PREPARED FOR THE U.S. DEPARTMENT OF ENERGY,
UNDER CONTRACT DE-AC02-76CH03073

PPPL-3947
UC-70

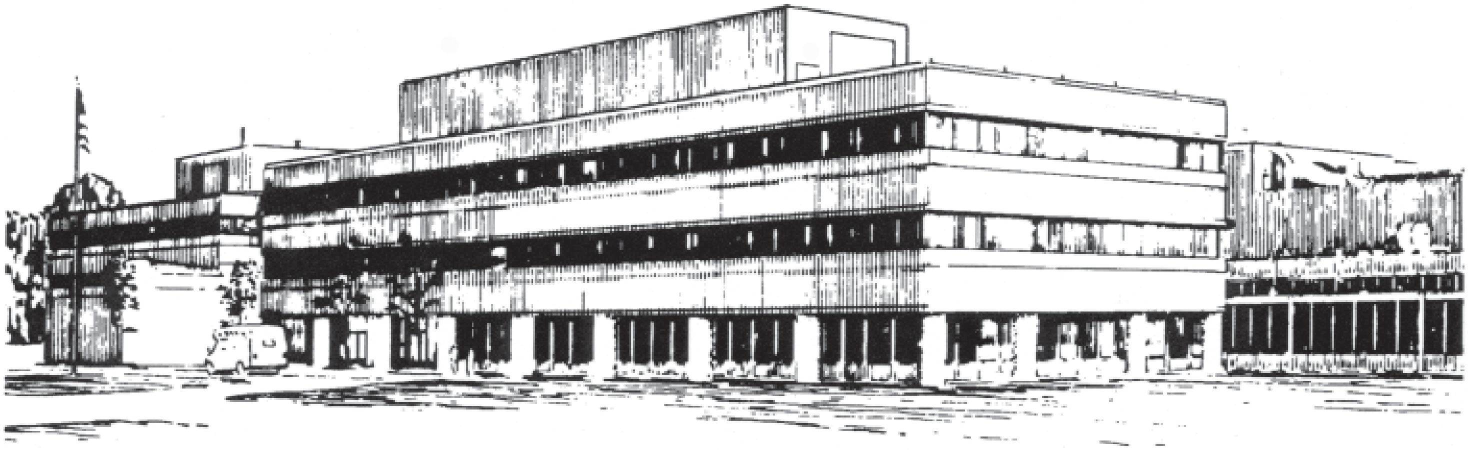
PPPL-3947

Design and Construction of a Fast Ion Loss Faraday Cup Array

by

D.S. Darrow, S. Bäumel, F.E. Cecil, V. Kiptily,
R. Ellis, L. Pedrick, and A. Werner

April 2004



PRINCETON PLASMA PHYSICS LABORATORY
PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY

PPPL Reports Disclaimer

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Availability

This report is posted on the U.S. Department of Energy's Princeton Plasma Physics Laboratory Publications and Reports web site in Fiscal Year 2004. The home page for PPPL Reports and Publications is: http://www.pppl.gov/pub_report/

DOE and DOE Contractors can obtain copies of this report from:

U.S. Department of Energy
Office of Scientific and Technical Information
DOE Technical Information Services (DTIS)
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865) 576-8401
Fax: (865) 576-5728
Email: reports@adonis.osti.gov

This report is available to the general public from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Telephone: 1-800-553-6847 or
(703) 605-6000
Fax: (703) 321-8547
Internet: http://www.ntis.gov/ordering.htm

Design and Construction of a Fast Ion Loss Faraday Cup Array Diagnostic for JET

D. S. Darrow[1], S. Bäumel[2], F. E. Cecil[3], V. Kiptily[4], R. Ellis[1], L. Pedrick[4], and A. Werner[2]

[1]Princeton Plasma Physics Laboratory

[2]Max Planck Institute for Plasma Physics

[3]Colorado School of Mines

[4]UKAEA Culham Laboratory

A thin foil Faraday cup array is being built to measure the loss of 3.5 MeV alpha particles and MeV ion cyclotron heating (ICH) tail ions on JET. It will consist of nine detectors spread over five different poloidal locations and three radial positions. They will measure the poloidal distribution and radial scrape off of the losses. The detectors will be comprised of four layers of thin (2.5 micron) Ni foil, giving some resolution of the lost particle energy distribution as different ranges of energies will stop in different layers of the detector. One detector will utilize eight thinner (1.0 micron) foils to obtain a better-resolved energy distribution. These detectors will accept particles incident up to 45° from the normal to the foils

