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ABSTRACT

Induced radioactivity in the blanket and other parts of a fusion reactor close to the plasma zone will dictate remote assembly, disassembly, and maintenance procedures. Time will be of the essence in these procedures. They must be practicable and certain. This paper discusses the reduction of a complicated Tokamak reactor to a simpler assembly via the use of a vacuum building in which to house the reactor and the introduction in this new model of cassette blanket modules. The cassettes significantly simplify remote handling.

INTRODUCTION

All Tokamak reactors are, unfortunately, complicated assemblies. This is because they must include divertors, beam lines, fuel injectors, vacuum pumps, cryogenic pumps, diagnostic devices, shields, and control systems in addition to their basic elements of toroidal and poloidal coils and plasma zone.

This complicated machine has at its center and immediately next to the plasma, the most inaccessible unit of the entire assembly. This is the neutron moderating blanket, the unit that converts the neutron kinetic energy to thermal energy while at the same time producing sufficient tritium for cycle continuity.

This blanket is most susceptible to neutron damage and must be replaced periodically, a change time of once every two to four years being currently representative. The induced activity in the blanket and the reactor parts dictates remote assembly, disassembly, and maintenance. The cassette blanket significantly relaxes the problem of remote maintenance by providing simple geometrical shapes to change and by minimizing the time required to make the change.

The cassette blanket concept has four design advantages:

- Cassette blanket module. This key unit resembling in shape a cassette used in a stereo receiver allows simplification of blanket replacement and maintenance. It also isolates the lithium from the plasma by enveloping it in the coolant.
- Zoning concept. Because radiation damage to a structure decreases exponentially with distance, the use of cassettes in series requires that only the front fraction of the blanket, the first

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cassette, be changed as a result of damage during the plant life.

- Rectangular blanket concept. Using this geometrical cross section for the blanket assembly, cassettes may be installed or removed by simple linear motion between the toroidal and poloidal coils.
- Internal tritium recovery. A favorable temperature gradient is used to diffuse tritium out of the lithium within the cassette.

THE CASSETTE AND THE VACUUM BUILDING

The idea of the cassette blanket fits in well with another concept introduced in the ORNL Fusion Power Demonstration Study,[1] that of housing the entire reactor in a vacuum building.[2] The vacuum building approach frees the blanket which surrounds the plasma from the requirement of providing via its own closed surface the necessary vacuum within which the plasma must exist. The building instead envelops the total blanket and the total reactor in a vacuum. Complex mechanical seals or welds that had been needed in the blanket zone, which substantially preclude any credible disassembly and replacement, are no longer required.

Not only the cassette blanket design but also blanket designs in general should benefit from the vacuum building approach.

The concept of housing a fusion reactor in a vacuum building appears to be a sound idea and may end up to be obligatory. It is worthwhile to highlight some of the observations favoring the vacuum building.

Fusion reactors, without the benefit of the vacuum building, have been excessively complicated, virtually inaccessible for some repairs and highly suspect as to their frequency of loss of function because of their complexity. The complexity will never disappear entirely. It is the nature of the fusion machine to be complicated. What we are able to separate, however, is the nature of the machine to be complicated from the nature of man to make the machine more complicated than it need be. With the latter we may be able to cope. A large part of the man-made complication of fusion reactors presently arises because the closed surface that separates the "hard" vacuum of the plasma zone from atmospheric pressure is (arbitrarily) located either at the first wall or between blanket and shield. This closed surface, in all designs of which we are aware, is one containing hundreds to thousands of linear meters of field welds or mechanical seals which are subject to radiation damage, cylic fatigue, and consequent failure or leakage. A typical conceptual Tokamak reactor is shown in Fig. 1. Arrows indicate the necessary weld zones. It is not unlikely that a fault in a weld which produces a pinhole leak, of say 0.1 cm in effective diameter, could quench the plasma in times substantially less than the burn time. The fault or leak will first have to be located by remote means; the radiation background precluding "hands on" contact. It is not obvious that finding the leak can be accomplished in a reasonable time since the sound created by small leaks is below the threshold of perception and the size is below remote visual acuity. Perhaps the leak can be found using a mass spectrometer. Assuming that the leak is located both quickly and with precision it must then be repaired by totally remote means.

