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GENERAL ATOMIC

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GA-A14021
ADDENDUM 1
UC-20

CONCEPTUAL DESIGN OF THE
BLANKET AND POWER CONVERSION
SYSTEM FOR A MIRROR HYBRID
FUSION-FISSION REACTOR
ADDENDUM 1: ALTERNATE CONCEPTS

12-MONTH PROGRESS REPORT ADDENDUM
FOR THE PERIOD JULY 1, 1975
THROUGH JUNE 30, 1976

by
K. R. SCHULTZ, J. B. DEE, G. A. BACKUS,
and D. W. CULVER

Prepared under
Contract No. E(04-3)-167
Project Agreement No. 38
for the San Francisco Operations Office
U.S. Energy Research and Development Administration

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1. INTRODUCTION

A study was performed at General Atomic Company during FY-1976 for the United States Energy Research and Development Administration to investigate the application of gas-cooled reactor technology to the Mirror Hybrid Fusion-Fission Reactor. Most of the results of this study were reported in the report GA-A14021 "Conceptual Design of the Blanket and Power Conversion System for a Mirror Hybrid Fusion-Fission Reactor," published July 6, 1976.

As a part of the study several alternate design concepts for the Mirror Hybrid Reactor blanket were developed. Several of these appeared to be of potential patent interest to ERDA. As a consequence, ERDA invention disclosures were filed for these concepts (Invention Disclosures F-69, F-70, and F-71). To assure a timely release of the project progress report, these alternate concepts were not described in that report. The purpose of the addendum to GA-A14021 is to document the work done on these alternate design concepts.

2. ALTERNATE CONCEPTS

During the course of the Mirror Hybrid Fusion-Fission Reactor study several alternate concepts were considered for various reactor components. Due to the limited scope of this study, these alternate concepts were not investigated in any detail. Several of the alternate concepts do appear to exhibit features with potential advantage for use in the mirror hybrid reactor. These are described below and should possibly be investigated further in the future.

2.1. ALTERNATE MODULE CONCEPTS

During the course of the study two alternate blanket module concepts were considered as possible means for reducing cost or increasing reliability of performance. The first alternate is based on minimal deviation from the reference concept and similarly employs radially oriented fuel rods. The second alternate is a pebble bed fuel concept contained in curved tubes of constant circular cross-sections. Although these are very preliminary concepts, they are considered to be sufficiently interesting to include here because they illustrate alternative approaches to problems with differences in design requirements from those for fission reactor blankets; e.g., complex geometry, large dimensions and weights, and the high temperature pressure vessel function of the fuel module outer walls.

Alternate I

This concept is aimed to simplification of the geometry of the reference design and is illustrated in Fig. 1. The plasma region is surrounded by an array of generally flatsided identical modules that together form a truncated double cone approximating a sphere as illustrated in Figs. 2 and 3. Each cone is split longitudinally to provide an opening directly over each magnet for the selective leakage port that leads to the direct converter.

Fig. 1. Module concept - Alternate I

Fig. 2. Alternate I - Blanket module

Fig. 3. Alternate I - Full blanket

Each module is enclosed by a pressure-containing outer wall which is made as thin as neutronically permissible by combining internal webs to oppose the pressure forces trying to separate opposite faces of the module and by providing local curvature of the module wall between webs to minimize bending stresses. To a first approximation the total amount of structural material required to contain a fixed volume of blanket fuel is the same as for a simple cylindrical shell, but it has the merit that the outer wall, and particularly the first wall, is thinner for the internally supported module and in principal the outer shape is relatively arbitrary. When compared with the cylinder, the weight of the complex structure would tend to increase somewhat since the redundant structure would be more susceptible to generation of thermal strains and progressive failure modes so that reduced values for acceptable design stresses would be required.

For reducing fabrication costs, the outer walls employ simple curves rather than compound curves, and this is consistent with the flat-sided geometry assumed for the basic module shape. The flat-sided geometry also has advantages for spent fuel handling, tending to require less shielded space for various operations.

The coolant flow arrangement was chosen to maintain constant flow velocity and to minimize the pressure drop turning losses. The arrangement shown also tends to minimize the space occupied between the plasma and the magnets. An additional advantage of the proposed path is the elimination of the coolant inlet region surrounding each submodule in the reference design. This will allow the fuel volume in the blanket to be increased by about 30% which would improve the blanket neutronics and would reduce neutron streaming through the blanket region.

