Paper to be presented at the 9th Symposium of Engineering Problems
of Fusion Research, Chicago, Illinois, October 26-29, 1981.

CONF-811040--197

DE83 007790

INITIAL PROGRESS IN THE FIRST WALL, BLANKET, AND SHIELD ENGINEERING TEST PROGRAM FOR MAGNETICALLY CONFINED FUSION-POWER REACTORS*

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October 1981

*Work supported by the U.S. Department of Energy.

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Introduction

The first wall/blanket/shield (FW/B/S) Engineering Test Program (ETP) progressed from the planning stage into implementation during July, 1981. The overall background and scope have been described in detail in earlier reports.[1,2] The program, generic in nature, comprises four Test Program Elements (TPE's), the emphasis of which is on defining the performance parameters for the Fusion Engineering Device (FED)[3] and the major fusion device to follow FED. These elements are:

TPE I: Nonnuclear thermal-hydraulic and thermomechanical testing of first wall and component facsimiles with emphasis on surface heat loads and heat transient (i.e., plasma disruption) effects.

TPE II: Nonnuclear and nuclear testing of FW/B/S components and assemblies with emphasis on bulk (nuclear) heating effects, integrated FW/B/S hydraulics and mechanics, blanket coolant system transients, and nuclear benchmarks.

TPE III: FW/B/S electromagnetic and eddy current effects testing, including pulsed field penetration, torque and force restraint, electromagnetic materials, liquid metal MHD effects and the like.

TPE IV: FW/B/S Assembly, Maintenance & Repair (AMR) studies focusing on generic AMR criteria, with the objective of preparing an AMR designers guidebook; also, development of rapid remote assembly/disassembly joint system technology, leak detection and remote handling methods.

The initial program is divided two into phases, the first being Phase 0, an initial six month planning period, to be followed by Phase 1, a two to three year period. In all cases, Phase 0 will culminate in a Detailed Technical Plan (DTP) for activities through 1985. Contracts for the performance of Phase 0 of TPE's I, II and IV have been awarded to industrial organizations, TPE III is being conducted by Argonne National Laboratory (ANL.)

Test Program Elements

TPE I, being conducted by the Westinghouse Electric Corporation emphasizes development of an experimental data base to aid in the design of first wall and related components (e.g.,armor, limiters, etc.) for fusion reactor applications. Recent progress, has been reported elsewhere.[4]

Facility parameters for TPE-I and "test windows" are given in Fig. 1. Two first wall flux test stands will provide for the thermal-hydraulic and thermomechanical testing of first wall components and systems. The first, designated ESURF, available in October, 1981, will have an evacuable, 1.0 m dia. x 1.5 m long chamber capable of accommodating first wall component test articles with surface area dimensions of approximately 700 cm^2 initially, to be expanded in Phase 1 to 1000 cm^2. A 50 kW electron beam gun with rastering capability over this area is included. Heat transfer capability is provided by a 6.9 MPa water loop which permits inlet temperatures up to 543 K. The second test stand, designated ASURF, which will be

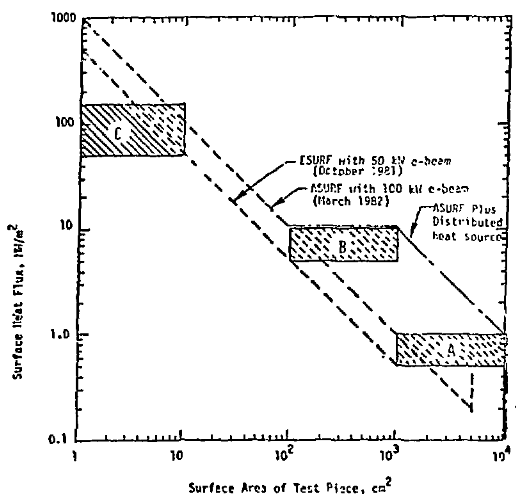

Fig. 1. Composite Surface Heat Flux Operating Map for TPE-I.

