CONF-781105--86

DESIGN IMPROVEMENTS SIMPLIFY REMOTE MAINTENANCE OF TOKAMAKS*

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No. of pages: 16

No. of figures: 4

*Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under contract W-7405-eng-26 with the Union Carbide Corporation.

CHANGES EASE TOKAMAK MAINTENANCE

ABSTRACT

The tokamak, by the nature of its plasma confinement concept, is a difficult device to maintain, and maintainability problems are compounded by the need to perform all operations remotely. This paper discusses the modifications to the Oak Ridge baseline TNS which led to significant improvements in device maintainability. They are:

1. a reduction in the number of toroidal field coils used and an increase in coil size,
2. a rearrangement of poloidal field coils to preclude the need for coil dismantling during a torus sector replacement,
3. use of a secondary vacuum enclosure.

Various types of secondary enclosures are discussed, and the rationale for selecting a vacuum building approach is given.

I. INTRODUCTION

For the past three years, ORNL has been involved in preconceptual design studies directed toward defining The Next Step (TNS) in the development of the tokamak concept. This device represents a major new phase in the U.S. Fusion Program, in which the major emphasis will shift from physics research to engineering testing and demonstration. The specific project has more recently been defined by the Department of Energy (DOE) as an Engineering Test Facility (ETF).[1]

Because the scientific basis required for a TNS/ETF will first be available for the tokamak concept, the reactor core of the facility is based on the tokamak concept. Our engineering studies, therefore, have focused on design issues relating to overall feasibility of the tokamak device.

One of the major engineering problems, that of tokamak disassembly, will be discussed in this paper. Improvements to the device configuration offer a means of easing the problems of remote maintenance.

II. MAINTAINABILITY ISSUES

The tokamak, by the nature of its plasma confinement method, is a difficult device to disassemble. Reactor operation will further compound the problem because of high levels of neutron activation in the walls and structural members of the device. To illustrate the recent improvements in the design configuration, a brief overview will be presented showing the evolution of the current reference design.

A baseline design concept was developed in FY 1977 based on a systems modeling effort.[2] Comprehensive systems models were used to establish cost comparisons for different toroidal field (TF) coil technology options within a range of device sizes. The baseline design, optimized on the basis of cost, was then used as a point of departure for the preconceptual design studies in FY 1978.

The most significant feature of the FY 1977 baseline design was that the torus consisted of ten sectors, with each sector including two TF coils. The sectors were joined by welding to ensure vacuum integrity. The TF coil was relatively small as dictated by a minimum cost design at a field ripple (peak-to-average) of 1%. The small TF coil bore and the large number of closely spaced coils (20) made sector replacement virtually impossible for the following reasons:

1. Closely-spaced coils provided insufficient horizontal clearance for torus sector removal; therefore, two coils were removed with each sector.
2. Removing coils with torus sectors was difficult because disassembly of the common dewar was required, and access for this operation was extremely difficult with the plasma chamber in place.
3. The equilibrium field (EF) coils, i.e., the poloidal coils trapped in the bore of the TF coils, required disassembly and removal to allow toroidal coil and sector removal.

Two additional complications, independent of the TF coil configuration, contributed to maintainability problems. First, the outer poloidal coils required repositioning to clear the removal of a torus sector with two TF coils; secondly, in-vessel cutting and welding was necessary to disassemble the torus. The latter operation is undesirable because it requires exacting reliability.

Evaluations of our 1977 baseline design indicated that an increase in TF coil size, a reduction in the number of coils, and elimination of the torus welds were the keys to improving device maintainability.

III. DEVELOPMENT OF A REFERENCE DESIGN

The design improvements incorporated in the 1978 Oak Ridge Reference Design include fewer and larger TF coils, fewer EF coils, and a mechanically assembled torus. The latter was made possible by use of a secondary vacuum enclosure (SVE). Following is a discussion of these improvements.

A Toroidal field coils

Recent work in plasma engineering[3] suggests a possible relaxation of the field ripple requirement. Using these results as a starting point, TF coil configurations (number and size of coils) were traded off against cost at ripple values up to 2%. The objective was to achieve an array of TF coils with sufficient horizontal clearance to allow sector removal between coils. After several iterations, we arrived at a design using 12 relatively large TF coils at a field ripple of 1.5% and a device cost increase of 7%.

