

Quantitative investigation of the neutron production in ASDEX Upgrade

M. Koleva¹, G.Tardini¹, H. Zohm¹, B.Wiringer¹,
the ASDEX Upgrade Team¹

¹ *Max-Planck-Institute for Plasma Physics, Boltzmannstr. 2, D-85748 Garching, Germany*

Introduction

Neutron rate counts reveal information about the fusion performance and fast ion dynamics in fusion machines. Even though fast ions play a key role in the plasma heating, their tendency to interact with instabilities can be detrimental to the fusion reaction and the plasma facing components. Hence, understanding and predicting their behaviour is imperative for reliable extrapolations to larger fusion reactors.

Over the course of neutron rate investigations at ASDEX Upgrade, systematic discrepancies between the experimental and the neutron rate predicted by TRANSP have served as a benchmark for potential calibration errors in the neutron detectors [1]. In order to minimize them, a new calibration technique has been performed, that is easily reproducible, spatially precise and longer compared to previous calibrations. The theoretical representation of the calibration is carried out by Serpent [2] the advantages of which will be discussed further in this paper.

Neutron rate predicted by TRANSP and current challenges

TRANSP [3] is a one dimensional time dependent transport code that relies on available diagnostics data as an input in order to simulate the evolution of a plasma. It solves a number of transport related equations and supports the incorporation of models describing sawtooth events, pellet injection, NBI and ICRF heating.

Comparisons on JET and MAST between the experimental neutron rate and the one obtained by TRANSP, however, show discrepancies referred to as 'neutron deficit' [4] [5]. It was shown that in both tokamaks the experimental neutron rate (considering a well performed calibration) falls short of expectations based on the TRANSP code. Clear explanation is still of research interest.

To check how this comparison currently looks like for ASDEX Upgrade and account for calibration errors, it is assumed that TRANSP correctly predicts the neutron rate. A set of NBI-heated discharges has been chosen for the TRANSP simulations. Variances in plasma parameters and their effect on the discrepancies have not been the focus of this analysis but additional information about them based on previous neutron rate investigation can be found here [1]. The outcome of the recent observation is shown in figure 1 and an example of neutron rate time traces on fig-

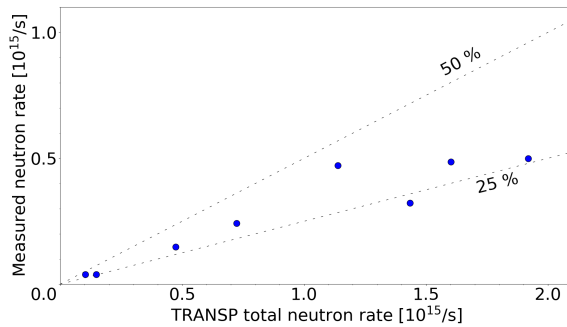


Figure 1: Comparison between the TRANSP calculated neutron rate and the experimental one obtained by the epithermal neutron diagnostics.

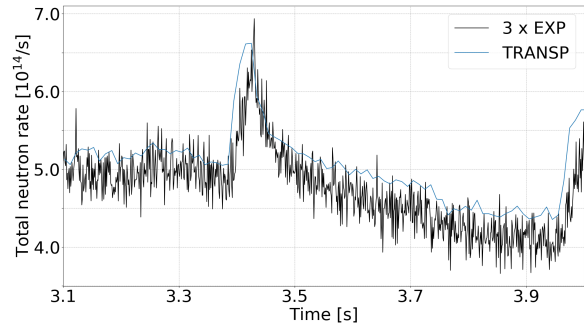


Figure 2: Example of the overestimated neutron rate by TRANSP for discharge pulse #33173.

ure 2. The experimental neutron rate falls even shorter of the predicted one by TRANSP by a systematic factor which adds to the results previously obtained at ASDEX Upgrade that calibration uncertainties introduce significant errors to the neutron rate evaluation. This imposed the necessity of a new absolute calibration that has more statistics and is more spatially precise.

Experimental set-up and simulation of the calibration

A toy train carrying a radioactive source (^{238}Pu) on top was run inside the tokamak vessel over two poloidal positions enabling neutrons to face all components on their way to the detectors. The longer calibration time provided better statistics and the fixed position of the railway tracks allows for a better reproducibility. The collected signals from the ^3He detector and spectrometer (figure 3) showed a periodicity in the neutron rate time trace which was expected from the clearly periodical toroidal path. In contrast, the signal from the BF_3 detector appears spiky and rather uncorrelated to the other two, a current possible explanation to which could be a bad signal to noise ratio or gamma counting.

