An Integrated Research Experiment (IRE) for Heavy Ion Fusion

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The goal of the performance extension phase of the IFE program is to develop the knowledge base, that, together with the results from the National Ignition Facility and other defense research programs, will provide the basis for fusion energy development. In particular, this phase of the program will provide the basis for the construction of an Engineering Test Facility. The Integrated Research Experiment (IRE) is the centerpiece of the performance extension phase. Research on target design, target fabrication, target injection and tracking, and chamber science and engineering are also important parts of the performance extension phase of the program, and they were discussed in various IFE and technology working group sessions at Snowmass. This summary discusses only plans for an IRE to investigate the remaining issues in an integrated driver system.

The IRE has two main functions: It must convincingly demonstrate that heavy ion accelerators are viable IFE drivers, and it should also be a flexible research facility to enable the exploration of advanced concepts. Simply stated, the two functions of an IRE for HIF are validation and improvement.

First consider validation. Any IRE must demonstrate driver science in addition to reliability, long life, repetition rate, efficiency, good economics, and good beam-target coupling. In this regard, it is important to emphasize that an IRE is not a nuclear facility. It is not proposed that an IRE will produce ignition or high target gain, though it should be able to test some issues related to the prepulse of full-scale HIF targets. For an HIF driver, the main scientific issue is preservation of high beam quality (focusability) in the accelerator and target chamber (at full scale in the presence of “dirty” physics issues associated with non-ideal machine effects resulting from particle loss, electrons, focusing and accelerating field errors, etc.). The IRE will address driver/chamber interface issues (e.g., beam propagation in a simulated post-shot environment) and enable a wide range of chamber transport experiments, including tests to hit targets in flight.

Now consider improvement. Numerous previous studies, e.g., HIBALL, Prometheus-H, Osiris, and HYLIFE II, have indicated that HIF can produce energy at competitive rates. Nevertheless, improvement is a principal focus of the HIF program. For many years, unneutralized ballistic transport in the target chamber has been the baseline for heavy ion fusion because the physics uncertainties are minimal. Neutralized ballistic transport allows the use of ions with a wider range of kinetic energies and may lead to improved economics. Channel transport, a speculative option, requires only very small entrance ports into the chamber. If channel transport is possible, it would simplify issues associated with neutronics and the shielding of the final focusing magnets. For these reasons, the IRE should allow the exploration of these more uncertain modes of transport.

Indirectly driven targets are considered the mainline approach for HIF because they allow two-sided illumination, an illumination geometry that is compatible with thick liquid wall chambers. Moreover, most of the target physics will be established on the NIF and elsewhere. Other target options such as direct drive, perhaps even aspherical direct drive, may offer higher target gain and/or lower driver energy. There has been almost no experimental work on these concepts for HIF. Ideally, the IRE would allow one to study issues such as stability and uniformity for a wide class of targets.

The necessary and desired goals of an IRE can be translated into IRE beam parameters. To validate the beam-target interaction physics, one would like the beam plasma frequency and target conditions to be close to driver values. How close is a matter of judgement and involves tradeoffs between cost and performance. Multi kilojoules of energy with a focused intensity greater than 3 TW/cm^2 appears adequate. Definitive experiments on a variety of focusing modes require ion kinetic energies exceeding 100 MeV and beam currents exceeding 100 A per beam at the final focus system. Demonstrating preservation of good beam quality in the accelerator requires total currents (sum of all beams) exceeding 100 A and hundreds of lattice periods of focusing. In summary, the beam parameters of an IRE are already reasonably well known. On the other hand, the detailed design and cost of an IRE are not yet known. Designing an IRE and determining its cost are the main goals of the proof-of-principle phase of the program. This phase of the program is expected to require at least 4 years.

It would not be prudent to build an IRE based on present knowledge. During the next few years, we plan to perform high current transport experiments with a single beam at driver scale (also IRE scale, since the IRE will have driver-scale beams). This experiment will improve our understanding of transport at full driver scale in the presence of non-scalable effects (e.g., halo), thereby giving high confidence that an IRE will work as designed. The beam emerging from this high current transport experiment will enable compression and focusing experiments that, in relevant parameters, are roughly midway (geometric mean) between our present scaled experiments and a driver (or IRE). The next phase of the program will also include detailed end-to-end (ion source to target) numerical simulation of both drivers and the IRE. It will also include a technology development program to reduce costs to values approaching those required for economical power production.

