EUROPEAN FUSION DEVELOPMENT AGREEMENT

EFDA–JET–CP(07)03/25

G. Bonheure, E. Wieslander, M. Hult, J. Gasparro, G. Marissens, D. Arnold,
M. Laubenstein, S. Popovichev, A. Murari and JET EFDA contributors

MeV Ion Losses Measurements in JET using Activation Technique

MeV Ion Losses Measurements in JET using Activation Technique

G. Bonheure[1], E. Wieslander[2], M. Hult[2], J. Gasparro[2], G. Marissens[2], D. Arnold[3], M. Laubenstein[4], S. Popovichev[5], A. Murari[6] and JET-EFDA contributors*

[1]Partners in the TEC , "Euratom-Belgian state" Association LPP-ERM/KMS, B 1000 Brussels, Belgium
[2]EC-JRC-IRMM, Institute for Reference Materials and Measurements, Retiesweg, 111, B-2440 Geel, Belgium
[3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany
[4]Laboratori Nazionali del Gran Sasso, I-67010 Assergi, Italy
[5]EURATOM/UKAEA Association, Culham Science Centre, Abingdon, Oxon, UK
[6]Consorzio RFX, Associazione ENEA-Euratom per la Fusione, Padova, Italy
** See annex of M.L. Watkins et al, "Overview of JET Results ",*
(Proc. 21st IAEA Fusion Energy Conference, Chengdu, China (2006)).

Preprint of Paper to be submitted for publication in Proceedings of the
34th EPS Conference on Plasma Physics,
(Warsaw, Poland 2nd - 6th July 2007)

1. INTRODUCTION

Measurements of energetic particle losses from the plasma, in particular alpha particles, remain difficult in large fusion devices and further R&D is needed in view of ITER [13]. The present paper describes new measurements using activation technique [1, 2, 3]. Samples are activated due to nuclear reactions of type (X,n), (X, γ),... where X is a light charged particle p,t,d,^{3}He and α. After plasma exposure, samples are removed from the sample holder and analysis of samples is performed using high counting efficiency, ultra low-level and high energy resolution gamma-ray spectrometry [4].

2. ACTIVATION PROBE

The activation probe is the first of its kind in a tokamak to be specifically designed for charged particle activation [8]. It is 40mm in diameter, 100mm in length and it has an hexagonal cross section. Each of the six sides has a slot which can be filled in with samples. Sample orientations are shown in figure 1. Samples in slot 1 are facing toward the inboard radial direction. The activation probe is mounted on a manipulator arm system located in the JET ceiling. This mechanical set-up allows to 1) position the samples close to plasma edge, 2) expose the samples only in dedicated plasma discharges and 3) remove the samples quickly after the desired exposure. 36 samples with size indicated in table 1 were used. All samples were 10mm in height, except one type of samples that were 45mm. Each slot was filled with 6 samples: (i) Pure Ti near the tip of the sample holder (ii) First set of B_4C located just above the T_i and (iii) LiF (iv) Second set of B_4C (v) Pure W and (vi) Pure T_i (long samples). The short T_i samples were the nearest to the plasma edge while the long T_i samples were the furthest away. The long T_i samples were located at the back of the sample holder and in the plasma shadow.

3. MEASUREMENTS

Samples were exposed for 4 days and were irradiated in a total of 63 JET plasma pulses. Plasmas were D-3He fuel mixture with ^{3}He concentration ranging from 8 to 20%. The sample holder was removed from the vacuum chamber and a preliminary gamma spectrometry analysis was performed after a cooling time of 20 days. Due to low sample activity, low detection levels are needed and gamma-ray measurements are best performed in underground laboratories. As shown in previous work, JET samples are suitable for ultra low-level gamma-ray spectrometry [4]. In collaboration with 3 underground european laboratories, a detailed gamma-ray spectroscopy analysis of each individual sample was performed. 1)IRMM (Institute for Reference Materials and Measurements) in the 225m deep underground laboratory HADES located at the Belgian nuclear centre SCKCEN (StudieCentrum voor Kernenergie Centre d'Etude de l'energie Nucleaire) in Mol, Belgium [5]. , 2) PTB in the underground laboratory UDO located at a depth of 490 m in the ASSE salt mine close to Braunschweig , Germany [6]. 3) Laboratori Nazionali del Gran Sasso (LNGS) in the 3800 water meter equivalent (mwe) low background counting facility located in the Gran Sasso nearby Assergi in Italy[7]. See for more details on gamma-ray measurements in papers [11, 12].

