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A Perspective on the Fusion-Fission Hybrid Reactor

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The purpose of this paper is to review the reasons for study of the hybrid reactor's role as a source of fuel for fission converter reactors. We discuss the role of the hybrid reactor in the energy economy, the interface between the hybrid reactor and the present fusion program, implications of the Carter Energy Plan and the rationale for further hybrid reactor studies.

The Hybrid Reactor

A hybrid reactor is distinguished by the incorporation of fertile metals (^{232}Th or ^{238}U) in the blanket of a fusion reactor. Nuclear fission reactions initiated by the 14 MeV fusion neutrons in the fertile materials release large quantities of energy and convert the abundant fertile isotopes to valuable fissile fuels. For example, considering a hybrid reactor with a fast-fission uranium blanket plus a light water reactor (LWR) which burns the fissile fuel, the effective energy release from a D-T fusion neutron is

$n(14 \text{ MeV}) + \text{U blanket}$

$\rightarrow \sim 150 \text{ MeV} + 1.5 \text{ }^{239}\text{Pu atoms} + 1 \text{ T atom}$

$^{239}\text{Pu} (1.5 \text{ atoms}) + \text{LWR} \rightarrow \sim 570 \text{ MeV}$

or a total energy release of $\sim 720 \text{ MeV}$ per fusion neutron. Similarly, for a hybrid reactor with a pure thorium blanket plus a high temperature gas-cooled reactor which burns the fuel,

$n(14 \text{ MeV}) + \text{Th blanket}$

$\rightarrow \sim 40 \text{ MeV} + 0.5 \text{ }^{233}\text{U atoms} + 1 \text{ T atom}$

$^{233}\text{U} (0.5 \text{ atoms}) + \text{HTGR} \rightarrow \sim 480 \text{ MeV}$

or a total energy release of $\sim 520 \text{ MeV}$ per fusion neutron.

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Role of the Hybrid

There is presently a good deal of uncertainty in the estimated U. S. reserves of uranium ore and the cost of mining this ore. However it is generally accepted that with even modest growth in future nuclear power capacity, the uranium supply does not represent a long-term low-cost source of ^{235}U , the only naturally occurring fissile isotope (which is presently used to fuel fission reactors). To place nuclear power in the category of a long-term energy option requires conversion of the abundant fertile isotopes ^{232}Th and ^{238}U into the fissile isotopes ^{233}U and ^{239}Pu (respectively), a process generally called fissile breeding. To date, three different devices for fissile breeding have been identified: the fast breeder reactor, the hybrid (fusion-fission) reactor, and the electronuclear breeder.

A recent study by the Rand Corp. of the economics of fissile breeding by these three schemes (based on specific conceptual and preliminary reactor designs)* concluded that the most attractive breeder of the three was the hybrid reactor. This conclusion can be explained in general qualitative terms. The hybrid exhibits better economics than the electronuclear breeder because it is a net power producer, whereas the electronuclear breeder is a net power consumer. The advantage of the hybrid over the fast breeder is a result of much larger breeding rates in the hybrid (700-900 kg fissile/yr/GW_t) than in the fast breeder (70-150 kg fissile/yr/GW_t).

*fast-breeder: optimistic IMFBR

hybrid: LLL/GA reference mirror hybrid

electronuclear: LLL conceptual design (Van Atta, Heckrotte and Lee)

In addition to the advantage resulting from explicit economic arguments, the hybrid offers other potential advantages.

(1) The hybrid is a highly versatile breeding scheme, in that the neutron source (the plasma) is separate from the breeding reactions (in the blanket). Thus the hybrid offers the possibility of a wide variety of nuclear fuel cycles, based on either ^{239}Pu or ^{233}U .

(2) The hybrid option maximizes the investment in capital and experience in existing fission reactor technology by assuring a long-term fuel supply independent of realistic fast breeder performance.

(3) The hybrid does not require an initial fissile inventory, as does the fast breeder, and therefore no inherent constraints on doubling time exist. Thus, the introduction rate of hybrids will not be limited by doubling time constraints. This advantage, combined with the fact that a hybrid reactor can fuel 5 - 10 fission reactors (of comparable thermal rating), implies that sufficient hybrid capacity to support a large fission power economy could be readily deployed.

