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--ROLES IN THE ENERGY ECONOMY--

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ABSTRACT

The fusion-fission hybrid reactor consists of a fusion reactor and associated blanket which contains fissionable material. It has potential of becoming a versatile alternative energy source since it can be designed to produce electric power, fissile material to fuel fission power reactors or synthetic fuel to serve other markets. Consequently, it may fill many roles in the U.S. power economy. In this paper we will discuss these roles.

INTRODUCTION

The fusion-fission hybrid was first considered as a candidate for an alternative energy source in the early fifties(1). The concept was abandoned shortly thereafter when the fusion driver proved much more difficult to build than originally envisioned and, thus, at that time other sources of energy and fissile fuel production appeared to be more viable. The concept resurfaced in the early seventies(2) when advances in the development of magnetic fusion drivers gave promise that a hybrid reactor could be developed for energy production at an earlier date then pure fusion, since the plasma requirements for the hybrid were then conceived to be less demanding than for pure fusion. Later, the hybrid concept was extended to include inertial confinement devices as the fusion driver.

We will first describe the basic processes which occur in a hybrid reactor. Next, the scenarios in which these various processes may be utilized will be presented.

THE HYBRID REACTOR

Whether magnetically or inertially confined, the common denominator of most hybrid devices is the thermonuclear fusion reaction of deuterium and tritium nuclei which occurs according to the following equation:

$${}^{2}_{1}\mathrm{D} + {}^{3}_{1}\mathrm{T} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n} + \mathrm{ENERGY}$$

About 17.6 MeV of energy is released; 14.1 MeV is carried by the neutron (${}^{1}_{0}\mathrm{n}$), and the remainder by the alpha particle (${}^{4}_{2}\mathrm{He}$).

The constituents, tritium (${}^{3}_{1}\mathrm{T}$) and deuterium (${}^{2}_{1}\mathrm{D}$), are isotopes of hydrogen. It is expected that they will be the fuel for the first generation fusion reactors because their reaction cross section; i.e., probability of interaction, is two orders of magnitude greater than other possible fuels. Thus the D-T fueled fusion reactor would conceivably be the easiest to design to produce the temperatures and fuel densities necessary for themonuclear ignition.

The disadvantage of the D-T reaction is that tritium does not occur naturally. Thus tritium will have to be bred in the blanket surrounding the fusion reaction chamber, by the interaction of fusion or secondary neutrons with lithium according to the following equations:

$$^{6}_{3}\mathrm{Li} + ^{1}_{0}\mathrm{n} \rightarrow ^{4}_{2}\mathrm{He} + ^{3}_{1}\mathrm{T} + \mathrm{ENERGY}$$

$$^{7}_{3}\mathrm{Li} + ^{1}_{0}\mathrm{n}(\mathrm{FAST}) \rightarrow ^{4}_{2}\mathrm{He} + ^{3}_{1}\mathrm{T} + ^{1}_{0}\mathrm{n}$$

In the first equation, note that energy is produced, resulting in energy multiplication. In the second equation, which occurs only with fast neutrons, a neutron is released in addition to a tritium atom. In pure fusion devices these neutrons are in excess of those fusion neutrons which are lost through non-tritium producing captures and leakage. Thus tritium breeding ratios in excess of one may be obtained. The tritium produced is conceived to be removed from the blanket and is returned, along with deuterium, to the fusion reaction chamber as fuel.

In magnetic fusion devices the fusion reaction chamber contains a plasma which is maintained by a magnetic field produced by coils surrounding the plasma. The plasma itself is an extremely low density, hot ionized gas consisting of deuterium and tritium and in which the conditions for producing thermonuclear reactions are met.

In an inertial confinement device, a small pellet containing deuterium and tritium is compressed to extremely high temperatures, densities and pressures by ablation following the impingement of a pulsed laser or electron beam on the surface of the pellet. Again, the conditions necessary for thermonuclear reactions are met. Both magnetic and inertial reactors have been studied in depth and many conceptual designs have been presented (e.g., see references 3 & 4).

The 14 MeV neutron from the fusion reaction leaves the reaction chamber and enters the blanket surrounding it. In a pure fusion device, tritium, as discussed earlier, would be bred, and the neutrons kinetic and reaction energies would be deposited in a working fluid which would be used for the production of electricity.

