CONFIGURATION AND MAINTENANCE OF THE ARIES-ST POWER PLANT

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ARIES-ST is a 1000 MWe fusion power plant based on a low aspect ratio "spherical torus" (ST) plasma. The configuration and maintenance study of ARIES-ST was devoted to develop a credible configuration to accommodate the unique features of a highly-elongated low aspect ratio ST plasma, and to allow rapid replacement of the power core. Emphasis has been placed on design features leading to high overall availability of the power plant. Mechanical joints are possible in the normal conducting single-turn toroidal field (TF) coil system. This enables replacement of the entire power core as one single piece, and a relatively simple blanket and centerpost (CP) replacement scheme. Three general options for the ARIES-ST overall configuration and maintenance scheme have been explored. The final power core design configuration uses vertical maintenance from below.

1. INTRODUCTION

The ARIES-ST maintenance philosophy is based on rapid removal and replacement rather than in-vessel manipulation. The availability of the power plant is maximized by utilizing single piece maintenance of in-vessel components. Components that are known to require frequent scheduled maintenance, *e.g.*, the first wall, divertor plates, and blanket, are integrated as a single replacement unit. This approach is dramatically different from that of an experimental device such as ITER, due to several factors:

1. Experiments have very low neutron fluence, such that frequent power core replacement is not anticipated.
2. Availability is not driving motivation behind the design of experiments. Low availability is expected and tolerated.
3. Mature power plants are assumed to achieve relatively high reliability, or the technology will never be adopted. Availability in that case will be dominated by scheduled, as opposed to unscheduled outages.

Some of the components in the fusion power core are not exposed to the intense irradiation environment, and can survive for the entire lifetime of the plant. They must be designed to be maintainable in case of failure. The most important considerations in defining and choosing a maintenance scheme include:

1. Location of joints in the TF coils;
2. Vacuum vessel location and vacuum sealing concepts;
3. Type of segmentation of fusion power components;
4. Sector and centerpost removal paths;
5. Attachment and support of in-vessel components;
6. Coolant piping and disconnects;
7. Containment of radioactivity during maintenance.

In the sections that follow, three options for the overall configuration and maintenance scheme are described. The final design is described in detail, and the assembly and maintenance procedures are summarized.

2. CONFIGURATION & MAINTENANCE OPTIONS

In the ARIES-RS tokamak design, horizontal maintenance through large port in the vacuum vessel was adopted to help meet availability goals by enabling rapid sector replacement [1,2]. However, the configuration of a spherical torus is quite different from a "standard tokamak". A ST plasma has a relatively small major radius and high elongation. In addition, due to the lack of space to adequately shield the inboard TF coil, replacement of centerpost and inboard first wall and shield is required. The use of a normal conducting TF system allows electrical breaks, which enable removal of larger pieces of power core. Several classes of maintenance concept were assessed prior to choosing the final design [3]. These include vercial maintenance from above, vertical maintenance from below, and horizontal maintenance.

2.1 Vertical Maintenance from Above

Sliding joints are possible near the centerline because the constant tension loads on the outboard TF coil legs can be resolved with a reacting ring structure. Therefore, the centerpost stresses are dramatically reduced and the coil can be removed independently. The vacuum vessel could be located either inside or outside the TF coils. In this case, an inner vessel was chosen to avoid a massive vacuum port above the machine, needed to provide containment during maintenance operations. The inboard first wall structure serves as the vacuum boundary. To replace the centerpost vertically from top, an overhead bridge crane might be employed. For replacement of the power core, larger modules are desirable to reduce maintenance time; the size of components to be removed as a sector unit is limited only by crane capability. During maintenance, the removable sector unit would be lifted and removed; however, the remaining outboard shield and divertor shield still stay in the power core as permanent components. If radial blanket segmentation were used, then the outer zones would be removed and replaced during a later maintenance interval. The centerpost, TF coils and replacement units are supported separately from the bottom through pillars.

In this design, all replaceable items would be lifted out of the top of the machine. The major concern is the lifting and positioning capability of the overhead crane. This requires a very tall building with strong walls to support the crane.

