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MAKING ELECTRICITY AND HYDROGEN – THE FDF PORT TEST BLANKET MODULE PROGRAM

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GENERAL ATOMICS

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The FESAC Planning Panel Report states

“Power Extraction: *Understand how to extract fusion power at temperatures sufficiently high for efficient production of electricity or hydrogen.”*

“**Harnessing fusion power:** *The state of knowledge must be sufficient to design and build, with high confidence, robust and reliable systems that can convert fusion products to useful forms of energy in a reactor environment, including a self sufficient supply of tritium fuel.”*

Port Test Blanket Modules

With the use of test blanket modules, FDF will be able to develop fusion’s energy applications including the demonstration of electricity production and possibly hydrogen production. With neutron fluence at the outboard midplane of 1–2 MW/m^2 and a goal of a duty factor on a year of 0.3, FDF can produce fluences of 3–6 MW-yr/m^2 in 10 years of operation onto complete blanket structures and/or material sample volumes of about 1 m^3. This will provide necessary initial RAMI information for the design of DEMO.

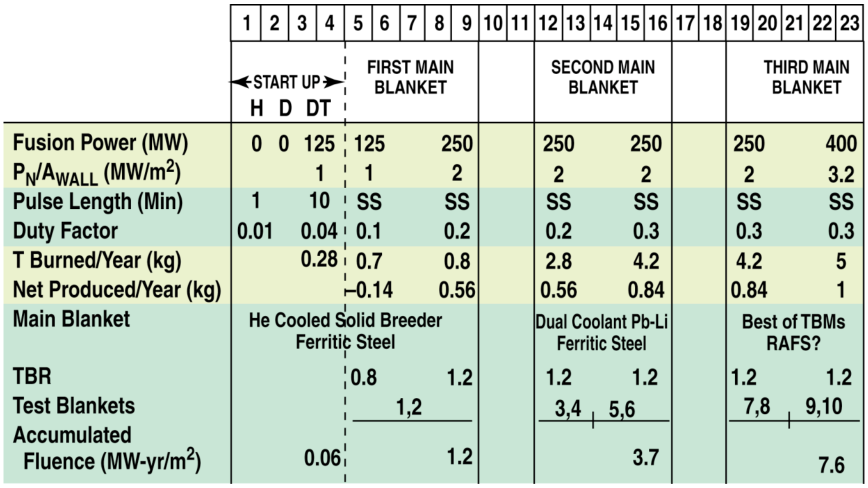
In the port blanket modules, the development of blankets suitable for both tritium production and electricity production will be made. FDF will provide the necessary facility to test perhaps ten different blanket concepts or variants in 2–3 ports over a 10-year period. FDF will be the necessary facility to learn how to make blankets that support high temperature, high thermodynamic efficiency for power conversion for electric power production. Another port site should be devoted to the development of blankets that can support hydrogen production, which can require even more demanding temperatures of extracted coolant, over 900°C. Although FDF will not attempt electric power production from its main blankets, actual demonstrations of both electricity production (300 kW) and of hydrogen production (one metric ton per week) should be made on test port blankets that are sufficiently successful to warrant that effort.

The data from this program will be essential for the validation of the scientific understanding and predictive capabilities; demonstration of the principles of tritium self-sufficiency and power production in practical systems. FDF will develop the technology necessary for the design of DEMO first wall and blanket components and provide knowledge on the reliability, safety, environmental impacts, and efficiency of fusion energy extraction systems.

Sequential Plan

FDF will provide the necessary facilities to test perhaps ten different blanket concepts or variants in 2–3 ports over a ten year time period. FDF will become the necessary facility to learn how to make blankets that support high temperature, high thermodynamic efficiency for electricity production. Another port site should be devoted to the development of blankets that can support hydrogen production, which can require even more demanding temperatures of extracted coolant at over 900°C. The test port test plan must remain flexible in order to respond to technical issues that are revealed only during and by testing,. Experience from the ITER TBM program will also be utilized for the FDF blanket development.

A possible schedule of the FDF nuclear science program is given in Fig. 1-1. An initial 4 year commissioning period is envisioned in which the working fuel will progress from H to D to DT. Fusion power will rise to 150 MW in 10 minute pulses. The basic operating modes of the machine can be developed in this phase. A helium cooled solid breeder blanket will be installed from the start and the TBR will gradually be improved from about 0.9 to ~1.1 by the end of the First Main Blanket phase. Until this first main blanket starts to produce net tritium, the facility will be a net tritium consumer with a need for about 1 kg of external supply. By the end of this First Main Blanket phase, true steady-state operation will have been developed with duty factor 0.2 and fusion power 250 MW and wall loading 2 MW/m^2. Net tritium produced will be 0.56 kg per year. In the port blanket sites, the first two TBMs will have been tested.



