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Accelerator & Fusion Research Division

To be published by Oak Ridge National Laboratory in Report ORNL/TM8498, 1982, entitled "Considerations of an Advanced Performance Fusion Engineering Device (FED-A)."

NEGATIVE-ION-BASED NEUTRAL BEAM SYSTEM FOR FED-A CURRENT DRIVE

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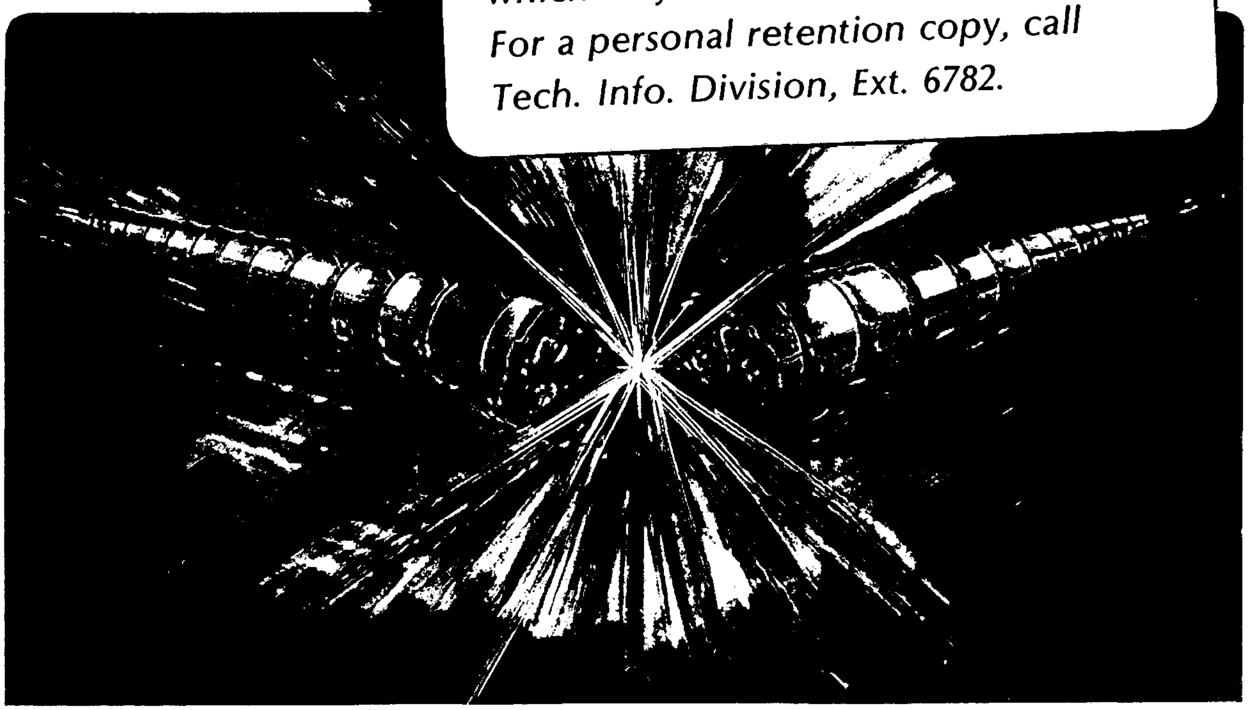
August 1982



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

DISCLAIMER

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In this report we present a preliminary study of the negative-ion based neutral beam system suitable for meeting current drive requirements of the FED-A tokamak.[1] This report will appear in slightly modified form as a subsection of Ref. 1.

Recent advances and new concepts in negative-ion-based neutral beam systems have enhanced the attractiveness of these systems for magnetic fusion applications. These new developments include 1) demonstration of DC H^- ion source operation at over 5 A per meter of source length,[2] 2) the concept of using strong-focussing electrostatic structures for low-gradient DC acceleration of high- current sheet beams and transport of these beams around corners,[3,4] and 3) the development of oxygen-iodine chemical lasers, which when combined with a configuring of the laser system in which the D^- beam passes through the laser cavity,[5] provides the realistic possibility of efficient conversion of negative ions to neutral atoms by photo- detachment of one electron from the negative ion.

We considered two options for the FED-A application: 1) a 400 keV, 50 MW system for periodic drive in the internal transformer mode,[1] and 2) an 800 keV, up to 100 MW DC system for steady state current drive. We have concentrated on the second option, as it was the more demanding.

