Will Magnet Problems Delay the SSC?

The Department of Energy wants $160 million next year to start constructing the SSC; Congress must decide whether to proceed or wait until some magnet problems are resolved

IN THE COMING MONTHS, Congress will decide whether to permit construction work to begin in 1990 on the Superconducting Super Collider (SSC). While it is wrestling with this $6 billion decision, physicists and engineers involved in the project are grappling with some difficult choices as well. Even as the particle accelerator moves toward a political turning point, some fundamental technical questions remain unanswered.

In recent weeks, officials from the Department of Energy (DOE) have assured congressional committees that there are no technical barriers that would compromise the undertaking. Scientists familiar with the project also are confident that the remaining details can be dealt with. What is uncertain, however, is how long it will take, and whether DOE will have to relax some of the performance goals for the machine.

The technical problems revolve around the collider's magnet system, which is expected to cost more than $1.5 billion. Still unsettled are such basic questions as the design of collars that play a critical role in clamping magnet windings to prevent loss of superconductivity through friction heating; the size of the magnet aperture; and the reliability and reproducibility of the magnets.

It is perhaps not surprising that there are still problems to be resolved, for building the machine will push accelerator engineering to the limit. Although the SSC is similar in many respects to other high-energy accelerators in the United States and overseas—much of its technology is based on systems developed for the Tevatron at Fermi National Accelerator Laboratory—the machine's colossal size, the energy with which the protons will smash into each other, and the project's huge cost set it apart from any particle accelerator ever built. Construction will require boring 53 miles of tunnel 165 to 200 feet underground, and the machine will use 10,000 superconducting magnets—each more powerful than any used on existing accelerators.

The SSC is designed to smash record numbers of protons together at record energies of 40 trillion electron volts (TeV). The magnets are the heart of the proposed SSC.


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A 17-meter magnet *nears completion at Brookhaven National Laboratory.*

Their function is to confine trillions of protons orbiting in separate rings around the race-track-shaped accelerator. At the point that proton beams collide, detectors must record the hadrons, leptons, photons, and other particles that are produced.

To attain collisions with center-of-mass-energies of 40 TeV, the SSC's helium-cooled, superconducting magnets must operate at a field of 6.6 teslas, more than 50% higher than the magnets used in the Tevatron. If even one of the SSC's 10,000 magnets fails to perform at 6.6 teslas, the machine will not be able to operate at its ultimate design goal. The task of building prototype magnets is challenging because of the high field requirements, a relatively compact diameter, and their extraordinary 17.3 meter length (56.7 feet). Tevatron magnets, in comparison, operate at 4 teslas and are 6.4 meters (21 feet) long.

SSC engineers also have had to struggle to design collars to control coils of superconducting wire cable, which when energized produces the magnetic field. The stainless steel collars must clamp the precisely wound 16.75-meter magnet coils in place along the beam tube through which flow protons. Movement in the cable, even when cooled to 4.35 Kelvin, can produce enough resistance to create hot spots. In a fraction of a second this heat can cause an SSC magnet to cease operating in a superconducting state, thus losing magnetic field strength.

The difficulty in designing these clamps is reflected in the fact that of the 12 full-length test magnets tested so far, only 3 have operated at design specifications. The magnet builders have a delicate task: they must clamp magnet coils at room temperature with enough pressure to ensure that the cable windings will remain immobile as they cool and shrink, but they must not clamp them too tight. If the Kapton insulation breaks, the cable may be damaged.

The successful testing of 3 of the 12 long magnets suggests that the collar clamping problem may be solved. There is, however, continuing concern about the potential for metal fatigue at the point where pairs of collars are locked together with metal wedges called "keys."

This worry may be alleviated by redesigned iron yokes that clamp more uniformly around the SSC magnet collars. The aim is to eliminate tiny gaps within the structure that would allow the collars and cable to move when the magnet is energized. Designers also are shifting to a stronger stainless steel for the collars, says Carl Goodzeit, deputy director of the magnet division at Brookhaven National Laboratory.

