INTOR Mechanical Configuration Concept

F. Farfaletti-Casali
Commission of the European Communities, Division Engineering,
J.R.C. Ispra Establishment, I-21020 Ispra (Varese), Italy

T.G. Brown, T.E. Shannon
Oak Ridge National Laboratory, Fusion Engineering Design Center, P.O. Box Y, Oak Ridge, Tennessee 37830, U.S.A.

G. Churahov, D. Serebrennikov
D.V. Efremov Scientific Institute, Leningrad, U.S.S.R.

S. Nishio
Japan Atomic Energy Research Institute, Japan

P. Reynolds
UKAEA, Culham Laboratory, U.K.

T. Uchida
Toshiba Corporation, Japan

The present phase of the International Tokamak Reactor (INTOR) study has been set up to critically address technical issues which affect the feasibility, cost, and engineering simplicity of the concept [1]. One objective of the study was to produce a new design concept with a significant reduction in the size of the tokamak device while maintaining the plasma size and performance. This paper defines the Phase II INTOR configuration that has evolved during this conceptual design period and represents the combined efforts of all participating countries: USSR, Japan, Europe, and the USA.

As a result of the new concepts developed in this phase, a new design configuration has evolved, using the same number of TF coils (12), yet permitting a reduction in the coil size by approximately 15%. The associated magnetic ripple for this design has increased slightly to approximately 0.9%. Due to the strong influence of TF coil size on the other tokamak systems such as PF coils, power supplies and machine structure, the overall cost of the INTOR project may be reduced by over 10%.

The revised design incorporates several major changes from the previous design related to the vacuum topology, the torus, and the structural design. The configuration also provides sufficient flexibility to accommodate the uncertainty involved in the choice of bulk heating and impurity control methods; i.e., neutral beam injection or ICRF for heating and a poloidal divertor or pumped limiter located at the bottom of the plasma chamber for impurity control.

The Phase II configuration is not fully optimized for either the limiter or divertor impurity control systems; however, the solution developed has been useful in this conceptual design phase to design and evaluate the many components associated with a tokamak device, i.e., TF coils, breeding blankets, heating systems, etc.

1. **Introduction**

Two configuration changes were adopted in the Phase II INTOR design which permit the decrease in the device size and its improved maintenance characteristics. These changes include (1) incorporating a combined vacuum boundary between the superconducting magnetic system and the torus plasma chamber and (2) locating the lower outboard EF coil in a separate vacuum boundary. Incorporating a combined vacuum boundary allows the TF coil size to be reduced by approximately 15%, and relocating the lower outboard EF coil separated the maintenance activities between this coil and the overall reactor device. The components that were altered are highlighted in the elevation view of the Phase I reference design, shown in Fig. 1.

There still remain some differences in opinion over the torus segmentation approach -- 12 or 24 sectors. A 12-sector option was selected for the Phase I configuration design based on the fact that it provided the maximum access surface for penetrations to the plasma, plus it offered the most simple design approach for assembly and maintenance of torus modules. By incorporating a combined vacuum boundary and modifying the shield concept, it appears that the 12-sector design is still feasible. The Phase II TF coil size, however, appears to be at the limit for which this concept applies. For this reason, it seemed prudent to develop a 24-sector concept in the event that ripple limits are substantially reduced or the TF coil cross section needs to be increased for magnetic or structural reasons. Figures 2 and 3 show the elevation view of the Phase II 12- and 24-sector torus configuration.

2. **Overall Design**

The INTOR Phase II device consists of 12 superconducting toroidal field (TF) coils, plus an all-exterior poloidal field (PF) coil system, which has the capability to establish either a divertor or pumped limiter-shaped plasma by changing the coil currents, not their position.

Twelve shielded vacuum ducts are located at the bottom of the device and attach to the torus plasma chamber between TF coils; the pumping ducts provide the gravity support for the torus. The torus has been configured to allow either a pumped limiter or poloidal divertor module to be installed at the bottom of the chamber and maintained independent of other components. The Phase II configuration can accommodate either rf or neutral beams, thus providing greater flexibility in choosing between the heating systems. The segmentation arrangement of the torus remains open to allow more time to consider both a 12- and 24-segmentation approach.

3. **Vacuum Topology**

The Phase II configuration design incorporates a single combined vacuum boundary separating the superconducting system and torus plasma chamber. To arrive at this concept, five design options were analyzed, weighing the advantages and disadvantages of different design aspects: safety, reliability, maintainability, productivity, cost, torus resistance, accessibility, and the influence of bakeout. The design options considered included the separate vacuum boundary option of the Phase I design, plus various alterations between the separate and the combined vacuum boundary design that was finally selected for Phase II. The combined vacuum boundary option, incorporating a double-wall construction to establish a safe tritium barrier and space for leak detection, was the preferred configuration because of its small size, improved productivity features, and its ability to lower the overall machine cost.
Two combined vacuum boundary designs have been established for the Phase II reactor configuration. Figure 4 illustrates the combined vacuum boundary concept incorporated in the 24-sector configuration. In this approach, the shield module is subdivided into a semi-permanent shield segment which acts as a vacuum boundary and structural member to support a removable shield sector that contains the blanket and remaining shield material. Bellows are incorporated in the semi-permanent segments to increase the electrical resistance of the system.

