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In-Vessel Activation Monitors in JET: Modelling and Experiments

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** See annex of M.L. Watkins et al, "Overview of JET Results ",*
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ABSTRACT.
Activation studies were performed in JET with new in-vessel activation monitors. Though primarily dedicated to R&D in the challenging issue of lost α diagnostics for ITER which is being addressed at JET with several techniques, these monitors provide for both neutron and charged particle fluence. A set of samples with different orientation with respect to the magnetic field are transported inside the torus by means of a manipulator arm (in contrast with the conventional JET activation system with pneumatic transport system). In this case, radionuclides with longer half-life were selected and ultra-low background gamma-ray measurements were needed. The irradiation was closer to the plasma and this potentially reduces the neutron scattering problem. This approach could also be of interest for ITER where the calibration methods have yet to be developed. The MCNP neutron transport model for JET was modified to include the activation probe and so provide calculations to help assess the new data. The neutron induced activity on the samples are well reproduced by the calculations.

1. IN-VESSEL ACTIVATION MONITORS

MeV particle losses measurements from fusion plasmas, in particular alpha particles, remain difficult in large fusion devices and further R&D is needed for ITER[1-2] and future fusion reactors. In-vessel activation monitors (fig.1) have been developed at JET with the aim to study activation induced by charged fusion products and other MeV ions[3-5]. Material samples are activated due to nuclear reactions of type (z, n), (z, γ),… where z is a light charged particle p, t, d, ^{3}He or α. After plasma exposure, samples are removed from the sample holder and ultra low-level gamma-ray spectrometry[5-7] of samples is performed. The main advantages of this technique are robustness, linear response, immunity to electromagnetic noise and temperature variation. A careful choice of the target allows particle identification and gives information on particle energy by selecting different nuclear reactions with different thresholds. Absolute measurements of fluence and spectral fluence (with multi-foil technique) are possible. The main limitation of the present method is the time resolution. Time-resolved measurements using prompt γ-ray emission have been proposed [5] but have not been tested yet. Recently, 14.7MeV fusion protons were measured for the first time in JET [8] and quantitative data on fusion proton fluence were obtained.

The boron-nitride probe head (figure.1) is 40 mm in diameter, 100 mm in length and has a hexagonal cross section. Each of the six sides has a slot which can be filled in with samples. Sample orientations are shown in figure 2. Samples in slot 1 are facing toward the inboard radial direction. There were 12 samples of titanium (Ti), 12 samples of boron carbide (B_4C), 6 samples of lithium fluoride (LiF) and 6 samples of tungsten (W) used in the experiment. Each sample was of natural isotopic composition.

2. NEUTRON TRANSPORT MCNP CALCULATIONS

This paper discusses the comparison of experimental results with the one, obtained with the MCNP[9] Monte Carlo neutron transport code. Significant progress has been already accomplished in the modelling using MCNP calculations while an overhaul of the complete JET model is under development for better understanding of experimental results. As origin the existing MCNP neutron transport model for JET[10] was used and modified to include the activation probe. In the model one quarter of the torus is represented, reflecting boundary conditions are applied on the two adequate edges. The model is simplified with respect to the engineering one; most of the smaller structures are not modelled in detail. A lot of care was taken for the gross neutron flux not to be influenced by the simplifications. The activation probe, however, is modelled to a great detail.

The spectral neutron fluence was calculated for each of the 36 samples for both 14MeV and 2.45MeV neutron energy and the results are similar. The 2.45MeV case is discussed below. Figure 3 shows the direct neutron flux calculated by MCNP in all sample rings with respect to the azimuthal direction. ‘Direct’ means that neutrons do not experience interaction/collision prior to reaching the sample. The simulations show a systematic variation of the direct neutron fluence with the sample orientation/position. The straightforward interpretation is as follows: the boron nitride sample holder attenuates the direct neutron flux. The largest reduction occurs for the position 4, i.e for samples directed radially outward while the sample looking radially inside the machine receives the maximum flux of direct neutrons. The effect increases with ring’s height. The largest effect is on the 6th ring which correspond to samples the furthest away from the probe tip and the plasma. Figure 4 shows the scattered neutron flux calculated by MCNP in all sample rings with respect to the azimuthal direction. In contrast with the results obtained for the direct flux, the scattered fluxes show much smaller systematic angular dependence and the main contribution to the fluctuations is the MCNP statistical noise – note that the scales in figures 3 and 4 are different.

The scandium-46 (half-life 83.8 days) induced activity were calculated using the FISPACT code[11]. FISPACT is an inventory code for neutron induced activation calculations in fusion devices. In addition to the neutron cross-section libraries, FISPACT runs also with protons and deuterons. The accuracy of the calculated induced activity is dependent on the quality of input nuclear data, i.e. cross sections and decay data. FISPACT shows that four reactions contribute to ^{46}Sc radionuclide production: ^{46}Ti (n,p)^{46}Sc (72.5%), ^{47}Ti (n,d) ^{46}Sc (7.4%), ^{46}Ti(n,p)^{46m}Sc (IT) ^{46}Sc (18.8%) and ^{47}Ti (n,d) ^{46m}Sc (IT) ^{46}Sc (IT means isomeric state transition) .