By way of summary, some of the goals of the various phases of the program are shown in Table I. A schematic of a possible IRE configuration is shown in Fig. 1.

Table I. HIF driver development goals for current research (Phase-I), the IRE, and a power plant driver.

	NOW	Phase I Goals	IRE	Power Plant
Beam Experiments	~10 mA ~1 MeV Correct dimensionless parameters; Brightness exceeds power plant requirement	~1 A 1-10 MeV Preserve brightness exceeding power plant requirement	~1 A/beam[a] > 100 MeV Preserve brightness exceeding power plant requirement.	~1 A/beam[a] > 1 GeV Adequate brightness.
Injector	1 A, 1 beam	~1 A/beam, Multi-beam module	~1 A/beam, Multi-beam injector	~1 A/beam, Multi-beam injector
Technology: **Quadrupole arrays** **Insulators** **Energy Storage** **Switches** **Magnetic Cores**	 Preliminary design ~ \$0.10/V \$10-30/J $\$10^{-5}$/W \$18/kg	 ≤ \$10/kA•m[b] \$0.01/V[c] \$3-10/J $\$10^{-5}$/W \$5-10/kg	 ≤ \$10/kA•m[b] \$0.01/V \$3-10/J $\$10^{-5}$/W \$5-10/kg	 ≤ \$10/kA•m[b] \$0.01/V \$1-5/J $\$3\times10^{-6}$/W \$5/kg

[a] At the beginning of the machine. Current increases with increasing kinetic energy.
[b] Cost of quadrupole arrays per kA•m of superconductor
[c] The order of magnitude reduction in cost between the first and second column requires the production of large cast insulators rather than the brazed alumina currently used.

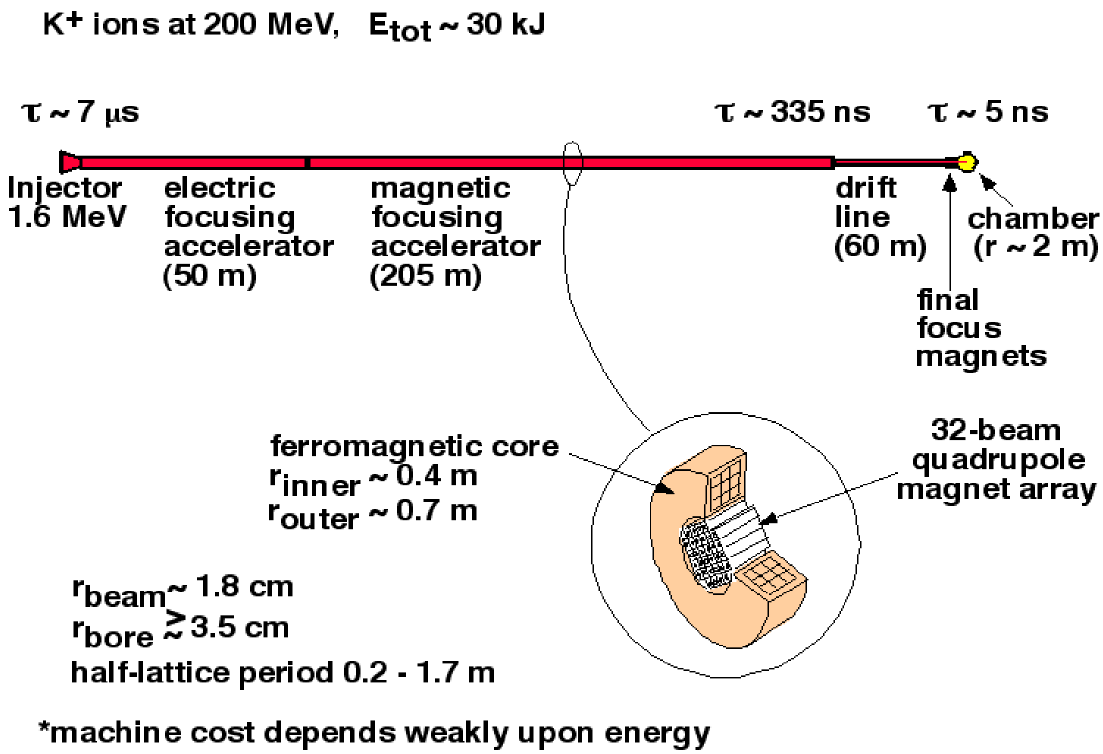

Fig. 1. Schematic of a possible IRE for HIF. We are exploring options producing from 30 to 300 kJ.