signed by both parties.	3/22/76
Contract signed by both parties.	6/30/76
Federal EIA approved by ERDA Chicago Operations Office.	4/22/77
Site Preparation work started.	7/25/77
Department of Energy (DOE) formed replacing ERDA.	10/1/77
Official ground breaking ceremony.	10/6/77
AC-DC Power Conversion Equipment subcontract awarded to AiResearch Manufacturing Co. of California, Division of Garrett Corporation.	10/17/77
Federal EIA approved by DOE, Washington, DC.	11/77
Monitor and Control System subcontract awarded to Honeywell Inc.	6/12/78
Building Construction and Mechanical Equipment Installation subcontract awarded to Branciforte Builders Inc.	6/20/78
Facility Shakedown Battery subcontract awarded to C & D Batteries, Division of Eltra Corporation.	7/7/78
Building construction started.	7/28/78
Fire Detection subcontract awarded to Walte Kidde Sales & Services Company.	9/18/78

EVENT	DATE
15-kV and 600-Volt Switchgear subcontract awarded to Federal Pacific Electric Company.	9/25/78
Plans for redesign of the AC/DC Power Conversion Equipment approved.	9/25/78
Uninterruptible AC Power Supply System subcontract awarded to Internationl Machines Corporation.	9/26/78
15-kV Metalclad Switchgear subcontract awarded to General Electric Company.	10/16/78
600-Volt Class Control Centers subcontract awarded to Gould Inc.	10/25/78
Closed Circuit TV subcontract awarded to Video Measurements Inc.	12/26/78
Temperature Controls for HVAC Systems subcontract awarded to Johnson Controls Inc.	1/8/79
DC Equipment subcontract awarded to Federal Pacific Electric Company.	1/15/79
Three-Phase Padmount Transformers subcontract awarded to Westinghouse Electric Company.	1/15/79
Proposal for Implementation of Second Test Bay submitted.	2/7/79
Station 125-Volt Battery Charger subcontract awarded to C & D Batteries, Division of Eltra Corporation.	3/29/79
Station 125/250-Volt Control Battery subcontract awarded to C & D Batteries, Division of Eltra Corporation.	3/29/79
Proposal for Advanced Converter submitted.	4/16/79
Diesel Generator subcontract awarded to Penske GM Power Company.	6/21/79
Instrument Isolation and Data Logger, RFQ No. 79222, issued.	7/17/79
Installation of Equipment subcontract awarded to S.M. Electric.	7/23/79
Contract modification to implement Bay #2 for the EDA battery issued to PSE&G by DOE/EPRI.	10/1/79
Proposal for Facility Operation submitted.	10/16/79
Roof complete, building weathertight.	10/15/79
Data Processing RFQ issued.	12/27/79

APPENDIX A-2

KEY FUTURE EVENTS

EVENT	DATE
C & D Lead-Acid Battery Installed	April, 1980
First Converter Installed	April, 1980
FMCS Installed	August, 1980
BEST Facility Construction Completed	September, 1980
BEST Acceptance Testing	October, 1980

APPENDIX B-1

DOE/EPRI/PSE&G TECHNICAL PAPERS ISSUED ON WORK COMPLETED UNDER THE BEST FACILITY PROJECT CONTRACT

1. BEST Facility Study Project Team, "Purposes and Features of a Proposed National Battery Energy Storage Test (BEST) Facility",American Power Conference, Chicago, Illinois, April 20-22, 1976.

2. Beck, J. W., "The Battery Energy Storage Test (BEST) Facility: Its Purposes and Descriptions", IEEE Power Engineering Society; Summer Meeting, 1976.

3. Lewis, P. A, and Abraham, J., "BEST Facility - Preliminary Design", BEST Facility Workshop II, New Orleans, Louisiana, February 8-10, 1977.

4. Hyman, E. A., "BEST Facility - Test Program and Data Analysis Methodology", BEST Facility Workshop II, New Orleans, Louisiana, February 8-10, 1977.

5. Snow, R. V., "BEST Facility - AC-DC Power Conversion Equipment", BEST Facility Workshop II, New Orleans, Louisiana, February 8-10, 1977.

6. Pivec, A., Whooley, J. P., and Green, R. N., "BEST Facility - Operation, Control and Data Acquisition", BEST Facility Workshop II, New Orleans, Louisiana, February 8-10, 1977.

7. Casazza, J. A., Lewis, P. A, and Mallard, S. A., "National Facility For Testing Utilities' Energy Storage Systems - The Battery Energy Storage Test Facility", World Electrotechnical Congress, Moscow, USSR, June, 1977.

8. Lewis, P. A, and Hyman, E. A., "The BEST Facility - At The Midpoint of Load Leveling Battery Commercialization", Electrochemical Society Meeting, Atlanta, Georgia, October 9-14, 1977.

9. Lewis, P. A, "The Battery Energy Storage Test (BEST) Facility Between the Laboratory and Initial Applications of Load Leveling Batteries", Edison Electric Institute, Electrical System and Equipment Committee Meeting, Boston, Massachusetts, October 19, 1977.

10. Lewis, P. A, and Pivec, A., "The BEST Facility--Accelerating the Development of Utility Load-Leveling Batteries", 28th Power Sources Symposium, Atlantic City, New Jersey, June 12-15, 1978.

11. Snow, R. V., "The Design of the Battery Energy Storage Test Facility", IEEE Power Engineering Society, Summer Meeting, Los Angeles, California, July 16, 1978.

