IMPORTANT CONCEPTS IN THE ASSEMBLY AND EARLY CHARACTERIZATION OF THE PBFA II ACCELERATOR*

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Summary

Planning and efficient execution of the assembly and early characterization phases of a large, multi-module superpower generator like PBFA II require development of concepts frequently not found in either the pulsed power R&D community or in the pulsed power industry. To meet the constraints of performance, cost, and schedule of the PBFA II Project, special skills for assembly and characterization of large facilities are being established. These likely will become the technology for activating Sandia's future large accelerators.

Some of the concepts for orchestrating large numbers of events associated with accelerator assembly and characterization include:

* structuring of activity into smaller workable and trackable packages, with associated subelements assigned to each section of the accelerator.
* establishing detailed assembly and characterization documentation to assist in component testing and subsystem integration.
* structuring the project team for efficient communication, identification of responsibility, and capability for problem and conflict resolution.
* developing technologies for receival, inventory, controlled storage, staging, and phased installation and testing of components and pieceparts.

The application of these and other concepts to PBFA II, and the progress of accelerator assembly will be discussed.

Introduction

Successful assembly and effective early use of PBFA II [1], a large, multi-module super power generator, require development and application of concepts other than those typically used on smaller facilities. Some of the unique features of PBFA II are as follows:

Magnitude of the Coordination Problem

The assembly and test activity leading to the first PBFA II shot requires the combined efforts of approximately 95 people in various areas of pulsed power research, engineering, and implementation. About $23M worth of pieceparts and subassemblies occupying 150Kft^3 must be procured, received on-site, staged, and assembled into the facility following proper sequences and detailed procedures. Labor costs alone for assembly are projected to run as high as $1.7M (42 man-years). Clearly, the coordination and communication problems associated with this effort are formidable, and special efforts have to be made to address them.

PBFA II Project Environment

The resource requirements for fielding PBFA II necessitate the formation of a Project Team to control the myriad of activities to be executed. Since PBFA II is a major DOE Project over $50M in total cost [2], the constraints of technical performance, cost, and schedule become very visible and must be adhered to. Success will require that all three be mutually met which sometimes is not rigorously required for smaller facilities.

Matrix-Mode Formalism

The distributed responsibility involved in the PBFA II Project matrix-mode of management limits the ability of a single individual or group to control all the assembly and testing activity. A formalism must be established to identify interfaces, to generate and to distribute information and documentation to a large group, and to provide configuration management control as changes arise during the assembly process. This formalism may not be needed for smaller or shorter term endeavors.

Phased Approach to the PBFA II Program

The end goal of the PBFA II Program, to ignite a pellet driven by light ion beams in the laboratory, cannot be met solely with construction resources. A phased approach to PBFA II implementation therefore has been taken, with Construction, Accelerator Characterization, Ion Source Development, and Target Campaign efforts occurring during a 1980 to 1988 timeframe. Within each phase, activities must be prioritized so that those most critical to the deliverables and milestones of that phase are met before resources are exhausted. An assembly/test philosophy therefore must be developed which matches the need for these priorities.

Proper and adequate planning, implementation, and facility characterization during the engineering process of PBFA II, as detailed below, will enhance the probability of this facility meeting its end goal.

Planning Strategies

Activity Structuring

An important element in planning PBFA II assembly and characterization is structuring the ensemble of activity into smaller workable and trackable packages. The project work breakdown structure and differing areas of pulsed power and electromechanical technologies led to a logical division of the work into five separate sections: facility systems, support systems, and accelerator structure; energy storage section; pulse forming section; front end section and experimenter subsystems; and control/monitor (C/M) and data acquisition (DAS) systems. Details of these sections and their technologies are outlined in Table 1.

