FUSION IGNITION RESEARCH EXPERIMENT
SYSTEM INTEGRATION *

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Abstract--The FIRE configuration has been designed to meet the physics objectives and subsystem requirements in an arrangement that allows remote maintenance of in-vessel components and hands-on maintenance of components outside the TF boundary. The general arrangement consists of sixteen wedged shaped TF coils that surround a free standing central solenoid (CS), a double wall vacuum vessel and internal plasma facing components. A center tie rod is used to help support the vertical magnetic loads and a compression ring is used to maintain wedge pressure in the inboard corners of the TF coils. The magnets are liquid nitrogen cooled and the entire device is surrounded by a thermal enclosure. The double wall vacuum vessel integrates cooling and shielding in a shape that maximizes shielding of ex-vessel components. The FIRE configuration development and integration process has evolved from an early stage of concept selection to a higher level of machine definition and component details. This paper describes the status of the configuration development and the integration of the major subsystem components.

Design Configuration and Integration

The isometric view of Figure 1 shows the FIRE experimental device with the insulation enclosure partially cut back to expose the core components. An in-vessel remote maintenance module is also shown attached to one port. Figure 2 highlights in greater detail the major device core components. The Burning Plasma Experiment (BPX-AT), an earlier design study, was used as a reference in developing the details of FIRE and some similarities are evident in the design. However, there are several very significant differences in the FIRE design. The main differences are:

- *Double null gaseous divertors are chosen over the "swept" double null used in* BPX-AT. Gaseous divertors have been shown to be effective in radiating most of the power going to the divertor regions throughout the first wall rather than depositing it in a localized toroidal stripe in the divertor.

- *A double-walled vacuum vessel with integral shielding has been adopted.* This is an important differentiating feature between FIRE and BPX-AT. Besides providing improved vessel structural stiffness, this configuration makes use of the cooling jacket as nuclear shielding. This shielding location reduces nuclear heating in the TF coils and reduces the dose external to the vessel. The reduced nuclear heating permits longer flat top times and higher current densities than would otherwise be possible. This "close in" shielding arrangement also reduces the dose outside the vessel and activation of nitrogen that is in the thermal shield.

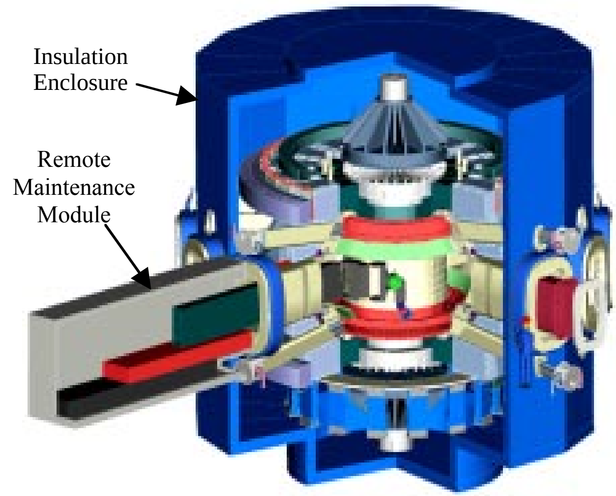

Figure 1. Cross-Sectional View of FIRE Through the Insulation Enclosure

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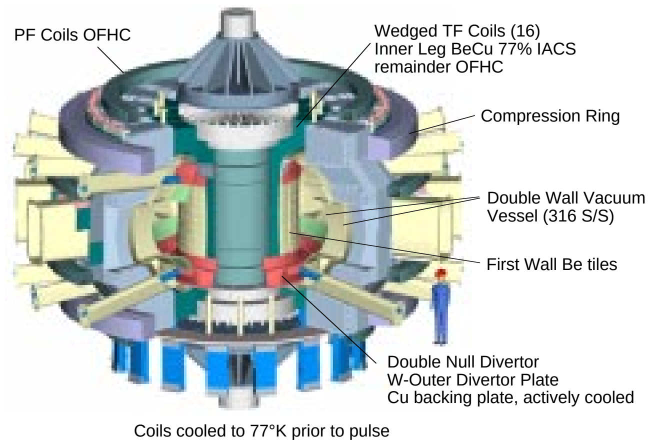


Figure 2. Isometric View Illustrating the Major Core Components

- *Higher plasma triangularity (δ_{95} of 0.4 vs. 0.2-0.3) is provided for improved performance.*

