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FUSION TECHNOLOGY FACILITY — KEY ATTRIBUTES AND INTERFACES TO TECHNOLOGY AND MATERIALS

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Fusion Technology Facility – Key Attributes and Interfaces to Technology and Materials

FTP

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On the way to a Demonstration Fusion Power Plant (DEMO), a number of fusion technology issues will need to be resolved including long burn or steady state DT operation, net tritium breeding ratio of >1 and the application of the Fusion Technology Facility (FTF) as a material and component testing vehicle. The FTF in this paper does not stand for the recommendation of a specific machine, but rather a consideration of a generic device with specific attributes that will need to be considered while the fusion community is moving towards the design of DEMO. The focus of this paper will be on the development of four selected physics and technology interface areas that will have significant impacts on the design of the FTF: 1) acceptable divertor peak heat flux, 2) acceptable uniform chamber wall heat flux, 3) robust chamber wall surface material, and 4) low activation DEMO-relevant structural material.

For the consideration of the first area on divertor peak heat flux, both water and helium-cooled divertor designs are projected to be able to handle a maximum heat flux of 10 MW/m^2. When extended to the FTF and DEMO with their higher plasma power density, in order to limit the maximum heat flux to ≤10 MW/m^2, both a radiative mantle and radiative divertor should be used. Furthermore, an innovative divertor configuration such as the snowflake [1] or super-X [2] divertor concept will also be needed. For a robust divertor design, based on results from edge localized mode (ELM) and disruption simulation experiments, both high power ELMs and disruptions will have to be avoided in the FTF class of machines; otherwise the surface material will suffer significant damage including the melting of the metallic surface material [3,4].

For the second area of uniform chamber wall surface heat flux, 1-D estimates were performed for the helium-cooled chamber wall design with the use of thin layers of W-coating/alloy, reduced activation ferritic martensitic (RAFM) steel, and the oxide dispersion ferritic steel (ODS). Due to the minimum temperature limit of >350°C and the maximum temperature limit of <550°C for the selected RAFM steel structural material, the maximum heat flux that the design can handle is <1 MW/m^2. As a consequence of impulsive heat flux from ELMs, the ITER design requires the blanket/shield module to be designed to the maximum heat flux of 2-5 MW/m^2 [5], which exceeds the above limit of <1 MW/m^2. This implies that for the FTF, high power ELMs will have to be avoided even for the consideration of the chamber wall as well as the divertor.

For the third area of robust chamber wall surface material, presently W is the favored surface material for the chamber wall and divertor. An effort was made to implant significant amount of Si onto the chamber wall, such that the combined Si/W surface materials could become disruption tolerant through the vapor shielding effect of the lower vaporization point of Si to protect the W-surface. However, recent vertical displacement event (VDE) exposures to Si-W samples in DIII-D indicated the formation of the lower melting point eutectic tungsten silicide, which forms when the surface temperature reaches 1400°C as shown in

Fig 1. This further emphasizes the need for disruption avoidance and the need to maintain the wall temperature below 1400°C when Si is used as the wall conditioning material.

For the fourth area of low activation structural material, recent boron-doped RAFM results to simulate the impacts from transmuted helium indicate the possible increase of the minimum operating temperature of RAFM steel to higher than 350°C [6]. This could significantly narrow the operating temperature window of the RAFM steel at higher neutron fluence, leading to the need for development of ODS and nano-ferritic-alloy (NFA) [7], which could be more tolerant of high helium concentration and dpa damage. On the other hand, these advanced materials for fusion application are at an early stage of development. This then points to the urgent need for a fusion neutron irradiation testing facility for fusion material development, and the need for the FTF to be operated in a staged approach such that advanced fusion materials and corresponding components can be tested in the bootstrap approach for the development of DEMO. These areas of plasma edge physics, chamber surface and divertor materials and advanced structural material interactions and the associated necessary research directions for both tokamak and stellerator approaches are discussed in this paper.

