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ABSTRACT

Fast ions measurements become increasingly important as we move closer to ITER or burning plasma experiments and further R&D is especially required in the field of fast ion losses measurements[1] in the perspective of ITER. A boron target mounted on a manipulator was exposed to deuterium plasmas during reversed field experiments at JET. Due to the $^{10}B(p,\alpha)^{7}Be$ reaction , ^{7}Be is produced in the boron target by MeV protons escaping the plasma. The proton losses are deduced from measurements of the intensity of decay emission of ^{7}Be. Excellent agreement is found between measurements and prediction from fast ion classical drift losses. The MCORBIT Monte Carlo simulation code was used to predict unconfined orbits fraction. Further developments are presented, including a new dedicated instrument to be used in experiments already planned at JET with ICRF accelerated alpha particles. The obtained results will be essential for the design of lost alpha diagnostics on ITER based on activation technique.

1. MEASURED GAMMA SPECTRUM

Gamma spectra of a plasma boundary probe shield cap, made of boron nitride have been measured with a high energy resolution high purity germanium detector. The red spectrum in figure 1 shows a clear line at energy of 477 keV which is the signature of ^{7}Be isotope decay emission . The background spectrum measured prior to exposure, the green curve in figure 1, does not show a line at this energy. The 477 keV line is therefore due to plasma exposure. ^{7}Be production is expected from bombardment of escaping fast protons through the nuclear reaction $^{10}B(p,\alpha)^{7}Be$. The line decays at a rate compatible with the ^{7}Be 53.3d half life. The total averaged peak count is 2763 ± 157[2] with statistical uncertainty below 10 %.

2. CALCULATION OF ^{7}Be LINE INTENSITY

The ^{7}Be isotope production rate[2, 3] depends on the cross section of the nuclear reaction involved, the stopping power of the proton in the target material and the proton incident velocity. The target thickness is such that fast protons are fully stopped. Between 1.5 and 5 MeV proton energy, the ^{7}Be yield varies within a factor of 10 whereas below 1.5 MeV the yield decreases very rapidly with energy.

Orbit loss is the simplest mechanism (dominant for $I_p \leq 3MA$) to lose fast ions in tokamaks, also referred as classical drift losses. Due to the grad B drift, a fraction of the plasma energetic particles are born on unconfined trajectories which intercept the vacuum vessel walls. The unconfined orbits fraction depends strongly on the plasma current and to a minor extent on the current profile. We consider 3 MeV fusion protons as the only source of protons contributing to the measured signal and we calculate drift losses both with an analytical model[4] and a numerical Monte Carlo simulation[5, 6]. As example of MC orbit code output, the poloidal distribution of 3 MeV protons impact coordinates is shown in figure 2 for JET pulse 59603. The figure 3 shows the predicted signal due to target accumulated exposure to 152 deuterium pulses. Given experiment uncertainties, we find a very satisfactory agreement between the prediction ($\simeq 2500$ counts) and the measurement ($\simeq 2763$ counts).

3. DISCUSSION OF THE RESULTS

Main factors limiting the accuracy of our results include the detector calibration (counting efficiency), the source geometry, energetic protons other than 3 MeV fusion protons , and parasitic source of ^{7}Be. The counting efficiency for the high purity Germanium detector is calibrated experimentally. However, this calibration is determined for a point-like source and an approximate correction factor is used for an extended source geometry. Some uncertainty in the irradiation conditions come from a possible partial screening due to limiters or other plasma facing elements. The analysis of other peaks in the spectrum give information on the level of neutron induced (n,p) reactions. We can assess the neutron induced protons production and the ^{7}Be parasitic contribution is about 1 %. Other nuclear reactions for the ^{7}Be production exist but their contribution is negligible.

4. CONCLUSIONS

The gamma ray spectrum of a boron target exposed during the reversed B experiments at JET shows a clear line at 477 keV. This line is the signature of isotope ^{7}Be decay which is produced by fast protons escaping the plasma. The nuclear reaction involved is $^{10}B(p,\alpha)^{7}Be$. A simple but very efficient model is used to predict the fast proton losses and the measured line intensity. In this model, fast proton losses are obtained from classical drift losses calculation for 3 MeV protons and the local unconfined orbit fraction is calculated with MCORBIT code. Measured and predicted signal agree very well given the experiment uncertainties.

5. FUTURE WORK

A new sample holder head with an optimized design has been prepared for further experiment with ICRF accelerated alpha particles on JET (figure 4). Several samples can be inserted in each of the 6 slots available. Multiple orientations for the samples allow to resolve the local pitch angle distribution of the incident fast ions. Multiple materials can be exposed such that 1) discrimination between various fast ions is possible 2) some information on the energy spectrum can be retrieved. The optimized design will improve a lot current measurements limitations. It will also strongly reduce inaccuracy linked to the target geometry and counting efficiency and diminish neutron induced signal. Analysis of recent results with the new instrument is in progress.

