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Thin foil Faraday collectors as a radiation hard fast lost-ion diagnostic

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We are investigating thin foil Faraday collectors as a diagnostic for lost fast ions from tokamak fusion plasmas. Prototype devices have been recently installed in the National Spherical Torus Experiment and DIII-D. Initial results from these devices indicate a loss of energetic ions from a variety of plasma conditions. Results from a device installed immediately outside a thin Be window on ALCATOR C-mod, as a test on the response to moderately intense fluxes of soft x rays indicate an upper limit of about 2×10^{-22} A/photon/cm^2 at a plasma electron temperature of 1.8 keV. An important property of the diagnostic is the expected ability to operate under fairly high neutron/gamma radiation backgrounds. We have tested this expectation by measuring the current from a thin (2.5 μm) Ni foil placed in the core of a TRIGA fission reactor. At a maximum steady-state power of 950 kW (10^{13} n/cm^2/s), a current of 1.2 nA/cm^2 was measured. © *2003 American Institute of Physics.* [DOI: 10.1063/1.1534400]

I. INTRODUCTION

The concept of thin Faraday collectors as charged particle spectrometers capable of operation in very hostile environments originated at JET in 1994 as part of an effort to develop a lost alpha particle diagnostic in preparation for their 1997 d-t experimental campaign. This effort included accelerator based testing at the University of Birmingham (U.K.)[1] and Sandia National Laboratory (U.S.),[2] *ex-vessel* testing at TFTR during their 1994 d-t campaign as a check on the calculated radiation insensitivity[1] and an in-vessel test (far from the plasma edge) in JET during a series of deuterium shots in 1995.[3] Following this preliminary testing, two devices, one consisting of four Ni foils, each a thickness of 2.5 μm and one consisting of two Ni foils, 250 μm thick, were installed near the plasma edge on JET and operated throughout the 1997 d-t campaign and continued operation until decommissioning in 2001.[4]

II. RECENT APPLICATIONS

Following the initial testing of the concept as just described, we have installed thin foil devices at a number of fusion plasma laboratories. On the National Spherical Torus Experiment (NSTX) a device consisting of a single 10 μm Ni foil at a major radius of 166 cm and two summed quartets of thick foils at major radii of 161 and 163 cm were installed near the torus midplane A more detailed description of this diagnostic is given elsewhere.[5] One of the experiments involving these collectors consisted of a series of neutral beam ‘‘blips,’’ typically 2.5 ms in duration and the measurement of the associated lost beam ions. Typical wave forms measured during the course of one of these shots is shown in Fig. 1. An initial analysis of these shots indicate that the total lost-ion charge is directly proportional to the time integrated beam power and inversely proportional to the derived plasma–wall gap and the plasma current (see Fig. 2). The analysis of these measurements is continuing.[6] A similar device consisting of two foils, one on each side of a midplane port located a few cm from the plasma edge has been recently installed on DIII-D. A photograph of the graphite housing of this detector mounted on the DIII-D wall is shown in Fig. 3. A recent shot indicates a strong correlation in one of the foils with the edge D-α signal and with precipitous drops in the neutron source strength (see Fig. 4). We are in the initial stages of our investigation of these losses on DIII-D. On ALCATOR C-mod, a detector similar to the ones on NSTX and DIII-D was installed *outside* of a thin Be window on a midplane flange The purpose of this device was two fold: (1) to measure the electromechanical noise associated with low current measurements on the outside of the machine as a rough estimate of the noise which might be encountered on the inside were such a device to be installed. We found this noise to be at the few nA/cm^2 level; (2) to determine the response of the foils to a moderately intense flux of soft x rays which, in turn, will affect the direction in the vacuum vessel at which the active

