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THE OAK RIDGE TNS/PEPR PROGRAM IS CONSIDERING MODIFIED PHYSICS AND ENGINEERING CRITERIA TO EASE REMOTE MAINTENANCE PROBLEMS*

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Early work on TNS/PEPR at ORNL consisted of systems trade studies to establish a baseline design. Representative parameters are shown in Table 1. Development of these parameters into a mechanical design focussed on the complexity of the device disassembly. Three modifications to the physics and engineering criteria are being studied to ease these problems of remote disassembly:

1) Increase allowable field ripple from 1% to a maximum of 3%, thereby reducing the number of TF coils. The result is increased access between coils.
2) Provide sufficient clearance in the bore of the toroidal coils to raise and lower the EF coils during torus segment removal. This assumes a requirement for equilibrium field (EF) coils close to the plasma.
3) Investigate a secondary vacuum enclosure (e.g. vacuum building concept) to eliminate the need for welded torus joints and TF coil dewars.

This paper discusses these modifications, as well as some overall cost implications relating to ripple.

INTRODUCTION

Early work on The Next Step (TNS) Program at Oak Ridge consisted of Systems Trade Studies for several tokamak configurations. Using consistent physics and engineering criteria, device cost sensitivities were evaluated, along with TNS objectives, in order to establish an initial configuration. The result of this effort is the baseline design[1] shown in Figures 1 and 2. Some of the key parameters and major components are listed in Table 1.

Development of the baseline drawings focussed attention on the difficulties of machine disassembly which should be accomplished with simple, radial, nonrotational removal of components. One of the most difficult areas to reach, from a maintenance perspective, is the toroidal joint on the inner vacuum vessel/shield, the torus area closest to the machine vertical centerline. Our early TNS studies indicated that operations on any inner joints would have to be done remotely from inside the toroidal shell; this is an operation

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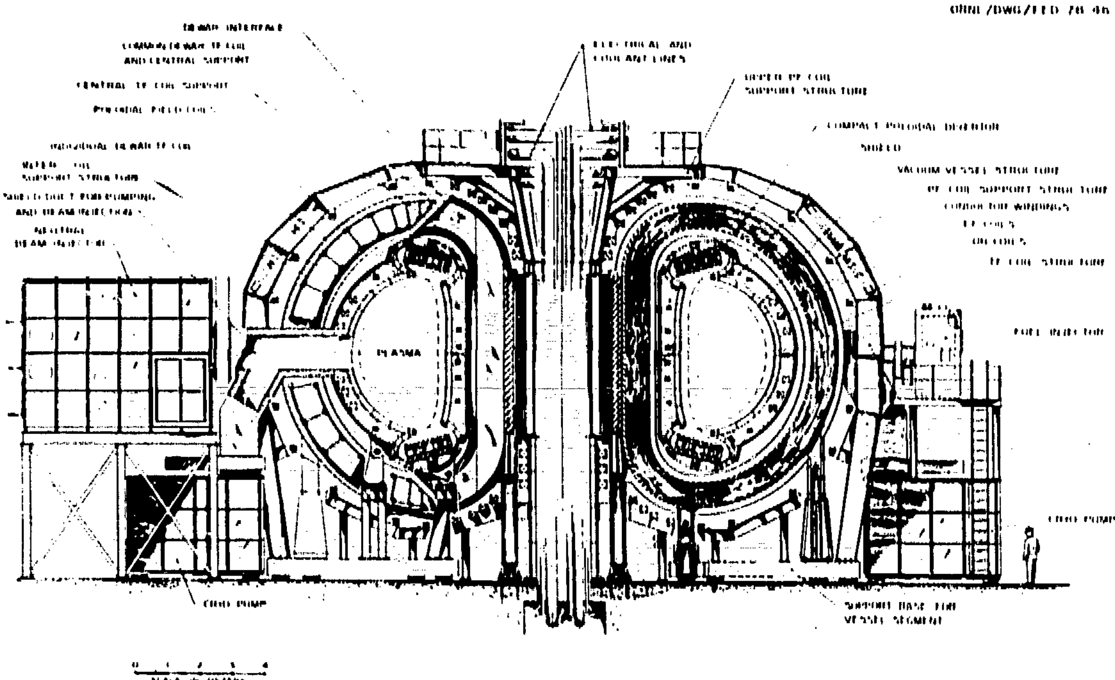
judged to be undesirable. Disassembling the dewar interface is equally difficult (Fig. 1) because of the diminishing access between toroidal field (TF) coils as one moves from the midplane of the machine to the vertical centerline. Moving the interface outward does not facilitate device disassembly because the inner leg of the TF coil is encased in the common dewar of the central TF coil support (bucking cylinder). It can only be accessed through the inner torus wall or by preremoval of toroidal segments of vacuum vessel/shield. Preremoval of a torus segment is not practical with the access shown between twenty TF coils. Hence, each of our segments is two TF coils and 1/20 of the torus. Any of the disassembly tasks are further complicated by three factors: 1) limited access between TF coils because of their large number; 2) the location of equilibrium field coils within the bore of the toroidal coils; and 3) the requirement for remote cutting, welding, and leak detection of the torus.