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*This work was supported by the U. S. Department of Energy under contract DE-AC04-76DP00789.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 1985**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Important Concepts In The Assembly And Early Characterization Of The Pbfa II Accelerator**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Sandia National Laboratories Albuquerque, NM 87185**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002371. 2013 IEEE Pulsed Power Conference, Digest of Technical Papers 1976-2013, and Abstracts of the 2013 IEEE International Conference on Plasma Science. Held in San Francisco, CA on 16-21 June 2013. U.S. Government or Federal Purpose Rights License.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

An individual was identified for each of the above five sections who had prior experience both in that particular technology (e.g. Marx generators, triggered gas switches, vacuum systems, digital instrumentation) and in the operation, assembly, and maintenance of large accelerators. These individuals were appointed Work Package Managers (WPM's) for five assembly/test work packages whose scope of work included:

- * Planning - establish a schedule for development of detailed assembly and test plans for all appropriate support subsystems and acquire initial drafts for all plans, including resource needs for implementation.
- * Integration - iterate initial plan drafts as more detailed design information becomes available and mesh all plans into an integrated facility assembly/test plan which will address issues necessary for meeting performance, schedule, and cost criteria.
- * Crew Formation - acquire the necessary mix of labor to implement both assembly and test activity.
- * Documentation - present final draft of plan to Project Team for review.
- * Implementation - carry out the integrated assembly and test plan.

An Assembly/Test Team was formed which was comprised of: the five WPM's; a Test Integrator in charge of global planning, philosophy, execution, and daily coordination of efforts; the Functional Representative from Pulsed Power Operations on the Project Team; and as a consultant, the Systems Integration Manager from the Central Project Office.

Collecting and Documenting Criteria

The five Assembly/Test WPM's solicited inputs from other WPM's who had accountability for designing the various components and subsystems of the PBFA II facility. Formats were established to aid research and engineering staff in the process required to successfully think through sequences of events for their components and systems to be properly installed, separately tested, and integrated with all other requisite systems. For the assembly plan, the format included topics such as assembly procedures, interface criteria, safety, floorspace and manpower needs, schedules, and support documentation. For the test plan, the format included items on calibration, testing procedures, interface criteria, manpower needs, schedules, and support documentation.

Of particular importance during this phase were requests for resources of manpower, space, and time, since acquisition and training of the labor force, establishment of suitable storage and workspace, and scheduling of activity logic and sequences would have to be planned in advance frequently with significant lead times (e.g. 1 year or more).

To generate this information as easily as possible, the initial criteria inputs were requested as separate submittals which did not consider the priority of requests, were not dependent on integration with other requests, and utilized time-independent schedules, i.e., durations but not specific dates.

Iterating Information to Generate an Integrated Plan

After digesting initial inputs, the Assembly/Test Team reformatted input information to include the constraints of priority, interfacing requirements, delivery schedules, and manpower availability. Each of the five section inputs to an integrated plan were prepared by first incorporating only those requests absolutely necessary to be honored in order to execute the first 36 module accelerator shot into a diode load within the project cost and schedule constraints (Priority 1), and then including additional needs which would be desirable to satisfy (Priority 2).

In general, the integrated assembly/test plan is based on a philosophy of assigning the highest priority to assembly activity to ensure that all hardware installation and interfacing is completed in time for an initial shot of the entire accelerator on the first date of the readiness period, i.e., December 1, 1985, at the potential expense of high voltage testing and characterization of components and subsystems. This approach, while ensuring the complete assembly of the facility in time for the first milestone shot, may result in greater technical risk for Phase 2 of the PBFA II Program in that the program may have to forego most characterization of the facility until after a first shot.

The plan in general recommends the narrowing in scope of some of the submitted subsystem test plans to accomplish Priority 1 testing first, and then to consider what Priority 2 testing might be affordable.

The integrated plan is not intended to be a finalized detailed description of all assembly and testing activity but rather a logical, time-phased sequence of events leading to the first full accelerator shot with minimum technical and schedule risk. Progress is tracked via computer-generated schedules, and changes in logic and strategy are updated regularly as developments arise. As assembly and testing progresses, the mechanism for acquiring more details for the plan is to hold a series of test phase fielding sequence meetings, commencing four weeks prior to the start of a major test series, when specific commitments to a scope of work, resource needs, and test durations will be made.

Implementation Strategies

Structuring the Project Team for Assembly/Test - Mode Operation

A detailed structure for the project team was established to define clear cut lines of authority and responsibility and to provide methods for effective communication, problem solving, and conflict resolution. Personnel involved in testing are assigned to positions on initiating and responding teams, as illustrated in Figure 1. The terminology for these team positions are described in Table 2.

There are several purposes for providing a more detailed structure for these teams. One is to minimize the number of cracks through which items can fall. This can be done by identifying somewhat generic job functions which typically must be performed during subsystem tests, and then ensuring that a person is appointed to act as a recognized information source/single point contact for these functions during each test.

