EFDA–JET–CP(10)03/17

D.S. Darrow, F.E. Cecil, V. Kiptily, K. Fullard, A. Horton, A. Murari
and JET EFDA contributors

Observation of Alpha Particle Loss from JET Plasmas during ICRF Heating Using a Thin Foil Faraday Cup Detector Array

Observation of Alpha Particle Loss from JET Plasmas during ICRF Heating Using a Thin Foil Faraday Cup Detector Array

D.S. Darrow[1], F. E. Cecil[2], V. Kiptily[3], K. Fullard[3], A. Horton[3], A. Murari[4]
and JET EFDA contributors*

JET-EFDA, Culham Science Centre, OX14 3DB, Abingdon, UK

[1]Princeton Plasma Physics Laboratory, Princeton, New Jersey 08543, USA
[2]Physics Department, Colorado School of Mines, Golden, Colorado 80401, USA
[3]EURATOM/CCFE Fusion Association, Culham Science Centre, OX14 3DB, Abingdon, OXON, UK
[4]Consorzio RFX-Associazione EURATOM ENEA per la Fusione, I-35127 Padova, Italy
** See annex of F. Romanelli et al, "Overview of JET Results",*
(Proc. 22nd IAEA Fusion Energy Conference, Geneva, Switzerland (2008)).

Preprint of Paper to be submitted for publication in Proceedings of the
18th High Temperature Plasma Diagnostics, Wildwood, New Jersey, USA.
(16th May 2010 - 20th May 2010)

ABSTRACT.
Loss of MeV alpha particles from JET plasmas has been measured with a set of thin foil Faraday cup detectors during third harmonic heating of helium neutral beam ions. Tail temperatures of ~2 MeV have been observed, with radial scrape off lengths of a few cm. Operational experience from this system indicates such detectors are potentially feasible for future large tokamaks, but careful attention to screening RF and MHD induced noise is essential.

1. INTRODUCTION

Magnetically confined fusion plasmas may be heated by Neutral Beam Injection (NBI), RF produced ion tails and, ultimately, fusion produced alpha particles. All of these methods rely on superthermal ions. Any loss of these ions diminishes heating efficiency and can potentially damage the wall of the vessel. For these reasons it is desirable to measure the loss rate of fast ions to the wall in order to understand the processes engendering the losses. The Joint European Torus (JET) is capable of applying all the above-mentioned heating methods and thus serves as an excellent test bed for development of loss diagnostics that could be used on larger future devices, such as the International Thermonuclear Experimental Reactor (ITER). It serves, similarly, as an ideal facility for investigation of fast ion loss physics.

2. INSTRUMENT

A loss diagnostic based upon stacks of thin foil Faraday cups has been implemented on JET. This instrument has been previously described [1,2] and consists of five pylons supporting detectors at different poloidal angles, allowing determination of the distribution of the loss vs angle. At each angle, there are detectors at three different positions in minor radius, permitting measurement of the radial scrape off or decay length of the fast ions. Each detector consists of a stack of thin nickel foils separated by mica insulators. The foils are instrumented so that the fast ion current reaching each can be recorded as a function of time, with nA accuracy. The distance that an ion must travel through the various layers to reach a particular foil determines the energy range of that foil. For deuterium and helium ions and the few micron thickness foils used in this system, the foils are sensitive to particles in the range of ~0.5−7MeV, as enumerated in Table I.

Foils in the detector are designated by a three digit sequence, given as PRD, where P is the pylon number (1 for the uppermost pylon), R is the radial position (1 for detector closest to the plasma, 3 for the detector closest to the wall), and D is the foil depth within the stack (1 for the first foil encountered by an entering ion). Previous tests of this sort of detector in fission reactors have shown negligible currents are induced by neutrons and gamma rays [4].

