JET–R(97)11

First Results in D-T from the Radiation Hardened Soft X-ray Cameras

R D Gill, B Alper and A W Edwards.

JET Joint Undertaking, Abingdon, Oxfordshire, OX14 3EA, UK.

October 1997

ABSTRACT

Two soft X-ray cameras(KJ5) have been constructed for the D-T phase of JET operation. The active Si detector elements are placed within a substantial radiation shield made mainly from barytes concrete. The initial part of the DTE1 experimental programme has provided an opportunity to assess the operation of this diagnostic. The results show that the shield and detectors are working as expected and that the system will continue to work well when the highest power levels are reached. A comparison is made with the signals from an unshielded detector.

INTRODUCTION

A pair of radiation hardened soft X-ray cameras have been constructed[1]), both to provide soft X-ray signals from mhd events in D-T plasmas and also to provide signals for vertical stabilization of the plasma. The two cameras, located on the main horizontal ports at octants 4 and 8, each contain 17 detector assemblies embedded into a large barytes concrete shield with the detectors viewing the plasma through precision machined stainless steel collimators and 250µm Be windows which separate the machine and diagnostic vacua (Fig 1).The effects of the neutrons on the detectors have been previously been discussed[2]). The detector vacuum is maintained at 10^{-2}T. Each detector assembly has a stack of different elements (Fig 2) as follows:

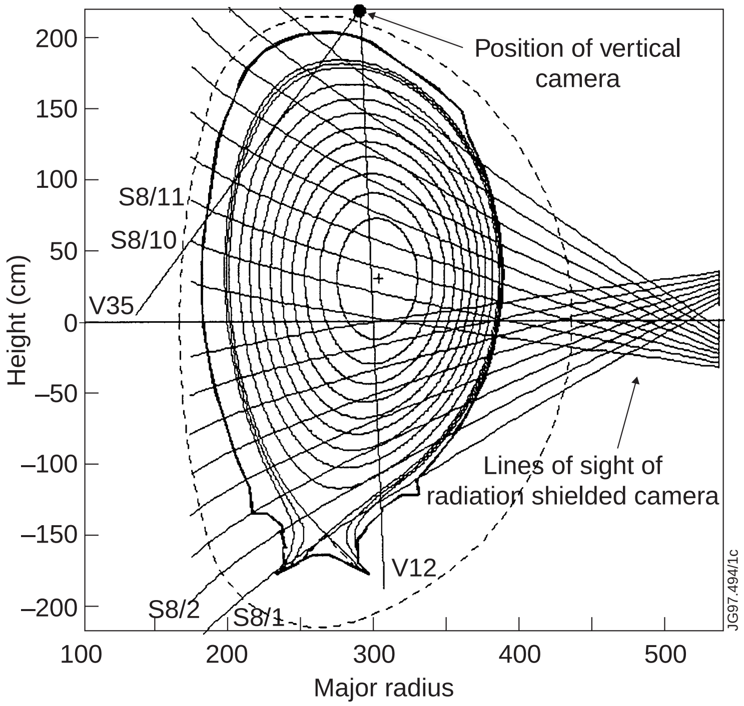

Fig. 1 The lines of sight are shown for the radiation hardened soft X-ray camera (KJ5) and the position of the unshielded vertical camera is also shown.

1. A Centronics Si diode detector (type OSD196-OG(CER)). This detector is 14x14 mm square and has an efficiency of 100% for X-rays with energy less than 10 keV but a very much lower efficiency for 14 MeV neutrons which are mainly transmitted through the detector with very little attenuation. The neutrons provide a noisy background signal.

2. A Si diode detector, identical to the first, which is used to measure the neutron induced background signal.

3. A plastic scintillator (Bicron BC 400) 20cm long and 20mm diameter which has a high detection efficiency for the detection of neutrons. The light subsequently emitted by the charged particles produced by the neutrons is detected by a third identical Si diode

   In the remainder of this report the performance of the soft X-ray detectors will be discussed, particularly in relation to the predictions of the original design.

