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FUSION REACTORS — A REMOTE POSSIBILITY

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FUSION REACTORS — A REMOTE POSSIBILITY*

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Summary

The next generation of controlled thermonuclear reactor experiments will be faced with the handling problems of tritium and neutron activation that will dominate the safety and maintenance problems of future fusion reactors. The nuclear industry has been working with highly radioactive systems for many years and has developed the tools and methods to do safely productive work in the presence of high radiation fields. These methods can be applied to CTR work by extending them to the unique problems associated with fusion reactors.

Introduction

Although fusion reactors do not present any new problems in handling hazardous materials, they do require a combination of remote handling and protective systems beyond the capabilities of any system built to date.

Beyond the very difficult job of designing the reactor proper, the designer will have to contend with:

1. Large size components. CTR reactors employ massive components that become activated and require remote maintenance.
2. Heavy shielding. Shielding for 14-MeV neutrons (predominant product of DT reactions) is typically about 3 m of concrete. The windows and doors become massive, and remote manipulators become a necessity.
3. Tritium. Large quantities (kilograms) of tritium requiring extensive cleanup and storage facilities are needed along with a leak-tight reactor room.
4. Inert atmospheres. Nitrogen atmospheres have been proposed for some reactors that, if employed, complicate maintenance operations by requiring crews to work in "breathing suits."

These problems will first be encountered in the next generation of plasma experiments such as the Tokamak Fusion Test Reactor (TFTR), where limited quantities of tritium will be employed at various times in the experimental program.

Component Size

A typical fusion reactor consists of a plasma region surrounded by a blanket, a layer of shielding, and the coils and coil support structure (Fig. 1).

In present reactor designs, the blanket provides the bulk of the activated material. The blanket sections are heavy (1.5 tonne/m^2) and always installed in relatively inaccessible locations. Neutron damage to the first wall limits its useful life to about 2 yr (2 MW yr/m2 at a wall load of 1 MW/m^2). The blanket then requires very large handling machinery to remove and replace blanket sections in times short enough to not seriously reduce the plant operating factor.

For example, a blanket presently proposed for the LLL mirror reference reactor is 625 m^2 divided into 32 segments (Fig. 2), each segment with its associated plumbing manifold weighing 86 tonnes. Fifty percent of these modules must be replaced each year. Assuming a quarterly shutdown for maintenance and a desirable 75% plant factor, four modules must be replaced within the 23-day shutdown.

Shielding

There are two primary sources of radiation in a fusion reactor: the 14-MeV neutron production of D-T plasma and the large mass of activated material in the reactor proper.

It takes about 3 m of ordinary concrete to successfully stop 14-MeV neutrons and associated gamma rays. In reactor designs the bulk of neutron shielding is provided close in by the blanket and its surrounding shield. For experiments such as TFTR and

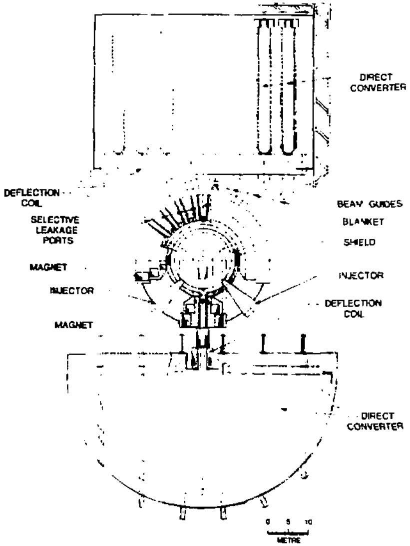

Fig. 1. Mirror fusion reactor cross-section.

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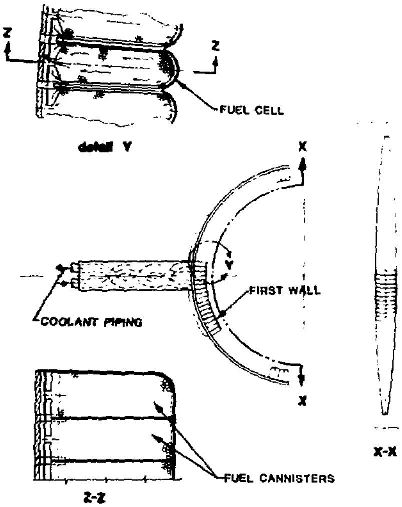

Fig. 2. Reactor blanket segment.

facilities such as the Fusion Engineering Research Facility (FERF), there will be a large source of uncollided neutrons reaching the walls of the facility that will have to be fully capable of shielding the 14-MeV neutrons.

The walls of a reactor containment structure will be required to absorb the large gamma-ray flux emitted by the blanket modules and other activated components that are removed during maintenance operations. These walls will be approximately 1.5-m-thick concrete or an equivalent.

The large sizes of the components that must be removed from the containment room will require massive shield doors (thousands of tonnes).

Tritium

Tritium considerations permeate the entire design of these reactors. Even with a vacuum degassing cycle before machine disassembly, residual tritium is found on the surfaces of most reactor components and diffused into the volume of the material. In some designs, the reactor room is backfilled with inert gas to prevent the buildup of an explosive mixture in the event of a major up-to-atmosphere leak. If this approach is used, a breathing apparatus is required in the reactor room even when the machine is closed and the tritium level is below maximum permissible concentration.

All reactor designs incorporate some sort of seal membrane to contain tritium in the event of a major leak. The membranes are generally composites with one of the materials having a high affinity for tritium. The need to maintain the integrity of the membrane complicates the introduction of piping, wiring, doorways, and windows in the containment structure.

Amplification of Problems

A multiplier of these problems is the complex nature of fusion devices that combine systems with: high voltages, large currents, high vacuums, cryogenic fluids, superconducting coils, high temperatures, and high-pressure fluids. To varying degrees, all these systems will require remote assembly, disassembly, maintenance, and repair.