The advantage of the larger coils is significant. Horizontal clearance between coils allows sector removal without moving the superconducting magnets (see Figures 1 and 2). This represents a major reduction in weight of equipment to be moved, it simplifies facility design, and it eases the design requirements for remote handling equipment. Disassembly of vacuum dewars is simplified because torus sectors may be removed for access. Lastly, the coils can be maintained at

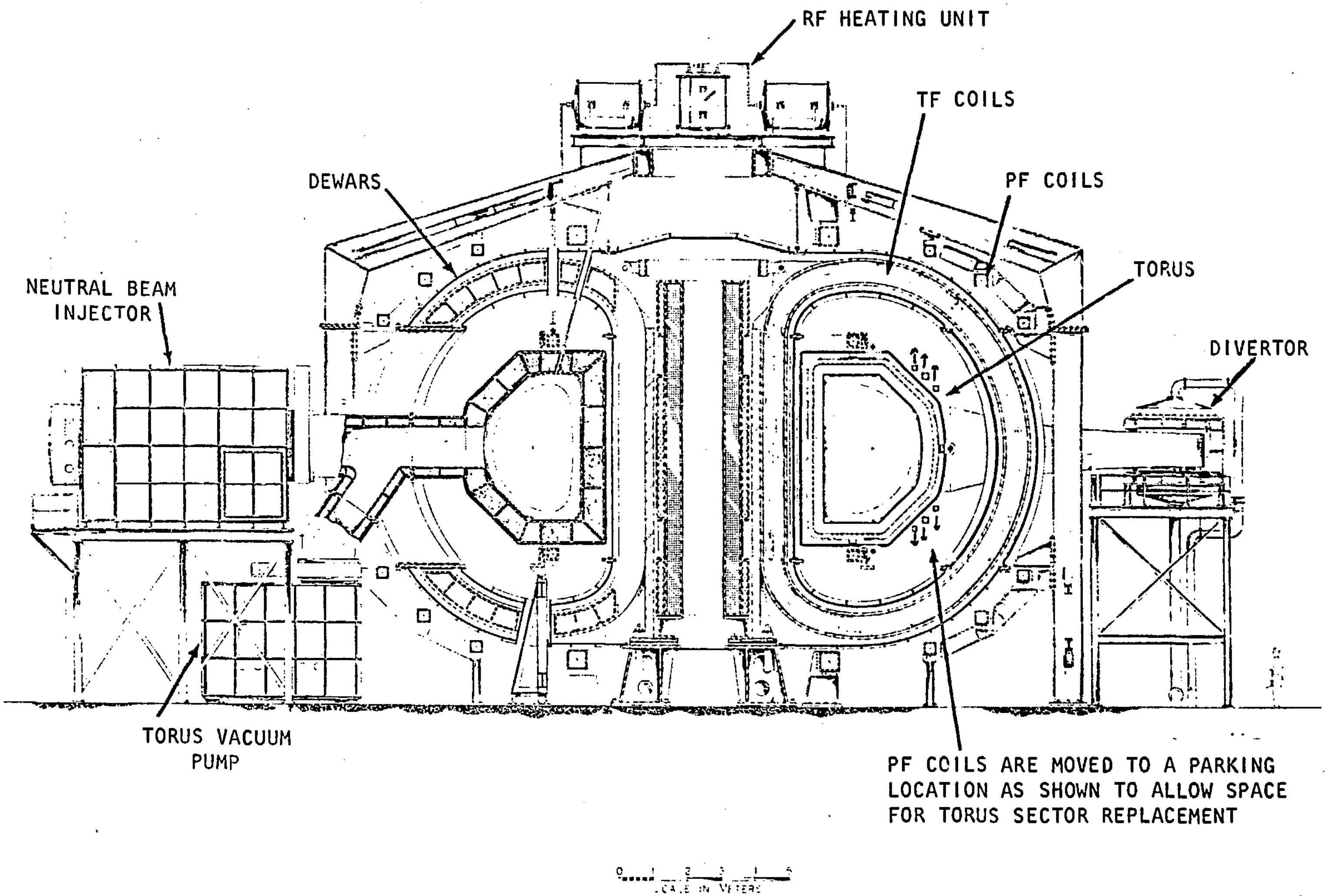

Figure 1 TNS Baseline Elevation

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Figure 1

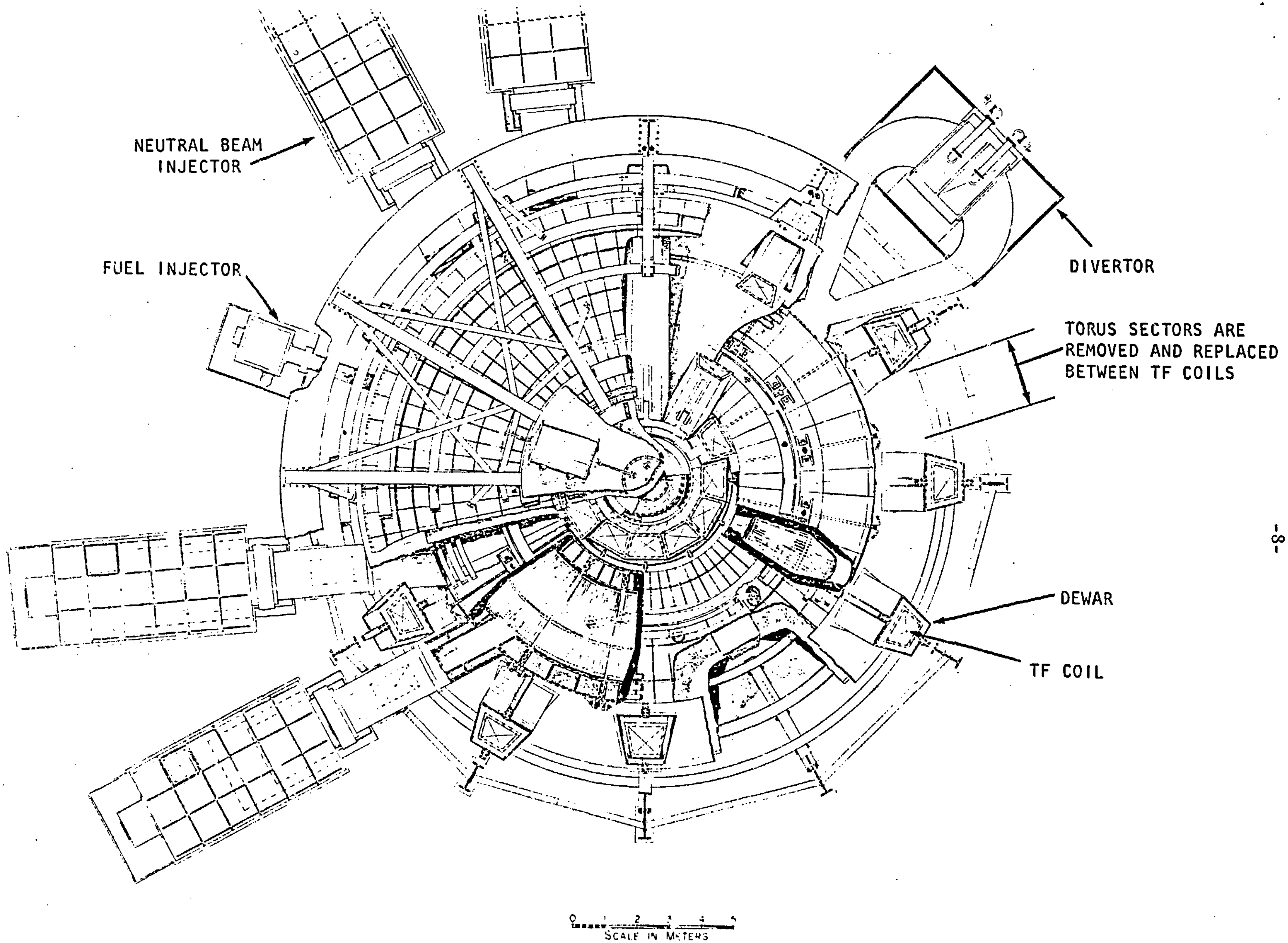

Figure 2 TNS Baseline Plan View

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Figure 2

cryogenic temperatures during sector replacement, thus eliminating thermal cycling of the coils and the downtime it represents.

