ITER REACTOR BUILDING DESIGN STUDY*

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ABSTRACT

The International Thermonuclear Experimental Reactor (ITER) is at the midpoint of a two-year conceptual design. The ITER reactor building is a reinforced concrete structure that houses the tokamak and associated equipment and systems and forms a barrier between the tokamak and the external environment. It provides radiation shielding and controls the release of radioactive materials to the environment during both routine operations and accidents. The building protects the tokamak from external events, such as earthquakes or aircraft strikes. The reactor building requirements have been developed from the component designs and the preliminary safety analysis. The equipment requirements, tritium confinement, and biological shielding have been studied. The building design in progress requires continuous iteration with the component and system designs and with the safety analysis.

EQUIPMENT REQUIREMENTS

The arrangement of equipment in the reactor building is based first on the operating and maintenance requirements of each system. Within these constraints, the systems are located to provide an efficient layout, with provisions for the transfer of equipment, the location of service lines, and the grouping of related systems external to the reactor building. Specific equipment in the reactor building includes neutral beam injectors; lower-hybrid, ion cyclotron, and electron cyclotron rf launching systems; torus vacuum pumps; reactor maintenance equipment; fueling equipment; diagnostics; test module services; blanket tritium extraction equipment; and primary heat transfer circuits.

The systems requiring the greatest space in the building are the in-vessel maintenance and the neutral beams. Remote maintenance equipment that operates inside of the plasma vacuum vessel is required for inspection and general cleanup, for first-wall tile replacement and possibly tile mount repair, and for replacement of the divertor plates. The complete divertor plate, including the cooling channels, is removed as a unit. This requires the cutting and welding of cooling pipes from outside the vacuum vessel and the handling of a large and massive structure internally. The divertor scheduled lifetime is nominally one calendar year,

so rapid replacement of all divertors is required. These divertor maintenance requirements are beyond present technology, and the equipment concepts and operating procedures are still in development. Given the range of required operations and the uncertainty in the equipment capabilities, the Assembly and Maintenance Unit has specified the use of four midplane ports, preferably 90° apart. Two of these ports would be connected to in-vessel equipment storage areas, and two would be used for component transfer.

The reference current drive system for ITER requires an injected neutral beam power of 75 MW. This is delivered by three beam lines at each of three ports. The vertical stack of beam lines at a port extends approximately 40 m from the vacuum vessel and is approximately 20 m high. Since the total length of the beam line communicates with the plasma, it will be in a confinement area.

The lower-hybrid system delivers 50 MW through two midplane ports. The launcher extends ~5 m beyond the vacuum vessel, at which point transmission lines are routed to the klystrons. These transmission lines can include bends and can have a length of about 50 m with acceptable loss so that they can be routed through shielding and the klystrons can be located in a personnel access area.

The electron cyclotron wave system delivers 20 MW through a single midplane port. The launcher, waveguides, and gyrotrons are arranged in a layout similar to that of the lower hybrid. The launcher itself is larger, extending ~9 m beyond the vacuum vessel port. Maintenance space is required behind both the lower-hybrid and the electron cyclotron launchers so that they can be removed from the torus after the transmission lines are disconnected.

Torus vacuum pumping ducts are connected to the lower divertor exhaust chamber at each sector. The ducts are routed down to clear the tokamak and then out radially through a shielding wall. Each pumping station includes high-vacuum pumps, turbomolecular pumps for initial pumpdown and torus conditioning, roughing pumps, and isolation valves. The space required extends ~15 m radially from the vacuum vessel and 10 m vertically and includes the complete periphery of the reactor. Both compound cryopumps and turbomolecular pumps are being considered, and concepts for the pump layout are in development.

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A representative group of ITER diagnostics has been selected for preconceptual design to provide better understanding of the layout and interface requirements. The number of diagnostic penetrations to the torus and the range of viewing angles are the significant layout issues, rather than the total area requirements or number of dedicated ports. Multiple data points are required by the variety of operating scenarios for ITER, the important profile effects, and the redundancy required by long pulses. The multiple line-of-sight views through the plasma result in large angular spreads of detectors external to the vacuum vessels.

The materials and blanket test programs are nominally allotted two ports during the physics phase and six ports during the technology phase. Since the test program access to the machine will be less than that which could be productively used, port sharing and changes in port use with diagnostics or other systems are required. Extensive space allocations and maintenance operations are required for the test elements and their support systems.

Ring headers are located above the cryostat vacuum vessel to supply water coolant to the divertor, first-wall, blanket, shield, and plasma vacuum vessel segments. These headers are each supplied by two independent circuits, with the primary heat exchangers and pumps located above the reactor. The definition of the pipe routing from the components to the headers, which is complex because of the restricted space and the large number of internal components, is complete.

CONFINEMENT

The reactor building is the last physical barrier to control the release of radioactive material to the environment. It will be designed to contain or confine to acceptable levels any routine or accidental release of tritium or activated material. The external walls of the reactor building form a gas barrier under slightly negative pressure, with a maximum atmospheric inleakage of 1% of the building volume per day, and the building has a filtered exhaust. Preliminary accident scenario analyses do not predict an internal overpressure greater than that which could be held by a well-designed confinement building.

