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TANDEM MIRROR FUSION FISSION HYBRID STUDIES*

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ABSTRACT

Initial Tandem Mirror Hybrid Study predicts the ability to produce large amounts of fissile fuel (2 to 7 Tonnes per year U233 from a 4000 MW plant) at a cost that adds less than 25% to the cost of power from an LWR.[1]

INTRODUCTION

The fusion-fission hybrid system concept combines the neutron rich but energy poor fusion process and the energy rich but neutron poor fission process. High energy neutrons are produced in a fusion driver ($D + T \xrightarrow{fusion} n$ (14.1 MeV) + α(3.5 MeV)). The high energy fusion neutrons are intercepted by a blanket generating energy and additional neutrons via (n, fiss.), (n, 2n) and other nuclear processes. The neutrons in excess of that needed to breed tritium (T) are used to breed fissile material, Pu239 from U238 and U233 from Th232. The fissile material produced can be fissioned insitu or removed and used to fuel fission reactors.

During 1979 we began studying hybrids based and Tandem Mirror fusion drivers and U233 producing fast fission as well as fission suppressed thorium blankets.

This paper discusses the tandem mirror drivers and the thorium blankets examined and summarizes estimated system performance.[1]

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TANDEM MIRROR

The tandem mirror concept, invented in 1976, [2,3] has great potential for magnetic fusion. Work on the tandem mirror concept is international in scope. The U.S. effort is centered at Lawrence Livermore Laboratory in California. Both the USSR and Japan have research programs as well.

The tandem mirror consists of a linear assembly of mirror cells having two distinct functional parts: a cylindrical central cell, where the fusion reaction and fuel breeding are the main function; and two end plug regions, where fusion plasma axial confinement, heating, refueling, and dumping take place.

In previous reactor designs based on minimum-B mirrors (standard mirrors), we found that the large losses out the open ends limited the Q values (fusion power divided by input power) to about unity.[4] In 1976, Dimov et al.[2] and Fowler and Logan[3] found it possible to essentially remove any limit on Q($Q = P_{fusion}/P_{injection}$) by placing three mirror devices in tandem. The two end devices (plugs) are, in effect, the standard mirror device operated at high density. The central cell is cylindrical, which is a desirable shape for the incorporation of blankets. The plugs are maintained at a density higher than that of the central cell by neutral-beam injection. As a result of the higher density, the electrostatic potential in the plugs is higher than in the central cell, thus forming a barrier to the leakage of central-cell ions. Because of this barrier, the central-cell ions are confined for much longer times, resulting in higher Q. Of course power must be expended in maintaining the plug plasma, which produces no power; but if the plug volume is much less than that of the central cell, the Q can be made quite high.

Two modes of tandem mirror operation are considered, two component and thermal. Theory predicts the 2 component mode to have $Q \simeq 1.1$ insensitive to wall loadings up to 5 MW_n/M^2, and the thermal mode to have Q ranging from 3.2 down to 2.0 as wall loading varies from 1.0 to 2.0. Wall loading is the fusion neutron kinetic energy current through the blankets first wall. Magnet and beam technologies are 9 tesla peak central field in the plugs and peak neutral beam injection energy of 300 keV. Neutral beams provide all the

plasma heating for the 2 component mode while RF provides most for the thermal mode. Plasma performance is also sensitive to fusion power, dropping 20% and 10% for the thermal and 2 component modes as power is dropped from 2500 MW to 1500 MW. The thermal mode was found to make the better driver.

The tandem mirror has potential features that make it attractive as the fusion driver of a fusion-fission system.

- o Cylindrical geometry
- o Steady state
- o Fusion power gain (Q plasma) > 1
- o Power densities resulting in first wall loadings >2 MW/m^2 (kinetic energy flux of fusion neutrons)
- o Requires modest extrapolation of fusion component technologies.
- o Low first wall heating and bombardment by the plasma.

BLANKETS

During the initial scoping phase of the 79 Tandem Mirror Hybrid study various blanket types with four different coolants (H_2O, He, liquid metal, molten salt) were considered. From these, 2 were chosen for continued investigation; a He cooled Th fast fission blanket (Th/He) and a beryllium plus molten salt (Be/MS) fission suppressed blanket.

We are concentrating on U-233 producing blankets because U-233 is a better thermal fission reactor fuel than Pu239. U-233 could also be denatured with U-238 to inhance its 'diversion' resistance.[5]

The Th/He blanket consists of Th fuel plates followed by LiO_2. Neutron multiplication is by Th (n, fiss.), (n, 2n) etc. reactions. Cooling is by high pressure helium. Refueling is done off line by replacing blanket segments. Processing to recover U-233 is done by a batch thorex process. Tritium is purged continuously online.

The Th/He blanket is based on contemporary gas reactor technology. The major development challenge attributable to the hybrid aspects of this blanket is after heat cooling since fission power density may be as high as 200 w/cc. Blanket replacement time is also more important because U-233 must be removed.

The Be/MS blanket[6] consists of an assembly of clad Be (for neutron multiplicaton) and C (for additional moderation) rods plus a Li and Th bearing molten salt (MS). The MS is circulated for online removal of tritium, Pa-233 and U-233 as well as heat. The MS processing loop is an integral part of the plant.

The Be/MS blanket is an interesting candidate because of its fission suppressed nature coupled with its good breeding potential. A molten salt technology base exists because of the molten salt Breeder Reactor Program (MSBRP).[7] Major Be/MS blanket development challenges arise because the environment is more severe than that faced in the MSBR. The Be/MS blanket has beryllium, magnetic fields, tritium and structure in high neutron flux regions to contend with.