Examples

Some of the approaches to handling fusion reactor problems are illustrated by the results of the several design studies[1-3] that have been done on reactor systems.

The FERF design represents a relatively small reactor system (Fig. 3) that does not incorporate a

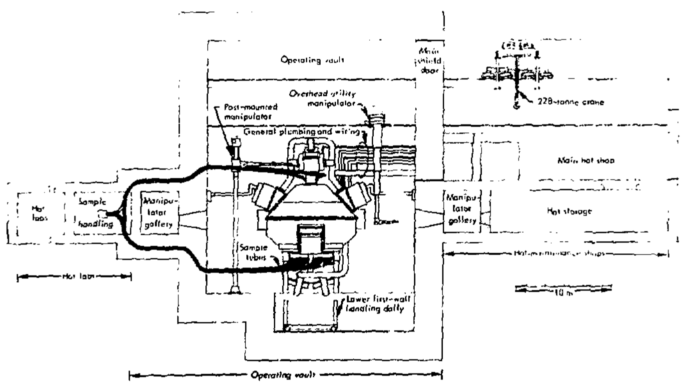

Fig. 3. Elevation of FERF.

blanket. Even here the first-wall replacement operation requires the handling of a 50-tonne unit (Fig. 4). The large shield door and the complex of remote maintenance facilities are almost as large as the reactor room.

Figures 5 and 6 show two approaches to blanket handling for power reactors. Figure 5 shows a concept for a hybrid fusion-fission reactor employing flat plate blanket modules that are extracted through the ends of the machine. A typical module weighs 100 tonnes.

Figure 6 shows a scheme for a fusion-fission reactor with a spherical blanket. The entire reactor is opened to expose the blanket segments that can be replaced. Here, a typical segment weighs 86 tonnes.

Conclusion

To date, the bulk of component development has been aimed at experimental devices where low plant factors and a high reliance on direct maintenance are acceptable. Although the scheduled introduction of power reactors is in the next century, the need to build highly reliable, remotely maintainable reactor

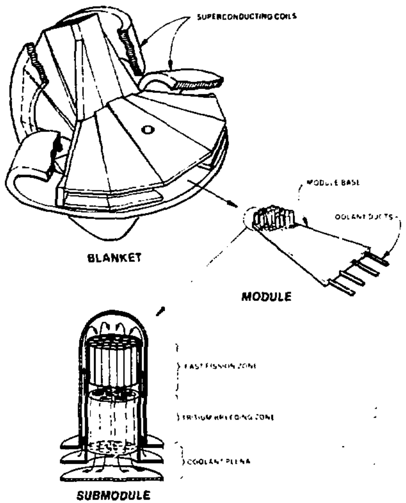

Fig. 5. Blanket scheme for a fusion-fission hybrid reactor.

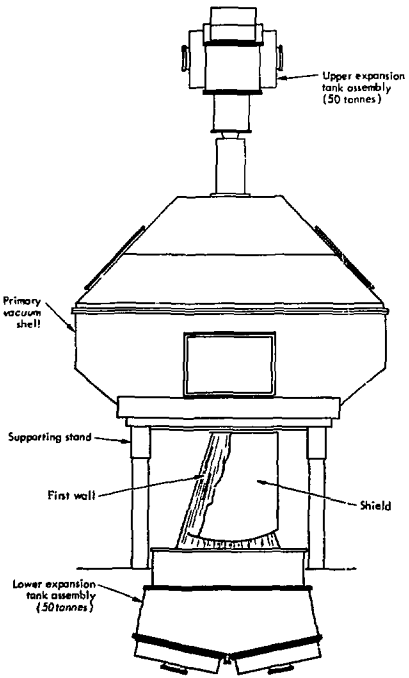

Fig. 4. Removal of the first wall and expansion tank from FERF.

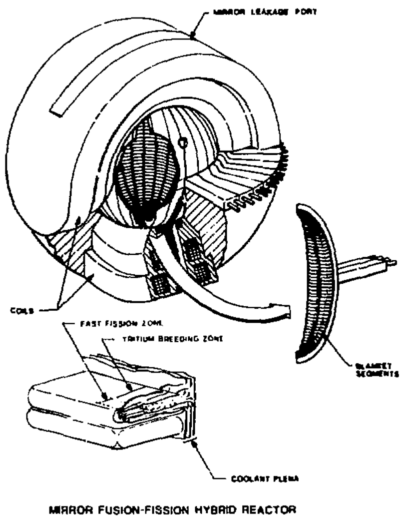

Fig. 6. Blanket scheme for a fusion reactor.

components will be here in the next decade for use in the Experimental Power Reactor 1, TFTR, and FERF. FERF, for example, requires a high plant factor to fulfill its mission of providing a high flux of neutrons to test specimens in a reasonable time period.

It is clear that the complications caused by the need to work with large, heavily shielded, contaiminated components will have an important effect on the costs of building and operating fusion reactors. Most of the problems lend themselves to solutions with existing technology, but the shear magnitude of the components both in size and quantity requires careful planning and design.

References

1. T. H. Batzer et al., Conceptual Design of a Mirror Reactor for a Fusion Engineering Research Facility (FERF), Lawrence Livermore Laboratory, Rept. UCRL-51617 (1974).

2. R. W. Moir et al., Progress in the Conceptual Design of a Mirror Hybrid Fusion-Fission Reactor, Lawrence Livermore Laboratory, Rept. UCRL-51797 (1975).

3. J. N. Doggett, Remote Operations in a Fusion Engineering Research Facility (FERF), Lawrence Livermore Laboratory, Rept. UCRL-51778 (1975).