available in March 1982 for similar but larger scale testing up to 100 kW will have a vacuum chamber 1.8 m dia. x 1.8 m long. Test articles having areas up to of 1.0 m^2, and a 2 MW_t heat rejection capability by means of a 15.2 MPa water loop at inlet temperatures up to 573 K are possible. The relative merits of a high voltage rastered electron gun vs. low voltage distributed linear electron emitters are being evaluated. Cathode life and probability of success with replacement cathodes is much higher with the LV system (~1000 hrs. vs. ~ 60 hrs.) and there is better ability to maintain rated performance because contaminants lead to arcing in the HV gun, necessitating reductions in operating voltage. Also with the LV system, shielding costs are lower, no beam dump is needed and SF_6 insulation is unnecessary in the power supply. However, for disruption simulation with the distributed system, a capacitor driven electron gun must be added. Further ASURF upgrading to achieve a

*Work supported by the U.S. Department of Energy.

power level of 1 MW on target with later addition of a helium coolant loop is in the planning stage. Such capability could be by means of additional electron beam capacity or some type of radiant heater (e.g., graphite heaters are efficient for radiant cooled armour tiles testing in which the heater power required is minimal since the power radiated back from the tile reduces the electrical power requirements).

Initial emphasis is on validation of procedures and techniques using test articles which closely simulate by their design and method of fabrication, first wall concepts for FED. The scope will later be expanded to encompass engineering scale first wall components and assemblies (including armor and limiters.) The immediate objective is path-to-failure and design margin studies, design code improvement and combined effects simulation (electromagnetic/thermal-hydraulic/thermo-mechanical/structure damage). Long pulse, 1-10 MW/m^2 heat fluxes with up to 300 MW/m^2 for short pulses (transient simulation) will be applied to surfaces up to 1.0 m^2 in area.

Phase 0 test articles are shown in Fig. 2. A test plan has been completed for the first type, a single, 316 stainless steel tube having an I.D. of 2.14 cm., a 0.8 cm. wall thickness and a heated length of 25 cm. In addition to demonstration of the ESURF test facility capabilities and validation of test procedures, thermal mapping will check the accuracy of predicted temperature distributions and distortions. Confirmation, or otherwise of predicted stress distribution will follow, from which design margins and failure thresholds will evolve. Test article integrity following thermal shock (from simulated disruption heat loads) superimposed on the steady state heat flux will be investigated, as well as the effects of high intensity local heat loads on surface melting and vaporization.

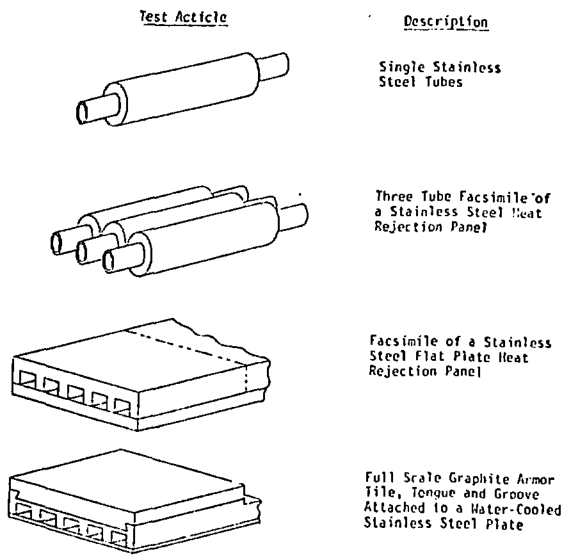

Fig. 2. Phase 0 Test Articles (TPE I)

A test plan for the second type of test article has also been completed. The objective is to study thermal fatigue limits and failure thresholds of the first wall tube panel concept.

The test program commenced in October 1981 with the four types of test article shown in Figure 2. A series of tests will be completed by the end of 1981 and the results reported.

TPE-II is being conducted by the General Atomic Company in concert with EG&G Idaho, Inc. Thermal-hydraulic/thermomechanical data requirements for blanket and shield concepts which currently appear to be feasible are being reviewed and critical testing needs identified. Also, potential FED blanket/shield test modules are being examined from the viewpoint of forming the basis for developing non-nuclear and subsequent nuclear testing strategies. The DTP for implementation of tests based on this phase of work will be completed in early 1982. Initial emphasis is on simulating the fusion bulk (nuclear) heating environment in blanket and shield facsimiles to provide test data for normal and off-normal (transient) conditions. Test articles under consideration and test conditions have been described previously.[5]

As a first step in identifying blanket/shield testing needs, various concepts proposed to date were reviewed and broadly categorized according to the basic blanket/shield designs, as outlined in Table 1. A matrix of data needs was developed, Table 2. Based on the review, data requirements were identified for which a set of criteria is being developed to focus the testing program. Integrated multiple component tests preceded by supporting single effect (bench type) tests will be investigated.