	1 2 3 4			5 6 7 8 9		10 11	12 13 14 15 16		17 18	19 20 21 22 23	
	←START UP→ H	D	DT	FIRST MAIN BLANKET			SECOND MAIN BLANKET			THIRD MAIN BLANKET	
Fusion Power (MW)	0	0	125	125	250		250	250		250	400
P_N/A_{WALL} (MW/m^2)			1	1	2		2	2		2	3.2
Pulse Length (Min)	1		10	SS	SS		SS	SS		SS	SS
Duty Factor	0.01		0.04	0.1	0.2		0.2	0.3		0.3	0.3
T Burned/Year (kg)			0.28	0.7	0.8		2.8	4.2		4.2	5
Net Produced/Year (kg)				–0.14	0.56		0.56	0.84		0.84	1
Main Blanket	He Cooled Solid Breeder Ferritic Steel						Dual Coolant Pb-Li Ferritic Steel			Best of TBMs RAFS?	
TBR				0.8	1.2		1.2	1.2		1.2	1.2
Test Blankets				1,2			3,4	5,6		7,8	9,10
Accumulated Fluence (MW-yr/m^2)			0.06		1.2			3.7			7.6

Fig. 1-1. Operational and blanket development schedule of FDF.

Then there will be a 2 year shutdown to change to the Second Main Blanket phase. This blanket is envisioned to be the dual coolant lead-lithium blanket. By the end of this phase, the duty factor will be 0.3 and the tritium produced per year 0.84 kg. TBMs 3,4,5,and 6 will have been tested. Accumulated fluence on anything that has remained in the machine all 16 years will be 3.7 MW-yrs/m^2.

Then there will be a 2 year shutdown to change to the Third Main Blanket phase. The third main blanket will be built from the best result of the first two TBMs. At the end of this phase, the machine will reach for its very advanced operating modes, perhaps with fusion power reaching 400 MW and wall loading 3.2 MW/m^2. Net tritium production per year will reach 1 kg. TBMs 7, 8, 9, and 10 will have been tested. Accumulated fluence for the machine lifetime to date may reach 7.6 MW-yrs/m^2.

Ancillary systems

Similar to the main-blanket system and its corresponding ancillary plant systems, dedicated but smaller ancillary plant systems will be needed for the specific blanket option to be tested. Four interface systems between the test blanket module and the FDF will be needed. They are the port cell system, the hot cell system, the Test Blanket Heat Removal System (TBHRS) and the Tritium Extraction System (TES).

The port cell system is dedicated to the change out and transport of the test modules between the port cell area and the hot cell. Remote handling equipment will be utilized for the transport, assembly and disassembly of the test blanket modules. The TBHRS is for the exchange and removal of the power generated from the test modules. Possibly a power conversion system can be utilized for electricity production demonstrated. The hot cell system is for the preparation, maintenance, testing and disposal of test blanket modules. The TES is for the monitoring, handling and accountancy of the bred tritium from the specific test module.

Expected Accomplishments

FDF test blanket program will fill in many of the gaps between ITER, the new superconducting tokamaks, IFMIF and the DEMO. The following lists specific gaps that this program can fill.

Power Extraction: High Neutron Wall Loading (Γ_n @ ~ 2 MW/m^2).

FDF will make the definitive contribution here since it will be designed for $\Gamma_n \sim 2$ MW/m^2 into the mid-plane test port blanket modules and will have a goal of duty factor 0.3 for an integrated fluence of 3–6 MW-yr/m^2. These are essential capabilities for fusion nuclear technology development. ITER's goals are 0.5 MW/m^2 mid-plane neutron flux and a lifetime fluence of 0.3 MW-yr/m^2. FDF will be about 1/10 and ITER about 1/100 of reactor fluence.

Tritium Self-Sufficiency developd in test blankdet module research.

The limited pulse length on ITER (perhaps as high as 3000 seconds) may not allow an adequate demonstration of continuous extraction and accountancy of tritium from the test blanket modules. FDF will develop test blankets in port modules at 1–2 MW/m^2 neutron flux operating durations of up to 2 weeks will enable demonstration of the kind of actual continuous closed loop tritium extraction to be used in fusion systems. FDF will demonstrate the whole fuel cycle that of the plasma and tritium breeding blanket, including extraction, accountability, and safety issues of a steady-state DT device to pave the way for DEMO.

FW/Blanket Materials and Components Lifetime.

This issue could be phrased much more broadly. Fusion has yet to capture its first fusion neutron in a blanket. Everything in combined first wall/blanket development remains to be done experimentally. FDF will test whole, real size first wall/blanket structures as main-blankets and test blankets with significant neutron fluxes and fluences, relevant first wall heat and plasma fluxes, and in a real system with mitigated disruptions and other challenges. FDF will be designed with the flexibility and maintainability to allow ten test blanket variations to be tested in ten years. FDF will be a test bed for learning how to engineer reliable first wall/blanket structures and make first efforts on reliability growth.

High Temperature Blankets (Hydrogen Production).

FDF will have reactor relevant neutron fluxes and fluences to develop such blankets in test port modules. FDF should extrapolate from the knowledge of main-blanket design development and work in concert with the latest development of advanced high performance structural material like SiC/SiC composite and/or refractory alloys to design a module for the demonstration of high helium outlet temperature suitable for hydrogen production.

RAMI

The FDF Program will be a test bed for learning how to engineer and operate reliable first wall/blanket structures and gain first information on reliability growth for the blanket system. The machine must be reliable to achieve two week continuous operation and the availability to achieve a 30% duty factor on a year. It must be maintainable because it is a research environment and failures must be repairable and the blankets must be changeable. Inspection of the components is an integral part of the research; we need to find out what is happening to these components and provide data to fusion reactor RAMI data base.