strategy cools the atoms by another factor of 5; at the same time, it boosts their density as they cluster at the center.

That was the good news. At a meeting in Anaheim, California, a year ago, however, the Colorado group and others pursuing the hybrid strategy—which also included an MIT group led by Wolfgang Ketterle—faced the bad news: the spot of zero field at the center of the trap. The coldest atoms do indeed cluster at the center as predicted, but because there's no magnetic field there to keep them aligned, they leak out, leaving the researchers four orders of magnitude short of the density-temperature threshold of BEC.

Ketterle proposed one fix: Aim a laser beam at the zero point to repel any atoms that approached it. Ketterle's laser-plugged trap worked, but not as well, or at least not as quickly, as the idea Cornell came up with, which even Ketterle calls "a real gem."

Cornell simply added a second magnetic field to his existing trap, one that would swing the zero point around in a circle—which is one reason why he and Wieman call the result a TOP trap. "The TOP trap," says Wieman, "simply takes this zero field point and moves it away from the center and spins it around. Now what you've got is this orbit of death. As long as the atoms are cold enough to stay in the center and not get out to the orbit of death, they stay there forever and you can keep cooling them down."

By the end of May, the researchers were confident they could achieve the temperature and density needed to create a BEC, but they hadn't figured out how to see it if they did. The Bose condensate would consist of a few thousand atoms in a ball 10 microns across, too small to allow them to see whether the atoms' velocities had dropped to the levels of BEC—"All we'd see is a little smudge," says Wieman.

The solution was what they called ballistic expansion: They would open up the trap, leaving the atoms free to fly apart. Says Cornell: "We wait for a while, and the cloud gets a lot bigger, and then we take a picture of the cloud" using a laser. The structure of this expanding cloud, he says, reveals the velocity distribution in the original cloud before the trap was opened. Hotter atoms should have spread out, but at the center, the density of the atoms should rise steeply. These, he says, are the relic of the BEC that existed until the trap was opened.

That was the theory, anyway. On 5 June, the predicted density peak appeared on the experimenters' video screens. "It was so close to what we have been telling people that it ought to look like that we were initially kind of suspicious," says Cornell. Now his doubts have vanished. Asked whether he and his colleagues could be wrong, Cornell says simply, "I hope not," which he quickly amends to "No. The data are pretty clean. We're not averaging data for 300 hours, getting a [weak] effect, and just happy-talking ourselves into seeing what we want to see."

Indeed, the very first images seem to have cleared up some of the theoretical speculation about what a BEC might be like. For starters, says Wieman, "it takes a couple seconds for it to form, and there's some interesting physics behind that." But one of the most intriguing questions about BEC remains to be answered: What does it look like? Light waves should interact very differently with atoms whose own wave functions have merged than with ordinary matter, but theorists' predictions about the result have been all over the map, with some opting for transparency, some for inky blackness, and some for a silvery sheen. "We have finessed that whole issue by letting the stuff expand out before we ever look at it," says Wieman. But now, he says, it will be very easy to shine a laser on it before it expands and see what happens.

And that's just the beginning of the scrutiny they plan for their prize, he adds. "A thousand atoms [of BEC] is a big chunk, and we'll be able to make a lot more." Then "we will have a whole bunch of [other] knobs we can turn" to probe the new material.

Cornell and Wieman won't be the only researchers doing so. Perhaps half a dozen experiments are still on the verge of creating a BEC, and other groups are likely to join them, inspired by the Colorado group's success—and by the low price of admission. Costing perhaps $50,000 for hardware, plus several months of labor, Wieman and Cornell's apparatus was breathtakingly cheap by modern physics standards. "We worked hard to pursue this using techniques that were cheap and simple," says Wieman, "so if it actually worked it would be opening up the field."

–**Gary Taubes**

PLASMA PHYSICS

Go Back to Basics, Says NRC Panel

The hottest spot on Earth is the interior of a huge, donut-shaped vessel at the Princeton Plasma Physics Laboratory. The device, called a tokamak, uses a spiraling magnetic field to trap million-degree plasma, or ionized gas, allowing some of the plasma's ions to fuse—a process that could someday be a practical source of energy. In the field of plasma physics, though, the hottest thing right now is an assessment of the field released this week by the National Research Council (NRC) suggesting that an exclusive focus on applications like tokamak fusion may actually pose a threat to the field as a whole.

