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International Fusion Research

By Ian H. Hutchinson July 8, 2005

The announcement in the last week that the site for the International Thermonuclear Experimental Reactor (ITER) is finally resolved is a source of relief and anticipation to nuclear fusion researchers worldwide. It opens the way to the construction of an experiment that promises the scientific demonstration of controlled fusion energy production. It also removes perhaps the last major impediment to embarking on a project that has been under consideration for nearly 20 years.

Decades of fundamental scientific research and detailed engineering design have bolstered confidence that this project can succeed. But, despite the strong support of the leaders of the major industrial nations, including President Bush, the project had seemed stalled by a diplomatic impasse, as Japan and Europe vied for the prestige and economic benefits associated with hosting so major a technological undertaking. The agreement announces a compromise whereby the non-host (Japan) will be supported in the development of a subsidiary fusion research facility with financial assistance from the ITER host (France), and will also be guaranteed a major role for its industries in the ITER construction project.

This is a good deal for both of the major parties, and for the rest of the ITER consortium. It is a good deal, too, for the citizens of the world, since it enables us to take the next step towards a sustainable energy source that will have zero climate-changing emissions.

The nuclear reactions that release energy by combining light nuclei, like hydrogen, to form heavier nuclei, such as helium, are called fusion. They are, in a sense, the opposite of the nuclear fission reactions that power present-day nuclear plants; fission breaks up the nuclei of heavy elements such as uranium. Fusion has the potential to provide practically inexhaustible energy with greatly reduced levels of radioactive waste compared with fission.

To make fusion reactions take place requires the fuel to be heated to tremendously high temperatures (over 100 million degrees), so that it enters an electrically-conducting state beyond that of a gas. This state of matter is called plasma. The plasma must also be maintained long enough for the reactions to occur.

Fusion is the energy source that powers the sun and stars. In these natural fusion reactors, it is gravity that confines the plasma in a wonderfully stable and long-lived configuration. A human-scale fusion reactor must also use a non-material container, but to make the reactor small enough, it must use a much stronger force than gravity: the force of a magnetic field. ITER is to be a magnetic confinement device of the type called a tokamak, which has a toroidal (donut-shaped) configuration and a strong, confining magnetic field. The tokamak configuration has been under study by fusion plasma scientists since the 1960s, and has proven to have the best confinement of all the configurations so far envisioned.

Even so, the achievement of sufficiently good confinement of the plasma to permit useful release of energy has turned out to be far more difficult than the first fusion researchers hoped. Many important optimizations have been discovered and developed. One unavoidable way to obtain sufficient confinement is to make the plasma large. The existing large tokamak experiments typically have plasma radii of three meters. Fueled with the most reactive isotopes of hydrogen, those tokamaks demonstrated substantial release of fusion energy. For example, the world's largest tokamak, JET (Joint European Torus), obtained up to 16 megawatts of fusion reactions for just under a second. But, to sustain the plasma in these devices required additional heating that was larger.

The next big step in fusion development is to create a plasma that keeps itself hot by the energy released in its own fusion reactions. The ITER international collaboration has developed a design to sustain such a so-called "burning plasma," generating about 500 megawatts of fusion reactions for approximately 1,000 seconds. To achieve this requires a plasma about twice as large, and also requires the use of superconducting magnets that consume negligible electric power for their operation.

Because of its size and technological complexity, ITER will cost about $5 billion to construct. It is not a commercial power plant, nor even an engineering demonstration plant; it is an experiment that is designed to establish the scientific feasibility of controlled fusion. Sharing its significant cost is one motivation for pursuing it as an international collaboration. But other motivations include the long-term nature of fusion research. ITER will take about 10 years to build. A road map recently developed in the United States for a relatively fast-track to fusion envisages over 30 years before fusion would be sufficiently developed for commercial deployment. Therefore, fusion is a technological grand challenge that is not dominated by short-term economic competition, and is ideal for international cooperation. Indeed, ITER will be one of the largest joint-scientific projects ever undertaken by an international consortium. The present ITER partners are the European Community, Japan, the United States, Russia, China, and South Korea.

The long development time of fusion could be a handicap, though. It serves to discourage some policy-makers from a major commitment to its research, and it breeds skepticism in fusion's critics. As the earlier ITER engineering design activity neared its end in the mid-1990s, major cuts in the U.S. fusion research budget led to a change of U.S. Department of Energy policy for fusion, and to an eventual pull-out from the ITER project, of which the United States had initially been one of the leaders. With the closure of our largest tokamak and of several smaller experiments, the canceling of a major, planned follow-up device, and deep cuts in funding for other national fusion facilities, the U.S. fusion community recognized that its research program had to be reoriented to focus on the underlying fusion science of plasma physics and related engineering. We did not then have a program that was truly one of fusion energy development. Thankfully, the United States rejoined the ITER project in 2003, but in a much more junior role, reflecting the fact that U.S. fusion research funding is very modest (about $290 million in fiscal year 2006), less than half the level of Europe's efforts.

The United States still has two world-renowned tokamaks (one of which is at MIT), whose research will be crucial during the ITER construction phase in helping to resolve and prepare for important scientific and technical challenges that ITER faces. It is also important for the United States to maintain fundamental research and innovative initiatives into the basic science of magnetically confined plasmas, which may lead to breakthroughs that eventually enable faster fusion development and more cost-effective fusion systems. But, the U.S. capability in fusion plasma science cannot be sustained without a renewed commitment of resources. The United States' 10% share of ITER construction will call for peak expenditures of up to perhaps $150 million per year, mostly for industrial procurements, not research.

If this funding were drawn from the already overconstrained budget of $290 million, the drain would devastate fusion research. That is the reason the overwhelming consensus of the U.S. fusion community in favor of ITER is predicated on the maintenance of strong domestic fusion and plasma physics research, plus additional funds for ITER construction.

Whether such an increase in overall fusion expenditures is justified depends on the importance of this energy research. Even if fusion were only funded at the resulting level (less than $0.5 billion per year), it would still be substantially less than the Department of Energy currently spends on each of high energy physics, fossil energy research, and basic energy sciences. And it pales into insignificance in comparison with the long-standing budgets of the Star Wars missile defense research agency (typically $3 billion per year) and NASA ($14 billion). The United States spends close to $1 trillion per year on the energy it consumes. In the context of that economic reality, fusion research would be cheap at twice its price.

Just how important is energy research to the United States? Today, more than ever, I think, policy-makers and the U.S. public realize that energy is going to remain one of civilization's key challenges for the future. MIT's new president, Susan Hockfield, recently announced a major Institute-wide initiative in energy research. We are going to need a broad range of environmentally friendly energy supply options, as well as conservation to ensure that we use our energy wisely.

Fusion offers one of the most environmentally attractive independent energy options for the long term. ITER is an exciting next step in this global technological challenge. The United States should seize the opportunity to play a strong role in its success by renewing our overall fusion program, by acting to reassure the other partners that the United States is a reliable scientific collaborator with a committed long-term vision, and by engaging in the project with the expertise and enthusiasm that our nation possesses in such abundance.

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