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Volume I

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PROGRAM PLAN FOR THE DOE OFFICE OF FUSION ENERGY FIRST WALL/BLANKET/SHIELD ENGINEERING TECHNOLOGY PROGRAM

Volume I - Summary, Objectives and Management

FUSION POWER PROGRAM

Argonne National Laboratory
9700 South Cass Avenue
Argonne, Illinois 60439

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Revision 2

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Volume I

This document defines a plan for conducting selected aspects of the engineering testing required for magnetic fusion reactor FWBS components and systems. The ultimate produce of this program is an established data base that contributes to a functional, reliable, maintainable, economically attractive, and environmentally acceptable commercial fusion reactor first wall, blanket, and shield system.

This program plan updates the initial plan issued in November of 1980 by the DOE/Office of Fusion Energy (unnumbered report). The plan consists of two parts. Part I is a summary of activities, responsibilities and program management including reporting and interfaces with other programs. Part II is a compilation of the Detailed Technical Plans for Phase I (1982 - 1984) developed by the participants during Phase 0 of the program (July - December 1981).

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Section 1. Brief Summary

First Wall/Blanket/Shield Engineering Technology Program

The First Wall/Blanket/Shield Engineering Technology Program (FWBS Program) is a broadly scoped experimental program sponsored by the Office of Fusion Energy of DOE with the overall objective of providing engineering data that will define performance parameters for nuclear systems in advanced fusion reactors. Argonne National Laboratory has the responsibility for technical direction of the program through the Management and Technical Coordination Center (MTCC) and Argonne itself performs one of the four separate program elements. Industrial partners perform the other three elements. The organizational structure of the program is shown in Figure 1.1. Brief descriptions of the program elements, including recent highlights and near term goals are given below.

1980 and 1981 brought major strides in the development and implementation of the program culminating in contract awards for the initial six month work period (Phase 0) in the last half of 1981. The essential element in Phase 0 for each TPE was the preparation of a Detailed Technical Plan. The general objective (achieved) in Phase 0 was preparedness for experimental work. Work on experimental programs has now started in 1982.

MTCC: Program management and technical guidance (Argonne National Laboratory).

The MTCC has responsibility for contract management of all program elements and technical leadership of the FWBS Program. The program management is assisted within ANL, by a coordinating committee and support of the staff in ANL's Fusion Power Program and from outside ANL by an advisory committee which brings together diverse expertise in fusion relevant to the program. In addition to matters of overall programmatic direction and budgetary priorities, the MTCC is also active in the analysis of data and the evaluation

FIRST WALL/BLANKET/SHIELD ENGINEERING TECHNOLOGY PROGRAM ORGANIZATION CHART

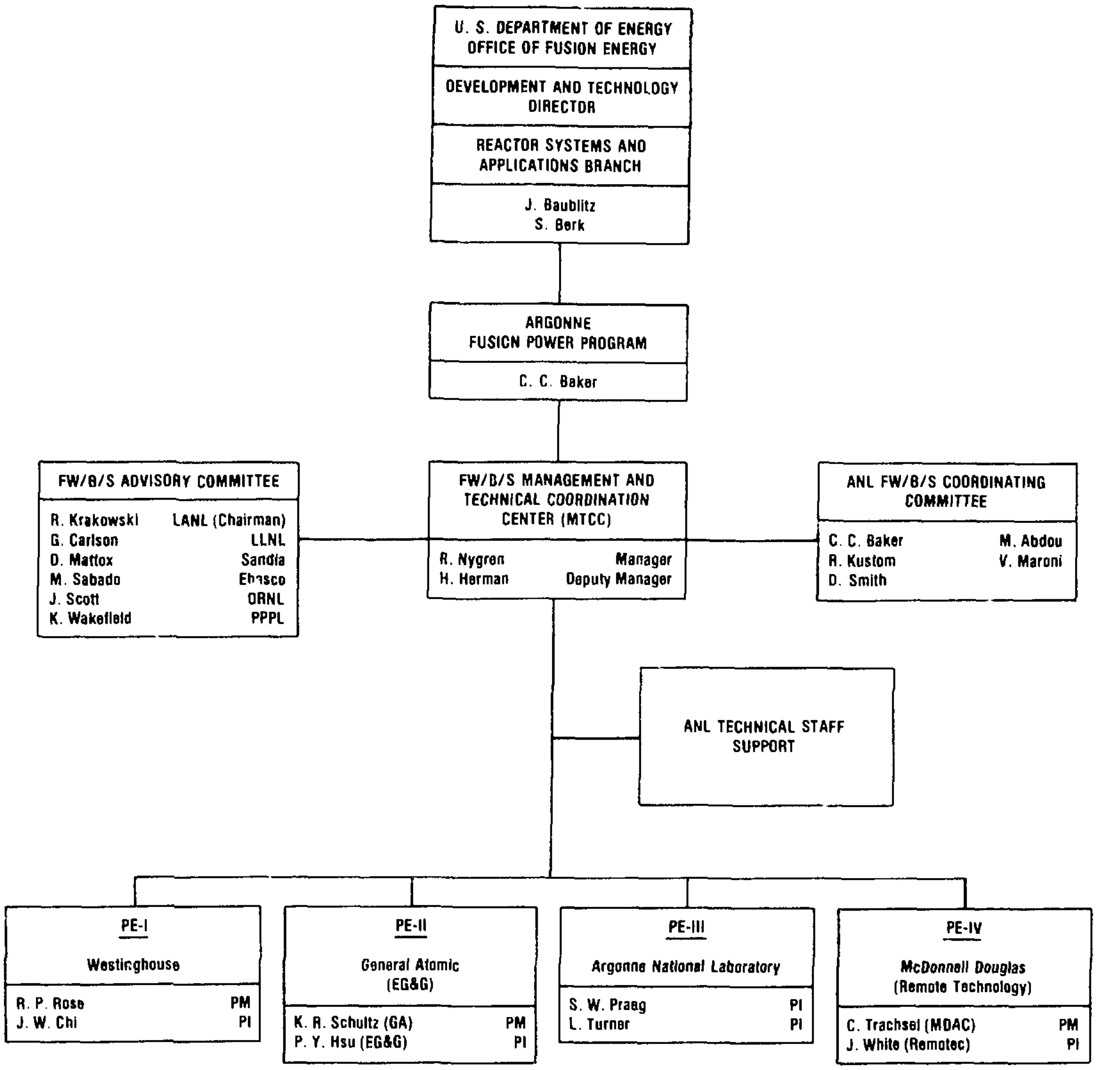

Fig. 1.1 Organization Chart of FWBS Program

of experimental procedures proposed and implemented in each of the program elements.

Program Element 1: Thermomechanical and thermal-hydraulic testing of first wall component facsimiles with emphasis on surface heat loads (Westinghouse).

The first wall and other structures, such as limiters, directly face the plasma -- a harsh environment. Given the parallel constraints of materials selected to minimize adverse effects on the plasma, the primary systems design problem for the first wall is adequate heat rejection of the surface heat loads. Indicated in Fig.1.2 are different surface heat loads expected in fusion reactors. The axes in this figure are power and heated area, the two major parameters characterizing heating sources.

Westinghouse began surface heating tests in December 1981 using a 50 kW e-beam source (ESURF, Fig.1.3). In June of 1982 a more powerful 100 kW facility (ASURF) capable of accommodating test pieces of 1 m^2 m in size was completed and a future upgrade of ASURF to 1 MW is anticipated. The progressive increases in the power of these sources corresponds to a capability to test progressively larger test articles that more accurately simulate the large multi-channeled heat rejection panels used in first-wall, limiter and divertor/collector designs. The experimental data will support the development and verification of analytical models that can accurately describe the temperatures, gradients, distortions and hydraulic behavior of advanced heat rejection components.

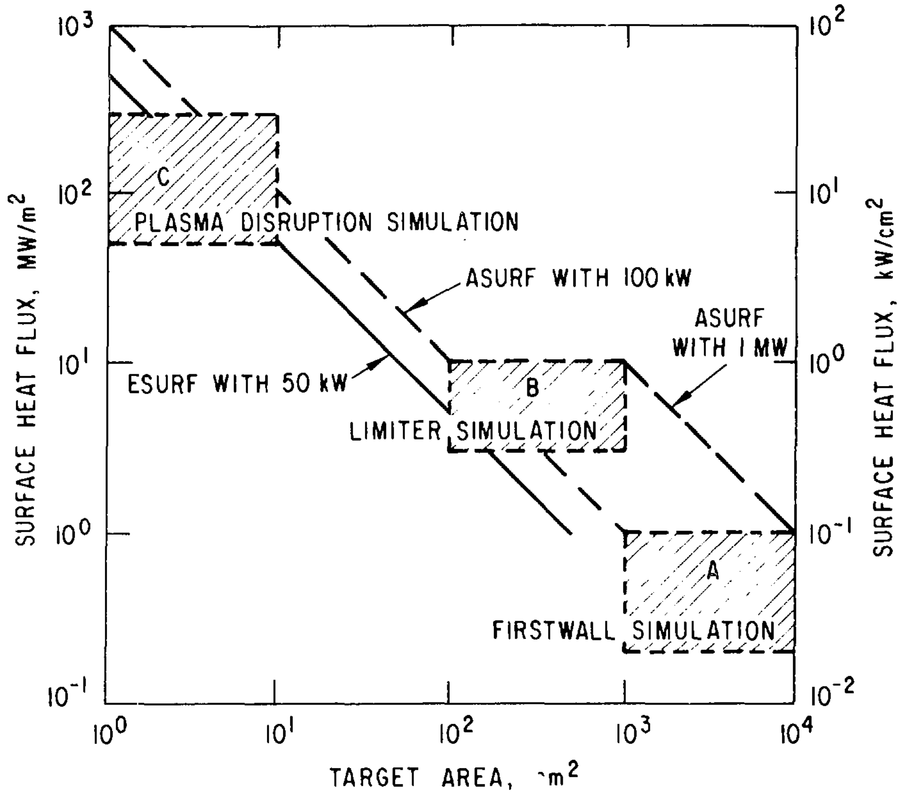

Fig. 1.2 Parameters of surface heat flux and target area. Figure shows useful ranges of parameters to simulate fusion applications and the capabilities of Westinghouse facilities (ESURF and ASURF).

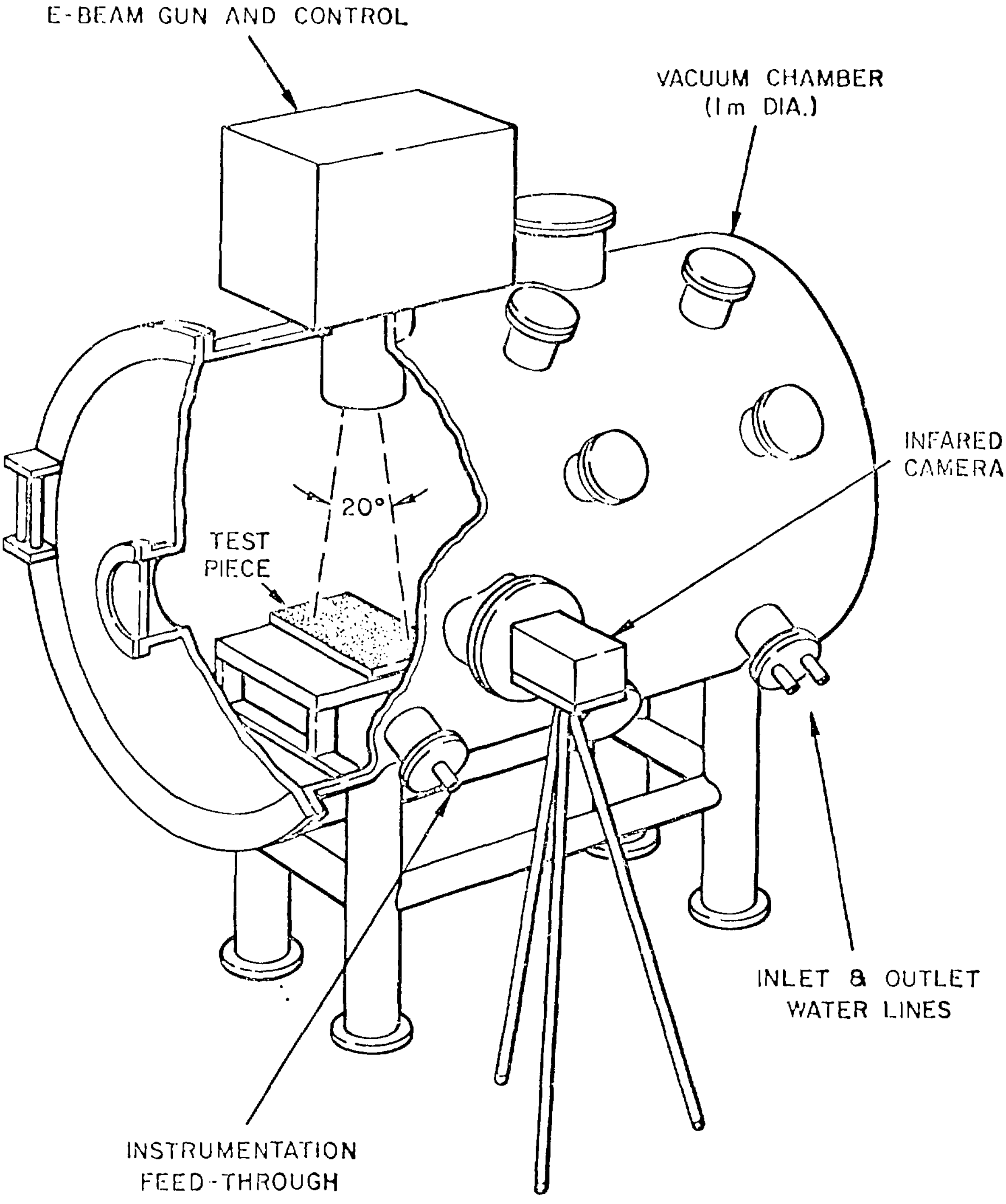

Fig. 1.3 Sketch of ESURF facility with vacuum tank and other components shown.

Program Element 2: Thermomechanical and thermal-hydraulic testing of blanket and shield component facsimilies with emphasis on bulk heating (General Atomic and EG&G, Idaho).

The blanket in a fusion reactor will collect process heat and will produce tritium (from lithium bearing materials). The focus in the FWBS Program, like the overall fusion program, is primarily directed toward solid rather than liquid breeding materials. Most solid breeders are ceramic lithium compounds such as Li_2O and $LiAlO_2$. Limited data on these materials when applied to blanket designs for fusion reactors suggest that the useful temperature window for a given solid breeder will be fairly narrow. This constraint on operating temperature has been problemmatic in recent reactor design studies primarily because of lack of data on heat transfer characteristics and materials properties that are needed for predictions of the performance of breeder systems. Among the critical engineering issues with high priority identified by General Atomic and EG&G, Idaho for resolution in PE-II are (1) the rate of heat transfer from a (ceramic) solid breeder to a (stainless steel) heat sink i.e., the "gap conductance problem" and (2) the long term configurational stability of solid breeders operating at temperature in a system with temperature gradients and flowing purge gas. In PE-II scoping tests will begin in FY82 to address these key engineering issues. The issue of long term stability under reactor conditions will depend on the response of breeder materials to radiation damage as well as system parameters. The strategy of the FWBS Program is to develop tests on the engineering aspects of solid breeder systems that complement ongoing investigations in other programs on tritium recovery and materials behavior.

Program Element 3: Electromagnetic testing of first wall, blanket and shield component facsimilies with emphasis on transient field penetration and eddy current effects. (Argonne National Laboratory)

In typical fusion reactor designs, the first wall, blanket and shield lie between the plasma and the magnets. Rapid changes in either the magnetic field or the plasma current result in eddy currents in the structure surrounding the plasma. The eddy currents can produce unwanted results of two types. First, when changes in the magnetic field are desired for either plasma control or ohmic heating, the eddy currents degrade the field. Second, eddy currents interacting with the magnetic field can produce significant forces on components.