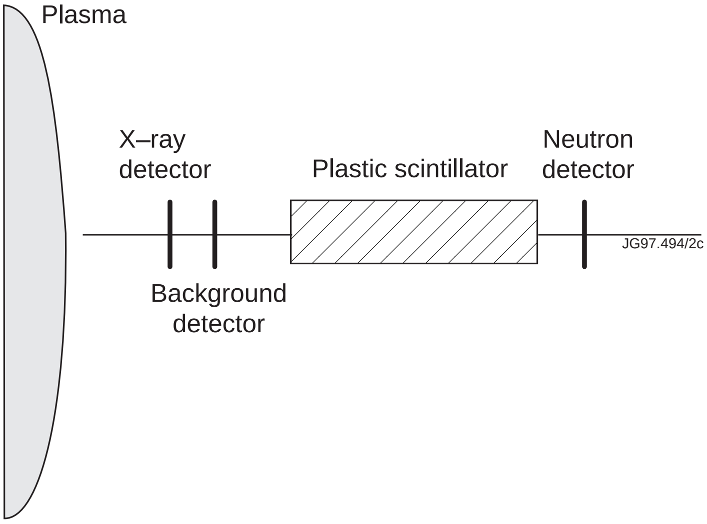

Fig2. The arrangement of the detectors in the radiation hardened camera is shown schematically.

RESULTS FROM SHOT 41726

This shot was one of the last high power D-T shots of the initial part of the DTE1 campaign of 1997 and produced 14 MeV neutron at rates up to $7x10^{17}s^{-1}$, equivalent to a power level of 2 MW. In Fig 3 traces are shown of the plasma density, electron temperature, neutral beam and total power, and the D-T reaction rate. Typical data is shown in Fig 4 from the radiation hardened camera, taken during the heating pulse, for an edge, a near edge, and a central soft X-ray channel. Mhd activity is seen clearly on two of these channels, and the low signal strength on the edge channel confirms the efficiency of the neutron shield in removing neutrons which do not originate in the direct line of sight of this channel. A comparison of the neutron induced signals in the edge and central channels suggests that neutrons from outside the direct line of sight of the central channel contribute only 1/8 of the measured signal (see table 1). The noise levels of the signals look reasonable, but would increase by a factor of 2.2 when the D-T power increases to 10MW.

Table 1. Observed signals at t = 6.2s during shot 41726

Channel	f(kHz)	P(W/m^{-2})	P(10^{-6} W)	I(μA)	δI(rms μA)
S8/1	500	30	0.15	0.04	0.011
S8/2	500	200	0.97	0.27	0.008
S8/4	500	780	3.79	1.05	0.027
S8/10	500	3000	14.6	4.05	0.085
S8/11	500	3400	16.5	4.58	0.085
B8/4	250	40	0.19	0.05	0.03
B8/11	250	120	0.58	0.16	0.072
V35	250	2100	1.59	0.44	0.08
V12	250	4000	3.04	0.84	0.026

δI is the estimated root mean square noise and the peak to peak noise is double this.

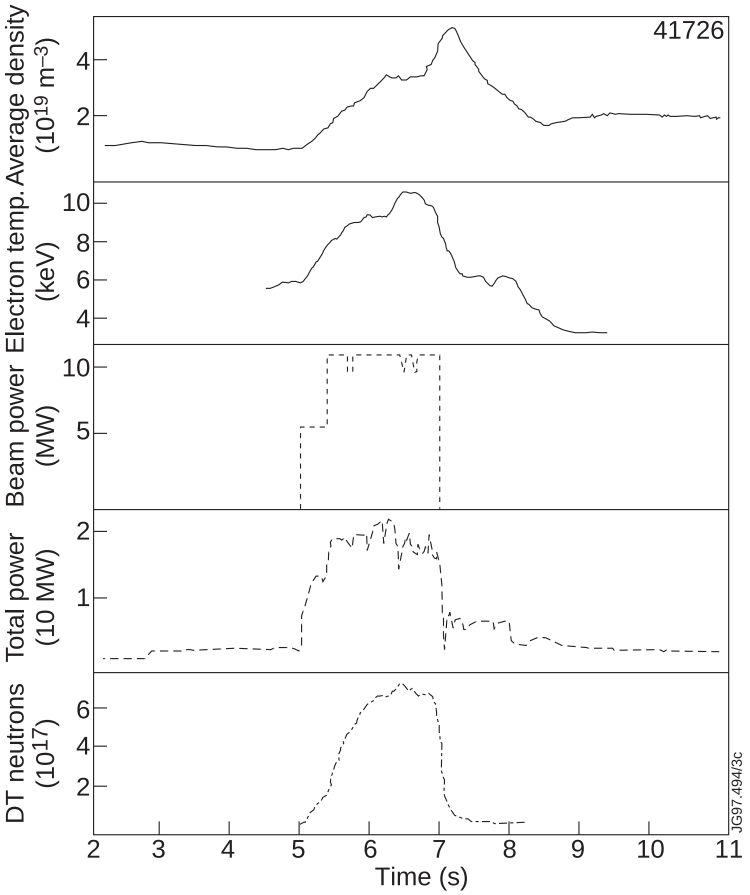

Fig 3 Time dependence of plasma parameters during shot 41726.