[illegible]

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
TF Coil Horizontal Bore (m)	4.9
Plasma Minor Radius, a (m)	1.2
Plasma Major Radius, R (m)	5.0
Plasma Elongation, [illegible] ( )	1.6
Aspect Ratio, A ( )	4.2
Field at TF Coil, B_m (T)	10.9
Field on Axis, B_t (T)	5.1
Plasma Current, I_p (MA)	4.9
Total Volt-seconds	57.6
Plasma Volume, V_p (m^3)	222.6
Neutron Wall Load (MW/m²)	1.20
Total Fusion Power (MW)	698
Fusion Power Density (MW/m³)	2.6
Neutral Beam Power (MW)	50.0
Steady State Burn Time (s)	16.0
Time Between Pulses (s)	100.0
Shielding	Stainless Steel with Borated Water
Neutral Beam Injectors	5 @ 150 keV
UV Pumping	9 Cryo pumps
Fueling	1 Pellet Injector



ELEVATION (CUTAWAY)

FIGURE 1. ORNL/INS Baseline Design

CRITERIA MODIFICATIONS

Field Ripple

One of the criteria used in establishing our original baseline design is a peak to average field ripple of 1%. This parameter, along with cost and geometrical considerations for component sizes, established the "twenty-coil" configuration in Fig. 2. In this design, removal of the vacuum vessel/shield segments cannot be achieved without also removing adjacent magnets as shown in Fig. 2.

Recent developments regarding plasma sensitivity to these magnetic perturbations indicate that increased ripple may be tolerated,[2] resulting in a reduced number of toroidal coils. This could allow segments of the machine to be removed between coils, resulting in a stationary installation of the TF magnets (Fig. 3). This is desirable from the maintenance aspect as the coils are expected to have a much longer operating life than the first wall components.

Two investigations regarding ripple were established: 1) the number and size of the TF coils which would satisfy ripple limits of up to 3%, and 2) the effect on total device cost for these configurations.[3] Using the COAST (COsting And Sizing of Tokamaks) Code to evaluate machine designs ranging from 12 to 18 coils,[4] we established that a 12 coil configuration with 3% ripple would increase the total device cost 2% over the original baseline (Fig. 4). However, this design did not solve our disassembly problems because there