2.2 Vertical Maintenance from Below

The TF coil system is composed of a centerpost, an outer leg, and a bottom platform. The electrical sliding joints could be located at the top between the centerpost and outer TF legs to minimize the centerpost stresses. The electrical bus could be attached to the centerpost and outer TF legs at the bottom. During maintenance operations, the electrical bus can be disconnected from the bottom and lowered down to the pit. The vacuum vessel in this case is located outside the TF coils; therefore, radioactivity is contained during maintenance procedures. The blanket is segmented into two zones, i.e., front and outer zones. The front zones including the first wall and breeding blanket have a short lifetime and need to be replaced frequently. The outer zones, for example the shields, have longer lifetime and would be replaced during a later maintenance period. The outboard FW/blanket is curved to follow the plasma shape, but a cylindrical shield is adopted to make the movement of power core easier over curved shield design. For replacement of the power core, the de-mountable joint is located at the bottom lid. To allow for rapid maintenance, the power core is attached to this bottom lid only, and all lead-throughs for coolant lines, instrumentation cables and so on are located on the lid. After all access lines have been opened and the bottom plate is disconnected from the outer leg by working from bottom region, the bottom lid with attached power core can be lowered into a large pit providing a closed containment for mobile activated materials (such as dust) as well as radiation shielding. In view of the extreme weight of this assembly, a system of hydraulic jacks is employed for this operation rather than an overhead crane.

With this design, very limited space is required above and at the outer peripheries of the biological shield, minimizing the size of building. Unrestricted access to the power core in the pit facilitates rapid replacement. Confinement and shielding of radioactive components and particles should be easier than vertical maintenance from the top.

2.3 *Horizontal Maintenance*

This configuration requires horizontal removal of the fusion power core, including the biological shield, for replacement of the inboard shield, outboard first wall, divertor, outboard blanket and shield. The inboard shield, divertor structure, and outboard first wall and blanket form a strong skeleton ring attached by shield, and vacuum vessel. Therefore, the removable sector includes the structure ring and its attachments. Similar to the configurations of the vertical maintenance, the sliding joints are possible at the top between the centerpost and outer legs. The vacuum vessel is located immediately behind the outboard shield, and the inboard shield will be a part of the vacuum vessel. The TF coils are supported from bottom through an operating floor. The centerpost is supported by a removable structure. The removable sector unit is supported from the bottom through a torus support rail system, which potentially allows rapid replacement in the radial direction. The centerpost would be replaced vertically from below by using an overhead crane without disturbing the vacuum. Maintenance of the power core requires moving PF coils, and one or more TF outer legs to perform a large-scale modular maintenance procedures. In order to avoid exposure of the surrounding system to activated components and dust, the replaceable sector should be transferred into an enclosure, such as a transfer cask, for delivery to a hot cell. A new sector is delivered to the maintenance cell with transfer cask and supplied to the vehicle/manipulator using the radial transporter for installation on the position.

A critical issue for replacing the 32-m long centerpost is lifting and positioning capability of the overhead crane. This also requires a very strong and tall building. The major concern for the upward and downward movement of the superconducting PF coils, horizontal removal of TF coils, and fusion power core components require a large volume surrounding the machine.

3. FINAL POWER CORE CONFIGUATION

Configuration and maintenance options strongly depend on the TF coil design. If the TF coils were made without joints, the maintenance would necessarily be similar to the horizontal removal scheme of ARIES-RS. Three configurations and maintenance options have been explored based on the premise of a demountable joint for TF coils and all designs offered the option to remove the centerpost separately without disturbing the vacuum system and the replaceable power core components. The critical issue for the options of vertical maintenance is that if the TF coils with the demountable joint can be designed, and where the joints can be located. The mechanical and electrical connections between the centerpost and the outer TF legs and electrical bus are critical design issues for all the three configurations and maintenance options.

Figures 1 and 2 show a 2D elevation view and 3D solid model of the ARIES-ST power core. The main elements of the power core include (starting from center): the centerpost, inboard shield and first wall, blanket and divertors, combination TF shell and vacuum vessel, and superconducting PF coils. A unique feature arising from the use of normal conductors is the dual use of the outer TF shell as the primary vacuum boundary and poloidal field (PF) coil shield. Radiation protection of the PF coils is achieved using localized shielding for the top and bottom coils which are located within the TF shell, and using the TF shell itself for outer coils.

