US Demo Test Blankets in ITER

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ABSTRACT

This paper summarizes the current status of the Demo blanket test systems and how the ITER reactor design and operations are being accommodated. The US blanket program is planning to develop a liquid metal breeder and a solid breeder blanket for testing and evaluation. The test blanket modules will have prototypical components, materials, and coolants representative of power reactor systems. The modules are to be located in the ITER horizontal test ports and installed/removed with special remote handling equipment. Adjacent ITER blanket neutronic and temperature conditions suggest the use of an isolation frame surrounding the test blanket modules or submodules. This frame will also provide additional shielding to protect the adjacent vacuum vessel. The frame and blanket module are attached to the surrounding backplate to transfer static and dynamic loads. All coolants and tritium-bearing fluids will be routed out of the midplane port to special heat exchangers and tritium separation systems. Special remote handling equipment is being designed to install and extract the test blanket modules. Dedicated transporters will be used to move the blanket and shielding modules to dedicated hot cells. Special facility areas will be provided immediately outside the port areas for the heat exchangers, pumps, and tritium-separation systems.

I. INTRODUCTION

The ultimate goal of fusion is to provide an affordable, limitless, and safe source of energy. Throughout the world, this goal is being pursued. One of the necessary ingredients to reach this goal is the ability to demonstrate a power-producing, tritium-breeding blanket system. One of ITER's goals[1] is to "test design concepts of tritium breeding blankets relevant to a reactor. The tests foreseen on modules include the demonstration of a breeding capability that would lead to tritium self-sufficiency in a reactor, the extraction of high-grade heat, and electricity generation." ITER has dedicated five horizontal ports to provide plasma exposure and a relevant fusion environment to enable testing of tritium breeding blankets. The US plans to collaborate with the other parties, with particular preference to two blanket concepts: (1) self-cooled lithium-vanadium and (2) helium-cooled solid breeder.

An international Test Blanket Working Group (TBWG) has been formed to review the blanket testing plans by each party, to promote coordination between parties on development plans, and to help integrate the test blanket systems into ITER. The objective of the blanket test program is to verify that prototypical blanket systems can demonstrate reactor relevant technologies.

II. HIGH LEVEL SYSTEM REQUIREMENTS

The test blanket modules must demonstrate three requirements to satisfy Demo relevancy: (1) achievement of a net tritium breeding ratio greater than 0.8, (2) generation and extraction of high grade heat with reactor-relevant coolants (outlet temperature 7600°C), and (3) generation of a nominal amount of electricity.

When the test blankets are inserted into ITER, they become an integral part of ITER and, as such, must satisfy an additional set of requirements:

- Be compatible with existing mechanical geometry and remote handling equipment
- Provide adequate shielding
- Accommodate all surface and nuclear heating
- Handle all static and dynamic loads
- Support overall vacuum requirements
- Conform to all safety criteria
- Have minimal impact on operational availability

III. TEST BLANKET SYSTEM DESCRIPTION

The US self-cooled, liquid-lithium breeder test blanket module will operate at much higher temperatures than the ITER shielding blanket. The lithium blanket will operate in the range of 350°C to 600°C to adequately validate and characterize the performance of the breeding media and the extraction of the bred tritium. The first wall of the test blanket module will operate at or near the maximum breeding zone temperature. The structural material for the entire module will be a vanadium alloy, V-4Cr-4Ti. Behind the breeding zone, there will be reflector and primary shielding zones largely comprised of Tenelon. The coolant and operating temperature of the reflector and primary shield zones will be similar to the breeding zone to maximize the generation of high-temperature coolant for power production. The secondary shield and the interfacing structures will operate at a lower temperature to be compatible with the temperature of the ITER shielding blanket backplate. Figure 1 illustrates the general configuration of the self-cooled lithium blanket and shield.

