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A SELF-SUSTAINING NUCLEAR PUMPED LASER-FUSION REACTOR EXPERIMENT

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A major impediment to scaling up current laser-fusion hardware to the commerical power reactor level is the inefficiency of the electrically pumped laser system and the large recirculating energies that this entails.[1] A possible solution to the problem is the use of neutron feedback nuclear pumped (NFNP) lasers which do not require the recirculation of energy.[2] We have studied the features of a NFNP laser-fusion reactor experiment with the intention of establishing the feasibility of the concept. Such an experiment could represent the next step, after the achievement of breakeven, towards the development of commercial laser-fusion reactors.

In Figure 1 the NFNP laser-fusion concept is compared schematically to electrically pumped laser-fusion. It can be seen that nuclear pumping avoids several of the inefficient energy conversion steps required for electrical pumping. The fact that the pump energy comes uniformly from within the laser medium rather than being beamed in from the outside provides nuclear pumped lasers with another substantial advantage, especially for large apertures.

Referring again to Figure 1, several requirements must be met for the NFNP laser-fusion scheme to succeed. First, the laser must produce a pulse powerful enough to compress the pellet to ignition. Next, the pellet burn must produce (a) substantially more energy than is deposited by the laser pulse and (b) enough neutrons to cause sufficient fission reactions in the laser medium after propagating through the moderator (neutronic self-sufficiency). Finally, as shown in Figure 2, the sum of the neutron propagation delay in the moderator and the energy storage time in the laser system must equal the time between pellet implosions.

The NFNP laser-fusion concept, as described above, represents a hybrid fusion-fission system in which the gaseous medium of the nuclear pumped laser takes the place of the usual solid fission blanket. Using the standard definitions of pellet gain, Q_p; blanket multiplication, M_B; and total laser efficiency, η_L;[3] the required efficiency of the nuclear pumped laser is

$$\eta_L \geq \frac{1}{Q_p(M_B-1)} \quad .$$

For example, for a system with a pellet gain of 50 and equal energy released from fission and fusion, $M_B = 2$, the required laser efficiency would be 2%.

A NFNP laser-fusion reactor utilizing the XeF* excimer laser, pumped by fissioning ^{235}U contained in the laser medium as UF_6,[4] has the potential of meeting the requirements described above. The XeF* laser is currently the subject of nuclear pumping experiments at the University of Illinois and preliminary results indicate the existence of gain.[5] Efficiencies for conversion of electron energy to laser energy of 3% have been obtained with electrical pumping of XeF*[6] and nuclear pumping efficiencies should be similar.

Neutronic self-sufficiency requires that the largest possible fraction of the fusion neutrons reach the nuclear pumped laser. Our calculations show that self-sufficiency can be achieved by using a helium cooled graphite moderator, by positioning the tritium breeding blanket outside the nuclear pumped laser, and by using D-D-T pellets[7] which maximize neutron production and minimize tritium breeding requirements.

The most critical requirement is for a delay time to allow neutron feedback. Since the propagation delay in the moderator will be only about 3 ms,[8] and the majority of laser-fusion schemes envision 10-1000 ms between implosions, most of the delay must be provided by energy storage in the laser system. Two approaches to the energy storage problem are currently being considered. The first would store energy in long-lived states in the nuclear pumped laser. Energy storage times of up to 5 ms have been demonstrated by the recently discovered nuclear pumped 1.45 μ atomic carbon laser in He-CO_2.[9] The second would utilize the nuclear pumped laser as a photolytic driver for a Group VI laser. Group VI lasers, though not experimentally demonstrated, could be effective storage devices since the upper laser levels are metastable states with lifetimes of .1-15 sec.[10]

In conclusion, our study has shown that, once a method of energy storage has been demonstrated, a self-sustaining fusion-fission hybrid reactor with a "blanket multiplication" of two would be feasible using nuclear pumped XeF* excimer lasers having efficiencies of 1-2% and D-D-T pellets with gains of 50-100.