ANL is now constructing a large magnet facility, the Fusion Electromagnetic Induction Experiment on FELIX (Fig. 1.4) to study electromagnetic effects. Operation is expected in 1983. The calculational tools for analysis of electromagnetic effects in the segmented, inhomogeneous configurations of fusion reactors need further development. Using FELIX and test pieces with progressively more sophisticated configurations, calculational models appropriate for use by designers of fusion reactors will be developed.

Program Element 4: Studies of assembly, maintenance and repair with emphasis on remote handling techniques. (McDonnell Douglas Astronautics Company and Remote Technology)

Remote maintenance and repair can be anticipated in fusion reactors because large components (first wall, blanket, shield, etc.) and small (diagnostics, coolant manifold, etc.) will become activated either directly from neutron radiation or indirectly from the presence of tritium or of activated corrosion products transported by the coolant. The range of operations to be performed remotely is large, from the lifting and transport of reactor segments weighing perhaps hundreds of tons to the delicate and precise work of coupling electrical leads or locating vacuum leaks. The potential scope of this subject is vast and many undertakings would imply large scale efforts.

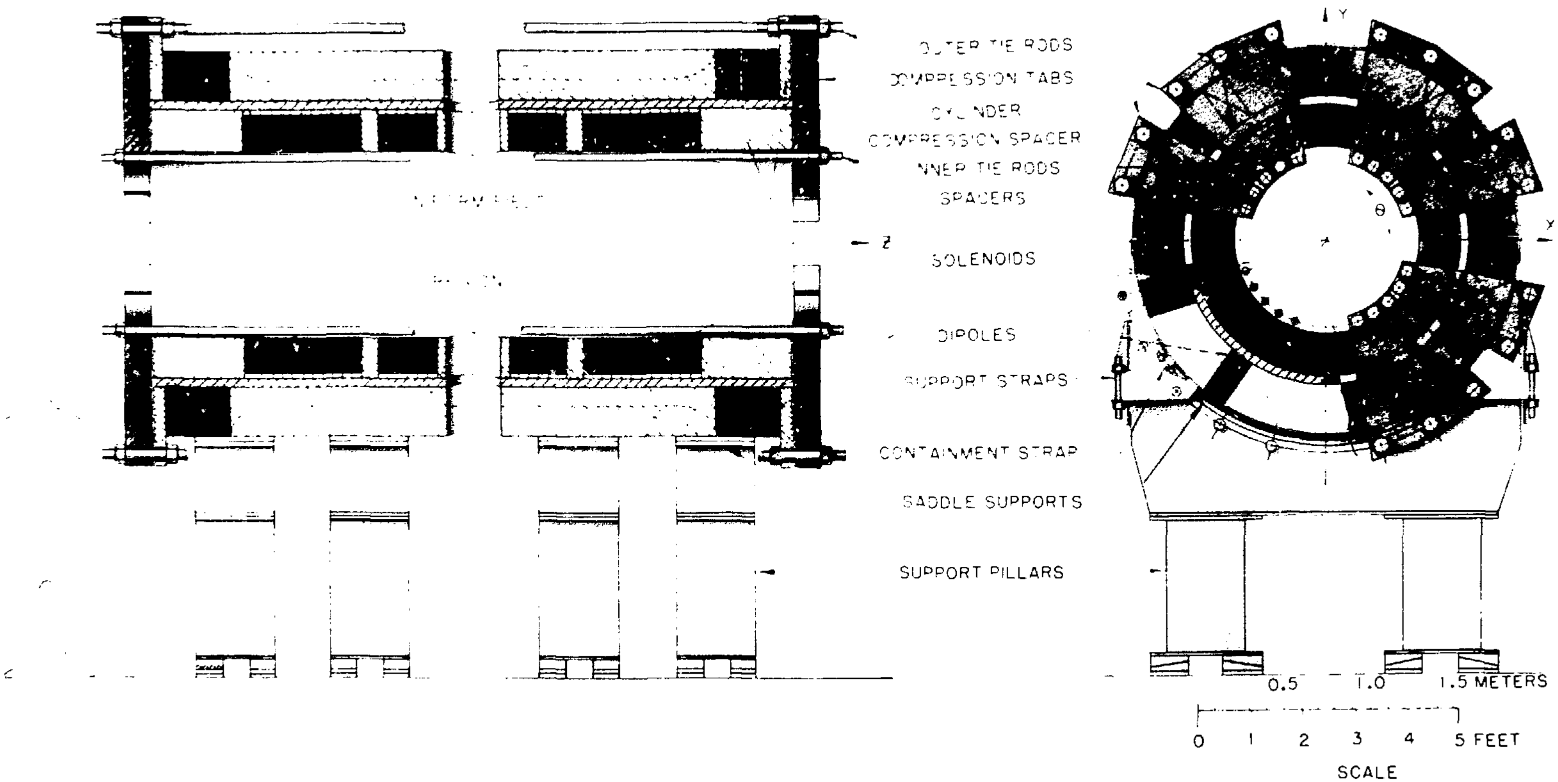

Fig. 1.4 Drawing of FELIX, an electromagnetic effects test stand, which is being constructed at Argonne National Laboratory.

In PE-IV McDonnell Douglas and Remote Technology have been working together in 1981 and 1982 to identify key issues that are appropriate for study in PE-IV in that meaningful results can be obtained within the program's resources. The twofold approach taken in PE-IV is to (1) seek out and compile existing useful information in a Designer's Guidebook and (2) proceed with a series of tasks involving limited development of test hardware such as (a) remotely activated fasteners for vacuum joints and (b) remotely activated electrical contacts that provide a preferred current shunt between adjacent first wall sections.

Major milestones for each Program Element are shown in Fig. 1.5 and detailed schedules for each Program Elements are presented in Volume II of this program plan. The milestones and activities of the MTCC are presented in the discussion of program organization and management in Section 5 of this volume.

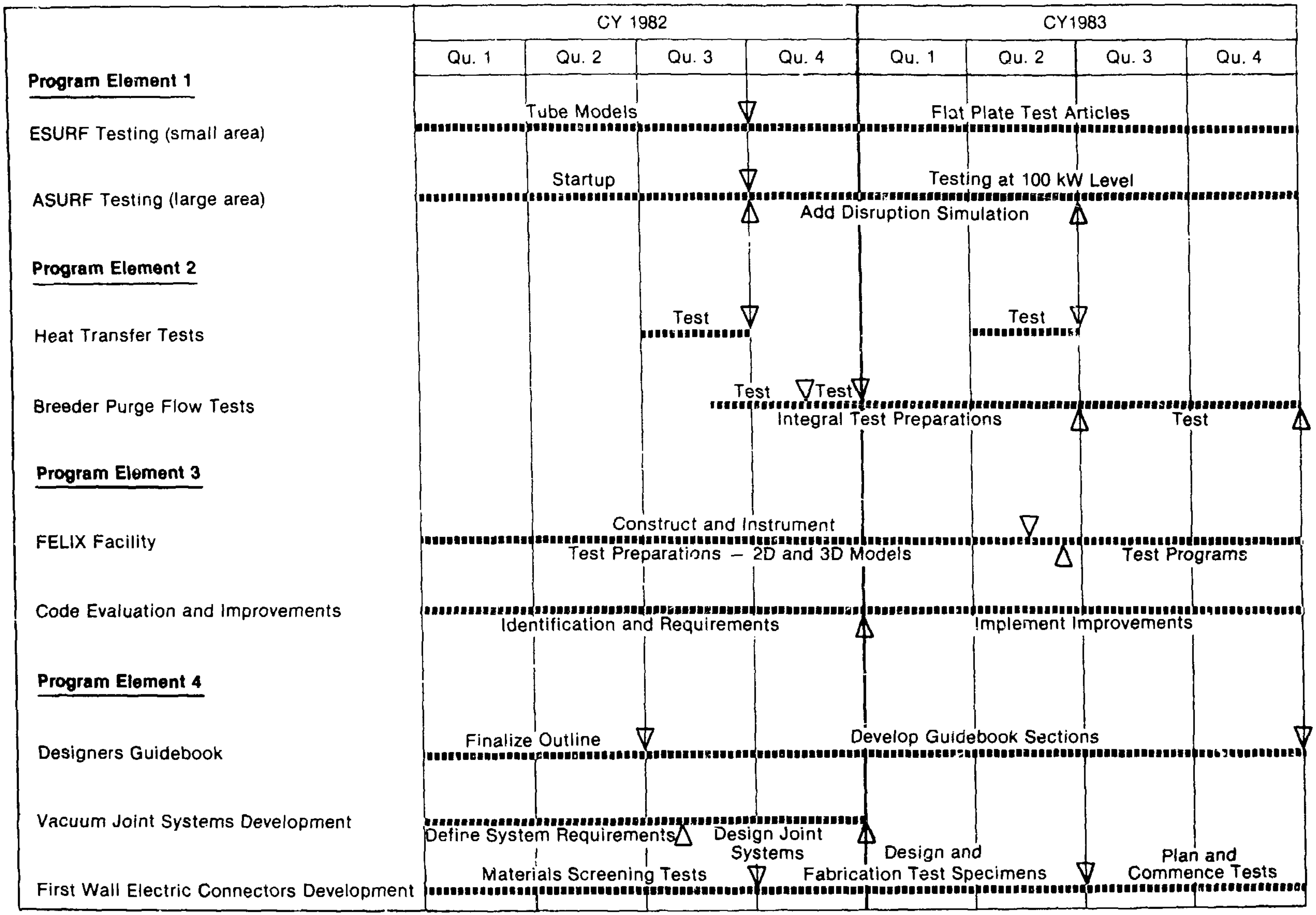

Fig. 1.5 Schedule for Major Tasks in the FWBS Program.

Section 2. Introduction and Objectives

First Wall/Blanket/Shield Engineering Technology Program

Together the first wall, blanket and shield provide a nuclear envelope that isolates the fusion plasma and the energetic particles produced by the plasma from the rest of the fusion reactor. Figures 2.1 through 2.2 show these components in STARFIRE, a conceptual design for a commercial tokamak fusion reactor, and in a tandem mirror reactor.

First wall components will directly face the plasma and be subjected to a severe environment including intense (photon) radiation and bombardment by high energy neutrons and energetic particles from the plasma. The primary function of the first wall and first wall components (armor, limiters, divertors) is to maintain the physical boundary that defines the plasma chamber without adversely affecting the plasma (by introducing impurities). Rejection of the intense surface heat loads is an important requirement in fulfilling this function. The blanket has two functions: generating heat and producing tritium with methods suitable for their extraction from the blanket. The shield provides biological protection for personnel and reduces radiation and nuclear heating to levels acceptable for the operation of sensitive components such as superconducting magnets. More information on design features of fusion reactors is presented in Section 3 in which technical issues are summarized.

The ultimate goal of the First Wall/Blanket/Shield Engineering Technology Program is to provide the engineering and component test support required to design and construct functional, reliable, maintainable, environmentally acceptable FWBS systems for magnetic fusion reactors The anticipated products from the program are a combination of experimental results and computational

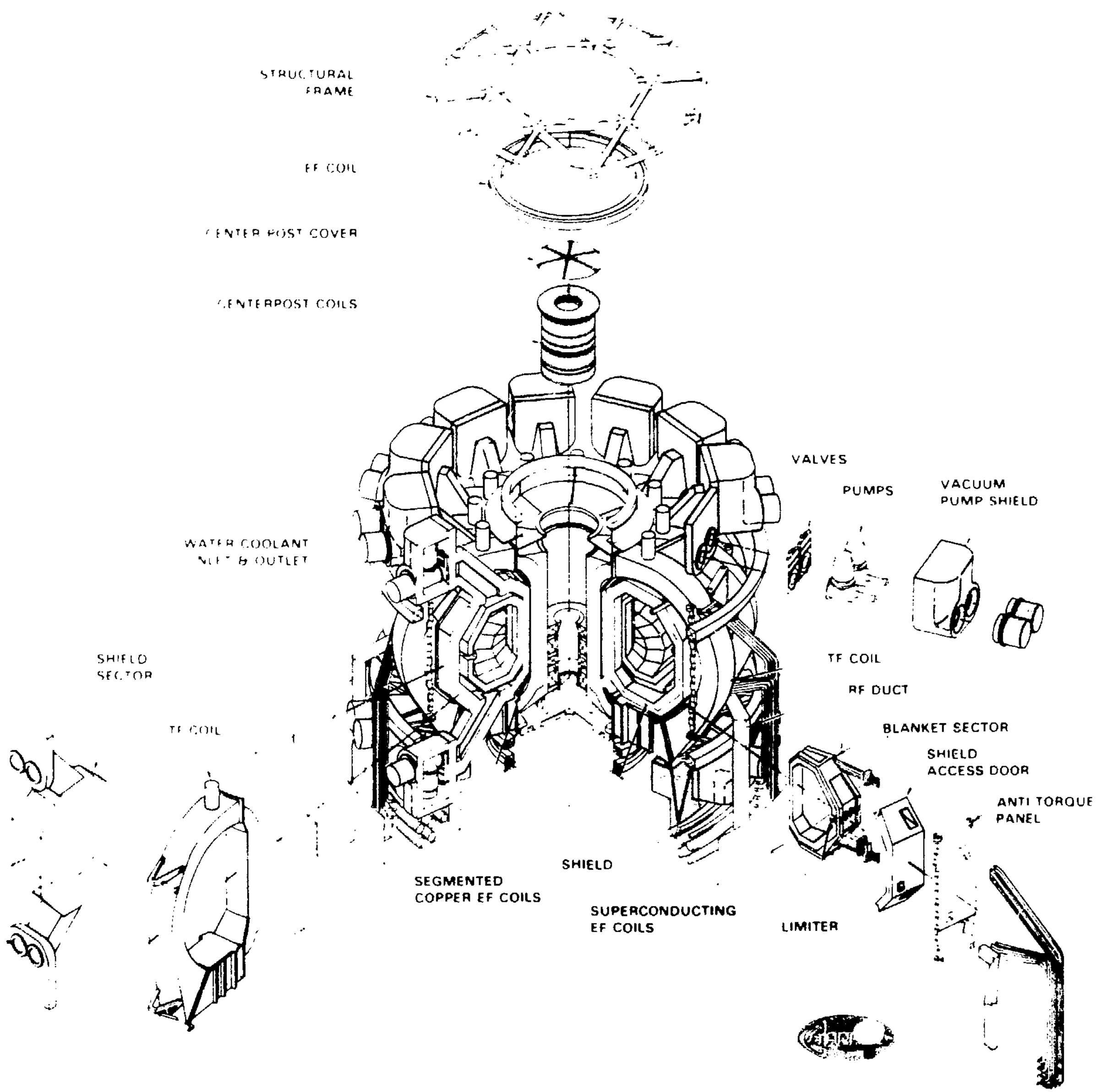

Fig. 2.1 Components in STARFIRE, a design study for a commercial fusion reactor.

