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NEUTRAL BEAM INJECTOR RESEARCH AND DEVELOPMENT WORK IN THE USA

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The US neutral-beam-injector research and development work primarily is carried out at DOE Laboratories: The Brookhaven National Laboratory (BNL), The Lawrence Berkeley and Livermore Laboratories (LBL/LLL), and The Oak Ridge National Laboratory (ORNL).

The objective of the BNL program is to develop multiampere (equivalent) high-energy injection systems based on direct extraction from negative ion plasma sources. Two types of direct extraction negative ion plasma sources have been extensively investigated, namely the magnetron source and Penning type source. Several improvements were implemented on these sources, which are basically of the cold cathode type operating in a mixture of deuterium gas and cesium vapor. These improvements (independent cesium vapor control constant gas flow during the beam pulse, cooling of the cathode) together with extensive probe and spectroscopic studies of the plasma parameters (such as plasma and gas densities as well as atom energy distributions) enabled us to improve our fundamental knowledge of the negative ion creation and to construct a multiampere negative ion plasma source for extracted beam currents between 1-2 A in beam pulses up to 50 ms.

Negative ion acceleration and beam transport are being studied on a 150 kV test stand. Two accelerator systems have been investigated, the close coupled geometry in which 1 A beams have been accelerated across a 2 cm accelerating gap and a system with the accelerator separated from the source and extractor by a bending magnet. Beam transport studies include the effects of space charge neutralization and beam focussing by means of a quadrupole doublet.

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[‖] Operated by Union Carbide Corporation for the ERDA.

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The Lawrence Laboratories Neutral-Beam Development Group's work proceeds along two lines: The first, based on positive-ion technology, is required for the near-term (at least through 1985) applications. The presently identified experiments, 2XIIB, TMX, MFTF, TFTR, and DIII, require injection at energies up to 120 keV, ion currents per module up to 80 A, and pulse lengths to 0.5 sec. We have achieved 120-kV, 0.5-sec operation of a fractional-area (14 A) TFTR prototype source, and have tested a full-size TFTR source to 70 KV and 30A for 20 ms. A first model of a fractional area, unoptimized, MFTF/DIII 80 kV source has been operated with 80 kV, 14 A, 0.5-sec pulses. No basic problems with the source designs have shown up.

The second development effort is oriented toward longer-term applications requiring efficient neutral-beam systems at energies well above 120 keV. Most of these systems probably will require the production and acceleration of large currents of negative ions. Two of our goals are the demonstration of a 200-kV, 20-A (D^o), ∿dc system by 1981, and a 400 kV, 20-A (D^o), ∿dc system by 1983.

The production of negative hydrogen ions by double charge exchange in cesium or other vapors offers the possibility of being scalable to arbitrarily large currents and long pulse lengths. We start with a 1-keV D^+ beam, of which somewhat more than 1 A passes through a cesium charge-exchange cell. The measured conversion efficiency is about 20%, in reasonable agreement with the value of 24% obtained in an atomic collision experiment. The plasma produced in the charge exchange cell is greatly reduced by flow transverse to the propagating (1 keV) beam, so the random electron current is less than the beam current. A 100 mA negative deuterium beam produced in this way has been accelerated to 60 keV. The accelerator was designed to yield good beam optics over a wide range of currents; in the present case $\pm 2.5^o$ divergence was obtained. Alternative techniques for producing negative ions are being studied.

A large part of our effort in recent years has been the development of suitable test facilities. We now have four beam lines for 100- to 200-kV development work with the current, pulse-length, and vacuum capabilities required for the MFTF, TFTR, D III, and efficient beam (based on negative ions) development work.

The ORNL Plasma Technology Section participates in a variety of fusion plasma heating activites. An intense research and development program provided a dense (400 mA/cm^2), uniform ($\pm$5%), and quiescent ($\pm$10%) plasma from which 75 amperes of postive ions have been extracted at 40 kV. Neutral beam transport systems have been designed for use on several state of the art tokamaks (PLT, ISX, PDX, LPT and TNS). The development and qualification of four PLT injection systems was recently completed with operating parameters of 0.75 MW (1MW) neutral beam power per injector utilizing hydrogen (deuterium) extraction. Initial operation of two (four systems will be installed on PLT) of these systems at about half power produced record tokamak ion temperatures of about 2.3 keV.

ISX and PDX ion sources have been operated at plasma parameters consistent with 100 A extraction. The PLT transport system has been upgraded in pumping and will transport 50-60 keV neutral beams for pulses of 0.5 sec (0.1 sec) for PDX (ISX). Both ISX and PDX systems are in fabrication and assembly. LPT and TNS systems are in the conceptual phase and half scale ion sources are available for testing.

Future research and development includes simplifying and increasing the reliability of 40 to 80 keV injector systems. Energy recovery and negative ions are being studied and experimented with in order to address the high energy injection needs of the future. Three methods of negative ion extraction have been studied and beams of ∿0.5 amps were produced. Optics, scaling, gas efficiency, and electron contamination are now being assessed.

Computer simulation are available and are found to be an extremely valuable aid in every phase of this program.