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White Paper on Ion Beam Transport for ICF:

Issues, R&D Needs, and Tri-Lab Plans

C. Olson (SNL), E. Lee (LBNL), B. Langdon (LLNL)

November 16, 1995

1.0 Introduction

There is considerable interest in coordinating research on all types of ion drivers for inertial confinement fusion (ICF). Presently, light ion fusion (LIF) research in the USA is primarily concentrated at Sandia National Laboratories (SNL), and is funded by DOE Defense Programs (DP). Heavy ion fusion (HIF) research in the USA is primarily concentrated at Lawrence Berkeley National Laboratory (LBNL) and Lawrence Livermore National Laboratory (LLNL), and is funded by DOE Energy Research (ER). In addition, there is the conceptual possibility of an ion driver using a middle-weight ion. A Tri-Laboratory (LLNL, LBNL, SNL) meeting supported by ICF Program Managers Mike Campbell (LLNL), Roger Bangerter (LBNL), and Jeff Quintenz (SNL), and organized by Grant Logan (LLNL), was held on February 8, 1994 in Livermore, California. The purpose of the meeting was to enhance cooperation between the HIF and LIF programs for mutual benefit, and to consider the possibility of a middle-weight ion driver that could be used for a combined Laboratory Microfusion Facility (LMF)/Engineering Test Facility (ETF). Results of this meeting were reported in a Tri-Lab letter to Marshall Sluyter (DOE DP) and David Crandall (DOE ER) on February 11, 1994 (copy included in Appendix). One result of this meeting was the recommendation that working groups be formed in the areas of ion beam transport, targets, and accelerator concepts. The transport group, co-chaired by Craig Olson (SNL), Ed Lee (LBNL), and Bruce Langdon (LLNL) was commissioned to begin, since it was felt that the greatest commonality between LIF and HIF appeared to be in the area of ion beam transport. It was envisioned that the transport working would ultimately overlap and interact strongly with the target working group and the accelerator concepts working group.

The Tri-Lab Transport Working Group met at LBNL in Berkeley, California on June 5, 1994, and determined that a useful method for assessing ion beam transport would be to hold an informal workshop. As a result, the Workshop on Ion Beam Transport for a Common Ion Driver was held at SNL in Albuquerque, New Mexico on September 20-21, 1994. A total of 32 people attended, with representatives from SNL, LBNL, LLNL, NRL, MRC, University of Wisconsin, UNM, and DOE. It was expected that several transport modes, and especially self-pinched transport, would be of interest for all ions. Advantages and disadvantages of each concept were discussed, and comments about relevance toward a common ion were encouraged. The workshop proceedings were assembled into a large report (SAND95-0116, UC-712) and distributed. The conclusions of this workshop are reproduced here in Table 1. Notice that no clear optimum was detected for any particular middle-weight ion transport scheme. This means that HIF and LIF transport research complement each other and accordingly have many common concerns and development needs. In particular, self-pinched transport was recognized as being very attractive for all ions, if feasibility can be demonstrated.

The Tri-Lab Working Group met again at LBNL on February 17, 1995. The purpose of this meeting was to foster further cooperation between the HIF and LIF transport areas, and to begin preparation of this white paper on ion beam transport. Specific topics discussed included:

Table 1. Ion Beam Transport Workshop Conclusions

- There is an excellent commonality in the physics of transport for LIF and HIF. Workers in both HIF and LIF have already worked together, and they share a vision of increased cooperation. A synergy between HIF and LIF exists, and it should continue to be nurtured.

- Certain LIF and HIF transport schemes will be useful for all ions. In particular, self-pinched transport looks very attractive for LIF, HIF, and a common ion. It should be noted that no resonance was detected for any particular middle-weight ion or any particular middle-weight ion transport scheme.

- Experiments to demonstrate self-pinched transport should be performed on SABRE or GAMBLE II. The results should be of great importance for LIF, HIF, and a common ion driver.

- Charge-neutralized transport is important for HIF, common ion driver schemes, and possibly LIF. Research should continue in all of these areas, and neutralized transport experiments should be performed on ILSE and LIF machines.

