# In-situ cross calibration method for alpha particle loss diagnostics at JET

<u>Georges Bonheure</u>[1], Christian Perez Von Thun[2], M Reich[2], S Jachmich[1], A Murari[3], S.D Pinches[4], J Mlynar[5], M Hult[6], D Arnold[7], H Dombrowski[7], M Laubenstein[8], E Wieslander[6], T Vidmar[6] and P Vermaercke[9], F.E Cecil[10], M Cecconelo[11], T Craciunescu[12], D Darrow[13], E Lerche[1], M Tardocchi[14], D Van Eester[1], A Salmi[15], M Garcia-Munoz[2], V Yavorskij[16], S Popovichev[4], R Koslowski[17] and JET-EFDA Contributors[18]

JET-EFDA Culham Science Centre OX14 3DB, Abingdon, UK
[1]ERM-KMS, B1000 Brussels, Belgium, Partner in the Trilateral Euregio Cluster

[2]Max-Planck-Institut für Plasmaphysik, EURATOM-Assoziation, D-85748 Garching, Germany

[3]Association EURATOM/ENEA, Consorzio RFX, 4-35127 Padova, Italy
[4]EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon, OX14 3DB, UK.
[5]Association EURATOM-IPP.CR, CZ-182 21 Prague 8, Czech Republic
[6]European Commission, Joint Research Centre, Institute for Reference Materials and Measurements (IRMM), Retieseweg 111, B-2440 Geel, Belgium
[7]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany
[8]Laboratori Nazionali del Gran Sasso, S.S. 17/bis km 18+910, I-67010 Assergi (AQ), Italy
[9]SCK•CEN, Boeretang, B-2400 Mol, Belgium
[10]Colorado School of Mines, 1500 Illinois Street, Golden, Colorado, USA
[11]Association EURATOM-VR, Department of Physics and Astronomy, Uppsala University, SE-75120 Uppsala, Sweden
[12]The National Institute for Laser, Plasma and Radiation Physics, Association EURATOM-MEdC, Magurele-Bucharest, Romania
[13]Princeton Plasma Physics Laboratory, James Forrestal Campus, Princeton, NJ 08543, New Jersey, USA
[14]Associazione EURATOM-ENEA sulla Fusione, IFP Milano, Italy
[15]Helsinki University of Technology, Association EURATOM-Tekes, P.O.Box 4100, FIN-02015 TKK, Finland
[16]Association EURATOM-Österreichische Akademie der Wissenschaften (ÖAW), Austria
[17]Forschungszentrum Jülich GmbH, Institut für Plasmaphysik, EURATOM-Assoziation, Trilateral Euregio Cluster, D-52425 Jülich, Germany
[18]See the Appendix of F. Romanelli et al., Proceedings of the 22nd Fusion Energy Conference, Geneva, Switzerland, 2008, IAEA, (2008)

## 1.Introduction

Diagnosing alpha particles in reactor-scale fusion plasmas remain difficult and progress are needed in view of ITER[1]. A new method for in-situ cross calibration of time-resolved alpha particle loss diagnostics at JET – scintillator[2] and faraday cups[3] - using the D-$^3$He fusion reactions and using an activation technique [4-5, 7]. is presented in this paper. The method is in analogy with neutrons, where cross-calibration of neutron yield monitors is obtained using a neutron activation foil system. A calibration factor is determined below for the scintillator plate which allows to compare quantitatively with model estimates the time-resolved scintillator measurements of MHD events. The faraday cups are not considered in this calibration work. Considerable effort was dedicated to fusion product loss diagnostics on TFTR [6]. However, no complete *in situ* calibration of the lost alpha detector could be performed. Typical 60% uncertainty for P46 scintillator material ($Y_3Al_5O_{12}:Ce^{3+}$) was reported. In ASDEX Upgrade experiment, a faraday cup was embedded recently behind a scintillator plate of the TG green type ($SrGa_2S_4:Eu^{2+}$) in an attempt to measure the total ion rate to the scintillator plate[10].

