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The examination of the FNSF maintenance approach

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ABSTRACT

This paper addresses an approach to maintain and sustain the high-intensity Fusion Nuclear Science Facility (FNSF) experimental fusion facility that would enable it to have extended operations exceeding several exchanges of the primary power core components. The maintenance approach must be safe, quick, reliable, repeatable and precise. Moreover, this approach and equipment should be able to be extrapolated to the future fusion demonstration power plant (DEMO). A preliminary evaluation is presented for the underlying maintenance and safety requirements and the key design approaches that will define the FNSF and shape future high-power fusion facilities.

1. Introduction and guidance for Power Core maintenance

The Fusion Nuclear Science Facility project is structured to consider and define the research and development needs for an experimental fusion facility that would span the physics and technology gaps between ITER (International Thermonuclear Experimental Reactor) and the U.S. DEMO.

This FNSF study project is not intended to provide a detailed conceptual design, rather it examines the important aspects and issues of the first large fusion facility to achieve a high-performance, magnetically-confined, long-duration DT plasma with a net tritium-breeding ratio at or near unity. It is only an initial assessment of what may be required to build and operate FNSF for extended durations. It is a snapshot of a limited number of systems with many more systems left to examine and develop. The assessment of maintenance and hot cell operation of a high-power fusion plant is based on a minimal existing database of applicable maintenance equipment and processes. Further, future technologies promise safe, affordable, and efficient maintenance operations. Many improved or new technologies will be available while more stringent safety and environmental regulations may exist. These designs and concepts represent our current understanding and visualization of how the FNSF may be designed and operated.

1.1. Scope of FNSF

The scope of the FNSF has considered a wide range of capabilities, ranging from a very low-technology, copper coil version up to an advanced physics and technology version approaching the U. S. DEMO capability. The former would represent a low-risk FNSF while transferring most of the risk to the R&D, design, and operation of DEMO. On the other hand, with the advanced physics and technology version, the greater risk resides with the FNSF, which would utilize and demonstrate nearly-qualified subsystems for the DEMO. As an intermediate approach, the FNSF study adopted a moderate approach to balancing the risk between FNSF and DEMO that could achieve the requisite FNSF plasma and technology goals with a similar level of risk to the DEMO facility.

The moderate FNSF approach implies the demonstration of an intrinsic plant availability approaching 40%. (The definition of plant availability is the ratio of the annual time the facility is available for operation divided by the total annual time. The 40% value may occur near the end of the plant lifetime when all operational processes have matured and all systems have achieved a high level of reliability.) Likewise the FNSF thermal generation and out-of-core systems capability must be sufficiently high to demonstrate thermal-to-electrical conversion efficiencies that can be reasonably extrapolated to the DEMO. In the moderate FNSF option, it was felt that a high thermally-efficient heat conversion system was adequate to demonstrate system capability without actually employing an electrical generation capability (the applicable electrical generation technology has been demonstrated).

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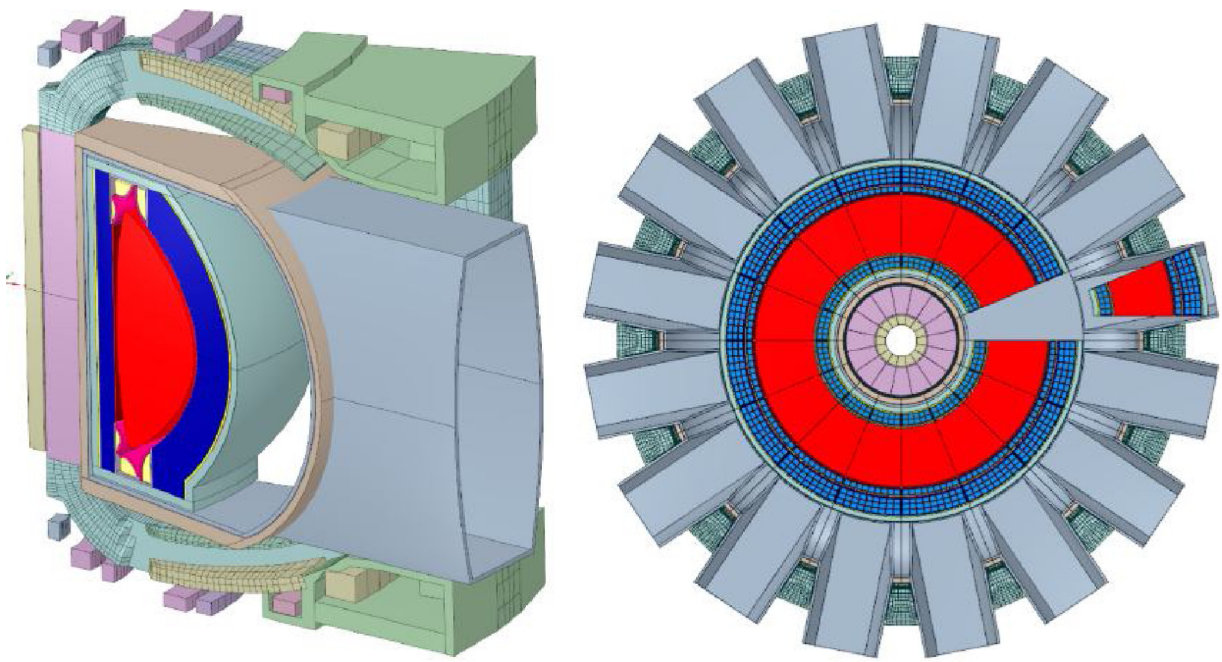

Fig. 1-1. FNSF Section View and Top View.