- Code development (IPROP, WARP 3D, BICrz, QUICKSILVER, BUCKSHOT, MFOCUS, etc.) and cross utilization of codes (LIF codes for HIF problems, and vice-versa) should be encouraged.

- Channel issues should be resolved so that an allowed range of channel radii for HIF and LIF can be justified.

- Accurate atomic physics cross sections (impact ionization, stripping, recombination, etc.) are needed for all ions.

- A common ion target might involve concepts somewhere between the traditional HIF two spot irradiator targets and LIF spherical targets. No consensus could be reached for a target spot-size parameter range because of the variety of possibilities. This issue should be of prime concern for the target working group.

- A common ion accelerator might presumably involve a new technology somewhere between present accelerator concepts for LIF and HIF. However, no consensus was reached as to what middle-weight ion parameters might be ($20 < A < 50?$), or if a multi-gap accelerator with charge neutralization is required. This issue should be of prime concern for the accelerator concepts working group.

Ion Beam Transport Issues
Research and Development Needs
Plans and Priorities for each Laboratory

This white paper is a result of that meeting and subsequent discussions.

In the following, we discuss ion beam transport issues (Section 2), ion beam transport R&D needs (Section 3), and complementary laboratory plans and priorities (Section 4).

2.0 Ion Beam Transport Issues

The Tri-Lab Transport Working Group has developed a working list of specific ion beam transport issues. This relatively comprehensive list is summarized in Table 2. The value of this listing is that it is a concise summary of issues affecting all ions (light ions, heavy ions, middle-weight ions). The main research areas of gas breakdown, self-pinched transport, charge-neutralized transport, pre-formed channels, and stability are all clearly important for both near-term and long-term development of the LIF and HIF programs. These beam transport issues and their resolution will have an important impact on ion target design and performance, as well as on the design of suitable chambers.

3.0 Ion Beam Transport R&D Needs

To address the list of issues given in Table 2 requires substantial research and development. This includes development of experimental facilities with high-quality, high-intensity beams; diagnostic development; small-scale experiments; code development; atomic physics calculations; and analytical theory developments. A summary of these R&D needs is given in Table 3.

4.0 Laboratory Plans and Priorities

The research and development needs of Table 3 must be developed to address specific ion beam transport issues in Table 2. Each laboratory has specific research plans and priorities to address certain issues. In the following, these plans are discussed for LBNL, LLNL, and SNL. Note how each laboratory's plans complement those of the other laboratories.

4.1 LBNL Ion Beam Transport Plans and Priorities

Most heavy ion fusion transport studies have been aimed at commercial power production, rather than near-term fusion experiments. Therefore, the final focusing

Table 2. Ion Beam Transport Issues

(1) Gas breakdown
- charge neutralization (residual ϕ)
- current neutralization (residual I_{net})
- electrical conductivity σ (t)
- cross sections
- validity of electron models for small radius, intense beams
- faster running codes

(2) Self-pinched transport
- simulations (IPROP, MFOCUS)
- experimental demonstration
- feed-in (cones, lens, etc.); matching to transport channel
- wall guiding (halo, bends, image forces)
- bends for small radius beams; B_{ext} or $B_{solenoid}$ needed?
- stability; need simple overview for hose, sausage, etc.
- self-pinched transport in containment vessel ($R \rightarrow \infty$)

(3) Charge-neutralized transport
- simulations (BICrz, QUICKSILVER)
- stripping vs. neutralization
- cross sections
- experimental demonstration
- technology to provide neutralization

(4) Pre-formed channels
- small radius limit (hydro expansion, radiation heating)
- high voltage breakdown problem
- high brightness issue
- multiple channel formation and overlap near target

(5) Mainline HIF final focus (vacuum/quadrupoles)
- experimental demonstration
- velocity tilt removal by space charge in final lens

(6) Mainline LIF transport/focus (gas/solenoid)
- current neutralization with $B_{\perp}$
- experimental demonstration