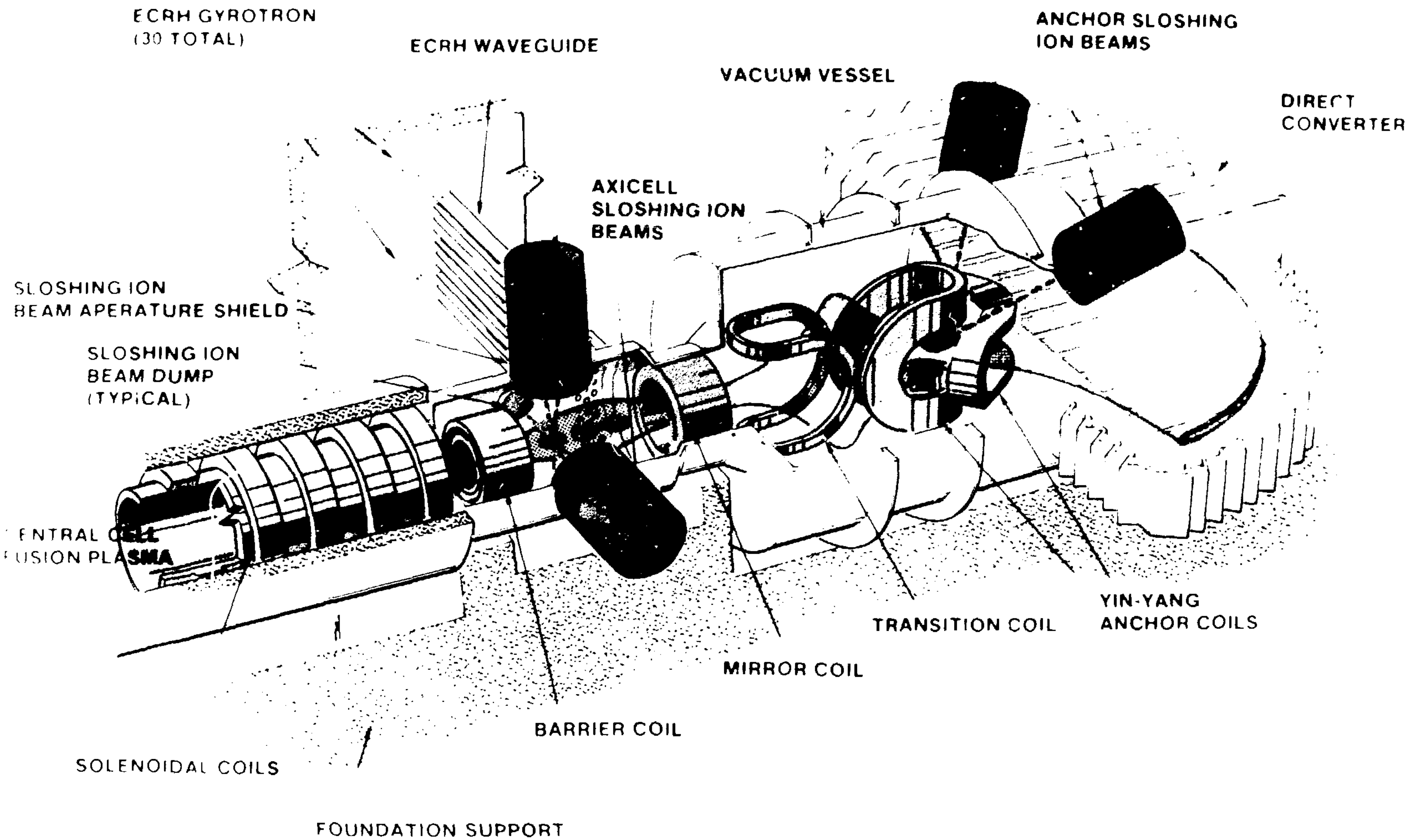

Fig. 2.2 Components for TMR, a design study for a tandem mirror reactor.

tools (design codes) that will provide an adequate engineering data base to support the successful design of FWBS components and their integration into a comprehensively verified FWBS system.

In the near future, between the operation of TFTR and the decision to begin construction of an advanced engineering test reactor (ETR), the US Fusion Program will be defining the end product for fusion development. The appropriate near term strategy for the FWBS Program is to advance the capability to produce credible reactor designs and, specifically to produce data needed for useful comparisons among candidate FWBS systems.

2.1 FWBS Program Philosophy and Objectives

The FWBS Program is intended to be a multi-organizational effort that will call upon the facilities and expertise of laboratories, industry, and universities in a manner which most expeditiously and cost-effectively accomplishes the programmatic objectives. One important aim for the work in this program during the 1980's will be empirical resolution of generic issues related to the first wall, blanket and shield components of the next major fusion engineering device to follow TFTR, defined here as the Engineering Test Reactor, ETR. A second equally important aim will be to buttress a sound decision making strategy in DOE concerning the role of ETR and future devices (DEMO) by providing data on key issues in FWBS systems.

Background information on key issues in FWBS systems and the rationale for the selection of the specific scopes of work for the program elements are presented in Section 3 and 4.

It is important to recognize at the outset of this program that the first series of engineering experiments to be conducted within the FWBS Program will not be comprehensive tests in the environment to which a typical FWBS component is likely to be exposed in a fusion reactor system. Rather, these first experiments will focus mainly on the study of isolated effects and, to a limited extent, groupings of two or three effects. The combined results of all tests will be used to (1) supply fundamental design data, (2) confirm specific assumptions and calibrate selected aspects of computational models,

(3) to correlate potentially important interrelated engineering issues, (4) generate insights concerning dominant failure modes for specific component concepts, and (5) develop and test the instrumentation and control strategies required for meaningful FWBS experimentation. A key activity of the FWBS Program will be to examine in detail the features, requirements, configurations, costs, and general feasibility of one or two comprehensive, integrated FWBS test facilities to be constructed and made operational by the mid-1980's. In the light of this goal, an additional purpose of the first series of engineering tests will be to provide the guidance and insight needed to bolster the planning and design of these integrated test facilities. (See Section 7.0)

2.2 Inception of FWBS Program

The challenge of finding a credible combination of materials (coolant, breeder, structure, etc.), operating conditions (temperatures, pressures, etc.), and subsystem configurations has produced numerous philosophies, strategies, designs, and analyses of magnetic fusion reactor first wall, blanket, and shield systems both in the USA and abroad for over ten years. Although numerous FWBS concepts already exist, the task of completely determining their viability in the total fusion environment cannot be done by analytical and computational methods alone. From the long-standing awareness of this limitation, there has evolved, within the U.S. Department of Energy/Office of Fusion Energy (DOE/OFE) and the fusion community as a whole, a recognized need to embark on a program that would seek to resolve the critical engineering issues concerning the design of FWBS systems. The urgency for such a program is further heightened by the committed intention of DOE/OFE to build and operate in the early 1990's a fusion device that will burn a D-T plasma and advance the engineering of systems relevant for power reactors. The design of an Engineering Test Reactor (ETR) as it is currently evolving, represents a bold initiative for the magnetic fusion program, particularly in the first wall/blanket/shield area where the capability to accommodate the environment of a fusion power reactor will be fully tested for the first time. To fulfill these needs for the ETR and follow-on devices that will lead to the commercialization of fusion energy, the DOE/OFE Division of

Development and Technology (D&T) announced the establishment of the First Wall/Blanket/Shield Engineering Test Program in December of 1979, and designated Argonne National Laboratory (ANL) as the lead technical organization. The program organization and responsibilities are discussed in Section 5 and Appendix A.

The First Wall/Blanket/Shield Engineering Test Program (now the First Wall/Blanket/Shield Engineering Technology Program or FWBS Program) was developed and implemented through an extensive inquiry and evaluation involving over thirty organizations. The resulting definition of both objectives and scope for the program can properly be judged as a strong community-wide consensus. The events in this process are summarized in Appendix B. Interested readers may find more information on the developmental stage of the FWBS Program during 1979 and early 1980, in the initial (November 1980) version of the program plan.

Section 3.

FWBS System, Functional Features, and Design Requirements

Because of the diversity of magnetic confinement concepts (tokamaks, mirrors, EBTs, etc.) and the broad range of engineering approaches that have been utilized in reactor designs for these concepts, there exists no single global design strategy that generically represents all aspects of the fusion FWBS system. This section will describe general features and design concerns that are common to many FWBS systems. Figure 3.1 is a simplified view of the basic features typical of many designs for FWBS systems. Although there is no completely generic FWBS system or concept, a comprehensive summation of engineering issues incorporated from many possible design for FWBS systems is possible and is necessary for programmatic guidance. The principal design features and design concerns for the three major subsystems of the FWBS system are summarized in Tables 3.1 through 3.3. While it is true that some individualized functions and concerns listed in the tables are heavily design dependent and in many ways the FWBS system must be viewed as serving an integrated function, nevertheless the categorized information in these tables generally typifies the thinking and planning that provides the basis for the initiation of a reactor conceptual design. Furthermore, collectively these features and concerns are a comprehensive framework for identifying initial engineering issues.

3.1 Selection of Engineering Issues The identification of critical engineering issues is an ongoing process derived primarily from the regeneration of designs for advanced fusion reactors such as FED, INTOR, STARFIRE, DEMO and MARS, which in turn build on previous designs and interim progress in confinement and the various base technologies of fusion. The FWBS Program Plan emphasizes engineering studies that will be useful to all design efforts regardless of confinement concept or reactor approach.

Table 3.1 SYSTEM DESIGN FEATURES AND DESIGN CONCERNS COMMON[a] TO FIRST WALL COMPONENTS

Design Features	Design Concerns
Heat Ejection Capability	Irradiation Damage
Coolant Manifolding	Thermal Stress
First Wall Header Access	Thermal Energy Recovery
Disruption Protection	Low Cycle Fatigue
Neutral Beam Dump Armor	Loss of Coolant Flow
Vacuum Seals	Plasma Disruptions
Impurity Control Devices	Electromagnetic Disruptions
Plasma Limiter	Eddy Current Effects
Plasma Driving System Access	Coolant Leakage
Evacuation System Access	Loss of Vacuum Integrity
Low Atomic Number Coatings	Assembly
Instrumentation and Controls	Economy of Construction
	Maintainability
	Tritium Migration
	Induced Activation
	Corrosion

[a]The features and concerns listed in this table are not necessarily intrinsic to all magnetic fusion design concepts.

Table 3.2 SYSTEM DESIGN FEATURES AND DESIGN CONCERNS COMMON[a] TO BLANKET COMPONENTS.

Design Features	Design Concerns
Tritium Breeder Material	Tritium Breeding/Recovery
Tritium Removal Loops	Neutron Streaming
Neutron Multipliers	Radiation Attenuation
Neutron Reflectors	Thermal Energy Recovery
Heat Ejection Capability	Low Cycle Fatigue
Evacuation System Penetrations	Thermal Stress
Divertor Penetrations	Irradiation Damage
Plasma Driving System Penetrations	Induced Activation
Coolant Manifolding	Assembly
First Wall Supports	Maintainability
Instrumentation and Controls	Economy of Construction
	Loss of Coolant Flow
	Tritium Migration
	Electromagnetic Disruptions
	Eddy Current Effects
	Corrosion

[a]The features and concerns listed in this table are not necessarily intrinsic to all magnetic fusion design concepts.

Table 3.3 SYSTEM DESIGN FEATURES AND DESIGN CONCERNS COMMON[a] TO SHIELD COMPONENTS.

Design Features	Design Concerns
Low-grade Heat Removal Loop	Assembly
Efficient/Light Weight Shielding Materials	Maintainability
Coolant Manifonding	Low-cost construction
First Wall and Blanket Header Access	Weight
Evacuation System Penetrations	Induced Activation
Plasma Driving System Penetrations	Electromagnetic Disruptions
Divertor Penetrations/Access	Eddy Current Effects
First Wall/Blanket Supports	Neutron Streaming
Instrumentation and Controls	

[a]The features and concerns listed in this table are not necessarily intrinsic to all magnetic fusion design concepts.

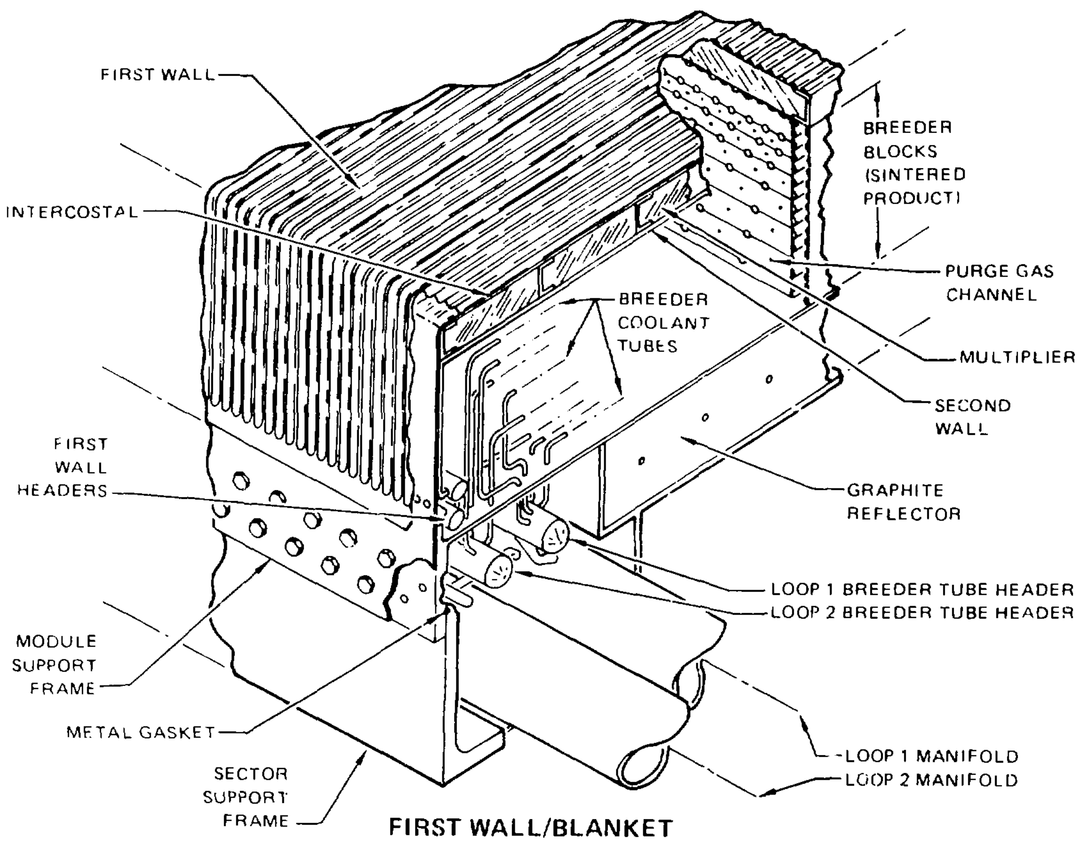

Fig. 3.1 Example of one possible style of first wall and blanket design. Sketch shows coolant passages, manifolding, etc. for system with a first wall, neutron multiplier, solid breeder blanket and graphite reflector.

From an engineering point of view, the concerns listed in Tables 3.1 - 3.3 can affect the credibility of reactor designs in the following ways:

(1) They have impact on the operability of the reactor to a first order of approximation, i.e., the reactor would not operate at all if the engineering design were seriously inadequate.

(2) They have impact on the integrity of FWBS components and of other reactor systems, either in the sense of basic short term operation (design adequacy) or long term operation (reliability).

(3) They have impact on the overall safety of the device from the point of view of serious damage to systems and components, worker safety, and public safety.

(4) They have impact on the overall economic performance of the reactor from the point of view of capital cost, cost of electricity, availability, and cost of recovery from off-normal occurances.

Table 3.4 consolidates the information from previous tables and presents three types of additional information. First, the technological concerns listed are limited to those which have created the most persistent FWBS related engineering issues and uncertainties in past fusion reactor design studies. Second, column two (Major Impacts) lists the pertainent impacts among those given above (1 through 4). Third is timing -- when data will be needed to establish credible solutions for the concerns listed (i.e., whether data are needed in the conceptual design phase or later, for the detailed design.) While these judgements are most assuredly design dependent in many respects, they represent the type of thought that has motivated a vast majority of the fusion reactor conceptual designs carried out to date.

In this program plan distinctions are made between design concerns and engineering issues related primarily to systems and design applications and those arising from questions on materials behavior per se. The term "engineering issues" here is used selectively and excludes "materials issues", where materials effects such such as radiation damage is the central issue. This clarification of terms is made to distinguish the scope of the FWBS Program from related work in other programs, primarily the US Fusion Reactor Materials Program. A clear division of experimental scope may not be apparent in all cases, but it is expected that the cooperation among reseachers in related work, and perhaps future collaboration on experiments, will minimize any unnecessary duplication of effort and maximize mutually supportive work on parallel paths. Two cases of closely related work are (1) PE-I and the High Heat Flux Test Program and (2) PE-II and materials tests on properties of and irradiation efforts on solid breeders.

