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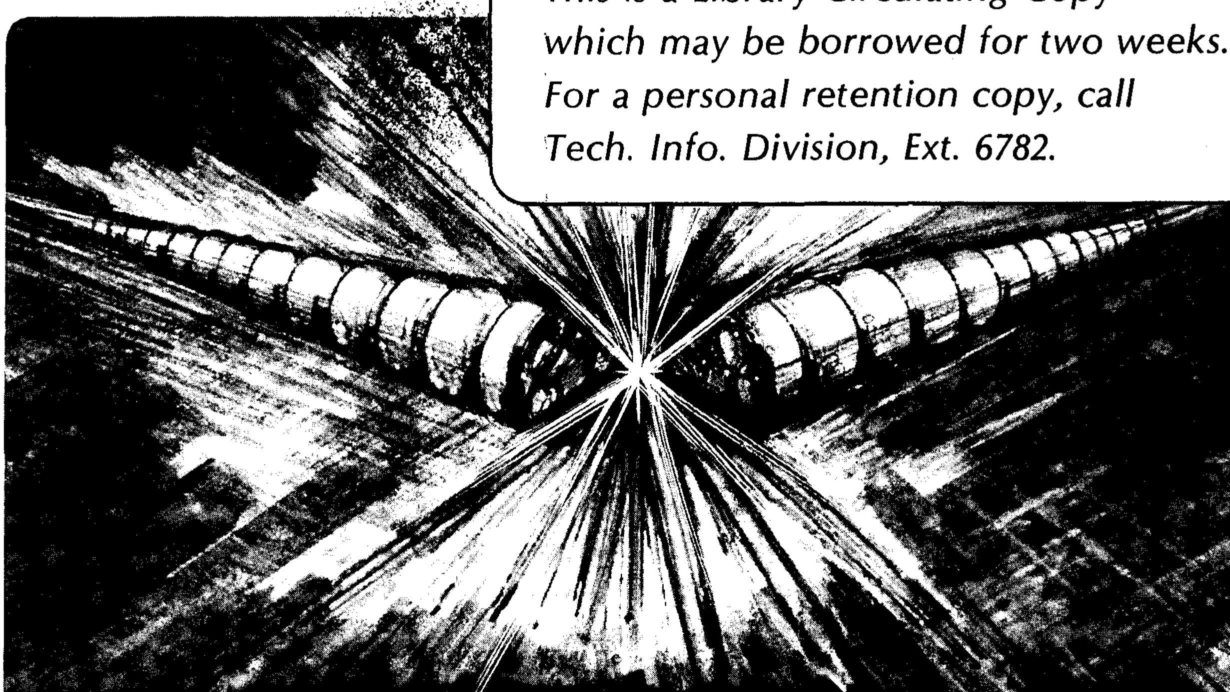

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Heavy Ion Accelerators as Drivers for Inertial Confinement Fusion*

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An aspect of the inertial confinement approach to fusion is that the problems of a practical fusion power plant are simplified by the separation of the driver from the reactor vessel. Amongst the candidates for a power plant driver an accelerator of intense beams of heavy ions seems closest to meeting the engineering and economic requirements of power production.

Economic feasibility demands that the recirculating power supplied to the driver be less than about 30% of the total power produced. Assuming thermal to electric conversion at 33% efficiency this requires a product of driver efficiency times target gain of ten or more. If the driver efficiency is less than about 10%, complicated high-gain pellets and high driver beam energies are required. Ion accelerators however, can achieve efficiencies between 10 and 25%, satisfying this economy criterion with low gain pellets and allowing power plants to be smaller, involving drivers of energies around 3-4 MJ.

Accelerators meet a second essential requirement in that they are intrinsically high repetition rate devices. A 25% efficient driver delivering 4 MJ 25 times per second would produce 1-2 GWe of net power.

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The engineering problems of a reactor are greatly alleviated by use of frequent smaller yield shots. It may be possible to use reactor vessels whose size and power density is comparable to that of a typical fission reactor.

Heavy ions have efficient and straightforward collisional mechanisms by which they give up their kinetic energy to the outer target shell. As the deposition layer becomes ionized there is no fundamental change in the beam-target coupling mechanism. The required ion range ($\approx$ .2 mm) corresponds to high ion kinetic energies (10 GeV) for heavy ions (A = 200) so that smaller ion currents are required to carry the beam energy ($\approx$ 4 MJ) compared, for example, with the high currents required from light ion diodes.

Table 1 shows typical heavy ion driver parameters. The flux of ions would be divided into about 20 beams for final focus. This also ensures uniform illumination of the pellet.

Table I TYPICAL BEAM PARAMETERS

Ion Mass	A $\approx$ 200
Kinetic Energy	10 GeV
Beam Energy	4 MJ
Peak Beam Power	200 TW
Pulse Length	40 ns
Beam Spot Radius	2–3 mm
Number of Beams	~ 20
Peak Particle Current per beam	~ 1 kA
Normalized Emittance	20 πmm-mrad
(10 cm radius lens, 10 m away)	

U.S. sponsored research in pursuit of a heavy ion fusion driver[1) involves the development of linear induction accelerator technology for heavy ions. The ion beams will pass through a series of induction modules, in each of which the beam current behaves like a single turn secondary winding of a transformer, picking up energy from large currents switched into the primary windings as the beam passes. Suitably shaped accelerating voltages will accelerate the tail of the beam pulse more than the the head so that an initially long (50 μs), low current ($\approx$ 6A) pulse becomes a short (40 ns), high current ($\approx$ 20 kA) pulse at the pellet.

Induction linacs are well suited to accelerating intense beams in the multi-kilo-amp range. High current electron beams have been accelerated by this technique at LLNL, LBL and NBS in the U.S.A. and at other laboratories in the U.S.S.R. A heavy ion fusion induction linac will accelerate multiple beams of heavy ions simultaneously. The number of ion sources will be equal to the number of beams finally incident on the target. Acceleration of heavy ions (Cs^+) with an induction device was recently achieved at Lawrence Berkeley Laboratory[2).

A second approach to heavy ion driver development involves the application of conventional RF accelerator and storage ring technology, which has been developed over the last twenty years for research in high energy and nuclear physics. A design study of such a driver forms part of the comprehensive HIBALL[3) heavy ion fusion power plant scenario. Beams of Bi^+ from 32 ion sources are accelerated and combined pairwise into a single RF linac for acceleration to 10 GeV, then split into storage rings for current amplification. The technology for such a machine is available today. The scheme may suffer from beam physics problems; the high beam currents in the storage rings may cause growth of instabilities which would limit the storage time. Also, the many operations of beam joining and splitting may cause transverse emittance growth which could ultimately spoil the final focus.

The final focussing of heavy ion beams to the pellet is most easily achieved with conventional focussing magnets outside the reactor vessel. Assuming a liquid lithium first wall, one requires rapid re-condensation of the metal vapor between shots to allow the next beam pulse to focus correctly. This question has been addressed as part of the HIBALL study. Reactor vessels ten meters in diameter are expected to achieve a 5 Hz repetition rate, so that four such chambers would be served sequentially by a 20 Hz driver.

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