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NEUTRON PRODUCTION IN A HIGH-INTENSITY DEUTERIUM NEUTRAL BEAM FACILITY

Author
Berkner, K.H.

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Klaus H. Berkner, William S. Cooper, Joseph B. McCaslin and Robert V. Pyle

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Lawrence Berkeley Laboratory University of California/Berkeley

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NEUTRON PRODUCTION IN A HIGH-INTENSITY DEUTERIUM NEUTRAL BEAM FACILITY*

Klaus H. Berkner, William S. Cooper, Joseph B. McCaslin, and Robert V. Pyle
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

Yields of d-d neutrons, produced in various parts of a developmental high-power neutral-deuterium beam facility for magnetic fusion experiments, are being measured to provide input data for the design of shielding and diagnostics experiments.

Most of the multi-megawatt neutral-beam injectors used in the Magnetic-Fusion-Energy Program will operate with deuterium. Unavoidably, these injectors will generate large numbers of d-d neutrons. The main sources of neutrons will be the neutralizer, the ion-beam dump, the neutral-beam calorimeter and any collimators that intercept substantial amounts of beam. In the neutralizer, the beam interacts with deuterium in gaseous form, the density of which is fairly well known. The other sources exist because deuterons in the high-energy beams become imbedded in materials that they strike, and become high-density targets for following beam particles.

Estimates of neutron production and the shielding required have been based on low-current accelerator experiments, the status of which is described by Kim.[1] However, these experiments do not allow us to predict the consequences of the different conditions that will exist in the neutral-beam injection lines, e.g., higher surface temperatures and smaller angles of incidence on surfaces.

Prototype injectors for the Princeton TFTR tokamak are being designed, built and tested at the Lawrence Berkeley and Livermore Laboratories.[2] The nominal requirement is that each ion source accelerate 65 A of deuterium ions to 120 kV in 0.5 sec pulses. A fraction of the ion beam is neutralized while passing through a gas target, after which the ion and neutral beams are separated by a magnet. The high-power-density unneutralized ion beams are stopped on copper plates that are cooled between pulses. The neutral beam that eventually will be injected into the fusion plasma is stopped on a (retractable) calorimeter. This calorimeter, located after the sweep magnet, is instrumented to measure beam power density profiles so that the beam can be tuned up.

Until recently our experiments at energies above 40 keV have been carried out with protium (^{1}H) beams, because of the intense neutron radiation expected during high-power, high-voltage deuterium operation. A fractional-area TFTR source has been operated recently with protium at 120 kV, 14 A, 0.5 sec. This success allows us to switch to experiments with deuterium, but only occasional operation is possible because there is no radiation shielding to limit personnel exposure.

The measurements are made with two moderated BF_3 counters 8 meters apart. One is 1.5 m from the calorimeter, at 90^{o} to the beam line; the other is 2.5 m from the center of the neutralizer, again at 90^{o} to the beam line. Neither has any directional collimation at present.

The first experiments were made with 42 kV, 2 A, 0.5 sec deuterium pulses at intervals of one minute. We did not measure the molecular species mixture in the accelerated beam, but from other experiments, we estimate that about 50% of the accelerated ions are D^{+}, and the remainder are D_2^+ and D_3^+. (Because of the steep dependence of the fusion cross section on energy, most of the neutron production is due to the atomic-ion component.) The source strength approached a plateau in about 200 pulses, after which time the instantaneous source strength was roughly 10^8 n/sec at the neutralizer, and 10^9 n/sec at the calorimeter. These very approximate results at low power densities are in order-of-magnitude agreement without estimates from material in Ref. 1, and other references. With 120 kV, 10 A, 0.5 sec operation, the neutron yield plateaued in about one hour at an instantaneous neutron yield from the calorimeter of about 10^{11} n/sec, again roughly in accordance with our expectations.

As noted earlier, our neutral yield data must be obtained at a very slow rate because the beam line is in an unshielded area. In the future, additional measurements can be made on shielded beam lines now under construction: The High Voltage Test Stand at LLL and the TFTR prototype beam line at LBL. There also are questions that may be answered with facilities such as the rotating target neutral source at LLL, e.g., if a calorimeter is coated with a refractory material to reduce sputtering, how will the neutral production change?

Finally, we note that neutron measurements provide a useful diagnostic tool. For example, because the yield rises so rapidly with energy, we can use the neutron signal to adjust source conditions so as to maximize the full-energy (most useful) fraction of the neutral beam on the target. This approach complements a more sophisticated technique that has been developed to give the angular divergences and fractions of various energy components by analyzing Doppler-shifted light from the beam near the neutralizer.[3] Another diagnostic example is the measurement of density in the neutralizer with the aid of a collimated neutron detector.

In summary, neutral-beam-development technology has reached the stage where experimental data are being obtained from high-intensity systems for application to shielding and diagnostic problems.

References

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