4. RESULTS

Only a few radionuclides of interest are discussed below. Remaining radionuclides are discussed in more detail in [11, 12]. Table 2 shows the list of radionuclides. Activity value refers to sample highest measured activity at the reference date. The main producing reactions and the samples on which these radionuclides were found are indicated.

^{48}V (half-life 15.98d) was found on two samples (T1,T2). Figure 2 shows a spectrum of the T1 sample with a peak at 983.5keV from ^{48}V decay. Counting time for this spectrum was 7 days and the total number of count in the peak reached about 40. Such ultra low-level activity could not have been detected above ground using conventionnal gamma-ray spectrometry. ^{46}Sc (half-life 83.8d) was found on all titanium samples (T1-T6) located nearest to the tip of the probe and on all (Titop1 Titop6) samples located at the back of the sample holder. These samples were shielded from plasma particle flux. ^{7}Be (half-life 53.3d)was found on nearly all B_4C samples (B1-B3,B5-B12) and on nearly all LiF samples (F1-F3,F5-F6). 7Be was below threshold for sample B4 and F4. T2 and T6 had some ^{7}Be deposited on the surface.

DISCUSSION AND MODELLING WORK

Two radionuclides were produced primarily from charged particles. Observation of ^{48}V (see in fig.2) provides evidence of high energy proton fluxes from the plasma. ^{48}Ti(p,n) reaction energy threshold (≃ C5 MeV) is too high for 3.02MeV D-D fusion protons to contribute to ^{48}V production. Therefore, protons most likely originated in D-^{3}He fusion reactions and were born with an energy of 14.7MeV. Confined protons were observed with a gamma-ray spectrometer [16].

A deuteron contribution (energy threshold ≃ C2MeV) is possible. ^{7}Be angular distribution on Lithium fluoride samples and the two set of boron carbides samples are shown in figure 3. Anisotropic angular distribution were found for the 3 sets of samples. In contrast, ^{46}Sc angular distribution with is dominantly produced from neutron irradiation was found rather uniform. See details in [11]. The activation variation did not exceed 10 percent in case of the T1-T6 and 15 percent in the case of the Titop1-6 set. However, a small contribution from charged particle is possible and could explain the slight increase observed for T2. A low level of ^{7}Be was found on T2 and T6 samples. It is a result of sputtered particles deposition. The level was approximately 30 times less than in the previous experiment [8] in which two maxima were similarly found at the same sample orientation (T2 and T6).

Quantitative data on charged particle losses and in particular, absolutely calibrated measurements of the particle fluence to the wall were obtained for the first time. The detailed elaboration of all the activition results is outside the scope of this paper It involves an unfolding algorithm which takes into account all possible nuclear reactions. More than 100 nuclear reactions have already been examined [11], including charged particle reactions, neutron reactions and photonuclear reactions. A model has been prepared for simulations with MCNPX [15] and the sample responses will be studied with the FISPACT code [14].

Charged particle losses modelling has begun. Theory predicts classic drift losses (or orbit losses) is the dominant loss mechanism in plasmas with $I_p \leq 3MA$ and in absence of strong magnetic ripple or other losses[9]. Figure 4 shows a typical calculation of distribution of 14.68MeV losses for Pulse No: 66424 (B_t = 3.35T, I_p = 2.1MA), obtained with MC Orbit Monte Carlo code[10] and using an EFIT magnetic equilibrium. As clearly seen, calculated orbit losses are very low in the ceiling region where the activation probe is located. It is yet unclear whether orbit losses can explain the measured losses. Before a detailed quantitatm is performed, important modelling issues need to be addressed including the statistical uncertainty in the Monte Carlo calculations and the definition of the charged particle source.