The simulation of the calibration is performed by means of Serpent which is a 3D Monte Carlo particle transport code in which the geometry can be either built inside the code or imported as already available CAD files in STL format. For the purpose of a detailed simulation the latter was used.

ASDEX Upgrade geometry was divided into sectors and each sector broken down into smaller components using CATIA. The first and main reason for this was to check the water-tightness of each component due to the high sensitivity of the code. This was performed with another CAD program - NetFabb, that allowed the fixing of tessellation gaps and coinciding points in the triangular facets. Drawings with consistency of $\approx 96\%$ and below introduce errors that appear as extra pixels in the plots and lead to the lost of simulated particles which eventually terminates

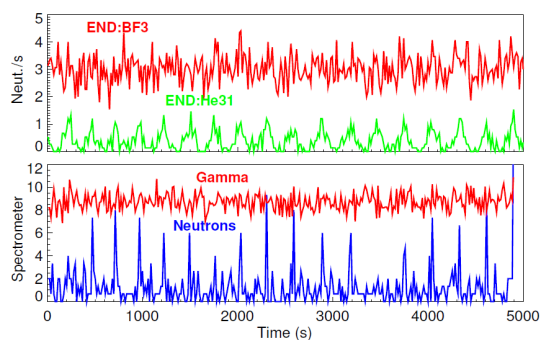


Figure 3: Neutron rate calibration signal from three neutron diagnostics.

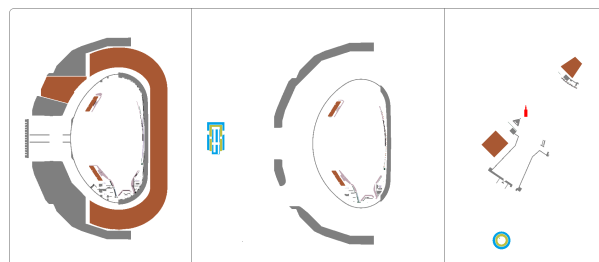


Figure 4: Poloidal view of ASDEX Upgrade Sector 11 (left) rotated by an arbitrary angle for a clear view of the neutron detector chamber (middle) and a top view (right).

the run. Second reason for the decomposition is the prescription of materials to the geometry. Imported STL files can not be divided into smaller components in the code itself, therefore each element (or group of elements) of specific material has to be provided separately. Poloidal cut and top view of the sector closest to the neutron detector chamber is shown in figure 4 where different colours correspond to different materials. Each material is given by a list that includes the material density and constituent nuclides in atomic or mass fractions and each nuclide is associated with a cross section library. Hence, calculating and giving the correct values is crucial for the detector output. Detectors, on the other hand, can be assigned to any material or surface of interest and the input parameters set up spatial and energy domains, response functions, etc. The detector chamber in ASDEX Upgrade consists of several neutron detectors (including ^3He and BF_3) that are surrounded by polyethylene as a moderator and lead for blocking the gamma rays. In this work, however, the preliminary result is obtained by using only the ^3He detector, a point source of thermal neutrons (0.025 eV) at a fixed position (figure 4 (right)) and no moderator. The integrated neutron rate in this scenario is 120 n/s which is higher in comparison with the experimental result (figure 3, END: He31). Proposed sources of discrepancy are the use of a monoenergetic thermal neutron source instead of spatially distributed one and the exclusion of the moderator. To further check the capabilities of the detector another case with a point source of 4 MeV was run as well. The obtained result was zero which is in agreement with the expectation based on the smaller cross-sections for highly energetic neutrons.

Future short-term goal of this study would be including the polyethylene moderator and a ^{238}Pu radioactive decay source. Long-term goals include a dynamic simulation allowing to check the periodicity of time traces and improve the statistics. Last but not least, the simulation of fusion

reactions using Serpent will make further fusion related studies available in this project.

Conclusions

TRANSP simulations allow the identification of calibration uncertainties in the neutron diagnostics. The observed systematic overprediction of the experimental neutron rate posed the urge to a new calibration of the neutron detectors for more accurate neutron measurements. A new calibration procedure in ASDEX Upgrade allowed for more statistics of the neutron counts and higher spatial consistency. For the simulation of the calibration, the tokamak vessel was decomposed first into sectors and then into smaller parts in order to check the water-tightness and assign the materials. Recent results from the simulation of the calibration shows significantly higher neutron rate compared to the experimental one, the reasons for which might be the exclusion of the moderator and the usage of mono-energetic neutron source. A proper absolute calibration would open space for further TRANSP investigations not only of the neutron rate deficit but also of the fast ions behaviour in fusion machines as a part of this research activity.

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