This system was thought through to the "pre-conceptual" stage, meaning that space and vacuum requirements, electrode shapes and sizes, component feasibility, and overall system performance (e.g., currents, voltages, beam admittance) were considered, but no detailed engineering study was performed.

The proposed beamline is shown in plan view in Figure 1. The beamline design uses electrostatic strong focussing provided by alternating transverse electric fields[3,6] (the TFF or Transverse Field Focussing concept) in the pumping/transport section, in the main accelerator, and in the neutron shield. The main accelerator raises the D^- beam energy from 200 keV to 800 keV with low gradients (nowhere exceeding 40 kV/cm); the transverse fields can be expected to inhibit total column breakdown by preventing the acceleration of locally-produced electrons and positive ions through more than one stage. TFF sections are also used to transport the beam around two 60-degree bends in the channel through the neutron shielding. These bends, plus the duct configuration in the transport section (shown schematically in the insert in Figure 1) prevent line-of-sight shine-through of neutrons. Each sheet beam is 1.1 m high and 1.5 cm wide in the transport section, and carries 5.5 A. The beams are generated by surface-conversion negative ion sources of the types being developed at LBL and BNL; there are six of these sources per beamline, each 1.1 m high, three per channel. Each source has its own isolation valve. The beams from each set of three sources are aimed to intersect at the target.

Pumping is by cryopumps capable of on-line regeneration, under development at LLNL.[7] A 200 keV transport section is provided for beam matching and pumping; additional pumping is provided after acceleration to the final beam energy of 800 keV.

After transport around the final 60-degree bend, the negative ion beam passes through an array of vertically-oriented laser cavities, where approximately 97% of the negative ions are converted to neutral atoms by electron photodetachment. The length of this array in the beam direction is 3 m. Suitable lasers in the 10-kW range are now under development in programs funded by the Air Force. These oxygen-iodine chemical lasers operate at a wavelength of 1.3 microns, which corresponds to a photon energy adequate to remove the electron from a D^- ion, but inadequate to strip the electron from common impurity ions such as O^- and OH^-, or to create D^+ ions. The beam in the neutralizer is about 3 m high, but is very thin (a few cm) in the narrow direction, which permits efficient use of the lasers. This narrow cross section also permits electrostatic deflection of the remaining 3% of the negative ions and any impurities into an ion dump at one side of the beam.

The beamline vacuum vessel is a double-walled chamber constructed of low-activation 5254 aluminum alloy; the volume between the walls is filled with water for neutron moderation and absorption. The shielding thickness shown, 1 m, is probably thicker than is necessary. First estimates indicate that the 1.5 m thick neutron plug at the end of the beamline will attenuate the direct-streaming 14 MeV neutrons by a factor of 10^5, and that the ducts and bends will attenuate the slow neutrons by a factor of 10^3 to 10^4. More work is required in this area to obtain better estimates of these numbers and to verify that hands-on maintenance can be performed on the sources.

A single beamline would inject 25 MW of 800 keV deuterium atoms into FED-A; four ports would therefore be required for injection of 100 MW. For current drive, tangential injection would be used, as is shown in Figure 1. Analysis of a similar system[8] operating at 250 keV indicated an overall system power efficiency of the order of 70%. A higher overall power efficiency can be expected at 800 keV.

The major uncertainties center around the TFF acceleration and transport sections, and the laser photodetachment neutralizer. Transport has been demonstrated in an electron device using a similar principle,[9] but the first experimental demonstration of acceleration and transport of negative ion beams at relevant current densities by a TFF device will not take place for 2-3 years as presently scheduled. Laser development is proceeding independently of MFE, and is probably a lower-risk item than is the TFF accelerator. This beamline design requires an extrapolation by a factor of about 1.4 in deuterium negative ion current density at the ion source above what has been achieved experimentally at LBL. We expect at least this much progress in negative ion source development at either LBL or BNL or both, given the probable FED-A timescale.

The conclusion of this short study is that the injection of 100 MW of 800 keV deuterium atoms into FED-A is probably feasible, and can be considered as an option for current drive.

Acknowledgment:

This work was supported by the Director, Office of Energy Research, Office of Fusion Energy, Development and Technology Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF-00098.

