Computer simulations of the ITER fusion reactor

Federico D. Halpern, Glenn Bateman, Christopher M. Wolfe, Alexei Pankin, and A. H. Kritz*
Department of Physics, Lehigh University

ITER [1], the thermonuclear experimental device currently under construction in France, is the first fusion reactor that is expected to produce large amounts of power. In ITER, energy will be produced from the fusion of hydrogen isotopes (deuterium and tritium) into helium. In order to overcome the electrostatic repulsion between atomic nuclei, the mixture of deuterium and tritium gas must be heated to extremely high temperatures. The resulting gas forms a plasma in which atomic nuclei and electrons are no longer bound together. Fusion reactors such as ITER confine plasmas using strong magnetic fields.

Plasmas must be confined for a long enough period of time at sufficiently high temperature and density to produce more fusion power than input power. This energy confinement prerequisite for fusion, usually expressed using the Lawson criterion [2], cannot be achieved in present day reactors. ITER is expected to confine plasma discharges for 500 seconds, at a density of 10^{20} m^{-3}, and a temperature of 20 KeV, which is about 15 times the temperature of the center of the sun. It is anticipated that ITER will produce about ten times more fusion power than input power. The first plasma operation is projected to be in 2017.

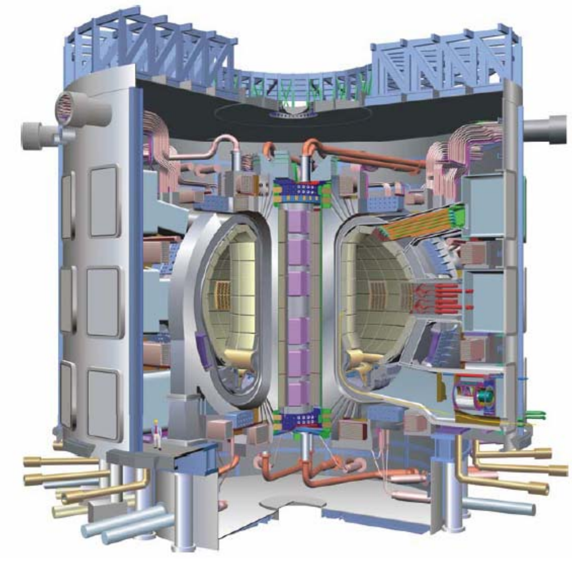

Figure 1: Rendition of the ITER design. To illustrate the colossal scale of the device, a person is shown standing on the lower left portion of the figure.

In the research described here, the performance of ITER is predicted with computer modeling simulations that are carried out using leading theory-based models for whole-device simulations. These models have been validated by comparing simulation results against experimental data. Since no existing fusion experiment can recreate the conditions that are expected to occur in ITER plasmas, theory based models are preferred over empirical models in computer simulations.

Physical processes in fusion reactor plasmas are strongly coupled. Consequently, whole-device, integrated modeling computer simulations must compute the effects of many physical processes self-consistently. The ITER simulations involve the self-consistent time evolution of: Plasma temperature, rotation, and density; heating due to fusion reactions as well as neutral beam injection and radio frequency heating; conditions at the plasma edge; and instabilities that can degrade plasma confinement.

Energy confinement in plasmas is limited by thermal losses due to turbulence. Two leading models for turbulent thermal transport, the Multi-Mode 95 model (MMM95) [3] and the Gyro-Landau Fluid model (GLF23) [4], are utilized in the ITER simulations. Simulation results using these two models agree with experimental data from existing devices about equally well. All the simulations are carried out using a predictive model for the edge transport barrier that has a strong effect on plasma confinement [5]. When the input power is 30 MW, the simulations predict a fusion power of 205 MW with the GLF23 model, and a fusion power of 325 MW with the MMM95 model. Since the core plasma temperature is strongly influenced by the edge conditions, the predicted fusion performance of ITER increases when the temperature at the edge barrier increases.

One of the principal scientific objectives of the ITER project is to study the properties of burning plasmas. Most of the heating power in a burning plasma originates from fusion reactions as opposed to input heating power. When more input power is injected into a burning plasma, more fusion power is produced. However, it is found that the increase in fusion power does not offset the increase in input power. The fusion performance of ITER can be optimized by finding the minimum amount of input power that is required to achieve significant self-heating. The computed ratio of produced fusion power to input power is shown in Fig 2 as a function of input power. The predicted optimal input power is close to 20 MW.

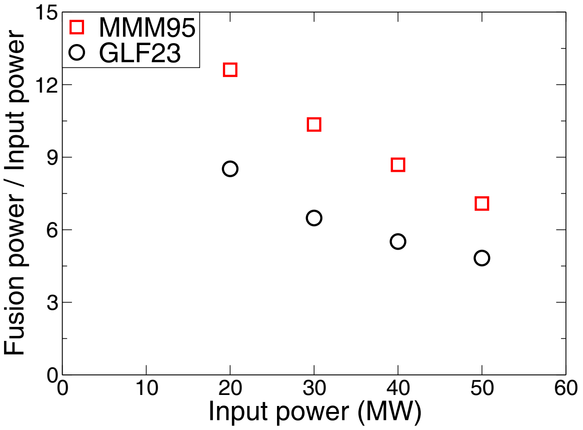

Figure 2: Ratio of fusion power to input power is shown as a function of input power.

It is found that with less than 20 MW of input power the fusion power production decreases significantly. This result is caused by the following effect. If the input power is less than 20 MW, the edge transport barrier does not form and, therefore, the plasma reverts to a lower confinement regime with lower central temperatures. Under these conditions, the plasma cannot sustain enough fusion reactions to initiate significant self-heating.

In conclusion, theory-based computer simulations predict that ITER will produce hundreds of megawatts of fusion power. The simulations use predictive, theory-based models for turbulent thermal transport and for the edge transport barrier that improves plasma confinement. The predicted fusion power is 205 MW with the GLF23 model and 325 MW with the MMM95 model with 30 MW of input power. This difference in fusion power is due to different predictions of central temperatures when the two models are used. Our simulations indicate that the ITER fusion reactor should achieve its objectives.

[1] R. Aymar, P. Barabaschi and Y. Shimomura (for the ITER Team), *Plasma Phys. Control. Fusion* **44** (2002) 519-565.
[2] J. D. Lawson, Proceedings of the Physical Society B, **70** (1957) 6.
[3] G. Bateman, A. H. Kritz, J. E. Kinsey, A. J. Redd, and J. Weiland, *Phys. Plasmas* **5** (1998) 1793-1799.
[4] J. E. Kinsey, G. Bateman, T. Onjun, A. H. Kritz, A. Pankin, G. M. Staebler, and R. E. Waltz, *Nucl. Fusion* **43** (2003) 1845-1854.
[5] T. Onjun, G. Bateman, A. H. Kritz, and G. Hammett, *Phys. Plasmas* **9** (2002) 5018.

* *Federico D. Halpern was born in 1980 in Buenos Aires, Argentina. He is a fourth year graduate student in the Department of Physics working with the Lehigh University fusion research group. His doctoral thesis, which is being carried out under the supervision of Prof. Arnold H. Kritz, is focused on integrated modeling simulations of tokamak plasmas.*