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Initial Results from the New Lost Alpha Diagnostics on JET

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
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ABSTRACT.

Two new devices have been installed in the JET vacuum vessel near the plasma boundary to investigate the loss of energetic ions and fusion products in general and alpha particles in particular during the up coming JET experiments. These devices are (i) a set of multichannel thin foil Faraday collectors and (ii) a well collimated scintillator which is optically connected to a charge coupled device. Initial results, including the radial, energy and poloidal dependence of lost ions from low yield plasmas during the 2005-06 JET restart campaign will be presented.

1. INTRODUCTION

Magnetically confined fusion plasmas of the present and future rely on good confinement of energetic ions, e.g. Neutral Beam Injection (NBI), Ion Cyclotron Resonant Frequency (ICRF) heating tail ions or fusion-produced alpha particles, to maintain efficient heating. The Joint European Torus (JET) has substantial NBI and ICRF capability, and may also conduct future experiments with Deuterium-Tritium (DT) plasmas that would generate 3.5MeV alpha particles. Consequently, it is an ideal facility for the study of fast ion losses. In addition, the design and construction of a fast ion loss diagnostic for JET may have application to the International Thermonuclear Experimental Reactor (ITER). Accordingly we have recently installed two new fast ion loss diagnostic devices on JET. These consist of a set of thin Faraday foil collectors and a scintillator probe. Thin Faraday-foil detectors, in which ions that are lost from a fusion plasma are detected as current to ground in a metallic foil near the plasma boundary, have been used to investigate ion losses on NSTX[1], DIII-D[2], and JET[3]. Similarly, scintillation detectors have been widely employed to study ion losses on TFTR[4], NSTX[5], and other machines [6]. The present devices are intended to study lost ions in general and d-t fusion product alpha particles in particular during the upcoming JET campaigns. The design and expected signal levels in these devices have been discussed in previous contributed papers to this conference series. [7,8].

2. FARADAY FOILS DETECTOR KA-2

The Faraday cup array will detect the current of fast ions at multiple poloidal locations, with a dynamic range of 1 nA/cm^2 to 10 mA/cm^2 at a temporal resolution of 1ms. The detectable range of α -particle energies is about 1-5MeV. The energy resolution for 3.5MeV α -particles is estimated to be about 15-50%. The array has been installed in Octant 7 and consists of nine detectors spread over five poloidal locations between $z = 22$ and 80cm below the midplane. A recent photograph of KA2 indicating the five poloidally distributed foils sets is shown in Figure 1. Radially, the detectors are equally spaced on three locations between 25 and 85mm behind the adjacent the poloidal limiter. Each detector consists of at least 4 $75\text{mm}\times 25\text{mm}$ Ni foils ($2.5\mu\text{m}$ in eight of the detectors and $1.0\mu\text{m}$ in the ninth) which are separated by insulating mica foils. Depending on its energy, a particle can pass through a certain number of foils before it is stopped

in one foil, thus causing a current signal. The detection of the temporal evolution of the current signals in all foils in the radially and poloidally distributed detectors will allow a map of particle energies at different locations.

3. SCINTILLATION DETECTOR KA-3

The scintillator probe has been installed in Octant 4, in a lower limiter guide tube (input slit: $z = -280\text{mm}$, $\varphi = 123.75^\circ$, $R = 3.799\text{m}$). A photograph of the probe is shown in Figure 2. The scintillator probe will allow the detection of particles with a pitch angle between 30° and 86° (5% resolution) and a gyroradius between 20 and 140mm (15% resolution). It is located in the lower limited guide tube of octant 4 about 28cm below the midplane. The underlying principle of scintillator measurements is the emission of light by a scintillating material after a particle strikes this material. Selection criteria for the particles that hit the scintillator are introduced by using a set of collimators within the magnetic field of JET. An optical arrangement within the scintillator probe is used to transfer the light emitted by the scintillator towards a coherent fiber bundle, a CCD camera and a photomultiplier array.

4. INITIAL RESULTS

4.1.A. FARADAY FOIL DETECTORS.

KA2 has observed lost ions during ICRH and NBI heating. Examples of results obtained during ICRH are shown in Figures 3 – 6. In Figures 3-5 we look, respectively, at the energy, radial and poloidal dependence of lost ions during a 1.4 MW ICRF pulse (Pulse No: 64556) with $B_T = 2.5\text{T}$ and $I_p = 2.0\text{MA}$. The energy dependence, Fig.3, in which the ions are largely stopped in the first three foils, is consistent with a flux of protons with a maximum energy of about 1.5MeV [9]. The radial dependence, Fig.4, indicates a drop-off of about a factor of ten in flux proceeding from the foil set closest to the plasma to that farthest (a distance of 60mm). The poloidal dependence, Fig.5, shows a predominance of ion losses at pylons 3 and 4 which are at angles of 21° and 27° below the machine midplane. While we have yet to carry out detailed orbit calculations for energetic protons, we have completed detailed calculations of alpha particle orbits from d-t fusion plasmas as part of the KA2 design process[7]. It is interesting to note that these lost alpha calculations likewise indicate a preferred poloidal angle between 15° and 27° . In addition, it is interesting to compare the currents measured with KA2 to other diagnostic indicators consistent with ion losses. In Fig.6 we compare the current in foil 121 with the intensity of the edge D_α light, the soft x-ray signal and the intensity of neutron production for JET Pulse No: 65558 ($B_T = 2.2\text{T}$, $I_p = 2.0\text{MA}$ and $P_{\text{ICRF}} = 2.7\text{MW}$). Not surprisingly, current bursts as picked up in KA2 correspond to spikes in the x-ray and D_α signals and to a drop in the neutron production. Finally we have observed an interesting correlation between neutron production rate versus plasma current and lost ion current versus plasma current during a series of very recent NBI “blip” experiments (JET Pulse No’s: 65971-65977 with blips of 1.2MW NBI power of duration 100ms every $\sim 500\text{ms}$ with the plasma current linearly decreasing with time