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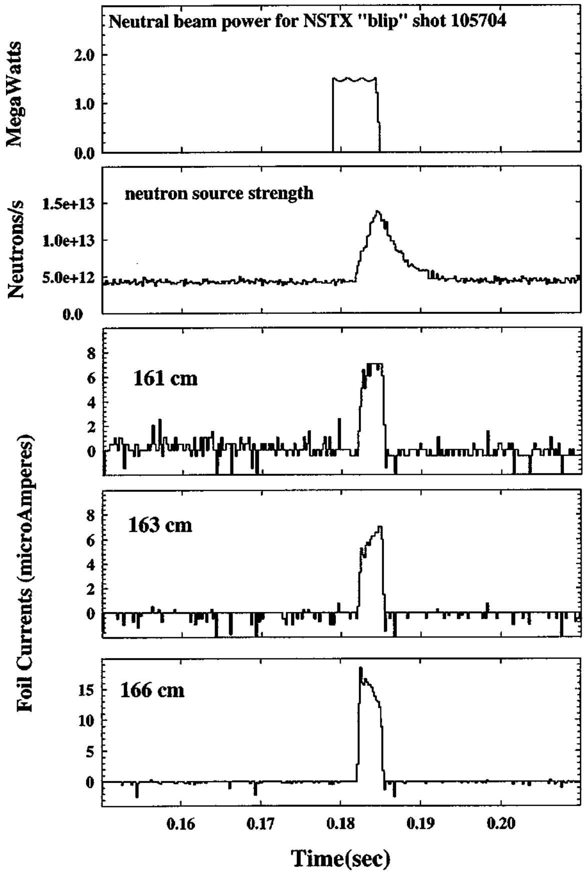

FIG. 1. Comparison of measured foil currents at major radii of 161, 163, and 166 cm on NSTX with beam power and neutron source strength during blip shot 105704.

areas of the foils might be oriented. No signal was seen and an upper limit of about 10^{-22} A/photon/cm^2 at an electron temperature of 1.8 keV was established.

An important attribute of thin Faraday foils as a diagnostic of lost ions from fusion plasmas is the relative insensitivity of neutron/hard gamma radiation. This insensitivity is de-

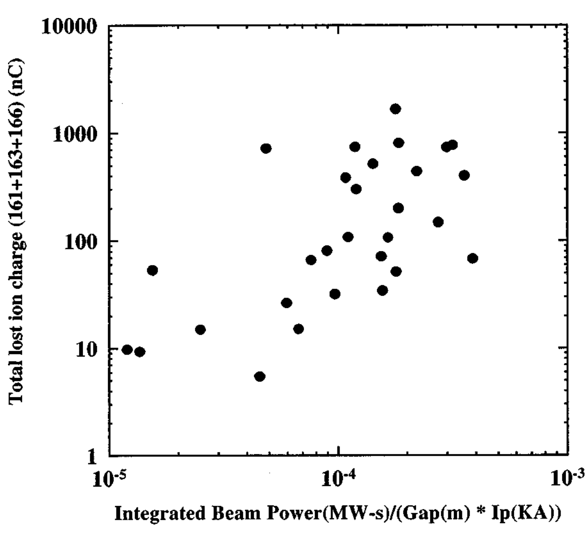

FIG. 2. Measured relationship between total lost-ion charges (integrals of currents as in Fig. 1) for beam blip shots on NSTX and the product of the beam energy with the reciprocal of the fitted plasma-edge gap and the plasma current.

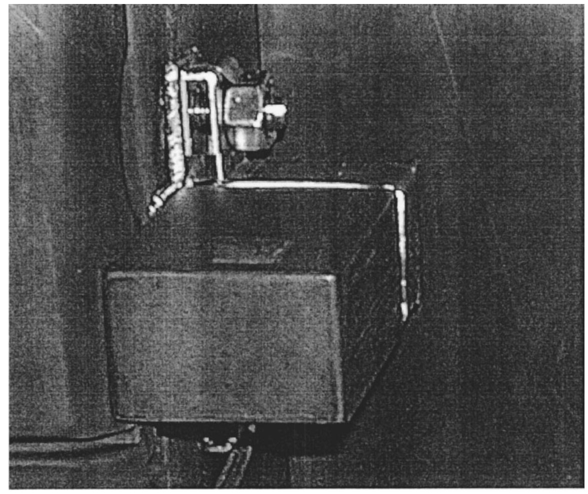

FIG. 3. Photograph graphite housing for foil detector at midplane on DIII-D. The aperture admitting the lost ions is facing upward.