(7) Stability
- hose, sausage
- 2-stream [stabilization by collisions , ΔV_z, $k(z)$]
- filamentation
- scoping studies of new regimes

Table 2. Ion Beam Transport Issues (continued)

(8) Neutralization between gaps for multi-gap acceleration
feasibility of concept
emittance growth
scaling to driver parameters

(9) Non-standard final focus lenses
plasma lens (preformed Z-discharge)

(10) Miscellaneous issues
beam overlap near target
target charge-up
voltage accuracy for bunching
focal spot position micro-management

Table 3. Research and Development Needs

beam experiments

LBNL: 2 MeV injector, SBTE injector; beam combiner; magnetic quadrupole development
SNL: Alias, SABRE, PBFA-X, HERMES III
GAMBLE II (NRL), COBRA (Cornell)
LLNL: Injector transport; bending; Recirculator

diagnostic development

- conductivity $\sigma(t)$
- $B(r)$ inside beam (Zeeman diagnostic)
- beam uniformity and centroid motion
- microdivergence measurement
- spectroscopy

small scale experiments

- z-discharge channel characterization
- plasma lens characterization
- solenoid lens characterization

code development

- IPROP, IVORY
- MFOCUS
- BICrz
- QUICKSILVER, TWOQUICK
- WARP
- BUCKSHOT
- benchmarking of codes

atomic physics

- cross sections (stripping, ionization, charge exchange,...)
- radiative effects
- scattering, dE/dx

analytic theory

models needed for all areas: gas breakdown
self-pinch
charge neutralization
channels
stability
...

systems have been designed for large standoff (> 3 meters) appropriate for repetitive-pulse target chambers. From a physics standpoint, unneutralized ballistic focusing is the most straightforward method of directing the beams toward the target. If the beams are not neutralized, the beams must have relatively high kinetic energy (≥ 10 GeV). High kinetic energy leads to large ion range (≥ 0.1 g/cm^2). Targets designed for large ion range require relatively small focal spots. These small focal spots are achievable with large aperture magnetic lenses located external to the fusion chamber, provided the current and thermal velocity spreads within the beams are sufficiently low. Relaxation of these conditions on the beams permits the design of economically more attractive heavy ion drivers and considerably more compact final focus lens systems. The primary change necessary to move in this direction is the introduction of some form of electrical neutralization into the ion beams following the final focus lenses. This neutralization may be co-injected electrons, or electrons produced by the beam's ionization of a gas medium in the chamber. A gas is always present in the chamber at low pressure (~ 10^{-5} - 10^{-2} Torr) depending primarily on the first wall type and temperature, and this can provide substantial neutralizing electrons at the higher end of the pressure range. Controlled gas flows may also be introduced to provide neutralization as required. This gas, as well as target x-rays, strip beam ions above their accelerated charge state of $q = 1$-3. A rather complex beam electrodynamics results, which is only crudely understood at present. A general program of effort is underway at LBNL, LLNL, and SNL, using particle-in-cell computer models and planned high-current experiments to explore the beam-gas interaction and neutralization dynamics.

Two very attractive gas-aided focal concepts under study are the plasma lens and self-pinched transport. The plasma lens employs an electrical discharge in a low pressure tube to provide a magnetic field which can drive the beam to a small spot size. Such a device could replace the large quadrupole lenses previously considered for the final focus. Very encouraging experiments with this type of lens have been recently carried out in European laboratories at CERN and Darmstadt (Germany), and similar experiments are planned at LBNL using a 2.0 MeV, 800 mA K^+ beam.

The self-pinched transport concept is motivated by the well-established mode of pinched transport observed for high current electron beams in gas. Significant differences would occur with ion beams, since they attract rather than expel electrons. The general idea is to focus an ion beam to a small radius through a foil or dense gas jet to strip most or all electrons. Subsequently, the beam would neutralize and propagate at small radius, held together in a pinch equilibrium by its own magnetic field. If successful, such a transport mode permits a drastic simplification of the reactor final focus configuration and reduces several critical requirements on the accelerator system. In addition, the beams could be transported over longer distances from the accelerator to the chamber by this means.