12. Hyman, E. A., and Pivec, A., "The Battery Energy Storage Test Facility: Test Programs and Data Processing - An Update", 14th Intersociety Energy Conversion Engineering Conference, Boston, Massachusetts, August 5-10, 1979.

APPENDIX B-2

PSE&G REPORTS ISSUED ON WORK COMPLETED UNDER THE BEST FACILITY PROJECT CONTRACT

1. PSE&G, "Battery Energy Storage Test (BEST) Facility Environmental Impact Assessment", prepared for U.S. Energy Research and Development Administration and Electric Power Research Institute, Contract No. EY-76-C-02-2857, April 15, 1977.

2. PSE&G, "Municipal Environmental Impact Statement for Battery Energy Storage Test (BEST) Facility", prepared for Hillsborough Township, Somerset County, New Jersey; May 4, 1977.

3. Hyman, E. A., "Phenomenologial Cell Modeling: A Tool For Planning and Analyzing Battery Testing at the BEST Facility", PSE&G Research Corporation Report RD77-1, October 21, 1977.

4. PSE&G, "Draft Functional Description of the BEST Facility Test Data Processor", presented at the Meeting of the EPRI Testing Methodology Group, Argonne, Illinois, September 19-21, 1978.

5. PSE&G, "Guidelines for BEST Facility Battery Testing Programs: A Working Paper", presented at the meeting of the EPRI Testing Methodology Group, Argonne, Illinois, September 19-21, 1978.

6. PSE&G, "Guidelines for BEST Facility Battery Testing Program: A Working Paper", presented at the meeting of the BEST Facility Developer Users Group, St. Petersburg, Florida; April 23-24, 1979.

APPENDIX B-3

DOE/EPRI REPORTS ISSUED FOR WORK RELATED TO THE BEST FACILITY PROJECT

1. Bechtel Corporation, "Preliminary and Safety Assessment for a Battery Energy Storage Test (BEST) Facility, prepared for Argonne National Laboratory, Contract No. 31-109-38-2962.

2. BEST Facility Study Project Team, "A National Battery Energy Storage Test (BEST) Facility: Conceptual Design and Cost Estimate"EPRI 225, ERDA 31-109-38-2962, Technical Report 1, August, 1975.

3. Bechtel Corporation, "Conceptual Design of a Battery Energy Storage Test (BEST) Facility", EPRI 225, ERDA 31-109-38-2962, Technical Report 2, August, 1975.

4. "The BEST Facility - Workshop II", Electric Power Research Institute and Energy Research and Development Administration, A compilation of the Workshop papers presented February 8-10, 1977 (WS 77-1) April, 1977.

   Lewis, P. A, and Abraham J., "BEST Facility - Preliminary Design",

   Pivec, A., Whooley, J. P., and Green, R. N., - "BEST Facility Operation, Control and Data Acquisition",

   Sudar, S., and Adler, E., "Lithium Silicon-Iron Sulfide Battery System",

   Anand, J. N., and Revak, T. T., "Design of a One Megawatt Storage Battery for BEST Facilities",

   Smith, J. C., "Lead-Acid Battery Workshop Summary",

   Klunder, K., "Lead-Acid Battery Recommendation for the BEST Facility Station Battery",

   The Facility Batteries Group: Birk, J., Klunder, K., Schneider, T., Walsh, W., and Zalosh, R., "Recommended Criteria For BEST Facility Batteries",

   Warde, C., "The Zinc-Chlorine Battery System",

   Chreitzberg, A. M., "Performance Projections of the Sodium/B-Alumina/Antimony Trichloride Molten Salt Battery for BEST",

   Mitoff, S. P., "General Electric Company Sodium-Sulfur System",

George, James H. B., "Advanced Battery Costing Methodology",

Hyman, E. A., "BEST Facility - Test Program and Data Analysis Methodology",

Snow, R. V., "BEST Facility - AC-DC Power Conversion Equipment",

Phillips, G. A., and King, J. M., "Advanced Converter for BEST Facility",

Smith, J. Charles, "Economic Assessment of Lead-Acid Batteries",

Beck, J. W., and Smith, J. C., "Workshop Summary".

5. U. S. Department of Energy, Division of Electrical Energy Systems, "Environmental Assessment: Battery Energy Storage Test (BEST) Facility, DOE/EA-0001, December, 1977.

6. Public Service Electric and Gas Company, "Battery Energy Storage Test (BEST) Facility First Progress Report", EPRI EM-1005, Project 225-2, DOE EY-76-C-02-2857, Interim Report, February, 1979.

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APPENDIX C

INTERNATIONAL INQUIRIES

Continuing interest in the BEST Facility is evidenced by the large number of visitors to the BEST Facility Project. Domestic visitations included a Congressional Staff briefing and site visits by representatives of many of the advanced battery systems developers. Less expected was the number of international inquiries received. During the period of this report, representatives of the following international organizations visited the BEST Facility project:

Organization	Main Points of Interest
Brown Boveri Corporation of West Germany	. General information about the Facility . Instrumentation, data acquisition, and analysis . Electrical design of battery plants . Battery storage devices and application
Energy Conservation R & D Study Team (Japan)	. Composition of the facility and system layout . Rating of items in the facility . Short circuit test method
Furukawa Battery Co. Ltd. (Japan)	Discussions of battery testing.
Korean Research Institute	Request for general information including an overview of current U.S. battery development in regard to load-leveling
Overseas Electrical Industry Survey Institute Inc., Japan	Cost estimates for advanced battery systems