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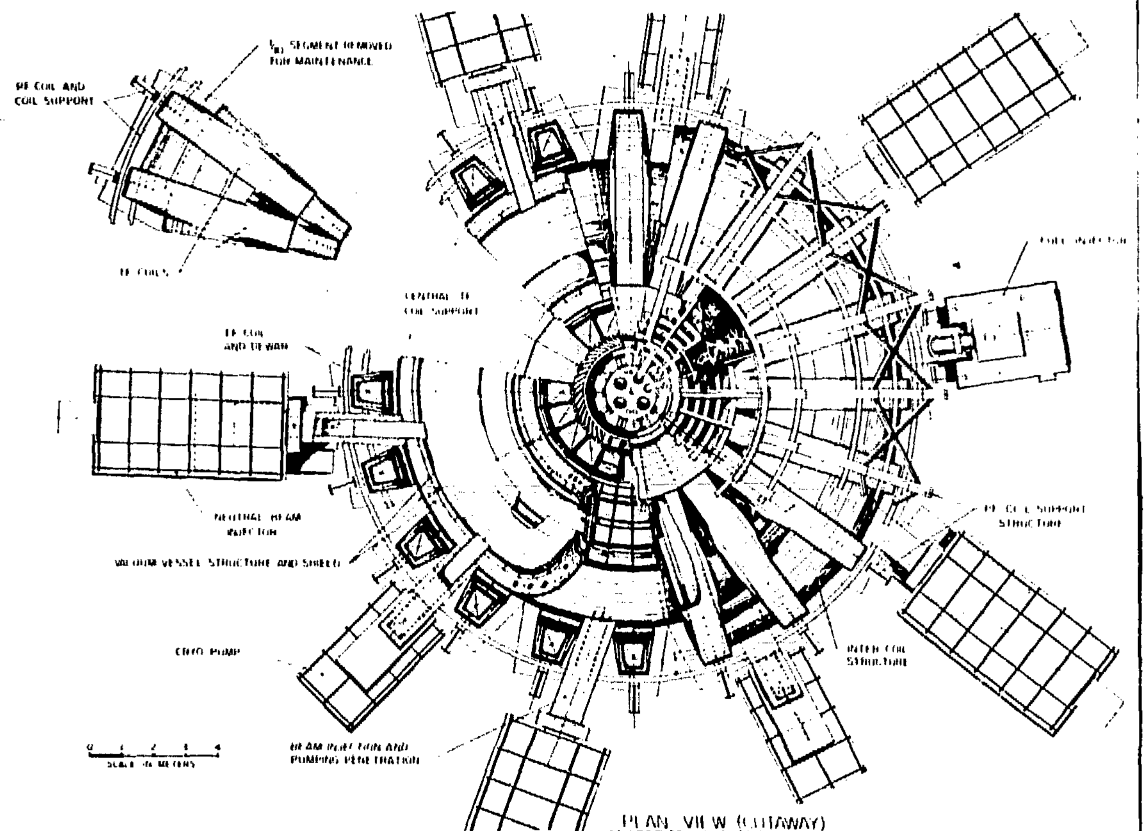

FIGURE 2. ORNL/TNS Baseline Design

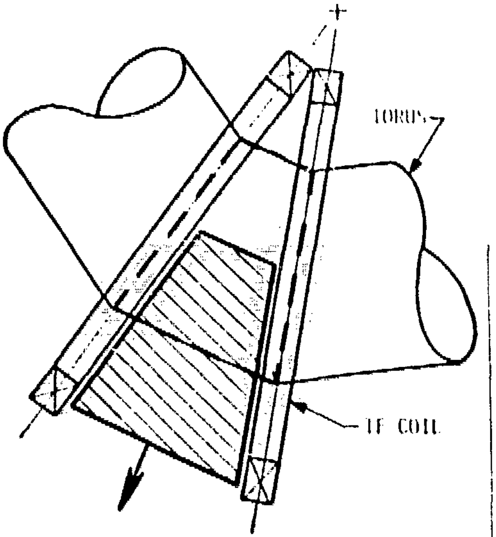

FIGURE 3. Torus Segment Removal Between Fixed TF Coils

was still not sufficient access between coils to remove 1/12 torus segments, and there appeared to be insufficient clear space to move the EF coils within the TF coil bore. Increasing the size of these 12 coils to allow 1/12 segment removal reduced the ripple to ~1% and increased the device cost by approximately 14%. Further tradeoffs between cost, ripple, and access resulted in a coil size (12-coil array) that provided torus removal of 36 segments, field ripple of approximately 2%, and an increased cost of approximately 5%. In addition, there is sufficient clearance to raise and lower the trapped EF coils to clear the segments being removed.