3. LOSS MEASUREMENTS

Figure 1 shows, as a function of time, the auxiliary heating power and currents measured in several foils in the top pylon in a 2MA, 2.4T discharge in JET with third harmonic He RF heating. The three traces plotted show successively smaller currents progressing from shallower to deeper in the stack (lower to higher ion energy), in accordance with the expected fast ion distribution where the abundance diminishes with increasing energy. Foil 134 is at the back of the foil stack, and its cabling runs along the same path as the other foils. Since it receives only the highest energy ions, where the current is very small or absent, it serves as an indicator of any RF pickup or noise in the detector. Although early operation of this detector revealed some RF pickup that could be mistaken for ion current, we are confident this pickup has been completely filtered out of the signals (see below for more details) and that the data presented here is true MeV alpha particle current striking the detector. This interpretation is further supported by gamma ray measurements showing the emission of gamma lines excited only by alphas with energies in excess of 4MeV. In addition, the peak neutron rate in this pulse is 6×10^{13} n/s, indicating a very low fraction of D among the fast ions. As such, this constitutes the first clear observation of MeV alpha loss using the Faraday cup technique.

Figure 2 displays the fit of a tail ion temperature to the foil 31x current data, giving an inferred temperature of 2.24MeV. A similar fit to foils 11x gives a tail temperature of 2.10MeV, in very good agreement with the 31x data. For these fits, the foil currents have been averaged over the full duration of the RF pulse.

Because there are three detectors on each pylon, it is also possible to fit a radial decay length or scrape off length to the loss currents. Figure 3 depicts two such fits, both giving a decay length of ~4.2cm. Since this decay length is the same for two different energy ranges, it suggests that it represents the scale of the source profile of the energetic ions and not a scale characteristic of their radial diffusion

4. OPERATIONAL EXPERIENCE

The Faraday cup array was installed in JET in 2005. The foil stacks were assembled from discrete nickel foils and 2.5μm phlogophite mica sheets. When installed, the array had 41 functional foils. In the ensuing five years, up to this writing, JET has run more than 10,000 plasma pulses. At present, 26 foils are still functional. Most of the remainder have shorted to adjoining foils, although a few have failed due to a break in the wire leading to the foil or in the thin lead that connects the main collection foil to a terminal block inside the detector assembly. During assembly of the foil stacks, a number of foil to foil shorts arose that could be traced back to minute fractures in the mica sheets creating small holes in the insulating layers that could permit shorting when the compression spring beneath the stack was installed. We conjecture that similar breakage in the mica layers has developed while the diagnostic has been in service. Each plasma pulse delivers shock and vibration to the vacuum vessel, which can stress the foil stacks. We note also that the phlogophite mica used was not absolutely planar but was slightly wavy, providing the opportunity for stresses to localize and induce cracking. Although the more commonly used muscovite mica would have been flatter and might have avoided these failures, the anticipated peak foil temperatures would have caused decomposition of the muscovite, possibly also leading to shorting of adjoining foils. Ultimately, we recommend that future implementations of thin foil Faraday cup detectors be based upon thin film deposition on a solid substrate. This would avoid the potential problem of mechanical breakage of the insulating layers. In addition, such deposited layers are in much better thermal contact with each other, allowing thermal transport in three dimensions rather than the two dimensional heat conduction on which the present detector must rely.

Another topic of operational importance is that of spurious signals in the detector system. This array has proven sensitive to several sources of such signals. First, the front foil in each stack is instrumented to measure current. Although these foils have no direct line of sight to the plasma, there is evidence of electron photoemission from the front foil due to plasma produced UV light reflected from the vessel or nearby structures5. Similarly, even though these front foils are recessed in 3mm deep holes in the cover plate, with no connection path along magnetic field lines to the plasma, there is data suggestive of Langmuir probe type behavior of these front foils, perhaps from rapidly diffusing tenuous edge plasma. Given these confounding signals, we recommend future detectors be constructed with a thin, grounded conducting layer as the first element in the stack.

The second set of spurious signals can be generally categorized as inductive pickup. These have been observed from several sources, namely the ICRF heating system, the confining magnetic field coils of JET, and magnetohydrodynamic (MHD) activity. In the case of RF pickup, apparent currents were seen during ICRF heating, even in foils whose depth would make them sensitive only to particles above 100 MeV, which would not be present in JET. This noise was remedied by installation of two series 90 dB 1.9 MHz low pass filters on each channel along with ferrite beads around each coaxial cable from the vessel to the electronics. Since this filtering system was in place, there have been many hundreds of RF pulses with no evidence of such noise. It is on the basis of the absence of RF pickup in these pulses and the corroborating evidence of the gamma ray lines that we assert the data presented in Figs. 1–3 are real fast ion signals.

