Impurities in a Magnetically Confined Fusion Reactor

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Impurities play a two-sided role for the operation of a fusion reactor plasma, as their presence dilutes the fusion fuel, i.e. a 50:50 mixture of deuterium and tritium, while the power exhaust requires also a minimum amount of seeded radiating impurities to be dealt with. Additionally, the fusion reaction produces energetic helium particles inside the plasma, providing an impurity source proportional to the plasma heating. A model describing the equilibrium state of a reactor with respect to the presence of impurities exists since the 1960s and has been elaborated in 1990 [1]. However, an appropriate evaluation of the role of the impurities with bound electrons requires atomic data such that the radiative cooling can be described with a reasonable quality. Such data was calculated in the present work for more than 35 elements, relying on codes calculating the electronic structure (MCHF), the ionization (CADW) and recombination rates (Burgess general formula) and electron impact cross sections (plane-wave Born) for more than 1000 different ions. The strength of the produced results is not linked to the employed calculation method, but rather to the fact that the data is obtained for all ionization states (some exceptions for neutrals and lowly charged species) of each element, and that for isoelectronic sequences the same sets of input configurations have been used. The resulting set of data is expected to well reproduce the experimental data at temperatures above a few 100 eV, which are typical for the confined reactor plasma.

Additionally, the simple equilibrium model [1] is extended and now handles parameterized temperature and density profiles and self-consistent fusion power performance. This extended equilibrium model has been validated by comparing it for a specific reactor design to the results of a 1D transport code with a much higher degree of detail. This extended, but still simple equilibrium model predicts impurity levels (including He) as well as the fusion power per external heating to a high accuracy. As a second step, the parameter space suited for a fusion reactor is scanned considering the estimated electrical energy production and ensuring the compatibility with technologically achievable power removal for various impurities in the reactor plasma. Using realistic boundary conditions on dilution and radiative power exhaust, a region in the parameter space best suited for a fusion reactor is identified. Based on these results, the contamination of the main plasma by low-Z impurities must be avoided. This implies that helium removal is of high importance, and that if a low-Z radiator is used in the plasma boundary, it must not leak into the main plasma.

References

[1] D. Reiter et al., Nucl. Fusion **30**, 10 (1990).