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Presented at the Thirtieth Annual Meeting of the American Physical Society Division of Plasma Physics, Hollywood, FL, October 31–November 4, 1988

Abstracts Submitted for the Thirtieth Annual Meeting, Division of Plasma Physics

July 1988

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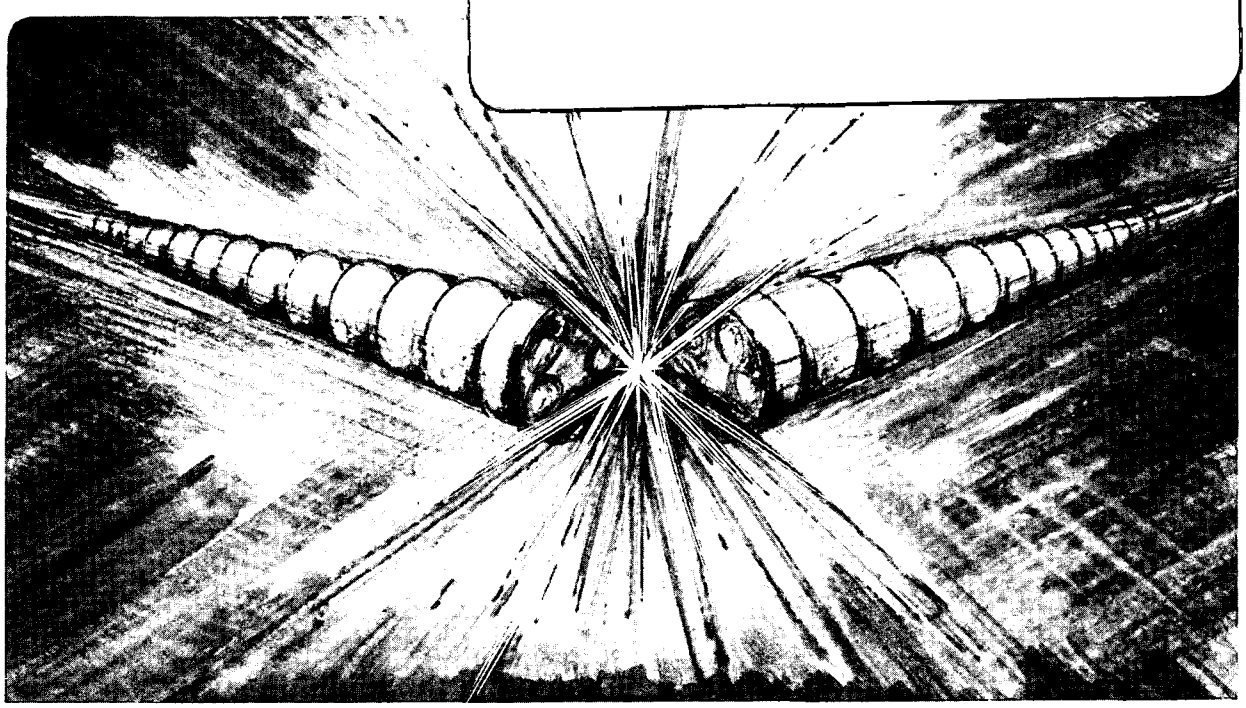

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Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

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Abstracts Submitted
For the Thirtieth Annual Meeting
Division of Plasma Physics
October 31 - November 4, 1988

By Members of the
Accelerator and Fusion Research Division

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

July 1988

This work was supported by the Director, Office of Energy Research, Office of Fusion Energy of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098

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ION AND PLASMA SOURCES

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ABSTRACTS SUBMITTED

FOR THE THIRTIETH ANNUAL MEETING

DIVISION OF PLASMA PHYSICS

OCTOBER 31, 1988 - NOVEMBER 4, 1988

Second-Harmonic Gyroresonant Heating Coefficients: an Analytic Theory.* Huanchun Ye and Allan N. Kaufman, *LBL and Physics Department, University of California at Berkeley*——The fundamental processes associated with ICRF second-harmonic heating lead to coefficients for transmission, reflection, mode-conversion, and absorption. We have used the techniques of phase-space propagation[1], congruent reduction[2], and spectral deformation[3] of van Kampen modes to obtain explicit expressions for these coefficients, for a slab model. Our results agree with those of Fuchs and Bers[4], whose theory embraces also minority heating. We plan to extend our methods to the two-dimensional case, and will report our results.