between 50 and 60 sec into the pulse). A comparison of NBI power, neutron yield and ion current in foil 111 during one of these pulses is shown in Fig.7. These parameters are compared in Fig.8, where there is an increasing correlation between reaction yield and I_p and a roughly decreasing correlation between foil current (lost beam ions) and I_p .

4.1.B. SCINTILLATOR DETECTOR.

The scintillator detector has recently begun to generate images during JET pulses. One of the first images is shown in Fig.9. In addition to CCD images of the scintillator, KA3 is able to measure the ion current onto the scintillator, using basically the same electronics as used by the foils in KA2. In Figure 10 the current from foil 111 (the front foil of the radially innermost of the three foils sets in the top pylon) in KA2 is compared to the current incident upon the scintillator foil in the companion lost ion diagnostic KA3 which is roughly one third the way around the torus from KA2. The KA3 current signal is correlated both with particle losses showing also on the CCD and with some of the signals picked up by the foils of KA2. These are very promising indications that both diagnostics, while different in design will be aiding to explain the same processes originating in the plasma. They will be complementing each other with good synergy. Finally in Figure 11 there is a comparison of the energy signal as a function of time obtained from the scintillator by integrating over the isoenergetic pixels at successive times with the currents from the front, second and back Faraday foils in the top pylon. This is for JET Pulse No:65857 in which there is a sawtooth crash at about 15.2s. In addition to the strong signals associated with this crash, there is a good correspondence at times of weaker signals such at 18.5 and 19.6 seconds.

CONCLUSIONS

Both the Faraday foil and scintillation lost alpha diagnostic detectors have been successfully installed in JET and observations during initial commissioning plasmas indicate that both systems are properly working. The assessment of their performance limits is under way and will be extended using synergies that have been demonstrated.

ACKNOWLEDGEMENTS

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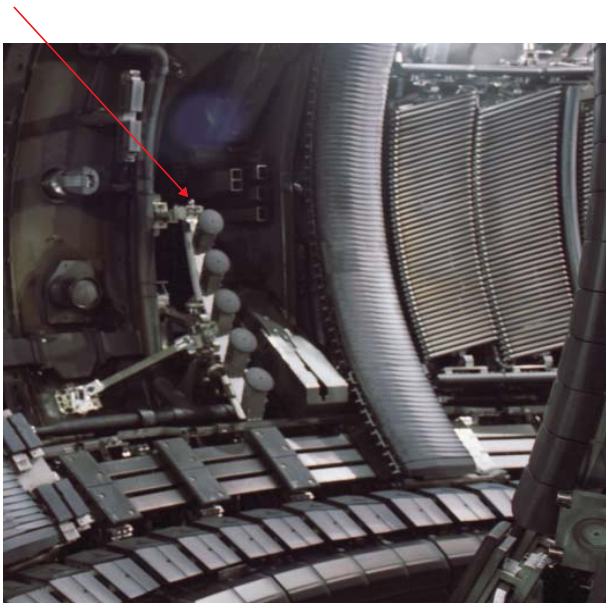


Figure 1. Photograph of the JET Faraday foil lost ion diagnostic KA2 showing the five pylons.

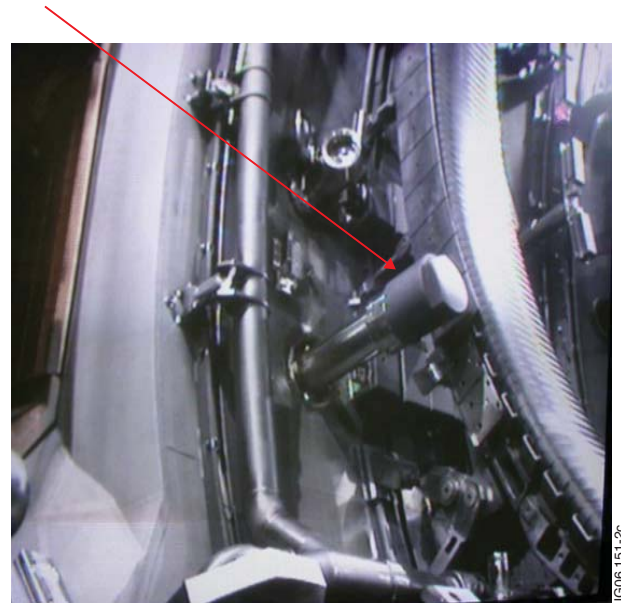


Figure 2. Photograph of the JET scintillator lost ion diagnostic KA3.