EF Coils in the TF Coil Bore

The difficulties of disassembling toroidal vessel segments are compounded by the trapped EF coils (Fig. 1). Part of the TNS work for this year is a re-evaluation of the poloidal coil systems, including an iron core vs. air core design. A portion of this work will consider placement of the equilibrium field coils outside of the TF coil bore and may indicate that some, or possibly all, of these poloidal

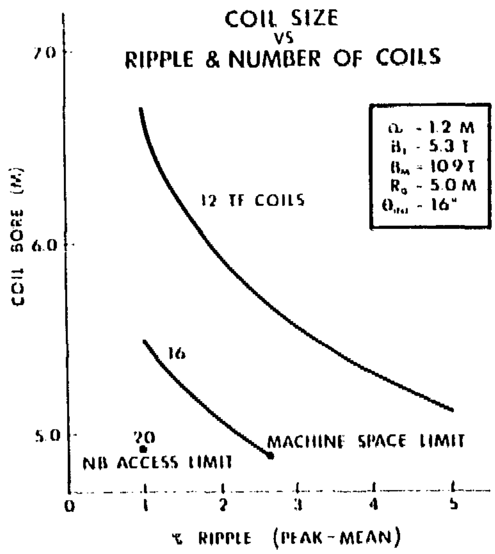

FIGURE 4a. Coil Size vs Ripple and Number of Coils

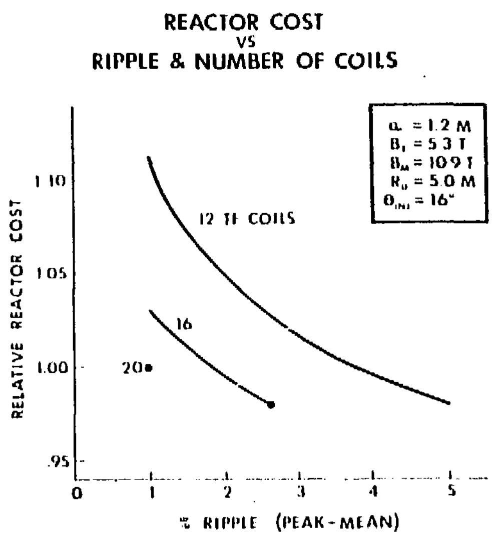

FIGURE 4b. Reactor Cost vs Ripple and Number of Coils

coils could be superconducting. The cost implications regarding power supplies and power conversion will be evaluated along with questions concerning plasma stability. Current PF coil considerations have allowed for a reduced number of EF coils[5] which is a great step toward reducing the complexities of segment removal; ideally, from a mechanical point of view, it is desirable to locate no coils within the TF bore. However, assuming the EF coils must remain close to the plasma, they must either be remotely disassembled along with the torus segments, which does not appear possible at the inner coils for reasons already mentioned, or they must be moved away to clear the segment removal (Fig. 5). The latter has been chosen as one of the requirements for sizing the TF coil bore discussed above. In this manner, toroidal segments can be removed from the machine using straightline, nonrotational motion. The upper midplane EF coils are simply raised as whole units and jury-rigged to the TF coil structure; similarly, the lower midplane coils are lowered to rest on the TF coils.