* Supported by US DOE under Grant # DE-AC03-76SF00098

[1] H. Ye & A. Kaufman, Phys. Rev. Lett. **60**, 1642 (1988); A. Kaufman & L. Friedland, Phys. Lett. **123A**, 387 (1987).
[2] L. Friedland & A. Kaufman, Phys. Fluids **30**, 3050 (1987).
[3] J. D. Crawford & P. D. Hislop, Ann. Phys. (N. Y.), in press.
[4] V. Fuchs & A. Bers, PFC/JA88-19 (May 1988), to be published.

Scattering of Magnetosonic Waves by Edge Turbulence.* D. R. Thayer and A. N. Kaufman, *Lawrence Berkeley Laboratory, University of California*--During ion-cyclotron-range-of-frequency (ICRF) heating, the incident fast magnetosonic wave passes through the highly turbulent edge. For high-density ignition-type devices (such as CIT), this wave can scatter significantly due to the large density fluctuations. In this work, we investigate the scattering of the incident wave, in a regime where the expansion parameter of the propagator theory can be of order one (here we consider $\delta n/n_0 \sim O(1)$, $k_0 \sim O(1)$, and $k_0 L >> 1$ [where is the density correlation length, and L is the turbulent-edge layer width]). Consequently, a renormalized theory for the statistically-averaged scattering process is developed and utilized to determine the backscattering (1D) and angular spread (2D) of incident energy. Results are given for a typical range of parameters; numerical evaluations of equivalent stochastic equations are presented and compared with the analytic results.

* Supported by the U. S. Department of Energy under contract No. DE-AC03-76SF00098.

Measurement of vibrationally-excited H_2 in a discharge by VUV absorption * G.C. STUTZIN, A.T. YOUNG, A.S. SCHLACHTER, and W.B. KUNKEL, Lawrence Berkeley Laboratory, Berkeley, CA 94720 --The density and temperature of H_2 in specific vibrational and rotational states has been measured in a discharge using VUV absorption at various B-X and C-X transitions, using a system originally designed to measure hydrogen atom densities. Vibrational levels up to v=5 and rotational levels up to J=8 have been observed. Line densities of $\sim 1 \times 10^{12}$ cm^{-2} per quantum state are observable, corresponding to number densities of 3×10^{10} cm^{-3}. The rotational distributions are found to be non-Maxwellian, with the high J states having anomalously large populations. The lower J states have rotational temperatures of ~500°K. The vibrational populations have an effective temperature at 4000°K, much higher than other temperatures in the system. Dependence upon other plasma parameters will be discussed.

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* Work supported by Los Alamos National Laboratory, AFOSR, and U.S. DOE Contract DE-AC03-76SF00098

Plasma-Cathode Development for the LBL Sheet Plasma,* A.F. LIETZKE and G.GUETHLEIN, Lawrence Berkeley Laboratory, -- A long-life plasma cathode is being developed at LBL as part of its negative-ion-based neutral beam development program. The cathode, a variety of duo-plasmatron,[1] follows the concept of J. Uramoto,[2] and is a further step in our attempts to reproduce the high negative ion current density that he reports from his sheet plasma. The cathode consists of a small iron chamber (5cm I.D. by 5cm) and one or more well cooled, molybdenum lined magnet throats (>0.6cm I.D. by 5cm). The emitter (W or LaB_6) is inside the field- free region of the iron chamber, where the pressure is 200 to 400 mTorr. The cylindrical magnetic throat (B ~ 100 G, axial) maintains the cathode pressure at moderate flows of 0.5 to 1 Torr-l / sec and serves as a local starter / keep-alive anode for ease of startup and quiescent steady-state operation. The dependence of output current upon gas flow, magnet field, and anode pressure is suggestive of two electron-accelerating double-layers (one near the throat entrance and one near the throat exit). Arc noise can be greatly reduced by capacitive feedback to various segments of the cathode or by thermionically limiting the emitter. The anode chamber no longer gets coated with cathode materials. Thus far we have not reproduced either the high H^- or high H_3^+ level reported by Uramoto. Efforts to push the exit sheath into a higher pressure region will be reported, particularly the effect upon H_3^+ delivery and high-current sheet plasma operation.