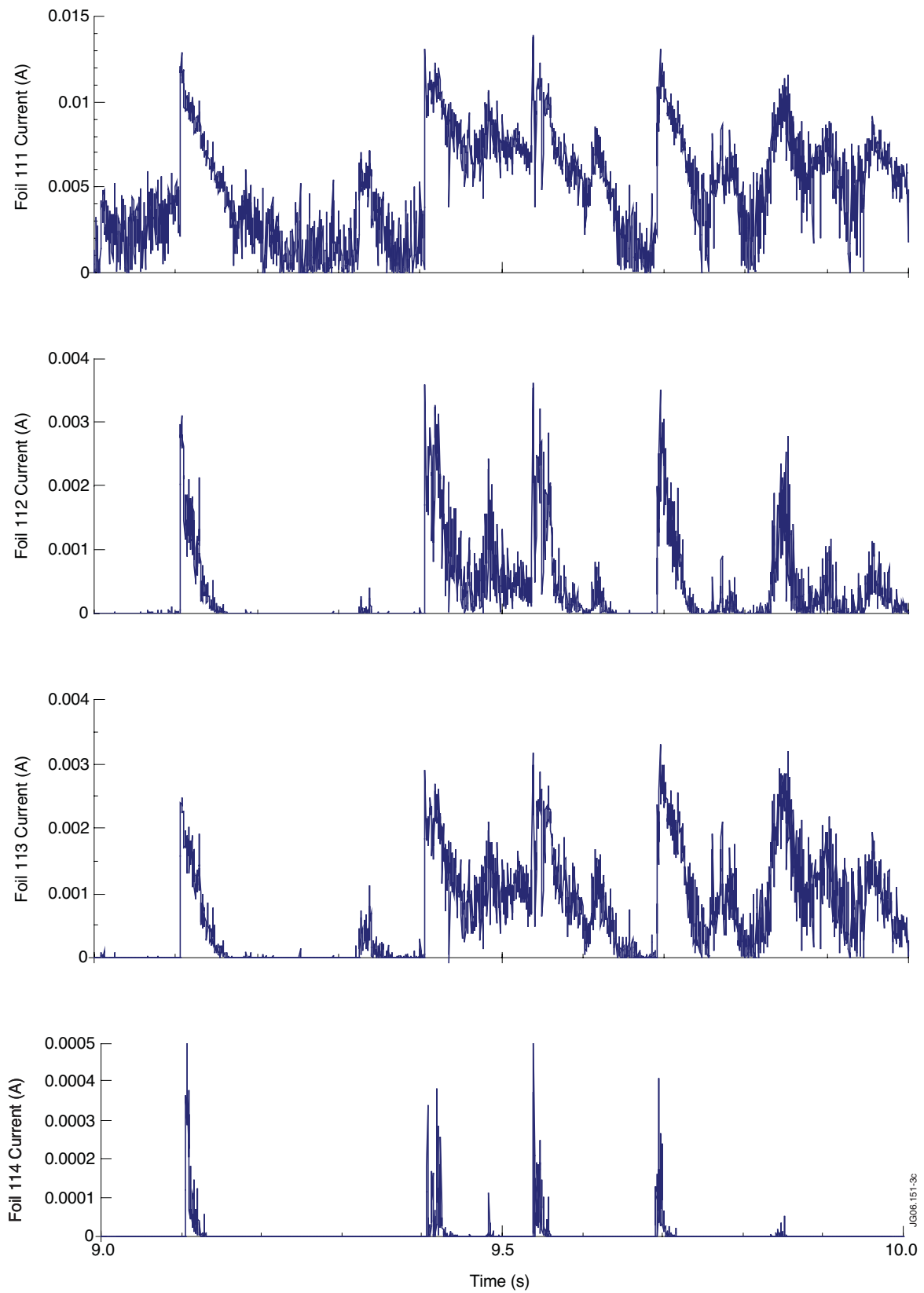


Figure 3. Comparison of currents in four successive foils 111,112,113, and 114 for JET Pulse No: 64556 indicating energy discrimination capability of KA2. The energy of the proton flux is roughly 1.5MeV.