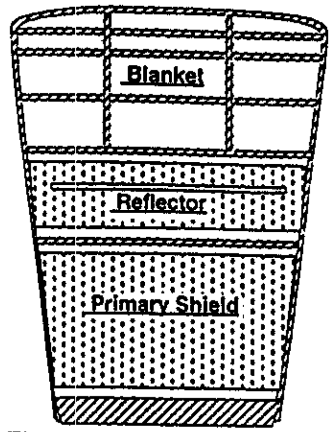

Figure 1. Li/V Test Blanket Arrangement

The larger surface area of the test blanket (1.6m x 2.6m) indicates the more massive nature of the test blanket subsystem as compared to a standard ITER shielding blanket module. The test blanket systems, including first wall, blanket, reflector, primary shield, backplate support, manifolds, low-temperature shielding, and some piping, will weigh approximately 20 tonnes. Because of the lower neutron attenuation of the breeding module, shielding is required behind and around the perimeter of the module to protect the ITER vacuum vessel walls and the superconducting coils.

In order to technically validate the design concepts for the test blankets, the test module must be exposed directly to the plasma. This will allow the module to demonstrate the ability to handle prototypical heat and particle fluxes. Moreover, the test blanket designer has the flexibility to control the neutron environment within the module.

The test blanket coolants must be compatible with the ITER materials and coolants and meet all applicable safety requirements. In addition, the plumbing must accommodate the space constraints of the ITER port and related facilities. The different coolant materials, coolant conditions, and coolant properties will require separate cooling and processing systems. The tritium purge stream will require a separate tritium processing system in order to properly interface with the ITER fuel system.

ITER will provide the common remote handling equipment for all horizontal port systems. All test blanket systems are to be withdrawn radially from the test port and removed to the hot cells for examination and/or refurbishment. ITER will provide the remote handling equipment to manipulate, position, and transport all the horizontal port equipment. All remote handling tools and equipment and transporters that are unique to the test blanket systems will be provided by the blanket testing party.

IV. INTERFACE WITH ITER BLANKET SUBSYSTEM

The test blanket module is installed radially into the horizontal test port to replace a portion of the shielding blanket. Thus for first order effects, it must act similarly to the shielding blanket and not adversely impact the operation of the shielding blanket. The clear opening through the shielding blanket backplate and the blanket modules is 1.600 m wide and 2.600 m high, centered on the horizontal port. The test blanket module is located and supported by the shielding blanket backplate. Figure 2 illustrates the current backplate and test blanket module attachment approach, which uses a flange with teeth for shear loads and bolts to take the radial loads. There is a gap allowance of 20 mm completely around the perimeter of the test blanket. The first wall shall be flush within ± 2 mm of the surrounding shielding blanket module first walls.

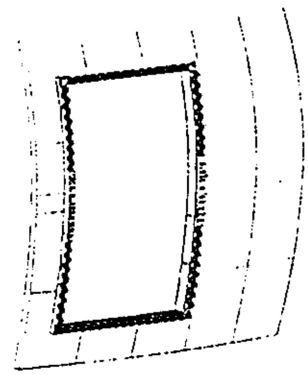
Figure 2. Opening in Backplate

There will probably be a mating frame around the test blanket (provided by the testing party), similar to the one shown in Figure 3. The test blanket module frame outside dimensions are 1.580 m wide by 2.580 m high. Attached to this frame are flanges that have a series of teeth to react the static and dynamic loads induced in the test module. The teeth have bolts to engage and secure the toothed-flange system and react the normal loading conditions. The flange structure will be integrated into the blanket module frame to react all the internal loads. The shielding blanket backplate will transmit the loads through a predetermined load path to the vacuum vessel. A connection between the teeth will provide an electrical current path for currents generated in the module. Although the nominal temperature of most of the test blankets may be in the neighborhood of 600°C, the mounting flange of the test blanket must be cooled with high pressure water to approximately 150°C to prevent excessive thermal stresses in the mounting flange.

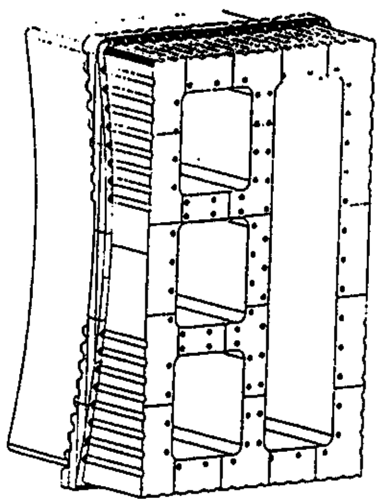

Figure 3. Test Module Frame and Shield

Because the breeding blankets are more neutron transparent than the ITER shielding blanket, additional shielding will be needed behind and to the side of the breeding module to protect the vacuum vessel. This illustration also shows the capability to insert one half-sized submodule and three small submodules, although the frame could accommodate any number of submodules or be designed integral to the blanket module itself.