3.2 Impact of Design Concerns

The individual entries in the list of "Technological Future/Concern" in Table 3.4 are described below. For each entry some or all of the concerns are crucial in developing credible design for any specific design concept, collectively, these concerns represent a summation of the limitations on our current knowledge of FWBS systems and their design.

Penetrating Radiation: The neutrons and secondary gammas produced as a result of the fusion reactions (e.g., D-T and D-D) constitute the means by which useful energy is extracted from the fusion process. These two forms of penetrating radiation are subsequently thermalized in the first wall, in the blanket, and to a limited extent, in the shield. The heat generated in the bulk of the first wall and blanket systems is extracted from the reactor via the coolant(s). Although the neutrons and consequently the bulk thermal energy are deposited nonuniformly in the blanket, a uniform temperature profile is generally maintained throughout the blanket by adjusting the pitch of the coolant distribution system. The principal design objectives with respect to the penetrating radiation in a fusion FWBS system are (1) optimization of the neutron slowing-down process to maximize tritium production (for D-T reactors) and permit efficient extraction of the thermal energy, (2) attenuation of the penetrating radiation to acceptable levels at the outboard surface of the shield to protect vital reactor systems (e.g., the magnets) from radiation damage and minimize induced activity at the perimeter of the nuclear island, and (3) accomplishment of the objectives above using a FWBS configuration of minimum thickness. Meeting these objectives requires detailed nuclear engineering data on cross sections, thermal energy production (Kerma) factors, nuclear performance of integrated materials configurations, and tritium breeding ratios.

Non-Penetrating Radiation and Energetic Particle Bombardment: The materials facing a fusion plasma (nominally, all the first wall components) are bombarded with a flux of charged and neutral energetic particles and a broad spectrum of electromagnetic radiation. The particles strike the first wall structural materials, and together with the electromagnetic radiation, deposit appreciable quantities of thermal energy at exposed first wall surfaces. In most fusion reactor designs, the recovery of this thermal energy as sensible heat is essential to an economically attractive power balance. The surface heat load during normal operation can be up to 25% of the total neutron wall loading for DT reactors, depending on the extent to which plasma energy is removed via a particle divertor or related device. During plasma disruptions, the particle and radiant surface heat loads may exceed 100 MW/m^2 in localized areas of the first wall. Also, in non-steady-state fusion devices, the cyclic heat load during normal operation can generate large time-varying thermal stresses in the first wall components. The design objectives for dealing with the non-penetrating radiation and energetic particles are to recover the energy deposited on the first wall surfaces as sensible heat, to accommodate the heat loads without disrupting the plasma or adversly affecting the integrity of the first wall, and to identify first wall materials and configurations that can function reliably under normal and transient particle/heat load conditions.

Thermal-Hydraulics and Thermomechanics: The technological concerns with thermomechanics and thermal-hydraulics stem from a basic requirement that design calculations accurately predict the "working parameters" of FWBS components, specifically the stresses, distortions, temperatures and (for liquids) pressures. Another important aspect of this type of characterization for the detailed design of FWBS systems is the capability to incorporate the effects of time-dependent phenomena, such as stress relaxation, creep, corrosion, changes in thermal conduction and heat transfer, and transient behavior associated with startups and shutdowns. In addition there will evolve the need to assess the impact on operation from a spectrum of conditions of stress, temperature and (coolant) flow which deviate from nominal design points. This information on response to "off normal" conditions will form the basis in detailed design for assessments of "worst case" behavior, potential failure scenarios, safety analysis, setpoints for FWBS component instrumentation and operating guidelines for tolerable departures from nominal operating conditions. Experience from the (fission) breeder reactor industry has shown that such considerations often become controlling factors in establishing design requirements. Given the anticipated requirements for long lifetimes and difficulty in repair for FWBS components, no less an impact on design should be expected for fusion. Our current familiarity with conceptual designs for advanced fusion devices reveals general areas for fruitful endeavor but as yet detailed basis of need for design information of the type mentioned above is beyond our level of sophistication.

Heat Transfer and Energy Conversion Coupling: The extraction of sensible heat (or some other useful form of energy) is the primary goal for any fusion concept. The movement of coolant(s) from the FWBS system to a power generator or intermediate heat exchanger, the subsequent return of coolant to the reactor, and the manner in which energy conversion is accomplished (particularly in non-steady-state devices) pose special problems to the design of fusion FWBS systems. Further, these problems must be resolved using methods that do not result in large releases of tritium or radioactive material to coolant systems, energy conversion systems, the plant facility, or the environment. Thus there are important requirements related to the interfaces between coolant heat transfer and processing systems and FWBS systems.

Electromagnetic Reactions and Effects: The mechanical reactions of the electrically conductive portions of FWBS systems to large DC electrical fields and, in some designs, time varying magnetic and electrical fields are an important area of concern in FWBS design. The fields generate large forces, torques, and other mechanical loads. Also, they can produce resistive (eddy current) heat loads, vibrations, and perturbations to FWBS instrumentation readings. Electromagnetic effects resulting from plasma disruptions can also induce large instantaneous mechanical loads. In addition, their are concerns related to magnetohydrodynamics of liquid metals and magnetization of ferritic steels in fusion magnetic fields.

Coolant Flow Transients: Pertubations to coolant flow (oscillations, depressurization, loss of flow) in various regions of a fusion FWBS system and the consequences to reactor component performance and integrity are beginning to receive attention in fusion design studies. The consequences of these types of transient effects are often difficult to predict, and some engineering simulations will be required. The principal impacts are on system integrity and worker safety.

Plasma and Confinement System Disruptions: Although the detailed nature, frequency, and potential impact of plasma disruptions and confinement system malfunctions for power reactors are difficult to gage at the present time, it is well recognized that such events can seriously affect the integrity and subsequent performance of FWBS components. These events are likely to result in the local deposition of large quantities of energy on first wall surfaces and the creation of sizeable forces due to electromagnetic imbalances. While future advances in our knowledge of plasma behavior may result in disruption free operation, it is not yet evident that this circumstance will arise, especially at an early enough date so that the potential consequences of disruptions in ETR could be disregarded during its design. Thus, the methodology to mitigate and withstand the consequences of plasma disruptions will likely be developed as a part of FWBS engineering and materials R&D activities.

Assembly/Maintenance/Repair(AMR): Concerns about AMR belile pivotal issues for the successful operation of any fusion device and remain among the least well resolved of these key issues (Table 3.4). In all detailed reactor studies, AMR of the FWBS system is of prime concern; yet, only limited work has been done to date to develop generic criteria and approaches. The strategies for dealing with AMR in fusion designs have varied both in approach and in emphasis on the various aspects of AMR. Although AMR affects the performance of fusion systems through operability, integrity, and safety, the most frequent common denominator for evaluating AMR has been gross economic performance as reflected by cost of construction, cost of maintenance, and downtime for maintenance and repair.

Previous comparative studies of tokamak and mirror reactor designs have shown that the most extensive scheduled maintenance requirement is changeout of the firstwall and blanket and that this can be accomplished most efficiently (i.e., minimum downtime) by replacement of large sections of an integral firstwall and blanket (e.g., torus sectors in a tokamak) through use of maintenance equipment external to the plasma chamber and by using only external access. It is essential that the practicality of this type of configuration be demonstrated and the appropriate efficiency be developed. This goal contains a variety of technological concerns such as demonstrating the capability to maneuver and transport large sections remotely with adequate precision, disengaging and rewelding (or reconnecting) a myriad of small and large sealed ducts and joints, leak detection and location, and methods for identifying and locating problemmatic failures in FWBS components. In addition to the general concerns above about replacement of large sections of FWBS systems, various other technological concerns include methods for surveillance and inspection (preventive maintenance), remote installation and removal of special items within the plasma chamber such as electrical connectors (between sectors), and methods and facilities for repair work.

Tritium Breeding and Recovery: The achievement of adequate tritium breeding (breeding ratio >1.0) and efficient tritium recovery from the breeder blanket under conditions of low steady-state tritium inventory in the blanket and connected systems is a paramount concern (for D-T fueled reactor systems). Breeding questions relate for the most part to optimization of choices for the breeder and structural materials and to the FWBS configuration. Tritium recovery is dependent on the chemical characteristics of the breeding material over its operating range, and in the case of solid breeders, sensitivities to operating temperatures and breeder configuration are expected.

Materials Compatibility and Response: The performance of materials in the fusion FWBS environment is a central issue to all features and concerns listed here. Selected materials (depending on the particular FWBS application) must withstand penetrating and non-penetrating radiation, energetic particle bombardment; corrosion by coolant, breeder, neutron multiplier, etc.; time varying thermal stresses; mechanical loads; large instantaneous forces; electrostatic and electromagnetic fields; and more. Aspects of these problems for fusion that relate specifically to the response of materials to isolated phenomena (neutrons, ions, coolants, etc.) are addressed as part of the Materials and Radiation Effects Program. The engineering performance of fabricated components will be studied in large part by the FWBS Program.

Instrumentation and Control: FWBS systems require a variety of instrumentation to measure temperature, coolant pressure and flow rate, stress, strain, vibration, deflection, neutron flux and fluence, etc. A unique feature of these needs in instrumentation and control (I&C) for magnetic fusion reactors is that the instruments and controls must respond reliably and accurately in modest time and in varying and steady magnetic and electric fields. Although I&C problems seldom have primary importance in technology programs, in the case of the FWBS Program, addressing these concerns early would be preferable in order to assure that meaningful engineering data are recorded from the outset for each individual program element. Some early work on I&C hardware will be necessary to identify and resolve key I&C issues in FWBS systems.

Some of the features and concerns in Table 3.4 (e.g., tritium breeding and recovery) are not in the scope of near term activities of this program and consequently are not dealt with in any further detail in this version of the plan. The specific types of tests to be conducted for a given component and the character and ranges of the test parameters will be based on projections made using the most recent and most thoroughly developed information from state-of-the-art reactor conceptual design studies, such as FED, INTOR, STARFIRE, MFTF,MARS, EBT-P, etc. Although these studies will be used to provide the justification for perceivably interesting test parameter values, the range of values to be studied will be extended where possible to determine optimum operating regimes and operational limits of individual component concepts. This information will in turn be fed back to the design studies to help provide new design guidelines where revised thinking is an obvious requirement based on test results. In addition, since only a limited number of component types and component concepts are likely to have undergone testing in the next few years, the choices of component type and concept will be based on exigencies that come from the design studies themselves.

Table 3.4 RELATIVE IMPORTANCE FACTORS FOR NEAR-TERM TESTING OF FUSION REACTOR FIRST WALL/BLANKET/SHIELD SYSTEMS

Technological Feature/Concern	Major Impacts[a]	Timing of Importance to Major FW/B/S Subsystems Design[b]		
		The First Wall	The Blanket	The Shield
Penetrating Radiation (n,γ)	S,E	I/CD	I/CD	I/CD
Non-penetrating Radiation $(\Sigma\nu)$	O,I	I/CD	-	-
Energetic Particle Bombardment (D,T,He)	O,I	I/CD	-	-
Thermal-Hydraulics/Thermomechanics	O,E	I/CD	I/CD	I/DD
Heat Transfer/Energy Conversion (Coupling)	E	I/CD	I/CD	-
Electromagnetic Reactions/Effects	O,I,S	I/CD	I/CD	I/CD
Coolant Flow Transients	I,S	I/CD	I/CD	I/DD
Plasma/Confinement System Disruptions	I,S	I/CD	DOC	DOC
Assembly/Maintenance/Repair	E	I/CD	I/CD	I/CD
Tritium Breeding/Recovery	E,S	DOC	I/CD	-
Materials Compatibility/Response	E,I,S	I/CD	I/CD	I/DD
Instrumentation and Control	O,I,S	I/DD	I/DD	I/DD

[a] O = operability of device; I = device integrity; S = safety; E = economics.

[b] I/CD = a high level of importance of feature/concern to subsystem conceptual design.
I/DD = a high level of importance of feature/concern to detailed design phases.
DOC = onset of importance depends on design concept.

Section 4.

Technical Base for TPE Work Scopes

In this section are general descriptions of the technical basis for work in each of the test program elements (PEs) of the First Wall/Blanket/Shield Engineering Technology Program (FWBS Program). During Phase 0 of the program (July-December 1981), detailed plans within the general scope of work were developed for the PEs. This detailed information is presented in Volume II of this program plan.

In the discussion that follows a somewhat specialized terminology has been adopted to differentiate between types of components, subsystems, test article, etc. The definitions are given in Table 4.1.

Table 4.1 Definition of Terms Used in Section 4 to Describe Test Pieces

Component: A readily definable and/or isolatable constituent of the FWBS system of a fusion device. (Example: A first wall heat ejector panel.)

Segment: A section (possibly scaled down in size) of a specific FWBS component possessing only those features of the component that relate to the particular set of effects being tested. (Example: A partial section of a blanket block designed for localized testing of bulk blanket performance.)

Facsimile: A reasonably complete but scaled-down representation of an FWBS component, containing as a minimum all the functional features of the component (including its interfaces with adjacent systems). (Example: A first wall heat ejection panel with support and suspension fixtures and coolant manifold connections.)

Assembly: An integrated collection of FWBS component facsimiles designed to test both individual component performance and component coupling effects.

Test Piece: A component, segment, facsimile or assembly that is being subjected to test.

4.1 Technical Basis for PE-I (First Wall Heat Load Studies)

The first wall provides the primary heat removal for the radiant and particle-imparted contributions of the fusion energy released by the plasma. The thermal-hydraulic and thermomechanical performance of the first wall has long been recognized as a critical concern in fusion reactor first wall design. Even though operational constraints are somewhat relaxed in current designs for near term reactors where sensible heat recovery is not a requirement, (e.g., INTOR and FED) hydraulic and mechanical responses are nevertheless an important area of engineering uncertainty from the standpoint of reliability and integrity of FWBS systems in these devices. In subsequent fusion such as ETR and DEMO higher power and higher temperatures for the first wall structures are anticipated and these problems will be exacerbated. Although computational methods do exist to model the performance of simple heat transfer interfaces, the combined thermal and mechanical response of a fully structured first wall component (including bends, welds, fasteners, supports, etc.) subjected to time varying and transient conditions cannot be modeled accurately (or reliably) without engineering simulations that provide calibration, verification, and a fixed (input) parameter data base for the model. Furthermore, in the analytical descriptions of fully structured components, the failure modes and limiting performance parameters are more difficult to assess; hence, engineering testing appears to be more reliable and more cost effective as a near term approach to evaluation of component performance especially since any modeling formalisms developed for a given component must ultimately be subjected to engineering test in any case. Conducting the engineering tests and model development activities in a closely-tied, parallel fashion should permit timely creation of the needed design capability.

Of equal importance with the need for engineering tests on the performance of heat removal systems is the parallel need to develop data on the hydraulic and mechanical responses for other specialized first wall components such as limiters, protective liners, disruption armor, etc. For these types of components even larger normal operational and transient heat fluxes and energy depositions are expected than for heat removal systems. Work on some of these specialized first wall components should parallel work on first wall surface heat removal systems.

4.2 Technical Basis for PE-II (Blanket/Shield Thermal-Hydraulic Thermomechanical Testing)

Within the general scope for PE-II of thermomechanical and thermal-hydraulic testing of blanket and shield component facsimiles, the present near term emphasis is on engineering problems in solid breeding systems. (The first priority in the initial design plan of November 1980 was for testing of the "ETF/FED blanket/shield matrix".) This redirection is consistent with developments in the fusion program and also relects the evaluation of blanket and shield engineering issues performed during Phase 0 of the program.

In PE-II the blanket and shield may be treated separately with respect to many aspects of their thermomechanical and thermal-hydraulic performance, although the blanket and shield are closely coupled in other respects; (i.e., together they determine the nuclear performance of the breeding blanket, the radiation environment and therefore affect the integrity and lifetime of magnet systems and other radiation sensitive components, the extent of induced radioactivity outside the FWBS perimeter, and the accessibility of the device for maintenance and repair.)

