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DESIGN FEATURES OF THE ELMO BUMPY TORUS REACTOR (EBTR)*

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The reference ELMO Bumpy Torus Reactor (EBTR)[1] is the first comprehensive reactor design based on the EBT confinement concept.[2] This concept is an attractive alternative to other mainline confinement systems and offers potential advantages in the reactor physics and technology areas.

An ideal fusion reactor, from the viewpoint of a reactor designer, would include a steady-state system of moderate-to-high-β, a relatively large aspect ratio, modular construction, a reasonable surface/volume ratio, and a neutron wall loading of a few megawatts per square meter and would permit relatively straightforward maintenance and assembly-disassembly. There may be numerous plasma configurations which ultimately meet these requirements. The EBT concept, pioneered at the Oak Ridge National Laboratory, is of great interest in this regard. Inspired by the potential of EBT, self-consistent treatment of an EBT reactor has been developed and a reference design has been selected. There are, of course, uncertainties in extrapolating the present plasma physics knowledge to predict the behavior of future devices. These projections are a part of fusion research and are necessary to determine the best steps in a concept-oriented program.

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The principal advantages of an EBT reactor stem from steady-state operation at high beta. A reactor design and the required research and technology development programs have resulted from the EBT Reactor Study which was undertaken in 1976. The study integrates the necessary elements to determine reactor prospects. These are plasma physics (theory and experiment), plasma engineering, magnetics, neutronics, and design engineering. A set of plasma parameters and a range of machine characteristics for the EBTR have been established (see Table I for parameters). This design is based on a presently acceptable plasma model[3] and relatively conservative engineering parameters. It is a large aspect ratio, steady-state, ignited system (microwave and/or neutral beam heated) which operates at high power density.

The EBTR described in this summary is based on specific present and near-term technologies, practical design approaches, and flexible plasma characteristics. The design should be viewed as a representative system, not an optimum one, since there is no unique solution to the overall design problem. The "optimum design" is strongly dependent on the weight given to the constraints in each area. The essential features of the EBTR are described below.

Plasma Engineering and Physics. In order to establish the confinement properties of the EBT concept, a time-dependent D-T plasma model[4] has been formulated to simulate the dynamic behavior of the system and to provide a framework for testing physics assumptions and models. Power density scaling with respect to magnetic field strength, beta, wall loading, etc. have been assessed parametrically. The trade-offs involved in optimizing the high-β cycle are unique and have been formulated as part of the study. The trade-offs between β and B have been considered and high-β and low-B (the

minimum field strength assumed feasible is ~25 kG) operation is found to be desirable. The overall reactor power balance has been analyzed. Particle orbit behavior and equilibrium and stability have been studied. Due to equilibrium requirements and efficiency of use of the magnetic field, the displaced aperture-inner wall design has been adopted.[1] A first preliminary cost breakdown has been completed. The resulting costs per KWhr are quite similar to those from recent cost estimates for tokamak power plants.[5] Relevant technical results in each area will be presented.

Magnetics. The main goal in the magnetics area was to satisfy the plasma constraints with a coil design which could be built with existing technology. The number of coils, mirror ratio, coil radius, and reactor major radius can all be related by the geometry of the vacuum magnetic field. Plasma physics considerations further relate the mirror ratio to the aspect ratio, electron ring beta, stable plasma volume, magnetic axis shift, and similar quantities.

EBT has no pulsed fields; hence, the more advanced conductor designs are not required. With respect to superconducting materials, the cheaper and more ductile NbTi is preferred. EBT has a large aspect ratio so that the magnetic field is reasonably uniform at the coils and the magnetic forces are nearly symmetrical. Circular coils are used. Natural convection pool boiling is employed as the cooling method.

A basic module which is repeated to form the toroidal reactor has been defined. As long as the ratio of reactor major radius to the number of modules (which include the coils) is constant, the axial field strength produced is not sensitive to the size of the reactor. Thus, an important advantage of an EBTR is that the same module-magnet design can be used in reactors of different size and output. The feasibility of including an impurity control system consistent with the physics and engineering

requirements was also evaluated.

Mechanical Design. Conceptual designs of EBT reactors based on the modular concept (with identical superconducting coils) were studied for a wide range of sizes, i.e., for major radii between 30 m and 120 m. The mechanical design consists of the following: the nuclear blanket, the radiation shield, the superconducting coil support, and the concrete enclosure and biological shield. The plasma and the blanket and shield are concentric. Coil structure aperture has been shifted outward approximately 25 cm in order to improve the confinement properties of the system. These regions are continuous around the torus and are composed of cylindrical modules. The assembly-disassembly procedures for the torus are straightforward.[1]

The reference design has a major radius of 60 (30) m which is made up of 48 (24) identical modules containing blanket, shield, vacuum pumping, and microwave injection ports. The blanket is divided into segments both toroidally and poloidally and totally encloses the plasma. It uses stainless steel structure, metallic lithium for breeding, stainless steel spheres for gamma ray absorption, and helium for cooling. The shield consists of stainless steel tanks filled with stainless steel spheres and borated water. These tanks are divided into appropriate shapes and sizes to permit access to the blanket with relative ease because the blanket will require replacement several times during the reactor lifetime. The shield is cooled by circulating the borated water.

The torus is assembled in a concrete moat which is evacuated to provide a secondary vacuum enclosure for the machine. This greatly simplifies the remote maintenance problem since it is not necessary to provide a vacuum-tight envelope for the plasma. Two gantry cranes travel around the moat for

maintenance. The large area encircled by the moat is used for the electrical power supplies, cryogenic refrigerators, primary heat exchangers, and other equipment. This central location minimizes the lengths of lines running to these auxiliaries.

Neutronics. The nuclear performance of the blanket has been evaluated using a one-dimensional analysis. The energy deposition rate in the blanket is found to be high enough ($\geq$98%) for extraction of the heat and generation of electrical power. The effectiveness of the shield in reducing the radiation incident on the magnets has been determined by comparing the energy deposition rate and radiation in the coils as a function of the shield thickness. A 50-60-cm-thick shield is found to be adequate. The tritium breeding ratio is about 1.30 and provides the margin necessary to allow the inclusion of required ports and penetrations.

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*Research sponsored by the Energy Research and Development Administration under contract with Union Carbide Corporation.

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Table I

EBTR Reference Parameters

Plasma radius (m)		1.0	
Aspect ratio	30		60
Mirror ratio		1.78	
Number of coils	24		48
Ion temperature (keV)		15	
Ion density × 10^{-20} (m^{-3})		1.4	
Beta (%)		27	
Magnetic field on axis (T)		2.51-4.48	
Total fusion power (MW)	3000		6000
Power density (MW/m^3)		3.77	
Neutron wall loading (average) (MW/m^2)		1.47	
Cold zone (m)		0.2	
Blanket and shield thickness (m)		1.55	
Coil inner radius (m)		3.00	
Coil outer radius (m)		3.70	
Coil half axial length (m)		1.00	
Current density (A/cm^2)		1525	