To explore the feasibility of the self-pinched transport model, a program of particle-in-cell numerical simulation, which includes its principal physical processes, is underway at LBNL. Highly-stripped simulation ions moving at sub-relativistic velocities are introduced into a gas-plasma column and subsequent dynamics of all components are computed assuming an axisymmetric geometry is preserved. The electromagnetic model makes no approximations in Maxwell's equations, since a rather delicate cancellation of field components is expected. Preliminary results indicate that a pinch configuration forms. However, the plasma column expands rapidly and this may significantly degrade its confinement capability. Computations are limited by the very slow running speed of this type of simulation. Assuming a favorable equilibrium is found, stability of the pinch beam against hose-like disturbances will be examined.

Transport in discharge-created channels has been studied in connection with final transport for light ion fusion. We are revisiting this transport mode for heavy ion fusion. The potential advantage of this mode is that it relaxes the driver requirement on energy spread, emittance, and head-to-tail current variation. It may also be more stable than the self pinch. The heavy ion scenarios involve beam emittance, energy and charge that are significantly different from light ion scenarios. As a result, channel architectures (number of channels, pinch current, distance of propagation, etc.) are also quite different. Gas breakdown and channel stability issues in the HIF regime are currently under study at LBNL. In addition, an experiment to look at beam compression with an adiabatically tapered z-pinch is in preparation. In this approach, the tapered z-pinch provides focusing as well as radial compression.

LBNL Priorities and Recommendations

Stability of Self-Pinched Transport

To date, studies of self-pinched transport have concentrated on determining consistent conditions for creation of an axisymmetric equilibrium. Such configurations are potentially subject to both microinstability (e.g., the two-stream modes) and gross instability as exemplified by the hose instability. An overview treatment of instability is a high priority before making new code models specifically intended to treat particular aspects of the problem.

Code Development

There are several codes that treat charged particle beam propagation in the presence of background plasma with varying degrees of chemistry, electro-magnetic completeness, sophistication in numerical algorithm, number of dimensions, and representation of the particles. The most complete descriptions are given by the relativistic particle codes coupled with full EM field solvers, such as BICrz of LLNL, MFOCUS of LBNL, FRIEZR of NRL, and BUCKSHOT of SNL. In high pressure regimes where a generalized Ohm's law is applicable, the fluid representation of cold electrons can be used as in IPROP of MRC and in ULYSSES of LBNL. IPROP has the additional capability of PIC treatment of energetic electrons simultaneous with the cold fluid component. Some models, such as EMPULSE of LLNL, employ a 'frozen field" approximation effectively simplifying Maxwell's equations. The availability of a variety of codes with varying degrees of sophistication suggests the need for code comparison in the regime of small beam radius and high beam density currently envisioned for ion-driven fusion. It is specifically recommended that the newest code, MFOCUS, receive benchmark verification against the most closely-related existing PIC codes (BICrz and IPROP).

Channel Experiments

A variety of channel formation and light ion propagation experiments were performed in the past at NRL and SNL; these have a considerable similarity of physics and objectives to the current program of small-scale experiments at LBNL. However, detailed reports of apparatus and results are not immediately available. A high priority is placed on tracking down this detailed information where it exists at the several Laboratories or in published reports. Aid from the original workers in the area will be very valuable here.

4.2 LLNL Ion Beam Transport Plans and Priorities

Work at LLNL in recent years emphasizes regimes of partial charge neutralization as may be anticipated for HIF reactor concepts such as HYLIFE. Research has concentrated on "vacuum propagation" and "propagation through moderate densities of FLiBe vapor."