In a hybrid device, however, the blanket will also contain a fertile material (uranium-238 or thorium-232) and, depending on the design, some fissionable material (uranium-235, uranium-233, or plutonium-239). Because of their high energy, the fusion neutrons can induce fission in either uranium-238 or thorium-232, both of which are normally not fissionable by neutrons of the average energy in a thermal fission reactor. The fission reaction releases about 200 MeV of energy in addition to 3 to 5 neutrons. These neutrons may in turn produce additional fissions and thus more energy, or they may be captured in fertile $^{238}\mathrm{U}$ or $^{232}\mathrm{Th}$ nuclei thereby producing fissile plutonium-239 or uranium-233, according to the reactions:

$$^{1}_{0}\mathrm{n} + ^{238}_{92}\mathrm{U} \rightarrow ^{239}_{92}\mathrm{U} \xrightarrow{\beta^-} ^{239}_{93}\mathrm{Np} \xrightarrow{\beta^-} ^{239}_{94}\mathrm{Pu}$$

$$^{1}_{0}\mathrm{n} + ^{232}_{90}\mathrm{Th} \rightarrow ^{233}_{90}\mathrm{Th} \xrightarrow{\beta^-} ^{233}\mathrm{Pa} \xrightarrow{\beta^-} ^{233}_{92}\mathrm{U}$$

In Figure 1, a cross section of a conceptual hybrid reactor design is shown(5). This particular hybrid has a tokamak fusion driver, in which the reaction chamber is in the shape of a torus. The blanket assemblies containing uranium and lithium, which are penetrated by the fusion neutrons, partly

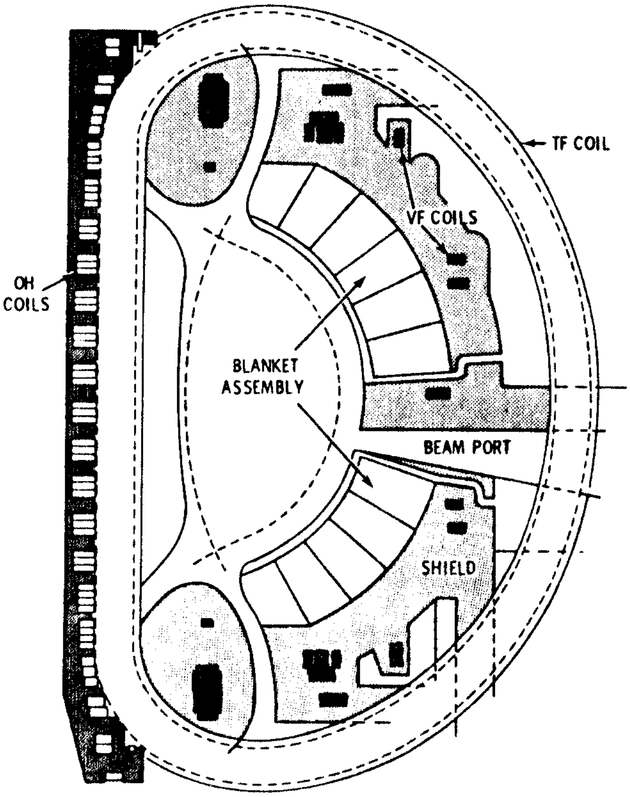

FIGURE 1. Cross Sectional view of a conceptual tokamak fusion-fission reactor (ref. 5). High energy neutrons produced from fusion reactions in the center of the device enter the blanket where various reactions occur to produce energy and/or fissile fuel.

surround the fusion reaction chamber. It is in the blanket where the fissile fuel and tritium is produced. In this reactor, helium is the working fluid and the energy released is transmitted to the helium for the production of electricity.

In recapitulation, we note that the fusion process produces about 18 MeV of energy per fusion. If the fusion neutron enters the blanket and produces a fission an additional 200 MeV of energy is released, resulting in considerable energy multiplication. Depending on the design, which determines the role of fission neutrons, additional fissions or fissile fuel production may result. This then determines the mission of the reactor and its place in the energy economy. These roles will be discussed next.

