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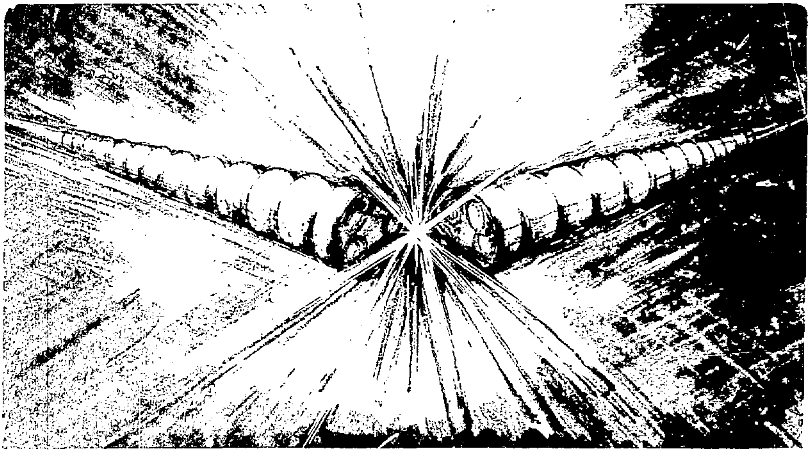

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AN OVERVIEW OF THE LBL/LLNL NEGATIVE-ION-BASED NEUTRAL BEAM PROGRAM*

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Abstract

The LBL/LLNL negative-ion-based neutral beam development program and status are described. The emphasis has shifted in some details since the first symposium in 1977, but our overall objectives remain the same, namely, the development of megawatt d.c. injection systems. Until last year we concentrated on a system in which the negative ions were produced by double charge exchange in sodium vapor. At present, the emphasis is on a "self-extraction" source in which the negative ions are produced on a biased surface imbedded in a plasma. A one-ampere beam will be accelerated to at least 40 keV next year. Studies of negative-ion formation and interactions help provide a data base for the technology program.

I. Introduction

The Lawrence Berkeley Laboratory and the Lawrence Livermore National Laboratory have a joint program to develop high-power neutral beam systems based on the production, acceleration, and neutralization of negative hydrogen and deuterium ion beams, for heating and fueling fusion devices. The rationale for negative-ion based systems was discussed in the first symposium[1] in 1977.

The work described here is supported by the Applied Plasma Physics Division and the Development and Technology Division of the Office of Fusion Energy. As the titles of papers in the first and Second Symposia indicate, the activities in this field include as much "physics" as "technology", indicative of the fact that the development of negative-ion-based systems for fusion still is in its infancy. Nevertheless, we shall see that substantial progress has been made since the previous meeting, and can expect to present the applications designer with some actual demonstrations of useable and scaleable components by the time of the Third Symposium.

The approaches and status of program components for meeting the R and D goals are outlined in the following sections. It will be indicated how the technical studies described here by other LBL and LLNL staff members fit into the overall program; these technical papers do not encompass all of our activities but they reflect the emphasis fairly well.

II. Program Elements - Status

Our research and development program must have the potential of producing neutral beam systems that will be used in the confinement programs. We anticipate, and users specify, parameters and development schedules, based on needs and perceptions of the state of the art. For example, LLNL has requested the development of high-current beams in the several-hundred keV range for use in its next generation of mirror devices.

The LLNL staff continues to devote a substantial effort to studies of systems needed for future experiments and reactors. These studies, an example of which is presented at this symposium[2], not only help define the basic parameters, but also help identify the engineering questions that must be answered as we move from the research to the application stage.

The discussion of the program elements and their present status is based on the neutral beam hardware system.

A. The negative ion source

This may be a double-charge-exchange or direct-extraction source.

1. Double-charge-exchange sources

Because the physics of producing negative ion beams by double charge exchange of positive ions in metal vapors was reasonably well understood, our first efforts toward a technology demonstration were based on this approach. Theoretical estimates and experimental measurements of yields of D^- ions are now fairly complete[3], except at low energies.

In a short-pulse experiment a beam of approximately 10 keV D^+ ions was converted to 2A of D^- ions in a supersonic sodium vapor jet, demonstrating one way to produce a useful negative ion source. The potentialities of this approach are discussed in an accompanying paper.[4] Although this system-approach has been carried farthest toward an actual neutral beam system, it is in principle more complicated than the "direct extraction" sources now under investigation, and we are not planning to accelerate negative ions produced in this way, in the near term.

We shall continue studies of negative ion yields in vapors, especially at low D^+ energies.

