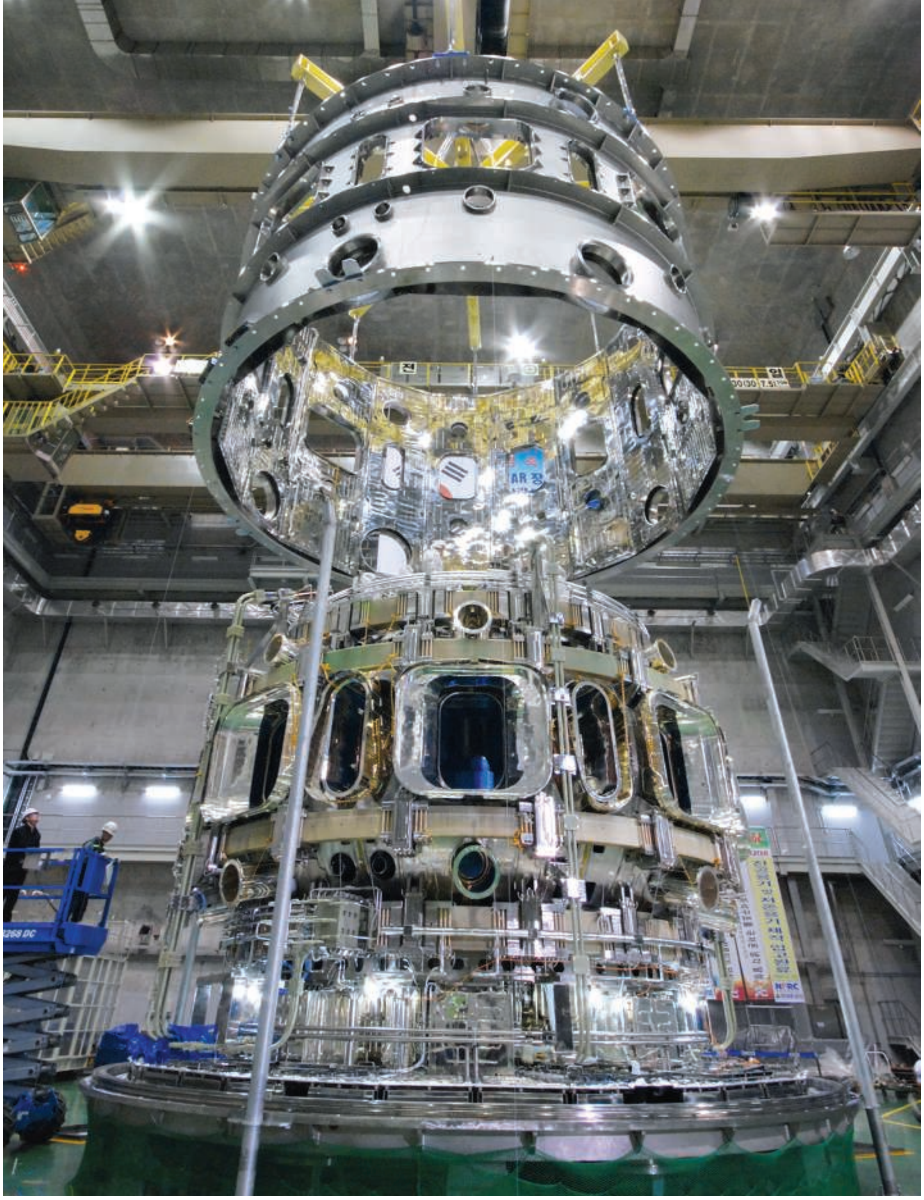

All fired up. KSTAR research will start this fall.

CREDIT: NATIONAL FUSION RESEARCH INSTITUTE

APPLIED PHYSICS

New Facility Propels Korea to the Fusion Forefront

Using innovative magnets that should confine plasmas for minutes rather than seconds, KSTAR is poised to become a premier testbed for fusion research

DAEJEON, SOUTH KOREA—At first glance, the fist-size bundle of wires on a conference table at the National Fusion Research Institute (NFRI) here looks like scrap metal doubling as a paperweight. But then NFRI President Gyung-Su Lee points to it as evidence of the engineering prowess that has thrust Korea to the fusion frontier: The wires are a sample of superconductive cable that's wound into magnets at the heart of the world's most advanced fusion research facility, the Korean Superconducting Tokamak Reactor (KSTAR).