rived from the fact that while a charged particle is registered with unit efficiency, a neutron or gamma ray is only registered when a charged particle is produced, for example, by an (n,p) or (n,α) reaction in the case of a neutron or photoelectric emission or Compton scattering in the case of a gamma ray. For neutrons and gamma rays with energies in the MeV range, this efficiency is about 10^{-3} for neutrons and about 10^{-4} for gamma rays for Ni foils with a thickness of a few μm. Because of the potential application of the Faraday foil collectors as a lost alpha particle diagnostic in future burning plasma experiments, we felt it important to

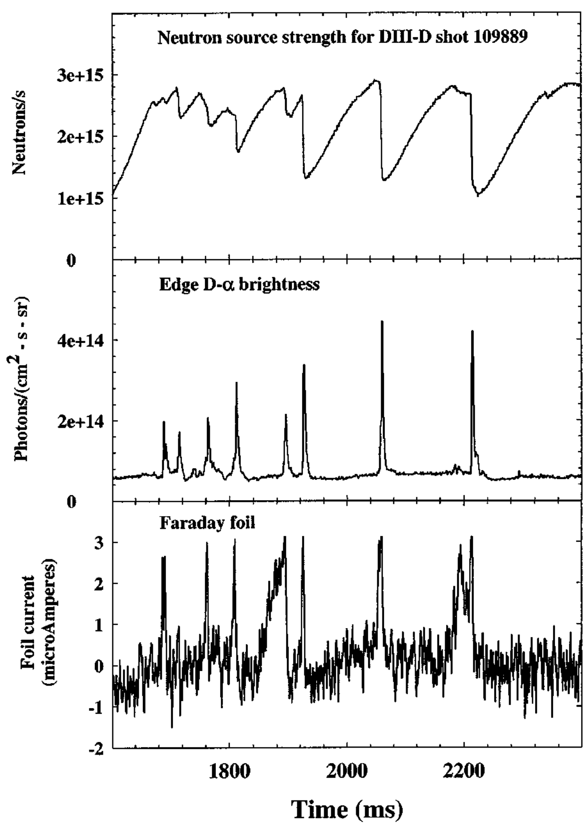

FIG. 4. Comparison of measured Farday foil current with edge D-α brightness and neutron source strength for DIII-D shot 109889.

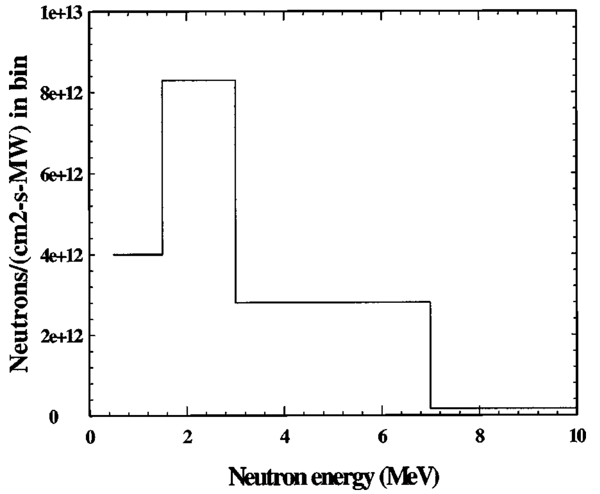

FIG. 5. The measured neutron energy spectrum at the center of the core of the United States Geological Survey TRIGA reactor. This spectrum was measured with a series of threshold activation reactions.