V. INTERFACE WITH ITER VACUUM VESSEL

One of the important requirements for the ITER vacuum vessel is to provide access ports for in-vessel components. Large ports in the vacuum vessel are provided at the machine's horizontal mid-plane for the test blanket systems and other users. Figure 4 indicates the internal clear area of these port extensions. As stated in the GDRD,[1] the opening size is to be 3.00 m high and 1.80 m wide to accommodate the opening in the backplate. As shown, the vertical opening is reduced by 20 cm to accommodate six water coolant pipes for the ITER lower baffle and limiter modules.

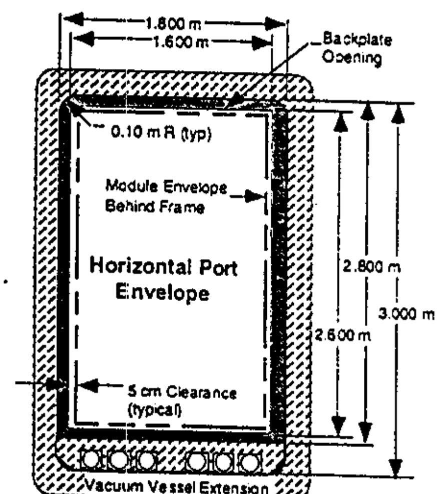

Figure 4. Horizontal Port Envelope

Provisions will be required in the floor or walls of the vacuum vessel extension for remote handling equipment to service and remove/replace the test blanket subsystem. If required, ITER will modify the wall or the floor of the vacuum vessel extension to accept the unique remote handling equipment. Remote handling equipment will be provided for replacement of all common modules. The vacuum vessel extension subfloor for the piping and handling equipment shall be capable of supporting the weight of the test blanket subsystem, which is anticipated to weigh approximately 20 to 30 tonnes.

Since the static and dynamic loads of the test blanket subsystem are borne by the shielding blanket backplate, there must be sufficient clearance between the test blanket subsystem and the vacuum vessel extension to accommodate the relative movements of the backplate to the vacuum vessel. As shown in Figure 4, there is a clearance of 5 cm provided for relative movement during operational conditions. This clearance will also provide sufficient conductance to eliminate trapped gases behind the test blanket subsystem.

VI. TEST BLANKET SUBSYSTEM INSTALLATION

Figure 5 illustrates the complete installation of the test blanket subsystem in the ITER device. The test blanket module is installed on the backplate (partially shown). Test blanket plumbing is routed from the back of the test article along the walls of the vacuum vessel extension. At the end of the vacuum vessel extension, there is a vacuum-tight door that completes the primary vacuum boundary. This door and the remote equipment to handle the door will be provided by the ITER project. Six water coolant pipes for the limiters and baffles are routed through a subfloor in the bottom of the port extension. They are designed to penetrate the wall of the vacuum vessel extension before the vacuum boundary door. Some room may be available in this area to route a few of the test blanket module lines, such as the helium purge lines or the shield water coolant lines. Lines routed through this area will be small and cannot accommodate the internal pipe cutting and welding tools.

At present, there are several options regarding the routing of the test blanket coolant lines. Figure 5 illustrates routing these lines through the sides of the vacuum vessel extension which allows the removal of the vacuum vessel door without disturbing the lines. After the door is removed, external cutting and welding tools can be used to detach and reattach the lines leading to the test blanket. Another option is to have the lines penetrate the vacuum vessel door, which enables the door to be an integral part of the assembly and eliminates installation welding of coolant pipes within the vacuum chamber.