SUMMARY

Charged particles losses were observed for the first time on JET using an activation technique. Remarkably, these losses were measured in the ceiling of JET tokamak in D-^{3}He plasmas (Bt 3.35T, I_p 2.1MA and in standard field configuration). This technique combined with ultra low-level measurements pushes detection levels significantly lower. Two radionuclides were identified as produced dominantly from charged particles reactions. Quantitative data on charged particle losses were obtained for the first time. Angular distribution with respect to the magnetic field and distribution versus the distance to plasma edge were measured as well. Modelling work of charged particles losses has begun. Some modelling issues need to be addressed. It is unclear yet whether classical drift losses will be sufficient to account for the measured losses Finally, the technique has wide potential in view of applications to ITER and further development and optimisation is expected on JET.

ACKNOWLEDGEMENTS:

We gratefully acknowledge the contribution of all team members of IRMM, PTB and Gran Sasso and the support of the JET plasma boundary group, including M.Stamp, G. Matthews, J. Vince, G. Kaveney and T.Edlington. This work was carried out under the European Fusion Development Agreement.

REFERENCES

[1]. R.E. Chrien et al, Physical Review Letters **46** (1981) 535
[2]. E. Cecil et al, Rev.Sci.Instrum **57** (1986) 1777
[3]. G. Bonheure et al Rev.Sci.Instrum **75** (2004) 3540
[4]. J.Gasparro et al, Appl.Radiat.Isotopes **64** (2006) 1130

Nat. Ti	6	10mm × 10mm	1mm	0.39g	T1-T6
B_4C	12	10mm × 10mm	1mm	0.26g	B1-B12
LiF	6	10mm × 10mm	1mm	0.33g	F1-F6
W	6	10mm × 10mm	1mm	1.95g	W1-W6
Nat.Ti	6	45mm × 10mm	1mm	1.90g	TiTop1-TiTop6

Table 1: Composition, number, mass and size of samples used in experiment

Radionuclide	Activity (Max-mBq/g)	Production reaction	Sample
^{48}V	200±30	$^{48}Ti(p,n)$, $^{47}Ti(d,n)$	T1,T2
^{46}Sc	176±5	$^{46}Ti(n,p)$, $^{47}Ti(n,d)$, $^{48}Ti(d,\alpha)$	T1-T6,TiTop1-TiTop6
^{7}Be	97±5	$^{10}B(p,\alpha)$, $^{10}B(d,\alpha n)$, $^{7}Li(p,n)$, $^{6}Li(d,n)$	B1-B3, B5-B12 F1-F3, F5-F6,T2-T6

Table 2: List of radionuclides.

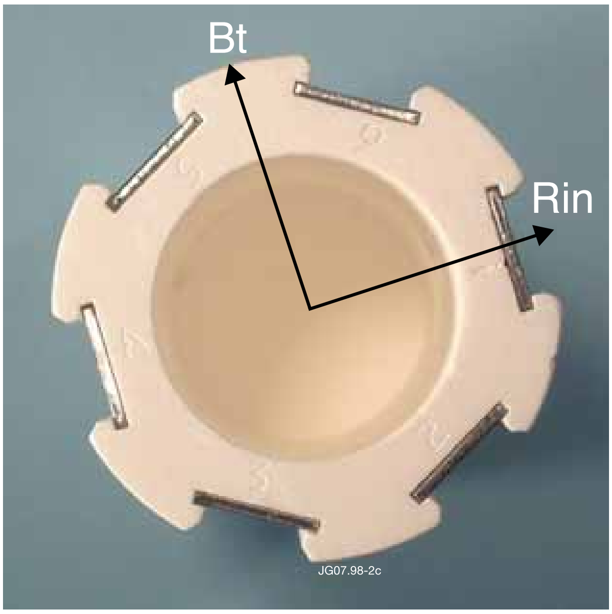


Figure 1: Sample orientations with respect to toroidal magnetic field.