A second purpose is to provide an orderly mechanism for supporting concurrent testing and assembly activities and for conducting simultaneous tests of separate systems likely to occur in a multiple shift mode.

A third is to provide a stable structure during Phase 1 so that continuity is preserved, a corporate memory for testing and operation is built up, and retraining personnel is not required for each new subsystem undergoing test. A fourth is to provide a smooth transition between Phase 1 and Phase 2 facility operations.

The Functional Representative (FR) for each Work Package requiring component, subsystem, or participation in integrated system testing is responsible for identifying a Shot Coordinator (SC) for each test who will provide interpretation of detailed test specifications and will recommend specific subsystem parameter settings, for reviewing and interpreting measured data, for comparing results with expected values and documenting the findings, and for participating in defining the next step in the subsystem test sequence.

For integrated system testing involving multiple work packages which are the responsibility of more than one FR, a single Phase 1 Test Integrator (TI) will be appointed to direct the overall test. Through the total testing period of Phase 1 there will only be one person who functions in this position in order to preserve continuity and momentum. This person will be appointed by and report directly to the Operations FR, and will carry out his duties under the Assembly and Test Work Packages.

One or more Diagnostics Coordinators (DC) and Shot Coordinators will be appointed in advance of the test by the accountable FR to support and advise the Test Integrator in detailed setup for these tests.

The Shot Coordinator and Diagnostics Coordinator will receive general instructions from the Test Integrator and other individuals deemed necessary by the accountable Functional Representative(s). The SC's and DC's prime responsibility is to see that the necessary steps are taken to have the shot configured appropriately, and, in conjunction with the Facility Supervisor (FS), to estimate time requirements. The TI must ensure that the initiating team members get their part of the test preparation completed at the appropriate time and should inform the Facility Supervisor(s) of status on a timely basis. The FS must ensure that the responding team members get their part of the test preparation completed at the appropriate time and should inform the TI of status on a timely basis.

Utilizing Special Technologies

The large number of components and pieceparts per module, the large number of modules, and the number of complex support subsystems mandated establishing some special technologies and procedures for controlling the assembly and test process.

One of these included methods for receival, storage, inventory, and on-site inspection of accelerator parts and subassemblies. Since storage and installation criteria were collected during the final design phase of many components, then packaging, shipping, and schedule requirements could be included during the procurement cycle to minimize receival and storage problems. Warehousing space was acquired and prioritized according to criteria such as temperature, humidity, sun exposure, cleanliness, and material security. Storage technologies used consisted of areas in the highbay laboratory next to the accelerator, an array of 15' x 20' metal storage sheds, a 60' x 100' air-inflatable storage building, and fenced-in open storage. Upon arrival, in addition to a formal quality control methodology [3], critical fitups with mating components and certain tolerance checks on each of hundreds of parts in a production run were performed using either real components or alignment fixtures. Inventory control was achieved by securing all storage locations and by logging out components from a master inventory database when items were removed for installation.

A second technology was the staging and preassembly of pieceparts on a time-available basis prior to the main assembly periods. Staging is the process whereby all required nuts, bolts, washers, fabricated hardware, supplies, and procedures sufficient to assemble one "unit" of hardware are collected together in a specific location. The unit may be a single component such as a gas switch or a complex module such as a complete Marx generator. Preassembly is the act of joining subcomponents together which do not require special tools or careful alignment in order to store the staged units more conveniently and to save time during the on-line assembly process.

A third technology used was assembly line procedures which, although not new to industry, have not been used extensively in the pulsed power R&D community. Handling fixtures, motive equipment, alignment jigs, and specialized tools were designed to aid in the rapid and efficient assembly of both small components and large modules. Assembly lines were tailored to the individual needs of various components, with safety and ergonomic considerations being included to minimize time and personnel required to complete the job. By thinking through assembly considerations, accurate forecasts of the duration and manpower requirements could be made. For example, assembly of the entire 36 Marx generator ensemble was predicted to take 2 1/2 to 3 people a total of 130 working days; the actual requirement totaled 140 days.

Assembly and Test Approach

Major Decision Points and Philosophy

A wide variety of integrated assembly and test plans could be written to accomplish the work required to complete accelerator implementation. When constraints of manpower, component delivery schedules, activity dependencies, and final completion date are considered, the number of viable options is narrowed considerably. Figure 2 presents a sample of one such sequence of events which the PBFA II Project has chosen to pursue. This sequence should successfully lead to a full 36 module shot no later than the end of January, 1986.

