FUSION ENERGY

Background Information, Position Statement 12

Given the long-term benefits of fusion energy, appropriate priority and funding levels should be set to maintain the momentum of both magnetic fusion energy (MFE) and inertial fusion energy (IFE) programs. Coordinated national laboratory, university, industrial, and power-producer involvement is essential.

At the present stage of fusion development, the tokamak is the most advanced MFE concept and the most technically viable approach to demonstrate a sustained, controlled fusion reaction producing net energy. Development of alternative MFE concepts with potential advantages is also an important part of the fusion program. The glass laser is currently the most developed driver for single-pulse inertial confinement fusion target physics studies. Several high-repetition-rate drivers are being developed for IFE, including diode-pumped solid-state lasers, krypton-fluoride gas lasers, heavy ion induction accelerators, and *Z*-pinch pulsed power devices. The fusion program also should include sufficiently broad components of basic research, supporting technology, and engineering to permit the development of the mainline concepts and, at a lower level, several other promising confinement and heating approaches.

Over time, the costs of the international research and development (R&D) for fusion will be a tiny fraction of the total expenditures for worldwide energy use. The American Nuclear Society believes that a balanced approach to MFE and IFE fusion research will facilitate and accelerate the timely introduction of an important, practical, reliable, safe, and environmentally attractive sustainable energy source.

THE FUSION PROCESS

At very high temperatures, electrons are stripped from atomic nuclei to form a plasma (ionized gas). Under such conditions, the repulsive electrostatic forces that keep positively charged nuclei apart can be overcome, and the nuclei of select light elements can be brought together to fuse and form other elements. Nuclear fusion of light elements releases vast amounts of energy and is the fundamental energy-producing process in stars. For a given mass of fuel, the energy released from fusion substantially exceeds the energy released from fission (the neutron-induced splitting of heavy elements such as uranium) and far exceeds (by millions of times) the energy released in chemical reactions (e.g., the burning of coal, gas, or oil).

Some fusion reactions are easier to produce than others. Some products of the various fusion reactions are more desirable than others. The first generation of fusion plants is expected to employ a plasma fuel mixture of the less common isotopes of hydrogen: deuterium and tritium. A helium nucleus and a neutron are the products of this fusion reaction. Deuterium constitutes 0.015 percent of the hydrogen content of the Earth's water and represents an essentially inexhaustible terrestrial fuel supply. Extraction of the deuterium fuel is inexpensive.

Tritium is radioactive and is not naturally available in useful amounts, but it can be produced in quantity by capturing fusion product neutrons in lithium-bearing components of the fusion machine itself. Lithium is a plentiful element available in the Earth's crust. Tritium poses a modest biological hazard, so fusion plants must incorporate safety features. Although fusion by-products tend to be benign, neutron activation of certain structural materials is another safety and environmental concern. By the appropriate choice of materials, most long-term radioactive waste generated from fusion should qualify for shallow land burial, rather than deep geologic disposal. By the standard measures of environmental impact (land use, mining, emissions, waste disposal, etc.), fusion should rank as an attractive energy source. With only a small inventory of fusion fuel in the machine at any time, the risk of accidental power excursions is negligible. Advanced fusion fuel cycles can be expected to reduce both the tritium and neutron-activation concerns but will require further development.

Two general approaches to fusion technology have received emphasis: magnetic confinement and inertial confinement. In magnetic fusion, a hot plasma (more than 100 million degrees Celsius) is confined by strong magnetic fields and heated by external sources until the fusion reaction becomes self-sustaining. A "burning" plasma, with sufficient size and density to sustain itself by self-heating, is said to be "ignited." The magnetic field also prevents the hot plasma from contacting the machine structures. In inertial fusion, small fuel pellets are bombarded by intense laser or particle beams to produce an ignited, dense plasma, held by inertia for brief energy-producing pulses. Several distinct variations of these broad approaches are being pursued in a number of laboratories worldwide.

PROGRESS IN FUSION RESEARCH

Begun more than 40 years ago, fusion research, particularly in the last two decades, has made outstanding progress, incorporating state-of-the-art advancements in physics understanding and technological developments. Producing 16 megawatts of deuterium-tritium fusion power in 1997 in the Joint European Torus (JET) and 10.7 megawatts (approaching energy breakeven) in the Tokamak Fusion Test Reactor (TFTR) at Princeton Plasma Physics Laboratory in 1994 are important milestones in MFE development. Experiments continue to be performed in specific tokamaks operating around the world to build upon these achievements and to provide increased scientific understanding. Recent advances include the achievement of improved energy confinement and improved methods for handling high heat fluxes. With the object of sharing the benefits and reducing the costs to each country for a "next step" burning plasma tokamak experiment, Canada, China, the European Community, Japan, the Russian Federation, and the United States are involved in negotiations to collaborate on the design, construction, and operation of the International Thermonuclear Experimental Reactor (ITER). The programmatic objective of ITER is to demonstrate the scientific and technological feasibility of fusion energy for peaceful purposes. The ITER timetable envisions a 10-year construction phase followed by a 20-year operation phase. ITER will produce about 500 megawatts of fusion energy. The present mission of the U.S. Fusion Energy Sciences Program is to advance plasma science, fusion science, and fusion technology—the knowledge base needed for an economically and environmentally attractive fusion energy source. The combination of such a knowledge base and the information from running an experimental reactor such as ITER would provide the basis for construction and operation of a demonstration plant followed by construction of commercial power plants.

Significant progress has also been made on all aspects of IFE, including target physics and technology, driver development and fusion chambers, and power plants. The National Nuclear Security Administration funded National Ignition Facility (NIF) has already started experiments with the first activated beam lines. When fully completed, NIF will demonstrate ignition and gain (planned for 2010), setting the stage for energy applications. Both directly driven and indirectly driven targets appear to be feasible. R&D on high pulse rate drivers is also progressing well. Laser systems have made impressive progress in efficiency, pulse rate, and lifetime. The heavy ion fusion program has made excellent progress in basic beam science, and several new science experiments have recently begun operations. There has also been impressive progress in *Z*-pinch targets as well as good progress in conceptual power plant designs. Chamber technology and target fabrication and injection are being placed on a sound scientific basis. There is broad international interest in fast ignition, where a superintense laser beam is used to trigger ignition. If successful, fast ignition promises improved target performance and power plant economics.

Duplicating the conditions of stars on Earth in order to realize controlled fusion energy will require complex and expensive machinery. The fusion energy program supports progress in advanced structural and high-heat-flux materials, superconducting magnets, powerful laser and particle beams, power-conversion apparatus, advanced computers, robotics, and other applications. It is important to develop power plant design concepts that minimize the construction, operating, maintenance, and decommissioning costs to ensure that electricity generation by fusion will be economically competitive. The present studies of magnetic and inertial fusion power plants show that with continued success in improving the physics performance of fusion experiments and developing the required technologies, fusion has the potential to provide mankind with a very long-term energy source that is both economically competitive with other long-term options and has many safety and environmental advantages.

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