Figure 4 shows a pulse that exhibits both magnetic field coil and MHD pickup. The field coil pickup varies slowly (i.e. on the 0.1–1 s time scale) and is evident at the start and end of the plasma current, at 0 and 18 s, respectively. This signal is fairly predictable and it should be possible, with some further effort, to determine the applicable mutual inductances and subtract it from the digitized data. The MHD pickup is the higher frequency, bipolar noise seen between ~5 and 11 s. Because this is an NBI only discharge, this signal cannot be attributed to fast ions–there is not a sufficient population of ions at the energy needed to reach the foil shown. Consequently, this must be pickup. Because MHD activity can modulate fast ion loss at the mode frequency, it is very challenging to imagine how MHD induced fast ion loss can be distinguished from MHD pickup in this detector.

We believe that all of the types of inductive pickup seen arise in the cabling inside the JET vacuum vessel. There, the Faraday cup signals are carried on single insulated wires in a covered cable tray with little noise screening (these were the only wires available for use at the time this diagnostic was designed and built, and they had been adequate for a previous prototype of this diagnostic.) For future Faraday cup implementations, we recommend strictly coaxial cabling in order to minimize this pickup, especially near the plasma. The signal vacuum feedthroughs are also single pin feedthroughs and this is another potential source of noise. Coaxial vacuum feedthroughs should be used in future installations.

ACKNOWLEDGEMENTS

This work supported by Euratom and by US DoE contract DE-AC02-09CH11466 and carried out within the framework of the European Fusion Development Agreement. The opinions expressed herein do not necessarily reflect those of the European Commission.

REFERENCES

[1]. D.S. Darrow, S. Bäumel, F.E. Cecil, V. Kiptily, R. Ellis, L. Pedrick, A. Werner, Review of Scientific Instruments **75**, 3566 (2004).

[2]. D.S. Darrow, S. Bäumel, F.E. Cecil, B. Ellis, V. Kiptily, L. Pedrick, M. Reich, A. Werner, Review of Scientific Instruments **77**, 10E701 (2006).

[3]. J. Zeigler, et al., http://www.srim.org

[4]. F.E. Cecil, A. Aakhus-Witt, J. Hawbaker, J. Sayers, A. Bozek, W. Heidbrink, D. Darrow, T. Debay, E. Marmar, Review of Scientific Instruments **74**, 1747 (2003).

[5]. F. E. Cecil, et al., these proceedings.

Foil number	Thickness (μm)	α energy range (MeV)	D energy range (MeV)
1	2.5	0–1.58	0–0.54
2	2.5	2.35–3.68	0.78–1.18
3	4.0	4.24–5.87	1.35–1.83
4	2.5	6.32–7.17	2.00–2.16

Table I: Energy ranges of D and 4He ions reaching the various foils in a standard stack in the JET detector, as computed by the SRIM code3 and including 2.5 micron phlogophite mica insulators between each pair of foils.

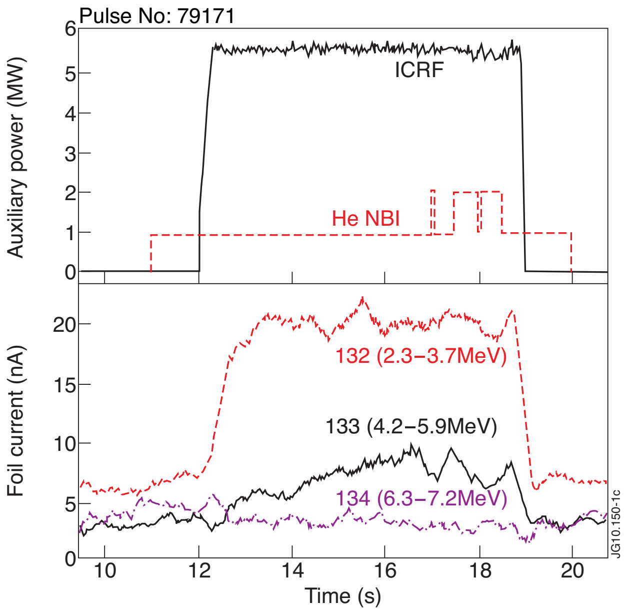

Figure 1: Auxiliary heating power and thin foil Faraday cup currents for a JET discharge with He NBI and third harmonic RF heating of the injected He. The signals show diminishing current at increasing energy, as expected. There is essentially no current in foil 134, indicating also the absence of RF pickup.