Man, in this case, has literally boxed himself in. He has carefully assembled all of the required elements immediately surrounding the plasma, those elements, incidentally, subjected to the most extreme environmental conditions of the total reactor, and then welded the access door shut.

It is our contention that a vacuum building causes this man-made problem to disappear substantially. The use of the vacuum building changes the character of this welded, tight, closed surface from one requiring absolute vacuum integrity to one of high pumping impedance. Two or three differentially pumped vacuum zones can be assumed: one clean zone for the plasma, one

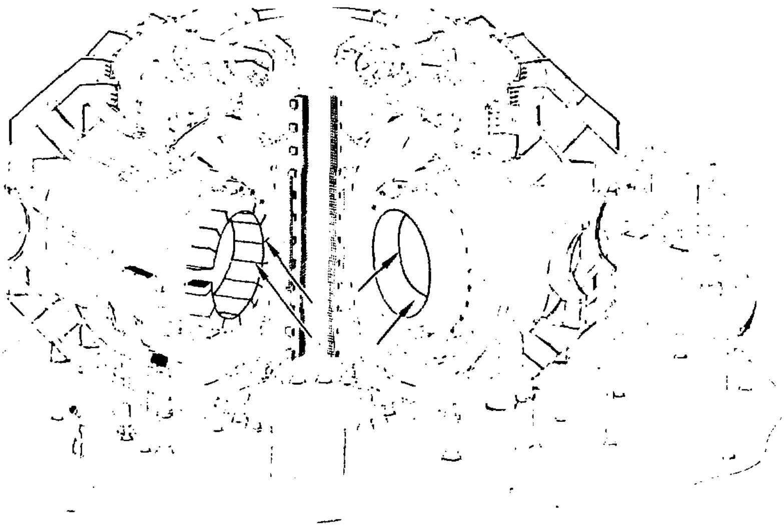


Figure 1. Typical Tokamak reactor (Oak Ridge National Laboratory energy-producing reactor reference design). The arrows indicate the necessary vacuum seals and weld zones when the reactor is housed in a conventional atmospheric-pressure building.

for the balance of the building volume, and one for special equipment. The first two zones would be at substantially the same pressure, presumably $\sim$133 GPa ($\sim10^{6}$ Torr) while the third could be at a higher pressure, say 0.13 Pa (10^{-3} Torr). It is not difficult to imagine with this approach an assembly of blanket modules that would be fitted together side-by-side without the necessity of a welded closure tying them all together. Not only are the field welds eliminated, but the assembly-disassembly process is considerably simplified. With design latitude available, the idea of the cassette blanket was conceived.

Figure 2 illustrates the basic reactor as it might be housed in an existing vacuum building, that of the NASA Space Power Facility at Sandusky, Ohio. This existing facility in 1963 dollars cost approximately $23 million. At an average escalation rate of 7%, the facility today would cost approximately $80 million. For that number of dollars not only was the test chamber itself acquired but also assembly-disassembly areas, control room, offices, etc. Considering this, the price is not unreasonable for a 1000-MW(e) reactor. Notice in Fig. 2 that the cassettes are a major feature. A principal motivation for introducing the cassettes is that they may be removed from the reactor or replaced by simple linear motions, between toroidal and poloidal coils without interference. The proposed method for removal and replacement will be reviewed. However, there are total benefits to the cassettes beyond ease of assembly and disassembly which first might be briefly summed up. There are:

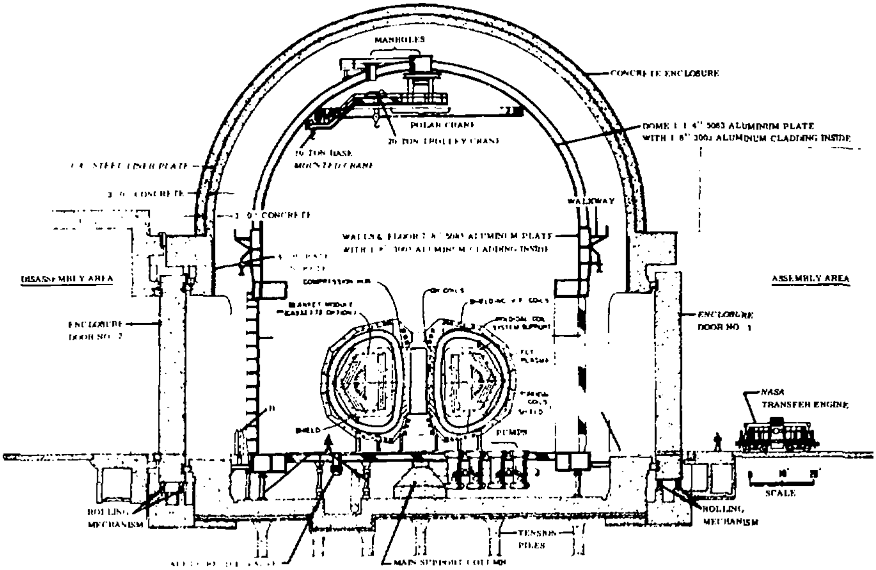


Figure 2. Illustration of the basic Tokamak reactor housed in an existing vacuum building at the NASA Space Power Facility at Sandusky, Ohio. Housing the reactor in the vacuum building eliminates the need for the blanket to provide, via a closed surface, the necessary vacuum within which the plasma must exist. In addition, the mechanical seals and welds in the blanket zone are no longer required, substantially reducing maintenance problems.

- Cassette. The cassette is a long, slender, fairly elementary structure designed to furnish the key unit for simplification of blanket replacement and maintenance. It also isolates tne lithium moderator from the plasma by enveloping it in the coolant. The basic structure is a series of connected "U" tubes carrying the coolant and surrounding the moderator. Each cassette is an independent unit (see Fig. 3).
- Blanket zoning. The concept of blanket zoning uses to advantage the fact that radiation damage to structure decreases exponentially with distance. With the use of cassettes in series, only the front fraction of the blanket, the first cassette, will need to be changed due to radiation damage over the life of the plant (see Fig. 4 for an illustration of the lessening of radiation damage with radial distance into the blanket).
- Rectangular blanket. The rectangular blanket concept recognizes that blankets must envelop the plasma but need not conform to plasma shape. With this geometry (actually an irregular pentagon is used), cassettes may be installed or

An Individual Cassette

The cassette is a slender assembly of contiguous U tubes which carries the helium coolant and envelops the lithium moderator.

In situ tritium recovery is provided.

Remotely operated quick disconnects are provided for the helium lines and the tritium recovery capillary.

