

High-Performance Computing for Fusion

Just a few months ago, on 1 August 2009, a new supercomputer was turned on at the Forschungszentrum Jülich Supercomputing Centre in Germany. The new High Performance Computer for Fusion (HPC-FF), which is dedicated to the study of magnetically-confined fusion plasmas, will help physicists make reliable predictions of the conditions inside fusion reactors -- including the International Thermonuclear Experimental Reactor (ITER), now being built at Cadarache, France.

The supercomputer consists of 1080 computing nodes each equipped with two Intel Quad Core processors and can achieve a peak performance of about 100 teraflops per second. A high-level support team has also been created to improve the performance of existing computer codes and bring new numerical techniques to the fusion community. The core of the team is at the Garching Computer Centre of the Max Planck Society, which has extensive expertise in computational plasma physics. The rest of the support team are at various European fusion institutions and the team's activities are partly funded by the European Union. The team's work is co-ordinated by the European Fusion Development Agreement (EFDA), which comprises various leading fusion research institutions and the European Commission in an attempt to strengthen Europe's work in the field.

ITER is expected to begin experiments in 2018, and in 2026 it should achieve its ultimate goal of using magnetic fields to confine a high-temperature plasma of deuterium and tritium. When that happens, some nuclei in the plasma should undergo fusion reactions that convert a portion of their rest mass into energy -- in the same way that energy is produced by the Sun. Physicists hope that ITER will be the first such reactor to generate substantially more power (by a factor of 10) than is supplied to the plasma from the outside for heating. Each experimental run will last about 7 min and will cost about €500 000, which means that experiments must be planned very carefully using state-of-the-art computer codes.

To achieve this goal, the complex behaviour of such plasmas is being studied in numerous experimental devices world-wide – ranging from large facilities like the Joint European Torus (JET) in the UK to smaller university-based experiments. At the same time, advances in high-performance computing along with the development of more elaborate physics models and their implementation in complex computer codes have driven plasma modelling to a new level of realism. These models are tested continuously against experiment, and form an integral part of the preparations for the operation of ITER.

Among the first physics problems to be tackled by HPC-FF will be the simulation of turbulence in plasmas, which can degrade the performance of a reactor. The primary aim of this research is to gain a better understanding of turbulence in present-day experiments and extrapolate this knowledge to a reactor such as ITER. HPC-FF will allow physicists to perform direct numerical simulations that cover larger computational domains (up to an entire reactor such as ITER) and to include more physical effects than had been possible in the past. An added benefit of a greater understanding of turbulence is that it could be used in the future to design smaller (and therefore less expensive) reactors.

A new effect that must be investigated for ITER is "thermonuclear self heating", whereby charged fusion products (energetic ions with MeV energies) are expected to transfer their energy via Coulomb collisions to the thermal plasma particles (of a few 10 keV energy) -- heating the plasma in the process. These energetic ions can resonate with and possibly destabilize plasma waves in the reactor. This could in turn lead to energetic ions being expelled from the plasma, bombarding the surrounding walls and reducing their life-time. Numerical investigations of the non-linear interactions between plasma waves and energetic particles are therefore of utmost practical relevance to the design of ITER and other reactors.

A further focus of the HPC-FF is to gain a better understanding of how materials used within a reactor deteriorate when exposed to large numbers of neutrons created in fusion reactions. This is an extremely complex process beginning with the formation of tiny defects during collision events and culminating in macroscopic changes in material properties over the lifetime of a reactor. As a result such models must bridge the range from nanometres to metres and from picoseconds to years.

The ultimate goal of our modelling is to provide physicists with the tools to simulate all relevant processes in magnetic a fusion device, just as a flight simulator helps aeroplane pilots to fly. This goal is not yet achievable, even with the most powerful computers available today. Europe and Japan have therefore agreed to join forces to provide fusion researchers with a next-generation high-performance computer. This system will start operating by 2012 in Rokkasho -- Japan's candidate site for ITER -- and is expected to have a peak performance in the few petaflop per second range.

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