B. Poloidal field coils

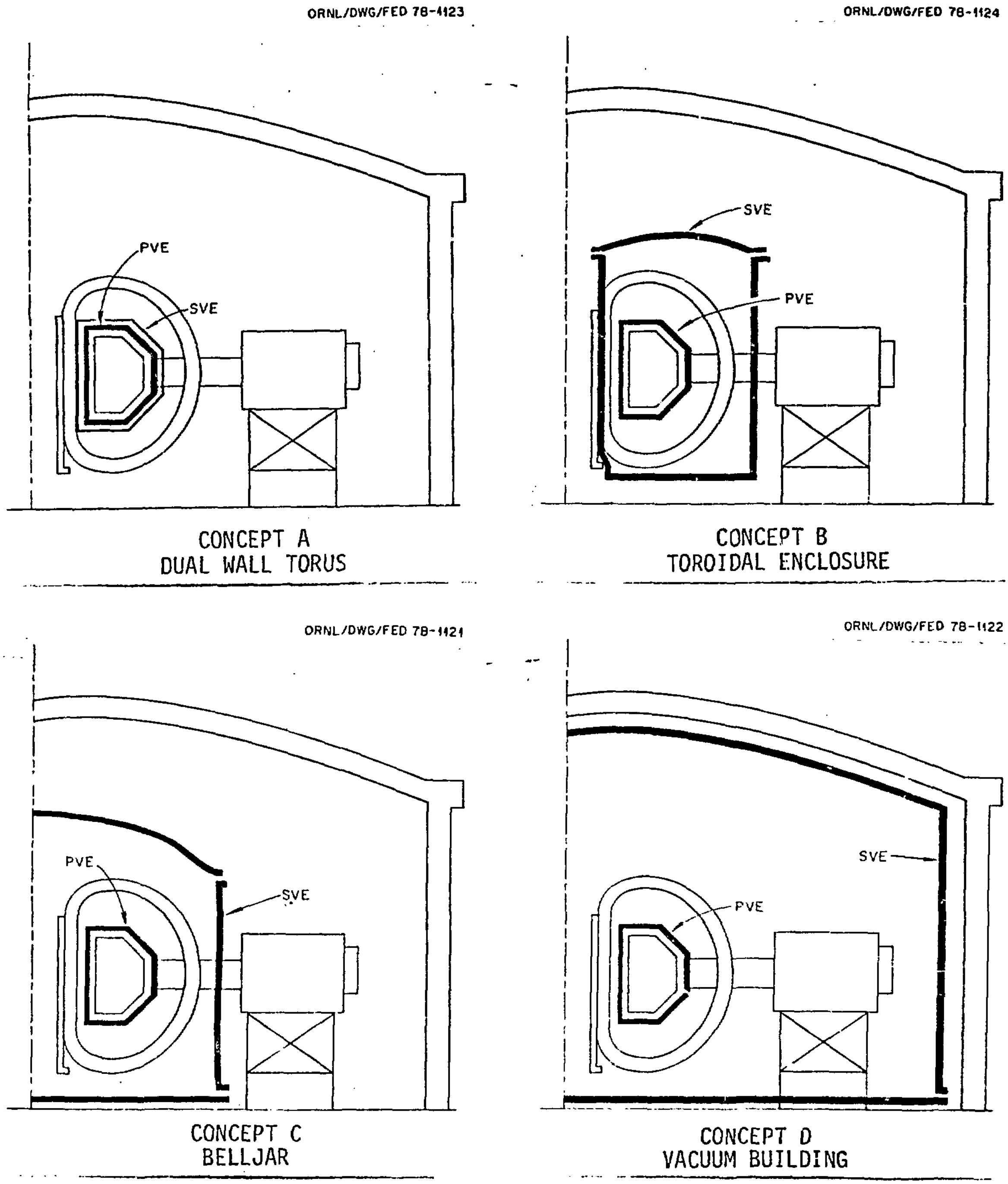
In addition to the improved midplane access between TF coils, the larger bore of the 12 coils provides a secondary benefit related to the disassembly problems of the EF coils. The increased vertical access allows raising and lowering of the EF coils as whole units in order to clear the removal of torus segments (see Figure 1). This design improvement was further enhanced by plasma engineering studies[4] which reduced the total number of EF coils next to the plasma by relocating some of the innermost coils out of the TF coil bore.

C. Secondary vacuum enclosure

The use of an SVE around the plasma chamber has long been recognized as a means of reducing the vacuum tightness required at the first wall and thereby allow use of a mechanically assembled torus. This permits considerable freedom of design which can be used to improve tokamak maintainability.

At ORNL, we identified the various configurations possible for an SVE and selected the one which showed most potential for improving maintenance characteristics. A conceptual design was developed, and the maintenance operations required for replacement of a torus sector and a TF coil were identified.