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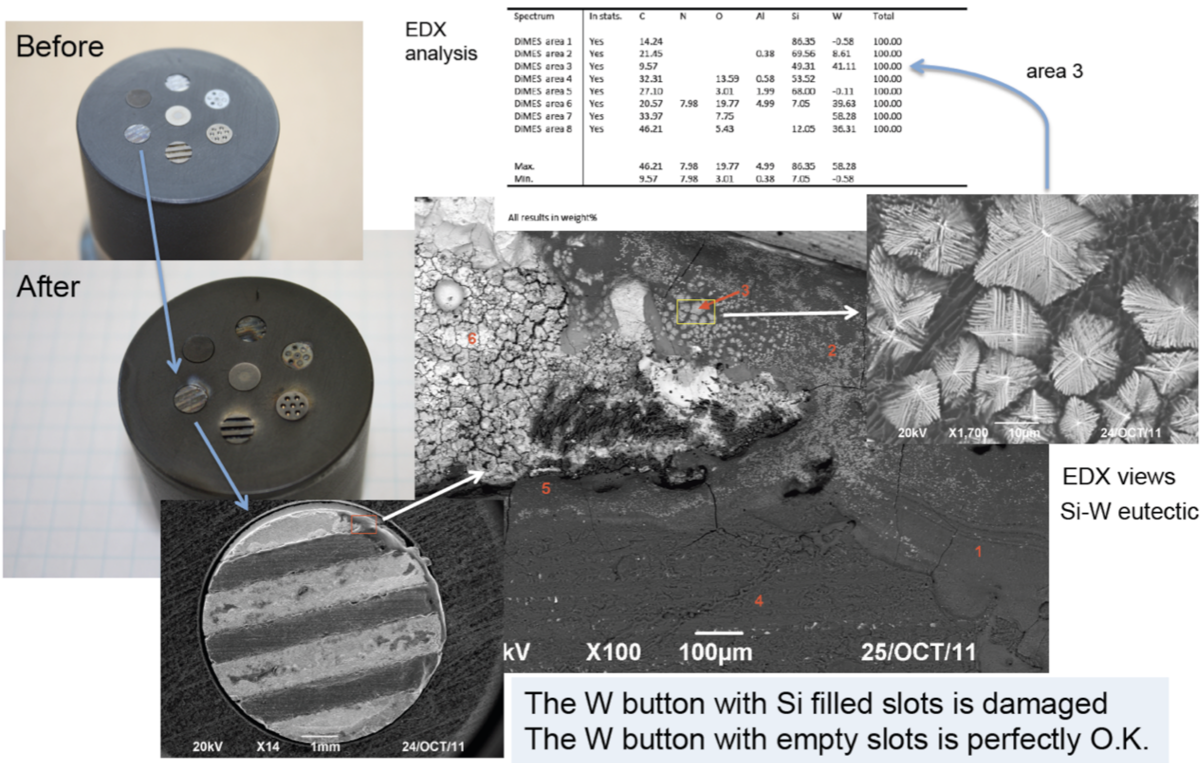

Spectrum	In stats.	C	N	O	Al	Si	W	Total
DiMES area 1	Yes	14.24				86.35	-0.58	100.00
DiMES area 2	Yes	21.45			0.38	69.56	8.61	100.00
DiMES area 3	Yes	9.57				49.31	41.11	100.00
DiMES area 4	Yes	32.31		13.59	0.58	53.52		100.00
DiMES area 5	Yes	27.10		3.01	1.99	68.00	-0.11	100.00
DiMES area 6	Yes	20.57	7.98	19.77	4.99	7.05	39.63	100.00
DiMES area 7	Yes	33.97		7.75			58.28	100.00
DiMES area 8	Yes	46.21		5.43		12.05	36.31	100.00
Max.		46.21	7.98	19.77	4.99	86.35	58.28	
Min.		9.57	7.98	3.01	0.38	7.05	-0.58	

Fig. 1. Exposure of Si-W buttons to several VDEs in DIII-D indicated Si-W reactions and the formation of low melting point Si-W eutectic. This implies that the use of Si and W at >1400°C operation should be avoided.

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