*Supported by DOE Contract No. DE-AC03-76SF00098.

1. C.C. Tsai, et al, Nucl. Tech. / Fusion 4, 1424 (1983).
2. J. Uramoto, Inst. of Plasma Phys., Nagoya, Res. Rept. IPPJ-760 (1986).

H^- and D^- Production From a Plasma-Cathode Initiated Sheet Plasma* G.GUETHLEIN and A.F. LIETZKE, Lawrence Berkeley Lab, Berkeley, Ca. 94720--The sheet plasma geometry of J. Uramoto[1] is being investigated as a possible low pressure, large area source of D^-. Previous experiments[2] with a tungsten filament initiated sheet plasma failed to produce an adequate H^- current density. We describe a more faithful reproduction of Uramoto's sheet creation mechanism, wherein a round electron beam from a plasma-cathode is transformed into a sheet electron beam by means of strong bar magnets. Thus far we have difficulty producing tall sheets (~15 cm) with currents above 10 - 15A, but for short sheets (~3 cm high) J_{H^-} saturates at moderate currents (I_{arc}< 50A) and low levels (J_{H^-} < 1mA/cm^2); In contrast to the filament initiated sheet, the saturated H^- is independent of the anode pressure (despite the usual decrease of T_e as the pressure is increased); the maximum H^- occurs farther from the sheet (4cm vs. ~3cm); the plasma outside the ionization channel is hotter and less dense; the anode wall does not get coated with cathode material. The cathode emitter material (LaB_6 or W) doesn't effect H^-. Production of H^- is more efficient with a round beam, i.e., without magnet bars. Species measurements at 10cm from the sheet indicate a high H^+ fraction (>80%), contrary to reports by Uramoto,[1] and local probe data indicate a low density +ion / -ion plasma. Further research will include cathode changes (to provide more H_3^+) and wall material changes (to raise the excited molecule density).

*Supported by DOE Contract No. DE-AC03-76SF00098.

1. J Uramoto, Inst. of Plasma Phys., Nagoya, Res. Rept. IPPJ-760 (1986).

2. G. Guethlein & A. F. Lietzke, Bull, Am. Phys. Soc. 32, 9, 1893 (1987).

Optimization of H^- Production from a 7.5-cm Diameter Multicusp Source* K. N. LEUNG, C. A. HAUCK, W. B. KUNKEL, and S. R. WALTHER, Lawrence Berkeley Lab., Berkeley, CA. 94720--A small (7.5-cm-diam) multicusp source[1] has been developed to generate volume-produced H^- ion beams in pulse mode operations. To obtain high H^- current densities ($J > 250$ mA/cm^2), this source requires relatively high gas pressure and high discharge power. Experiments have been conducted to improve the arc and gas efficiencies, the pulse shape, and the H^- to electron ratio in the extracted beam by optimizing the filter magnetic field, the thickness and position of the extraction aperture, and by mixing xenon or other elements with hydrogen in the discharge. The biggest improvement is obtained by adding cesium into the source, resulting in a five-fold increase in the extractable H^- current and a substantial drop in the e/H^- ratio. Thus far, H^- current densities higher than 1 A/cm^2 have been achieved and the accelerated beam current is found to increase with the aperture size.