Organization	Main Points of Interest
Skikoku Electric Power Co., Inc.	. Policies in conjunction with trends in energy resources selection . Power plant siting and strategic planning . Project planning
Siemens Corporation of West Germany	Energy development and application of new technologies; particularly, utility load-leveling applications of advanced battery systems
Tokyo Electric Power Co., Ltd.	General interest in project . Key milestones of project . Listing of advanced battery types to be tested and their developers . Projected arrival of zinc-chlorine and sodium-sulfur batteries
Ministry of International Trade and Industry (Japan)	General information of battery development and the BEST Facility

APPENDIX D

BEST FACILITY DEVELOPER USERS GROUP

CHARTER

1.0 Background

The Battery Energy Storage Test (BEST) Facility is a service organization serving Battery Energy Technologies Developers, the Department of Energy and the electric utilities in their mutual desire to bring effective battery energy storage technologies to commercial realization. The service offered by the BEST Facility is the impartial testing of batteries and converters in a utility environment.

The concepts of the BEST Facility were developed by the BEST Facility Project team with consultation by the Bechtel Corp. Public Service Electric and Gas Company (PSE&G) was selected by the Department of Energy (DOE) and the Electric Power Research Institute (EPRI) as contractor for construction of the BEST Facility and was given responsibility for taking the lead in the development of a test program. PSE&G is now preparing guidelines and procedures for battery energy storage technologies testing in anticipation of initial testing in 1981.

2.0 BEST Facility Developer Users Group

Recognizing that there are a number of batteries and converters to be tested, and wishing to ensure fair treatment and effective services to all developers submitting equipment for testing, PSE&G has undertaken formation of a BEST Facility Developer Users Group with the approval of the Department of Energy and the Electric Power Research Institute. The purpose of the Developer Users Group is to advise PSE&G in the development of those test program policies, guidelines and procedures which should apply uniformly to all equipment developers, both initially and on a continuing basis during facility operation. This group is formed solely on the initiative of PSE&G as an aid in meeting its contractual requirements; formation of this group is not a contract requirement.

3.0 Other Advisory Groups

Direction of the BEST Facility and its activities, policies, and procedures is vested in the DOE Program Manager, with the concurrence of the EPRI Program Manager and by direction to the PSE&G BEST Facility Program Manager. DOE/EPRI Program Management may, at its

discretion, adopt recommendations of its contractors or advisory committees.

The following groups that now exist, or are proposed, pursue complimentary but distinct activities and represent distinct constituencies:

3.1 Utility Battery Users Group

The Utility Battery Users Group, as proposed by EPRI, would analyze the commercial opportunities for battery energy storage and define items of information which will be required by utilities in making commercialization decisions.

3.2 EPRI Facility Batteries Group

The Facility Batteries Group (FBG) recommends requirements for admission of equipment to the BEST Facility for testing and reviews admissability of individual pieces of equipment. Membership is characterized by persons well acquainted with technologies to be tested but who are not employees of the commercial equipment developers. The TMG is an EPRI technical support group.

4.0 Participation

4.1 Regular Members

Membership in the Developer Users Group is open at the invitation of PSE&G to all developers of major equipment with an active interest in bringing such equipment to the BEST Facility for testing. One additional member will be designated from the PSE&G BEST Facility Project Team.

4.2 Associate Members

PSE&G may designate additional members as non-voting associate members from among the members of the following organizations:

1. PSE&G BEST Facility Project Team
2. The Battery Utility Users Group
3. The EPRI Testing Methodology Group

4. The EPRI Facility Batteries Group
5. Argonne National Laboratory
6. National Battery Test Lab

Associated members will be called upon to supply information developed from the activities of the organization to which they belong.

5.0 Specific Activities

5.1 Test Program Guidelines

The initial activity of the Developer Users Group is to advise PSE&G on development of a document entitled BEST Facility Test Program Guidelines. The Guidelines will cover objectives, pre-test obligations, control, operation, safety, test programs, test schedules, data monitoring, data dissemination and reporting. PSE&G will present successive working papers and drafts to the Developer Users Group for consideration.

5.2 Continuing Activities

The Developer Users Group will convene during the life of the BEST Facility as required, or at least once annually, to consider recommendations for continuing improvement in BEST Facility policies, procedures or services.

6.0 Initial Meeting

PSE&G will convene an initial meeting of the BEST Facility Developer Users Group under the pro-tem chairmanship of the designated PSE&G member. A PSE&G associate member will serve as pro-tem secretary. The Developer Users Group will select a chairman and secretary for succeeding meetings from among the regular member organizations. The secretary will be responsible for maintaining an appropriate record of meetings and issuing timely minutes to members and attendees. The following items will be on the Agenda of the initial meeting:

1. Review of a working paper for BEST Facility Test Program Guidelines (see section 5.1) in order to recommend modifications/changes or provide general comments.
2. Permanent arrangements (selection of officers, etc.)