Table 1. Blanket and Shield Categories

Concept	Description	Examples
Shields (low temperature, nonbreeding)		
I	Stainless steel structure with integral water cooling	FED
II	Stainless steel/boron carbide composite with internal cooling channels	Alternative FED, STARFIRE
Blankets (high-temperature, tritium-breeding)		
I	Solid breeder in low-pressure canister with integral cooling channels	STARFIRE
II	Clad solid breeder in pressurized, coolant-filled module	GA Demo UWMAK-II GA/EIR Tokamak INTOR
III	Stagnant liquid metal breeder with integral cooling channels	ORNL-W, FINTOR-D, NUWAK CCTR-II
IV	*Flowing liquid metal breeder*	ANL-Maroni, UWMAK-I WITAMIR-I UWMAK-III
V	Mobile solid breeder	SOLASE

In order to study simulation possibilities, a literature survey was conducted of techniques for simulating bulk heating due to fusion neutrons. Discrete element heating was concluded to be the best for thermal hydraulics studies where the main concern is with heat flux across a fluid boundary. For thermomechanical studies, the bulk heating of fission neutrons can accurately simulate fusion bulk heating. But depending on the particular issues under investigation, distributed discrete sources such as resistance wires or hot fluid conduits may be acceptable. Resistance heating by passing a current through the structure itself also has some merit if direct current is used. Alternating current resistance heating and induction heating are not satisfactory because of skin depth effects. Microwave heating in dielectric materials suffers similar restrictions.

Table 2. TPE II Data Needs

DATA NEEDS	DESIGN OPTION: SHIELD I	SHIELD II	BLANKET I	BLANKET II	BLANKET III	BLANKET IV	BLANKET V
THERMAL-HYDRAULIC CONCERNS							
THERMAL CONDUCTIVITY		2	1	1			1
THERMAL CONTACT RESISTANCE		2	1	1			1
HIGH PRESSURE GAP FLOW				1			
PURGE FLOW DISTRIBUTION		1	1				
FLOW DISTRIBUTION	3	3	2	1	2	1	1
RE-ENTRANT PRESSURE TUBE		3	1		1		
HEAT TRANSFER PROPERTY CHANGES		2	1	1			2
PLENUM DESIGN	3	3	2	2	3	1	1
THERMOMECHANICAL CONCERNS							
THERMAL EXPANSION COEFFICIENTS		2	1	2			3
THERMAL RATCHETING			1	2			
THERMAL STRESS		3	1	2			3
MODULE JOINT DESIGN	3	3	3	2	2	2	2
MATERIALS CONCERNS							
MATERIAL SWELLING	3	3	1	1			3
COUPLED SWELLING, CREEP AND EMBRITTLEMENT	3	3	2	1	2	3	3
SINTERING			1	1			2
COMPATIBILITY			1	1	1	1	1
VAPORIZATION			1	1	3	3	2
MHD CONCERNS							
THERMAL-HYDRAULIC EFFECTS					2	1	
HYDRAULIC OSCILLATIONS					3	2	
TRITIUM CONCERNS							
TRITIUM RELEASE			1	1	3	3	2
SINTERING EFFECTS			1	1			3
PERMEATION			1	1	1	1	1

PRIORITY:
1 = Critical concern
2 = Concern
3 = Relevant but not expected to be of concern

DESIGN OPTIONS:
SHIELD I: Stainless steel with integral water cooling
II: Stainless steel/boron carbide composite with internal cooling tubes

BLANKET I: Low pressure solid breeder canister with coolant tubes
II: Clad solid breeder in high pressure module
III: Liquid metal breeder with coolant tubes
IV: Flowing liquid metal breeder
V: Mobile solid breeder

TPE-III, being carried out by ANL addresses electromagnetic effects, both from plasma displacement or disruption, and from normal or abnormal magnetic field changes. The importance of electromagnetic effects in the FW/B/S system and the uncertainty in the ability to accurately calculate them led to the selection of these phenomena as one of the four areas for study in the FW/B/S ETP. Basically two different kinds of experiments are planned: those to study geometrical effects and those to study material and assembly effects. The initial geometrical experiments will investigate eddy currents in flat plates. Instrumentation and data acquisition will be very simple, as will comparison with results from computer codes. Three dimensional geometrical effects studies as they apply to shielding and segmentation will follow. After this series, assembly effects experiments will alternate with component concepts, component models, and, finally, component prototypes. Two-dimensional and three-dimensional computer codes for eddy current calculations will be identified, compared, evaluated, and improved.

