After decades of division, researchers meeting in the Rockies found some surprising overlap in approaches as different as laser and magnetic fusion

# Common Ground for Fusion

Fusion researchers strive to get atomic nuclei to overcome their antipathy and join together. But on a human scale, few fields are more fractious, riven by differences in technology, philosophy, and—recently—sharp funding cuts for some areas while other areas thrive. Now, the community of nuclear fusion researchers in the United States has sought some unity of its own. A 2-week meeting in Snowmass, Colorado*—conceived by physicists Hermann Grunder and Michael Mauel—went further than anyone expected in inching the field toward a consensus on scientific priorities. But as a careful diplomat might say, there is still a long way to go.

**FUSION'S FUTURE**

Having withdrawn from a giant reactor project, U.S. fusion researchers are pursuing new approaches, while Europe's main experiment is back on track after labor troubles.

▶NEXT STEPS
ALTERNATIVES
EUROPE

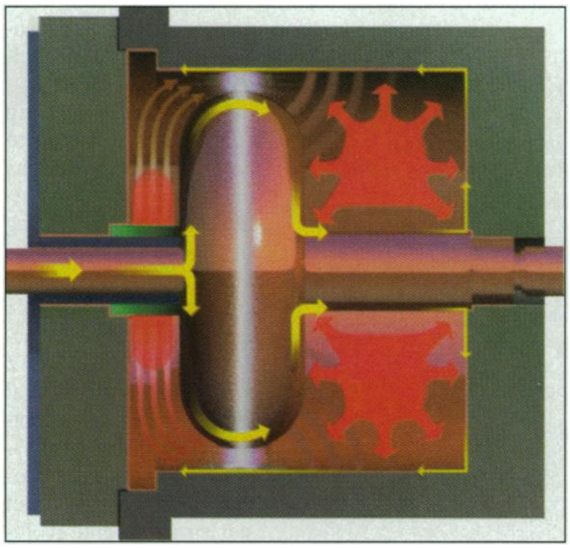
The meeting was designed to help set a new course for the U.S. fusion program after Congress last year finally pulled the plug on U.S. funding for the International Thermonuclear Experimental Reactor (ITER), a $10 billion behemoth that had been the focus of one branch of the fusion power program throughout the 1990s. It brought together scientists who make the energy-producing fusion reactions in entirely different ways—by crushing a fuel pellet with laser pulses, say, or by trapping a much more diffuse gas in magnetic fields. Included were proponents of fresh new concepts as well as old reliables; nitty-gritty technologists sat cheek-by-jowl with basic scientists.

"A number of people who came to Snowmass obviously are unwilling to talk to each other," chuckles Grunder, the director of the Thomas Jefferson National Accelerator Facility in Newport News, Virginia. "That Snowmass happened is a major success for the fusion community." Agrees Richard Siemon of Los Alamos National Laboratory (LANL) in New Mexico, "This was a very refreshing meeting—very open."

* 1999 Fusion Summer Study, held from 11 to 23 July in Snowmass, Colorado.

Participants found an unexpected degree of overlap in their research, especially in technology. For example, researchers in inertial fusion energy (IFE)—laser fusion—have planned to equip their reaction chambers with walls of flowing liquid metal; at the meeting, the concept grabbed the attention of researchers in magnetic fusion energy (MFE) as well. There was also some unanimity within subfields. The magnetic fusioneers agreed that their next step should be to ignite a plasma, creating a brief, self-sustaining fusion reaction, although they debated which of various proposed machines is the best bet for doing so. The IFE researchers, for their part, agreed that their current approach, relying on massive lasers, will have to give way to other technology if they are ever to build a working power plant.

"We tried to make this meeting inclusive and welcoming to everyone," says Mauel, who is at Columbia University. "We didn't want to say … 'My experiment is better than your experiment.' " The areas of agreement that emerged should have a practical effect on the direction of the field, because the meeting's conclusions will be combined with those of other recent panels to help politicians and government agencies decide which fusion programs should be funded in the 2001 budget.



**Crosscurrents.** In magnetized target fusion, plasma (*red*) is crushed by interaction of current and its own magnetic field.