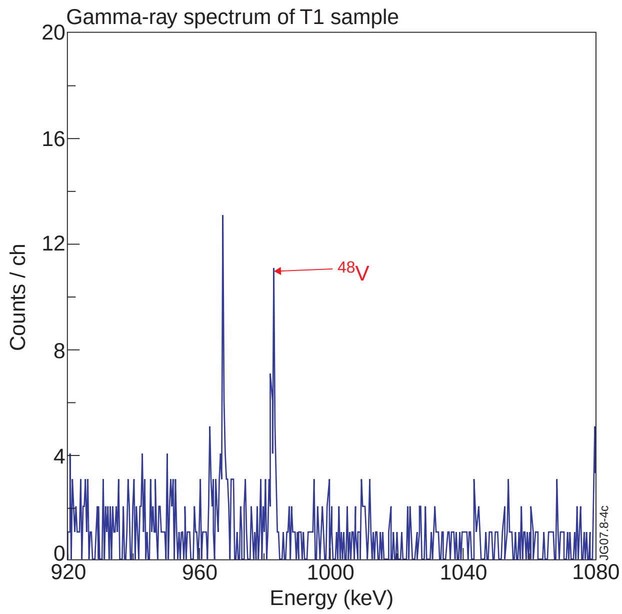
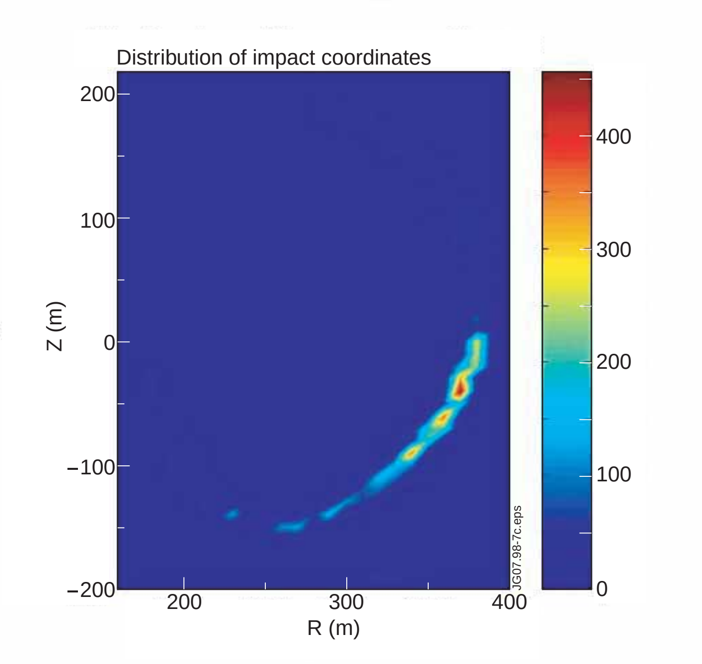


Figure 2: Gamma-ray spectrum for T1 sample. A peak at 983.5keV from ^{48}V decay is visible. Counting time ≃ 7d. Counts in peak ≃ 40. Such ultra low-level activity could not have been detected above ground using conventionnal gamma-ray spectrometry.



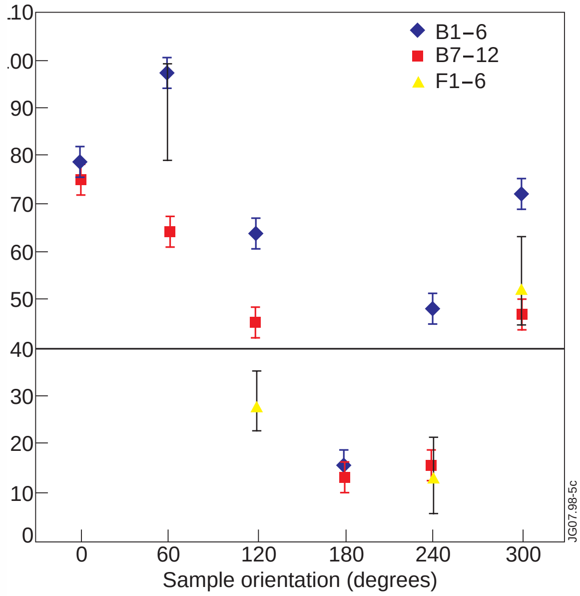


Figure 3: Angular distribution of ^{7}Be in 3 sets of samples.

Figure 4: Calculated distribution of 14.68MeV proton losses in R-Z plane for Pulse No: 66424 (B_t = 3.35T, I_p = 2.1MA).