All of the coolant lines are routed vertically through the lower TF shell segment, which serves as the power core platform. A vacuum break is located between the middle and lower TF shell segments in order to allow removal of the power core as a unit. Vacuum is maintained here with a reweldable bellows seal. A relatively large vacuum plenum space exists surrounding the blanket. The shape of the TF shell was chosen to minimize stresses in the shell, relatively large, but acceptable PF coils result. A more detailed description of the power core components was made by Tillack [5].

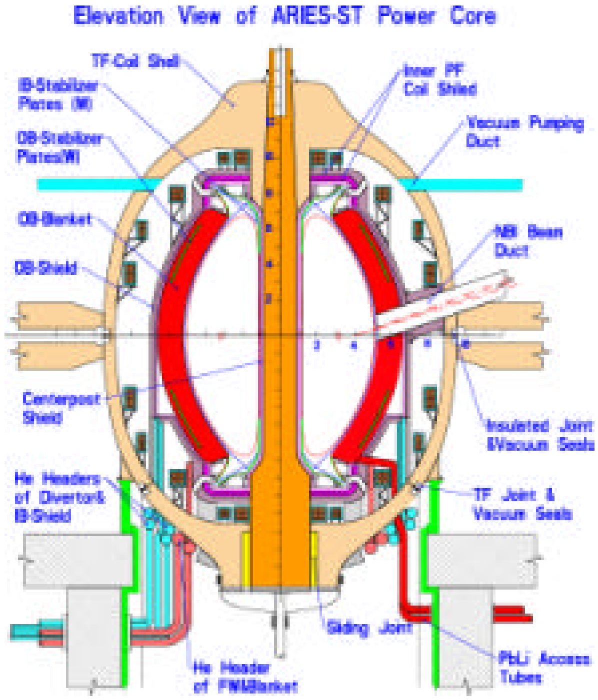

Fig.1. Elevation view of the ARIES-ST power core

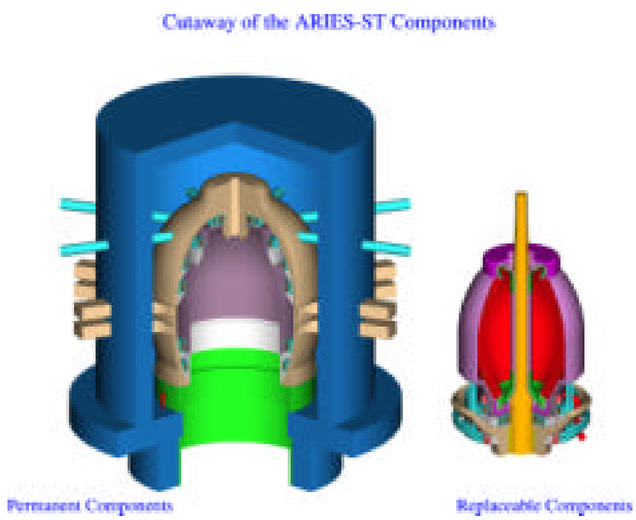

Fig.2. Solid model of the ARIES-ST power core, showing permanent and replaceable components

Figure 2 highlights the permanent and replaceable parts of the power core. The majority of the TF shell, the bus bars, the upper TF coils with their low-temperature shielding, and the outer TF coils and coil structure are permanent components. The replaceable power core consists of a high-temperature portion, including the first wall, blanket and divertor, and the low-temperature center post. The total weight of the drained replacement unit is 3911 metric tonnes.

4. ASSEMBLY AND MAINTENANCE

As mentioned in Section 2, the ARIES-ST power core maintenance paths are below the core. Figure 3 depicts the assembly and removal sequence. The power core is assembled in the assembly rooms and placed on rails. The core is transported through maintenance corridors onto telescoping hydraulic cylinders located directly below the power core vault. Continuous containment is provided using steel liners on the concrete structures and a large entry door at the bottom of the pit. The pit itself serves as a secondary containment area in which coolant lines can be connected and disconnected outside of the primary vacuum and contamination boundary.