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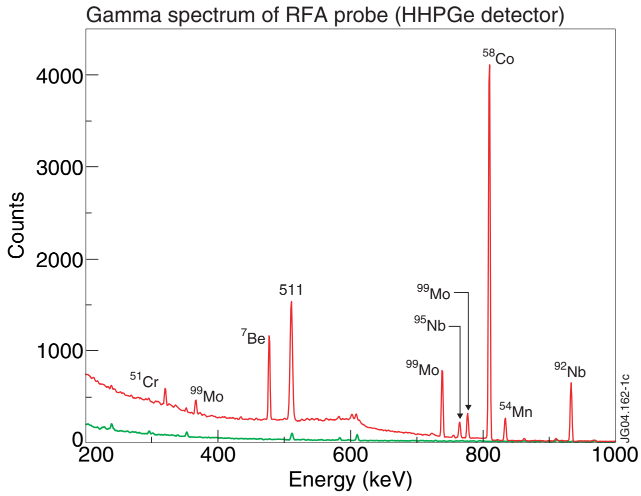

Figure 1: Gamma spectrum of RFA probe measured with high purity germanium detector. In red: spectrum measured after plasma exposure. In green: spectrum measured prior to plasma exposure.

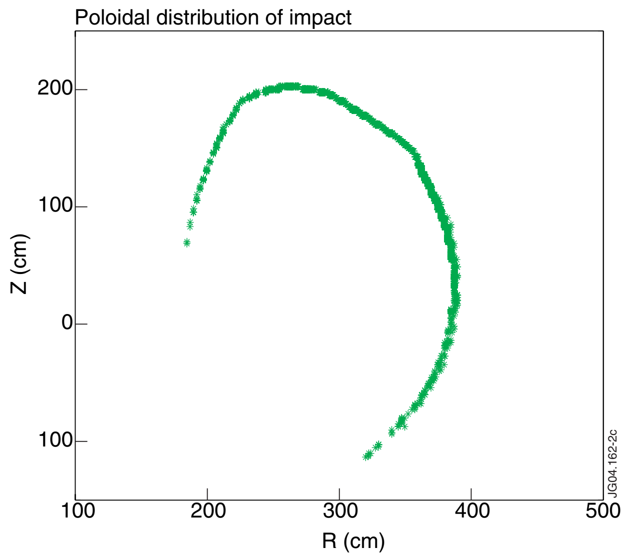

Figure 2: Poloidal distribution of 3 MeV proton losses at the wall for JET Pulse No: 59603 with reversed toroidal field.

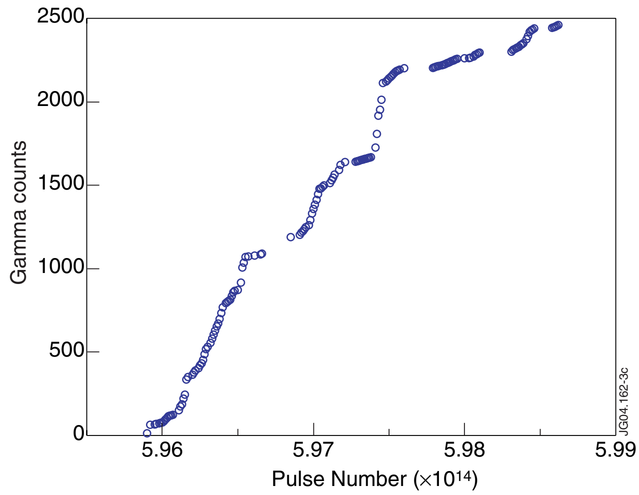

Figure 3: Predicted gamma ray signal due to activation after exposure to 152 deuterium pulses of C9 campaign

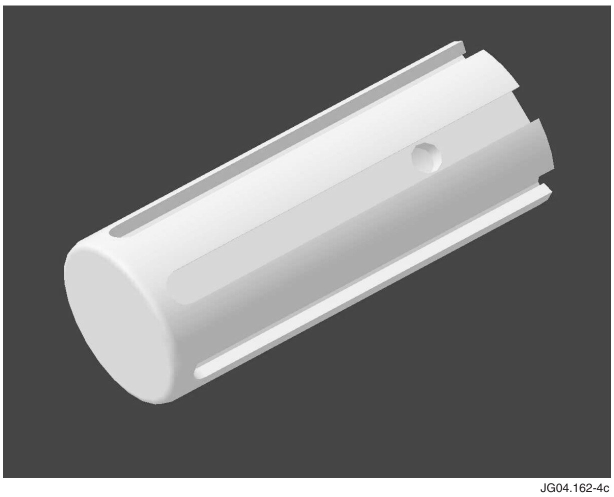

Figure 4: Sketch of new sample holder