(4) Because the hybrid uses natural and depleted fertile materials, it significantly reduces the mining and enrichment requirements of the current LWR fuel cycle.

Hybrid Interface with the Present Fusion Program

The generation of electrical power from fusion, at an economically competitive cost, requires high plasma Q (Q = fusion power output/power input) and high power density. Experimental machines that would demonstrate the existence of these plasma conditions are not yet under construction. However because of the large energy generation rates in the blanket of a hybrid, in the form of direct thermal energy and stored nuclear energy (fissile fuel), the plasma performance parameters necessary for an economically attractive hybrid are much less demanding than for a fusion reactor.

Conceptual hybrid reactor designs based on the plasma physics conditions to be achieved in the next generation of fusion experiments (MFTF, TFTR, T-10M), have indicated that these systems are very near the point of being economically competitive. A modest increase in Q , by a factor of 2 - 3, would place these systems in a highly competitive position.

Thus the hybrid option offers the potential of a relatively near-term benefit from the present direction of plasma research being conducted in the fusion program. Further, one can view the near-term benefits generated from the hybrid as an argument for continued funding for plasma research that is directed toward achieving high Q , high power density plasma conditions.

The demonstration of engineering and economic feasibility of the hybrid will require a significant development program, combining elements of both fusion and fission technology. Here we have the ad-

vantage that hybrid fusion technology is quite similar to that required for a fusion reactor so that no significant changes in the presently planned fusion technology program are required (with the exception, possibly, of advancing the time schedule). Also, conceptual hybrid designs (LLL/GA Mirror, Westinghouse Tokomak) have shown that a great deal of existing fission reactor technology can be used in the hybrid reactor. Thus hybrids can provide an additional benefit to fusion development by serving as a test-bed, providing experience in developing and operating fusion components, and introducing fusion technology to the utilities in a gradual (5 - 10 fission reactors per hybrid) manner.

Implications of the Carter Energy Plan

A review of the details of the nuclear power portion of the Carter Energy Plan reveals the following specific proposals which impact the hybrid option.

(1) Pu Economy

- a. defer Pu recycle indefinitely,
- b. defer construction of the Clinch River Breeder Reactor,
- c. evaluate alternate breeders, fuel cycles and advanced converters.

(2) Domestic Nuclear Power

- a. expand U enrichment capacity,
- b. improve assessment of and exploration for U and Th resources,
- c. develop firm siting guidelines,
- d. streamline the licensing procedure,
- e. expand waste disposal R & D.

President Carter's decision against Pu recycle has no significant impact on the present competitive position of nuclear power, as Pu recycle will not have a strong economic advantage over the present (once through, enrichment U) LWR fuel cycle until high-grade uranium resources are exhausted (in the early 21st Century). This consideration argues in favor of continued studies for the U/Pu fuel cycle in hybrids, as the application is in a later time-frame than the Carter Energy Plan will impact. However, even paper studies of the Pu cycle may be considered unacceptable under the Carter Energy Plan. If this is the case, we have the option with the hybrid studies of supporting item 1c of the Carter plan, in particular, by examining the Th/U fuel cycle.

The proposals that deal with domestic nuclear power (items 2a - 2e) will serve to strengthen the short-term position of the nuclear industry by attacking the current difficulties that this program faces. Implimentation of these policies should promote growth in our nuclear power capacity and thus increase the probability that a long-term fissile fuel source would be desirable to protect this investment. Again, the hybrid

can contribute within the guidelines of the plan.

Rationale for Continued Hybrid Studies

Thorium and uranium represent long-term fuel resources if we choose to tap them, as it appears the rest of the industrialized world is preparing to do. The hybrid reactor is a means of accomplishing this end, with a wide variety of options available. We should continue to perform hybrid studies to assess the potential of this concept and to quantify comparisons with other energy options (coal, fast breeders, fusion, solar).

Hybrid studies should be a continuing and integral part of the fusion technology effort. At the present time, we have only a preliminary evaluation of the design details and the fuel cycle options. As our understanding of plasma physics and engineering improves, and as new confinement concepts are developed (such as the tandem and field-reversed mirrors), it is important to continually assess reactor performance implications. Failure to do so may result in the potential advantages of the hybrid option being lost by default.

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