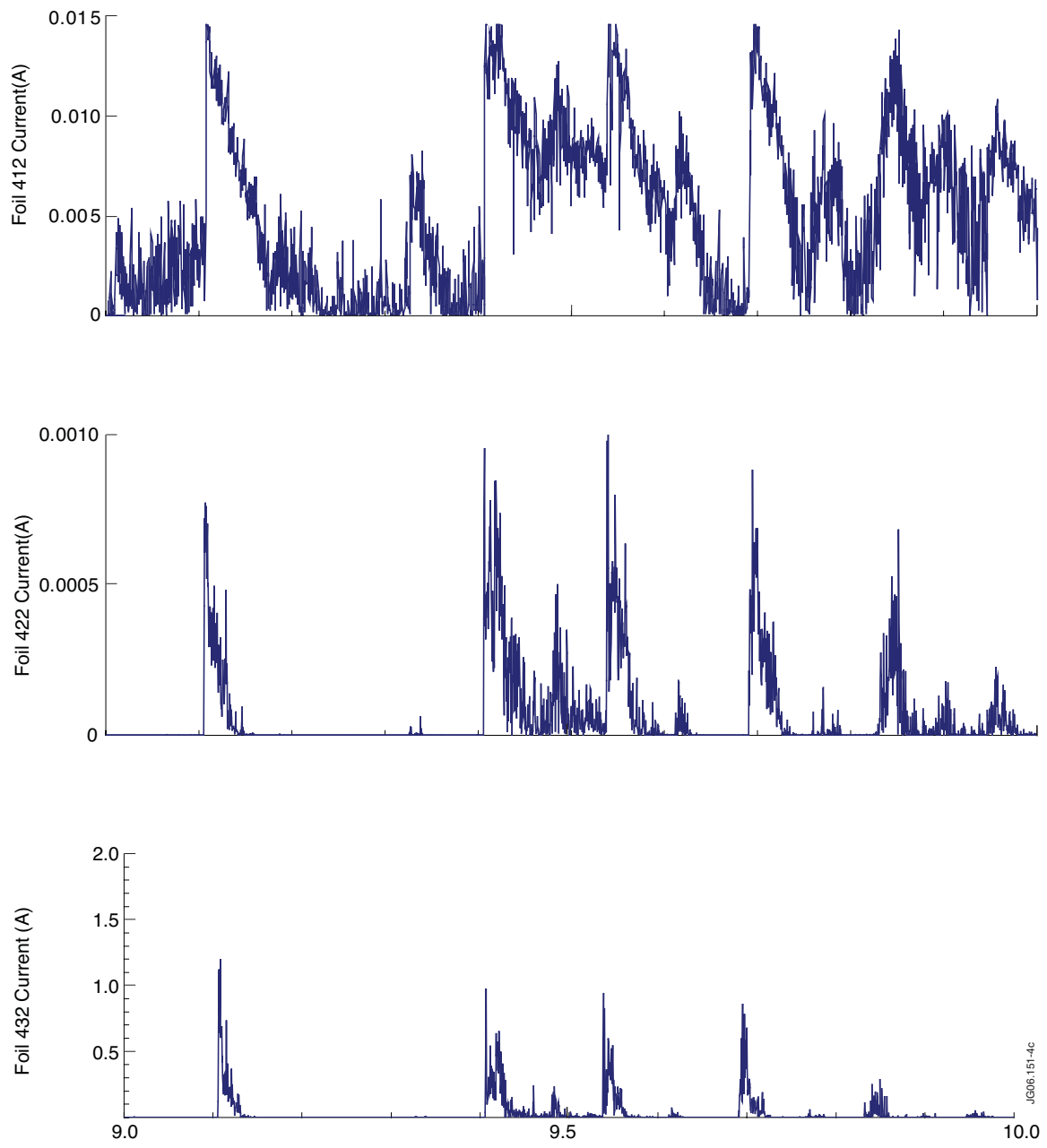


Figure 4. Comparison of currents in foils 412, 422, and 432 for JET Pulse No: 64556 indicating radial dependence of lost ion flux.