1.2. Visualization of the FNSF Power Core and Hot Cell

The present FNSF concept has configuration and maintenance roots in all prior conceptual tokamak power plant (PP) studies, such as Starfire [1] and the ARIES studies of Pulsar [2], ARIES-RS [3], ARIES-AT [4] and ARIES-AT1] [5]. These power plant studies laid the essential framework on how large, steady-state fusion plants could be designed, operated, and maintained. The horizontal extraction of large sectors between the TF coils has been the maintenance basis of all the U.S. tokamak fusion plant studies and this approach continues in the FNSF concept. To grasp the basic FNSF configuration, Fig. 1-1 illustrates, on the left, a 1/16 slice of the Power Core, Vacuum Vessel, Maintenance Port, TF and PF coils and the structural supports. The top view of the entire power core is shown on the right of Fig. 1-1. The scale of the power core is depicted in a later graphic.

To better understand the components inside the FNSF, Fig. 1-2 provides a side view of the Power Core and identifies the other internal elements. The removable Sector assembly contains the following elements – First Wall, Blanket, Divertor and Structural Ring. These subsystems are closest to the plasma and will see the most neutronic damage, thus they will be frequently replaced as an integral unit. As the name implies, the Structural Ring contains and supports all the other items and contains and/or holds all the plumbing connections for all the other elements. The Sector will be disconnected and then withdrawn from its central location and exit through the Maintenance Port. The Vacuum Vessel and coils are currently considered (and designed) to be the life of plant elements as all other components beyond the Vacuum Vessel. Portions of other subsystems, such as the vacuum ducts, RF launchers and tubes, pellet injection tubes and diagnostic ports are also subject to neutron damage and, thus, will also have a finite lifetime and will need to be replaced, as required. However, at the present time, these components are largely undefined. (Note, these subsystem components are not shown in Fig. 1-2).

To assist the reader in understanding the maintenance topics, concepts, and hardware developed in the FNSF project, a pre-conceptual sketch, Fig. 1-3 , of the Power Core, Maintenance Corridor, and Hot Cell (for the Sector) was generated to illustrate the basic principles and requirements of maintaining and supporting a high-power, long-lived fusion power plant. The Fig. 1-3 illustration is not intended to be an optimal facility design, rather it portrays the essence of the maintenance function. It concentrates on the safety needs of plant personnel (and the public) while investigating the performance of the in-vessel systems and assuring efficient maintenance operation to assure the maximum plant availability.

As discussed more fully later in this document, this layout assumes the Horizontal Sector Replacement is the most efficient tokamak power core maintenance concept. As shown in Fig. 1-3, a concentric Maintenance Corridor allows docking of sealed, mobile Casks that will contain and transport a used Sector (or a new Sector) and a Maintenance Robot between the Power Core and the Hot Cell. These Maintenance Robots will disconnect, remove, replace, and reconnect the Sectors from inside the Cask. They will also move the Sectors throughout the Hot Cell. The Hot Cell facility, shown in Fig. 1-3, enables examination, cleaning, disassembly, refurbishment (or replacement) and final checkout of all Sectors before re-entering the Corridor and the Power Core.

The following sections of this document will explain in more detail how the FNSF maintenance approach and facility concept evolved. Again, the FNSF is not intended to be an actual fusion power plant, however, it must examine and demonstrate key aspects of the fusion DEMO and power plant so the programmatic risks of designing, constructing and operating those facilities are acceptable.

1.3. Definitions

A few definitions are in order to help the reader understand the ensuing discussions.

The broad interpretation of the Power Core (PC) includes all systems necessary to create, contain, and sustain the fusion plasma as well as extract the generated fusion power. A more narrow subset of the Power Core (mainly used in this paper) contains those subsystems that are life-limited due to exposure to the intense neutron exposure, thus requiring replacement every several years (e.g., First Wall (FW), Blanket, Divertor and Structural Ring (SR)). The Structural Ring provides support and alignment for the FW, Blanket, and Divertor in the Power Core and is a conduit for all related plumbing.

The FNSF adopted a horizontal maintenance scheme that assumes the extraction of a portion of the frequently replaced Power Core (namely, the First Wall (FW), Blanket, Divertor, and SR). The entire frequently-replaced Power Core is divided into elements called Sectors that will be extracted between the TF Coils (Toroidal Field coils). Each Sector corresponds to a space between each TF coil so the number of Sectors equals the number of TF Coils.