The ability to fashion high-performance superconducting magnets from a niobium-tin alloy was a key technology that NFRI's industrial partners mastered while building a machine that fired up its first plasma a few months ago. Engineers are now installing control and diagnostic equipment that will allow research to begin in earnest this fall. KSTAR's explorations will reverberate all the way to Cadarache, France, where a consortium is assembling the most important fusion experiment ever, the International Thermonuclear Experimental Reactor (ITER), expected to come online in 2016.

"We definitely [wanted to] make KSTAR a really useful device for ITER preparation," says Lee. Fusion physicists say the Koreans have succeeded. "KSTAR has a very important role to play [in providing data] that will be used to design operating scenarios for ITER," says Hutch Nielson, a plasma physicist at the Princeton Plasma Physics Laboratory.

ITER will tackle a decades-old question: whether the fusion process that powers stars can be harnessed to produce electricity (*Science*, 13 October 2006, p. 238). It will use powerful magnets to confine a plasma within a doughnut-shaped high-vacuum vessel called a tokamak. At about 1 million degrees Celsius, the plasma's charged particles fuse, releasing energy. ITER will be several times larger and, at $6 billion, far more expensive than any existing tokamak.

Because ITER could cost more than $1 million a day to run, "you're going to have to operate as efficiently as possible," says David Campbell, ITER assistant deputy director general for fusion science and technology. Before ITER comes online, he says, researchers will be learning to control plasmas using the world's existing half-dozen major tokamaks. KSTAR, 1⁄25 of ITER's size, is the youngest in this cohort and will cost about $800 million after upgrades planned over the next several years. KSTAR's biggest advantage is its superconducting coils, which will enable it to confine plasmas for up to 300 seconds, compared with the 20 or so seconds of older tokamaks.

Catching up

Soviet Premier Mikhail Gorbachev proposed building what became known as ITER to U.S. President Ronald Reagan in 1985. The original four partners represented all those nations with a serious investment in fusion research—the Soviet Union, the United States, the European Union, and Japan. Twenty years later, as ITER was moving from design to construction, three Asian nations wanted in. China and Korea joined the project in 2003, and India joined in 2005.

The newcomers were intent on showing that they could bring expertise as well as cash to the table. India embarked on its Steady State Superconducting Tokamak in 1994; technical problems have delayed commissioning. Korea initiated KSTAR in 1995, although it was put on hold for 2 years because of the 1997 Asian financial crisis. China completed its Experimental Advanced Superconducting Tokamak in 2006 (*Science*, 19 May 2006, p. 992). The three countries "are much more significant players in fusion than they were a decade ago," says Nielson.

Of the new facilities, experts say

Fusion star. Gyung-Su Lee of Korea.

KSTAR is particularly outstanding given Korea's limited experience in fusion research. Before KSTAR, Korea had a handful of fusion researchers working with pint-sized tokamaks. Building the most advanced tokamak to date "was courageous and visionary," says Nielson, who consulted on KSTAR's design. He and others credit Korea's success to Lee. The physicist, like his colleagues in China and India, drummed up support for fusion research and for joining ITER by raising the alarm over future energy supplies. Korea is totally dependent on imported energy. "Because of the energy crisis and global warming, someday [fusion energy] had to get going, but Korea was not prepared," Lee explains.

Lee first won backing from Korea's industrial titans by convincing them to get in on the ground floor or risk having to license fusion reactor technology from others. He then got the government to put up "a huge magnitude of money" by persuading bureaucrats that investing in a future energy source was like buying insurance.