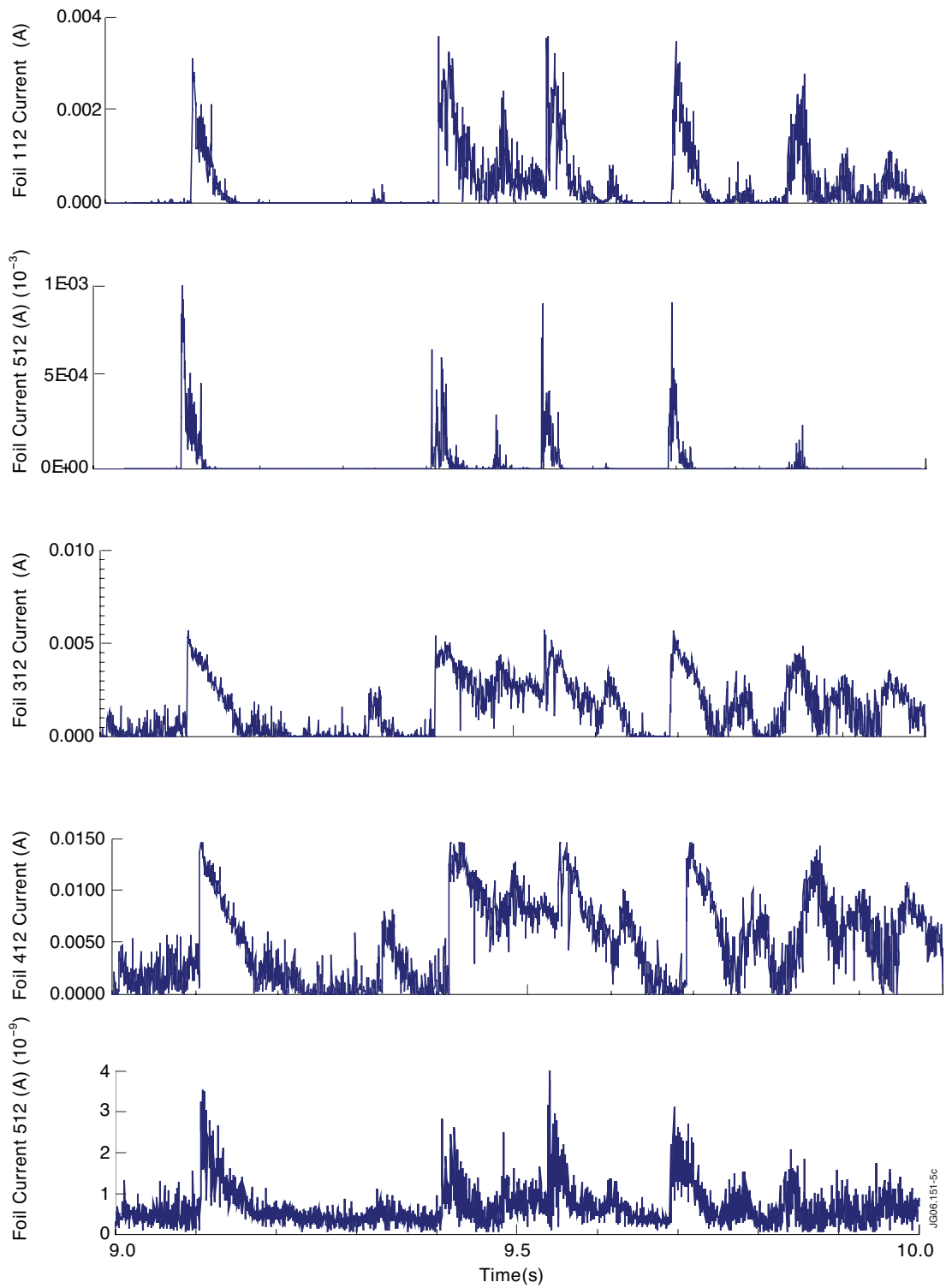


Figure 5. Comparison of currents in foils in pylons at poloidal angles 9° , (top trace), 15° , 21° , 27° , 33° (bottom trace) for JET Pulse No: 64556 indicating poloidal dependence of lost ion flux.