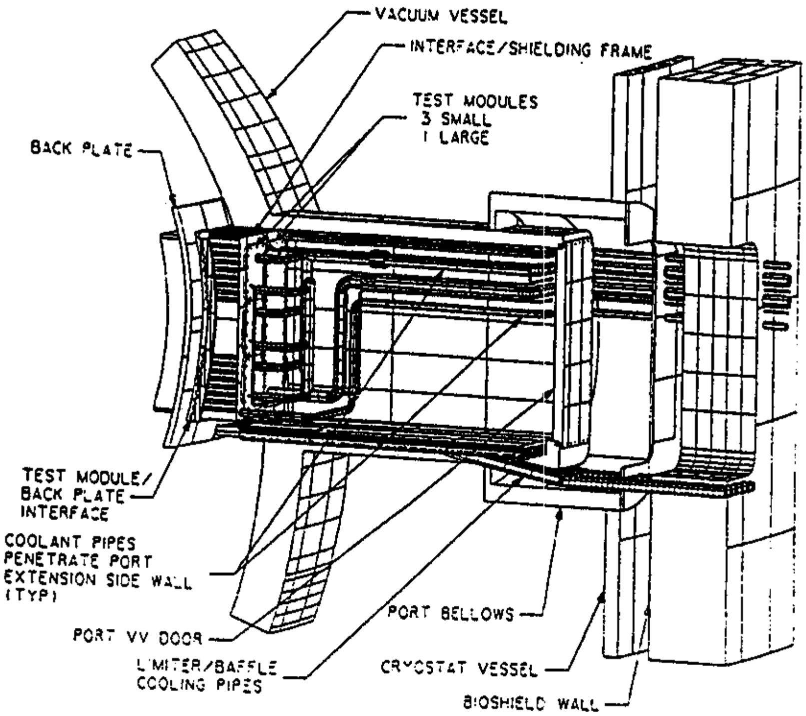

Figure 5. Test Blanket Assembly Installation

Figure 5 also illustrates a new arrangement of the cryostat and bioshield in the area around the horizontal port. This arrangement has no penetrations through the bioshield, thus it can be removed for access to the door of a secondary cryostat chamber around the end of the vacuum vessel extension. This secondary chamber allows access to the extension without disturbing the conditions within the main cryostat. This area also allows passage of piping without penetrations through the access doors.

Figure 6 presents more detail on the test blanket components in an exploded view. The frame shown has four test volumes for testing a large full-height, half-width module (best for testing liquid lithium MHD effects) and three smaller modules (for concept development). There are other frame options, including two full-width, half-height modules (best suited for solid breeders). The figure shows all the modules being supplied by a common header and supply piping; however, it may be likely that two parties will share a common port. In this case, it may be necessary to have two separate supply systems.

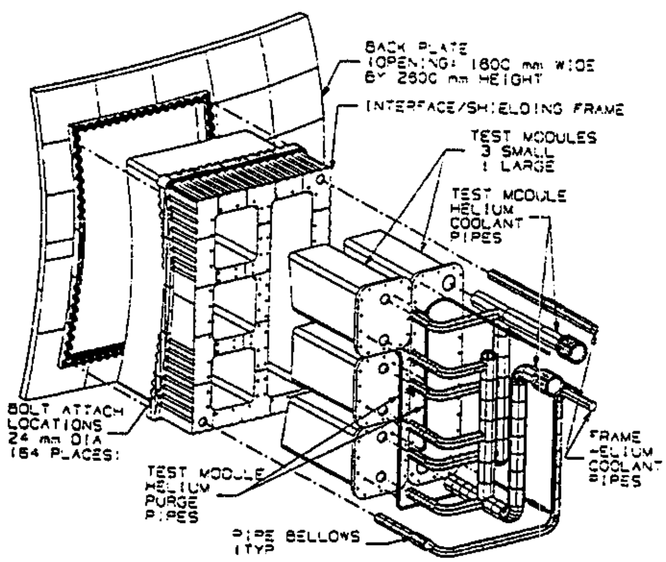

Figure 6. Exploded View of Components

For physical safety of the in-vessel hardware, all piping containing the lithium coolants shall be contained in double-jacketed pipes, both within and external to the vessel. An exception to this may be a short segment of piping between the vacuum vessel plug and cryostat wall where pipe cutting and welding operations can be performed. Leak detection and monitoring equipment will be installed on all plumbing. In addition, all liquid metal lines will be heat traced to prevent solidification and blockage. For safety reasons, all tritium bearing fluid lines will be double-jacketed after exiting the primary containment barrier. To assure passive safety, the lithium subsystems must provide the capability to passively drain all coolants into a storage tank located at a lower elevation. ITER shall provide such a location near the related horizontal port.