Fusion energy is created when two hot, light nuclei collide and join, and the product then splits into a fast neutron and a new energetic nucleus. The neutron strikes a surrounding wall or blanket, depositing heat that, in a fusion power plant, would be converted to electricity. The scheme would generate no greenhouse gases and create vastly less long-lived radioactivity than fission plants do.

But although the method works spectacularly well in hydrogen bombs, harnessing it in controlled fashion has proved elusive. Hot plasmas are inherently unstable, and they often break up and belch the heat needed to keep the fusion reactions going. To offset those losses, magnetic fusion experiments, which aim to create a steady fusion burn, tended to become ever bigger and more complex. ITER, which would have confined plasma in magnetic fields threading a doughnut-shaped device called a tokamak, was a case in point.

Congress also mandated that MFE researchers join forces with their colleagues in IFE—traditionally a separate effort aimed in part at studying bomb physics—to come up with a common plan for the field (*Science*, 3 July 1998, p. 26). "The program's at a crossroads," says Grant Logan, a physicist at Lawrence Livermore National Laboratory in California who has worked on both types of fusion and was an organizer of the conference. "So where should the scientific program go?" To begin answering that question, the meeting broke into half a dozen subgroups, which then presented summaries that were debated in plenary sessions by the approximately 300 attendees.

The liquid-wall concept gathered support in breakout discussions between IFE and MFE researchers. Inertial fusion researchers have been exploring the concept as a way to cope with the energetic neutrons generated by fusion, which weaken and erode solid walls. The flowing, molten metals could not only be recycled, but could carry lithium, which would combine with the neutrons to make tritium—an extractable fusion fuel. For the first time, says Logan, "I was

CREDIT: T. KUNUGI AND S. SATAKI

aware of people in magnetic fusion getting interested in liquid walls. They almost dominated the discussion." Designing liquid walls for a magnetic fusion reactor is a challenge, because the strong magnetic fields they generate can interfere with the flow of liquid metals. But smallish, university-scale experiments could begin to address the challenges, says Logan.

Another intersection between these long-separated areas of fusion research emerged from IFE. The IFE effort is thriving, with plans—and funding—to briefly crush and ignite fuel pellets with 200 converging lasers at the $1.2 billion National Ignition Facility (NIF), scheduled to be in operation at Livermore sometime after 2001. Yet although no one doubts the utility of NIF for studying bomb physics, some MFE researchers say they don't believe the concept will lead to a practical energy source. Among the biggest problems: Lasers are far too expensive and inefficient for a power plant.

"Rightfully, the MFE community is saying we haven't worked out all those questions," says Logan. One possible answer came from Sandia National Laboratory in Albuquerque, New Mexico, where the so-called Z machine has achieved a series of striking results by imploding a pellet of fuel using x-rays generated with blasts of electrical current (*Science*, 18 July 1997, p. 306 and 3 April 1998, p. 28). But Siemon of Los Alamos suggested a hybrid approach that might solve both the IFE's driver problem and the challenge of producing a stable plasma in MFE.

Called magnetized target fusion, the concept would resemble the Z machine in using a burst of current to crush fusion fuel. But instead of a pellet, the fuel is a hot plasma caged in a magnetic field. The pulsed compression would not only compress and heat the plasma but also amplify the magnetic field, enhancing its insulating properties and relaxing the need to start with huge fields. "I think it's kind of intriguing," says Sandia's Craig Olson, who is working on the Z machine. "It's potentially relatively low cost."

The MFE community is also trying to get its house in order. As in a less comprehensive meeting last year (*Science*, 8 May 1998, p. 818), researchers generally agreed that creating a burning plasma should be their next major milestone. "What we're arguing about is the best way to do it," says Dale Meade, head of advanced fusion concepts at the Princeton Plasma Physics Laboratory. One route might be the so-called ITER Lite, a slimmed-down version of the original that would cost roughly half as much. Another option, with a price tag of about $1 billion, would be Meade's Fusion Ignition Research Experiment—a smaller tokamak that would eschew ITER's superconducting magnet coils for plain copper. A tokamak called the Ignitor, being designed at the Massachusetts Institute of Technology, would also create very strong magnetic fields with copper coils and be still smaller and less expensive.

