Magnetic mirror fusion-fission early history and applicability to other systems

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Topics: Mirrors as drivers for hybrids, fission-suppressed breeders, role of U233 with U232, Q requirements on economics

In the mid 1970s to mid 1980s the mirror program was stuck with a concept, the Standard Mirror that was $Q{\approx}1$ where $Q=P_{fusion}/P_{injection}$. Heroic efforts were put into hybridizing thinking added energy and fuel sales would make a commercial product. At the same time the tokamak was thought to allow ignition and ultra-high Q values of 20 or even higher. There was an effort to use neutral beams to drive the tokamak just like the mirror machines were driven in which case the Q value plunged to a few, however this was thought to be achievable decades earlier than the high Q versions. Meanwhile current drive and other features of the tokamak have seen the projected Q values come down to the range of 10. Meanwhile the mirror program got Q enhancement into high gear and various tandem mirrors projected Q values up towards 10 and with advanced features over 10 with axi-symmetric magnets (See R. F. Post papers), however the experimental program is all but non-existent.

Meanwhile, the gas dynamic trap mirror system which is present day state-of-the –art can with low risk produce Q of ~0.1 useful for a low risk, low cost neutron source for materials development useful for the development of materials for all fusion concepts (see Simonen white paper: “A Physics-Based Strategy to Develop a Mirror Fusion-Fission Hybrid“ and D.D. Ryutov, “Axisymmetric MHD-stable mirror as a neutron source and a driver for a fusion-fission hybrid”).

Many early hybrid designs with multi-disciplinary teams were carried out in great detail for the mirror system with its axi-symmetric blanket modules. It is recognized that most of these designs are adaptable to tokamak or inertial fusion geometry. When Q is low (1 to 2) economics gives a large economic penalty for high recirculating power.

These early studies covered the three design types: Power production, fuel production and waste burning. All three had their place but power production fell away because every study showed fusion machines that were extensively studied by multidisciplinary teams came up with power costs much higher than for existing fission plants except in very large sizes (3 GWe). There was lots of work on waste burning—Ted Parrish—comes to mind. However, fuel production along with power production became nearly everyone’s goals. First, fast-fission blankets were favored but later to enhance safety, fission-suppressed blankets came into vogue. Both fuel producing and waste burning hybrid studies were terminated with the advent of accidents, high interest rates, rising “green like” movement and cheap natural gas for power production.

For waste burning and fast-fission fuel producing designs, the blanket energy multiplication was about 10 and economics was OK relative to recirculating power for Q over 2. For fission-suppressed fuel producers, where the blanket multiplication is under 2, the Q needed was over 5.

In the mirror program we came at this problem by trying to find a product for mirror fusion technology. We hoped we had a product and studied and promoted it. There was no market pull and when the mirror program collapsed in the US, so did both hybrid programs for mirrors and tokamaks and IFE by the mid 1980s. Today, the problem of what to do with wastes that were supposed to be accepted by the government appears to be a high value market pull. It remains to be shown if fusion neutrons can be generated at low enough cost so that economics will not be a showstopper. For burning only the minor actinides, the economics will be the most favorable. Burning the Pu as well will lower the number of fission reactors supported by each burner fusion machine and hurt economics of the system.

The fuel-producing role of fusion to fuel fission reactors remains an important possible use of fusion especially in the early stages of fusion development. It is not clear that burning fission wastes in a fusion machine is more appropriate than burning these wastes in specially designed fission machines. Fusion can produce U-233 along with over 2.4%U-232 making the material largely nonproliferating and this material can in effect add neutrons to a fission reactor that would otherwise be short of reactivity to burn wastes. Similar ideas apply to Pu production. Unlike enrichment, producing U-233 does not burden the system with lots of U-238 with its source of more actinide wastes. The idea is fission plants are already designed and proven to fission at impressive power density and safety whereas fusion machines will have a harder time showing workability with thin walls separating the awkward geometry of the high curie inventory from the vacuum chamber that will get lots of radiation damage.

For many early fusion-fission hybrid reports see:
http://www.geocities.com/rmoir2003/fusFisHyb.htm

R. W. Moir, et al., "Design of a Helium-Cooled Molten Salt Fusion Breeder", Fusion Technology, Vol. 8, No. 1 Part 2(A) 465 (1985). See website for Moir references: www.geocities.com/rmoir2003

R.W. Moir, “Recommendations for a restart of molten salt reactor development,” *Energy Conversion and Management* **49**(2008) 1849-1858.