Figure 3 shows the various SVE arrangements which were considered. Concept A is a dual walled plasma chamber. The interspace is evacuated and continuously pumped; therefore, the outer wall serves as a secondary



PVE = Primary Vacuum Enclosure SVE = Secondary Vacuum Enclosure

Figure 3 Secondary Vacuum Enclosure Arrangements

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Figure 3

vacuum enclosure for the plasma chamber. The torus, both inner and outer walls, is divided into 16 sectors which are mechanically joined and sealed.

The main advantage of this arrangement is its compactness and simplicity. A disadvantage, however, is the high compressive forces required for the outer seal due to the 1-atm pressure differential. To seat the seal requires continuous bolts around the torus flange including within the poloidal bore, and access to these bolts is extremely difficult, if not impossible.

The second arrangement (Concept B) is a toroidal SVE enclosing the TF coils and the plasma chamber. A single seal is required at each torus joint, and since a high vacuum exists on both sides of the seal, seal contact forces are low. This enables joint assembly with a minimal number of bolts, and bolts in the poloidal bore may be eliminated. A disadvantage of this configuration is that sector replacement is complicated by the need to dismantle large SVE sections to access the torus. Also, the coils are closely confined, making routine inspection and adjustments of service lines extremely difficult.

The third arrangement (Concept C) is a belljar SVE. It differs from the toroidal SVE in that the entire structure may be lifted to gain access to the torus. The deployment mechanism, however, is complex and extremely bulky. Large floor-to-ceiling guides are required, and they severely restrict access around the torus during sector replacement.

Concept D is a vacuum building SVE. Dismantling or deployment of structure is not required for torus access. Capital costs, however, are higher due to the large SVE structure and additional vacuum pumping system required.

On the basis of detailed evaluation of the above concepts, a vacuum building was selected for the following reasons:

1. Removal and replacement of torus sectors is not hampered by either SVE structure or SVE deployment mechanisms.
2. Access to electrical and coolant lines exterior to the torus is not restricted.
3. No increase in ceiling height is required.
4. There is no requirement for additional cell area for stowage of SVE panels during maintenance.
5. Maximum design freedom is afforded in the torus design because seal compressive force is minimal.

D. TF coil dewars

Serious consideration was given to elimination of dewars for the superconducting coils. Previous reports[5,6] have stated this to be a possibility and, indeed, one of the major advantages of using a secondary vacuum enclosure. Our investigation of the interaction of superconducting coils with other systems led to the conclusion that dewars should be retained. Reasons are:

1. Cryogenic surfaces within the vacuum building will collect tritium which is released into the cell. When the vacuum building is repressurized, tritium will desorb and mix with incoming air, necessitating a difficult and lengthy clean-up process.
2. Hydrogen desorbs from cryogenic surfaces during reactor cell repressurization and creates an explosive mixture when combined with incoming air.

3. Pumpdown of the vacuum building requires time sequencing with TF coil cooldown to prevent particle buildup on the coils and degradation of thermal properties.
4. The superconducting coils must undergo a warmup/cooldown cycle each time the vacuum building is repressurized. Depending on coil design, the thermal cycle time is between 6 and 22 days, thus making it impossible to perform a rapid, unscheduled maintenance operation.
5. A mass release into the vacuum building, such as may occur with a coolant line leakage, may result in a pressure rise sufficient to quench the TF coils.

E. Description of the vacuum building

The vacuum building (Figure 4) is a cylindrical concrete structure with a spherical dome. Its external dimensions are 56-m diameter and 40-m maximum height. An aluminum inner shell, 48 m in diameter and 33 m high, is used to house the tokamak. The space between the inner and outer shells is maintained at ∿20 torr to provide the moisture requirement for concrete.

The outer structure has a dual function; it supports the atmospheric pressure load, and it serves as the biological shield. The inner chamber is the high vacuum barrier and is designed for an internal pressure of 0.1 atm, which occurs during a leak checking operation.

Initial pumpdown of the vacuum building is by a combination of mechanical and roots pumps. High vacuum pumping is by five oil diffusion pumps having a combined pumping speed of 1.6×10^5 liters per second. Pumpdown time from atmospheric to base pressure is six hours.