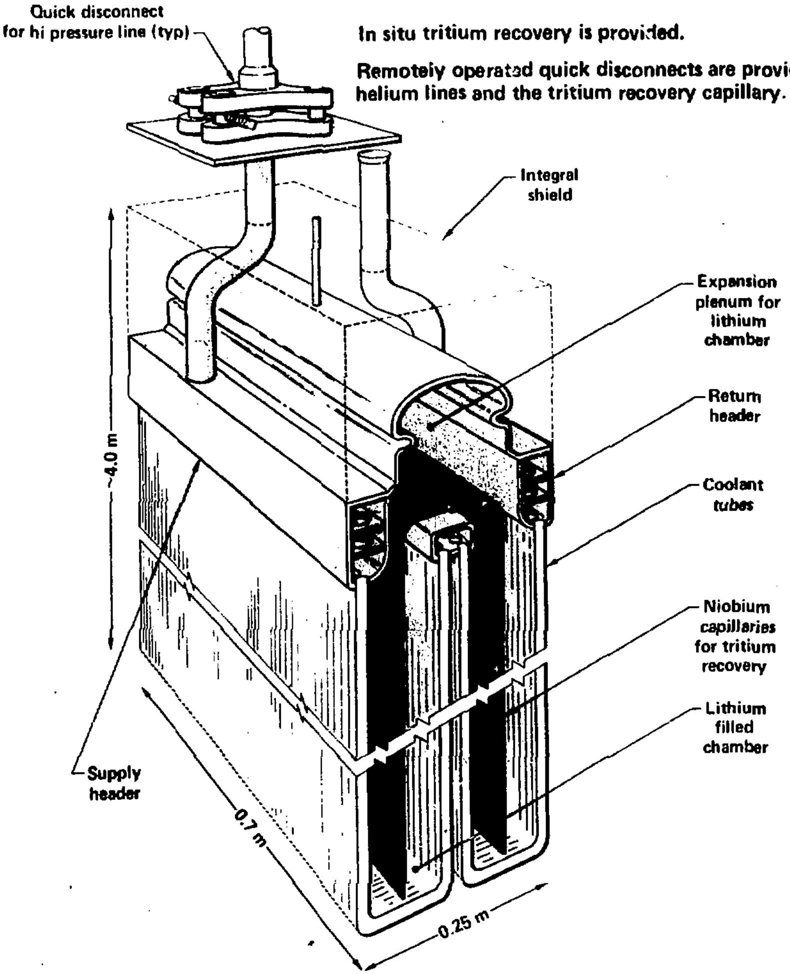


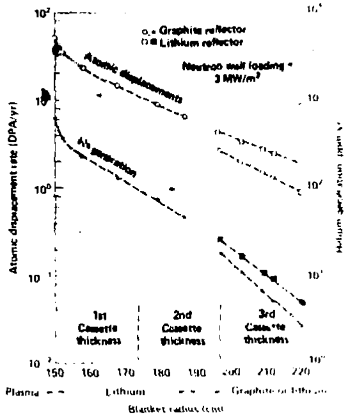
Figure 3. Illustration of an individual cassette blanket module.

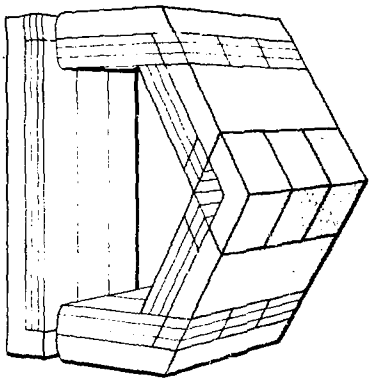
Why Zoning?

Radiation damage decreases exponentially with radial distance.

With the cassettes in series only the innermost cassettes need be changed every 3 yrs during the life of the plant.

The figure suggests that in a distance of ~25 centimeters, the thickness of a cassette, damage has decreased about 6x or 8x.





A Sector of the Cassette Assembly

For each toroidal coil T there is a sector S.

Radial planes divide the sector into 3 parts so that there are 3T slices.

To clear toroidal coils cassettes are installed or replaced via the center slice.

Figure 4. Plot of the exponential decrease of radiation damage with increasing radial distance into the blanket (upper right) and diagram of a sector of the cassette blanket assembly (lower left).

removed by simple linear motion between toroidal and poloidal coils.

- Internal tritium recovery. Internal tritium recovery uses a favorable temperature gradient in the lithium to diffuse tritium out of the cassette through niobium "windows" located at the cassette centerline where the lithium is hottest.
- The blanket assembly. The combination of these four major design ideas produces a blanket assembly which eases the total design problems, is relatively simple, and can be serviced and maintained with a minimum of difficulty. The detailed design analysis of a typical cassette including thermal-hydraulic, heat transfer, structural, cyclic stress, deformation and bending stresses, tritium production and recovery are available to the interested reader.[3]

ASSEMBLY-DISASSEMBLY

The assembly-disassembly process and some first-round estimates about time requirements will now be described using a sequence of figures with their associated script. Clearly, the disassembly time of 28 days, or the about two months for disassembly-assembly, shown in Figs. 5

The replacement sequence assumes four remotely operated manipulators working in series/parallel

1. A unit for removal and replacement of the segmented plug shield
2. A unit for removal and replacement of the structural separator located between toroidal coils
3. A unit for high pressure pipe line disconnects & reassembly
4. A unit for cassette removal and replacement

The location, parts flow and sequencing of these four units is suggested in the figure.

