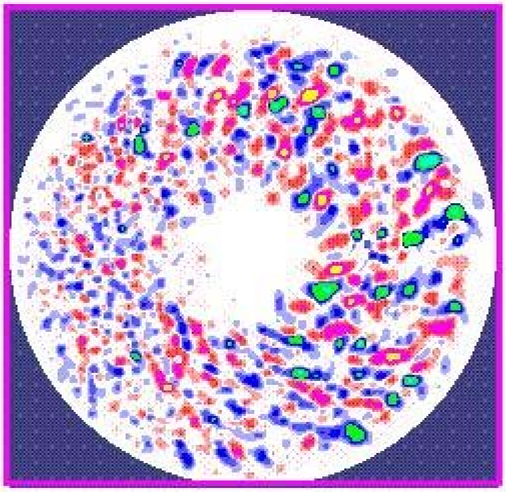
Fueling
the
Future

U. S. Leadership in Scientific Computation -----
FUSION ENERGY SCIENCES

Fusion is the power source of the sun and other stars. It occurs when forms of the lightest atom, hydrogen, combine to make helium in a very hot (100 million degrees centigrade) ionized gas called a plasma. In this process a small amount of the matter involved in the reaction is converted to a large amount of energy. On earth, fusion could provide a safe, environmentally benign, and affordable long-term energy source. It is one of the most important technological and scientific challenges of the 21st century and can be viewed as an integral component of the nation's research portfolio for national energy security.

The importance of a strong U.S. computational effort in fusion plasma research is well recognized. Building upon a prominent history beginning with the establishment of the predecessor to the National Energy Research Scientific Computing Center (NERSC) over 25 years ago, the U.S. fusion community has been rewarded by impressive advances in the simulation and modeling of plasma confinement.



SCIENCE 9/18/98

Simulation of Plasma Turbulence

Since effective prediction of the properties of energy-producing fusion plasma systems depends on the integration of many complex phenomena spanning vast ranges of time and space scales, advanced scientific computing cross-validated with theory and experiment is an essential tool for discovery. The most advanced approach involves confining a thermonuclear plasma by magnetic fields. A key issue, which impacts the cost of such a magnetic fusion reactor, involves optimizing the balance between the self-heating of the plasma from the fusion reactions and the heat leakage caused by electromagnetic turbulence. Fusion reactor design studies today rely on empirical extrapolations of turbulent transport properties from present-day experiments to future larger devices. The scientific understanding needed to improve upon such estimates and provide a path forward to actually control the turbulence requires first-principles direct numerical simulations. A good example of the exciting progress in this key area is the effective usage of the full power of the most advanced civilian supercomputer at NERSC to produce 3-dimensional particle-in-cell simulations of turbulence suppression, which is illustrated in the figure. Valuable new insights into how plasma confinement might be significantly improved in a reactor-scale plasma were gained from these terascale computations which produced terabytes of data. These electrostatic simulations, which typically utilized a billion particles, showed full scalability for 2000 processors, indicating a clear path forward to efficient future use of more powerful parallel computers. This is most encouraging since more realistic physics models, which include electromagnetic dynamics, will require about a factor of 50 to 100 increase in computing power. The Earth Simulator class of supercomputers is expected to meet these petascale computational demands. If access to such resources is made possible, fusion research in the U.S. will be revolutionized by the accelerated pace towards greatly enhanced simulation and modeling capabilities and be able to maintain its internationally recognized leadership in this area.

Linkage to the dramatic advances in supercomputing technology, such as the Earth Simulator computer, will enable U.S. fusion researchers to continue to lead the world in producing thermonuclear plasma simulations with the highest level of fidelity. The combination of petascale computers, increased research in requisite advanced algorithms, software, and modeling capabilities, and enhanced data management and network capacities will help maximize the return on investments in present national facilities, produce more confident design of future experiments, and effectively leverage participation in a proposed large-scale, multi-billion-dollar class of international facilities, such as the International Thermonuclear Energy Reactor. The net effect will be to produce a more rapid and cost-effective development path toward the best approaches to fusion energy production; i.e., a "faster" pace toward "smarter" concepts for more practical fusion systems.