1. K. N. Leung, K. W. Ehlers, C. A. Hauck, W. B. Kunkel and A. F. Lietzke, Rev. Sci. Instrum., 59, 453 (1988).

* Work supported by AFOSR, AFSTC, McDonnell Douglas Corp., USASDC and U.S. DOE Contract #DE-AC03-76SF00098.

Formation of H^- ions in a pure hydrogen and in a barium-seeded hydrogen discharge* W. B. KUNKEL, K. N. LEUNG and S. R. WALTHER, Lawrence Berkeley Lab., Berkeley, CA. 94720--
Recent experimental investigations in two small multicusp ion sources demonstrated that both *cesium* and *barium* could provide a large enhancement (a factor of five or more) in the extracted H^- current.[1,2] In order to understand the H^- formation mechanism, we have operated a multicusp source with the plasma potential either above or below the anode potential. It is found that the majority of the H^- ions are generated by volume processes in the bulk of the plasma when the source is operated in the pure hydrogen mode. However, when *barium* is added to the hydrogen discharge, the chamber walls or anode surfaces become the main source of H^- production. The dominant process for generating these H^- ions on the anode walls is still under investigation.

1. S. R. Walther, K. N. Leung, and W. B. Kunkel, J. Appl. Phys., Oct (1988).
2. K. N. Leung, C. A. Hauck, W. B. Kunkel, and S. R. Walther (this conference)
* Work is supported by AFOSR, USASDC and the U. S. DOE under contract No. DE-AC03-76SF00098.

Effect on H^- Ion Production in a Small Multicusp Ion Source with Addition of Xenon, Cesium or Barium to a Hydrogen Discharge*, S. R. WALTHER, K. N. LEUNG, and W. B. KUNKEL, Lawrence Berkeley Laboratory, Berkeley, Ca. 94720-- The effect on H^- ion production by adding cesium or xenon to a hydrogen discharge, in a small magnetically filtered multicusp ion source, has been investigated. Addition of cesium vapor to the hydrogen discharge resulted in a factor of sixteen increase in H^- output relative to the uncesiated discharge for the same operating parameters. Likewise, the addition of xenon gas to a hydrogen discharge resulted in a factor of 2.7 increase in H^- output over pure hydrogen operation at optimum H_2 source pressure, while maintaining the same discharge parameters. Operation of the source with the plasma electrode at optimum bias voltage was essential to obtain this result. Recent experiments on H^- ion production with the addition of barium to a hydrogen discharge will also be presented. Barium addition to the discharge is preferable to addition of cesium, because the vapor pressure of barium is much lower than cesium. It is found that H^- ion enhancement comparable to cesium-hydrogen operation is achievable with the addition of barium.

* This work is supported by the Air Force Office of Scientific Research and the U. S. DOE under contract No. DE-AC03-76SF00098.

Extraction of H^- Beams from a Multicusp Volume-Production Source* J. W. KWAN, G. D. ACKERMAN, O. A. ANDERSON, C. F. CHAN, W. S. COOPER, and J. DEVRIES, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720--H^- beams were extracted from a 20cm diameter multicusp source with a 2.9cm diameter aperture. The final delivered H^- current (after beam loss in the accelerator) was optimized with respect to gas flow, magnetic filter in the source, plasma electrode bias and arc power. Electrons extracted together with the H^- ions were deflected by permanent magnets 1cm downstream of the source aperture. These magnets were strong enough to couple with the filter in the source and therefore they became one of the optimization parameters. Operation with additional Cs or Xe both improved H^- production, but also caused serious problems in accelerator breakdown. The maximum H^- current obtained so far (without Cs) was 100mA. When the aperture radius was reduced, the maximum current density increased while the emittance decreased faster than the radius. This anomalous emittance scaling will be discussed.

