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Tutorial_2: Nuclear measurements of fusion products in magnetic confinement reactors

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Fusion reactions in magnetic confinement systems generate MeV range particles, both charged and uncharged, which are key to qualify the fusion process. 14 MeV neutrons from the d+t ⟶ alpha + n fusion reaction in deuterium-tritium plasmas carry information on the fusion power and its profile, as well as on the kinematic properties of the fuel ions. 3.5 MeV alpha particles are responsible for the self-sustainment of the fusion burn, but their detailed physics is still partially unknown, as the fusion community awaits the production of a burning plasma at the ITER tokamak by the mid-2030s.

While the nuclear measurement of both type of fusion products is recognized as being key for the development of a fusion reactor, this is also –perhaps - one of the most difficult tasks for fusion diagnostics. As neutrons escape the confining magnetic fields, they can be measured directly. Through a careful and lengthy calibration procedure, fission chambers and activation foils allow determining the neutron yield up to a demonstrated accuracy of about 10%. Systems made of solid state or liquid detectors, deployed at the end of several collimated lines of sight, determine the spatial profile of the emission. A range of spectrometers with different design analyze the relatively narrow distribution of neutron energies around their peak at 14 MeV, which tells the kinematic properties of the fuel ions that generate the emission.

Charged fusion products, such as alpha particles from d+t, are more elusive. Faraday cups and scintillator probes can measure ions that are lost to the machine first wall, but their deployment is increasingly challenging as the fusion performance approaches reactor conditions, and possibly unfeasible in a reactor at full scale. On the other hand, confined fusion products are indirectly observed by the gamma-ray emission they induce. As in the case of neutrons, gamma-rays escape the confining magnetic field and travel along dedicated lines of sight, where spectrometers sufficiently away from the vacuum vessel can detect them.

In this tutorial presentation, the most established techniques for the nuclear detection of fusion products will be introduced, with examples taken predominantly from experience at the Joint European Torus. A discussion of the challenges the systems face as full scale reactor parameters are approached will also be presented, including the need for further research and development.

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