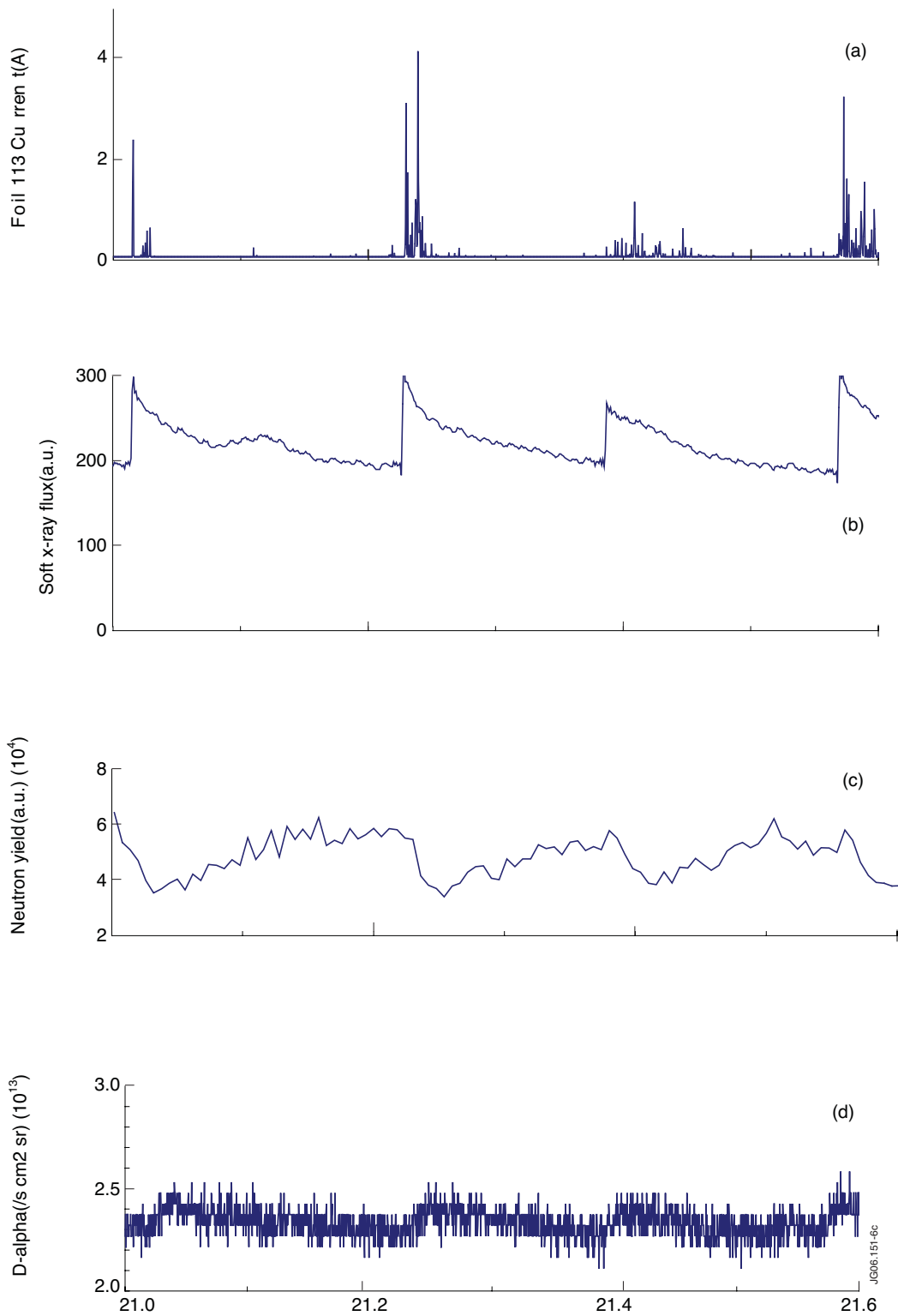


Figure 6. Comparison of current signal in KA2 (a) with soft x-ray flux at outer divertor (b) and neutron yield as measured in fission chamber (c) and edge D_α light (d) for JET Pulse No: 65558.

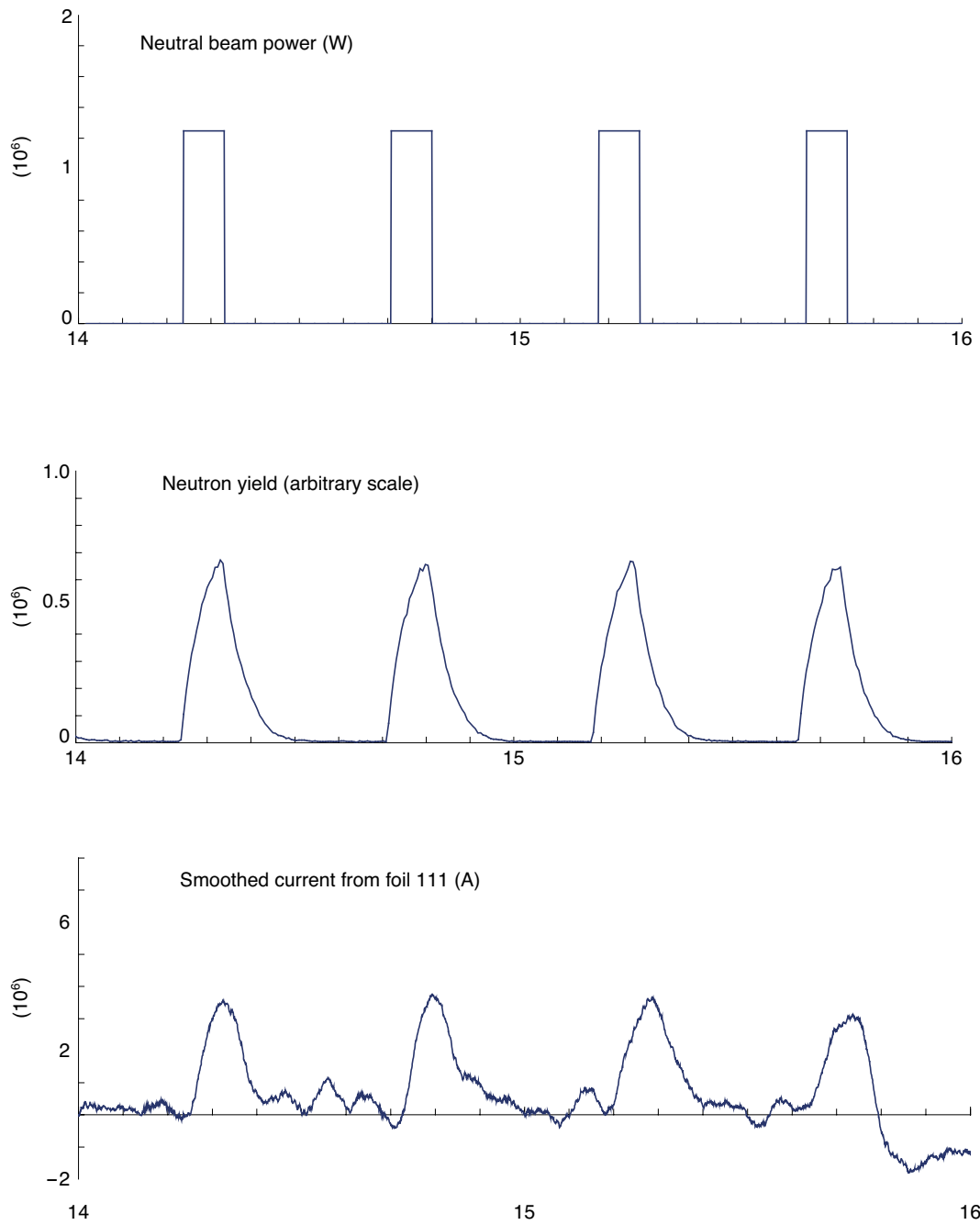


Figure 7. Comparison of NBI power , neutron flux measured in fission chamber and smoothed current signal from KA2 foil 111 for JET Pulse No: 65971