* Supported by USASD MIPR W31RPD-63-A087 and U.S. DOE Contract No. DE-AC03-76SF00098

Dynamics of Skew Beams and the Projectional Emittance*, C. F. CHAN, W. S. COOPER, J. W. KWAN and W. F. STEELE, Lawrence Berkeley Lab., Berkeley, CA 94720--We study the optics of a finite temperature ion beam, with skew velocity components in addition to the usual radial and axial components, in an axially symmetric electrostatic geometry. The effect of the centrifugal force from the skew velocity is included in the equations of motion. An ion optics program is used to trace the beamlets. The results show that the skew velocity produces a significant effect on the beamlets near the axis. Formulas for the conversion from r-r' emittance to x-x' projectional emittance are presented. Emittance diagrams produced with and without skew velocity are quite different. Comparisons are made with the experimental measurements.

Supported by USASDC MIPR W31RPD-63-A087 AND U.S. DOE Contract No. DE-AC03-76SF00098

Operational Characteristics of a H_2^+ Enriched Ion Source* M. D. WILLIAMS and K. N. LEUNG, Lawrence Berkeley Lab., Berkeley, CA. 94720 and G. M. BRENNAN and D. R. BURNS, McDonnell Douglas Astronautics Co., St. Louis, MO. 63166.---D^+ or D^- ion beams are required in many applications. In order to minimize neutron production for testing of high energy injector components, it is advantageous to employ H_2^+ ions which have the same mass as deuterium. A short multicusp generator (17-cm-diam by 10-cm-long) has been designed and fabricated at McDonnell Douglas Astronautics Co. to generate a positive hydrogen ion beam which is enriched with H_2^+. The source chamber is constructed from aluminum and is surrounded by 10 columns of samarium-cobalt magnets. The plasma electrode contains a radial distribution of smaller ceramic magnets which generates a field-free space in the extraction region. Preliminary testing at LBL shows that the prototype source is capable of producing a positive hydrogen ion beam with current density greater than 110 mA/cm^2 for a 65 V, 25 A discharge. The percentage of H_2^+ ions is larger than 73% as measured by a magnetic deflection spectrometer. A comparison between tungsten filaments and LaB_6 cathodes has been carried out. It is found that tungsten filaments can provide a better performance than LaB_6 in this source.

* Work is supported by McDonnell Douglas Astronautics Co. and the U.S. DOE under contract No. DE-AC03-76SF00098.

LaB_6 Cathode Development for Electron Beam Generation and for Steady-State Ion Source Operation* P. PURGALIS, K. N. LEUNG, S. B. WILDE, and M. D. WILLIAMS, Lawrence Berkeley Lab., Berkeley, CA. 94720--Large area cathodes are required in many electron beam experiments. Two types of LaB_6 cathode have been developed at LBL : (1) a large directly-heated planar cathode with diam > 5 cm and capable of generating electron current densities > 70 A/cm^2, and (2) a smaller (2-cm-diam) indirectly-heated cathode which operates at 1470°C with an external heater power of only 300 W. Directly-heated coaxial LaB_6 cathodes have been developed for ion source operation. In high power steady-state discharges, these cathodes operate without heater power and the discharge voltages V_d are low. We have tested several coaxial LaB_6 cathode arrangements. It is found that V_d varies for different cathode shapes and $V_d \sim 100$ V has been achieved with a short LaB_6 cathode in a volume H^- ion source.

* Work is supported by Lawrence Livermore Natl. Lab., Sandia Natl. Lab., USASDC and the U. S. DOE under contract No. DE-AC03-76SF00098.

A Neutral Beam System for Heating and Current Drive on ITER,* W.S. COOPER, O.A. ANDERSON, G.J. DEVRIES, W.B. KUNKEL, J.W. KWAN, A.F. LIETZKE, P. PURGALIS and R.P. WELLS, Lawrence Berkeley Laboratory, Berkeley, CA 94720; R.S. DEVOTO, W.B. LINDQUIST, and W.S. NEEF, Lawrence Livermore National Laboratory; J.H. FINK, Negion, Inc.--We propose a neutral beam system for heating and current drive on ITER that uses volume-production D^- sources and a new type of electrostatic accelerator.[1] The multiple aperture accelerator accelerates 0.1 A or more per channel and employs electrostatic quadrupoles to control the beam space charge; the use of these elements permits the beam energy to be varied from 0.8 MeV to a maximum of 1.6 MeV without changing the current. The beamline uses a plasma neutralizer and electrostatic deflection to remove the remaining ions. Each beamline delivers 12 MW of D^0 to the plasma. Radiation protection is provided by situating the beamlines 35-50 m from the tokamak and by providing radiation shielding in the intervening space. We will describe the system and the status of relevant development.