3. Planning for succeeding meetings.

INITIAL 'USERS GROUP' DEVELOPERS 2/28/79

Airesearch Manufacturing Corporation

Brown-Boveri Corporation

C & D Batteries

Dow Chemical

Eagle-Picher

Energy Development Associates

ESB Incorporated

Ford Aerospace & Communications Corporation

General Electric Company

Globe-Union Incorporated

Gould Incorporated

Oxy Metal Industries Corporation

Rockwell International

United Technologies Corporation

Westinghouse Electric Corporation

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APPENDIX E

BEST FACILITY STARTUP
AND ACCEPTANCE TEST
PROCEDURE MANUAL
VOLUME 1

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APPENDIX F

THE BATTERY ENERGY STORAGE TEST (BEST) FACILITY: TEST PROGRAMS AND DATA PROCESSING - AN UPDATE *

EMILE A. HYMAN, ALOIS PIVEC

Reprinted from Proceedings of the 14th Intersociety Energy Conversion Engineering Conference

THE BATTERY ENERGY STORAGE TEST (BEST) FACILITY: TEST PROGRAMS AND DATA PROCESSING - AN UPDATE

EMILE A. HYMAN, ALOIS PIVEC

Public Service Electric and Gas Co., Newark, NJ

ABSTRACT

The Battery Energy Storage Test (BEST) Facility is a Department of Energy (DOE), Electric Power Research Institute (EPRI) and Public Service Electric and Gas Co. (PSE&G) co-funded facility serving technology developers, electric utilities and the project sponsors in their mutual desire to commercialize effective battery energy storage technologies. Impartial testing of battery energy storage systems in an utility environment provides a focus for development of and a means for assessing the acceptability of new technologies.

A set of Test Program Guidelines is now under development at PSE&G with advice from user groups representing utilities and developers.* Highlights of proposed guidelines for development, prototype and mini-demonstration test services are presented. Data acquired from sensors implanted in the battery systems will reside in an off-line data processing computer. Authorized data users, including battery developers, PSE&G and DOE/EPRI personnel at their home locations, will appear to have terminal access to a 'personal' computer selectively accessing the test data through powerful query and presentation languages.

INTRODUCTION

The Battery Energy Storage Test (BEST) Facility is a Department of Energy (DOE), Public Service Electric and Gas Co. (PSE&G), and Electric Power Research Institute (EPRI) co-funded facility serving energy technology developers, electric utilities and the project sponsors in their mutual desire to commercialize effective battery energy storage technologies. The primary objective of the BEST Facility is the impartial testing of battery energy storage systems in an utility environment. Such testing forms a focus for development and a means for assessing acceptability of new technologies. Recent project updates (1,2,3) have dealt with facility design and electrical systems. The BEST Facility is now under construction and scheduled for completion and acceptance testing in mid-1980. This paper discusses the development of test programs and data processing.

TEST PROGRAM

A general test program concept was initially set forth in the reports of the BEST Facility Project Team (4,5). That concept called for testing of 1-2 MW, 5-10 mWh prototype modules of commercial energy storage batteries. Scheduled tests were to include cycling in projected utility use-modes and staging of stresses which, though normal to the utility environment, may not naturally occur during the planned test period. Objectives of the prototype testing service as presently conceived include successful operation in the first 15% of projected life, performance assessment, demonstration of developer's understanding of his product, and compilation of an information base including:

- Capacity, efficiency, and responsiveness.
- Ease of control.
- Capability to withstand faults, power system transients, and other severe operating conditions.
- Safety and environmental acceptability.
- Availability.
- Forced shutdowns: types, frequencies, associated events, probable causes.
- Changes in performance during testing; effects of changes.
- Effectiveness of commercially practicable diagnostic procedures.
- Shipping, installation, operation, maintenance and repair requirements, effectiveness, and cost.
- Reliability projections.
- Effectiveness of quality control procedures.
- Determination of component operating environment as a basis for life-testing.

Coordination meetings held with the battery developers have identified a requirement for two other services which will be offered by the BEST Facility:

- Development testing: A test bed for the use of developers in obtaining information to advance systems development.
- Mini-demonstration: Similar to prototype testing, but with increased emphasis on realism and on communication with potential customers.

A set of Test Program Guidelines is now under development at PSE&G with the advice of user groups representing utilities and developers. These guidelines will establish a uniform framework of requirements for test plans to be submitted by the equipment developers. The guidelines discuss objectives, qualifications, instrumentation, test schedules, operation, control, maintenance, data dissemination and reports. The main features of the

* This paper contains plans which are under review by battery and power conversion equipment developers meeting as a BEST Facility Developer Users Group which may be modified as a result of recommendations by this group.

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three battery test programs are summarized in Table 1.*

PROTOTYPE TESTING

Objectives: Objectives of prototype testing have been described, above.

Hardware to be Tested: The battery tested will consist of one or more 'super-modules' for a commercially marketable battery system together with an appropriate intelligent controller for battery system operation under supervision of the BEST Facility process control computer which will simulate a load dispatcher. Materials, construction and fabrications of the battery system tested will be representative of a potentially marketable technology according to cost and projected performance criteria established by the Facility Batteries Group.(6)

Instrumentation: Sensors will be provided by the developer which are sufficient to achieve the following purposes when used in conjunction with appropriate BEST Facility systems for data acquisition and processing:

1) Assure safe operation of the battery energy storage system and Facility.
2) Measure and verify expected operation of the battery energy storage system.
3) Document control actions.
4) Provide an information base concerning functioning of components within the system.
5) Localize malfunctions within the battery assembly and provide a sequence of events history prior to malfunction.
6) Document compliances with applicable environmental regulations.

Testing: Figure 1, opposite, shows a recommended test schedule for prototype testing. The schedule, calling for 300 charge/discharge cycles over an estimated 18-month period, provides a testing basis for fulfilling the program objectives. Following startup and verification, three application tests periods containing five repeated groups of tests exercise the battery in simulated utility modes over a period spanning the test program. A "staged utility conditions" experiment tests system resistance to stresses of the utility environment.