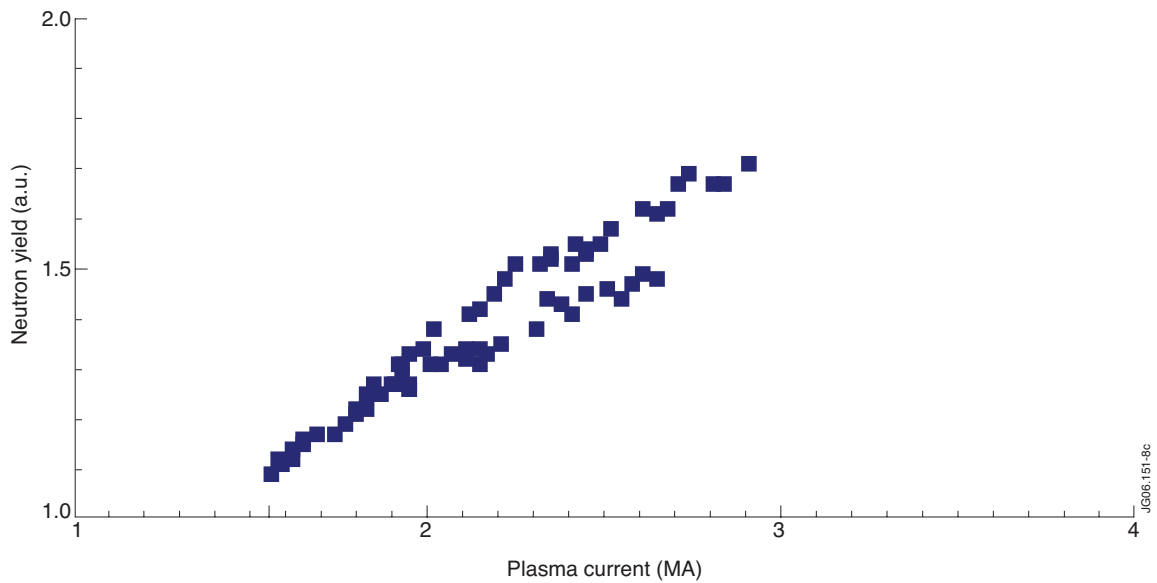
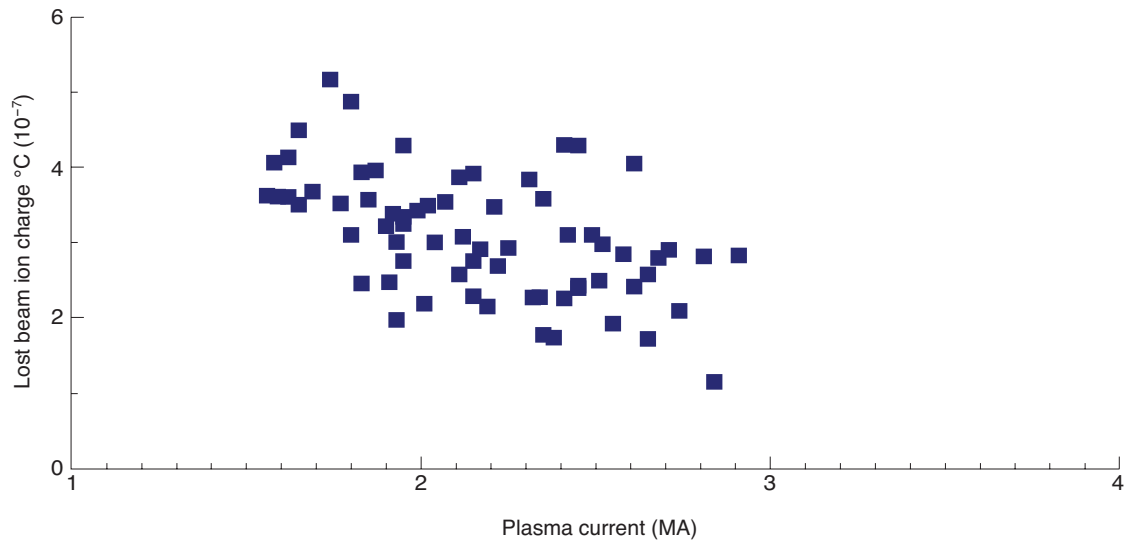


Figure 8. Comparison of neutron yield and integrated current in foil III versus plasma current during JET NBI blip pulses (for JET Pulse No's: 65971, 72, 75, 76 and 77). The foil currents and the neutron signals are integrated over a 200ms time interval starting with the onset of each beam blip of the beam blips. The maximum neutron yield following each blip is about $3 \cdot 10^{14}$ neutrons/sec

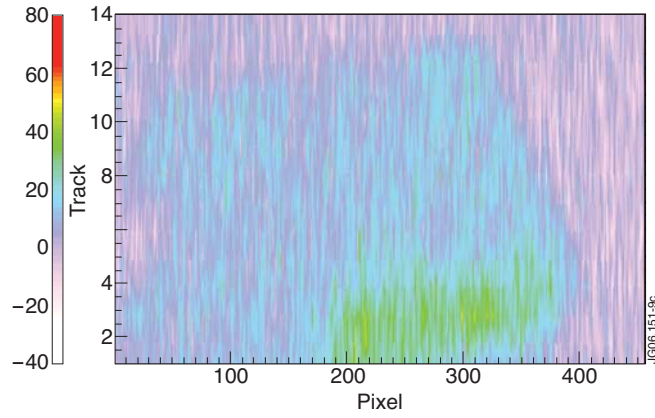


Figure 9. KA3 scintillator probe CCD Image of JET Pulse No: 65857 at 17.0sec.