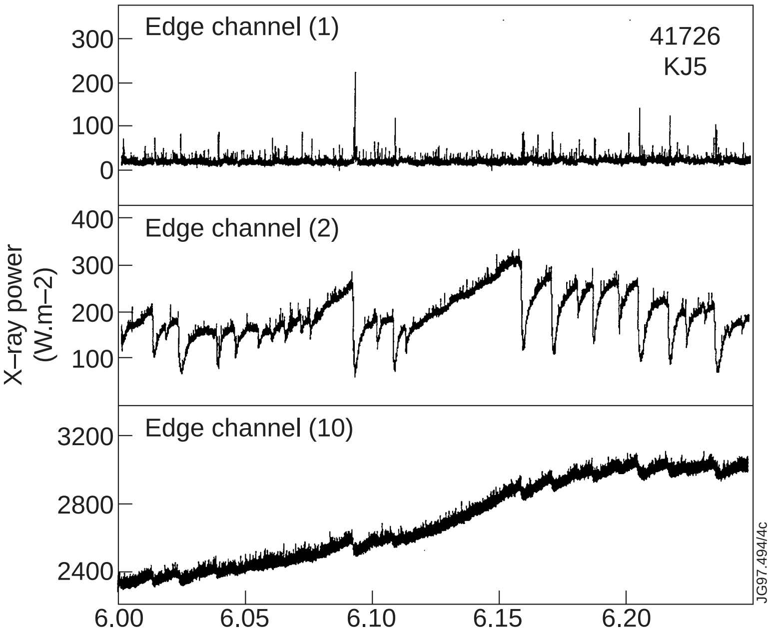

Fig4 Signals from three channels of the radiation hardened camera.

In contrast, the data from the edge and central channels of the unshielded vertical cameras (Fig 5) are extremely noisy and the edge channel has a very large signal produced entirely by neutrons. A comparison is made in Fig 6 of the central channels of the two cameras to illustrate the very considerable differences in the quality of the two data sets. It is remarkable that the vertical camera produces any data at all, as it was anticipated that its detector would be destroyed by a few high power D-T shots.

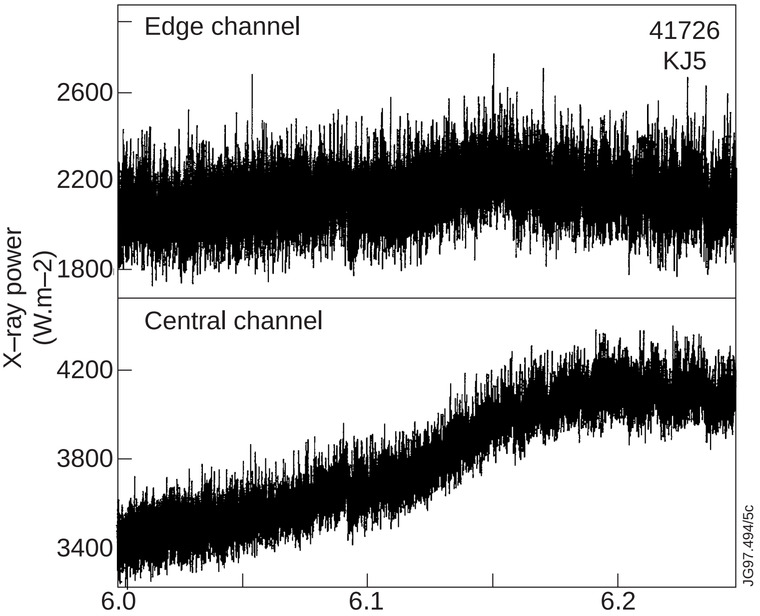

Fig 5 Signals from a central and edge channel of the vertical camera.