The location of the controlled building wall and the location and number of internal confinement walls or barriers are to be determined by safety requirements. Passive safety is a goal of ITER. The design philosophy for each system is to minimize the system volatilizable inventory, to use independent systems, to isolate the systems from each other, and to provide a high-quality, preferably passive, system barrier. The number of barriers will be determined case by case, on the basis of source inventory, concentration, and form. Multiple barriers will be required for any release that could exceed the ITER maximum off-site dose criterion.

As working guidance for the component design approach, it is assumed that the reactor and auxiliary system process boundaries form the first barrier and the

reactor building provides the final barrier. Owing to the large inventory of volatilizable tritium in the reactor, a third barrier is required during operation. This barrier must be provided around all systems that communicate with the torus during operation and that are not passively shut off from the torus by the onset of a transient. This barrier can take the form of a double process boundary or a confinement cell in the reactor building. The reactor building confinement is operational during maintenance. Prior to in-vessel operations, all systems will be deactivated to eliminate accident initiators, all systems will be isolated by valves, and the volume to be opened will be decontaminated to the extent possible. The maintenance operation will be performed within a second confinement barrier if required. The routine emissions will be controlled by monitoring and processing the atmosphere in each area and by monitoring and testing the integrity of the confinement barriers.

BIOLOGICAL SHIELDING

The reactor shield is designed to criteria established by the protection of the superconducting magnets; it is not intended to provide radiation shielding for the plant personnel or the public or to be adequate for personnel access to the tokamak after operation. Biological shielding for the plant personnel in unrestricted areas and for the public will be provided by the internal and external walls of the reactor building. Requirements to provide controlled access after shutdown for maintenance support are under review.

Space in the ITER reference configuration is adequate to provide shielding for personnel access 24 h after shutdown if required. Neutron shielding to provide access during reactor operations can be provided by a concrete wall, 1.5–2 m thick, in addition to the reactor shield. Detailed descriptions of all the penetrations through the plasma and cryostat vacuum vessels, and of the grouping of those penetrations, are required to implement the shield design to either criteria.

The maintenance requirements of the individual systems were reviewed, and no specific requirements for access to the main operating floor near the reactor were identified. The known maintenance requirements at the present level of design require access to the activated systems and are assumed to be remote. In addition, the design complexity introduced into the system by biological shielding and the loss of flexibility by the permanent shield penetrations are concerns.

BUILDING DESIGN

The ITER configuration is based on vertical assembly and maintenance of the major tokamak components. The floor levels (Fig. 1) are the basement, the vacuum pumping level, the service mezzanine, the operating level, the primary coolant mezzanine, and the high bay. The high bay (Fig. 2), used for component lifting and transport, is isolated from the tokamak during operation by confinement barriers and shielding.

Fig. 1. ITER reactor building elevation (split section showing two pumping arrangements).

Fig. 2. Top deck plan.

The high bay is 32 m wide to provide full crane access to the components inside the vacuum vessel. The length is nominally 100 m for component transfer and laydown, with hatches to the maintenance access areas below. The main cover over the tokamak, which is a

rotary shield that provides single-port access, can be rolled away for major component replacement.

The operating level configuration is based on the equipment mounted on the center ports of the plasma vacuum vessel. The arrangement is not symmetrical, and the equipment requirements are not well defined. Several arrangements are being evaluated for building size, location of confinement barriers and shield walls, maintenance equipment accessibility and transfer routes, and integration with building structure. The layout of Fig. 3 provides a 10-m-wide annular corridor around the vacuum vessel for maintenance access to the center port equipment and services. The corridor is broken by the neutral beams, which extend into a separate building. The maintenance equipment is stored outside the vault, with access tunnels from the wall to the vacuum vessel. Two of these tunnels are removable as required to transfer equipment around the reactor. The reactor vault, which forms the confinement and shielding boundaries, is irregular and approximately 40 by 60 m. The complete building, including access areas, is 60 by 80 m.

The main cooling headers are located above the maintenance corridor in the heat transport mezzanine (Fig. 4). Supporting structure for the high bay is provided at the cryostat wall. The service mezzanine (Fig. 5) beneath the reactor provides for service routing to accessible areas.

The vacuum pumping level, which is 60 by 80 m, is structurally continuous with the operating level. Eight pumping stations are located symmetrically around the vacuum vessel (shown in Fig. 6 with a single main header to each). Other pump arrangements are being

Fig. 3. Operating level.

Fig. 4. Heat transport mezzanine.

Fig. 6. Vacuum pumping level.

Fig. 5. Service mezzanine.

Fig. 7. Basement services.

considered. The basement below (Fig. 7) includes the tokamak support structure with access to the service lines and to cryogenic services.

CONCLUSIONS

The reactor building system requirements, including the equipment arrangement, confinement barriers, and

shielding, have been reviewed and design concepts described. The ITER configuration allows a well-defined confinement and shielding vault close to the reactor, which improves safety and reduces cost. The design concepts will be further developed jointly with the system designers to provide adequate space for operations and maintenance and to better define the building boundaries.