An "applications tests group" consists of cycles typical of projected utility dispatch modes (applications). Applications and their associated tests are selected by the battery developer from a 'menu' assembled in close cooperation with the utility industry. For example, one of the dispatch modes listed (and mandatory) is a five-hour constant-power discharge for peaking, with a seven-hour constant-power recharge. Selection of this dispatch mode leads to three weeks of testing incorporating variations in loading pattern such as partial and split discharges. These correspond to projected duty in various regions of the U.S. and during various seasons of the year. Other, more complex, (optional) dispatch modes will incorporate additional functions (4,5) such as area-requirement regulation, spinning reserve operation or load-following. The initial and final weeks of the applications tests group are identical, consisting of cycles most typical of the battery's intended use, labeled 'design cycle' in Figure 1. The entire 40-cycle applications group of test cycles selected by the developer is repeated identically five times during testing for a total of 200 cycles, comprising two-thirds of the schedule shown in Figure 1.

The series of repeated application groups tests is interrupted following the third such group by staged utility conditions tests. The objective of these tests is to verify battery ability to withstand various conditions which may be present in the utility environment but may not otherwise be part of the BEST Facility environment. Staged tests include prolonged idle stand, performance limits, transients, staged faults and credible accidents. Staged testing is scheduled during five periods between cycles 161 and 220. Tests are staged during or between 'design' cycles (defined above). A week of 'evaluation' cycling follows each staged test period consisting of a set series of five cycles representative of operations included in the applications groups. The evaluation cycles check the functional performance of the battery following each period of staged testing. More detailed evaluation of the total effect of staged testing will be obtained by comparing performance in the last applications tests period with that of the period preceding staged testing.

The staged testing group includes two innovations compared with the applications tests groups:

1) Staged testing itself.
2) The weekly alternation between design cycles and evaluation cycles during the staged testing period; this represents a change in cycling duty from that during the applications tests groups.

If major changes in battery performance appear following staged testing, these might be attributed to either the staged testing or to the change in cycling regime. A control group of cycles, alternating weeks of design and evaluation cycles, is therefore provided prior to the staged testing period in cycles 101 through 120. These are followed by an applications test period which serves to evaluate their effect, followed only then by the staged testing period.

Reports: The BEST Facility Staff will be responsible for data reporting and for interpretive reporting of battery system performance. The battery developer will be responsible for interpretive reporting useful to future battery system development. BEST Facility reports will include:

- A monthly data summary.
- Background and interpretive topical reports.
- A final report summarizing information gained during testing, including installation, operations and maintenance, will be issued following testing and will be supported by retrospective data analysis as appropriate. The final report will be reviewed by the battery developer and EPRI/DOE project management prior to issue.

The reporting described above is supplemented by electronically disseminated daily and historical reports and interactively accessible data bases described under 'data processing'.

*Converter testing programs are now under development. These programs are not included in this paper.

	DEVELOPMENT TESTING	PROTOTYPE TESTING	MINI-DEMONSTRATION TESTING
OBJECTIVES	TEST BED TO VERIFY SYSTEM DESIGN CONCEPTS	ASSESS PERFORMANCE IN UTILITY ENVIRONMENT	REALISTIC FIELD OPERATING EXPERIENCE; SHOWCASE
HARDWARE	PRE-PROTOTYPE > 500 KWHRS	PROTOTYPE COMMERCIAL: 5 TO 10 MWHRS	COMMERCIAL: 5 TO 10 MWHRS.
INSTRUMENTATION	SPECIAL PURPOSE	CAREFUL MONITORING	COMMERCIAL LEVEL + ADDITONAL AS REQUIRED
TESTING	DEVELOPER DEVISED PROCEDURES	UTILITY-ORIENTED EVALUATIVE TESTING	SIMULATED COMMERCIAL OPERATION
REPORT DISSEMINATON	SAME BASIS AS SUPPORTED IN-HOUSE TESTING	DEVELOPER TO ADVISE ON APPROPRIATE LEVEL OF PUBLICITY	FULLY PUBLICIZED

TABLE 1: OUTLINE OF BEST FACILITY TEST SERVICES

S = Startup & Verification
A = Applications Group
D = Design Cycle Test
E = Evaluation Test
SC = Control for Staged Testing

STAGED UTILITY CONDITIONS GROUP
U_1 = 1 Month Idle Stand
U_{2-5} = Performance Limits, Transients, Staged Faults, Credible Accidents

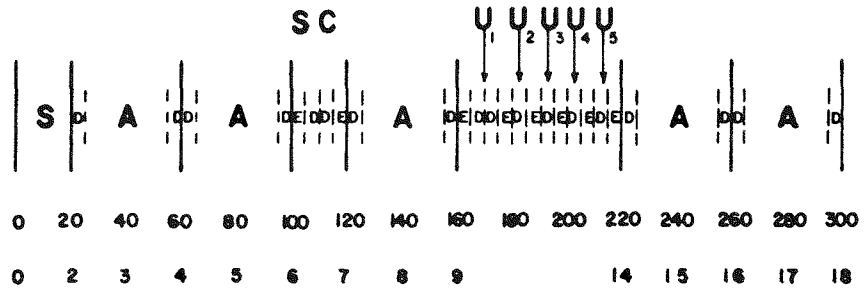

FIGURE 1: RECOMMENDED TEST SCHEDULE FOR PROTOTYPE TESTING

Dissemination of reports, other than the final report, will be on the same basis as that currently used for reports of development or testing done by the developer at his own facilities when funded or partially funded by EPRI and DOE, with the exception that the BEST Facility staff will be included among recipients. Dissemination of final reports will be at the discretion of DOE/EPRI project management with the advice of the equipment developer and with a view to the perceived best interest of the battery energy storage commercialization effort.