Even as Princeton's tokamak sets record after record for power output (*Science*, 2 December 1994, p. 1471), the report* concludes that the basic plasma research that made this achievement possible has become all but extinct in the United States. If the situation doesn't change, says the NRC, "a dangerous gap will develop" in the knowledge needed to continue the fusion program itself. The panel's prescription to fill this gap: Shift $15 million from fusion and other applied research into basic plasma science.

At a time when fusion research (*Science*, 23 June, p. 1691) and science in general are under siege in Congress, these measures were "not lightly recommended," says John Ahearne of Sigma Xi, a science and policy research society in Raleigh-Durham, North Carolina, co-chair of the NRC panel on opportunities in plasma science and technology. But he says that after "very difficult" discussions, even fusion researchers on the panel finally agreed on the need for a return to basic research. One of those panelists—Ronald Davidson, director of the Princeton Plasma Physics Laboratory—argues that the NRC's diagnosis doesn't hold true at his own lab, where "the component of basic plasma-science research is very, very strong." But he agrees that the fusion program as a whole may need a new infusion of basic research.

The report aims to remedy a situation dating back at least to the 1950s, when physicists realized that the nuclei of hot, confined plasmas would fuse, emitting enough energetic particles to drive large power plants. The result, says Ravi Sudan of Cornell University, chair of NRC's plasma science committee, a contributor to the report, was that "plasma physics got a little distorted in its development because it was driven by applications."

Plasma physics research came to focus on large plasma-confinement devices at government-run labs. As a consequence, says Sudan, the discipline "didn't sink its roots" into university curricula. Still, many plasma physicists say that funding agencies such as the Department of Energy (DOE) did keep basic science afloat until the 1980s. Then, says John Cary, a plasma physicist at the University of Colorado, Boulder, "it seemed we got into a situation where [DOE] said, 'We're not going to support any more basic stuff. We understand enough to build bigger tokamaks.' " Basic research funding dried up across the board, falling to less than 10% of the $370 million a year that now goes to fusion.

Although fusion is by far the largest consumer of funding in plasma science, it isn't the only reason the field is "suffering from

---

* "Plasma Science: From Fundamental Research to Technological Applications"

More Than One Way to Fuse a Plasma

When Stewart Prager, a plasma physicist at the University of Wisconsin, Madison, thinks of current tokamaks, the donut-shaped devices for confining fusion plasmas, he is reminded of 1950s-era computers. If computer scientists had contented themselves with refining the vacuum-tube behemoths of those days and not experimented with, say, transistors, "think of all that would be lost," says Prager. Like computers in the 1950s, fusion reactors won't come into their own for decades, if ever. And, says Prager, "you can't build a 2040 reactor based on 1990 science. It is far, far too early to lock ourselves into a single concept."

Prager has been pushing one alternative to the tokamak, called the reversed-field pinch (RFP), for years with only modest funding support. But he and other researchers who think there's more than one way to fuse a plasma are likely to receive a boost from a National Academy of Sciences report on the state of plasma physics research (see main text). Along with its controversial recommendation that funding be shifted to basic research, the report recommends that studies of alternatives to the tokamak, at a virtual standstill over the past 10 years because of funding constraints in the fusion program, be revived. Mentioning three alternatives—the stellarator, the RFP, and compact tori—the report says, "Each has potential advantages over the tokamak and is a unique source for new plasma physics information."

- *Stellarator*. Like the tokamak, this device confines plasma within magnetic field lines that spiral through a donut-shaped vessel. In the tokamak, a combination of external coils and electrical currents in the plasma produce the field, but in the stellarator it is entirely generated by external coils. Stellarators run continuously, unlike tokamaks, and aren't prey to damaging disruptions in the tokamak plasma current. The potential downside: These machines can be large and complex.
- *RFP*. In this concept, a specially prepared plasma spontaneously generates part of the magnetic field needed for confinement, through a mechanism like the "dynamo" that generates magnetic fields in stars. This process eliminates the need for superconducting coils that generate the field externally in a tokamak, but it may not be as effective at confining the plasma.
- *Compact tori*. Still untested, these resemble tokamaks but have no hardware such as transformer coils sticking through the "donut hole." Theoretical arguments that plasma donuts can be intrinsically stable imply that compact tori could be vastly smaller and cheaper than tokamaks.