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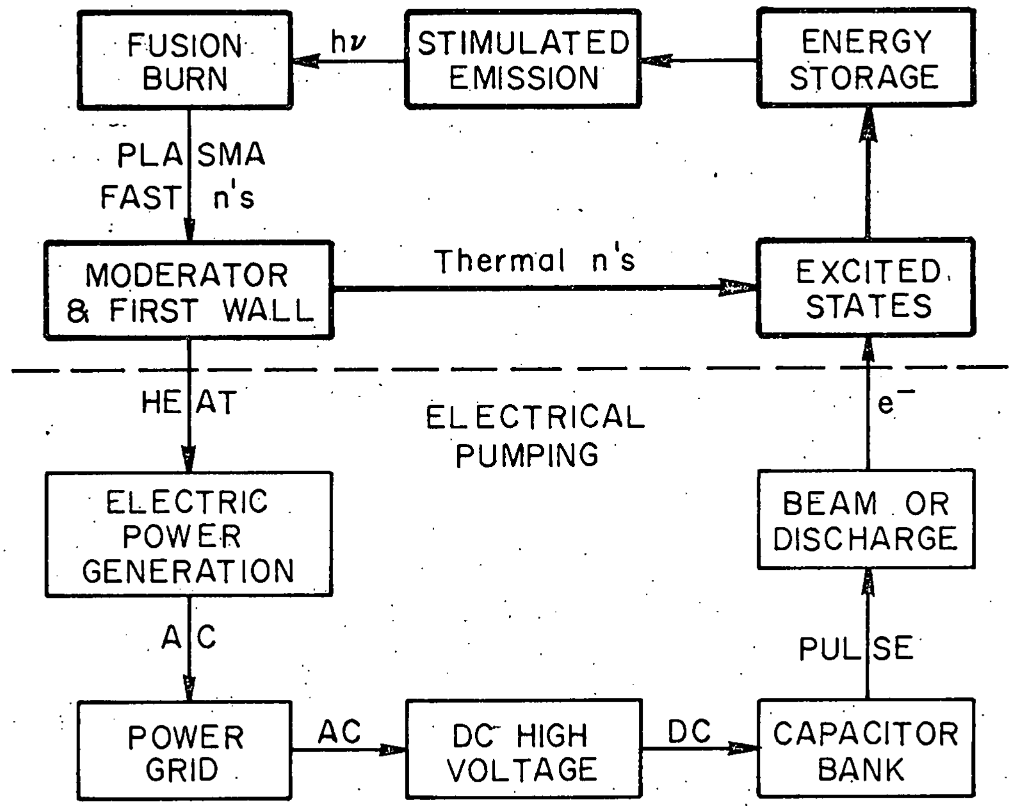

Figure 1. Comparison of nuclear and electrically pumped laser fusion concepts. Additional steps required for electrical pumping are shown below the dashed line.

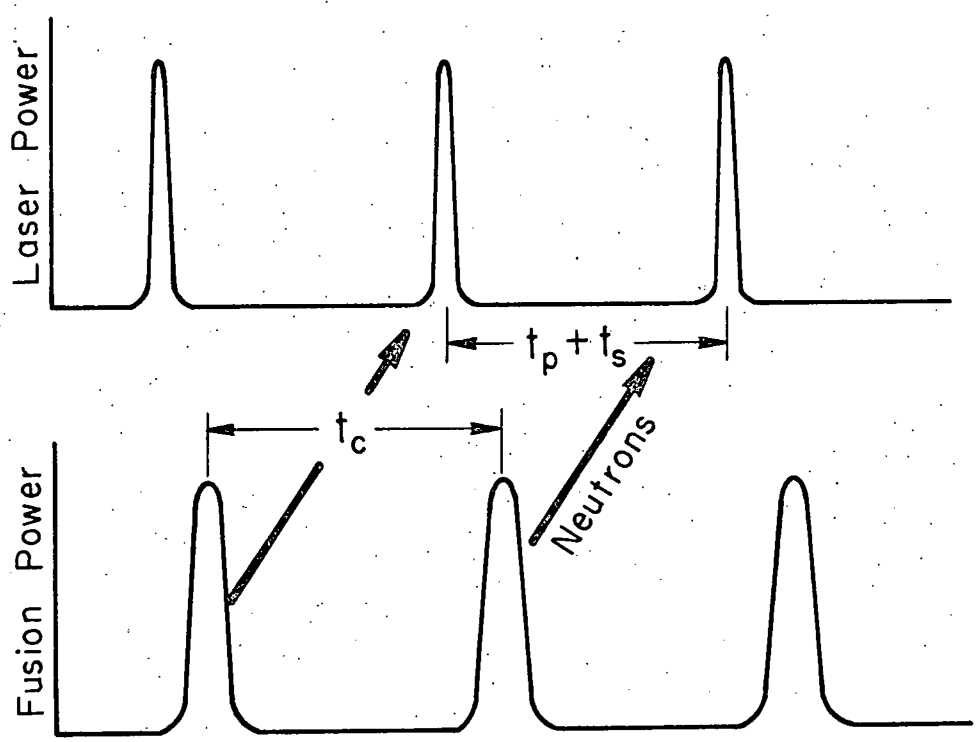

Figure 2. Timing of fusion laser pulse and pellet burn. For neutron feedback nuclear pumping $t_{propagation} + t_{storage} = t_{cycle}$.