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Experimental validation of an integrated modelling approach to neutron emission studies at JET

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Successfully confining, and heating D and DT plasmas in tokamaks results in the emission of neutrons, which carry a part of the excess energy produced in the fusion of fuel ions. Upon escaping the magnetic confinement neutrons effectively transfer fusion energy generated in the plasma to the device's first wall and other tokamak components, such as plasma diagnostics. In future fusion devices it will be the neutrons'kinetic energy that will be harnessed in reactor walls, producing heat and consequently electricity. In modern tokamaks neutrons predominantly play a different role –most importantly they are measured to evaluate the fusion power produced and monitor our progress on the path to extracting net power. Additionally the emitted neutrons act as a plasma diagnostics tool, carrying information on the ion temperature and fuel ion density ratio [1], fidelity of the coupling of external heating [2], and fast ion physics [3]. In DT plasmas neutron measurements will give insight into alpha particle physics, like their source distribution and secondary knock-on effects, of relevance for ITER and beyond.

Because of the important role neutrons play in advancing our understanding of confined plasma experiments, further development of integrated modelling codes for calculating properties of neutrons emitted from tokamak plasmas is needed. An integrated approach to realistic neutron emission modelling was recently developed [4], enveloping the use of the plasma transport code TRANSP [5], neutron spectrum calculation code DRESS [6] and neutron transport code MCNP [7]. The methodology is based on interpretative plasma simulations, with which we study the effects of NBI and RF heating on the distribution functions of thermal and fast ions and consequently fusion neutrons. **It was demonstrated that with such a comprehensive computational chain we can clearly observe the effects of heating on the properties of source plasma neutrons –such as significant changes in neutron emissivity profiles, and anisotropy in neutron energy spectra**. The methodology has been applied to a baseline D plasma JET discharge. By coupling the calculated neutron emission to a Monte Carlo neutron transport code, preliminary studies of the sensitivity of neutron yield measurements to changes in the plasma neutron source have been performed. These have shown that the **fusion power measurements are weakly sensitive to changes in plasma conditions, supporting the absolute neutron yield calibration procedure at JET**. This analysis has also shown that the **neutron activation system measurements can be largely sensitive to heating induced changes in neutron spectra in case activation material with high energy threshold reactions is used**.

The work presented in the paper can be seen as the evolution of the groundwork development and initial analyses detailed in [4], which was improved and expanded with the following objectives:
• The integrated modelling approach to neutron emission studies at JET has been applied to a wider set of JET D plasma discharges, focused on experiments aimed at developing plasma scenarios relevant for DT operation, and neutron diagnostics commissioning. Specifically we have analysed neutron emission characteristics of baseline and hybrid discharges, as well as those implementing concept heating scenarios. The differences in the distribution of fast ions arising from heating induced effects will be addressed. We will show how the successful formation of a fast ion tail induced by RF heating results in the production of a significant amount of fast neutrons, with energies of more than 4 MeV.
• In order to validate the neutron emission calculations plasma neutron source properties, i.e. neutron emissivity profiles and neutron energy spectra, have been compared with measurements of standard neutron diagnostics systems, such as the neutron camera [9] and time-of-flight spectrometer [10].
• **The main contribution is the experimental validation of the neutron emission computational methodology against neutron activation system measurements**. We have found that a set of activation foils with ^{115}In(n,n')^{115m}In, ^{27}Al(n,p)^{27}Mg, and ^{56}Fe(n,p)^{56}Mn reactions can act as a probe for the effects of external plasma heating on neutron spectra. This is a result of the combination of relatively high energy thresholds of these reaction, around the 2.45 MeV DD neutron peak, affecting the reactions'sensitivity to neutrons emitted in fusion of fast ions. It was calculated that the Al/In activation ratio can increase by up to a factor of 10 when going from a baseline to a concept RF heating scenario, while the Fe/In activation ratio increases for several orders of magnitude. These ratios will be validated against experimental measurements. Additionally the effects of triton burnup neutrons on the computed neutron spectrum and foil activation will be assessed. In order to obtain a realistic DT neutron spectrum component in D plasmas, the DD triton spatial and energy distribution functions will be calculated. **Although the In, Al, and Fe reactions have been used individually for neutron measurements before** [11], **a combination of these foils is used for**

experimental validation of plasma integrated modelling for the first time.

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