3. COMPARISON WITH EXPERIMENTAL DATA:

The induced activity of Scandium-46 on the titanium samples was calculated using MCNP and FISPACT. Results are shown in figure 5 and compared to the measured distribution. Figure 5 shows the case of the top titanium samples set (6th ring). The measured distribution of Scandium-46 ^{46}Sc activity on the samples is well reproduced by the calculations. Simulations explain well the variations of neutron induced activation observed in samples as function of sample orientation.

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Figure 1: View of the activation probe after an irradiation by 63 JET plasmas

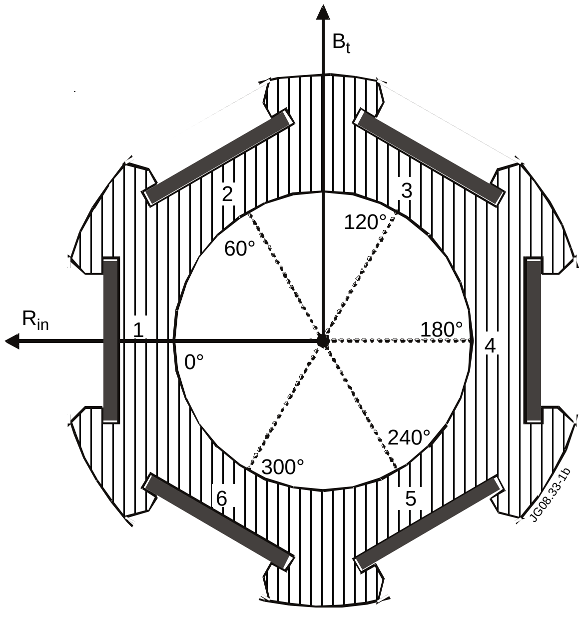

Figure 2: A cross section of the activation probe in which the 36 samples were held. B_t is the standard direction of the toroidal magnetic field and R_{in} is the azimuthal direction along the major radius of the Tokamak and pointing radially inward. The numbers indicate the 6 sample positions.

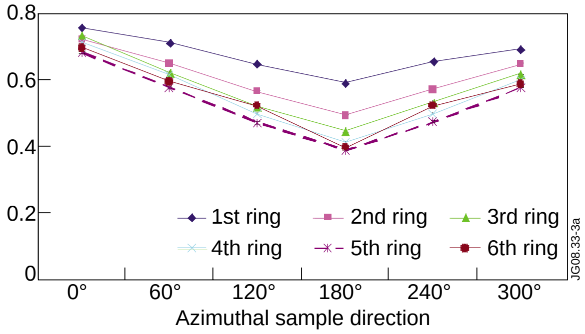

Figure 3: Direct neutron flux calculated by MCNP in all sample rings with respect to the azimuthal direction of the sample, DD plasma case.

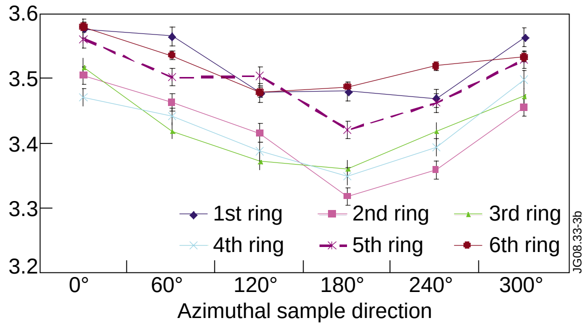

Figure 4: Scattered neutron flux calculated by MCNP in all sample rings with respect to the azimuthal direction of the sample, DD plasma case.

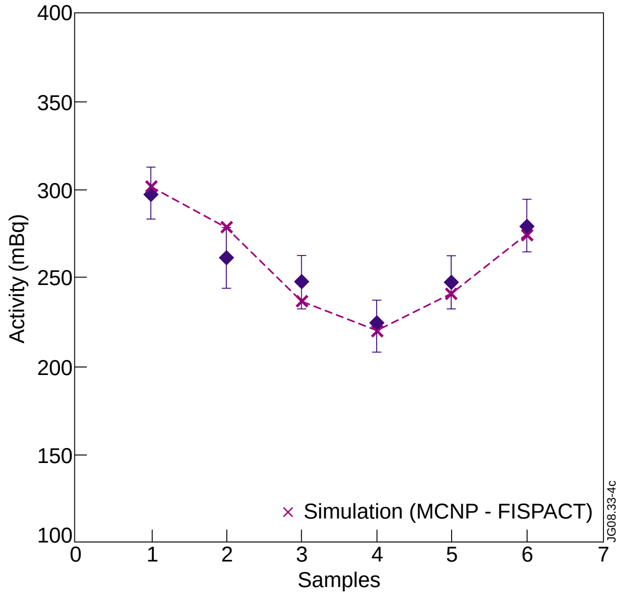

Figure 5: Comparison between the relative variation with the azimuth angle of the measured and calculated Scandium-46 radionuclide activity on the 6th ring. (The calculated values are relative).