Introduction

Magnetically confined fusion plasmas of the present and future rely on good confinement of energetic ions, e.g. ion cyclotron heating (ICH) tail ions or fusion-produced alpha particles, to maintain efficient heating. Conversely, poor confinement of the fast ions would not only impede heating, but could also damage the first wall surrounding the plasma. Measurement of fast ion losses allows determination of which plasma conditions promote or impede good fast ion confinement, and also can provide information about processes internal to the plasma that have induced the losses. The Joint European Torus (JET) has substantial ICH capability, and may also conduct future experiments with deuterium-tritium (DT) plasmas that would generate 3.5 MeV alpha particles. Consequently, it is an ideal facility in which to install fast ion loss diagnostics. In addition, the design and construction of a fast ion loss diagnostic for JET will have application to the International Thermonuclear Experimental Reactor (ITER). In particular, a loss diagnostic for JET will have to operate at elevated vessel temperature (250 C) and in a challenging neutron/gamma radiation environment (if DT operation proceeds). Two projects are underway to implement fast ion loss diagnostics for JET in 2005, a Faraday cup array described here and a scintillator probe described in a companion paper.[1] The system described here will replace a previously operating thin foil Faraday cup loss detector in JET.[2,3]

Design Goals

Interesting fast ion loss physics topics for JET include prompt orbit loss from optimized and reversed shear discharges, MHD induced loss, ICH tail ion loss, and ICH induced radial diffusion,. For all of these, resolution of the loss versus poloidal position on the wall, versus minor radial position, and good resolution in time are desirable. The Faraday cup array design provides these characteristics, with five poloidal positions, three radial locations, and a time resolution of 1 ms (1 kHz sampling). The system, because of a logarithmic detection system, will also have a eight decades of dynamic range.

Detector Arrangement

The design of the detector array has had to meet numerous constraints, including the ability of the supporting structure to withstand large electromagnetic forces due to halo currents during plasma disruptions. Carbon-carbon composite tiles will protect the detectors from plasma heat flux. The Faraday cups will be mounted in array at a single toroidal position, but extending poloidally from near the midplane to ~0.7 m below it, as shown in Fig. 1. The array is supported by a curved inconel I-beam which is attached to the vacuum vessel. Five “pylons” project from the I-beam toward the plasma and each pylon can contain up to three thin foil Faraday cup stacks. At the inner end of each pylon is a circular carbon-carbon composite tile to protect the detectors from plasma heat flux. The curved I-beam is mounted by a pin into its lower support and a doubly-hinged link at its upper end. This arrangement allows the beam to expand thermally at a rate different from that of the vacuum vessel without inducing additional stresses in the supporting structure.

An exploded view of an individual inconel pylon is shown in Fig. 2. The top plate contains three arrays of holes to admit fast ions to the foil stack–one array for each detector location within the pylon. Each Faraday cup assembly will consist of alternating layers of 2.5 μm Ni foil and 2.5 μm phlogphite mica sheets. The mica sheets insulate between adjoining foils, and phlogophite was chosen because of its ability to withstand temperatures over 1000 C, the calculated worst-case temperature the foils might reach. The fast ion currents reaching each foil will be transmitted to wires at a terminal block adjoining each stack. Glidcop wires will carry the signals to plug assemblies that will connect to pre-existing signal receptacles mounted inside the JET vessel. The recesses in each pylon that will hold the foil stacks will be flame sprayed with alumina to prevent shorting the foils to the pylon body.

The spacing between pylons was chosen to be approximately twice the DT alpha particle gyroradius under normal conditions in order to minimize the blocking of orbits reaching a detector by adjoining detectors. The detectors were moved as close to the plasma as deemed prudent by the engineering staff: the front face of each protective tile is 5 mm farther from the plasma than is the poloidal limiter. The tiles are 25 mm thick, the thinnest considered feasible for the heat flux generated by the plasma.

Each pattern of apertures consists of 112 3 mm diameter holes, giving a total active area of 792 mm^2. The aperture hole patterns extend 31 mm along the top of the pylon in the radial direction and 67 mm toroidally. As a consequence of the tile setback noted above and the 45° inclination of each pylon (described below), the pattern centers are at 46, 74, and 102 mm behind the poloidal limiter. Each hole is 3 mm diameter in a 3 mm thick inconel plate, giving a large solid angle from which fast ion loss orbits are accepted. This choice of aperture aspect ratio was made to enhance the generally low signal levels and it has the associated consequence that the detectors have very little selectivity in pitch angle.