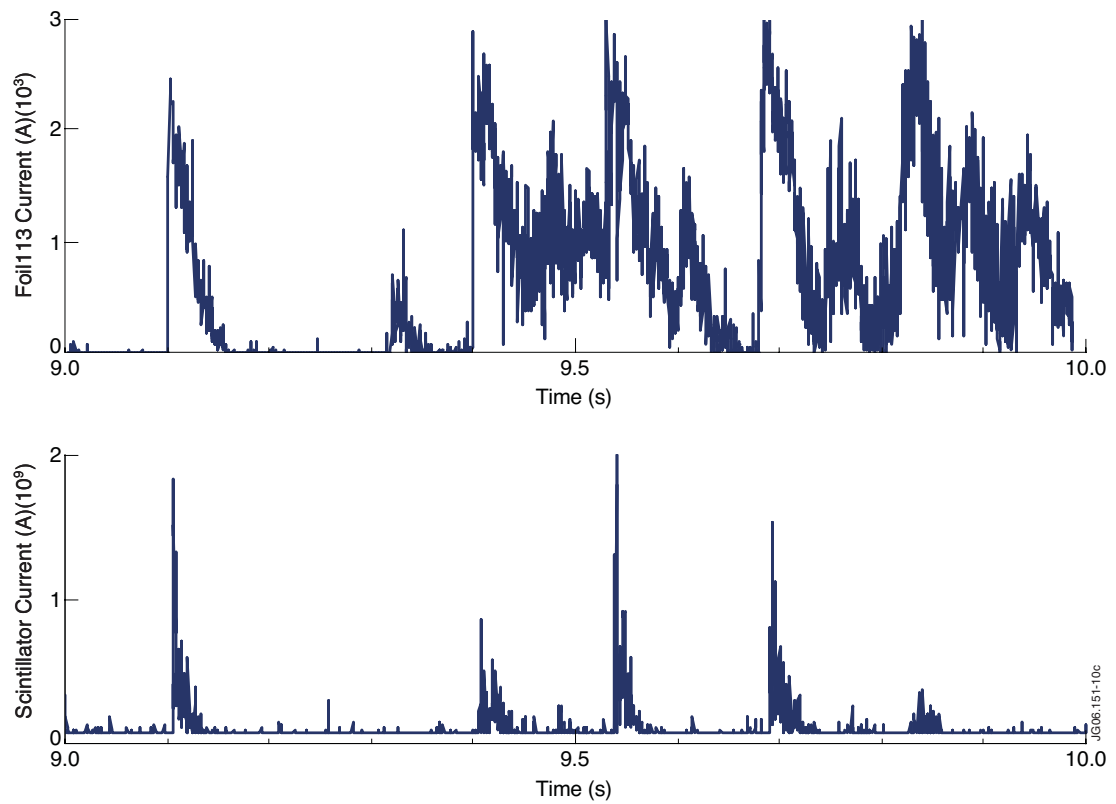


Figure 10. Comparison of current measured in scintillator probe KA3 (top) and Faraday foil detector KA2 (bottom) for JET Pulse No: 64556.

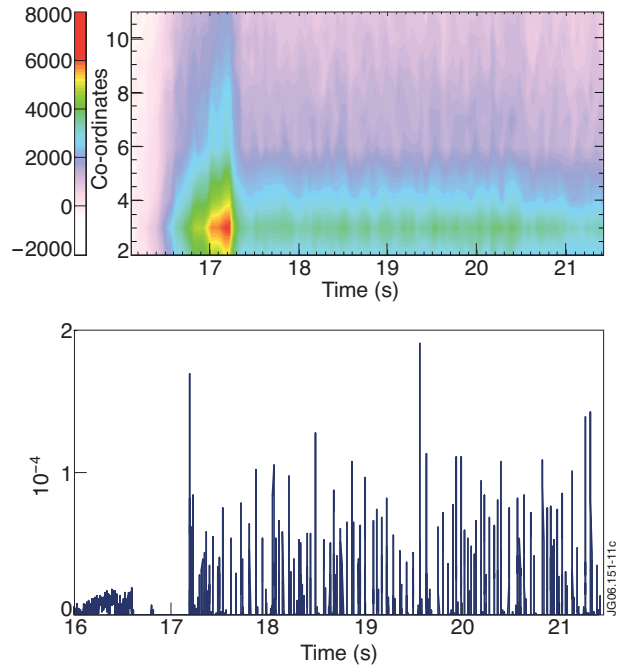


Figure 11. Comparison of energy distribution versus time from scintillator (top) and current in front Faraday foils in top pylon (bottom) in region of sawtooth crash at 17.2sec during JET Pulse No: 65587.