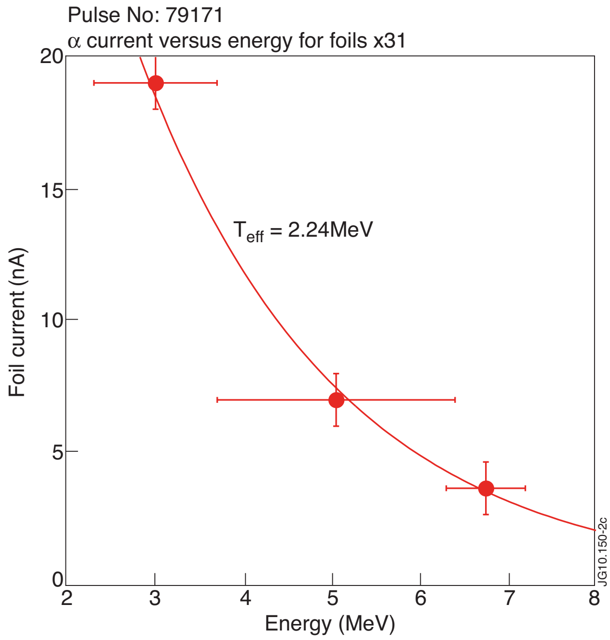

Figure 2: displays the fit of a tail ion temperature to the foil.

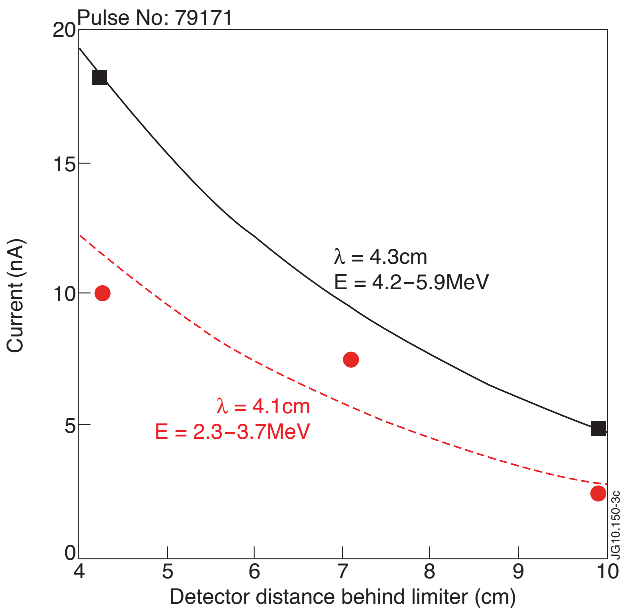

Figure 3: Fits of radial decay lengths to currents from two different energies. Both yield a length of ~4 cm.

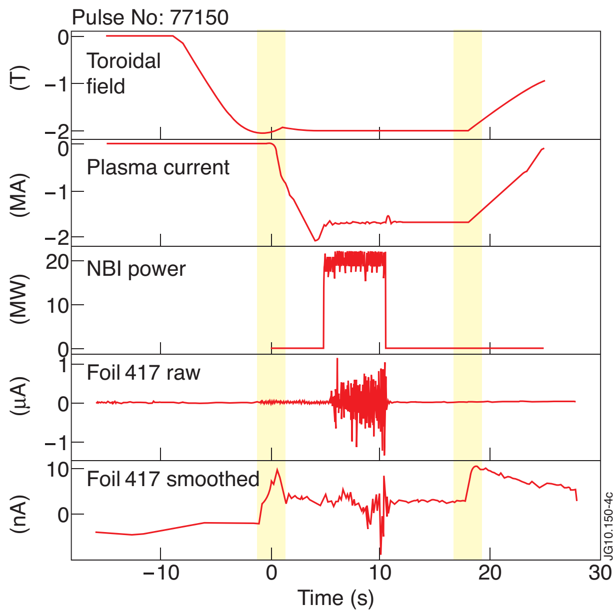

Figure 4: Field coil and MHD induced noise.