## 2. Instruments and method

A scintillator plate P56 ($Y_2O_3:Eu^{3+}$) [11](figure 1) is mounted inside the vacuum vessel in a lower limiter guide tube below midplane (z=-28cm, phi=123.75, R=3.799m). 2-D distributions of lost fast ions as function of larmor radius (25%-30% FWHM) and pitch angle ($5^0$ FWHM) with a 1ms time resolution are measured (see in figure 2).
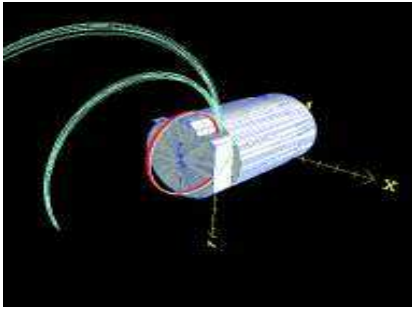
*Figure 1: CAD view (schematic) of the graphite cover enclosing the scintillator plate[3,10]. Some trajectories are illustrated. The ones shown in red are blocked by the detector itself*
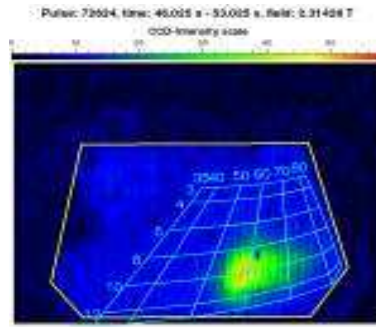
*Figure 2: CCD image of the scintillator plate[3].A typical prompt-loss signal is shown*

Activation samples were mounted on an activation probe (figure 3) which can be introduced inside the JET tokamak vacuum chamber near the ceiling. The activation probe is the first of its kind in a tokamak to be specifically designed for measuring charged particle activation [5]. Sample orientations are shown in figure 4. Samples in slot 1 are facing toward the inboard radial direction. See details in[5].

## 2.1 Method for determination of calibration factor:

The number of fusion products recorded by the detectors is determined by the source strength, source profile and the fusion products trajectories to the detectors.





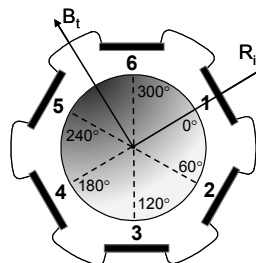*Figure 3: Picture of the activation probe*

*Figure 4: A cross section of the activation probe holding all the samples. $B_t$=standard direction of the toroidal magnetic field and $R_{in}$=the direction along the major radius pointing radially inward. The numbers indicate the 6 sample positions*

Collisionless MeV charged fusion product trajectoriess are uniquely determined by the magnetic field and their initial position and momentum. The source profile is identical for 3.7 MeV alphas and 14.7 MeVprotons and is in first order approximated by the D-D fusion profile. The D-D fusion profile is measured with the neutron camera[12]. The following relation gives the calibration factor **coeff**:

$$N_p \quad = \quad coeff \sum_{n_{pulses}} f_i \, d_i \, (1)$$

where $d_i$ are the scintillator light intensity data, $f_i$ the relative loss factor determined for each plasma by means of orbit calculations. $N_p$ the absolute proton fluence measured using the activation probe.

### 3. Results

The activation samples were irradiated in a total of 12 JET plasma pulses. All plasmas were in D-$^3$He fuel mixture up to 15% in $^3$He concentration except the first reference plasma.   In these plasmas, the toroidal magnetic fields were 2.2 to 3.45T  and  plasma currents were 1.5 to 2.2 MA. Plasmas were heated with neutral beam injection NBI(D) heating only. The total number of neutrons measured by the fission chambers and summed over all plasmas was $3.2 \cdot 10^{17}$ (with an uncertainty of $\pm 10\%$).

First complete angular distribution of $^{48}$V $_{(t_{1/2= 15.98d})}$ activation product (see in figure 5) was measured with an ultra-low background technique [7]. The production nuclear reaction is $^{48}$Ti(p,n) $^{48}$V with a proton energy threshold of $E_p = 4.9$ MeV. A strong anisotropy is clearly seen with a maximum at sample T1, the sample facing the inboard radial direction (see figure 4) as expected from the proton trajectories. Note also, about 50% more protons hit sample T2 (co-circulating protons) compared to sample T6.

Larmor radius and pitch angle distributions observed on scintillator are typical prompt losses In the lowest toroidal field case, part of signal was missing and a correction factor was needed.  As an example, data for pulse 72624 (Bt = 3.0T, Ip = 1.8 MA) is shown in figure 2 time-integrated between 46.025s and 53.025s. Larmor radius and pitch angle distribution observed are typical prompt losses. The accumulated (time-integrated ) alpha loss for each plasma pulse are given in the fourth column of table 1 below.