* Supported by the U.S. DOE Contract DE-AC03-76SF00098.

1 O.A. Anderson, L. Soroka, C.H. Kim, R.P. Wells, C.A. Matuk, P. Purgalis, W.S. Cooper, and W.B. Kunkel, IEEE Proceedings, First European Particle Accelerator Conference, Rome, June 7-11, 1988.

Operation of the Prototype CCVV Accelerator* O.A. ANDERSON, J.W. KWAN, G.D. ACKERMAN, W.S. COOPER, G.J. DEVRIES, L. SOROKA, and W.F. STEELE, *Lawrence Berkeley Laboratory*— Neutral beam injectors for future tokamaks will require efficient production of beams in the 1 MeV range, with variable energy to prevent shine through during startup. The CCVV (Constant-Current Variable-Voltage) dc accelerator[1] is intended to meet these requirements. Electrostatic quadrupole (ESQ) focusing maintains constant current while the voltage is varied and allows a conservative design that should give reliable dc operation. The beam is preaccelerated to a fixed energy of 100 keV, transported through an ESQ matching/pumping module, and then accelerated by a series of identical stackable CCVV modules which can handle up to 140 mA of D^- per channel. Our first prototype, with only one CCVV module, can accelerate the beam from 100 keV to 200 keVand can also be tuned to decelerate the beam to as low as 20 keV without any change in beam current; the latter feature may have applications in industry. We present preliminary measurements (using H^-) of beam stripping loss, power drain, heat loads, emittance, and tunability.

*Supported by U.S. DOE Contract DE-AC03-76SF00098.

[1]O.A. Anderson, L. Soroka, C.H. Kim, R.P. Wells, C.A. Matuk, P. Purgalis, W.S. Cooper, and W.B. Kunkel, IEEE Proceedings, European Particle Accelerator Conference, Rome, June 7-11, 1988.

Simulation Studies for Extended-Range CCVV Acceleration,* L. SOROKA and O.A. ANDERSON, *Lawrence Berkeley Laboratory*—For neutral injection in fusion reactors, the constant-current variable-voltage (CCVV) accelerator[1] only needs to have an energy range of about 2:1. In other applications, such as diagnostic beams in fusion plasmas, semiconductor processing, or surface modification, much larger energy ranges may be needed. The CCVV system operates at a fixed current determined by the ion source and preaccelerator. The output beam energy may be varied in two ways: (1) by adding or removing CCVV modules, and (2) by suitably tuning the acceleration voltages and the ESQ focusing voltages. If the variation needs to be made rapidly, the first method is excluded. We present numerical simulations that demonstrate energy tunability from 1 MeV down to 20 keV without changing the mechanical configuration. We also present simulations relevant to the prototype CCVV accelerator,[1] and perturbation studies that establish the sensitivity of the system to changes in voltages or beam current.

*Supported by U.S. DOE Contract DE-AC03-76SF00098.

[1]O.A. Anderson, J.W. Kwan, G.D. Ackerman, W.S. Cooper, G.J. Devries, L. Soroka, and W.F. Steele, "Operation of the Prototype CCVV Accelerator," *preceeding paper*.