FUEL FACTORY

The hybrid can be utilized as a fuel factory. In this role the hybrid would produce plutonium-239 or uranium-233 from neutron capture in uranium-238 or thorium-232, respectively, for use as fuel in fission reactors. In this scenario power production would be minimized by proper blanket design in order to maximize neutron capture in fertile material and thus maximize fissile fuel production. Since the fissile fuel produced in the reactor will begin to fission, rather rapid reprocessing of the fuel will be required. The cycle time would probably be determined by economic factors; i.e., reprocessing costs, fuel quality and burnup. The hybrid could also be used in a concept in which entire fuel assemblies are placed in the blanket for enrichment.

Since fissile material is used in the hybrid, safeguarding is a consideration in system design. In principle, the mechanisms involved to make fission breeder fuel cycles proliferation resistant should be applicable to the hybrid design.

POWER PRODUCER

The hybrid can be designed as a stand-alone power producer. In this scenario the blanket may be enriched, natural or depleted of fissionable materials at startup. Buildup and burnup of fissionable material, uranium-233 or plutonium-239, would reach an equilibrium and would result in an energy multiplication many times greater than the fusion power. With proper blanket designs energy multiplications of greater than forty have been obtained, even with small enrichments. For example, the LLL-PNL Mirror Hybrid(6) had an energy multiplication of 40 with an uranium-235 enrichment of about 1 percent.

It may be noted that combining power production and fuel production may also be an alternative. However, economic studies indicate that on an individual basis, the most economical situation is a power producer that burns the bred fissile fuel in place(7). Such arguments may not be the case, however, if it were necessary to shut down light water fission reactors for the want of fissile fuel which could be supplied by a hybrid.

SYNTHETIC FUEL PRODUCTION

The hybrid, because it has the potential for extremely high temperature operation, can be used for the production of hydrogen for use in the manufacture of synthetic fuels. Hydrogen may be used for the production of such synthetic fuels as methane, coal liquid, or methanol. The high temperature, high radiation fields in the blanket could conceivably be used in such processes as electrolysis, thermal decomposition, electrothermal decomposition, thermochemical decomposition, and radiolytic decomposition although none of these processes have been developed for specific hybrid application. It is important to note that power production and or fissile fuel production could accompany the hydrogen production.

HYBRIDS AS AN ALTERNATIVE TO THE LMFBR

Hybrids may be an alternative to the fast breeder reactor should environmental or other constraints prevent its introduction into the power economy. Both the hybrid and fast breeder reactor produce fission products and other radioactive material. However, hybrids are subcritical devices and are not subject to power excursions. The hybrid then may be acceptable in some areas where the fast breeder is not.

In any case, it is not necessary for the hybrid to compete with the fast breeder for positions in the power economy. Studies(8) have shown that because of its prolific fissile fuel production (a 1000 MWe plant can supply fuel for about four light water reactors), there are economic windows in which the hybrids would feed the light water reactor industry until the fast breeder, with its long doubling time, becomes established.

THE HYBRID AS A TECHNOLOGICAL BASE FOR PURE FUSION

The pure fusion power reactor offers several advantages over a fission reactor. However, the introduction of a pure fusion device into the power economy is some time in the next century. Currently, experimental fusion devices have not produced plasma conditions in which the thermonuclear reactions would produce as much energy as is required to obtain the fusion reactions. Since the hybrid blanket has the capability for energy multiplication, a hybrid device could be built which was a net exporter of electricity, in spite of the fact that the fusion driver was a net consumer of electricity. Such a device then would be self sufficient, perhaps even profitable and competitive, yet still provide the technological base for future generations of pure fusion reactors.

SUMMARY AND CONCLUSIONS

We have outlined the basic processes that occur in a fusion-fission hybrid reactor and have discussed those areas in which a hybrid reactor could fit in the U.S. energy economy; namely, power production, fissile fuel production, and synthetic fuel production. The hybrid may be an alternative to the fast breeder reactor although there are economic windows in which the hybrid may fit without being in competition to the fast breeder. It may provide a technological base for the introduction of pure fusion reactors into the power economy. Since the hybrid has near term applications and long-term potential, it should be considered among the most promising of the alternate energy sources.

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