Vacuum propagation means that the density of gas in the fusion chamber is so low that it plays no role in the beam propagation. This is the classical propagation mode, in which beam momentum and small f-number of the final focus compensate for electrostatic self repulsion. Most LLNL calculations for this scenario assume beam ion mass A ~ 200, energy 10 GeV, and spot size 2-3 mm. Although the basic physics is simple for a single, long thin beam, there are complications, as follows:

1. In most reactor concepts, there are many beamlets that can interact electrically in vacuum. These interactions, and a beamlet's electrostatic self-repulsion, vary between the beam head, middle, and tail. Such variations cause different parts of the beam to arrive at different locations on the target, increasing the effective spot size. However, LLNL calculations indicate this need not be significant even in vacuum.
2. Beam charge deposited on the target raises its potential to a significant fraction of the beam energy, according to a simple calculation, that might deflect the later part of the beam. LLNL calculations show several effects relocate positive charge to radii far larger that the target, reducing the positive potential to harmless levels. These include electrostatic expulsion of protons from adsorbed hydrogen on the target, and photoionization of residual chamber gas.
3. As the target surface heats to ~ 100 eV, it radiates thermally. A simple calculation indicates that beam ions can be photoionized to much higher charge state before reaching the target. The ions then respond much more strongly to the electric field in a non-neutral beam. However, calculations using BICxy (a 'slice' code) that included both beam photoionization and the merging of beamlets show that beam photoionization occurs too close to the target to have much effect on spot size.

4. In order to reduce accelerator costs by using larger beam q/m or lower energy, with the same or smaller spot size, charge neutralization of the beam has long been suggested by all three laboratories (LBNL, SNL, LLNL). LLNL modeling, using the BICrz electromagnetic particle code, has considered partial neutralization by a preformed plasma that the beamlet passes through or very near to. This plasma was assumed to be near the chamber wall; no specific plausible plasma generator has been proposed in detail, to our knowledge. As predicted by others, neutralization is not complete, the electrons entrained in the beam have random velocities like the beam velocity, and the degree of neutralization decreases near the target. We find also some increase in beam emittance because the electron density is nonuniform, overneutralizing the beamlet axis.

In summary, the vacuum propagation case is probably less attractive for energy applications with pulse repetition rates of several Hz, for which most reactor concepts have a vapor of sufficient density to interact via collisional ionization with the beam. Perhaps this case has been studied sufficiently for now.

Propagation through vapor in the reactor chamber adds several new features: collisional ionization of the beam ions (stripping), ionization of the vapor collisionally by the beam and by deliberate external means. Stripping places beam ions in higher charge states, in which they respond more strongly to the electric field in an imperfectly neutralized beam. In agreement with earlier predictions, recent LLNL calculations using BICrz show that degradation of spot intensity results, and also show the expected mitigations as the beam is charge neutralized. Collisional ionization of the vapor provides electrons to be entrained in the ion beam, providing neutralization in addition to whatever is provided by preformed plasma. This additional neutralization is valued near the target when preformed plasma extends only near the chamber wall.

LLNL calculations show great benefit from preionizing chamber vapor in the beam path all the way to the target, as well as by collisional ionization of the vapor Deleterious effects of stripping are overcome, and only by such means have we found it possible to achieve smaller spot size than in the idealized vacuum envelope solution . LLNL calculations some years ago demonstrated the benefit to target discharging of photoionization of the chamber vapor near the target by thermal radiation from the heated target. Target charging is further reduced when the beam arrives partially neutralized. Photoionization provides copious electrons to provide beam neutralization near the target. It does not appear that D. Ho's "autoneutralizing" target (in which the ion beams pass through a foil, and draw co-moving electrons to provide neutralization) is needed.

Streaming instabilities may also be a concern. Unless the beam is very well-neutralized, the accompanying electron cloud has a random velocity distribution width comparable to the beam speed. Such a distribution is expected to be stable against streaming instabilities. If present, streaming instabilities would appear in BICrz simulations with adequate resolution. We will check this especially near the target where the instability wavelength could be small. At higher densities than we have considered, the electron velocity spread may be smaller, permitting the instability.

LLNL Priorities and Recommendations

Cross sections

Stripping is bad, collisional ionization of chamber vapor is good. The ratio of harm/benefit is mainly dependent on the ratio of cross sections for the vapor and beam ions. Uncertainty in theoretical cross sections, especially for FLiBe, needs to be reduced. Our best estimate is the stripping in FLiBe is important; Li vapor appears to be much better. Experimental information on the ratio of cross sections would be very useful.

