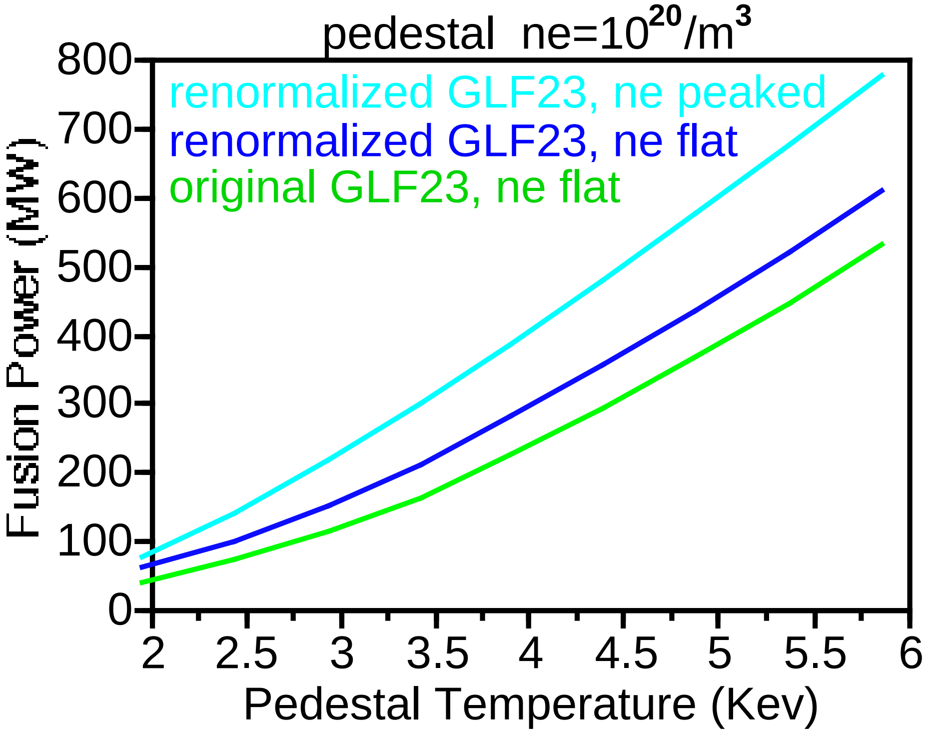
Improved fusion performance with density peaking and negative neutral beam driven rotation.

Gary Staebler and Holger StJohn
General Atomics
San Diego, CA

The fusion power predicted for given tokamak design is strongly dependent on the pressure at the top of the H-mode pedestal (taken to be at r/a=0.9). The theory-based transport model GLF23 predicts that the fusion power will scale approximately like the pedestal pressure squared. If the pedestal pressure is held fixed, the fusion power can only weakly be increased by adding more auxiliary power. This is due to the strong onset above a threshold temperature gradient (stiffness) of the ion temperature gradient mode in the GLF23 model. There are several ways to improve the fusion performance of a given tokamak. The shape can be optimized to get a high pedestal pressure. The core q-profile can be controlled for improved transport and even transport barriers. Here two more ordinary means of improving fusion performance are discussed: density peaking and momentum injection.

In Fig. 1 are shown the fusion power verses pedestal temperature for the ITER-FEAT base design at a pedestal density of $1.0x10^{20}/m^3$ (84% of the Greenwald density).



The lower curves are for a flat density profile comparing the original GLLF23 model with a new version renormalized to obtain a best fit to the stored energy for a set of 50 ELMing H-mode discharges. The ion and electron temperatures were evolved to equilibrium using GLF23 for all cases. The upper curve is for a density which has been self consistently evolved by GLF23. The core particle source was adjusted to find the maximum fusion power for a given pedestal condition. Thus, the upper curve is the optimum density. A realistic pellet fueling source was not used for this study. Nevertheless, it demonstrates that a significant improvement of the fusion power can be achieved by peaking the density profile. There is no transport barrier or reversed magnetic shear in these cases just density peaking. The density profile is broad with a central density of about $1.8x10^{20}/m^3$.

Another way to improve the fusion performance is to inject toroidal momentum. This creates an ExB velocity shear, which raises the ion temperature gradient needed to excite the ITG mode (ion temperature gradient mode). Using the ONETWO transport code, the power and momentum deposition for a 1MEV negative ion neutral beam (NNBI) injected into ITER-FEAT was computed. This is only an approximate calculation using the NFREYA package designed for much lower energy positive ion neutral beam sources. It was assumed that 40MW of NNBI was injected tangent to the magnetic axis toroidally. The impact of the rotation on the fusion power can be seen in the following table.

ITER-FEAT	Bal. flat ne	Co. flat ne	Bal. peaked ne	Co. peaked ne
fusion power	281 MW	350MW	353MW	539MW

Here the pedestal temperature was 3.5Kev and the pedestal density was $1.0x10^{20}/m^3$. The first column is for balance injection (no momentum) with a flat density. The second column is for co-injection and flat density. The last two columns use the density profile found for the optimum fusion power (upper curve) in Fig. 1 at this pedestal temperature. The density is not evolved. The ion density is about 15% higher for the cases in the table than for the cases in Fig.1 because these are for a pure D-T plasma whereas the runs in Fig. 1 had carbon impurities included. This is why the balanced injection cases have a somewhat higher fusion power than in Fig.1. There are no internal transport barriers but the toroidal rotation induced ExB shear does increase the ion temperature gradient threshold for the ITG mode. It was found that the fusion power is only a weak function of the pedestal toroidal rotation velocity boundary condition. This is because it is the velocity shear not the speed which impacts the ITG modes. The velocity shear is proportional to the NNBI torque density not the boundary speed. The toroidal rotation speed at r/a=0.9 for the cases in the table was taken to be 92Km/s which is the velocity measured in a particular DIII-D discharge (106029 at 1.5sec). The toroidal rotation needed to stabilize resistive wall modes in ITER-FEAT has been computed by Ming Chu (GA-internal report) to be about 1.2% of the central Alfven velocity or 88km/s for ITER-FEAT at this density. The central toroidal rotation in the co-injected cases is at least a factor of two above this level even if the pedestal value is reduced by a factor of 10. The gain in fusion power is about the same for density peaking and rotation. The gain with both together is even larger than their sum. This preliminary study warrants more accurate calculation of the NNBI impact on toroidal rotation and fusion power. It also shows that there are ordinary means to improve the performance of a tokamak like ITER-FEAT if the pedestal pressure is too low to reach performance goals in a flat density ELMing H-mode.