The long axis of each pylon is inclined 45° above the normal to the surface of the I-beam at that pylon's mounting point. This insures, in spite of the large aperture opening angle, that none of the foils have a direct line of sight into the plasma. This prevents possible photoemission from the foil surface from plasma-generated UV and soft X-rays, a signal which could be easily confused with fast ion deposition in the foils. Finally, each pylon is rotated in its mounting plane on the I-beam to turn the apertures toward the flux of co-going fast ions. Inclination in this direction is limited by a nearby beryllium evaporator: there should be no direct line of sight from the evaporator head onto the foil surfaces, so that a Be coating does not accumulate on the foil stack and change its energy calibration. The resultant inclination angles this constraint imposes are, starting from the top pylon and continuing down, 20°, 20°, 15°, 0°, and 0°.

For the bottom pylon, better energy resolution will be obtained by using eight 1.0 μm thick Ni foils. The aperture holes for this detector will be only 1.6 mm in diameter. In each pylon, the location closest to the plasma will always contain a foil stack. In the pylons at poloidal positions of 9° and 21°, all three positions will be populated with foil stacks in order to measure the radial scrape off profile of the fast ions.

Anticipated Signal Levels

The DT alpha particle signal levels expected for a range of plasma currents and toroidal field values are shown in Fig. 3 for the detectors closest to the plasma. These calculations have been made with the Lorentz orbit code[ref Felt], using actual plasma equilibria and fusion source rate profiles from several JET plasmas from its 1997 DT experiments. Signal levels are detectable over a reasonably wide range of conditions. Signal levels for the detector positions farthest from the plasma for each poloidal position and each assumed plasma are calculated to be roughly a factor of ten less than the signal levels shown in Figure 3, indicating the radial scrape off of alpha particles will be measurable under at least some conditions. Note that the loss rate of DD fusion products will be ~100 times smaller than that of DT alpha particles and, given the noise levels, is not expected to be measurable in most circumstances. On the other hand, losses of the energetic protons during D-^{3}He plasmas should be observable by virtue of the very large gyroradius.

Calculation of the expected ICH tail ion loss rate is a complex effort and has not been attempted in the process of designing these detectors. The loss currents could exceed the alpha particle currents by several orders of magnitude in some situations. The large dynamic range of the detection electronics should allow measurement of these losses.

Signal Transmission and Detection

Current from each Faraday foil is carried from outside the vessel to detection electronics ~100 m away. To minimize EMI effects on the signal, “superscreened” coaxial cables[4] are used in this long cable run. Each foil is instrumented with a logarithmic amplifier[5] capable of registering currents from 100 pA to 10 mA with a 1 kHz bandwidth. A total of 44 foils and channels of instrumentation are planned.

The entire diagnostic is intended to be operational beginning in spring 2005.

Acknowledgements

This work is supported by US Department of Energy contracts DE-AC02-76CH03073 & DE-FG03-95ER54303 and conducted under EFDA.

References

1. S. Bäumel, *et al.,* these proceedings.
2. O.N. Jarvis, *et al., Fus Tech* **39**, 84 (2001).
3. F.E. Cecil, *et al., Rev. Sci. Instrum*. **70**, 1149 (1999).
4. Canberra MM20/75 and equivalent.
5. Analog Devices AD8304ARU