Experiments on charge neutralization

Experiments are needed to hone and "validate" BICrz. For this purpose, the relevant dimensionless ratios need not be the same as for our reactor scenarios. Charge-neutralization experiments using the low divergence beamlets from the SABRE accelerator at SNL might be very useful for this purpose. Another possibility is to use the 2 MV injector at LBNL.

Devices for preionization of chamber vapor

Calculations support our intuition that preformed plasma, if possible all the way to the target, is extremely beneficial. It would be useful to identify specific technology for this.

Chromatic aberrations, etc.

LLNL modeling results encourage hope that spot size may not be limited by effects discussed above, but by beam emittance. It may soon be time to review the final focus system and drift compression system, transverse and longitudinal emittance, and chromatic aberrations.

4.3 SNL Ion Beam Transport Plans and Priorities

Most light ion fusion transport studies have been aimed at high yield (for the Laboratory Microfusion Facility, LMF) and power production (for the LIBRA light ion reactor concept). Typically, for either application, ion beams must be brought to a focal spot radius of ~ 1.0 cm at a standoff distance of about 4 m from the diode. The LIF baseline transport scheme for LMF is an achromatic lens system. Back-up schemes include self-pinched transport, channel transport, and wire-guided transport. Channel transport and wire-guided transport have been thoroughly demonstrated at NRL at low energy (for 1 MeV protons), and these schemes are expected to work at higher energies (for 35 MeV Li). For example, 1 MeV proton beams with currents up to 400 kA have been transported with wall-confined z-discharge channels over distances up to five meters. Our main concern for both wall-confined channels and wire-guided transport is that some transport apparatus (low-mass tubes or wires) will be required inside the containment chamber. The achromatic lens system (and self-pinched transport) are attractive because no apparatus is required inside the containment chamber. However, for the achromatic lens system, the standoff length from the end of the solenoid magnet lens to the target must be only ~ 1.5 meter for the required microdivergence of 6 mrad. For self-pinched transport, the standoff length from the channel entrance to the target can be many meters, the beam radius is small (<1 cm) during transport, and the microdivergence acceptance can be large (~12 mrad), depending on the net current. This makes self-pinched transport the most attractive transport scheme, provided feasibility can be demonstrated experimentally.

The overall goal is to continually improve our understanding of gas breakdown and to show that we can achieve operating conditions for both ballistic transport and self-pinched transport for LMF parameters. Experiments will be performed at ever-increasing power levels to span the parameter range from the present Gamble II level to the full LMF level. IPROP (a 3D EM code) will continue to be refined and benchmarked with these new experiments and will be used as a predictive tool for LMF parameters.

Detailed studies of gas breakdown and the resultant charge and current neutralization are crucial to our understanding of beam transport. For ballistic transport of ion beams in gas, complete charge neutralization (100%) and essentially complete current neutralization (~100%) are desirable. For self-pinched transport, it is generally desirable to have complete charge neutralization (100%), but only partial current neutralization (~90-98%). Our goal is to develop a detailed physics understanding of both charge neutralization and current neutralization on a macroscale and a microscale. Specifically, we intend to study the effects of charge non-neutrality on microdivergence, and we intend to understand current neutralization, so that by varying certain parameters (e.g., gas type, gas pressure, beam risetime, beam radius, etc.), we can achieve either essentially complete current neutralization (for ballistic transport) or partial current neutralization (for self-pinched transport).

For self-pinched transport, the ion beam is focused down to a small radius and then transported at small radius to the target. The ion beam is contained by the net self-magnetic field. Typically, net currents of about 50 kA are needed for LIF parameters. Recent IPROP results show that very large net currents should be possible for self-pinched propagation in low pressure gas (≤ 0.1 Torr).

SNL Priorities and Recommendations

Experimental Demonstration of Self-Pinched Transport

Self-pinched transport experiments are planned, starting in spring, 1996. Pending adequate beam quality (divergence, uniformity, brightness, etc.), experiments will be performed with 1 MeV protons on GAMBLE II, and with 5 MeV Li ions on SABRE. IPROP code results will be used to help guide the experiments.