The technical basis for the detailed work in PE-II was established by an assessment in Phase 0 in which engineering issues were identified for many styles of blanket and shield configurations. Studies of engineering issues for solid breeder systems were given high priority primarily because of the attention given these systems in recent design studies and the potential for providing key data fairly quickly which will enable designers to evaluate the credibility of blanket designs using solid breeders.

There are also appropriate subjects that will require investigation in liquid metal breeder systems and are within the general scope of PE-II. An example is detailed thermal-hydraulic characteristion of MHD pumping losses in reactor relevant configurations, i.e., with headers, flow straighteners, baffles, etc. However such work is not yet scheduled in the program because of the precedence given to solid breeders.

Reactor designs utilizing solid breeders show great potential but are not yet wholly convincing for several reasons. First, there is very little margin in most cases to permit increases in the overall tritium breeding should uncertainties in neutronics or the allotment of (high flux) space for the blanket ultimately require increased (or more efficient) production. Second, the data are extremely limited on the operating conditions in which tritium will easily migrate out of the breeder material (high temperatures favored) and the breeder will still remain chemically and physically stable for long periods of time (low temperaures favored). Third, and most important for this program, basic data on system interactions, such as heat transfer from the breeder to the coolant and stability after repeated heating and cooling, are not yet available for use in comparative design evaluations of solid breeders for reactor designs. The heat transfer across the interface between the breeder and coolant structure is currently the primary source of uncertainty in designers' ability to predict the operating temperature of solid breeders. The problem is simply lack of data on relevant heat transfer systems and this problem is compounded by the potential for sensitivity to changes in physical dimensions of the breeder and structure due to differences in thermal expansion. Ultimately design solutions to enhance or control the conductivity of the interface through bonding (or other solutions) may be required.

Li_2O is of special interest as a solid breeder because its lithium atom density of 1.36×10^{23} atoms/cc is roughly two times greater than other candidate solid breeders. The preference for Li_2O also brings more stringent requirements for control of impurities (H_2O and CO_2 in particular) in the purge gas used to collect tritium because these impurities are readily assimulated and small concentrations are expected to produce deleterious effects on the microchemical and physical stability of Li_2O. Thus, establishing a useful temperature range for Li_2O operation requires that these impurity effects are understood to some degree and limits acceptable for reactor operation are demonstrated in practice.

Baseline data on thermodynamic equilibria and tritium combination reactions are being generated in the US Fusion Reactor Materials Program, as are data on physical properties and radiation effects. Also, tritium production and recovery are being studied in radiation experiments (e.g., TRIO). Because radiation experiments are expensive and the number of variables must be pared, the most cost effective approach to obtain the required data on impurity effects on breeder systems with reactor-relevant configurations is to perform (less expensive) out-of-reactor tests (where tritium production and recovery does not occur). Initially such tests will study the changes in isothermal systems and also the effects of temperature cycling (does cracking occur?) Follow-on tests will study the effects of purge gas flow with controlled impurity levels on breeder stability in the presence of thermal gradients similar to those expected in a fusion reactor; later, long term integral tests will be performed.

Along with the well recognized need for engineering studies in PE-II there is the implicit requirement that the experimental capability to perform appropriate tests either exists or can be readily developed. Meeting this requirement is less straightforward in PE-II than in the other test program elements. In particular, the internal (bulk) heat generation in FWBS components produced by nuclear heating in a fusion device is difficult to simulate by methods other than nuclear heating. The thermal gradients in the blanket and shield structures and in the breeder material are extremely important to meaningful simulations of the performance of these systems. The experimental conditions of interest for preliminary "separate effects" tests (e.g., one directional heat transfer) can be provided fairly easily. For integral tests where the objective is to provide a simulation of a reactor relevant physical configuration (a blanket facsimile with several "unit cells", i.e., multiple coolant passages and associate breeder material) with appropriate thermal gradients, purge gas flow, etc an in-pile integral tests may be justified. However, useful alternatives to in-pile integral tests will also be developed and evaulated. The need to develop appropriate methods for heating of integral engineering tests introduces a constraint that will become more pressing as near term "separate effects" tests are concluded and the program proceeds with integral tests.

4.3 Technical Basis for PE-III (FWBS Electromagnetic Effects Evaluation/Testing)

The first wall, the blanket, and the shield of a magnetic fusion reactor are closely coupled magnetically with the plasma current and with the magnet systems that produce the confining, stabilizing, and heating fields. Examples of some of the electromagnetic reactions and effects produced are (1) plasma stabilization and reduction of plasma motion; (2) electromagnetic back-lash from plasma or confinement system disruptions; (3) delay and distortion of the penetration of igniting, heating, and stabilizing pulsed fields generated outside the blanket/shield region; (4) eddy current forces and torques on FWBS components due to pulsed or cross-field interactions; (5) magnetohydrodynamic braking of flowing liquid metals; and (6) magnetization interactions with ferromagnetic materials.

In most present day fusion physics devices, the vacuum wall is the only component between the magnet systems and the plasma and the wall thickness is either kept small or fabricated with insulating current breaks so that time varying magnetic fields generated by the external coil systems are transmitted to the plasma region nearly instantaneously. This instantaneous field penetration will be much more difficult to accomplish in neutron producing power reactors because the magnets are separated from the plasma by a meter-thick bulk shield, a breeder blanket and a first wall with some type of interconnected cooling passages, all of which increase considerably the volume of conducting material between the external coil systems and the plasma.

It is doubtful that the entire spectrum of electromagnetic design requirements for FWBS systems has been met in any fusion reactor conceptual design. The effects of concern are calculable in principle using Maxwell's equations for electromagnetic fields. However, the FWBS system is so complex in terms of geometry, composition, etc. that the realization of a predictive capability for design requires a program combining the development of computational tools and electromagnetic experimert. The experimentation will be particularly important in verifying the computational methods, providing calibration of empirical relationships, and uncovering unprogrammed effects so that no serious electromagnetic incompatibilities are encountered in the ETR and follow-on devices.

4.4 Technical Basis for PE-IV (Assembly, Maintenance, and Repair Evaluation/Testing)

The technical justification for work on PE-IV is derived from an awareness that assembly, maintenance, and repair (AMR) issues have unique and in many instances critical impacts on fusion reactor design strategies and gross plant economy. Many conceptual fusion reactor studies of the last ten years have addressed these issues from the standpoint of design credibility, mitigation of the impact of component failures, and optimization of capital and of operating costs. There are a number of well recognized fusion AMR concerns that relate to (1) manufacturability; (2) remote assembly and disassembly; (3) the relationships between repair and replacement schedules, reactor downtime, and plant economics; and (4) the handling within a plant of activated structural segments and materials. Although meeting AMR requirements is profoundly important to fusion economics and safety, little dedicated generic research and development has been conducted. Some detailed concept-specific AMR has been that done for the TFTR, but this device contains only a few of the features of a power reactor FWBS system.

The scope of potential work on AMR issues is vast and the need for work in this area is recognized. In the face of the vast need for engineering information on a variety of AMR issues, the strategy of the FWBS Program is to apply its comparatively limited effort in two parallel directions. The first is to collect existing pertainent information in a guidebook for designers and the second is to proceed sequentially with a series of hardware development tasks for which the rationale is summarized below.

Previous comparative studies of reactor designs have shown that the most extensive scheduled maintenance requirement is changeout of the first wall and blanket and that this can be accomplished most efficiently (i.e. minimum downtime) by replacement of large sectors of the torus through use of maintenance equipment external to the plasma chamber and by using only external access. The neutron dosage of experimental machines may not reach the level required for periodic first wall replacement but it is essential that the efficiency of this type of configuration be demonstrated. There are other approaches which require access to the first wall from within the plasma chamber, however, such maintenance is very time consuming, especially when a major part of the first wall is affected.

Accordingly, development tasks critical for designing the large sector configuration were sought. Two have been selected which, if solutions are unavailable, could force the design away from large sectors and towards internally maintained devices. Lack of these capabilities would have a major impact on reactor configuration.

One item is the development of connectors that will provide a controlled conducting path between sectors of a first wall. A conducting first wall is currently believed to be essential in tokamaks to minimize plasma disruption effects and is being recommended for all tokamak configurations. (The basic information generated also has applications for high current leads and jumpers which require remote connection and disconnection.)

Another item for development, critical to the design of FWBS systems in all advanced fusion devices, is remote joint systems for coolant, vacuum and various other lines and closures. Those joint systems required for accessing or removing the first wall, blanket or shield were considered more critical for PE-IV. Studies of tokamak reactors indicate that breaking and making joints for replacement of the large sectors requires approximately 25% of the total downtime, when advanced remotely operable joint concepts are utilized. The design of joints to reduce appreciably or even achieve this downtime is the objective of this present program's investigation. The need for high availability and implied requirements are similar for mirror reactors.

A joint in a large rectangular vacuum duct which must be disconnected for access to or replacement of the first wall, blanket and shield sectors was selected as a representative generic case. This selection was made primarily because various design concepts exist for most coolant lines or relatively small diameter circular vacuum ducts but not for large rectangular ducts. Development of mechanically joined seals were given priority over welded closures because of the more generic applicability of a mechanical joint (the primary problem in remotely welded joints is the more design specific task of obtaining proper tracking and configurational conformance of the welding device) and the benefit of providing more definitive engineering data for designers on alternatives to welded joints and their applicability.

Specific problem areas that have been highlighted for the ETF/FED (in the mission statement or in the FY-1980 R & D assessment) and are also pertainent to fusion reactors include the development of (1) heavy duty remote maintenance systems (transport pallets and the like) together with the required remote viewing equipment; (2) leak detection, location and repair techniques and tools; (3) electrical fault, detection, location, and damage assessment equipment; and (4) remote connection/sealing (e.g., welding) and disconnection/cutting technology suitable for radiation intensive, high vacuum environments. While much of this development work will tend to be concept dependent, there should be considerable value to (1) an early assessment of AMR technology status and (2) the generation of semiquantitative (nomographic-type) AMR design tools. It also appears possible that some early generalized development work on remote leak detection in fusion specific vacuum environments and coolant channel connection/disconnection methods could lead to useful concepts for several of the more difficult AMR concerns for advanced fusion devices.

4.5 Technical Basis for Integration of FWBS Design Data and Development of Design Tool (originally TPE V)

The need for an organized activity that will assimilate and evaluate data and promote development and verification of computational methods was apparent during the course of the FWBS program planning exercises of FY 1980 (see Appendix B). As a result of guidance from the Planning Workshop, the responsibililties for this activity have been directed to the Management and Technical Coordination Center (MTCC) but will include participation by other organizations as appropriate. Because of funding constraints, there has been limited effort on this activity but the need remains and will become more pressing as Phase I of the FWBS Program is fully implemented. As basis, scope, and corresponding technical details are developed they will be incorporated into the work of the MTCC, and descriptions thereof will appear in subsequent versions of the Program Plan. Interpreting experimental data, devloping analytical methods and disseminating the resulting information will therefore be a key activity. These types of analyses are extremely important. They show the design implications and sensitivity of the data, provide a working example where the pros and cons of design applications can be evaluated in a meaningful and quantitative way and are probably the most useful process for identifying in detail complementary data needed from other sources (e.g., materials behavior).

Section 5. FWBS Program Organization

The organizational structure for technical direction of the First Wall/Blanket/Shield Engineering Test Program (FWBS Program) is shown in Figure 5.1. and the participants are listed in Table 5.1. The program is sponsored by the DOE Office of Fusion Energy. Argonne National Laboratory has the responsibility for technical direction of the program through the Management and Technical Coordination Center (MTCC) and performs one of the four Program Elements (PEs) industrial contractors perform the other three. In PE-II and in PE-IV, the effort is shared between a principle contractor and a major subcontractor.

Table 5.1. FWBS Program Participants

Performing Organizations

MTCC:	Argonne National Laboratory (Argonne, IL)
PE-I:	Westinghouse Electric Corporation (Pittsburgh, PA)
PE-II:	General Atomic (San Diego, CA)
	EG&G Idaho-subcontractor (Idaho Falls, ID)
PE-III:	Argonne National Laboratory (Argonne, IL)
PE-IV:	McDonnell-Douglas Astronautics Company (St. Louis, MO)
	Remote Technology Corporation-subcontractor (Oak Ridge, TN)

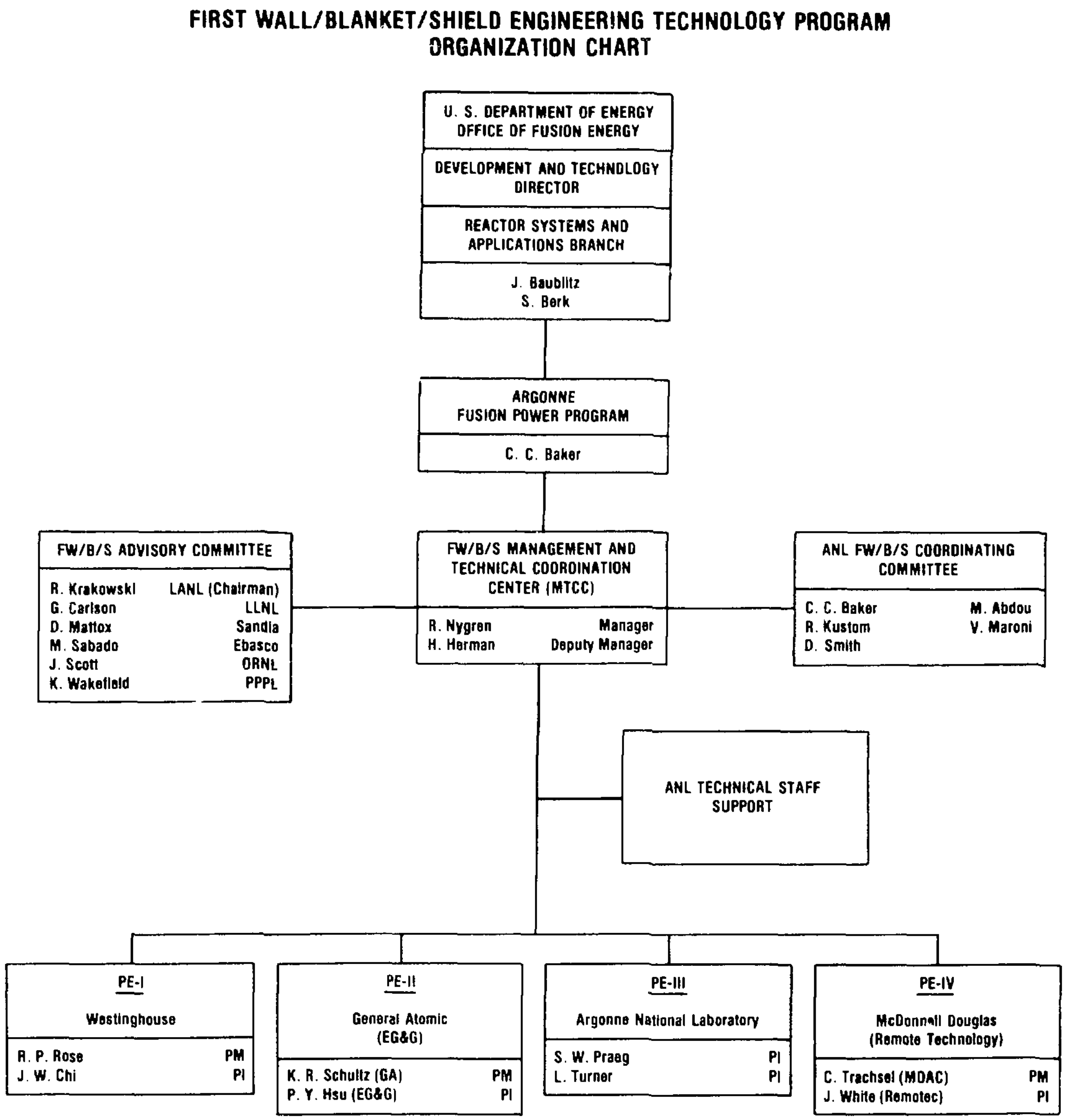

Fig. 5.1 Organization Chart of FWBS Program

5.1 Program Elements

The four Program Elements (PEs) of the FWBS Program are defined briefly below. The programmatic evolution of the scope of the PEs is described in Appendix B.

