Inertial Fusion Energy program within OFES

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Inertial Fusion is being supported by the NNSA for weapon physics and, although net gain has not yet been attained, significant progress has been made. National Ignition Facility (NIF) capsules have attained fusion gain within the fuel. MagLIF[1,2], which is presently being studied at the Z facility, has demonstrated the basic principles of Magneto-Inertial Fusion (MIF), which may provide an alternative path to fusion. Despite these successes there is presently no effort to determine if inertial fusion can be used to generate electrical energy. It would be prudent to have a small program directed to the application of inertial fusion for energy (IFE). This program would not have the same goals as the NNSA and should thus be funded by OFES.

The generation of useful energy requires a minimum fusion gain that depends on the efficiency of the driver, ε_D, the conversion efficiency to electricity, ε_C, and the maximum acceptable recirculated power, R_P.

$$G > (\varepsilon_D \varepsilon_C R_P)^{-1}$$

Steam driven turbines can obtain efficiencies of about 40%, and the maximum recirculating power is about 25% so the minimum gain is $10/\varepsilon_D$. The NIF laser stores 400 MJ and delivers 2 MJ to the target, with an efficiency of 0.5%, so a minimum gain of 2000 would be required. Although very expensive, diode pumped lasers could have efficiencies of 10% and would require a more modest gain of 100. The Z Machine, which stores 22 MJ and can deliver 1-2 MJ depending on the load, has an efficiency of 5-10%. Thus, a gain of 100-200 would be required. Clearly high gain is required for these systems to be viable for IFE.

The efficiency of pulsed power can be increased by using longer pulses, but probably not higher than about 30%, which would still require a gain of at least 30 and the energy required to drive fusion explosion increases with the implosion time[3]. Long implosion time schemes have been proposed based on MIF concepts. As an example, it has been proposed[4-7] to use imploding liners to compress Field Reversed Configurations (FRCs), which are plasmas confined by closed magnetic field lines. Note that FRCs, which were originally developed as magnetic confinement fusion systems[8], can be self-sustaining for tens of μs, which would allow time for compression by either a metal liner or plasma jets. FRCs could be formed and imploded at the Z facility using the AutoMag liner concept[9]. We have been

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developing an analytic model of the liner compression of FRCs to determine what fusion gains could be expected. The initial results indicate that gains of ~20 could be possible so this approach shouldn't be ruled out. However, simulations indicate[10,11] that MagLIF with a frozen layer of DT on the inside of the liner might produce gains approach 1000 and thus seems more promising.

The cost effective and repeated delivery of the required current to a MagLIF liner is a significant challenge. Pulsed power machines, such as Z, transport and temporally compress electrical power first with capacitors and transmission lines insulated with dielectric materials (e.g. plastic, oil, or water) and then with self-magnetically insulated transmission lines referred to as MITLs, which are vacuum pumped to a pressure of about 10^{-5} Torr. The transition is accomplished with a stack of plastic rings designed to withstand the high voltage. Inside this "stack", the Z machine uses four levels of MITLs that are connected in parallel by a post-hole convolute to a single final feed at a radius of about 6 cm. The entire assembly with an outer radius of 1.7 m weighs about 10 tons. If such an assembly were used in a fusion reactor, the central portion would sustain significant damage after each explosion, which could have yields approaching 10 GJ (~2.5 tons of high explosive). The cost of replacing (or recycling) that much metal (probably steel) would exceed the value of the energy created. A promising approach is to design the MITLs to have a much lower mass and recycle the material. Studies[12], indicate that such recyclable transmission lines (RTLs) could have masses of 20-100 kg. IFE funding would make it possible to test low mass RTLs with the existing Z machine.

Laser driven IFE schemes[12] have been proposed with 100-400 MJ yield capsules, which require the time between explosions to be 0.1-0.4 seconds to provide a GW thermal power typical of large power plants. The reactor chamber must be brought down to low enough pressure to allow the propagation of the laser beams in the relatively short time. The large yields possible with MagLIF (~10 GJ) increase the time between explosions to about 10 seconds, but this is still a short time to pump the RTL to the desired vacuum pressure. A solution to this problem is to prepump the RTLs before insertion into the reactor chamber and connection to the stack. After the explosion the stack must be closed off from the debris to avoid damage and maintain vacuum in the region adjacent to the stack. Using this approach there would be no stringent requirements on the pressure within the reactor chamber. IFE funding would allow valves to be designed and tested to accomplish this process.

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