Paving the way

As planned for ITER, KSTAR uses superconducting magnets for both the toroidal field, which vertically rings the vacuum chamber, and the poloidal field, which follows the curve of the torus horizontally. Only one other tokamak—China's—features fully superconducting coils and can confine plasmas for 300 seconds or more. Older tokamaks use copper magnets that operate in pulses of up to only 20 seconds or so before overheating. "The significance of KSTAR and [China's tokamak] is that they can run long pulses and explore how to operate for a long duration and also what kind of physics you're going to encounter in that long duration," says David Humphreys, a plasma physicist at General Atomics in San Diego, California. ITER is expected to initially operate in 300- to 500-second pulses before ramping up to 3000 seconds.

KSTAR will also manipulate the plasma in ways particularly relevant to ITER, says Campbell. Some older tokamaks form plasma into a circular cross section. But ITER and KSTAR will aim for a sharply angled "D," which is more effective for confining the plasma and reducing instabilities that can leak energy and damage the vessel. Scientists hope to refine the "D" in Daejeon. "The KSTAR magnets were designed to allow strong plasma shaping control research," says Yeong-Kook Oh, head of experiments and operations for KSTAR.

Also paving the way for ITER, KSTAR uses the same systems to heat plasma and boost plasma current. These include injecting neutral particles and zapping the plasma with radio waves. KSTAR will also test exotic methods of taming instabilities, such as firing pellets of frozen deuterium into the plasma to release pockets of pent-up energy that otherwise cause turbulence.

The KSTAR tokamak will initially be lined with carbon-based tiles, but it might be modified later to test tungsten-based materials favored for ITER, says Oh. Already, KSTAR has proven the feasibility of working with the finicky niobium-tin alloy that ITER intends for its magnets.

No existing tokamak, KSTAR included, can achieve a burning plasma, in which at least half the energy necessary for fusion is generated internally. ITER is designed to produce more energy than it consumes. It will achieve that goal in part by relying on a fuel mix of deuterium and tritium, which fuses at a lower temperature than other gases, including deuterium alone, which is what fuels KSTAR and most other tokamaks.

KSTAR can't prove fusion is the energy of the future. But until ITER is fired up, this Asian upstart will be the hottest testbed in the world for fusion research. **–DENNIS NORMILE**

PROFILE: RICHARD RICHARDS

Making Every Drop Count in the Buildup to a Blue Revolution

Richard Richards is breeding wheat varieties that can tough out prolonged droughts—and keep people fed

LEETON, AUSTRALIA—Kneeling in verdant young wheat at Leeton Field Station, Richard Richards uproots seedlings of two varieties and splays them out for inspection. Looking on are several stern farmers and scientists from the Grains Research and Development Corp., which funds his work. They're a tough bunch to impress—but Richards has them spellbound. One seedling, "Vigour X-25," has a coleoptile, or seed sprout, that's twice as long as the other's. To this audience, the meaning is clear. In drought, when the top few centimeters of soil dry out, seeds that grow longer coleoptiles can be sown deeper, in moist soil needed for germination.

In the 1950s, wheat breeder Norman Borlaug launched the Green Revolution by dwarfing wheat varieties, which diverts plant energy from stalk to grain and boosts yields several-fold. Today, a golden dwarf sea stretches from the U.S. Great Plains to southern Australia's Wimmera Plains. But dwarfs have a major shortcoming: short coleoptiles. That's a serious problem in many regions, where water availability is a key constraint for crop yields. With a rallying cry of "more crop per drop," Borlaug exhorted fellow breeders to foment a Blue Revolution.

After 3 decades of dogged effort, Richards, a soft-spoken geneticist at CSIRO Plant Industry in Canberra, has nudged wheat to the brink of a Blue Revolution. "Richards uses a surgeon's scalpel" to tweak just the right physiological processes, says Brett Carver, a wheat breeder at Oklahoma State University, Stillwater. As a result, although most breeders these days content themselves with wheat yield gains of about 0.5%, Vigour X-25 and another Richards creation, Drysdale, are yielding 10% to 20% gains in arid conditions.

Hailing his achievements, the American Society of Agronomy last October awarded Richards its Martin and Ruth Massengale Medal for "significant contributions to new and innovative research in crop physiology and metabolism." He's not resting on his laurels. Using DNA tags that track genes conferring more efficient transpiration and long

Sow moist. The longer coleoptile of Vigour X-25 (*left*) helps it tough out drought.

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