Fusion-Fission Hybrids Driven By Heavy Ion Inertial Fusion

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There is a desire to resolve fuel cycle issues for increasing the role of nuclear energy. The recent Laser Inertial Fusion-Fission Energy (LIFE) initiative that builds upon NIF ignition, is likely to rekindle national interest in developing intense, high power ion beam accelerators for fusion energy production and for fusion-fission hybrid concepts that combine an ion beam driven fusion neutron source with a fission blanket.

While serving as a carbon-free energy source, hybrids offer the enormous potential benefit of transmuting the long-lived radioactive byproducts of fission-based nuclear reactors, thus dramatically reducing the nuclear waste problem. Systems with sufficiently efficient neutron sources to achieve deep or complete burn-up would eliminate the need for chemical separation reprocessing and make it possible to limit fuel shipments to non-weapons-usable materials, thus achieving a high level of proliferation resistance. In all inertial fusion energy (IFE) concepts, the driver and the reactor chamber are separate, which leads to savings in cost, improved access, ease of maintenance, and reduced concerns for safety and radiation contamination.

For ion-driven fusion, the choice of accelerator has very significant consequences for the achievable energy gain, burn-up and the overall design and efficacy of an ion-driven hybrid system. This is the right time to take a fresh, comprehensive look at the ion-beam energy options. <u>The advantages of heavy ion fusion</u> (HIF), identified in many past DOE reviews [1], still apply now:

- Accelerators with total beam energy of $\geq$ 1 MJ have separately exhibited intrinsic efficiencies, pulse repetition rates (>100 Hz), power levels (TW), and durability required for IFE.
- Thick-liquid protected target chambers are designed to have 30-year plant lifetimes. These designs are compatible with indirect-drive target illumination geometries, which will be tested in NIF experiments. Thick-liquid protection [2] with molten salt having high thermal and radiation stability (LiF-BeF_2, or flibe) has been a standard aspect of most HIF power plant concepts in the past ≈20 years.
- Focusing magnets for ion beams avoid most of the direct line-of-sight damage from target debris, neutron and γ radiation. Thus, only the final focusing magnet coils need to be hardened or shielded from the neutrons (diminished flux due to the thick liquid protection).
- Heavy ion fusion power plant studies have shown attractive economics and environmental characteristics (only class-C low level waste) [3]. Accelerator design efforts have converged on multiple heavy ion beams accelerated by induction acceleration. After acceleration to the final ion kinetic energy, the beams, which are non-relativistic, are compressed axially to the 4-30 ns duration, (few-hundred TW peak power) required by the target design. Simultaneously they are focused to a few millimeter spot on the fusion target.

<u>A research and development effort</u> culminating in a credible, integrated design for a HIF based hybrid prototype would include these topics:

- <u>Design fusion targets</u> that are able to give satisfactory yield and gain with lower driver beam energy. This will enable lower-cost drivers than for pure fission. Target designs aimed at pure HIF show total driver beam energy requirements as low as ≈2 MJ for indirect drive [4] and 0.5 MJ for direct drive [5].
- <u>Reactor design, neutronics, and radioactive material handling</u>: One objective is to attempt to preserve the significant advantage of thick liquid protection of the reactor chamber structural wall.

  - Can flowing liquid jets feasibly contain the fissile material? Dissolving the fissile material in the flowing jet of molten salt presents significant material handling challenges. Another way to introduce the fissile material to the flowing jets is to have it contained in TRISO pebbles. This mitigates the material handling issues, but presents significant hydraulic challenges that must be explored.
  - Alternatively, should the liquid jets be thinner, allowing a somewhat moderated (but not thermal) flux of neutrons to reach a fissile blanket behind a solid structural wall? Is this advantageous compared to a dry or wetted wall reactor design (no neutronics protection inside the first structural wall)?
- The design of lower-cost-driver accelerators for hybrids may be derived in many ways from existing pure-IFE concepts. However, the choice of final kinetic energy, ion species, ion acceleration schedule and transverse beam focusing architecture will depend on primarily the target design. Thus, an accelerator research program would include beam physics modeling, smaller-scale experiments, and system studies. The near-term objective this program would be the design of two facilities:
  - A prototype experimental facility, capable of doing hybrid-relevant fusion target experiments at >100 eV, integrated with all key ion beam manipulations.
  - A demonstration power plant design.

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