SYSTEM PERFORMANCE

The major elements of a fusion fission system are the fusion driver, the blanket and the fission reactors supported with fissile fuel remove from the blanket. Fuel cycle cost, consisting of fuel processing and fabrication costs, and the hybrids ballance of plant (BOP) are also important economic elements.

The estimated performance of 2 fusion fission system consisting of a tandem mirror driver (thermal mode), the Th/He or Be/MS blanket and light water reactors (LWR's) is summarized in Table 1.

Both blankets produce 1.0 tritium atom plus about 0.8 U-233 atoms per D-T fusion, but the Th/He fast fission blanket multiplication (M) of the fusion neutrons kinetic energy (14 MeV) is about three times more than for the Be/MS fission suppressed blanket. The major differences in the drivers for the two cases is the fusion power level needed to keep both hybrids at 4000 MW maximum nuclear power $\left(P_f = P_n/(0.2 + 0.8M_{max})\right)$. Higher fusion power is achieved mainly by increasing length and to a lesser extent by increasing first wall loading. First wall radius and plasma Q $(P_f/P_{trapped\ injected})$ are about the same for both cases.

The Be/MS blanket hybrid produces 3 times more fissile product (U-233) but 3 times less net electrical power than the Th/He case. Thus the electric power support ratio of the Be/MS case is almost 9 times higher than the Th/He case.

Our estimate of system economics ($/gram fissile and mills/kwhe) show the two cases having similar costs. In both cases hybrid produced fuels add 20% to the cost of power from an LWR. With costs similar, choosing between the two blanket types can be based on other considerations such as development cost and time, beryllium resource and cost questions, support ratio, safety and operational advantages.

FUTURE WORK

Because of perceived advantages and comparable economics of fission suppressed blankets we plan to pursue further this class of blankets in our future Tandem Mirror Hybrid Reactor Studies. Our objective is to develop conceptual designs of fission suppressed blankets that are competitive but that do not require the materials development needed for the Be/MS blanket.

The Tandem Mirror fusion reactor concept looks to be an excellent candidate for the driver of a fusion fission hybrid. We plan to pursue this application on the Tandem Mirror concept matures.

The tandem mirror physics effort is now pursuing a new mode of tandem operation, the thermal barrier mode. This mode is predicted to perform better with less demanding technology than the thermal mode used in the 1979 study.

Our long term objective is to demonstrate practical fissile production by fusion before uranium ore depletion inhibits the expansion of nuclear power.

Table 1
TANDEM MIRROR FUSION FISSION SYSTEM PERFORMANCE*

Blanket Type	Th/He	Be/MS
Blanket parameters		
Fissile breeding ratio	0.83	0.81
M (ave)	5.2	1.58
Hybrid nuclear power level, peak (MW)	4000	4000
Driver parameters		
Fusion power (MW)	813	2733
Wall loading (MW_N/m^2)	1.5	2.0
Wall radius (m)	2.0	2.1
Central cell length (m)	35	82
Plasma Q	2.0	2.2
Fissle production rate, hybrid (kg/y)	2915	9554
Electric power (MW)		
Hybrid net	892	362
LWR's	9,634	31,194
Power support ratio (P_{LWR}/P_{HYB})		
Nuclear	8.5	24.6
Electric	10.8	87.0
Hybrid direct cost (M$)	1993	4126
System direct cost ratio ($/kWe system/$/kWe-burner)	1.23	1.20
Hybrid fissile cost ($/g)		
Capital	97.1	61.3
Fuel cycle	14.6	(included in cap. cost)
Blanket replacement	6.0	1.4
O&M	8.0	2.8
Power	-55.1	-6.6
Total	70.6	58.9
LWR electricity cost (mills/kWh)		
Capital	9.9	9.9
O&M	2.5	2.5
Fuel cycle (less fissile makeup)	4.1	4.1
Fissile makeup (from hybrid)	4.0	3.3
Total	20.5	19.8

*Both hybrids are 4000 MW peak nuclear power and have a 75% capacity factor. Capital charge rate is 6.74% based on constant dollars.

REFERENCES

1. R. W. Moir, et al "Tandem Mirror Hybrid Reactor Design Study Annual Report;" LLL Report UCRL 52875, 1980.

2. G. I. Dimov, V. V. Zakaidakov, and M.E. Kishinevsky, Fiz. Plasmy 2, 597 (1976); also G. I. Dimov, V. V. Zakaidakov, and M. E. Kishinevsky, "Open Trap with Ambipolar Mirrors," in Proc. 6th Inter. Conf. Plasma Physics and Controlled Nuclear Fusion Research, Berchtesgaden, Fed. Rep. of Germany, 1976 (IAEA, in preparation), Paper C4.

3 T. K. Fowler and B. G. Logan, "The Tandem Mirror Reactor" Comments on Plasma Physics and Controlled Fusion Research, 2, 167 (1977).

4. R. S. Devoto and D. J. Bender, "Plasma Models for Standard Mirror Reactors", UCRL 81792 (October 1978) also Nuclear Fusion 19, 1151 (1979).

5. H. A. Feiveson, et al, Bulletin of the Atomic Scientists, December 1976, p. 10.

6. J. D. Lee, "The Beryllium/Moten Salt Blanket", UCRL 82663, 1979 also to be published in proceedings of the 3rd US/USSR Symposium on Fusion-Fission; Princeton, NJ, January 1979.

7. M. W. Rosenthal, et al, Molten-Salt Reactor Program, The Development of Molten-Salt Breeder Reactors, Oak Ridge National Laboratory, Rept. ORNL-4812, August 1972.

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