To achieve the necessary goals, a test stand, FELIX (Fusion Electromagnetic Induction Experiments) is being designed and constructed.[6] It consists primarily of a solenoid magnet, a surrounding pulsed dipole magnet, associated power supplies and a non-magnetic support structure. A horizontal solenoid field of 1.0 T is excited by six identical solenoid coils over a cylindrical volume of 0.76 m^3 (radius r = 0.45 m, length ℓ= 1.2 m). Field uniformity is traded off for accessibility to the desired volume. A vertical dipole field of 0.5 T is excited by two sets of two nested dipole coils. This field is superimposed on the solenoid field; it can be forced to decay with $\dot{B}$ up to 50 T/S. The constant field is modelled by a slowly pulsed solenoid field that has a rise and falltime of < 3 s and a flattop of 8 s. The pulsed field is modelled by a pulsed dipole field that has a rise time of 1 s, a flattop of 3 s, and a variable decay time of 5 ms or more. The repetition rate is 1 ppm. The coil parameters are given in Table 3; Fig. 3. is a pictorial view of the test stand.

Table 3. "FELIX" Coil Parameters

Table 3. "FELIX" Coil Parameters

	Solenoid Per Coil	Half a Dipole Inner	Half a Dipole Outer
Field Strength (T)	1.0	0.5	
Inner Radius (cm)	55.0	80.0	80.0
Outer Radius (cm)	75.0	100.0	100.0
Axial Length (cm)	30.0	280.0	320.0
Azimuthal Length (cm)	--	12.0	19.0
Angle to Center (deg.)	--	54.0	18.0
NI (kiloampere turns)	417.0	247.2	395.2
Stored Energy (KJ)	254.5	537.0[a]	
Inductance L (mH)	27.0	28.0[a]	
Resistance R (mΩ)	17.2	39.5[a]	
Peak Current (kA)	4.4	6.2[a]	
DC Voltage Drop (V)	75.68	245.0[a]	
Power Consumption (KW at 1 ppm)	55.5	95.7[a]	

[a] One inner and one outer coil in series

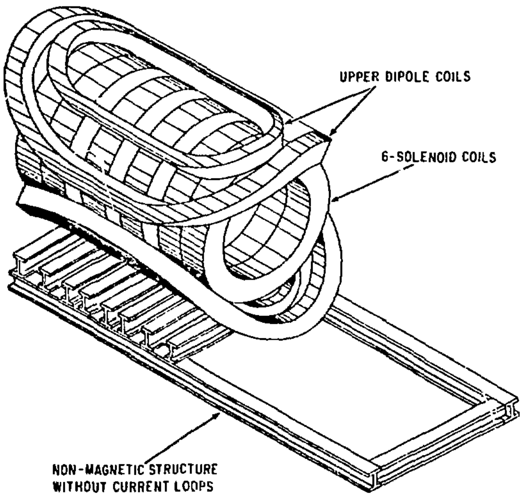

Fig. 3. Electromagnetics Effects Test Stand "FELIX"

TPE-IV is a two-fold assembly, maintenance, and repair (AMR) task. A contract has been awarded to Remote Technology Corporation to survey and assess existing multi-disciplinary (e.g., nuclear, space, undersea) technology pertinent to remote AMR, which will lead to preparation of an AMR designer's guide book. A contract was also awarded to McDonnell Douglas Astronautics Corporation (MDAC) to pursue a related program for development of remotely operated small scale AMR penetrations and vacuum joint systems. These two contractors collaborate very closely in their efforts.

An extensive literature search is in progress for the guidebook. More than 5000 abstracts, summaries and papers have been acquired. Of these, over 200 were selected for detailed review and more than 40 were judged to be highly relevant to the guide-book. A survey on commercially available manipulators and robotics devices is also being conducted.

Approximately one hundred and fifty solicitations have been made to industrial organizations. The range covered is from the simplest hand held tongs to highly dextrous force feedback master-slave manipulators and computer controlled robots. The preliminary outline for the designers guide-book, in work breakdown structure format, is given in Fig. 4.