DEVELOPMENT TESTING

OBJECTIVES: Development testing provides the battery developer with a test bed for experimentation designed to verify basic system design concepts and to develop a technical information base needed for completion of system design. Batteries may be brought to the BEST Facility explicitly for this purpose, or may be diverted to this purpose from prototype testing by mutual agreement of the developer and project management. Development testing directly serves both battery developers and project management.

Hardware To Be Tested: Battery components should be of a design and using materials projected for commercial operation and should have been tested individually prior to BEST Facility operation. Assemblies, sized to at least 500 kWh, may be experimental versions of a projected commercial supermodule, modified to permit testing of a subportion of a supermodule; or, to facilitate disassembly and modification; or, to facilitate special diagnostic tests to be performed. It is preferred that a controller and status interface for internal battery functions be supplied as well as any special auxiliaries (scrubber, etc.) required for safety.

Instrumentation: Instrumentation will be designed and installed by the battery developer sufficient to fulfill his testing objectives. Sensors will be provided which are at least sufficient to achieve the following purposes when used in conjunction with appropriate BEST Facility systems for data acquisition and processing:

(1) Assure safe operation of the battery, battery system and facility.

(2) Document control actions and compliance with applicable environmental regulations.

Testing: Development testing is designed by the developer to meet his information needs consistent with BEST Facility capabilities. An initial startup period will be required to establish baseline performance and conformity to Facility interface requirements.

Reports: Interpretive and final test reports will be the responsibility of the battery developer and/or EPRI/DOE participating consultants. The BEST Facility staff will provide weekly data summaries, monthly progress reports, and a final data summary report in addition to data displays available from the BEST Facility Test Data Processor via graphics terminals. Report dissemination shall be on the same basis as that currently used for reports of testing done by the developer at his own facilities when funded or partially funded by EPRI and DOE, with the exception that the BEST Facility Staff will be included among recipients.

MINI-DEMONSTRATION TESTING

Program Objectives

1) To obtain field operating experience with complete supermodules of commercializable energy storage systems.

2) To assess instrumentation, controls, environmental withstand and operating performance when operating in a manner identical to commercial operation.

3) To serve as a "showcase" for exposure of utility personnel to operation of the battery energy storage system.

4) To assemble information similar to that listed for prototype testing.

5) To serve as a test bed for extended testing, as appropriate.

Hardware to be Tested: The battery shall be one or more modules of a system suitable for economic manufacture together with a complete control and safety system, also suitable for commercial manufacture. Evidence from testing concerning the suitability and safety of the battery shall be provided.

Instrumentation: The level of instrumentation will depend on the degree of experience previously obtained with modules of the size to be demonstrated. The minimum is that which would be provided with a commercially marketed module. The maximum is that described for prototype testing.

Testing: Testing will be similar to prototype testing described above.

Reports: The BEST Facility Staff will be responsible for data reporting and interpretive reporting of battery system performance. The battery developer will be responsible for interpretive reporting useful to future battery system development. Notification of the existence of a demonstration and the availability of select reports will appear in appropriate form in DOE/EPRI literature or mailings.

Utility Coordination Program: The BEST Facility will make its facilities available for activities designed to expose utility personnel to the systems under test. These activities can include:

- Invitations of utility representatives to program review meetings;
- Tours;
- Demonstrations of systems operation;
- Production of documentary slides or movies.

DATA PROCESSING

Data processing comprises:

1) Acquisition, monitoring, checking, display and recording of data from sensors implanted within components of each battery system in real time, available at the BEST Facility site.

2) Storage, characterization, retrieval, summarization, and display of recorded data retrospectively off-line at the BEST Facility and at remote locations.

The data acquisition, monitoring, checking, display and recording reside in the BEST Facility Monitor and Control System. The remaining functions reside in an off-line data processing computer system distinct from the Facility Monitor and Control System, called the BEST Facility Test Data Processor. An overview of the BEST Facility Data Processing Systems is shown in Figure 2.

Data Monitoring: The Facility Monitor and Control System (FMCS) will sample each of the sensors implanted in the operating hardware at repetition rates from once each one second to once each sixty seconds, depending on the sensor. Higher sampling rates may be supplied for a small number of selected sensors. The FMCS computer will process the sampled information and classify component status as a basis for operating decisions. The status of all sensors is displayed via color-coding on color video 'alarm status' displays located in the control room and the battery developer's data analysis room. The displays takes the form of a diagram of the battery system with color-coded component status squares in appropriate locations. A list of acknowledged and unacknowledged alarms is maintained. Alarms may be acknowledged and further information called up by means of a light pen applied to the sensor component status square. Criteria for alarm status, based on sensor information, may take into account limits, moving averages or sensor validity status indications. Criteria will be proposed by the developer in his test plan.

Digital Data Recording: Data recording refers to the preservation of a portion of the data which has been sampled and checked on-line as a permanent record for off-line analysis and is performed by the FMCS. All data sensors are recorded at a frequency determined prior to each cycle, with repetition rates higher during operation.* A typical pattern might be: half-hour readings during idle stand and 6-minute readings during 5-hour discharge and 7-hour charge, including the 1/2 hour following termination of charge or discharge. The measurements recorded per sensor each cycle are called 'normal' data. Sensor data from the sensor array within the battery system are recorded in as nearly simultaneous fashion as the hardware will allow (snapshotting).

A sensor in 'alarm' status is recorded during additional times. An additional recording is then initiated whenever the sensor reading value has changed by given amount compared with the last recorded value. Such data is called 'fast' data. Certain key sensors such as those measuring string current will produce 'fast' recorded data even if the sensor is not in alarm status. These sensors produce 'fast' data whenever the sensor value (string current, for example) has changed by an amount greater than a pre-specified amount since its last recorded reading.