- *FIRE has the potential for a much greater range of operation*. The primary mode for FIRE is to operate as a high Q (5-10) burning plasma experiment. In this mode, FIRE is capable of D-T shots at 10T with a flat top time of 21 s and a plasma current of 6.44 MA. Based on TFTR experience, many of the pulses leading to a D-T shot are performed with D-D plasmas to establish pulse requirements. With D-D, nuclear heating will be insignificant and the pulse can be extended to 31 s. It can also operate in a "TPX-like" mode (4T, 2 MA) with flat top times up to 243 s. Recently, a study was made of a high field (12T) option for FIRE. This requires the use of a higher strength version of the C17510 BeCu used in the highly stressed inner leg of the TF coil. This could make possible operation with a 7.7 MA plasma, 12 T field for 12 s in D-T, and 18.5 s in D-D with modest reductions in the flat top times in the other operational modes.

Design Features

Figures 1 and 2 illustrate the design features of the reference design. The major components and features are:

- Sixteen wedged TF coils. They are inertially LN_2 cooled, with a partial coil case. High strength BeCu C17510 is used in the inner legs; OFHC copper is used in the remainder of the coil. Compression rings girdle the TF coils to suppress "dewedging" in the upper and lower inside corners of the coils. A central tie rod reacts a portion of the vertical separating force.
- Two pairs of divertor coils (up-down symmetric). These coils are inertially LN_2 cooled and strip wound with oxygen-free high conductivity (OFHC) (C10200) copper.
- Two pairs of external ring coils (up-down symmetric). These are similar in construction to the divertor coils and use OFHC copper.
- A free standing segmented central solenoid (CS). These coils will be made of LN_2 cooled, OFHC, water jet cut, discs.
- A double-walled vacuum vessel. The inner space is filled with steel and water for nuclear shielding.
- Internal plasma facing components (shown in Figure 3). The Be coated Cu first wall and tungsten pin-type inner divertor module and baffle are inertially cooled through the vacuum vessel; the tungsten pin-type outer divertor module is actively cooled. The divertor is designed for a high triangularity, double-null plasma with a short inner null point-to-wall distance and near vertical outer divertor flux line.
- Two outboard poloidal limiters, spaced 90 degrees apart, enclose the ICRH quadrant.
- A passive stabilization system consisting of an inboard pair of ring coils and an outboard saddle coil.

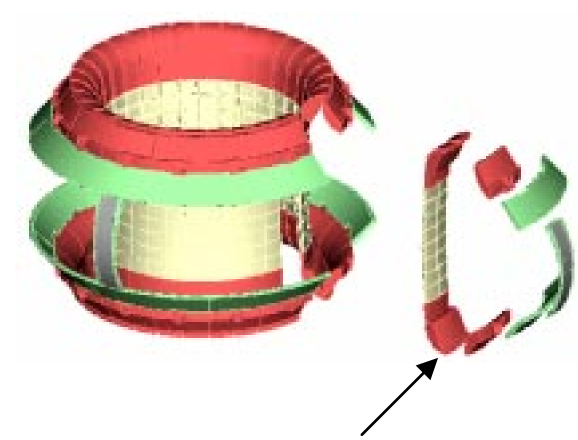


Figure 3. FIRE Plasma Facing Components

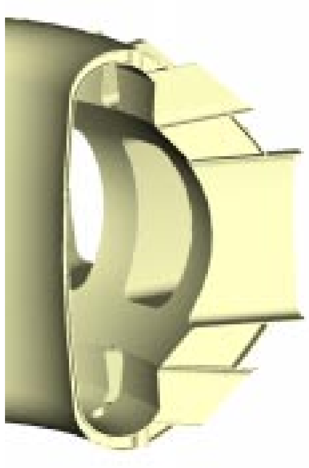
- An active control coil system consisting of a pair of coils located within the outboard vessel jacket.

- A thermal enclosure similar to the design used for C-Mod (i.e., polyimide foam insulation with fiberglass inner and outer protective/structural skins).

Design Choices

Sixteen TF coils were selected as the number of coils to provide reasonably large openings between coils for in-vessel access. The radial position of the coil back leg is set by a number of considerations, including access, ripple, and shield thickness requirements; FIRE's design has good balance between these considerations. The inner leg of the TF coil, where the stress is highest, is made of a high strength, high conductivity variant of C17510 BeCu. This alloy was developed for BPX, and commercialized since then by its developer, Brush-Welman. The variant we propose to use has a 0.2% yield strength of 720 Mpa and an electrical conductivity of 68% IACS. The stress in the outer regions of the coil is low enough to permit less costly oxygen free copper (C102) to be used.

