ASCOT simulation of fusion product activation probe experiment in ASDEX Upgrade tokamak

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In quest for an escaping fast ion measurement diagnostics applicable for ITER, the escaping fusion product flux in ASDEX Upgrade was measured using an activation probe [1, 2]. This contribution presents the numerical analysis of these experiments using the ASCOT code [3], currently the most comprehensive fast ion code in the world.

The thermal and beam-target fusion reaction rate is calculated with the ASCOT code and, for verification purposes, also with TRANSP [4]. (The dominating reaction is beam-target. Further details are in Figure 1.) Orbits of the fusion products (protons (E=3.02 MeV) and tritons (E=1.01 MeV) from D(d,p)T and helium (E=0.82 MeV) from D(d,n)^{3}He) are followed, using ASCOT, including the detailed 3D first wall and the toroidal field coil ripple. The particles that hit the detector are further analysed to calculate the flux to various parts of the probe.

The main result of the contribution is the comparison of measured and simulated fusion product flux into the probe. These simulations facilitate optimisation of the AUG activation probe diagnostic and further validation of the ASCOT code for fast ion wall load calculations. The probe was in the limiter shadow and therefore, the bulk of the fusion products hit the various limiters and other plasma facing components. Of the few reaching the probe, most hit the probe tip, while the active elements are located behind a narrow opening in a protective graphite cap. All in all, a few tens of ppm of the test particles remain relevant for this study.

Millions of test particles representing the fusion products were simulated for 1 ms to acquire the fusion product flux to the probe for #29226, as shown in figure 2. Also two experimental data for protons are included. Several tens of percent of the test particles were still confined after 1 ms. But a test simulation with 10 ms length and smaller number of test particles didn't significantly increase the yield to the probe. The median time for a proton test particle to reach the detector is ~ $0.8\,\mu$s. For for ^{3}He and tritons the time is ~ $0.2\,\mu$s. This seems to be enough

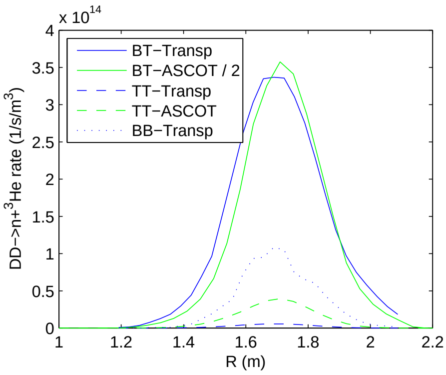

Figure 1: *A comparison of calculated fusion rates at the midplane. The fusion rates were calculated with TRANSP to validate the ASCOT code. The beam-target rate is the dominating fusion process. The difference of a factor of 2 between ASCOT and TRANSP could be due to the different use of the term* $1/(1+\delta_{ij})$ *needed for identical particles reacting with each other [5]. ASCOT currently assumes* $\delta_{ij} = 0$ *for beam-target reactions. The difference in thermal fusion rates is attributed to differing* T_i *in ASCOT and TRANSP, but this needs further verification. Also the ASCOT beam-beam reactions will be compared in a future contribution.*

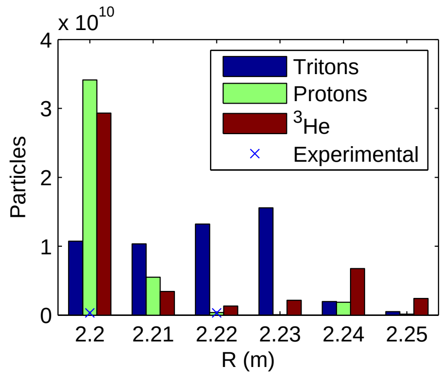

Figure 2: *Flux to the 6 active detector elements positioned in row in major radius. The particle flux to each location for each modelled fusion product is shown. Two experimental datapoints of the proton measurement are shown. The simulation fits the measurement within the uncertainty of the measurement at R=2.22m, while at R=2.20m the results disagree strongly.*

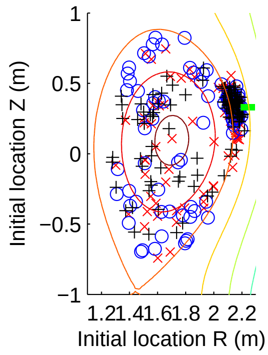

Figure 3: *The poloidal birth locations of the test particles that reach the probe. Symbols:* × *Tritons,* ∘ *Protons,* + ^{3}*He,* ■ *the probe*

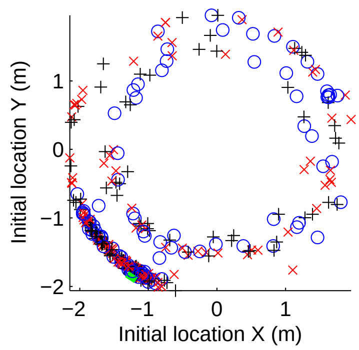

Figure 4: *The toroidal birth locations of the test particles that reach the probe. Symbols:* × *Tritons,* ∘ *Protons,* + ^{3}*He,* ■ *the probe*

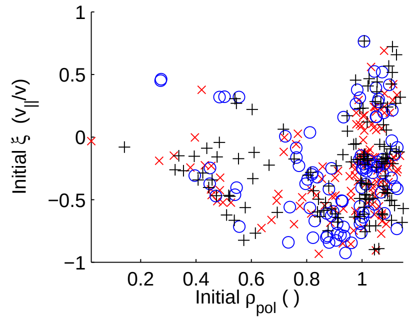

Figure 5: *The birth locations of the test particles reaching the probe. The axes are the minor radius and direction of velocity:* $v_{||}/v_{tot}$*. Symbols:* × *Tritons,* ∘ *Protons,* + ^{3}*He*

time for test particles to reach the probe from anywhere in the plasma. Figures 3, 4 and 5 show the birth locations of the test particles that hit the probe. Each test particle represents different number of real fusion products depending on the local fusion reactivity (shown in Figure 6). This *weight* is very low for the particles born outside the plasma separatrix ($\rho_{pol} > 1.0$) and, therefore, they are unlikely to contribute significantly to the flux even if the number of such test particles is relatively large.

In this paper, we have described the first steps in simulating the activation probe experiments for ASDEX Upgrade. The simulation concurs excellently with the measurements for one data point, while not at all for the other. With only two datapoints, no conclusions can be drawn. This situation should become clearer as more experimental measurements become available. Future modelling work includes further validation of ASCOT against TRANSP and extending the simulation to modelling the burn-up effect: ^{3}He (produced in DD-reactions) further reacting with deuterium and producing 14.7 MeV protons.

References

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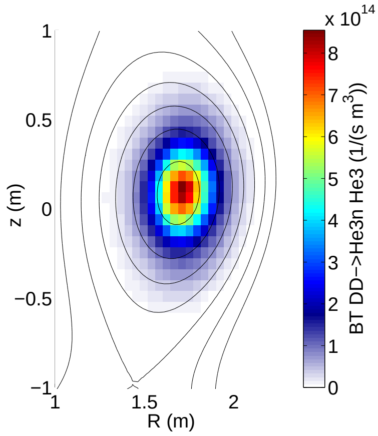

Figure 6: *The beam-target D(d,n)^{3}He fusion reaction rate. The rate for both D(d,·)· reactions is nearly identical. The reaction rate quickly diminishes when moving away from the core.*

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