Transport of Warm Ion Beams,*

B. ABRAHAM–SHRAUNER, *Washington University in St. Louis* and O.A. ANDERSON, *Lawrence Berkeley Laboratory* —New self-consistent solutions of the reduced nonlinear Vlasov-Maxwell equations are given for the transport of warm ion beams. As a first step toward more general cases, we use the sheet beam model, which has some practical interest in itself. We assume an inverted-parabola density profile in the transverse spatial coordinate. This physically realistic profile yields a single-humped distribution function for a stationary ion beam with a linear focusing force. The BGK type solution, which can be found by Lie group invariance of time-dependent nonlinear Vlasov-Maxwell equations, appears to be stabilized for this case. The conditions for a matched beam are given for a special nonlinear focusing force which in general leads to a rippled, nonuniform beam. The electric fields and emittance are calculated in addition to the beam density and distribution functions. Envelope equations arise directly from the self-consistent solution rather than being derived from single-particle orbits. Comparisons with the standard warm sheet-beam case (uniform density profile) are made.

*Supported in part by U.S. DOE Contract DE-AC03-76SF00098.

LBL-25540(17)
HIFAN-400

Acceleration Experiments with the Multiple-Beam Device MBE-4*
H. MEUTH, S.A. VEITZER, and A.I. WARWICK, Lawrence Berkeley Laboratory--Various acceleration schedules were implemented on MBE-4, an experimental multiple-beam induction linac for heavy ions. These experiments investigate beam dynamics in heavy-ion drivers for inertial-confinement fusion. To date we have achieved a nine-fold current amplification (of the initial 10 mA per beam) by current-bunch acceleration and compression, with a final beam energy of 0.9 MeV. The acceleration schedules were established through a combination of a one-dimensional simulation code and an empirical tuning procedure. The limits of our capability for controlled bunch compression emerged as an important issue. We also characterized the longitudinal transport properties and the transverse emittance along the accelerator with and without acceleration. The head-to-tail velocity tilt in the bunch combined with alignment errors of the accelerator lead to coherent betatron oscillations, to be corrected by pulsed beam steering.

*Work supported by the Office of Energy Research, Office of Basic Energy Sciences, U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

LBL-25540(18)
HIFAN-401

Design of the Induction Linac Systems Experiment* T.J. FESSENDEN for the HIFAR group; Lawrence Berkeley Laboratory--The LBL Heavy Ion Fusion Accelerator Research group has designed the Induction Linac Systems Experiment to study, in a scaled way, virtually all the accelerator physics issues of an induction linac pellet driver. In the ILSE design, 16 parallel, one microsecond beams of carbon ions are focused electrically and accelerated from 2 to 4 MV. The 16 beams are combined transversely to four and accelerated in a magnetic-quadrupole focused induction linac. One beam is bent 180 degrees and transported through a drift-compression section in which the current amplifies by a factor of approximately three. The beam is then focused to a small spot in a scaled target-chamber experiment.

This paper will present details of the conceptual engineering design of ILSE.

*Work supported by the Office of Energy Research, Office of Basic Energy Sciences, U.S. Department of Energy under Contract DE-AC03-76SF00098.

LBL-25540(19)
HIFAN-402

Simulation of Beam Dynamics for the Induction Linac System Experiment(ILSE)* K. HAHN, C. CELATA, E. LEE and L. SMITH, Lawrence Berkeley Laboratory--In the ILSE design, four space charge dominated beams are combined transversely to one at an energy of 4 MeV. We have studied the combining process using the HYCURBE envelope code and the SHIFTXY 2-D PIC code. As the beamlets are combined in a non-symmetric way, the transverse dynamics of the merged beam in the major(x) and minor(y) axis directions differ substantially. The x-emittance shows a sharp increase in the first quarter betatron period followed by a gentle decrease with residual oscillation. The y-emittance, on the other hand, shows a gentle but steady increase with oscillations superimposed. At later times the x and y emittance tend to become equal and approach an asymptotic value of about five times that of an initial beamlet before merging. However, both the envelope and the PIC code show that the beams are merged and matched smoothly to the next acceleration section despite a head-to-tail velocity difference of 20%. The results from the codes and their implications will be presented.

*Work supported by the Office of Energy Research, Office of Basic Energy Sciences, U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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