Trajectory and detection efficiency calculations give the relative distribution of losses at the different detector poloidal locations. These were performed using an adapted version of Gourdon Code for JET geometry and EFIT equilibrium[13]. Trajectories (projection in the poloidal plane) reaching the T1 sample (top) and scintillator plate (bottom) are shown in figure 6. Calculated relative average losses based on the assumption of prompt losses of protons (14.7 MeV) versus alphas (3.7 MeV) are shown in the last column of table 1.

| Pulse number(JPN) | Toroidal field (T) | Plasma current (MA) | Scintillator light (La) ( $10^5$) (a.u) | Relative losses factor ($cm^2$ str) |
|---|---|---|---|---|
| 72622 | 3.45 | 1.8 | 0.31 | 0.013 |
| 72624 | 3.0 | 1.8 | 9.27 | 0.027 |
| 72626 | 3.0 | 2.2 | 1.73 | 0.026 |
| 72628 | 3.0 | 1.5 | 7.67 | 0.023 |
| 72629 | 2.5 | 1.5 | 9.73 | 0.045 |
| 72631 | 2.5 | 1.8 | 7.1 | 0.053 |
| 72632 | 2.5 | 2.2 | 1.81 | 0.058 |
| 72633 | 2.2 | 1.8 | 9.08 | 0.045 |
| 72634 | 2.2 | 1.8 | 0.67 | 0.065 |
| 72635 | 2.2 | 1.8 | 4.80 | 0.077 |

### 3.1 Calibration

A calibration factor of $6.4 \ 10^4$  alphas cm$^{-2}$ str$^{-1}$ /light unit was found using formula (1)above. The detailed discussion on the uncertainties is outside the scope of this 4 page contribution and will be studied systematically in a dedicated paper. Uncertainties include the magnetic equilibrium (flux surfaces), the plasma movements, geometry (particle shadowing by limiters and other structures), particle mixing at the scintillator, scintillator linearity, errors in source measurements as well as the assumptions on the source profile. It was assumed that both

measured losses at the activation probe and the scintillator plate were predominantly due to the prompt losses and other losses were negligible. The preliminary study indicate the uncertainties are 8% and 15% respectively for the $^{48}$V activation data and the relative loss factor. Future work includes a benchmark study against another Orbit Code in order to minimize systematic errors. In this preliminary study, the largest error is from scintillator data. The experiment parameters were not optimized for the calibration purpose. There was a systematic variation in magnetic field and current and the reference pulse for correcting the particle mixing effect at the scintillator is available for one value of magnetic field and current only. In conclusions, a new method for in-situ cross calibration of the alpha particle loss diagnostics at JET was presented and has delivered first preliminary results. A future experiment dedicated for the calibration with improved scintillator data could lead to significantly better results.
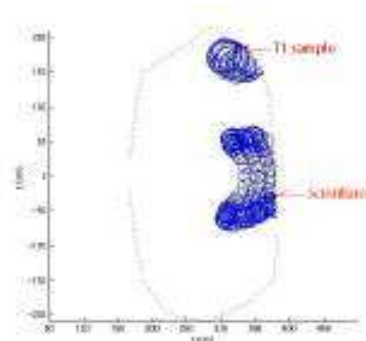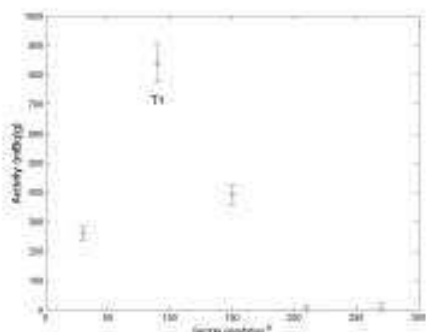


*Figure 5 (left): Angular distribution of 48V activation product measured in the 6 samples T1-T6. Figure 6 (right): Typical trajectories reaching the T1 sample (14.68 MeV protons) and scintillator plate (3.7 MeV alphas)*

**Acknowledgements**:

[1] A.J.H DONNE et al, Nucl.Fusion, **47** (2007) S337-S384
[2] D. DARROW et al, in proceedings of 16th HTPD conference, Williamsburg, Virginia, USA (7-11 May 2006)
[3] M. REICH et al, in proceedings of 33rd EPS conference, Rome, Italy (19-23 June 2006)
[4] G. BONHEURE et al, Rev.Sci.Instrum **79**,1 (2008)
[5] G. BONHEURE et al, Fus.Sci.Technol**. 53** 3 (2008) 806-815
[6] S.J.ZWEBEN et al, Nucl.Fusion **40** (1999) 91
[7] E.WIESLANDER et al, Nucl. Instr. Meth **A. 591** (2008), 383-393

[8] R.BOIVIN et al, Rev.Sci.Instrum **63,** 4418 (1992)
[9] D. DARROW et al Rev.Sci.Instrum **66,** 476 (1995)
[10] M GARCIA MUNOZ et al, Rev.SciInstrum **80**, 053503 (2009)
[11] K. KAJIWARA, J.Vac.Sci.Technol B **21**, 1622 (2003))
[12] M.ADAMS et al Nucl.Instrum.Methods A **329** 277
[13] G.BONHEURE et al, to be submitted
[14] W.W.HEIDBRINK, PhD Thesis, Princeton University (1984), chapter 2