

ments built by engineers based on new knowledge that came from physics, chemistry, and basic biology.” What is particularly troubling about the failure to invest properly in the physical sciences, she said, is that “students are trained in the context of research. So we will be training many more biology, medical science, and biomedical engineering students.” In the next decade, she said, “the balance of trained brains” will be skewed toward life sciences, and that, in turn, could exacerbate the shortage of people in the physical sciences and engineering.

Foreign programs improving

Another threat to US science and technology leadership is the improving quality of science training programs in other countries, the report says. “Other countries are building up the natural sciences and engineering [NS&E] capabilities of their younger cohorts at a greater rate than the US has been able to achieve,” the report says. “They have been able to raise—by large increments—the rate at which their college-age youth earn first university NS&E degrees.” The report lists 13 countries, led by the UK, that are ahead of the US in the percentage of 24-year-olds earning undergraduate science degrees. While the UK is near 10%, the US “has fluctuated between 4 and 5% of the nation’s 24-year-olds for the past four decades and barely reached 6% in the late 1990s,” the report says. “US pre-eminence [in science and technology] may erode as competing centers of excellence are established elsewhere,” the report concludes.

Tapia’s fear that the US economy could lose foreign-born scientists and be unable to replace them with highly

educated US-born science and technology workers is discussed at length in the report. “In the US in 1999, 10% of those holding baccalaureate degrees in [science and engineering] were born abroad,” the report notes. “This figure was 20% for master’s degree recipients and 25% for doctorate-holders.” The field with the highest percentage of foreign-born PhDs was civil engineering, with 51.5%.

“The troubling question is, because of our openness, will other countries use what they have learned [by sending students to US schools] and establish strong and eventually competing programs of their own?” Tapia said. “The answer is, ‘Of course.’” Since 1997, there has been a decline in the number of foreign students coming to the US, he said, so we “must learn how to build our own [science and technology] workforce.”

To do that, he said, the US must first solve the crisis in its elementary and secondary school education system. The problems the report identifies in K–12 education, especially in mathematics and science, are longstanding and well known: too few science and math teachers with relevant academic backgrounds; inadequate ongoing training for teachers already on the job; low salaries that keep top science graduates from going into teaching; science and math textbooks of poor quality; and uneven standards and testing across school districts. The report expresses little optimism that the problems with science teachers will be corrected soon: “Over the past three decades, teachers with low academic skills have been entering the profession in much higher numbers than teachers with high academic skills.”

Another trend revealed in the report is that, although more students are taking advanced science courses in high school, universities and colleges have to offer an increasing number of remedial science courses for incoming freshmen. “It is clear to me,” Tapia said, “that advanced courses in high schools are being watered down. Today’s advanced courses are not what yesterday’s advanced courses were.” (See PHYSICS TODAY, May 2002, page 48.)

Some of the other education trends highlighted by the report are the following:

▷ Although mathematics and science achievement, as measured by the National Assessment of Education Progress (NAEP) standards, have improved since the 1970s, few students are attaining levels deemed “proficient” or “advanced” by a national panel that evaluates the scores. Only 17% of 12th-graders scored at the “proficient” level or higher on the NAEP mathematics assessment in 2000.

▷ Female and male students have similar patterns in the science courses they take, although there are some differences. In high school, girls are as likely as boys to take advanced mathematics classes and are more likely to take biology and chemistry; they remain less likely to take physics.

▷ Since the publication of the landmark education study *A Nation At Risk* nearly 20 years ago, most states have increased the number of mathematics and science courses required for high-school graduation. In 2000, 25 states required at least 2.5 years of math and 20 states required 2.5 years of science. In 1987, only 12 states required that much math and only 6 required 2.5 years of science.

JIM DAWSON

Stellarator Fusion Gets a New Look

If the National Compact Stellarator Experiment planned for the Princeton Plasma Physics Laboratory is successful, stellarators could become prime contenders in the snails’ race to achieve fusion energy. The \$70 million NCSX is allotted \$12 million out of the Bush budget’s \$257 million for fusion research in fiscal year 2003. Assuming the money comes through, construction would begin in 2004, and the stellarator would be due to come online in 2007.

Like tokamaks, their currently more advanced cousins, stellarators use magnetic fields to confine plasma in a torus for fusion reactions. But unlike tokamaks, in which the field



Symmetry has rekindled interest in stellarators as a possible path to fusion energy.

varies in only two dimensions, in stellarators the field is fully three-dimensional, with the advantage of sustainability (the plasma doesn’t suddenly collapse, or disrupt) and the disadvantage of poor plasma confinement (the plasma loses particles and energy). New stellarators beat the confinement problem by creating a quasi-symmetric field—trading fiendishly complex magnetic fields for fiendishly complex magnets.