Charge Neutralization

Experiments with low divergence beamlets from SABRE are being performed to study the fundamental limits of charge neutralization on a micro-scale. These results are of importance to all ion beams (LIF, HIF, common ion). The same beamlets could be used to study plasma neutralization and wall neutralization, as is of interest for HIF. Collaborative research among SNL, LLNL, and LBNL would be particularly appropriate.

Gas Breakdown

Experiments are planned to measure gas breakdown and conductivity growth. This will extend the GAMBLE II experiments to similar experiments with more intense beams on SABRE, COBRA, and PBFA-X. Development and benchmarking of IPROP will continue. The goal is to demonstrate control of the net current and electrical conductivity σ by varying specific parameters (e.g., gas pressure, beam radius, total current), and to demonstrate high current neutralization (> 99.8%) for ballistic propagation and limited current neutralization (≤ 98%) for self-pinched propagation.

Instabilities

Experiments are planned to observe, diagnose, and control the filamentation instability, the two-stream instability, and hose instabilities. We plan to select parameters so as to spoil σ and make the filamentation instability observable with existing brightness beams, and then increase σ to remove the instability. Similarly, we plan to select parameters so as to make the electron-ion two-stream instability observable, and then vary parameters (collision frequency and axial energy spread) to remove the instability. IPROP, and possibly other codes, will be benchmarked with the experimental results.

5.0 Concluding Comments

To date, most resources for ion beam fusion have been devoted to development of accelerators and target physics; relatively few resources have gone into ion beam transport development. Because of theoretical studies and substantial experience with electron beam transport, the ion beam transport community is now poised to develop and optimize ion beam transport for ICF. Because of this Tri-Lab effort, a path for coordinated development of ion beam transport has been established. The rate of progress along this path will now be determined largely by the availability of resources.

Appendix

Lawrence Livermore National Laboratory

February 11, 1994

Marshall Sluyter, Acting Director
Office of Research and Inertial Confinement Fusion
U.S. Department of Energy, DP-28
19901 Germantown Road
Germantown, MD 20874

David Crandall, Director
Division of Advanced
Physics and Technology
Office of Fusion Energy
Office of Energy Research
U.S. Department of Energy
Washington, DC 20585

Dear Marshall and Dave,

Recognizing the resource limitations that the DOE and U.S. Government will be facing for the foreseeable future, we believe that it is necessary to evaluate the possibility of structuring long range strategic research activities for the widest possible benefit to multiple DOE missions. Following suggestions made at the joint DP/ER workshop in Washington last summer, we have begun informal discussions to assess the technical feasibility of a combined LMF/ETF facility with multiple target chambers sharing a common ion driver. We believe that ion drivers currently have great potential for providing the durability, efficiency, and rep rate required for energy. Most system studies for energy indicate that the optimum target yield is a few hundred megajoules. This matches the desired LMF yield for defense programs applications.

The goal of these discussions is to identify a research program that would provide the more demanding driver requirements for energy production, at a reasonably small incremental cost compared to the cost for the LMF's single shot needs. If such a driver could be identified, DOE would then be able to satisfy the needs of two of its major missions, advanced energy technology for fusion and nuclear defense, with a single facility. With the significant declassification of ICF, it should even be possible for this facility to play a major role in an international program.

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So far, we have identified chamber transport as a critical issue for both the defense program and energy application of ions, and we have established a technical working group to assess ways in which we could coordinate our research activities. We anticipate that other working groups addressing the issues of ion driven targets and novel acceleration concepts would also be of benefit to the national ion program. When we have a more definite proposal for coordinated activities, we will contact your offices to schedule formal discussions.

Sincerely,

John Lindl
Acting ICF Program
Leader, LLNL

Jeff Quintenz
Light Ion Program Manager
SNL

Roger O. Bangerter
Roger Bangerter
Program Head, Fusion Energy
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cc:
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