The debate revealed that "there's a lot of potential yet to be discovered in the tokamak line," says Ron Stambaugh, a physicist at General Atomics in San Diego. At the same time, Snowmass participants agreed that MFE researchers should explore reactor designs that rely on alternative ways of caging a fusion plasma (see following story).

Similar conclusions about MFE appear in a draft report by the high-level Task Force on Fusion Energy of the Secretary of Energy Advisory Board, some of whose members were at Snowmass. Now its report and the results of Snowmass, along with a third report on fusion still being prepared by the National Research Council and other sources, will figure in the deliberations of the Fusion Energy Sciences Advisory Committee (FESAC). By September, FESAC will make comprehensive recommendations about fusion's roadmap, including the balance of funding between MFE and IFE and the next steps toward a burning plasma, to Martha Krebs, director of the office of energy research at the U.S. Department of Energy.

"We delayed answering the charge from Martha Krebs ... to be able to hear what people had to say at Snowmass," says John Sheffield, a physicist at Oak Ridge National Laboratory and the University of Tennessee, who is the FESAC chair. By bridging some of their differences, U.S. fusion scientists may have helped shape their future.

—JAMES GLANZ

CREDIT: LANL

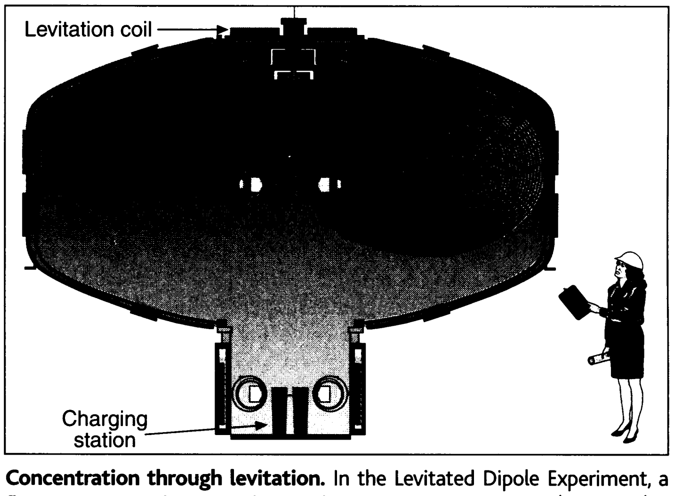
FUSION'S FUTURE

▶ ALTERNATIVES

# Fusion Power From a Floating Magnet?

**In one radical design for a magnetic fusion reactor, energy-producing plasma would be trapped around a levitating ring of superconductor**

At first glance, something seems to be missing from the diagram Jay Kesner is describing. With a wave of a pointer he indicates a pumpkin-shaped vacuum vessel, 3 meters tall and 5 across, designed to contain a plasma of hot electrons and ions. Kesner, a physicist at the Massachusetts Institute of Technology (MIT) Plasma Science and Fusion Center, explains that a ring hovering at the center of the diagram with no visible means of support is a superconducting magnet that weighs nearly 500 kilograms. The lack of supports is not a draftsman's oversight. Kesner and his colleagues plan to levitate the ring magnetically as part of a novel experiment that may ultimately lead to a simple, safe, and inexpensive fusion power source.




**Concentration through levitation.** In the Levitated Dipole Experiment, a floating superconducting coil traps plasma in its magnetic field (blue lines).

The Levitated Dipole Experiment (LDX) is a 5-year study of a plasma confinement scheme inspired by observations of ionized gases trapped in the magnetic fields of planets like Jupiter and Earth. Funded by the Department of Energy, the $6 million collaboration between MIT and Columbia University in New York City is under construction at the Plasma Science and Fusion Center on the MIT campus and should begin operation by the summer of 2000. In the current phase of the project, which will stop short of actual fusion, principal investigators Kesner and Michael Mauel of Columbia hope to determine whether a dipole-based machine—a sharp departure from current