Symmetry solution

In quasi-symmetry, the orbiting plasma particles see the magnetic field as having a constant magnitude in some direction—the long (toroidal) or short (poloidal) way around the torus, or along a helical path, resulting in quasi-axi-, quasi-poloidal, and quasi-helical symmetry, respectively. “[Fusion scientists] have found a way out of the leaky stellarator problem,” says David Anderson, research leader of the two-year-old Helical Stellarator Experiment at the University of Wisconsin–Madison. “HSX is the first of a new generation of stellarators—where we design from the inside out. We target the physics and then design

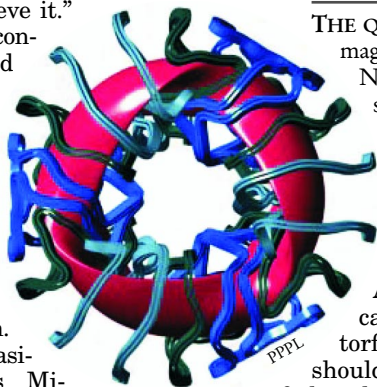
the magnets to achieve it.”

Research on plasma confinement at HSX and on stability of current-carrying plasmas at another small stellarator, the Compact Toroidal Hybrid under construction at Auburn University in Alabama, will feed into NCSX’s research.

NCSX will be quasi-axisymmetric, says Michael Zarnstorff, who heads the experiment’s physics group. “We are trying to make it so that the magnitude of the field doesn’t change as you go around the torus. If you do that, the particles don’t know if they are in a tokamak or a stellarator. The lack of symmetry [in traditional stellarators] means that the orbits of the particles in the magnetic field are not necessarily bounded. They can leave the device.”

Hand in hand with quasi-axisymmetry come other tokamak features. The shape can be chubbier—more like a truck tire than a bicycle tube—which lowers the cost for a given plasma volume. And a plasma current creeps in. But where plasma current alone creates the confining poloidal field in a tokamak, in NCSX, the current will contribute about a quarter of that field, with the rest coming from

THE QUASI-AXISYMMETRIC magnetic field confining NCSX’s plasma (red in this simulation) will be created using 18 modular coils (blue), plus some other weaker magnets.



external magnets. According to theoretical calculations, says Zarnstorff, having some current should drive up β —the ratio of the plasma pressure to magnetic field pressure and a measure of plasma confinement—without introducing disruptions. NCSX is designed for a steady β of 4–6%—in line with projected reactor requirements. For comparison, stellarators recently topped β values of 3%, and tokamaks have typically achieved 11%, but only transiently. “The big challenge at the moment is how to sustain sufficient β to make fusion attractive in terms of reactor cost and power output,” says Zarnstorff. And the big advance in stellarators, he adds, is the use of computers to sift through the infinity of possible three-dimensional shapes. “That, and the realization that you don’t have to make the coils helical.”

The bulk of NCSX’s magnetic field will come from 18 contorted coil modules, with another 28 weaker coils for tweaking. The plasma, consisting of hydrogen, deuterium, or perhaps helium isotopes, will have a major radius of 1.4 meters and a periodically varying cross-sectional shape.

Stellarator renaissance

In going ahead with NCSX, the US is

rejoining the stellarator fold. First proposed in 1951 by Lyman Spitzer of Princeton University, stellarators were later largely abandoned by the US fusion community in favor of tokamaks. Stellarator research continued elsewhere, however—notably in Japan, where a record-size stellarator has come close to matching tokamak results, and Germany, where the numerical computations used to design HSX and NCSX were developed. Germany’s stellarator in Garching will be shut down on 31 July. A successor, Wendelstein 7-X, is slated to start up in 2007 in Greifswald, in the former East German state of Mecklenburg–West Pomerania. Wendelstein 7-X will have quasi-poloidal symmetry and zero toroidal plasma current.

The international stellarator community must form a consensus as to the most promising stellarator concept for fusion energy, says Friedrich Wagner, director of Wendelstein 7-X. There won’t be the time or the will, he says, to build a stellarator comparable to the International Thermonuclear Experimental Reactor, a hoped-for tokamak intended to show the feasibility of fusion energy. “The decision between the ITER tokamak line and the stellarator line may come in the definition of DEMO [a post-ITER prototype commercial fusion power plant],” Wagner says.

“Sociologically, stellarators and tokamaks represent two separate camps,” adds Zarnstorff. “But not physics-wise—they have the same goals, with slightly different means.” In any case, he says, “it’s way too early to feel competitive.” **TONI FEDER**

BALCKE-DÜRR



THE PLASMA VESSEL will be adapted to match the plasma shape in Wendelstein 7-X, a quasi-poloidally symmetric stellarator under construction in Greifswald, Germany. This prototype is to scale.

House Legislation Calls for Doubling NSF Budget

In the months since President Bush released his fiscal year 2003 budget calling for a 5% increase in the National Science Foundation budget while simultaneously proposing a 17% increase for the National Institutes of Health, many budget watchers in both Congress and the scientific community have been grumbling. The call for a “more balanced portfolio” between life sciences and basic research has become almost a mantra on Capitol Hill. NSF Director Rita Colwell has repeatedly found herself facing skeptical congressional questioners who note that, because of program money being transferred to NSF from other agencies, her budget request is closer to 3%, or about

the rate of inflation.

In response to the increasing pressure to “fix” the NSF budget, several members of the House Science Committee, including Committee Chairman Sherwood Boehlert (R-N.Y.), introduced a bill in early May that would double the NSF budget within five years, beginning with a 15% increase in FY 2003. The bill, actually introduced by Representative Nick Smith (R-Mich.), chairman of the research subcommittee, was cosponsored by 16 representatives from both parties and is expected to give serious political momentum to reconfiguring the science budget to increase basic science funding.