The basic implementation philosophy has been to design, assemble, and test the accelerator starting at the outermost sections and progressing radially inward, since the pulsed power technologies used in the outer sections were more well known and less research oriented. An attempt was made to install many utilities (e.g. transformer oil, deionized water, insulating gas, electric power, compressed air) early to support the assembly and test of all sections of the accelerator.

Some of the major decision points and milestones leading to the first accelerator shot are as follows.

Overall Plan: Two high voltage testing "time windows" appear to be available for Marx generator and triggered gas switch testing. If hardware delays or manpower constraints result in the Project missing the first window, tests for both subsystems still can be performed during the second, just prior to the start of the readiness period.

Energy Storage Section (ESS): The expected late operational date of the SF_6 gas system resulted in a recommendation to postpone any major 36 module high voltage tests of the ESS until that system is ready and a decision to pursue a back-up installation which would prevent the main system from extending the first shot critical path. The 9/1/85 stop date for ESS testing is necessary to allow the vacuum stack/center section and the remainder of the water section to be installed by December.

Pulse Forming Section: The same dates noted above bracket the triggered gas switch test window. In addition, the first week or two of this window is necessary to bring up the ESS. A major decision will have to be made on 9/1/85 if testing is not completed. Depending on hardware delivery and specific subsystem testing progress, compromises will have to be made between gathering additional data or proceeding with assembly of the remainder of the accelerator.

Center Section: Installation of the vacuum stack in the tank may be mutually exclusive with water section filling until the stack is complete, leak checked, and compressed to stabilize radial stresses. The decision to begin stack installation is a major one. Should, for some reason, vacuum testing of the stack once it is installed be significantly delayed, a decision might be made to install power flow convolutes in an untested stack with the hope that the stack will not leak once tested. This is risky and could jeopardize the first shot.

The duration of installation, alignment, and interfacing of the convolutes, diode, plasma opening switch, and Lithium ion source is not accurately known at this time. Adequate time must be reserved to accomodate this installation and iron out integration problems.

Facilities: Installation of oil and water systems appears to be far enough along to support the first shot without remote C/M operation. If the gas system, however, should slip much past 8/1/85, possible consequences could be: (1) pushing the first test window into September, (2) pushing the second window into November/December, or (3) eliminating high voltage testing altogether prior to the first shot.

C/M-DAS: Unknowns in the DAS and C/M systems include turn-around times for testing, instrumentation system bring-up, and potential software support problems. While data acquisition will be possible, degraded data analysis capability may require longer than desirable turnaround time between test shots. The largest C/M problems appear to be the need for further detailed information to support remote subsystem operation and late arrival of hardware for key systems such as the Timing and Firing subsystem.

Present Status and Anticipated Progress

By May, 1985 virtually all major components and subsystems have completed their final design reviews. The latest to be completed are far enough through their procurement cycle so that production and delivery schedules are reasonably well known. The integrated assembly/test plan has gone through several iterations as a consequence of changes and slippages in delivery schedules. Alternative logic paths have been developed to accomodate these changes, and the critical path leading to the first shot appears to be readily executable by the required end date of the Project.

All major facility support subsystems with the exception of SF_6 processing have been installed and checked out, have met their design specifications, and are ready to support other subsystem testing. Additional work is required to fully interface these system with the control/monitor system so that integrated facility operation can be achieved.

All energy storage section components have been assembled and are undergoing electrical testing. Marx generators have already been certified individually at full charge voltage into dummy load resistors in a series of test tank verification shots. Charging and firing systems also have been exercised.

The pulse forming and front end sections of the accelerator are scheduled to receive the majority of their components in the summer and fall of 1985. Control/monitor and data acquisition system implementation is on schedule and sufficient to support priority 1 testing of all subsystems.

Two series of regularly scheduled meetings are held to track detailed progress during the final stages of assembly and testing. The first addresses the integration of various subsystems so that smooth interfaces in the operating and checkout procedures can be developed. The second series addresses weekly progress, problems, and plans, and is used to resolve conflicts in the Project decision making processes.