By employing the principle of concentric flow for the helium ducts with the cooler inlet gas on the outside, the pressure wall thickness is less than that for a hot wall and the thermal stresses are reduced by maintaining all of the pressure wall at the same constant temperature. The concentric inlet-outlet duct located at one end allows for a single structurally-fixed piping connection penetrating the vacuum wall. Single

ended piping helps to minimize thermal stresses imposed on the module by the external piping system. A secondary support for structural stability is applied at the other end.

For the case of 32 identical modules, each weighs approximately 32 metric tons and measures approximately 7.3 m long, 2.5 m wide and 1.7 m thick.

Alternate Module II

The essential features of this concept are (1) the modules are tubes of uniform circular cross-section, and (2) the fuel is pebble-bed in form. The concept is illustrated in Fig. 4 and consists of an assembly of tubular modules wrapped around a spherical plasma-containing region to form one or more fission-blanket layers. A similar outer layer(s) could be used to form a fusion-breeder layer which could be kept at a lower temperature than for the main heat transport system for better tritium containment. An entirely separate helium system might be used for the fusion breeder region to facilitate tritium recovery.

Each module has an outer wall which is the basic structural member and is analogous to the fuel element flow duct used in the gas-cooled fission breeder reactor except that the fusion-fission element duct is also pressure-containing. The circular cross-section provides maximum strength and resistance to creep or thermal stress induced shape changes. Maximum structural simplicity is consistent with minimum fabrication cost. Also the avoidance of redundant structural members greatly eases the difficulties of detailed stress analyses and associated development programs.

The fuel is made of identical pressed spheres of uranium silicide encapsulated between hemispherical shells pressed from stainless steel or Inconel sheet metal which are coated with a thin refractory oxide barrier to retard uranium diffusion, and seal-welded. The fuel spheres are contained between two perforated slightly-conical supporting shells. In principal, the spent fuel spheres could be drained from the modules into a

Fig. 4. Alternate-II blanket fuel module concept

spent-fuel storage pool while the module structures remain in place, thereby simplifying the spent fuel handling and reducing the radiation levels associated with module replacement.

The flow arrangement is concentric constant velocity for the inlet and outlet, includes minimum bends in flow direction for minimum pumping losses, and is consistent with constant external diameter. Also, the outer wall is uniformly well-cooled by the inlet gas temperature.

Fig. 5. Integrated blanket/steam generator

considerations of the steam generator unit and its transportation during refueling within the space enveloped by the fission blanket and magnet structure should be investigated. Also the thermodynamic performance of the unit should be evaluated in detail. A critical study has to be performed for the design of a turbocirculator with rotating components in the presence of a high energy magnetic field, creating large-scale eddy currents in the unit. The circulator power requirements to operate in such a magnetic field could be excessive. Hence, the discussion of this alternate concept presented here is preliminary, and it is recommended that the feasibility of this concept be further investigated in future work.

A major advantage of this concept is that radioactive helium will be primarily confined to the fission blankets. Tritium release from the Li sub-blanket through the primary coolant boundary into the secondary containment will be substantially reduced. In addition, the containment and support problems associated with the large diameter helium ducts would be eliminated.

Figure 5 is intended to depict an "orange peel slice" fission blanket, having a boronated shield at its outer surface which interfaces directly with a sealed shroud containing a triple bank of 1-inch diameter steam tubes arranged in a serpentine pattern. Heated helium from the blanket interior would flow downward across the tubes, through a circulator located near the bottom cusp of the blanket, and upward through a set of blanket inlet manifolds. Helium would pass through the fission and lithium layers of the blanket, and enter parallel outlet manifolds leading to the steam generator shroud inlet near the top cusp. Inlet manifolds could be adjacent to the outlet manifolds as shown, or they could be formed by the first wall.

Feedwater would enter steam generator tubes near the bottom cusp, and exit at the top as steam. An external line, integral with the shroud, would provide steam to the helium circulator turbine and to the plant power turbogenerator sets. The reheater, if cost optimization showed it to be

desirable, would be located in the uppermost section of the steam generator and could be provided with separate feed and return lines.

Other potentials of this integrated steam generator/turbocirculator concept are:

1. Helium manifolding problems are greatly reduced by comparison with the reference concept.
2. External module interfaces are reduced in size and number.
3. The need for a separate ACS helium circuit may be obviated. Conduction paths from the fuel to water loops could be included in the blanket structure.
4. Steam generators may be reused; the blanket subassemblies inside of the boronated shield may be changed out on site in a high activity lock within the containment building.
5. The consequences of a large steam leak into the primary helium may not be severe because of the metallic clad fuel (nongraphitic).
6. A modicum of natural helium convection (cooling) might be obtained after shutdown if cold feedwater were run through the generator tubes.