PE-I: Non-nuclear thermal-hydraulic and thermomechanical testing of first wall components with emphasis on surface heat load and heat load transient effects (for example plasma disruption).

PE-II: Non-nuclear and nuclear testing of FWBS components and assemblies with emphasis on bulk (nuclear) heating effects, integrated FWBS hydraulics and mechanics, blanket coolant system transients, and nuclear benchmarks.

PE-III: FWBS electromagnetic and eddy current effects testing, including pulsed field penetration, torque and force restraint, electromagnetic transient response, reactions of ferromagnetic materials, liquid metal MHD, etc.

PE-IV: FWBS assembly, maintenance and repair (AMR) studies focusing on generic AMR criteria, requirements, and critical problem areas including analysis of downtime and operational scheduling, technology for rapid assembly and disassembly, tools for leak detection, and advanced methods for remote handling.

Originally, a fifth PE was also identified and is described below. In the subsequent implementation of the program under DOEs direction this important technical area was incorporated into the responsibilites of the technical management effort.

(PE-V) FWBS technical evaluation and data integration with emphasis on developing background, basis, and criteria for the engineering tests conducted within the other PEs and preparation of integrated data packages for use by the fusion design community.

As the program progresses and as other engineering issues related to the FWBS are identified and their scopes outlined, the existing PEs will be expanded and additional PEs may be initiated to meet programmatic needs.

5.2 Reporting and Responsibilities of Participants

Detailed information on reporting and the responsibilities of program participants is given in Appendix A. The milestone schedule showing MTCC activities (presented in Section 5.4) also indicates many of the formal reporting and review activities.

5.3 The Management and Technical Coordination Center (MTCC)

The MTCC is a management branch within ANL's Fusion Power. Its manager, Richard E. Nygren, and deputy director, Harold Herman. are responsible for the technical direction of the FWBS Program. The MTCC is supported in its technical management role by the staff of the ANL Fusion Power Program and by two groups, the Advisory Committee and the Coordinating Committee, whose memberships are given in Tables 5.2 and 5.3.

Table 5.2 Advisory Committee

R. Krakowski, Chairman
Los Alamos National Laboratory (Los Alamos, NM)

G. Carlson
Lawrence Livermore Laboratory (Livermore CA)

D. Mattox
Sandia National Laboratory (Albuquerque, NM)

M. Sabado
Ebasco (at Princeton Plasma Physics Laboratory)

J. Scott
Oak Ridge National Laboratory (Oak Ridge, TN)

K. Wakefield
Princeton Plasma Physics Laboratory (Princeton, NJ)

Table 5.3 ANL Coordination Committee

Charles Baker, Chairman
Mohamed Abdou
Bob Kustom
Dale Smith
Vic Maroni

Argonne National Laboratory (Argonne, IL)

The MTCC acts as the technical manager for DOE in the FWBS Program and has the following general responsibilities: development, implementation and direction of the technical program; contract administration and assessments of technical performance; and technical interfaces with other fusion programs and projects. Table 5.4 summarizes these responsibilities.

Table 5.4 Responsibilities of the MTCC

1. Implementation of the OFE overall programmatic guidance
2. Technical, administrative, and financial management of the FWBS Program
3. Technical analysis and evaluation of the four test program elements
4. Integration of data into packages, formats and calculational models useful for design applications
5. FWBS planning and periodic update of FWBS Program Plan and the Detailed Technical Plan for each PE
6. Approval of PE test proposals prior to initiation of work
7. Approval of supporting participant selection
8. Development of technical interfaces with other magnetic fusion energy R&D programs
9. Development of financial and programmatic recommendations for OFE
10. Submission of a quarterly programmatic and financial status report to OFE

The second quarter of FY82 marked the onset of experimental work in the Phase I activities and there has been a corresponding transition in emphasis in the activities of the MTCC. Programmatic development, implementation and contract administration remain as necessary functions but require less effort. MTCC activities now focus more heavily on (1) program direction, (2) assessments of technical performance and (3) developing and maintaining working interfaces with other fusion programs and projects. Implicit in the satisfactory functioning of the MTCC is a fourth element: (4) continuing analytical evaluation of both experimental data and projected needs for data. The following discussion describes these four MTCC activities.

Program Direction - The essential character of the MTCC and ANL in directing the technical goals of the FWBS Program is leadership based on a broad and up to date understanding of the directions, strategies, problems and current work in the fusion program. The recognized products of ANL's Fusion Power Program such as the STARFIRE and DEMO studies, testify to the technical competence and (collectively) broad expertise of the ANL staff. Furthermore ANL has developed strong working relationships between itself and other institutions and projects in fusion, especially in areas related to the FWBS Program. Argonne's role in the engineering aspects of fusion development and current work in fields related to FWBS Program, e.g., Argonne's lead roles in analysis of nuclear systems for FED and development of solid breeders in the materials program, provide a continuing basis for leadership and technical guidance in the management of the FWBS Program.

Technical Assessment - Assessments of technical performance of the contractors (including ANL in PE-III) are critical for achieving successful experimental results and the technical manager of the FWBS Program has the responsibility to prescribe and oversee an adequate procedure for these assessments. The MTCC uses two forms of technical assessment, (1) formal reviews and (2) independent evaluation of problems. Formal reviews are useful as forcing functions, for exchange of information and for identifying general problem areas. Three types of reviews are held in the FWBS Program: (1) DOE Program Reviews - MTCC and contractor presentations to DOE/OFE; (2) ANL Program Reviews - MTCC and contractor presentations to ANL management and FWBS Advisory Committee; and (3) ANL Contractor Reviews - Contractor presentations to MTCC.

The importance of in-depth technical assessment during the planning stage of the experimental work cannot be overemphasized. It is the attention to details in configuration, instrumentation, assembly procedures, pre-test and post-test characterizations of samples, etc. and forethought aimed at any and all potential problems that keeps experimental work "on track" technically.

Interface with Other Fusion Programs - An important objective of the MTCC in FY82 is to extend and to formalize the interfaces between the FWBS Program and many other fusion programs. Section 6 of this program plan describes the FWBS Program Interfacing Plan. An informal network of interfaces between the FWBS Program and many other fusion programs already exists simply because of the working relationships of the ANL staff. Some examples of these working relationships have already been given. Two of the more important program interfaces are with FED and with the DOE Fusion Reactor Materials Program. ANL has strong ties in both programs. Working groups, such as the FED Nuclear Technology Group chaired by ANL during FY81 and the on going FED/INTOR working groups on nuclear systems and on testing directed by Mohamed Abdou are examples. The ANL Fusion Power Program has staff members (R. Mattas and D. Smith) in the Materials Program and the FWBS Program Manager, Richard Nygren, actively contributed in the Materials Program for several years and was a member of the FED Design Team in FY1980 and 81.

Analysis and Methods Development - "Analysis and Methods Development" here refers to the specific activity of interpreting experimental data primarily from the FWBS Program, developing analytical methods and applying these data and methods in sample calculations useful to fusion designers. To some degree this type of analysis and evaluation is performed on a limited scale as part of the program direction and technical assessment functions; however this key activity must be expanded in the future. The ultimate and necessary objective of this program is to provide not only raw data but the verified calculational capability to apply these data to design situations. The development and excerising of these calculational tools must occur in parallel with the development of data in order to demonstrate that critical elements of the data base have been identified and that the calculational models are relevant, have adequate accuracy, and can be used successfully. The successful development of raw data and calculational tools depends on their parallel evolution through continuing iterations of their interdependent objectives. Moreover, this type of analysis and evaluation shows the design implications and sensitivity of the data, and provides working examples where the pros and cons of design applications can be evaluated in a meaningful and quantitative way.

Some diminishing of scope in the near term program has resulted from budget constraints that resulted in a lower growth rate in the program than had been initially anticipated and the temporary dormancy of the analysis and evaluations activity has been an unfortunate but necessary result. The lack of activity in this area is a severe shortcoming in the current embodiment of the program and is not consistent with the overall objectives of the FWBS Program.

5.4 MTCC Activities

The activities of the MTCC are summarized below and in the accompanying milestone chart (Fig. 5.2.). This categorization of activities is useful for defining "deliverables" and milestones but tends to demphasize the continous effort necessary in activities such as evaluations of performance, planning, interfacing and general problem solving, described briefly in the previous subsection.

Implementation - Development of an overall program mission and general scope of work and selection of contractors lead to implementation with Phase 0. Development of detailed technical plans for each PE was completed in Phase 0 and marked the implementation of Phase 1, the onset of the experimental program.

Administration - The primary functions in this activity are contract administration and organizational development. Contracts for Phase 0 and Phase 1 have been awarded. The management structure of the MTCC was completed in the fall of 1981 with the addition of Dr. Richard Nygren as Program Manager and the formation of the FWBS Advisory Committee, a select panel of fusion experts from outside ANL.

Evaluation - Evaluation by the MTCC is a continuous activity that includes assessments of the technical performance in each PE, reviews of documents prepared by the contractors, and general troubleshooting on experimental plans, configurations, procedures, etc. In the future this activity will also include review and technical assessments of experimental data. Some effort in data review has already begun for PE-I. The MTCC has been assisted in its evaluations by the Advisory Committee which participated in program reviews on October 30, 1981 and June 15, 1982 and by the Coordinating Committee at ANL which has met frequently with the MTCC managers.

Planning - The initial major planning efforts have been accomplished with the original program plan, the development of Detailed Technical Plans for Phase 1 for all PEs and the revision of the program plan. The budgetary turmoil in FY82-83 has increased the attention to alternate scenarios and planning exercises. Another aspect of programmatic planning is the continuing review of ongoing and planned work in the fusion program and using this information to confirm or redirect the course of experimental investigation in the FWBS Program. A separate activity under planning is defining the mission for an Integrated Test Facility.

ITF Mission Statement - The importance of an Integrated Test Facility (ITF) that will provide the capability for engineering tests on first wall, blanket and shield components (or facsimilies) prior to and in parallel with FED has already been acknowledged in the FED Technology Report and the Engineering Development Plan for Fusion Power Systems. The MTCC will define more clearly the mission of an ITF and develop some preliminary ideas on possible system requirements. A work plan for this effort has already been prepared. The objective in FY82 is to prepare a document that recommends the mission and general concept for the ITF. Section 7 contains more information on ITF.

Interfacing - This program plan specifies a plan for developing interfaces between the FWBS Program participants and other fusion programs, projects and institutions. Among the tasks in this activity during FY82 are the publication of a newsletter and the organization of a network of specific contracts (individuals) for especially active interfaces such as FED/INTOR, TMNS and several elements of the US Fusion Reactor Materials Program. Section 6 gives details of the interfacing plan.

Reporting - Formal reporting to ANL management is done through monthly reports and periodic briefings. Formal reporting to DOE consists of highlights submitted biweekly, quarterly reports and yearly program reviews. Details of the responsibilities for reporting are given in Appendix A.

Section 6.

FWBS Program Interfaces with Other Fusion Programs

The First Wall/Blanket and Shield Engineering Technology Progam (FWBS Program) will use, develop and supply information on fusion technology. Efficient interfaces with many fusion projects and programs are necessary for the FWBS Program to function and are in fact implicit in its goals. This section describes the basis for a network of interfaces to be developed as part of the long range objectives of the FWBS Program. The general functions that these interfaces will fulfill are apparent in the following five perspectives on the program.

First is the development of an industrial base of expertise in fusion technology. In parallel with the technical objectives of the FWBS Program is a basic programmatic objective to foster industrial participation with the aim of incorporating the capabilities in industry into the problem solving resources of the fusion program.

Second is the dependence of the FWBS Program on raw data, design concepts and engineering problems from other fusion programs. For example, the information needed to establish testing strategies for the FWBS Program includes data from the Fusion Reactor Materials Program, design concepts from STARFIRE and TMNS and engineering problems identified in the INTOR/FED studies.

Third is programmatic relevance. For the FWBS Program, relevance comes from vigilant pursuit of the engineering problems and potential solutions being identified in other programs.

Fourth is the distribution of experimental data. Experimental results, partial results and test plans must be distributed promptly to the appropriate users of the data in order to realize the greatest benefit of the FWBS Program to other programs and to fusion development overall.

Fifth and final is overall coordination of the fusion program. The growth of the fusion program in the 1980s that is necessary to advance the engineering feasibility of fusion will introduce many new roles in R&D support for the fusion program and the network of programs and disciplines that interact will become increasingly more complex. Recognized channels of communication will be needed as a basic administrative tool and to assess the contributions to and from individual programs in the integrated effort.

6.1 Development and Implementation of the FWBS Program Interfacing Plan

An interfacing plan for the FWBS Program has been developed based on the detailed scope of work established during Phase 0 of the program and on related areas in other fusion programs. Its basic elements are listed in Table 6.1. and described in Sections 6.2–6.5.

Table 6.1 Basic Elements of FWBS Program Interfacing Plan

A. Network of contacts
   1. FWBS Program Advisory Committee
   2. Liaisons with projects and programs with areas strongly related to work in the FWBS Program.
   3. Recipients of general information on the program.

B. Activities to promote exchange of useful information
   1. A quarterly "highlights" bulletin with wide distribution.
   2. Workshops and working meetings.
   3. Publications, conference presentations, and topical reports.

C. Joint participation in FWBS experimental efforts
   1. Partnerships in experiments.
   2. Other programs using facilities of the FWBS Program.
   3. FWBS Program testing with facilities outside the FWBS Program.

The Management and Technical Coordination Center (MTCC) at ANL will initially be the primary point of contact for all interfaces and will continue adequate administrative control over these interfaces to assure that the following objectives are accomplished:

1. Requests for information from other programs are directed to the proper source and a pattern of use of the contacts is developed and encouraged.
2. Requests for information from other programs are coordinated among the TPEs in such a way that duplicate and repetitive requests to the programs are minimized.
3. Incoming requests for information on aspects of the FWBS Program are handled by the MTCC so that duplication and repetitive requests to contractors are minimized.

The implementation of this interfacing plan will occur during FY82 and FY83 with a major effort during FY82 to establish the organizational framework necessary to carry forward the interfacing plan. The MTCC will have the responsibility for implementing the interfacing plan but will seek assistance from DOE Office of Fusion Energy in the areas listed below.

1. Identification of contacts in fusion programs and projects.
2. Distribution list for "highlights bulletin".
3. Arrangements for joint participation (other programs) in experimental work in the FWBS Program.
4. Arrangements for working meetings and workshops involving participants from other fusion programs.

6.2 Network of Contacts

The FWBS Program will establish two types of direct communications with colleagues in the fusion community. The first is a system of liaisons; the second is a wide distribution of program information to the fusion community.

The MTCC will continue to establish active liaisons with projects, programs, design studies and working groups in which the work is related directly to ongoing efforts in the FWBS Program. Table 6.2 summarizes the types of active liaisons that will be sought as the program matures. The left column shows various programs, projects, etc. The right column characterizes the interface by the nature of information exchanged and shows anticipated contributions both to and from the FWBS Program.

Table 6.2 differentiates between three types of information that will be exchanged between programs.

1. (E) Experimental data and analysis - information used directly for engineering and problem solving.
2. (D) Design concepts and requirements - information used in FWBS program or other programs to correlate test results with programmatically relevant problems and to define test parameters.
3. (P) Program needs - results and information with which other programs extract and use to formulate, verify or redirect their own program goals.

For most of the active interfaces indicated in Table 6.2 the FWBS Program is both a supplier and a user of information from the various activities. Along with the exchanges of complementary data, methods of analysis, experimental procedures, etc. between programs there is also a general trend of data flowing from basic R&D programs into engineering programs. The primary "developer" role of the FWBS Program is in engineering data for design studies and projects.