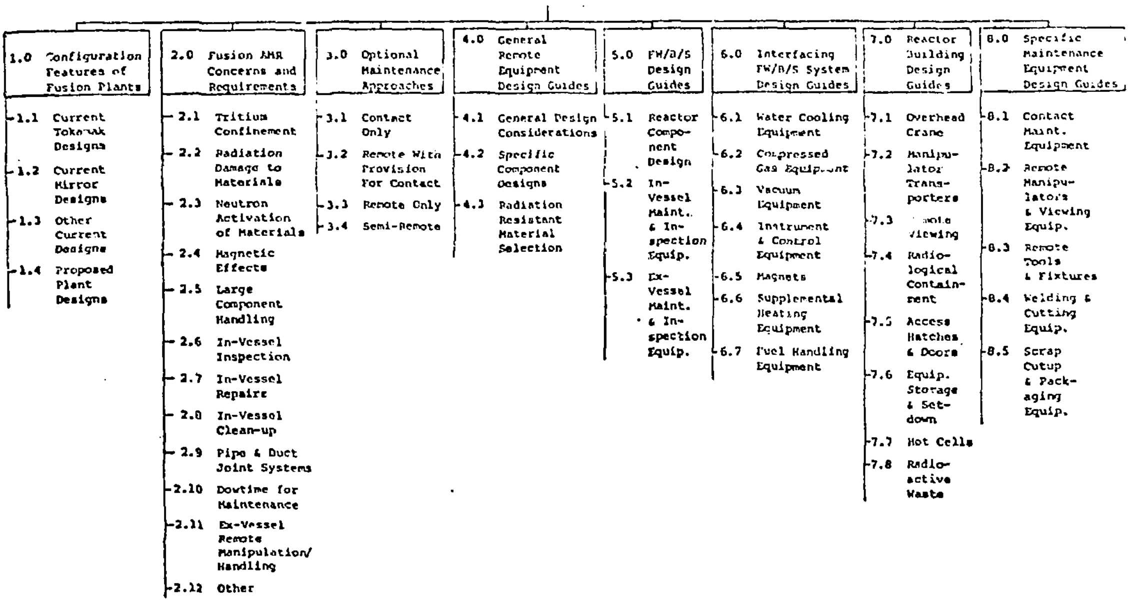

Fig. 4. Designers Guide Book Outline for Fusion AMR

MDAC is investigating requirements for testing the feasibility of remotely operable vacuum joint systems configurations. Considerable effort has been extended in the areas of seal closure methodology, remote operating means, joint system design objectives and preparation of testing plans. Rectangular openings are being addressed because this geometry is prevalent in FW/B/S systems of existing and near term anticipated fusion reactors such as the FED. Insufficient space exists for circular openings. Mechanically operated joints are essential for penetrations of the vacuum wall to attain reasonably quick access for maintenance and modifications.

Acknowledgements

We would like to acknowledge the contributions To this work made by T. Varljen, R. Rose and J. Chi, Westinghouse Electric Corporation, K. Schultz and A. J. Veca, General Atomic Company, P. Hsu and G. Longhurst, EG&G, D. Hagmann, W. Praeg and L. Turner, ANL, H. S. Zahn, McDonnell Douglas Corporation, and J. White of the Remote Technology Corporation.

References

1. Program Plan for DOE/Office of Fusion Energy First Wall/Blanket/Shield Engineering Test Program, Argonne National Laboratory Rep. (1980).

2. Maroni, V. A., "A First Wall/Blanket/Shield Engineering Test Program for Magnetically Confined Fusion Power Reactors" (Proc. 4th Topical Meeting on Technology of Controlled Nuclear Fusion, King of Prussia, Pa., U. S., 1980) Vol. III 571.

3. Fusion Engineering Device (Proc. 3rd Technical Committee Meeting and Workshop on Fusion Reactor Design and Technology Tokyo, 1981) to be published.

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

5. Baker, C. C., Herman, H., Maroni, V., Turner, L., Clemmer, R., Finn, P., Johnson, C., Abdou, M., "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.

6. Praeg, W. F., Turner, R. L., Bywater, R. J., Lari, R. J., Wehrle, R. B., "An Experimental Facility to Study Electromagnetic Effects for FW/B/S Systems" (Proc. of 9th Symposium on Engineering Problems of Fusion Research, Chicago, 1981) to be published.