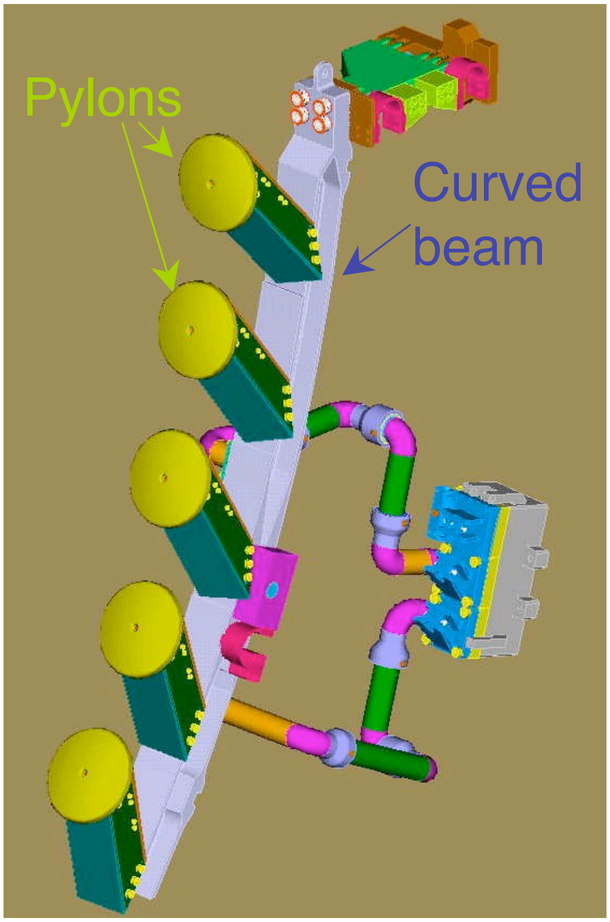


Figure 1: View of the Faraday cup detector array inside the JET vacuum vessel. The detectors are mounted on five "pylons" which are supported by a curved I-beam mounted to the vacuum vessel. Each of the pylons can contain up to three thin foil Faraday cup stacks.

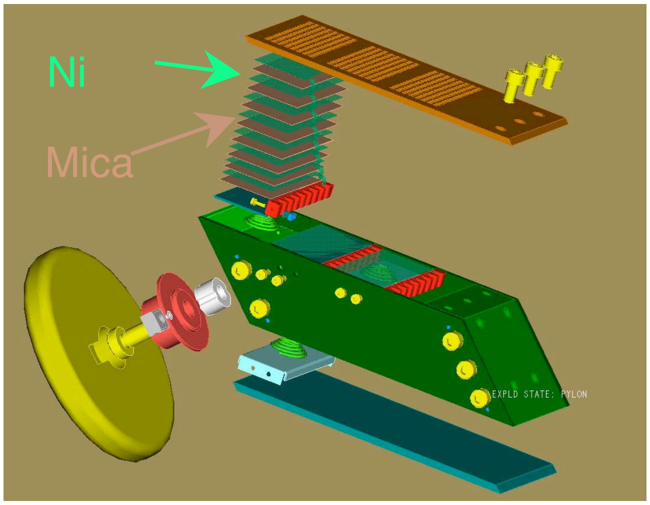


Figure 2: Exploded view of a single pylon, showing the top plate with aperture holes, a stack of alternating Ni foils and mica insulators, terminal blocks, foil stack mounting recesses, backing plate and spring, and carbon-carbon composite protective tile with mounting hardware.

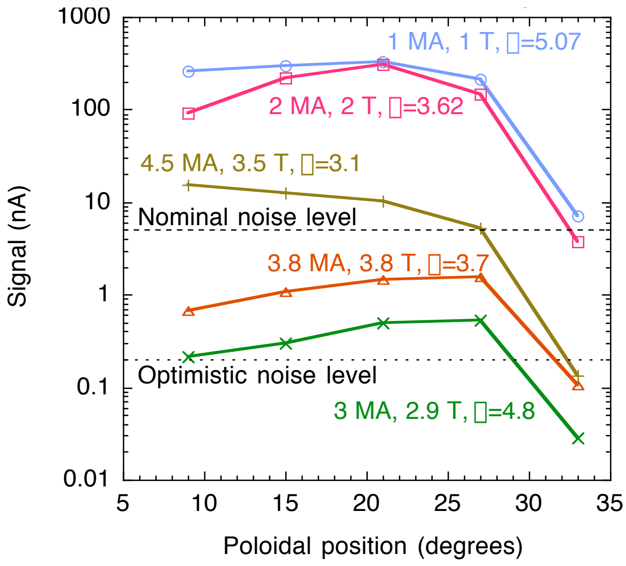


Figure 3: Calculated DT alpha particle loss currents at the detector position closest to the plasma in each pylon. Calculations are based upon actual magnetic equilibria for JET DT discharges, with an alpha source profile of the form $S(p) = S_0\ (1\text{-}p)^{\square}$, where p is the normalized poloidal flux at a given position (0 on the magnetic axis and 1 at the separatrix or last closed surface), □ is an exponent to match the experimentally observed profile, and S_0 is a constant. The line marked “Nominal noise level” is the noise level expected from a previous Faraday cup detector on JET, adjusted for the wider bandwidth of this system. The line marked “Optimistic noise level” assumes the data has been filtered to a bandwidth of 50 Hz and that common mode noise subtraction has been employed.