Table 6.2 FWBS Program Interfaces - Summary

	FWBS Program Role	
Programs	User	Developer
TRIO	E,P	E
Special Purpose Materials	E	E
High Heat Flux Component Dev.	E	E
Alloy Development for Irr. Perf.	E	-
Studies		
FED/INTOR	D,P	E
Mirror Advancer Reactor Study	D,P	-
DEMO/STARFIRE	D,P	-
Future Blanket Studies	D,P	E
Future ETR Studies	D,P	E
Projects		
TFTR	D	E
MFTF-B	D	E
Working Groups		
FWBS Program Advisory Committee	P	-
Analysis and Evaluations Task Group (Materials)	E	P
Future MFE Advisory Committee Support	-	P
Future International Exchanges	E,P	E,P

E = experimental data and analysis, D = design concepts and requirements, P = program needs

6.3 Exchange of Information with Other Programs

The FWBS Program will continue to establish and maintain close working relationships with other programs doing related work. Exchange of information will occur by letter, phone and occasionally through working meetings and workshops. Wider distribution of information will continue to occur through publications, presentations at meetings and conferences, topical reports and quarterly distribution of a highlights bulletin.

The FWBS Program Highlights Bulletin will begin in FY82 as a quarterly record and will provide brief descriptions of such items as test results, facility development, recent publications, forthcoming meetings and workshops and planned tests. This bulletin will be the mainstay for distribution of non-detailed information to interested researchers in the fusion community. The intended distribution of the FWBS Program Highlights Bulletin will include major fusion projects and programs, their administrative counterparts in the DOE Office of Fusion Energy and industrial companies who expressed interest during the inception of the FWBS Program.

FWBS Working Meetings and Workshops - At appropriate times the MTCC will draw from the expertise and technical accomplishments in other programs through working meetings and workshops. The objectives of such meetings will be to solicit current information and ideas on specific technical issues and to obtain feedback from experts outside the FWBS Program on data, test plans or methods development in the FWBS Program. For example, two small workshops have been held for PE-IV. In each case the meeting lasted one day, participation was limited to about ten people, and the technical merits and problems of experimental work on the respective topics (remote fastners for joints and remotely activated electrical contactors) were very effectively discussed. As the program matures and experimental data and computational methods evolve, then information meetings, probably in the form of workshops with greater participation, will become useful for interfacing with interested members in the fusion community.

Working Meetings and Workshops in Other Programs - Current arrangements in the FWBS Program do not include support for participation in meetings of other programs by participants in the four TPEs. However contributions to other programs are often possible because the individual participants are simultaneously involved with other programs. The contribution of information from the FWBS Program in such situations is encouraged. The FED Workshops and INTOR design activities are good examples of particularly useful forums for developing and exchanging design information.

The Advisory Committee in the FWBS Program already includes representatives from the materials program, TFTR, the mirror program, etc. The participation of the MTCC managers in planning and working meetings in other programs would also seem prudent. The MTCC will work with the DOE Office of Fusion Energy to implement this type of participation. One example, recommended by the MTCC, is participation in the Analysis and Evaluation Task Group of the US Fusion Reactor Materials Program.

Publications - In addition to the FWBS Program Highlights Bulletin the FWBS Program will produce publications of several types available to the public. A current publications list is given in Table 6.3 . Articles in open literature or published in conferences are encouraged. The program participants are expected to submit notification of their intentions for such publications to the MTCC in advance so that the contributions from different participants and from the MTCC itself can be coordinated.

6.4 Joint Participation in the FWBS Experimental Efforts

A variety of opportunities are anticipated for the productive collaboration between the principal contributors in the FWBS Program and researchers in other programs. A few hypothetical examples are given below to illustrate the possibilities.

1. Joint participation in FWBS experiments - (example) FWBS Program in collaboration with US Fusion Reactor Materials Program would develop an integral systems test on performance of solid breeders. The FWBS Program would develop test configuration and instrumentation and evaluate thermal

TABLE 6.3 Documents Issued in FWBS Program

Publications

Program Plan for the DOE/Office of Fusion Energy First Walll/Blanket/Shield Engineering Test Program, November 1980, preparedby Argonne National Laboratory Fusion Power Program for the DOE Office of Fusion Energy.

R. E. Nygren, H. Herman and C. C. Baker, "A Test Program on Thermomechanical and Thermal-hydraulic Aspects of Nuclear Systems for Magnetically Confined Fusion Power Reactors", Nuclear Engineering and Design 68 (1981).

H. Herman, C. C. Baker and V. A. Maroni, "Initial Progress in The First Wall, Blanket and Shield Engineering Test Program for Magnetically Confined Fusion Power Reactors", Proceedings of the 9th Symposium on Engineering Problems of Fusion Research, held in Chicago, IL October 26-29, 1981.

W. F. Praeg, L. R. Turner, J. A. Bywater, R. J. Lovi and R. B. Wehrle, "An Experimental Facility to Study Electromagnetic Effects for First Wall, Blanket and Shield Systems, Parts I and II, Ibid.

R. E. Nygren, "The First Wall/Blanket/Shield Engineering Test Program," Conference on Fast, Thermal and Fusion Reactor Experiments, Salt Lake City, Utah, April 12-25, 1982.

J. W. H. Chi, et al., "TPE-I and Experimental Studies on Fusion First Wall Components in ESURF," ibid.

L. R. Turner, "The FELIX Program of Experiments and Code Development," Second Eddy Current Seminar, Rutherford Appleton Laboratory, United Kingdom, April 27-29, 1982.

E. R. Hager and R. E. Field, "Remotely Maintainable Connectors for Fusion Development," American Nuclear Society 1982 Annual Meeting, Los Angeles, California, June 6-11, 1982.

H. S. Zahn, "Remotely Maintainable Magnetic Confinement Fusion FW/B/S," ibid.

D. B. Hagmann, C. A. Trachsel, L. S. Masson, "Development Plan for Fusion Maintenance," ibid.

C. A. Trachsel and H. Herman, "Fusion Reactor Remote Maintenance and Repair Operations Simulation," ibid.

Reports

T. C. Varljen., J. W. L Chi., H. Herman., Progress in Engineering Simulation Testing of Fusion Reactor First Wall Commponents (Proc. 3rd Technical Committee Meeting and Workshop on Fusion Reactor Design and Technology, Tokyo, 1981) to be published.

C. C. Baker., H. Herman., V. Maroni., L. Turner., R. Clemmer., P. Finn., C. Johnson., M. Abdou., First Wall & Blanket Engineering Development for Magnetic Fusion Reactors, (Proc. 3rd Technical Committee Meeting and Workshop on Fusion Reactor Design and Technology, Tokyo, 1981) to be published.

A. R. Veca., E. Hoffman., C. P. C. Wong., "TPE-II Data Needs Assessment Report", GA-C16571, Oct. 1981.

G. A. Deis, et al., "Evaluation of Alternative Methods of Simulating Asymmetric Bulk Heating in Fusion ReactorBlanket/Shield Components", EG&G, Idaho report EGG-FT-5603, Oct. 1981.

A. R. Veca, et al., Development of a Non-nuclear Testing Strategy for TPE-II", General Atomic Co. report GA-C16509, November 1981.

G. A. Deis, et al., "Development of a Nuclear Test Strategy for Test Program Element-II", EG&G Idaho report EGG-FT-5651, November 1981.

J. W. H. Chi and R. P. Rose, "Detailed Technical Plan for Test Program Element I of the First Wall/Blanket/Shield Engineering Test Program", Westinghouse Electric Corporation Fusion Programs, December 1981, WFPS:TN-81-030.

"Detailed Technical Plan for Phase I of TPE-II", General Atomic Company, February 1982, GA-C16655.

L. R. Turner and W. F. Praeg, "Detailed Technical Plan for Test Program Element-III of the First Wall/Blanket/Shield Engineering Test Program", Argonne National Laboratory, March 1982, ANL/FPP/TM-155.

H. S. Zahn et al., "First Wall/Blanket/Shield Engineering Test Program--Test Program Element IV, Assembly Maintenance and Repair--Final Report - Phase O, Vols, I and II" McDonnell Douglas Astronautics Company, January 1982, MDC-E2484.

and hydraulic performance. The Materials Program would specify the solid breeder material (grain size, porosity, etc), prepare and characterize the material and perform post-test evaluations.

2. Outside use of unique facilities in the FWBS Program - (example) Groups developing experiments for TFTR or instrumentation for MFTF-B tests or for ETR would pretest hardware to investigate the effects of pulsed field on the response of instrumentation -- (example) ETR Project would build prototypic limiter blade and perform surface heating tests in ASURF.

3. FWBS Program use of other facilities - (example) FWBS Program would develop hardware mockups for a study on remote handling using equipment at TFTR or FMIT.

4 Collaboration on methods development - (example) As capability for modeling electromagnetic effects in complex geometries is developed in FWBS Program, detailed modeling cases will be solicated from FED/INTOR.

The FWBS Program will encourage the participation of scientists and engineers from outside this program in activities like those above and will work with the DOE Office of Fusion Energy actively to develop opportunities for this participation.

Section 7.

Integrated FWBS Test Facilities

A test environment that will simulate at least partially the fusion environment is essential in the overall strategy for fusion development and no existing facility has this capability. Accordingly, an Integrated Test Facility (ITF) that will provide the capability for engineering tests on first wall, blanket and shield components (or facsimilies) prior to ETR and later in parallel with the ETR is of major importance and has been recognized in the FED Technology Report and the (DOE/OFE) Engineering Development Plan for Fusion Power Systems. Such a facility would play a crucial role in the integration of the test program elements in the FWBS Program. As a preparatory step towards an ITF, definition of the mission is being undertaken, together with development of preliminary systems' requirements. Near term objectives are preparation of a document that contains a statement of the mission together with a general ITF concept.

The role of ITF will be to provide integrated operational and testing capabilities to qualify FWBS design concepts for a Fusion Demonstration Plant (FDP), and to checkout ETR test modules. Whereas the ETR will provide experience with operational systems in a fusion environment but with parameters (e.g., neutron flux and fluence) which only partially simulate FDP design goals, the ITF would provide for a broader range of test parameters, including off-normal/accident simulations, but still under conditions which only partially simulate the complete fusion environment but complement data from FED. The ITF will address the testing needs of several magnetic confinement concepts, with particular attention given to tokamaks, mirrors and EBT's.

Some characteristics of integrated FWBS test facilities were suggested in the November 1980 Program Plan but a concept still has to be established. The ITF could conceivably be one facility or a combination of various test stands. Some possibilities under consideration include the following:

- A modest combination of a few single effects test environments, such as first wall heat fluxes, magnetic fields, and vacuum conditions.
- A comprehensive, simulation facility, including first wall heat and particle fluxes, magnetic fields, simulated blanket bulk heating, and vacuum conditions. Non-fission sources of neutrons may be included.
- Use of appropriate fission test reactors suitably adapted to accommodate appropriate instrumentation, encapsulation and reasonably large test articles.

APPENDIX A

Details of Management Plan for the First Wall/Blanket/Shield Engineering Technology Program

Appendix A. Details of Management Plan for the First Wall/Blanket/Shield Engineering Technology Program

This appendix supplements Section 5, Program Organization, and describes details of the management plan that will be employed to carry out the technical objectives of the First Wall/Blanket/Shield Engineering Technology Program (FWBS Program). Section A.1 - A.6 describe the organization and responsibilities of the various participants; Section A.7 summarizes the approval and reporting procedures; Section A.8 describes the process for selecting participants. This plan is focused on the management aspects of the FWBS Program for the next two to four years.

The basic elements in the operational structure are shown in Fig. A.1. The role and responsibilities of each element are described in the following sections.

A.1 DOE Office of Fusion Energy

OFE's management role through its Reactor Systems and Application Branch in the Division of Technology and Development, is (1) the formulation of overall program guidance; (2) approval of the program plan and revisions thereto; (3) approval of workscopes for major procurement actions prior to their issuance for solicitation; (4) approval of Detailed Technical Plans; (5) approval of the Advisory Committee (AC) membership and its chairman; and (6) participation as an ex-officio member of the AC.

A.2 ANL Fusion Power Program

The ANL Fusion Power Program, under the direction of Charles C. Baker, is responsible for the overall programmatic and administrative direction of all magnetic fusion activities at ANL. Richard E. Nygren is the manager of the FWBS Program's Management and Technical Coordination Center (MTCC) at ANL (see next subsection) and reports programmatically to the Fusion Power Program Director who will ensure that the performance of the MTCC meets the objectives of the FWBS Program. The Fusion Power Program Director reports to John J. Roberts, Associate Laboratory Director for Energy and Environmental Technology.

FIRST WALL/BLANKET/SHIELD ENGINEERING TECHNOLOGY PROGRAM ORGANIZATION CHART

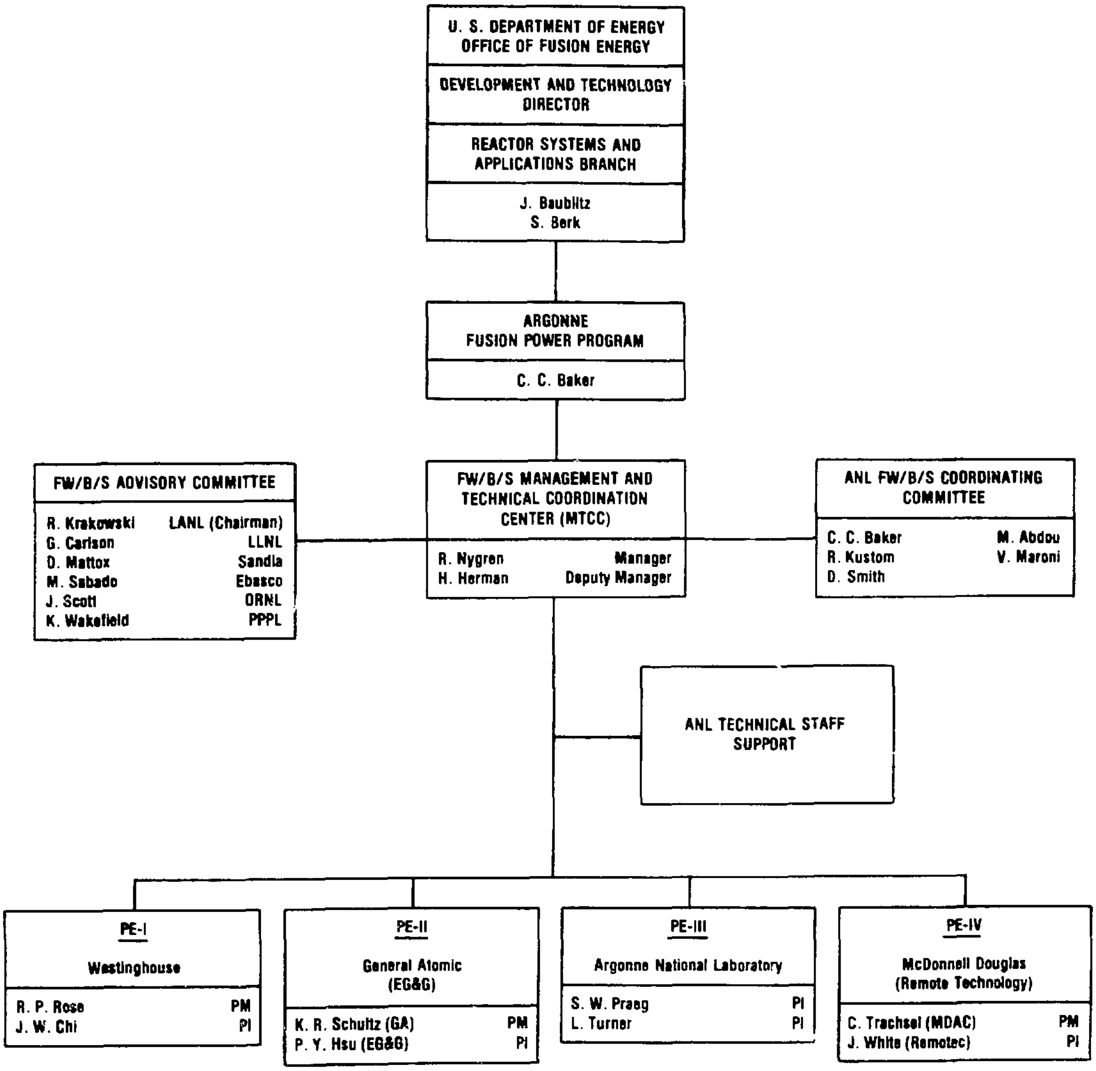

Fig. A.1 Organization Chart of FWBS Program.

