Hot and Dense Plasmas with Low Power Loads on Reactor Walls: A Hurdle to Fusion Energy Overcome in Alcator C-Mod

Experiments in the Alcator C-Mod tokamak have shown for the first time that plasmas with large fusion power production will not overheat the walls of the reactor

Developing magnetic confinement fusion into an energy source will require the achievement of plasmas sufficiently hot and dense for fusion reactions, simultaneous with sustainable power fluxes to the reactor walls. Attempts in experimental fusion devices to meet these requirements have typically resulted in plasmas that would produce abundant fusion power when scaled to a reactor but would lead to local overheating of the components protecting its wall or to the reverse, plasmas whose power outflow could be handled but which would produce too little fusion power. The critical component, called a divertor, is located at the area of the vessel wall where the highest power fluxes are expected.

New experiments in Alcator C-Mod with high levels of radiofrequency heating power used injected impurities to decrease local deposition of the exhaust plasma power. These experiments demonstrated that the requirements for high performance and acceptable power exhaust could be met in a fusion reactor, such as ITER (an international fusion project presently under construction in France with US participation). The results are summarized in Fig.1, where the confinement of energy in the plasma, normalized to the scaling law on which the ITER design is based, is plotted versus the fraction of total loss power reaching the divertor, for experiments injecting a variety of impurity gases (nitrogen, neon and argon). On the same plot, the requirements for 500 MW fusion energy production in ITER are plotted in red.

The Alcator C-Mod experiments confirm that the key parameter governing fusion plasma performance is the power that exhausts through the edge of the confined plasma, which needs to be above a critical value, the so-called high confinement power threshold. Research on Alcator C-Mod has also shown that this minimum exhausted power for good confinement can be safely distributed by enhanced radiation from impurity ions in the exterior layers of the plasma (as shown in Fig. 2), thereby avoiding both local wall overheating or deteriorating fusion performance. The key new feature of the Alcator C-Mod experiments is that the ratio of the plasma heating power to the minimum exhausted power for good confinement is large, allowing the requirements for good plasma confinement and large levels of electromagnetic radiation by impurities to be met for the first time.

While the results from Alcator C-Mod are already significant for ITER, the next step in fusion energy development, they are more so for the first fusion reactors which will provide electricity to the grid for commercial use. These reactors are expected to have a similar requirement with regards to the minimum exhausted power and for good confinement as in ITER, but with fusion energy production about 5 times larger, posing a much greater challenge for local wall heating. The Alcator C-Mod results show that for these future reactors, redistributing the exhaust power by impurity radiation at the plasma edge and the exterior layers of the plasma is a viable option.

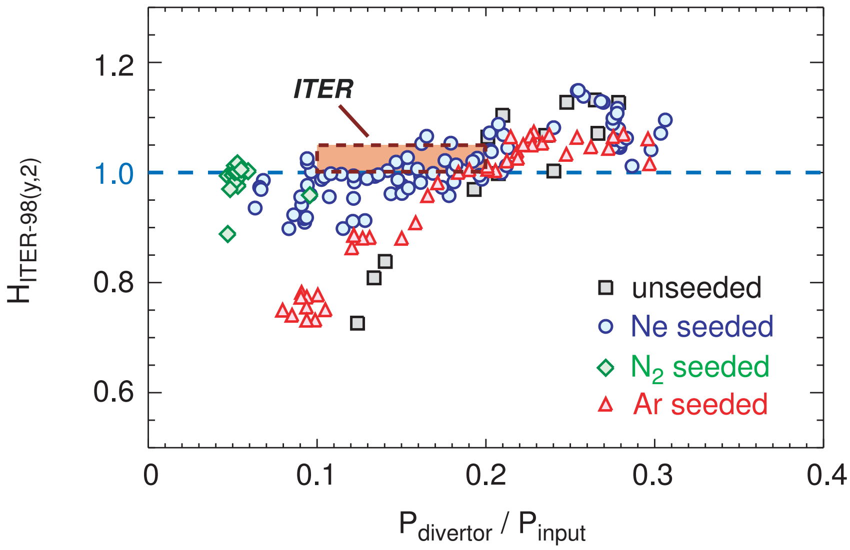

Figure 1. Normalized energy confinement in Alcator C-Mod experiments versus the ratio of the outer divertor power load to the plasma heating power for a range of experiments with/without impurity seeding (Neon, Nitrogen and Argon) together with the ITER requirements.

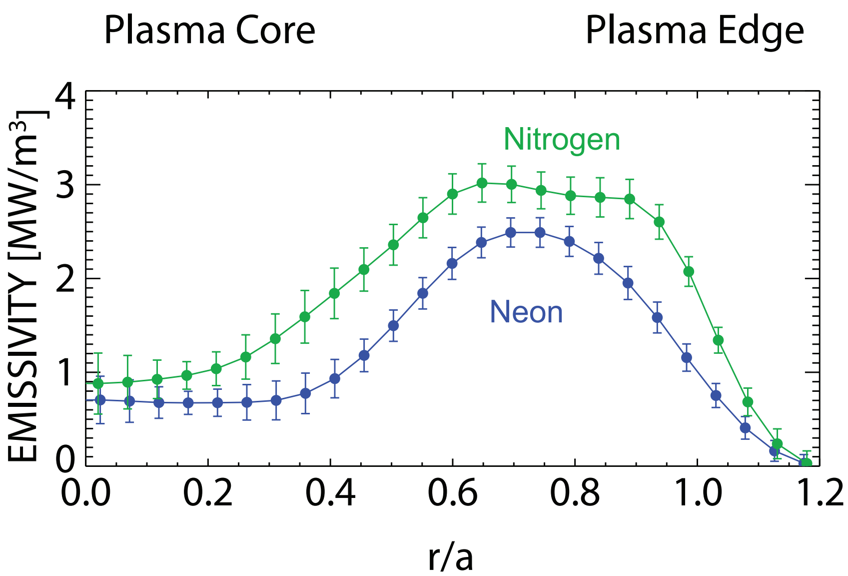

Figure 2. Radiated power density across the cross section of Alcator C-Mod plasma for Neon and Nitrogen impurity seeded H-modes.

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High confinement/high radiated power H-mode experiments in Alcator C-Mod and consequences for ITER $Q_{DT} = 10$ *operation*

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