* Note that data recording rates are far slower than data sampling rates above.

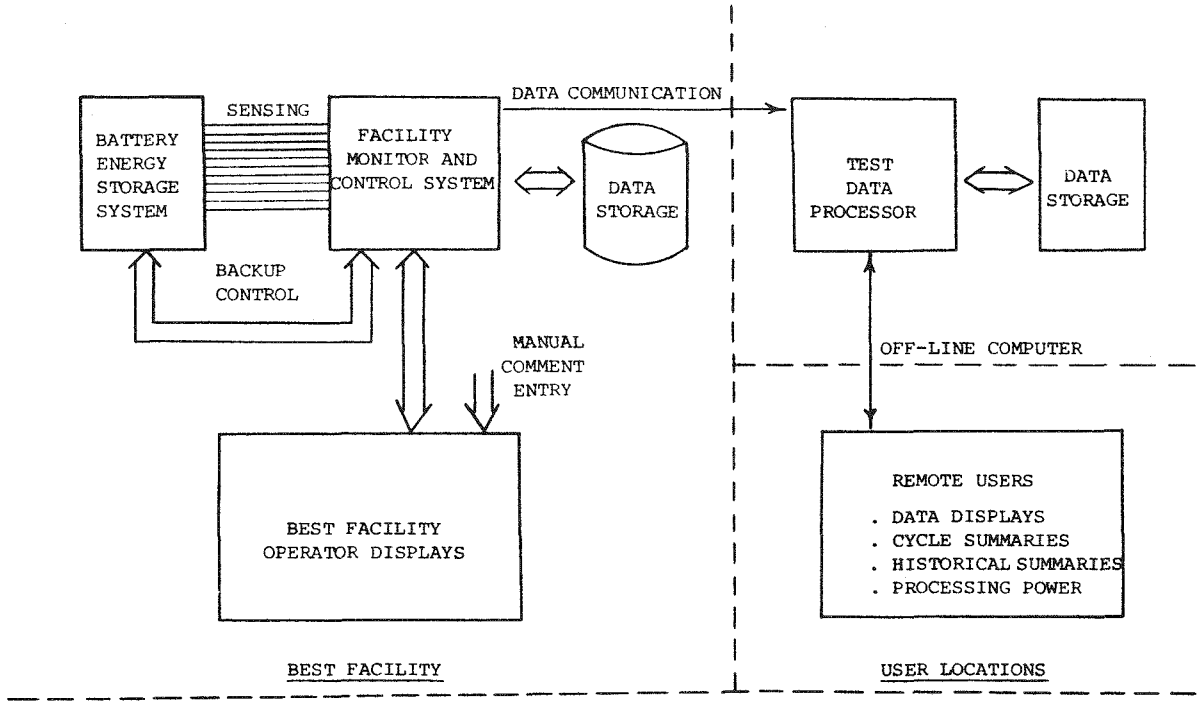

FIGURE 2 - BEST FACILITY DATA SYSTEMS

Analogue Data Recording: A multi-channel, triggered fast oscillograph with pre-fault memory will be deployed to record faults and transient events requiring recorder response in the 0-1000 Hz range. Transients incorporating higher frequencies may be recorded using oscilloscopes or other fast-response instrumentation as part of special investigations. Various triggers will be provided. The oscillograph will provide voltage, current and control sequence traces from key system points and for a sample of sub-components. The triggering of the oscillograph will result in an entry in the test log maintained by the off-line data processing computer, see below. Oscillographic records will be stored as part of the test record.

Slower analogue instruments (strip-chart recorders) will be provided as backup instrumentation to record steady-state parameters such as bus current, voltage and power.

Computerized Test Log: A computerized test log resides in the off-line test-data processor based on automatic entries originating from the Facility Monitor and Control System and on manual terminal entries originating from BEST Facility staff or other authorized personnel. Test log entries consist of formatted text statements together with retrieval keys identifying the time, date, source of entry and nature of the comment made. Information entered includes, Monitor and Control System alarms, operating and control actions, maintenance information and retrospective data interpretations.

Test Data Processor: The BEST Facility Test Data Processor (TDP) consists of an off-line computer distinct from the FMCS with massive on-line data storage capability (disc packs), a time-sharing operating system, and data communications facilities. Test data is batch-transmitted from the Facility Monitor and Control System to the TDP for processing and storage. Authorized BEST Facility program participants (BEST Facility staff, developers, DOE, EPRI and their consultants) may access the TDP using data or graphics terminals linked through telephone dial-ups from their home locations coast-to-coast. Each participant will have access only to information to which he is entitled (selective password protection) and will appear to be operating a virtual computer, dedicated to servicing his data access and processing needs.

Services Available: The following services will be available to TDP users:

- Retrieval and display of test data, test data characterizations and the test log.
- Cycle Summary.
- Historical Summary
- Processing of data using a virtual dedicated computer made available by the TDP operating system.