Plans for Characterization and Optimization

Early characterization of accelerator subsystems and the establishment of optimum operating parameters is scheduled to occur during Phase 2 of the PBFA II Program for a period lasting about one year after the first shot. Since Phase 1 testing generally is only sufficient to demonstrate that components work in their requisite environments (i.e. for identifying infant mortality problems), Phase 2 characterization time will be used to run subsystems through their full operating ranges and to select stable operating points which deliver peak power and energy to the diode load, with optimum powerflow symmetry and module synchronization. Typical parameters to be characterized will be:

* support system specifications (electrical, mechanical, and chemical).
* component electrical parameters (voltage, current, throughput delay and jitter).
* Single module powerflow chain parameters (forward going power and energy, coupling efficiency).
* 36-module ensemble parameters (jitter, spread, prefire rates, operating statistics, operating ranges).

General Approach and Philosophy

As with the assembly and initial testing logic, there are numerous options for a plan which characterizes accelerator subsystems. Given the constraints of budget for spares and supplies, number of data recording channels available to monitor performance, and state of development of some of the research-oriented subsystems in the accelerator front end section, the following characterization philosophy has been proposed.

After the first milestone shot, an extensive postmortem examination of subsystems and components will be conducted to locate and repair damage or make minor adjustments necessary to improve performance. A brief campaign of 36-module full power shots (i.e., perhaps 6 to 12) then will be conducted to exercise the total facility and to acquire the maximum amount of performance data in the minimum time. Component and subsystem performance which inhibits or compromises further characterization will be targeted, and workarounds or modifications will be developed if necessary to remedy these problems. A longer series of characterization experiments then will be pursued which characterizes subsystems in the order of those having highest potential for technical risk and requiring the greatest additional research and development being performed first.

With this approach any extensive development or redesign of major subsystems will be given the longest possible completion period, and during the redesign period items of lesser technical risk can be characterized in parallel.

Proposed Characterization Activity

Since the true operating status of the accelerator will not be known until the first shot is taken, characterization activities are to be scheduled by means of "priority windows", as shown in Figure 3, rather than by specific start and end dates. Experiments will be designed to exercise multiple systems in parallel; those identified in the priority windows will receive the greatest attention and resources, while lower priority system tests may be piggy-backed onto the mainline experiment. In this mode, the rate at which characterization and optimization information is generated is hoped to be maximized.

Conclusion

Rigorous planning and time-phased execution of assembly and test activities on the PBFA II Accelerator will likely result in the first shot being performed on the baseline schedule for Phase 1. By extending the same crew structure and partitioning of work into early characterization experiments, Phase 2 promises to deliver a fully operational research facility ready for beam focusing and pellet irradiation experiments in future phases of the program.

References

[1] B. N. Turman, et al., "PBFA II, A 100 TW Pulsed Power Driver for the Inertial Confinement Fusion Program", Proceedings of this conference.

[2] G. W. Barr, et al., "A Status Report on the PBFA II Construction Project", Proceedings of this conference.

[3] J. P. Furaus and G. W. Barr, "Quality Assurance Considerations for the Implementation of a Pulsed Power R&D Project", Proceedings of this conference.

Table 1. PARTITIONING OF LABOR INTO ASSEMBLY/TEST WORK SECTIONS

SECTION	COMPONENTS/SUBSYSTEMS	TECHNOLOGY AREAS
FACILITY	Transformer oil distrib. and process.	Fluid and gas process.
	Deionized water distrib. and process.	
	Insulating gas distrib. and process.	
	Pneumatic systems	Welding
	Diving air	
	Motive, lifting equipment, handling fixtures	Heavy construction
	Accelerator tankage	
	Radiation shielding	Plant Engineering
	Work platforms and personnel access	
ENERGY STORAGE	Marx generators	AC circuitry
	Marx trigger system	HV pulse techniques
	Marx high voltage charging system	
	Output transfer switches	Assy quality control
	High voltage testbed	
PULSE FORMING	Intermediate storage capacitors	Short pulse techniques
	Triggered gas switches	
	Laser trigger system	Pulse gas lasers
	Voltage conditioning network	Laser optics
FRONT END	Vacuum insulator stack	Power flow
	Magnetically insulated transmission lines	
	Plasma opening switch	Plasma diagnostics
	Ion Diode	
	Ion Source	Vacuum hardware
	Magnetic Field Banks	
	Vacuum system	
	Experimenter Diagnostics	
CONTROL/MONITOR & DATA ACQUISITION	Host and satellite computer hardware	Digital instrumentation
	Software	
	Signal cabling	Control theory
	Control and monitor cabling	
	Sensors	
	Pulse power monitors	Digitizers
	Trigger and timing instrumentation	Software development
	Signal recording and digitizing	