One cylinder is used to support the centerpost and four additional ones for power core. The centerpost can be installed separately, but for the purpose of this discussion, it is assumed that the centerpost is installed together with the full power core. As the cylinders are raised, each stage is locked in place. When the power core is aligned into its final operating position, retractable support beams are moved into place and weight is decoupled from the hydraulic cylinders. Gravity loads are thus supported through the primary structural columns of the building.

Once in place, the vacuum vessel is welded between the lower and middle TF shell segments. Following this, connections are made above the vacuum vessel for the upper centerpost coolant and in the secondary containment of the pit for all other coolants. Electrical connections for the lower set of PF coils also are made in this region. The blanket is filled with PbLi, and all remaining coolant circuits are pressurized.

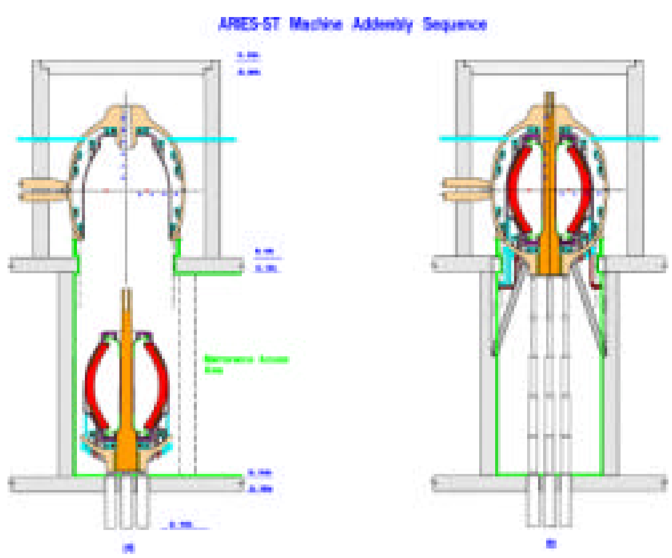

Fig.3. Power core maintenance paths

Figure 4 shows a simplified view of power core assembly sequence that takes place in the assembly hall. Four main assemblies are shown:

1. the lower TF shell and lower PF coils,
2. the lower divertor, inboard first wall and shield, lower primary manifolds and headers,
3. the blanket
4. the upper divertor and remaining primary manifolds.

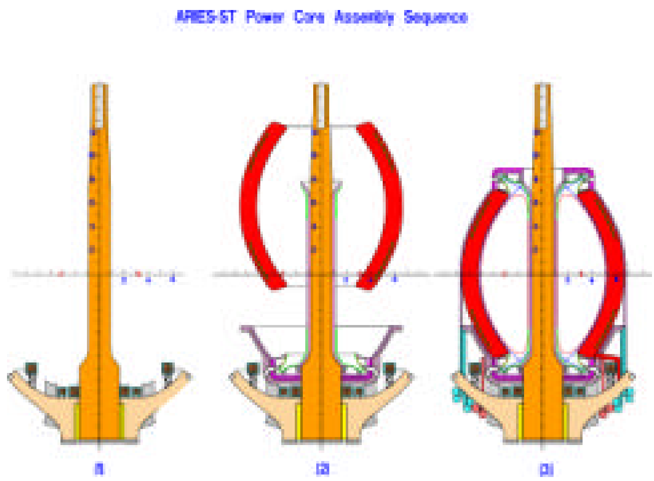

Fig.4. Power core assembly sequence

5. **Summary and Conclusions**

Three general options for the ARIES-ST overall configuration and maintenance scheme have been examined and the final power core configuration uses vertical from below. All the replaceable items, such as the first wall, blanket, divertor and manifolding would be lowered out the bottom of the machine as an integral unit and assembled and maintained in hot cell. Insertion and removal of the core is accomplished using novel telescoping hydraulic system for vertical motion and rails for horizontal motion. During maintenance procedures, radioactive is contained using maintenance paths through large sealed compartments into underground hot cells.

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