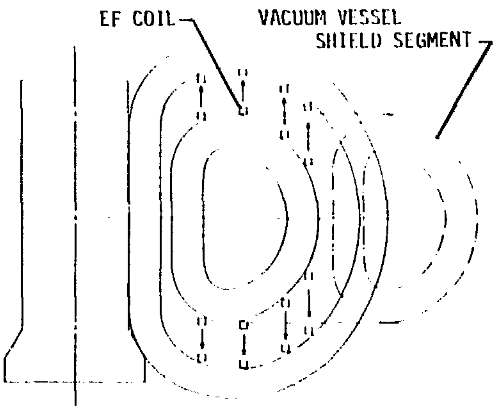

FIGURE 5. Torus Segment Removal Showing Relocated EF Coils

Secondary Vacuum Enclosure (SVE)

The last topic to be discussed deals with the joints for the toroidal segments. Disassembly of the device, even with the additional access discussed above, is still a complex operation, with some question of reliability. The ultrahigh operating vacuums in the conventional plasma chamber require welded torus joints, and the high levels of activation require remote cutting, welding, and leak detection of these joints. In order to avoid these internal torus-vessel operations, we are studying a secondary vacuum enclosure around the machine patterned after an existing facility at the NASA Lewis Research Center.[6]

The vacuum building option provides bilevel vacuum containment shown in Fig. 6 and may eliminate the need for welded joints.[7] Operation of TNS/PEPR in this vacuum environment will greatly simplify device disassembly if mechanically joined segments can be used instead of welded joints. Conductance leaks across these joints appear to be tolerable and can be handled by the cryopumping system of the torus. The use of bolted joints for the segments is not yet a proven concept, as the structural loads on the segments are still to be considered. However, the main point is that the joint interface is more easily handled on the outside of the torus where it can be readily reached by remote means than if it were hidden inside the vessel.

Another aspect of the SVE study is to investigate the possibility of eliminating the vacuum dewars which enclose the TF coils and the bucking cylinder. The difficulty of disassembling these components was mentioned previously and is a serious obstacle to the maintenance of our current configuration. If a vacuum of 10^{-5} in the building can be achieved as shown in Fig. 6, then the SVE could be the vacuum dewar for the cryogenic coils and structure. Not enough work has been done, at this time, to make any firm judgements, except to say that eliminating the need for these encasements simplifies the tokamak disassembly.

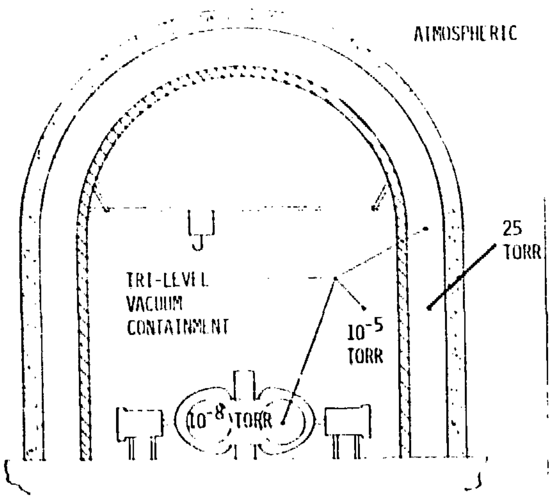

FIGURE 6. Secondary Vacuum Enclosure Modeled after the NASA Plumbrook Facility

CONCLUSION

The next generation of tokamak designs is focussing on reactor-like configurations. Some of the crucial problems being investigated are engineering in nature and relate to the viability of machine disassembly. The initial work on the Oak Ridge TNS/PEPF was systems oriented and dealt with establishing self-consistent physics parameters to achieve ignition. The baseline design that evolved from these parameters was, however, not self-consistent from a disassembly point of view. Hence, our FY 1978 work is focussing on criteria modifications for both physics and engineering to achieve a credible mechanical design which has some hope of being remotely maintained.

The preliminary conclusions of this study are:

1. An increase in allowable TF ripple from 1 to 2% will significantly increase access to the vacuum vessel/shield.

2. Increasing the TF coil bore may allow sufficient clearance to raise and lower internal EF coils for vacuum vessel/shield segment removal.

3. With increased access, vacuum vessel segments may be removed using straight line motions.

4. A Secondary Vacuum Enclosure (SVE) may eliminate the need for welded joints in the vacuum vessel.

5. The SVE may eliminate individual vacuum dewars for the TF coils.

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