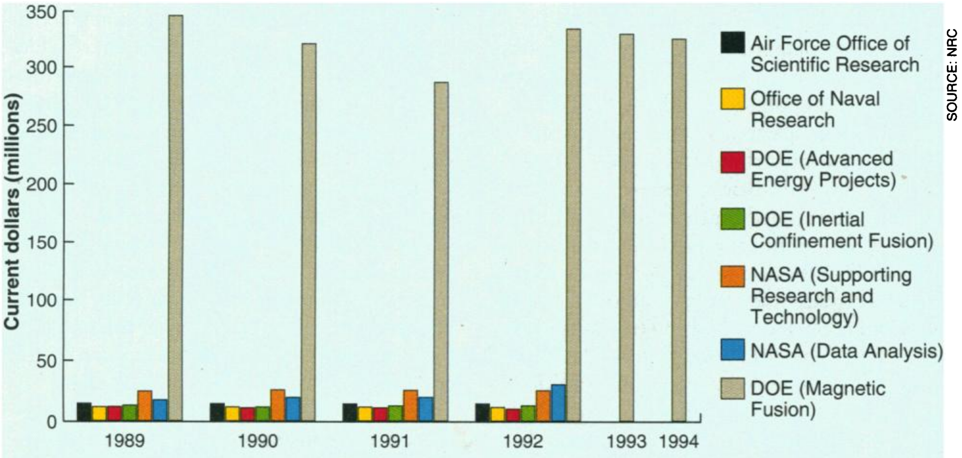
Despite thriving study of these concepts in Europe and Japan, support for them in the United States is "about zero," says Prager. The report doesn't give a dollar figure for remedying that neglect. But if the fusion program takes the funding hit that Congress now threatens to deliver, the alternatives might enjoy a quick comeback, says Martha Krebs, director of the Department of Energy's office of energy research. In that case, she says, "we'd be downsizing the program [and] going to smaller scale. I think that would open room for alternate … programs."

–J.G.

---

application without replenishment," the report says. Other subdisciplines have also emphasized applications such as plasma etching of semiconductor chips and waste processing and paid scant attention to building the field's scientific foundations—or its academic clout. Plasma physics, the NRC report found, "is not adequately recognized as a discipline." Plasma physicists "are less likely to be in tenure-track positions than other physicists," and courses in plasma science aren't offered at many universities. If this disintegration continues, the report warns, even fusion could fall prey to "a serious void" in the basic science that supports it. For example, says the report, the fusion program is rushing forward with "only extremely limited … understanding of the turbulence in fusion plasmas."

Martha Krebs, director of DOE's office of energy research, isn't convinced by this logic: "I think the future of fusion is threatened much more by Congress's lack of commitment [to it] than by the amount of basic plasma science being carried out." Nevertheless, the report recommends a modest shift in funding from "larger, focused research programs" to university-scale experiments. Such experiments, say panelists, might concentrate on phenomena like turbulence and the reconnection of magnetic-field lines, which govern the behavior of plasmas everywhere from tokamaks to interplanetary space.



Dangerous imbalance? Fusion funding dwarfs support for other areas of plasma physics. (1993 and 1994 figures are incomplete.)

The report also calls for a related shift of emphasis within the fusion program itself. Without giving specific numbers, it says the program—now focused almost exclusively on tokamak work—should support "a range of [experimental] devices … from small, basic experiments" to large fusion devices. And it says that tokamaks aren't the only confinement device that deserves study (see box).

For now, however, this call to action may have a moral rather than a financial effect on the field. Robert Eisenstein, director of the physics division at the National Science Foundation, notes that while finding $15 million for basic experiments "sounds intellectually defensible, it does not sound financially doable based on what I … see in the tea leaves" as the budget process inches along. Basic research may be a worthy cause, adds Krebs, but for now she is fighting to keep the fusion program alive—as she puts it, "weighing one kind of devastation against another."

Even so, say basic plasma researchers, the report is a valuable reminder that there is more to the field than the decades-old quest to build a fusion reactor. "Finding out how a tokamak works may be a very laudable thing," says Nathan Rynn of the University of California, Irvine, a member of the plasma science committee. "But it's not finding out how nature works. It isn't basic research."

–**James Glanz**