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Personal views on hybrid reactors

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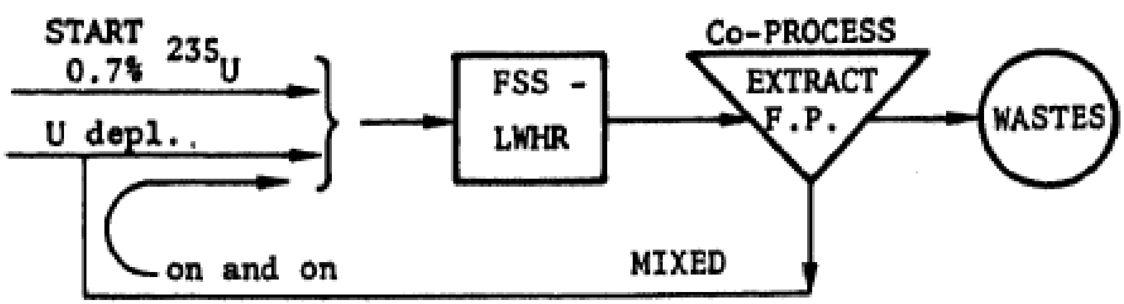
The objectives of this white paper, submitted to the Fusion-Fission Hydrid Workshop of September 30, 2009, is to express my views on the **preferred application for and approach to the design of hybrid reactors** and to inform the new generation of hybrid reactor researchers of the **hybrid reactor data base developed in the seventies and early eighties**.

On Hybrid Reactors

When I first became interested, in the mid seventies, in fusion-fission hybrid reactors I asked how one can make use of an intense source of neutrons to improve upon the performance of critical fission reactors so as to alleviate the difficulties faced by the nuclear energy economy. The primary difficulties perceived at that era included proliferation concerns and concerns about running out of economically recoverable uranium resources. Consequently the philosophy I have adopted for the design of an external neutron source-driven nuclear reactor system had the following ingredients:

- Breed when fuelled with natural or depleted uranium
- Be free from the need for uranium enrichment and for the separation of plutonium (or any other actinide)
- Be based on a proven fission reactor technology
- Have a high k_{eff} with relatively low equilibrium fissile fuel content

A schematic illustration of the preferred fusion-fission hybrid reactor energy system I came up with is illustrated below [1-6].



The fission blanket concepts examined used light-water or heavy-water for coolant-moderator and zircaloy clad solid fuel rods. Of the two moderators, light-water was found to offer a better neutron economy than heavy-water (as opposed to the case for critical reactors). The water-to-fuel volume fraction required to obtain a breeding ratio of 1.0 was found close to 2.0; smaller than in conventional PWR cores. The resulting Light Water Hybrid Reactor (LWHR) was conceived to be of a pressure-tube rather than a pressure-vessel design. The fuel was to be discharged as in critical PWRs but the reactivity was to be held nearly constant over the cycle by using lithium (tritium breeding) control and batch refueling as in conventional LWRs (on-line refueling, as commonly done in HWRs, could be another option). The average equilibrium blanket energy multiplication was calculated to be ~25. The fuel discharged from this LWHR was to be recycled using, yet not well defined process of fission products removal referred to in the figure as “Co-Process”; this process should not be able to partition plutonium or other weapons useable element. Natural uranium, depleted uranium or spent fuel from LWRs could be used for the makeup fuel. Fuel recycling was to proceed indefinitely so that the uranium ore utilization could approach 100% and the amount of plutonium and minor actinides to be disposed of would approach zero; a small fraction of the uranium and of the TRU would get into the waste streams during fission products extraction and fuel refabrication. A number of alternative design approaches were identified [1-6]; for example, by designing the fission blanket to have a water-to-fuel volume ratio of 1.0 the equilibrium fissile plutonium concentration becomes close to 3% and the corresponding blanket average energy multiplication would be significantly larger than 25. In summary, the LWHR concept offers a high utilization of the uranium resources with no doubling time limitation, with no need for enrichment and with no need for separation of plutonium while providing the highest possible fission energy generation per source neutron for reactors fuelled with natural uranium that feature low (less than ~1%) equilibrium fissile fuel content. My preferred approach to the use of fusion neutron sources for assisting the fission energy system is today the same, but my preferred embodiment is different.

The general design philosophy of the LIFE hybrid reactor concept recently proposed by LLNL shares many of the design philosophy elements of the LWHR concept. The primary difference is the LIFE requirement to fission most of the heavy metal loaded without any recycling or fission products removal. This is a great advantage that could possibly be realized by using TRISO-like fuel form in a soft neutron spectrum. The use of fuel in the form of pebbles is also advantageous as it enables to design the fission blanket to intercept a larger fraction of the fusion (and n,2n) neutrons, especially when the fusion neutron source is not of a linear geometry. The pebbles also provide flexibility in on-line fuel management.

Based on the above considerations and observations I am recommending pursuing the LIFE approach to fusion-fission hybrid reactors. In principle this approach could be realized using different fusion neutron sources. The most important technical issue to address, in my view, is the determination of the maximum burnup that TRISO-like fuel can withstand in the hybrid reactor environment. By TRISO-like I am referring to TRISO particles as well as other fuel forms that provide relatively large volume for fission products to accumulate and provide an outer barrier against fission products release that can withstand, up to very high burnups, the gaseous fission products pressure buildup as well as the radiation damage induced by the high neutron fluence. I think it is also important to perform system studies that will compare the economics, proliferation resistance, waste management, safety and resource utilization of energy systems based on LIFE-like reactors with alternative energy systems based on multi-recycling in critical fission-only reactors.

On Past Studies

Quite a number of hybrid reactor concepts have been proposed and analyzed and a lot of useful knowhow on hybrid reactor design and performance has been generated in the 70^{ies} and early 80^{ies}. As there was practically no hybrid R&D during the past couple of decades, hybrid reactor researchers that were not actively involved in the hybrid research of the seventies and eighties may find useful the compilation of information provided in the review of reference 7. Information compiled in the review of reference 8 could also be of interest to hybrid reactor researchers as many of the nuclear design considerations for fusion and hybrid reactors are similar.

References

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