June 14, 2011

Executive summary of the Workshop on Accelerators for Heavy Ion Fusion

May 23-26, 2011
Lawrence Berkeley National Laboratory

The National Ignition Facility has commenced its campaign of ignition experiments. These are stimulating interest in inertial fusion energy systems, including Heavy Ion Fusion (HIF). The purpose of the Workshop was to review the status of HIF research, and to identify the most promising areas of research.

We had participants from many laboratories, universities and companies: BNL, FNAL, GSI (Germany), LANL, LBNL, LLNL, ORNL, PSFC/MIT, MSU, PPPL, Univ. of Maryland, Technischen Universität Darmstadt (Germany), Utsunomiya Univ., (Japan), Fusion Power Corp., Vallecitos Molten Salt Research, and Voss Scientific.

A total of 68 participants, many from labs outside of the traditional HIF research collaborations, helped us grow the community. Plenary sessions were held on Monday May 23, and Thursday May 26. There were five working groups, which convened on May 24 and 25: IFE targets, RF approach to HIF, induction accelerator approach to HIF, chamber and driver interface, ion sources and injectors. The workshop was supported in part by the Heavy Ion Fusion Sciences Virtual National Laboratory, the DOE OFES, and DOE HEP.

International participants in the workshop expressed strong support for collaboration on heavy ion fusion research. There are opportunities for and interest in experimental collaboration on beam physics and accelerator research at LBNL, UMER, GSI, LANL, BNL, FNAL, ORNL, ITEP, KEK and elsewhere.

The unifying motivations and major challenges for further research into HIF have been noted by various high level reviews:

- Heavy ions of mass ~100 amu and ion kinetic energy ≥ 1 GeV have a stopping range suitable to drive IFE targets with yield >100 MJ and gain >50.
- A heavy-ion driver must deliver 1–10 MJ of energy, properly shaped, at a peak power ≥100 TW at ~10 Hz.
- Near the source and near the target multiple beams are desired for physics reasons. For the induction linac approach, multiple beams are desired for economic reasons. Because of the high charge per bunch, the adopted approach is to accelerate a longer bunch and then compress it to the short length required at the target.
- The beams' quality and alignment must be such that they can be focused onto the target to a radius of a few millimeters from a distance of several meters.
- Limitations due to space charge, emittance growth, beam-gas, and beam-plasma interactions must be sufficiently controlled throughout the driver.
- Nuclear and high energy physics accelerators, with total beam energy of ≥ 1 MJ have separately exhibited intrinsic efficiencies, pulse repetition rates (>100 Hz), power levels (TW), and durability required for HIF.

- Final focus elements can be protected from the energetic particles and X-rays produced by the fusion target.

The range of HIF target design simulations has broadened:

- A number of promising examples of HIF targets were reviewed, ranging from targets closely resembling NIF targets, to shock- and fast-ignition. All the targets deserve increased attention.
- The target work requires iteration among other elements of the power plant (e.g. chamber and accelerator).

Recent advances in accelerator science were discussed along with the potential impact on HIF. The three main types of heavy ion drivers are synchrotrons, RF and induction linacs with multiple beams. Noteworthy advances include:

- Large heavy ion accelerator facilities are operating with high availability and reliability, for example: The Large Hadron Collider (LHC, CERN), Gesellschaft für Schwerionenforschung (Germany), RIKEN Accelerator Research Facility (Japan), and the Relativistic Heavy Ion Collider (RHIC, BNL).
- Higher fields have been demonstrated in superconducting magnets. The operating range has doubled.
- Developments in control systems and diagnostics for high-intensity accelerators.
- The ability to simulate complex beam and target systems has improved dramatically. Simulation codes have been validated on a range of accelerators and basic science experiments.
- Driver scale ion sources with adequate beam parameters have been demonstrated for single beams. High charge state ions have potential advantages and should be further explored.

The chamber and chamber-driver interface is uniquely challenging for accelerator design:

- Multi-disciplinary, integrated chamber-driver interface R&D has shown encouraging results from both experiments and modeling. This effort must resume.
- Target injection has been demonstrated with surrogate plastic targets.
- There has been progress in the compatibility of the chamber design with the accelerator, for example, by reducing the solid angle subtended by the beams.
- One-sided illumination of the target would simplify the accelerator requirements.

The participants see opportunities for collaboration, and expressed interest in a follow-up workshop to address key issues in greater detail. Each working group has summarized its findings in reports.

Peter Seidl (LBNL) Organizing Committee (chair)
John Barnard (LLNL) IFE Targets working group chairman, Organizing Committee
Robert Garnett (LANL) RF accelerators working group chairman
Igor Kaganovich (PPPL) Chamber and Driver working group chairman
Joe Kwan (LBNL) Ion sources and injector working group co-chair
Grant Logan (LBNL) Director, Heavy Ion Fusion Sciences Virtual National Laboratory
Ralph Moir (Vallecitos Molten Salt Research) Chamber and Driver working group chairman
Subrata Nath (LANL) Induction Accelerators working group chairman
John Perkins (LLNL) IFE Targets working group chairman
Martin Stockli (ORNL) Ion sources and injector working group chairman