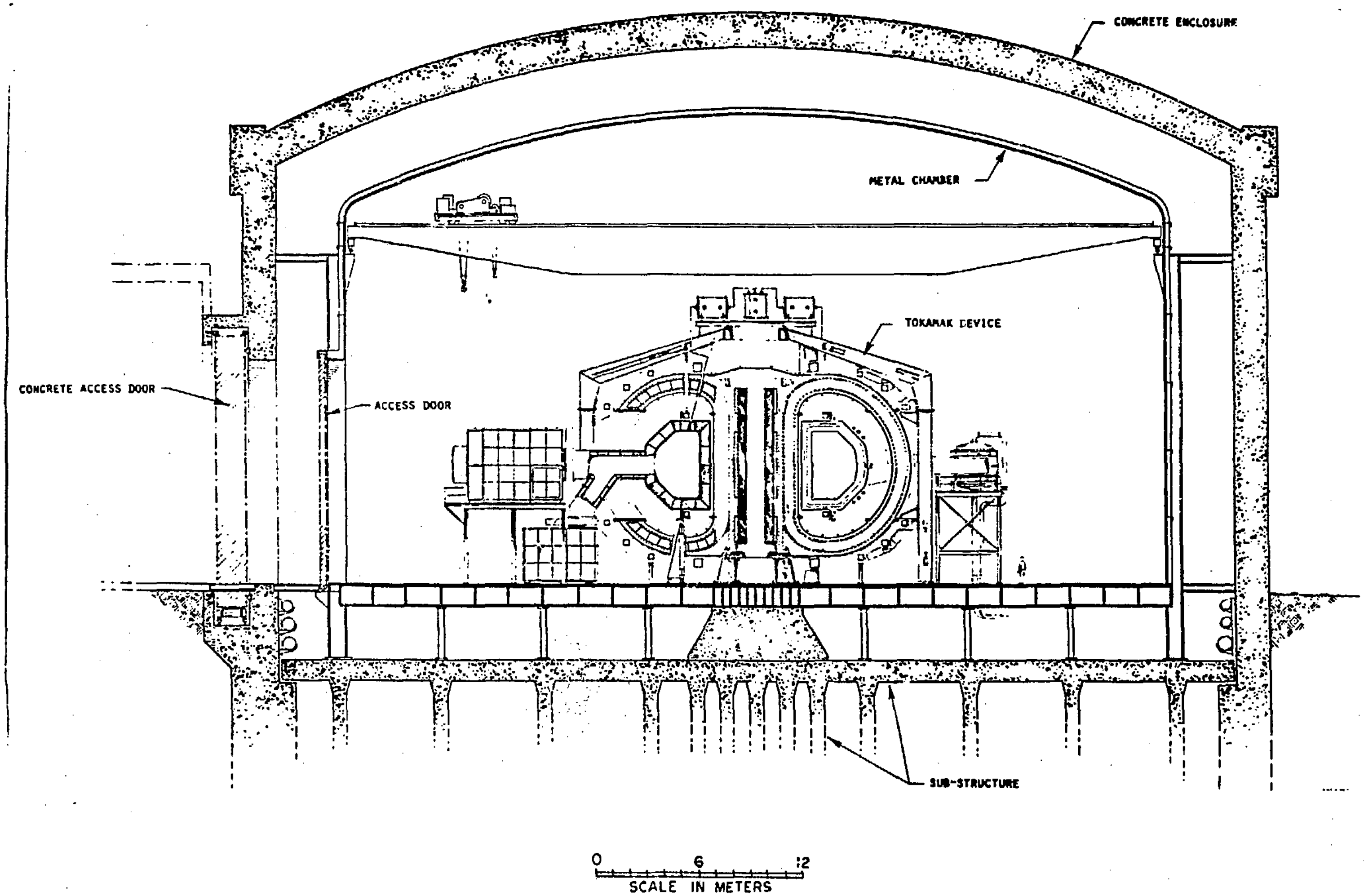

Figure 4 Cross Section, Reactor (Vacuum) Cell

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Figure 4

Access to the vacuum building is by a door 8 m wide by 13 m high. A tunnel connects the vacuum building with the maintenance cell.

CONCLUSIONS

Based on our FY 1978 TNS studies, we conclude that design modifications can significantly improve the assembly and maintenance features of the tokamak device. Specific conclusions are as follows:

1. Large TF coils improve tokamak access at low cost penalty.
2. New PF coil configurations allow plasma chamber sector replacement without segmenting the coil.
3. A secondary vacuum enclosure eliminates welded joints, resulting in a simplified torus design.
4. The vacuum building approach appears to be the most promising design for a secondary vacuum enclosure.
5. The vacuum environment of an SVE should not be relied on for thermal protection of coils. Dewars should be used.

ACKNOWLEDGEMENTS

The authors wish to acknowledge D. Steiner and R.L. Reid for their valued opinions and assistance.

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