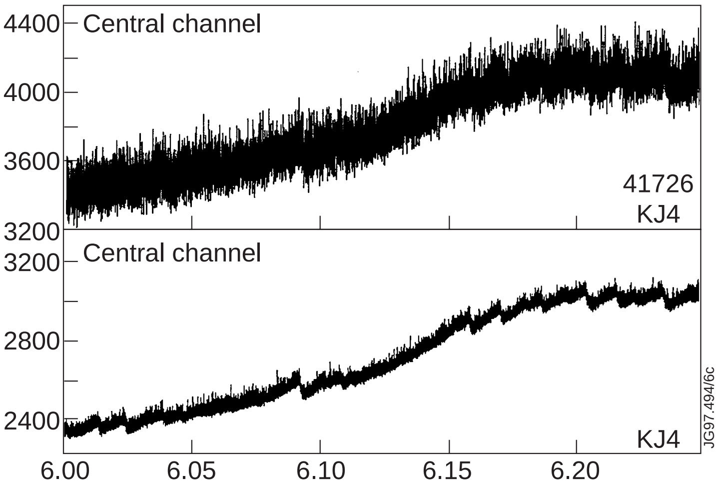

Fig 6 Comparison of the central channels of the vertical and radiation hardened cameras.

SIGNAL AND NOISE LEVELS

This section will contain a discussion of the observed signals and their noise levels, which have only been estimated from the plots of the data and are represent the root mean square values.

(a)The shielded camera

The neutron flux at the detectors of the shielded camera at t=6.2s can be estimated by assuming that the $6.4x10^{17}$ D-T neutrons are produced within the inner one third of the plasma radius. The calculations are done assuming 14 MeV neutrons only and using a kerma of $1.3x10^{-9}$ rad. cm^2 . This calculation ignores the effects of back scattering from the vessel walls and also the effects of thermal neutrons, although the contribution of these to the observed signals will be small. Taking the etendu of the detector as $4.86x10^{-5}cm^2$ and the effective detector thickness as 250mm the background detector signal (B8/11) is calculated to be 0.14µA in good agreement with the measured value of 0.16µA. Assuming that this current is produced mainly by 8MeV alpha particles, then the calculated noise is 0.07µA in reasonable agreement with the measured value of 0.072µA.

This same level of noise will affect the first detector but would be expected to be increased to 0.095µA because of the increased band width of the front detector(S8/11). This agrees well with the measured value of 0.085µA

The relative noise of the X-ray detector is δI/I=1.8% at a bandwidth of 220kHz which would be reduced to 0.7% if the bandwidth were to be reduced to 30kHz as was assumed in the design calculations

(b) ***The vertical camera***

The neutron flux at 14 MeV at the vertical camera for shot 41726 at t=6.2s may be easily estimated by assuming that the source is on a line on the axis of a cylinder such that the neutrons produced in a length 2πR correspond with the observed total production rate, N. The flux at the vertical camera is then $N/(4\pi^2 Rl)$ where l is the distance of the camera to the axis. This gives a flux of 2.9×10^{11} $cm^{-2}s^{-1}$ and a power deposition in Si of 3.6 mW/gm.s. Taking the detector element mass as 9.3×10^{-4}gm this gives a power of 3.4×10^{-6} W, or a current of 0.99μA. The observed current is 0.44μA which is less by a factor of 2.3.The X-ray component of the signal is observed to be only 1900 $W.m^{-2}$ compared with 3000 $W.m^{-2}$ observed in the central channel of the radiation hardened camera. Because of the plasma elongation of about 1.5, one would expect a vertical camera signal of 4500 $W.m^{-2}$ and this shows that the charge collection efficiency of vertical camera is reduced by a factor of 2.25. This is in good agreement with the similar factor found from considering the neutron part of the signal.

RADIATION DAMAGE

The neutron flux at the shielded detectors for shot 41726 is 1.71×10^{8} and this is less than the flux at the vertical camera by a factor of 1700. For DTE1 the calculated fluence for the shielded detectors for a total of 2×10^{20} is 5.34×10^{10} . For DTE2 the total fluence is 5×10^{21} and the detector fluence is 1.3×10^{12}. The detectors will continue to operate after fluences greater than about 1.5×10^{12} (2000 rads) and will therefore operate to the end of DTE2.

CONCLUSION

The new radiation hardened soft X-ray detectors are working as anticipated and the detectors will continue to operate without serious neutron radiation damage through both the DTE1 and DTE2 campaigns.

ACKNOWEDGMENTS

We would like to thank S.Dillon, R.Robins and P.Beaumont for their assistance in the design, construction and operation of the radiation hardened cameras.

REFERENCES

1. R.D.Gill, B.Alper, A.W.Edwards and S.Dillon, *A radiation hardened soft X-ray camera*, JET-IR(95)03.

2. R.D.Gill, B.Alper and A.W.Edwards, *Effects of neutrons on the Jet soft X-ray detectors,* 1992 International Conference on Plasma Physics, 2(1992)1051. (EPS, Innsbruck).