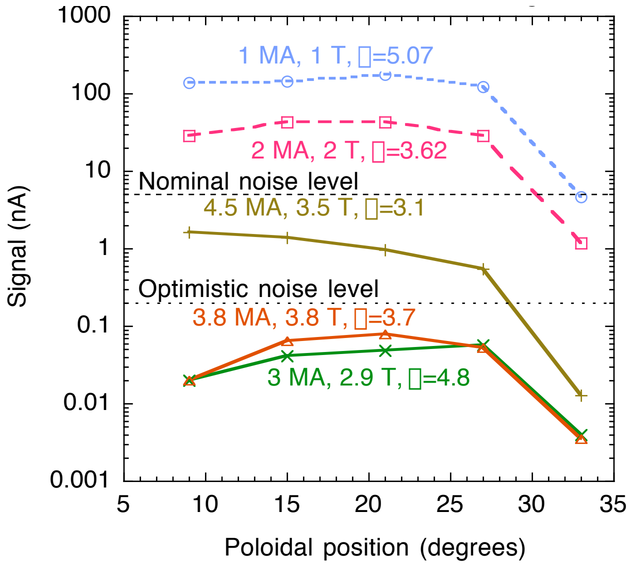


Figure 4: Calculated signal level for the detector position in each pylon farthest from the plasma. Cases and designations are as in Fig. 3.

External Distribution

Plasma Research Laboratory, Australian National University, Australia
Professor I.R. Jones, Flinders University, Australia
Professor João Canalle, Instituto de Fisica DEQ/IF - UERJ, Brazil
Mr. Gerson O. Ludwig, Instituto Nacional de Pesquisas, Brazil
Dr. P.H. Sakanaka, Instituto Fisica, Brazil
The Librarian, Culham Laboratory, England
Mrs. S.A. Hutchinson, JET Library, England
Professor M.N. Bussac, Ecole Polytechnique, France
Librarian, Max-Planck-Institut für Plasmaphysik, Germany
Jolan Moldvai, Reports Library, Hungarian Academy of Sciences, Central Research Institute for Physics, Hungary
Dr. P. Kaw, Institute for Plasma Research, India
Ms. P.J. Pathak, Librarian, Institute for Plasma Research, India
Ms. Clelia De Palo, Associazione EURATOM-ENEA, Italy
Dr. G. Grosso, Instituto di Fisica del Plasma, Italy
Librarian, Naka Fusion Research Establishment, JAERI, Japan
Library, Laboratory for Complex Energy Processes, Institute for Advanced Study, Kyoto University, Japan
Research Information Center, National Institute for Fusion Science, Japan
Dr. O. Mitarai, Kyushu Tokai University, Japan
Dr. Jiangang Li, Institute of Plasma Physics, Chinese Academy of Sciences, People's Republic of China
Professor Yuping Huo, School of Physical Science and Technology, People's Republic of China
Library, Academia Sinica, Institute of Plasma Physics, People's Republic of China
Librarian, Institute of Physics, Chinese Academy of Sciences, People's Republic of China
Dr. S. Mirnov, TRINITI, Troitsk, Russian Federation, Russia
Dr. V.S. Strelkov, Kurchatov Institute, Russian Federation, Russia
Professor Peter Lukac, Katedra Fyziky Plazmy MFF UK, Mlynska dolina F-2, Komenskeho Univerzita, SK-842 15 Bratislava, Slovakia
Dr. G.S. Lee, Korea Basic Science Institute, South Korea
Institute for Plasma Research, University of Maryland, USA
Librarian, Fusion Energy Division, Oak Ridge National Laboratory, USA
Librarian, Institute of Fusion Studies, University of Texas, USA
Librarian, Magnetic Fusion Program, Lawrence Livermore National Laboratory, USA
Library, General Atomics, USA
Plasma Physics Group, Fusion Energy Research Program, University of California at San Diego, USA
Plasma Physics Library, Columbia University, USA
Alkesh Punjabi, Center for Fusion Research and Training, Hampton University, USA
Dr. W.M. Stacey, Fusion Research Center, Georgia Institute of Technology, USA
Dr. John Willis, U.S. Department of Energy, Office of Fusion Energy Sciences, USA
Mr. Paul H. Wright, Indianapolis, Indiana, USA

07/07/03

The Princeton Plasma Physics Laboratory is operated
by Princeton University under contract
with the U.S. Department of Energy.

Information Services
Princeton Plasma Physics Laboratory
P.O. Box 451
Princeton, NJ 08543

Phone: 609-243-2750
Fax: 609-243-2751
e-mail: pppl_info@pppl.gov
Internet Address: http://www.pppl.gov