The combined vacuum boundary in the 12-sector configuration uses a separate double-walled structure to provide the vacuum boundary independent of the shield module. The details of this concept are illustrated in Fig. 5. All module interface joints are made with a continuous in-plane structural tie and a vacuum seal weld which forms an annulus for leak detection. The ring module can accommodate either a thin-skin concept or bellows to develop a high-resistance structure.

4. Torus

The 12-segment configuration maintains the basic approach of the number of torus sectors being equal to the number of TF coils adopted in the INTOR Phase I reference design (see Fig. 5). A full shield module (shield and blanket) is extracted in a radial straight-line motion between the outboard legs of the reduced-size TF coils, as in the baseline Phase I concept; however, a small shield post remains underneath each TF coil. Components exposed to the most severe damage from particle and heat loads (limiter or divertor) have been further modularized for replacement independent of the rest of the torus. More importantly, the vacuum seal for these sectors is entirely outside the torus, located in accessible regions between the TF coil outer legs.

The 24-segment configuration has been refined from earlier multi-sector designs and allows greater latitude to be taken with respect to TF coil envelope and ripple requirements without affecting the overall device size and cost. The segmentation aspects of this option are illustrated in Fig. 4. The final closure of the access port is integrated on the outer surface of module segments A and B, avoiding any triple-seal points along the sealing weldment. Segment B carries a frame which is welded all around to the semi-permanent vacuum boundary access port, while Segment A is introduced through the frame to which it is welded. Segment A can be removed with a straight radial motion, while Segment B is removed using a combination straight and translation motion.

5. Impurity Control System

The torus chamber can accept a pumped limiter or a poloidal divertor impurity control system which can be independently maintained without interfering with other reactor components. Twelve divertor modules with gaps between adjacent plates can be used if the plates are tilted in the toroidal direction to prevent a severe leading edge heat load condition.

In the case of the pumped limiter, the limiter plates must be toroidally continuous; since the flux lines pass beneath the limiter, any gap would allow impurities to be carried back to the plasma and degrade its pumping capabilities. To maintain continuity plus allow the limiter plates to be extracted requires that they be segmented; therefore, a 24-plate limiter design is needed.

6. TF Coil

The structural design concept shown in the Phase II design to support the TF coils against the magnetic out-of-plane loads consists of an intercoil structure plus stiffening
ribs welded to the case in the "window" region of the TF coil. In the centerpost region, both bucking cylinder and wedging concepts have been identified as possible means of supporting the TF centering force. A new concept has been proposed that eliminates a portion of the intercoil structure (see Fig. 6). In its place the structure that was used to stiffen the case was flaired outward locally to pick up the outer ring beam structure. The intercoil structural interface has been simplified with this concept, plus greater access and reduced eddie currents may be obtained.

The cross sectional area required for TF coil structure and conductor in the outboard region of the coil has a strong influence in determining the final mechanical configuration of the design, regarding 12- vs 24-torus sectors. Sufficient variations remain in the details of the conductor design and TF structural support method by the participating countries to preclude adopting one approach at this time.

7. PF System

The PF coil arrangement on the Phase II design was configured to allow a poloidal divertor or limiter-shaped plasma to be formed solely by adjusting the coil currents, not their positions. This "universal" PF system increased the design flexibility without adding any significant cost penalty to the device.

The maintenance scenario was greatly simplified in the Phase II design by locating the lower outboard EF coil in a separate vacuum boundary independent of the remaining superconducting magnetic system. To remove this coil, only those components and connecting lines protruding past the inner radius of the coil must be removed to allow it to be raised vertically up around the reactor device. Maintenance of the lower outboard coil in the reference Phase I INTOR design required dismanteling a major portion of the overall machine vacuum structure to gain access to this coil. Access for maintaining the lower inboard ring coils is provided by an access tunnel located at the bottom of the device.

8. Conclusions

As a result of the new concepts developed during the Phase II critical issues period, an improved mechanical configuration concept has evolved which offers greater design flexibility and improved maintenance features; although less expensive and smaller than the reference INTOR design, the Phase II configuration retains the plasma size and performance parameters.

Progress has been made in generating further design and analytical detail in many areas, including studies covering the vacuum boundary and TF coil structural support method. These advance our understanding of the components and assure the technical feasibility of the overall device.

The design concepts will continue to evolve as further information is generated; continued design effort should also narrow the differences among options and permit convergence on a commonly accepted mechanical configuration design.

References

Fig. 1. INTOR Phase I reference design, elevation view.

Fig. 2. INTOR Phase II 12-sector design, elevation view.
Fig. 3. INIUK Phase II 24-sector design, elevation view.

Fig. 4. 24-sector design segmentation/vacuum boundary concept.
Fig. 5. 12-sector design segmentation/vacuum boundary concept.

Fig. 6. Potential TF structural arrangement concept to simplify interfaces and reduce eddy currents.