The work flow starts at sector 1 adjacent to the cold cell access. Parts are removed and transported to the hot cell. The first 0° to 180° of the reactor is serviced followed by servicing the 360° to 180° so that the flow direction is maintained.

Reassembly reverses the process. The ability to do work in parallel minimizes down time.

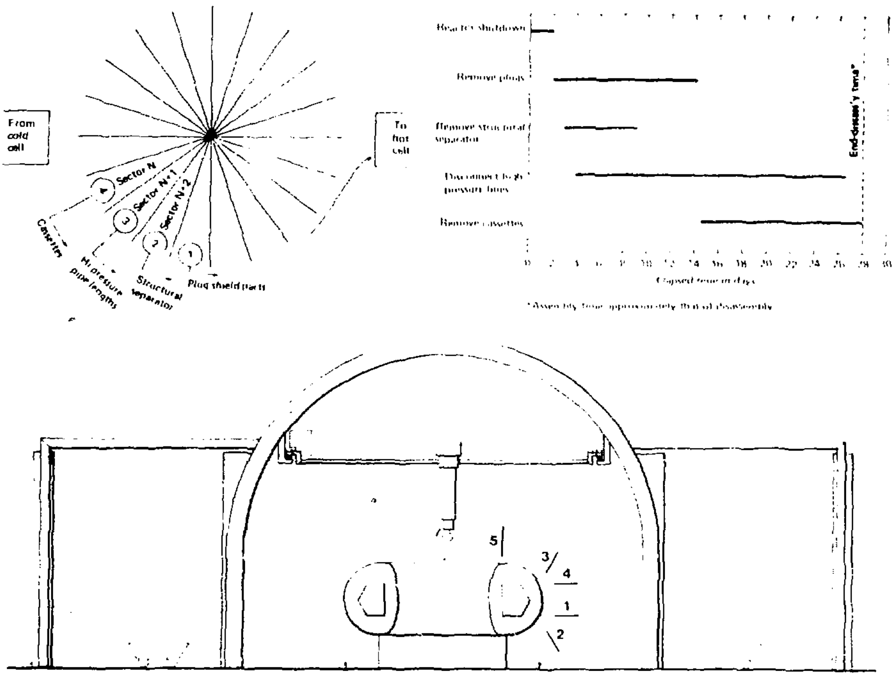


Figure 5. The replacement sequence for the cassette blanket modules. A plot of the time required for various disassembly tasks is provided: the time for assembly is approximately the same as that for disassembly.

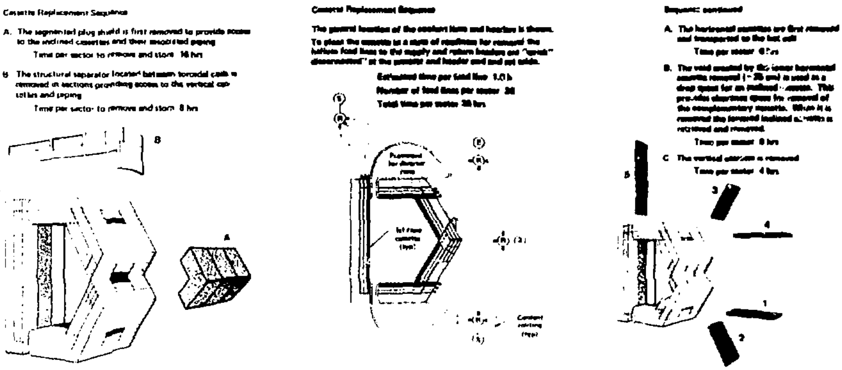


Figure 6. Diagram of the cassette replacement sequence showing the three major steps involved.