2. Direct extraction Sources

a. Surface production

Our proposed technology demonstration currently is based on negative ion production on a biased surface immersed in a plasma produced in a "magnetic bucket". Positive ions striking the surface produce negative ions that are accelerated into the plasma and then emerge ("self-extract") through the magnetic field at a slot in the bucket walls. The production mechanisms have been studied as basic processes[5,6] and in an actual plasma device.[7,8]

The non-plasma experiments showed that production on low-work-function surfaces is small for incident energies of about 1 eV, but is rising rapidly with energy.[5] At higher *energies, 200-300 eV/nucleon, the D^- yield* from backscattering reached about 10[6]. Unfortunately, we don't have measurements for energies between ~ 1 eV and about 200 eV per nucleon. Measurements made with a source producing a dc, ~ 1/2A, beam of H^- ions[8], are generally consistent with the results of the energetic-ion studies, but also show a strong low-energy (< 10 eV) H^- component coming from the surface; the production mechanism has not been identified with certainty. Ions formed at low energy may have less transverse energy, and therefore permit better optics of the accelerated beam.

b. Volume Production

Large H^- densities in a plasma are reported by Bacal and co-workers[9,10]. Substantial H^- current densities from ions produced in the plasma also have been observed in the LBL experiment.[7] It is thought that accelerated electrons will be a greater problem with a volume-production source, than with a "self-extraction" surface-production source, but the possibilities of volume sources must continue to be examined.

B. The Accelerator

We have not built any accelerator structure for negative-ion beams yet, but optimized dc accelerators for beams from double-charge exchange and "self-extraction" sources have been designed for energies up to 200 keV.[11] These four-electrode slotted structures are not unlike those used in our positive-ion program,[12] except that the current densities are lower. For example, a 10-ampere system may require an accelerator array 50 centimeters on a side. One of the design boundary conditions is that accelerators for multiple beams must pack together closely.

Mashke's Megalac proposal[13] has stimulated thinking about rf accelerators for energies above about 200 keV. We find the idea very attractive, but have not yet developed a conceptual design for an rf system.

In some cases it may be desirable to transport the negative ions from the plasma source to the accelerator, e.g. by a structure that permits transverse pumping of gas from the source.[14] Arrays of multipoles also might be used to transport high-energy negative-ion beams thorugh the shielding of a reactor.

C. The Neutralizer

Gas, plasma, and photon targets are being considered as neutralizers. Gas targets, perhaps supersonic jets[4], are the most straightforward, and should give neutralization efficiencies of about 60%.

Fully-ionized plasma neutralizers have been estimated to give neutralization efficiencies *of about 85-90%. Partially-ionized gases will* give values somewhere between 60% and 90%. Several aspects of plasma targets were presented in the first Symposium.[15]

The prospect of making fully-ionized plasma targets for beams with large cross-sectional areas is not very attractive. On the other hand, a partially-ionized (e.g 20%) target from many small beams might not be difficult. To bring some focus to this problem we have a program to study the interactions of 200-300 keV D^- ions with plasmas.[16]

Finally, photodetachment can be used as a method for converting the D^- beam to a D^0 beam. [17,18]

D. Other System Elements

As in the case for positive-ion beam systems, much of the size and cost of negative-ion beam systems will be in components other than the above: The vacuum system, power supplies and controls and beam dumps. Much of the technology being developed for positive-ion systems[12] will be applicable.

III. Status Summary

Substantial progress in understanding the principles of negative-ion-based neutral beam systems has been made since the first Symposium was held in 1977. In particular, a lot of the physics of negative ion formation in vapors, surfaces, and plasmas has been established, and negative ion beams with currents of the order of one ampere have been produced by both the double-charge-exchange and the surface-interaction techniques. System studies have been carried far enough to identify important design features for both the developers and the potential users. Neither the research programs nor the development programs are in want of good ideas.

A rough schedule and cost estimate for a "proof-of-principle" one-megawatt CW D^0 beam has been prepared in anticipation of a program to have a prototype of a useful injector operating in about ten years. It is not surprising that the required time and funding appear to be about the same as required for development of a prototype positive-ion-based TFTR injector.

IV. Plans

A. Near-Term

By the end of 1981 we expect to demonstrate the quasi-steady-state operation of a one-ampere H^- beam accelerated to 40-100 keV with acceptable beam optics. The fairly basic studies of negative-ion formation in gases, surfaces, and plasmas will continue as required for the development data-base.

B. Longer-Term

We hope to build and demonstrate a megawatt neutral beam system based on negative ions in the 1980's.

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