TABLE 2

PBFA II PHASE 1 ACCELERATOR TEST MODE **INITIATING TEAM** TERMINOLOGY

SHOT COORDINATOR
This individual specifys detailed day-to-day hardware setup and modification, and aids in interpreting the needs of the plans submitted by accountable FR's and WPM's. The individual will analyze all test data for accuracy and completeness, and determine when a series of tests has met the desired result. He/she is the main contact for delivering setup requests and requirements to the Test WPM's. There may be several persons active in this position for integrated subsystem tests.

DIAGNOSTICS COORDINATOR
Person in charge of detailed interfaces with DAS and C/M systems. This person oversees diagnostics installations, header setup and maintenance, and experimental trigger timing requirements. He/she also specifies criteria for DAS and C/M operating modes and generates bottom-level support requirements. There may be several persons active in this position.

EXPERIMENTAL SUPPORT CREW
Individuals temporarily or permanently assigned to the experimental team who assist in initiating test and characterization requirements.

RESPONDING TEAM TERMINOLOGY

PHASE 1 TEST INTEGRATOR
Person in charge of global experimental planning, philosophy, execution, and daily direction of efforts, for tests involving components, individual subsystems, or integrated systems. This individual also is responsible for documenting testing status and preparing test reports certifying that components or subsystems have met their design specifications for Phase 1. A single person will occupy this position during Phase 1.

FACILITY SUPERVISOR(S)
Person(s) in charge of global coordination of hibay activities. A person in this position assists in synchronizing simultaneous or sequential activities, establishes facility operating hours and shift work scheduling, and in general works all hibay and facility interfaces.

SECTION TEST WPM'S
Individuals responsible for directing crew members and support activities associated locally with the 5 separate accelerator sections, i.e., facilities support, energy storage, pulse forming, power flow front end, and C/M - DAS.

FIGURE 1

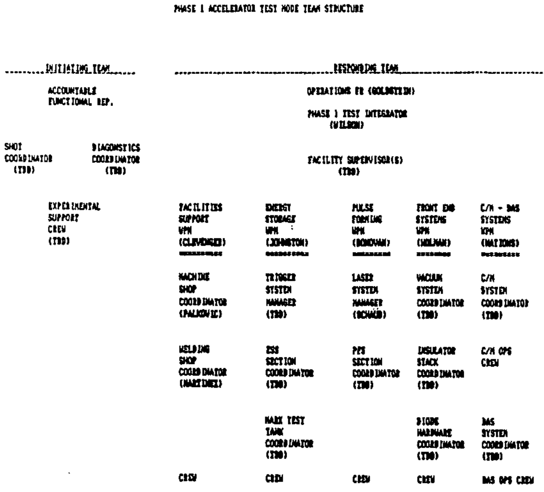
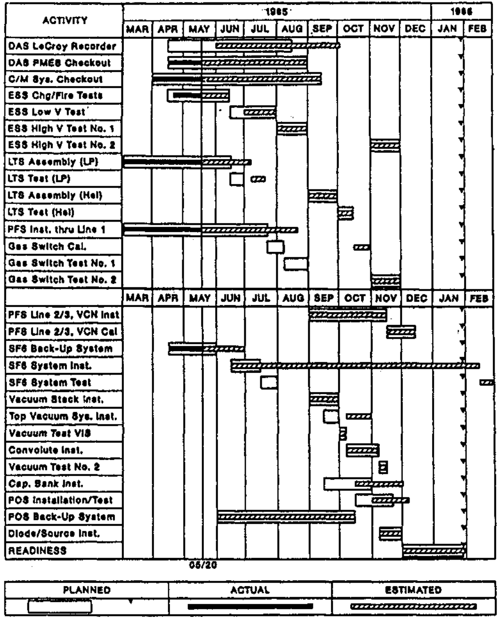

PHASE I ACCELERATOR TEST MODE TEAM STRUCTURE

FIGURE 2

SAMPLE PBFA II IMPLEMENTATION SCHEDULE



Characterization Phase (Phase II)
Priority Windows

FIGURE 3