Virtual Computer: The BEST Facility data user appears to address a 'personal' computer, consisting of processing facilities and disc storage partitions of the TDP Figure 3. The user accesses data residing in BEST Facility data bases from a terminal at his home location. Data access is selective, that is, data records pertaining to a given test program form separate disc partitions and are available only to users having the required passwords. Data access is facilitated by a library of BEST Facility macros, subprograms, each of which are invoked by the user's entry of a single English-like command including within it provisions for specifying options. For example, the command 'PLOT Capacity versus Resistance for cycle 137 Discharge' would cause a scatter-plot summarizing battery submodule performance correlations to appear on a graphics terminal for which the underlined words are selected options specifying the data desired. BEST Facility macros will provide a variety of tabular and graphics displays as well as a powerful query, plotting and reporting language allowing the user to form customized displays. Instructions for customized displays, including any of the BEST Facility macros or user routines in any of the common source languages, may be assembled by the user into command files (user macros) and stored for re-use. Hard copy devices for display (plotters and electrostatic printers) will enable the user to create tables and figures for publications. Program development, extract of data to files and processing of user's applications programs is available to the user through his virtual computer. Data may also be transmitted to an authorized user as computer media for use with other computer facilities.

Data Bases: Processing leading to creation of the BEST Facility data bases is illustrated in Figure 4. Data bases to be implemented include

- System test data.
- Component test data.
- The test log.
- Exception data.
- Data characterizations.

System test data is a subset of the test data describing external behaviors of the various major subsystems (battery string voltages and currents, for example); component test data is its complement, the remaining test data describing behavior

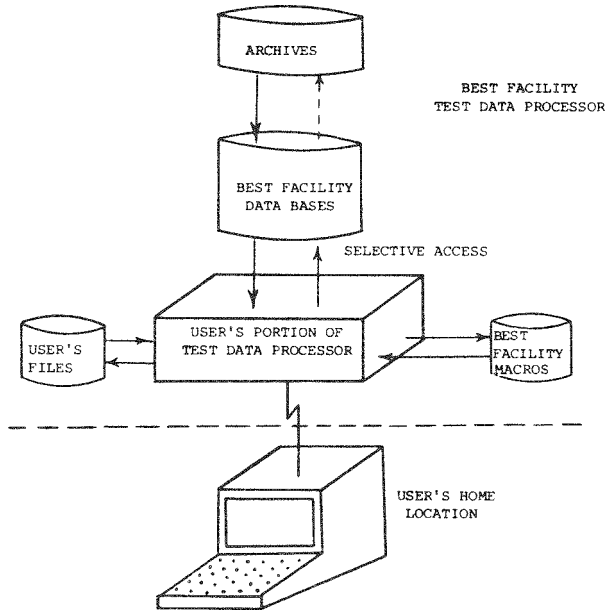

FIGURE 3: BEST FACILITY DATA USER'S 'PERSONAL' COMPUTER SYSTEM

of internal components. Test data and the test log are normally updated twice daily, following each charge or discharge, from data recorded by the BEST Facility Monitor and Control System. If required for consultation, an emergency data transfer from the monitor and control systems to the TDP will make the most recent data available to users within minutes of request. Data characterizations comprise results of data processing which characterize the time series test data, for example, initial, average and final voltage, results of curve-fitting procedures, efficiencies, etc., constituting an abbreviated data set. Characterizations will be individual to the systems tested and include calculations specified by the developer. Exception data is an extract of test data which has been computer-identified as unusual during data characterization.

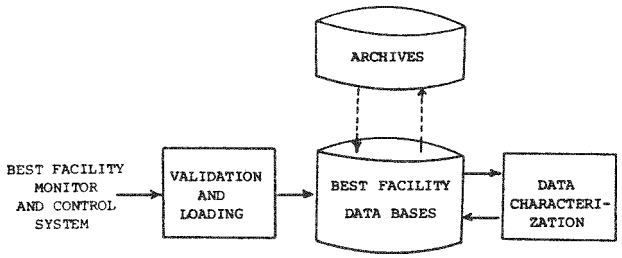

FIGURE 4: BEST FACILITY DATA BASE CREATION

All recent data (for several weeks prior to the current date) is maintained on-line. All data other than 'old' component test data is also maintained on-line. Component test data more than several weeks old may be off-loaded to de-mountable disc-packs for archiving. Extracts may be made from this archive for use on-line upon request from the user's terminal and will usually become available within a fraction of an hour.

Cycle Summary: The cycle summary is a set of tabular and graphics displays summarizing operation during one full charge and discharge cycle of a battery energy storage system or of selected portions of that system. Usually, but not always, the summary is used to obtain information about the most recent operation of the system tested. The displays are assembled by BEST Facility macros from data resident in BEST Facility data bases accessible to the data user. Displays may be accessed individually or selectively assembled into a batch report. Displays fall into four general categories:

- Systems overviews: summaries of system data (power profile, efficiency, depth of discharge, etc).
- Test logs: Displays amounting to a log-book of operation during the cycle.
- Component summaries: Statistics and graphics describing variability in component performance.
- Exception reporting: Identification of components showing exceptional behavior and information relating to the nature of the abnormality.

Historical Summary: Like the cycle summary, a set of user-selectable display macros based on BEST Facility data bases reporting historical (cycle-by-cycle) trends of significant parameters will be available.

CONCLUSION

The test programs and facilities for data processing, now under design in intimate dialogue with utilties, battery developers and the sponsoring agencies, will contribute to the BEST Facility mission of facilitating commercialization of battery energy storage technology to the mutual benefit of the facility users.

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6. The Facility Batteries Group is an EPRI ad-hoc Committee which recommends Facility entrance qualification criteria and also recommends acceptance of particular batteries for testing A paper, "Recommended Criteria for BEST Facility Batteries", appears in EPRI Report WS77-1, April 1977, titled "The BEST Facility Workshop II".

7. Descriptions of data characterizations will be found in a BEST Facility Report "Functional Description of the BEST Facility Test Data Processor" (Now in draft form and to be finalized prior to publication of this paper - a reference will be supplied).