The vacuum vessel double wall geometry was formed with an inner surface that closely follows the contour of the plasma, allowing space for the poloidal limiter, outboard passive plates and the divertor components. The geometry contour is shown in isometric and elevation views in Figure 4. The plasma-forming contour of the inner wall improves plasma control characteristics and maximizes the space for shielding.



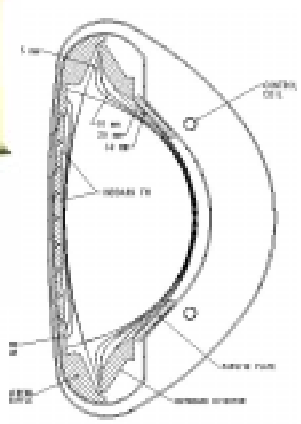


Figure 4. VV Contoured to Follow Plasma Profile

Machine Assembly

FIRE is assembled in four 90-degree sections built up from a four-coil TF assembly and a 90-degree vacuum vessel quadrant, as illustrated in Figure 5. A vacuum vessel quadrant is rotated into the bore of the TF at assembly. Sixteen large, “straight-in” view ports are equally distributed along the vacuum vessel mid-plane. Sixteen upper and lower auxiliary ports are provided, angled in a position to allow diagnostic view

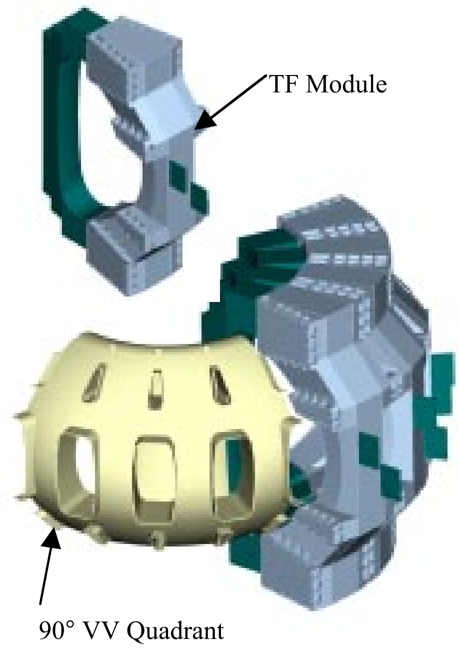


Figure 5. VV / TF Quadrant Assembly

of the divertor region.

Small circular ports are also located at the top and bottom of the vacuum vessel, passing through the region between the TF coil winding.

The horizontal ports will provide access to the ancillary systems outside the device. Three ports are assigned to RF heating, and the remaining ports allocated between diagnostics, vacuum pumping and a pellet injection system. Some port space will also be used for in-vessel PFC coolant routings. The electrical feed connection to internal control coils are located above/below two horizontal ports located 90° apart. The angled auxiliary ports, located in the upper and lower vessel regions, accommodate cryopumps, the divertor cooling lines and diagnostics.
The radial build dimensions, listed in Table 1, identify the space allocated to the components in the confined region inboard of the plasma center.

Conclusion

The FIRE design and integration process has proceeded to develop a first level device configuration that meets the physics objectives and subsystem requirements. The design of the major subsystem components has also been developed in sufficient detail to develop performance and preliminary cost studies. Future activities will expand the design to refine the system details, interfaces and the requirements for remote handling.

Table 1. FIRE Radial Builds

	COMP BUILD mm		**COMP** Dim	**TOTAL** Dim
	Machine Center			0.0
	gap	0		0.0
	inner Cylinder	310		310.0
	gap	100		410.0
CS	Insulation inside	10.0		
	Nom winding thk	380.0		
	Insulation outside	10.0	400.0	810.0
	bladder,shims,slip plane	0		
	gap	10		820.0
inbd TF	CS side case thk	0.0		
	Ground insul / filler	12.0		
	winding pack	464.0		
	ground insul / filler	12.0		
	plasma side case thk	0.0	488.0	1308.0
	Trapezoidal Effect	0.0		1308.0
	TF TPT	5.0		
	Minimum TF/VV gap	10.0		
	VV TPT	0.0		
	Thermal Shield	12.0	27.	1335.
inbd VV	VV shell thk	15.0		
	Shield material	20.0		
	VV shell thk	15.0	50.0	1385.
	TPT	5.0		
	Diagnostics/manifold	0.0		
	Alignment space	0.0	5.0	1390.
PFC Module	Blanket or Heat Sink	40.0		
	manifold space	0.0		
	FW (Cu-H2O-SS/Be)	10.0	50.0	1440.0
	Plasma SO	35.0		
	Plasma minor radii	525.0		
Plasma R0				**2000.0**