VII. TEST BLANKET REMOTE HANDLING

All equipment to be used in the ITER horizontal ports is to be installed and removed radially through the port extensions with remote handling equipment. One of the design goals is to minimize the amount of remote operations inside the port extension. Cutting and welding operations are to be minimized to eliminate the possibility of contamination from cutting and welding debris and to reduce the risk of leaks. The test blanket subsystem will be installed as a pretested assembly, thus enhancing system safety and reliability. Tracks or guide rails installed in the port extension floor or walls will be used to guide this test blanket assembly during installation and removal. A small manipulator will be used to access the fasteners of the blanket module flange and attach the entire module to the backplate. A large ITER remote handling manipulator will be used to support and remove/install the entire test blanket assembly. Both the test blanket assembly and the remote handling manipulator will be withdrawn into a transporter for removal to the hot cells for refurbishment or inspection. The combined length of this assembly and the transporter is within the allowed limits of the transporter of 8 meters. The weight of the assembly will be in the range of 20-30 tonnes, depending on the particular test blanket configuration being tested. The center of gravity of the assembly is anticipated to be at the back plane of the frame attachment surface.

VIII. TRANSPORTER INTERFACE

As indicated above, ITER transporters will be used to support the removal and installation of the test blanket modules. The nominal size of the transporter developed by ITER is 8 m long, 3.8 m wide and 5 m high (outside dimensions). Some of those transporters will perform standard tasks such as bioshield plug and cryostat door removal. Other transporters are designed to perform tasks specific to the test blanket program.

A transporter will be dedicated to housing the test blanket maintenance equipment and will transport the entire assembly to the hot cell. This transporter will interface with the cryostat double door. It will also house the deployable tracks and the other manipulators. Monitoring equipment will also be included in this transporter to constantly monitor the condition of the test module during transportation to the hot cell.

Another transporter will be modified to house the tritium processing systems for the test blanket concepts. These unique tritium processing systems are small in size because of the small amount of tritium to be processed. For safety reasons, it is advantageous to have the tritium processing very close to the test blankets. This type of transporter will reside in the gallery area just outside the bioshield at the designated port in an undocked state. Connections between it and the bioshield are limited to the tritium-carrying fluid line (supply and return) and monitoring and diagnostics cables. Connections between the transporter and plant services will include tritium-carrying lines, secondary heat removal fluids, and monitoring cables. Also, this transporter could house some heat transport subsystems that need to be closely located to the port. It is planned to have the intermediate heat exchanger and pumps for the lithium-cooled blanket in this tritium processing transporter, with the secondary organic coolant being circulated to the ITER Heat Transport System.

IX. FACILITIES INTERFACE

Recent discussions with ITER JCT personnel indicated that the only available area close to the test port is a wedge-shaped area outside the bioshield. However, heavy lifting equipment may not be readily available in these areas. Hence, components in this area should be limited to small sizes and be light weight. A clear path to the port opening must be available for transporter docking. During reactor operation, the tritium processing transporter may be kept at the port area until module replacement is required.

The self-cooled lithium blanket system will require a dump tank to be located below the equatorial port level. This dump tank will be used to drain the blanket module prior to module replacement. Its location below the equatorial port level will enhance natural circulation to drain the system in case of power failure. Indications are that it is possible to designate a small area in the divertor port level for the dump tanks.

All components removed from the test port will be transported to the hot cell for inspection, repair, assembly, and disposal. Many of the test blanket components may be refurbished or combined with new components to be reinstalled back into the reactor. Many of the hot cell operations needed for the test blanket module are similar to those of other components and will use the same tooling and process equipment for performing such operations.

SUMMARY

The US plans to test two blanket concepts in ITER: (1) a self-cooled lithium-vanadium and (2) a helium-cooled solid breeder. Testing plans are being developed. This paper presented some of the key aspects of the engineering interface between the test modules and the basic ITER device. Reasonable engineering schemes have evolved. The ITER Test Blanket Working Group is coordinating the efforts of the parties and the ITER Joint Central Team.

ACKNOWLEDGMENTS

This research was sponsored by the US Department of Energy under contract DE-AC03-94SF20282.

REFERENCES

1. ITER General Design Requirements Document, 22 March 1996.