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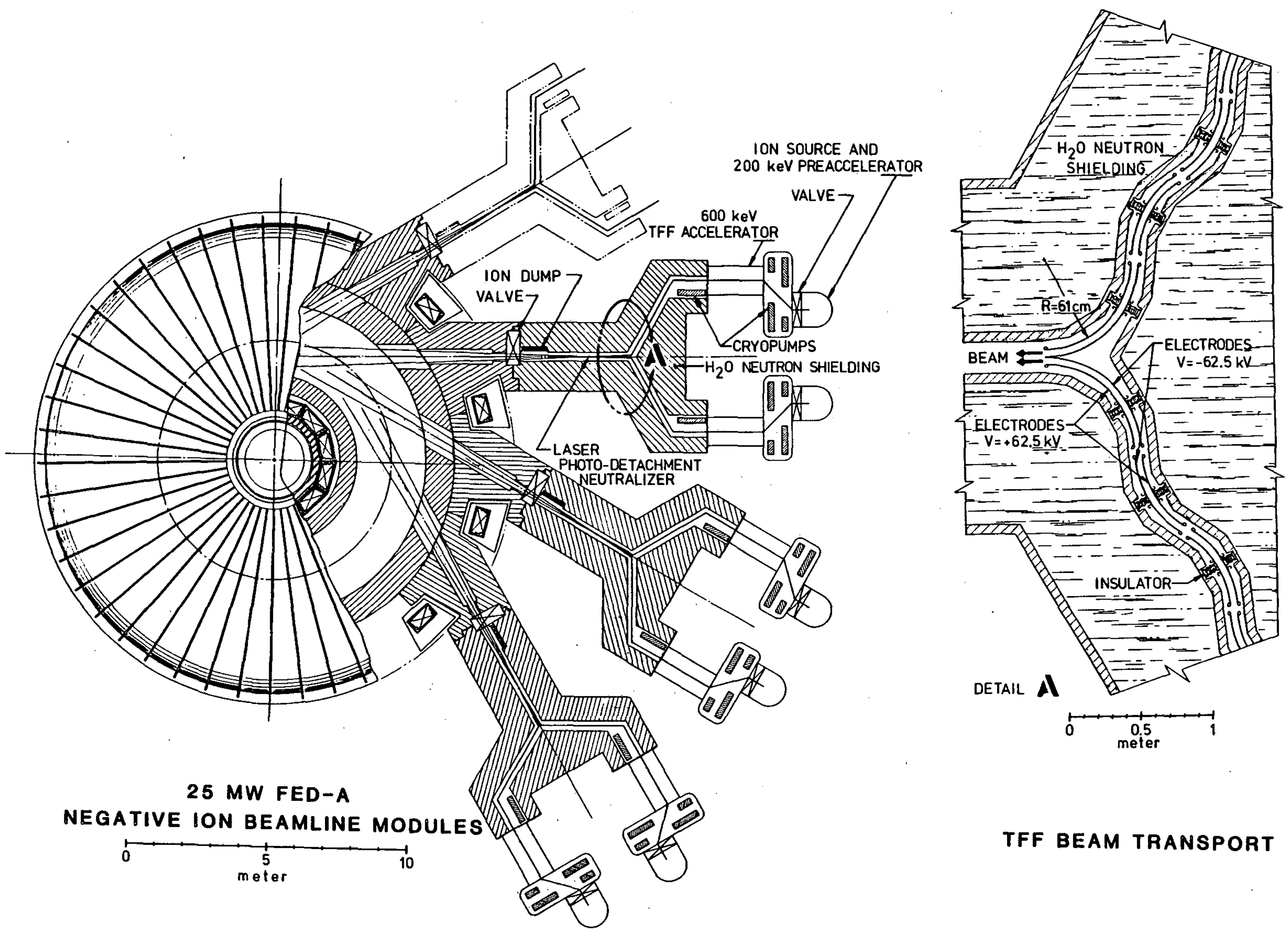
ION SOURCE AND
200 keV PREACCELERATOR
VALVE
600 keV
TFF ACCELERATOR
ION DUMP
VALVE
CRYOPUMPS
H_2O NEUTRON SHIELDING
LASER
PHOTO-DETACHMENT
NEUTRALIZER
25 MW FED-A
NEGATIVE ION BEAMLINE MODULES
0
5
10
meter
H_2O NEUTRON
SHIELDING
R=61cm
BEAM
ELECTRODES
V=-62.5 kV
ELECTRODES
V=+62.5 kV
INSULATOR
DETAIL A
0
0.5
1
meter
TFF BEAM TRANSPORT
XBL 828-11317

Figure 1

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