The Fusion Power Program Office will be responsible for interfacing with the appropriate ANL budget and subcontracting officers and for providing support to the MTCC in the area of subcontract and budget administration. The Associate Laboratory Director's Office is responsible for interfacing with the DOE Chicago Operations and Regional Office. The MTCC manager will also have direct interactions with DOE/OFE.

A.3 Management and Technical Coordination Center (MTCC)

The Management and Technical Coordination Center at ANL, under the direction of Richard E. Nygren is the nucleus for technical direction of the FWBS Program. The deputy manager of the MTCC is Harold Herman. The staffing of the MTCC is indicated in Table A.1 along with the anticipated levels of effort for FY 1982-83, assuming a total budget of approximately $3 M. As the program expands, some expansion of administrative support will be required. Expansion of the technical analysis and evaluation staffing can also be expected as the program grows, particularly in areas involving development of FWBS design tools and analysis of engineering results.

Staffing support for the technical analysis and evaluation function of the MTCC will be drawn from various ANL divisions as indicated in Table A.2. Individuals from these various divisions are engineers experienced in ANL's fusion reactor design and systems studies such as STARFIRE. In their capacity with the MTCC these various staff personnel will report directly to the manager of the MTCC.

A.4 Lead Participants (LPs)

The Lead Participants identified for Phase 0 and Phase I of each Program Element (PE) are shown in Figure A.1. Each LP will assume a major share of the responsibility for direction of the technical aspects of the assigned

PE. The Lead Participant were selected by a competitive process from a group of qualified organizations as described in Section 2 and Appendix B. The lead participant may, as it becomes necessary and appropriate, select supporting participants (SPs) to conduct specific parts of the PE. The SPs will report to the MTCC through the offices of the cognizant LP. As each PE moves from one phase to the next, it may be advantageous to select a new Lead Participant. This need will be assessed by the MTCC towards the end of each phase of a particular PE. The selection process for the LP is described in Section A.8.

A.5 Supporting Participants (SPs)

The lead participant (LP) may find that it is both cost and time effective to have specific packages of technical work pertinent to its assigned PE performed by selected supporting participants (SPs) as has already been done in PEs II and IV for Phase I. In this case the LP will prepare a clearly documented statement of work and conduct a competitive search for the best qualified SP. The SP will receive funding from the LP and will, in turn, report to and be responsible to the LP. Prior to conducting a search for an SP, however, the statement of work will be reviewed and approved by the MTCC. The final selection of the SP will be make by the LP, but will require the approval of the MTCC.

A.6 The FWBS Program Advisory Committee (AC)

A committee of six individuals from laboratories, industries, and universities was selected by the MTCC with OFE approval to provide overview of FWBS Program scope and objectives and to review the overall quality of technical work. (Members of the Advisory Committee are listed in Section 6.3) This committee will meet on a regular basis (generally twice per year) and will report its findings and recommendations to the MTCC, and ANL/FPP. The AC has had two meetings (October 30, 1981 and June 15, 1982.) Its reports (to the MTCC) have been distributed to OFE and the other program participants. The MTCC will be responsible to the DOE/OFE for the recommendation of a course of action for all findings and recommendations resulting from technical reviews of the FWBS Program by the AC. An OFE representative will serve as an exofficio member of the AC. Any changes in the membership or chairmanship of the AC will be submitted by the MTCC to DOE/OFE for approval.

A.7 Approval Levels and Reporting Procedures

A summary of the approval levels for various elements of the FWBS Program Management System is given in Table A.3. The MTCC will provide a quarterly report to DOE/OFE using DOE's Uniform Contractor Reporting System (e.g., DOE Form 536 - Contractor Management Summary Report), supplemented by narrative containing technical details of the work conducted on each PE during the quarter. This system is currently operational on the ANL computer system. Similar reporting obligations will be imposed by the MTCC on each LP. Each LP will be responsible for developing its own reporting requirements with its respective SPs.

In addition to the above reporting requirements, the MTCC will require annual technical reports from each LP beginning in Phase 1. At the completion of each PE, a comprehensive report will be issued which will include the following as a minimum: technical issues addressed and their relationship to the needs of the magnetic fusion program, objectives, methods, descriptions of apparatus and rigs, results and conclusions. The results will be distributed via the UC-20 distribution system. A format for these reports will be developed by the MTCC in FY 1982.

A.8 Selection of Lead Participants for Program Elements

The process described below was used to select the current program participants and is the model for any future selection. The primary objective in selecting a lead participant (LP) for each Program Element (PE) is to choose an organization which can fully meet the technical and schedular objectives of the PE in a cost effective manner. The procedure for each PE will be to issue an expression of interest (EOI) to candidate industries, laboratories and universities. The EOI will contain a description of the proposed PE, objectives and suggested methods, and anticipated level of funding. The EOI and list of potential candidates will be reviewed and approved by DOE/OFE.

Each responder will be asked to provide information on technical approach to carrying out the PE, available facililties, personnel qualifications, and an estimate of the required level of effort, schedule, and funding to carry out the task. The MTCC will evaluate these responses and take one of the following courses of action.

(1) Determine that the PE can best be carried out by a national laboratory. If the MTCC recommends that ANL be selected as the LP for a particular PE, this will require the additional approval of DOE/OFE.

(2) Select a suitable industry or university on a sole source basis subject to ANL's standard procurement policy and procedures.

(3) Issue a formal request for proposal (RFP) to qualilfied industrial organizations and carry out a RFP selection process based on ANL's standard procurement policy and procedures.

Table A.1 Staffing Plan for MTCC - FY 1982-83

Staffing Requirement	Level of Effort/Year
MTCC	10 man-months
MTCC Deputy	10 man-months
Administration and Secretarial Services	5 man-months
Technical Analysis and Evaluation	18 man-months

Table A.2 Analytical, Design Evaluation and Engineering Support for the MTCC

Discipline[a]	ANL Division(s)
Materials	Materials Science Division
Thermal-Hydraulics	Chemical Engineering and Components Technology Divisions
Structural Analysis	Components Technology and Reactor Analysis and Safety Divisions
Electromagnetics	Electromagnetic Technology Group
Neutronics	Applied Physics Division
Engineering Design	Engineering Division
Blanket Processing	Chemical Engineering Division

[a]Approximately 1 to 3 man months per discipline to support the MTCC. In all, 18 man months per year will be required in FY 1982-83.

Table A.3 FWBS ETP Approval Levels

Item	Prepared and/or Recommended by	Approved by
FWBS Program Plan	MTCC	ANL/FPP DOE/OFE*
Selection of Type of Organization for each PE	MTCC	ANL/FPP DOE/OFE*
Workscopes for Major Procurements (RFIs and RFPs)	MTCC	DOE/OFE*
Advisory Committee Membership	MTCC	DOE/OFE*
Quarterly Reports to DOE	MTCC	ANL/FPP
Selection of LPs	MTCC	ANL/FPP (DOE/CORO if RFP)
Monthly LP Reports	LPs	MTCC
RFPs for and Selection of SPs	LP	MTCC

*Final approval authority.

APPENDIX B

Approach to Developing the FWBS Program Plan

Appendix B. Approach to Developing the FWBS Program Plan

Formal planning of the FWBS Program actually started in June 1979 when F. E. Coffman (OFE/D&T) distributed a memorandum to selected organizations requesting information on capability and approaches for fusion power reactor first wall, blanket, and shield verification testing. Although the responses to Coffman's memorandum showed considerable variation of opinion, particularly with respect to approach, there was a unanimous sentiment expressed in these responses that an FWBS engineering test program was needed. Because of the absence of a common format in the responses to Coffman's memorandum and in light of the fact that a number of potential contributors did not participate in this initial activity, it seemed advisable that the FWBS Program technical management center at ANL conduct a comprehensive, inquiry in the hope of achieving a more complete and uniform community-wide response to the fundamental issues underlying the initiation of the FWBS Program.

The inquiry phase that led to the preparation of the (initial) November 1980 Program Plan was conducted in two parts. First, a Planning Inquiry Document was prepared and forwarded to cognizant organizations for their response; and second, after the responses to the Planning Inquiry Document had been received and assimilated by ANL, a Planning Inquiry Workshop involving all of the responding organizations was convened. A summary of the key findings of these exercises that have contributed to the 1980 Program Plan for the FWBS Program is given below.

B.1 Summary of the Results of the FWBS ETP Planning Exercises

The planning exercises conducted by the FWBS Program technical management center at ANL were carried out in two steps. Initially, a planning inquiry document was forwarded to over thirty organizations (laboratories, industries, and universities, see Table B.1). The Planning Inquiry Document (PID) described a set of five test program areas that were developed from the responses to F. E. Coffman's request for information of June 1979. These test program areas are summarized in Table B.2. The organizations receiving the

PID were asked to respond to questions relating to the importance of each test program area to a variety of issues (see Table B.3). The assimilated results of the responses to the PID revealed a strongly positive opinion concerning the importance of the proposed test program areas to FED and reactors beyond FED and the feasibility of initiating meaningful work at the $300 to $350 K/yr level. There was, however, a modest diversity of opinion concerning the scope of work and near term thrust (objectives) for each test program area. The FWBS Program Planning Workshop, which followed the PID, was organized to focus on revised, prioritized work scopes, and improved definitions of near term technical objectives for each test program area. (The same organizations that responded to the PID also participated in the workshop.)

The combined output of the planning exercises may be summarized as follows:

(1) <u>In the area of first wall thermal-hydraulic and thermomechanical effects,</u> the recommendation was made to focus approximately equally on normal operational and transient effects testing. The testing should be done in nonnuclear facilities using radiant heaters (or equivalent methods) to apply controlled heat fluxes to first wall component facsimiles. Bulk heating and related nuclear effects should be simulated to the extent possible. Armor, limiters, heat ejector panels and related first wall components should be examined separately, in appropriately constructed test facilities. The tests should address (i) normal condition thermal-hydraulics, (ii) the consequences of plasma and coolant system disruptions, including failure modes and effects, (iii) first wall instrumentation and control, and (iv) simulated mechanical upsets. Members of the plasma physics community should be called upon to provide guidance in the planning of meaningful plasma disruption effects test. The tests should also be geared to yield first wall design data (e.g., on component reliability, transient abatement requirements, configuration optimization, etc.), operational parameters (e.g., gross heat transfer coefficients), and computational method verification.

(2) In the area of blanket thermal hydraulic and thermomechanical effects, there was a diversity of opinion concerning the need for extensive near term work in support of the ETF/FED, since some viewed the present ETF/FED blanket shield concept (low temperature/nonbreeding) as being devoid of serious hydraulic and mechanical uncertainties. Others, however, sensed a need for some work in this area to establish the capability for verification testing of an ETF/FED blanket mock-up and to begin the required development work on power and breeder blanket modules. It was recommended that near term work in this area be directed towards non-nuclear, separate effects tests and towards the planning of subsequent power and breeder blanket performance tests in fission reactors. The focus should be on development/testing of a predictive capability for analyzing effects of coolant oscillations, mechanical perturbations, and related transient phenomena.

(3) In the area of electromagnetic and eddy current efffects testing, it was recommended that near term work be directed toward the establishment of design criteria for accommodating electromagnetic interactions in FWBS structures. Focus should be on validation of computational models, correlation of pulsed field penetration characteristics with FWBS composition and geometry, analysis and experimental evaluation of forces and torques on FWBS components due to electromagnetic interactions, response of FWBS instrumentation to non-uniform pulsed and steady magnetization, and reaction of FWBS components to electromagnetic transients. Work on ferromagnetic FWBS components and liquid metal MHD should be conducted when and as appropriate to fusion FWBS development needs.

(4) In the area of FWBS assembly, maintenance and repair (AMR), the recommendations were to (i) establish an expertise base for generic fusion AMR technology supported by experience from other advanced technologies (e.g., fission energy, aircraft technology, space exploration); (ii) develop AMR guidelines and criteria for near term and longer range fusion devices; (iii) evaluate and test failure detection, location, and repair methodologies, (iv) examine impacts

of AMR operations and operation sequencing considerations on FWBS design approaches and reactor down-time.

(5) In the area of FWBS design algorithms/equations, it was recommended that the scope of work proposed in the PID be revised and that the activity be conducted within the purview of the FWBS Program technical management center at ANL. The new scope should emphasize the potential utility of existing general purpose nuclear, hydraulic, and mechanical analysis codes, the development of fusion-specific transient analysis codes, and to a limited extent of coupling pairs of codes to achieve some semblance of design data integration. The desirability of preparing fusion-dedicated preprocessor packages for existing general purpose codes, and the need for a code to model tritium transport/inventory in FWBS systems were also mentioned.

Table B.1 Organizations and DOE/OFE Program Areas that Received the FWBS ETP Planning Inquiry Document[a]

Laboratories[b]

Argonne National Laboratory[*]

Battelle Pacific Northwest Laboratory[*]

Brookhaven National Laboratory[*]

EG&G, Idaho[*]

ETEC[*]

General Atomic Company[*]

Hanford Engineering Development Laboratory[*]

Los Alamos Scientific Laboratory[*]

Lawrence Livermore Laboratory[*]

Oak Ridge National Laboratory[*]

Princeton Plasma Physics Laboratory[*]

Sandia Laboratories[*]

Universities

Georgia Institute of Technology

Massachusetts Institute of Technology[*]

University of California, Los Angeles[*]

University of Illinois[*]

University of Wisconsin[*]

Industries

Babcock and Wilcox Co.[*]

Boeing Engineering and Construction Co.[*]

Combustion Engineering, Inc.[*]

Exxon Nuclear Co., Inc.[*]

General Dynamics Co.

General Electric Co.

Grumman Aerospace Corp.[*]

Mathematical Sciences Northwest, Inc.[*]

McDonnell Douglas Astronautics Co. - East[*]

TRW[*]

Westinghouse Electric Corp.[*]

DOE/OFE Programs

Alloy Development for Irradiation Performance Program[+]

Blanket Processing Program[+]

D&T Components Development Program[+]

Engineering Test Facility Project[*]

EPRI/TFTR Test Module[*]

Neutronics and Shielding Programs[+]

Plasma/Wall Interaction Program[+]

Fusion Safety Program[+]

Special Purpose Materials Program[+]

STARFIRE Project[+]

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[a] [*] Indicates that the organization/program responded to the Planning Inquiry Document and participated in the FWBS Planning Workshop.
[+] Indicates participation in the FWBS Planning Workshop only.
[b] For the purposes of the FWBS Program, "Laboratories" are defined as those institutions which are funded by DOE's regular financial plan system through the various DOE field offices.

Table B.2 Key Considerations Identified in the FWBS Planning Inquiry Document:

I. First wall thermal-hydraulic and thermomechanical testing.

II. Blanket thermal-hydraulic and thermomechanical testing.

III. FWBS electromagnetic/eddy current testing.

IV. FWBS assembly, maintenance, and repair concept development and testing.

V. Comprehensive design algorithms/equations for FWBS systems.

Table B.3 Key Considerations Identified in the FWBS Planning Inquiry Document:

1. Importance to (a) the ETF and (b) reactors beyond ETF.

2. Prospects for establishing a meaningful test program element at 300-350 K/year (initially).

3. Prospects for initiating test program element at existing or readily established facilities.

4. Capability of organization to perform one or more test program elements.

5. Major thrust of near-term test program elements.

   - Verification of computational tools
   - Development of design data.
   - Tests to scope engineering behavior.
   - Comprehensive subsystem tests.
   - Tests of totally integrated FWBS systems.

6. Capability of organization to respond to the test program element inquiries.

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