and 6 is not intended to be rigorous nor is it intended to be particularly imprecise. It is a reasonable guess, and we suspect it is accurate within a factor of two. Refinement beyond this is not justified at this time. What is important is that the overall process technique appears to have good continuity and logic. There is no cutting or welding required. Individual cassettes can be isolated to find defective units. The lithium is self-contained in each cassette and there are no external liquid metal lines to connect or disconnect; Fig. 7 illustrates the remote manipulators designed for this purpose. The weight of a unit is quite reasonable, the largest cassette weighing about 2000 kg, one third being blanket module proper and two thirds integral shield. The expansion plenum provided for the lithium in the cassette can act as a detection device in the event that the coolant gas vents to the liquid metal. Shear panels in the cassette are used to take up the shock of the helium vents to the lithium. Further work is required here. Fail safe features need to be incorporated. The stresses and cyclic fatigue problems seem tractable and are reported in Ref. (3).

It is strongly recommended that a scale model of a cassette blanket sector be fabricated and tested. There can be no substitute for testing in a condition as close to full scale as possible. The NASA Sandusky facility could be a reasonable site and it is available. Other blanket concepts should of course be tested. The timing for this, it seems to us, should be in the early 1980's.

REFERENCES

(1) D. Steiner, et al., ORNL Fusion Power Demonstration Study: Interim Report, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Rept. ORNL/TM-5813 (March 1977).

(2) R. W. Werner, ORNL Fusion Power Demonstration Study: Arguments for a Vacuum Building in Which to Enclose a Fusion Reactor, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Rept. ORNL/TM-5664 (December 1976).

(3) R. W. Werner, ORNL Fusion Power Demonstration Study: The Concept of the Cassette Blanket, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Rept. ORNL/TM-5964 (October 1977).

All four remote manipulators are basically the same machine. However, each is equipped with a particular drive head to perform its *special function.*

A conceptual manipulator and three heads are illustrated.

Head 1 provides for the quick disconnect of the high pressure *lines*

Head 2 illustrates one possible method for cassette *pickup*

Head 3 illustrates a backup method for cassette pickup

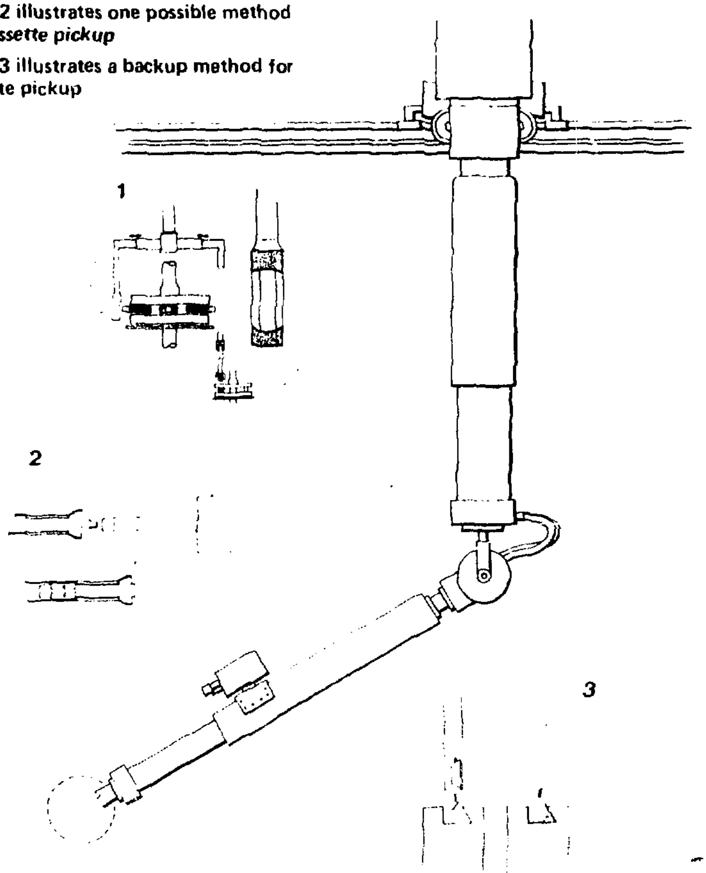


Figure 7. Diagram of a typical remote manipulator. *Four are used to replace the* cassette blanket modules, each equipped with a different head for a specific task.

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