test this predicted insensitivity under realistic conditions. We have measured the current from a thin (2.5 μm) Ni foil placed at the center of the core of the TRIGA fission reactor at the Denver Federal Center. At a maximum steady-state power of 950 kW (corresponding to a fast neutron yield of $1E13$ n/cm^2/s), a current of $+1.2$ nA/cm^2 was measured (see Fig. 5). From an independent measurement of the neutron energy spectrum based upon a series of threshold activation measurements (see Fig. 6), and from the known (n,p) and (n,α) reaction cross sections on the isotopes of Ni, we would expect a measured current of about -0.5 nA/cm^2 (recall that positive charged particles leaving the foil will be measured as a negative electric current). The discrepancy between the measured and expected currents is probably due to secondary electrons knocked out of the foil by the energetic protons and alpha particles produced by the neutrons. Specifically, the yield of secondary electrons per energetic ion varies from about 1 to 3 for protons and alpha particles in the MeV energy range.[7] It is very important to point out that this measured current is a demonstration of the viability of the detector concept in the very harsh environments of the future burning d-t plasmas. Specifically for a 100 MW d-t plasma in a machine with a wall area of 200 m^2 (such as JET), there will be a fast neutron flux at the wall of $1.5E13$ n/cm^2/s. Extrapolating our observed current in the fission reactor at a flux of $1E13$ n/cm^2/s, we would thus expect a neutron induced background of a few n/cm^2. This neutron induced background current should be compared to the current from the lost alpha particles. For this scenario (100 MW fusion power and 200 m^2 wall area) a loss of 10% of the alpha particles distributed uniformly over the vessel wall will result in a measured current of 600 nA/cm^2, well above the neutron induced background current. The hard gamma flux at the foil during the fission reactor experiment was comparable to the fast neutron flux and, consequently, the gamma induced current (photoemission and Compton scattering) should be at least an order of magnitude less than that of the neutron induced current by virtue of the cross section for the gamma induced reactions compared to the (n,p) and (n,α) reactions induced by the neutrons.

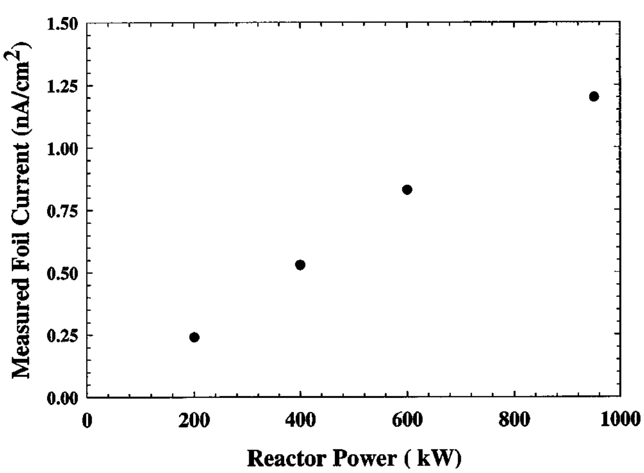

FIG. 6. Comparison of current through foil at center of reactor core with reactor power. The total neutron flux at the foil is about $1E13$ n/cm^2/s at a reactor power of 950 kW.

III. CONCLUSION

Initial results from Faraday foil detectors deployed at NSTX and DIII-D indicate potentially interesting correlations between measured foil currents and other plasma parameters. The detector placed outside a thin Be window on ALCATOR C-mod has established an upper limit of 10^{-22} A/photon/cm^2 for currents induced by a 1.8 keV electron temperature plasma. Finally, the current at the core a fission reactor was measured to be 1.2 nA/cm^2 at a fast neutron flux of 10^{13} n/cm^2/s. This measured current suggests the viability of thin Faraday collectors as the basis of a lost alpha particle diagnostic for future burning plasma experiments.

ACKNOWLEDGMENTS

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