In addition to these mechanical difficulties, the SSC designers still face a fundamental decision on the size of the aperture or bore in the center of the magnet. An error here could reduce the number of observable proton collisions or "luminosity," and adversely affect experimental productivity of the SSC. The current design calls for a 4-centimeter aperture across the inside diameter of the magnet coils, but some physicists would prefer 5 centimeters.

Helen T. Edwards, a physicist who recently left Fermi National Accelerator Laboratory to head the SSC's accelerator systems division, told *Science* that she is concerned about two problems related to the narrow aperture. The first is having a sufficiently good magnetic field to maintain the 1 millimeter focus of the stream of protons as they shoot into the SSC from the injector ring. Second, there must be sufficient room to steer proton streams smoothly into a proper orbit. If the 4-centimeter aperture turns out to be marginal, she says, then operating the massive machine would be made difficult.

"Personally, I would design in as much operating margin as I could," says Fermilab's Richard Lundy, who played a large role in building the Tevatron accelerator magnets. He questions whether simulation models supporting the 4-centimeter aperture are fully reliable.

Erich H. Willen, a senior physicist at BNL, however, is confident that the 4-centimeter aperture will be sufficient. Should that not be the case, he says the accelerator could be fitted with additional correction magnets for steering the beam. Alternatively, the injection energy could be doubled to 2 TeV. The higher energy would help maintain beam focus by keeping protons bundled together more tightly. This also would hike costs and undermine the very reason for adopting the 4-centimeter aperture—to hold down magnet production expenses and overall project outlays.

Alexander W. Chao, head of the SSC Central Design Group's accelerator physics division, contends that the 4 centimeter aperture "has a reasonable safety margin." He concedes, however, that there is a question of whether there are unanticipated issues the simulation tests have not addressed. Ultimately, he says, "It is a policy issue of whether one wants to spend more money to increase the safety margin. The main concern is to have a collider that works."

A decision to adopt a 5-centimeter aperture would involve more than increasing magnet costs; it could delay the magnet production program by as much as 18 to 24 months, according to physicists and engineers at Brookhaven and Fermilab. This slight increase in aperture would require reconfiguring and retesting the magnets.

Roy Schwitters, the new director of the "SSC Laboratory" that is to be built in Waxahachie, Texas, hopes to settle questions about the aperture and other critical design issues within the next 6 months. All aspects of the supercollider's design will be subject to scrutiny, he says, as part of an audit being done by Universities Research Association (URA). DOE awarded the group the management and operations contract for the SSC in January. Although URA has run the SSC Central Design Group for the department since 1984, Schwitters says project plans still must be checked before the SSC program goes much further.

Two outstanding issues that will not be cleared up in this review are magnet reliability and reproduceability. The SSC conceptual design calls for the magnets to perform for 20 years. Victor N. Karpenko, a mechanical engineer who was analyzing magnet reliability issues at the Central Design Group until last year, questions whether the design margins of magnet components are adequate to meet the advertised collision energy of 40 TeV on a regular basis.

He is not alone. "We have got to back down on the field or otherwise we are going to be operating on the hairy edge all the time," says one SSC official, who fears that the project could suffer from large numbers of magnet failures. Several program officials have told *Science* that DOE should consider settling for a collision energy of 35 TeV. This would help ease the potential operating and manufacturing problems related to the magnets without sacrificing much in the way of physics research.

Whether industry will be able to mass produce these magnets in an economic and timely fashion may not be clear for several years. DOE plans to bring industry into the magnet design and fabrication effort in 1990 and to have a number of companies make 5 magnets each in 1991. That process could produce further design changes. Until now, the CDG has conducted the research and designed the tooling largely with R&D support provided by Brookhaven, Fermilab, and Lawrence Berkeley Laboratory.

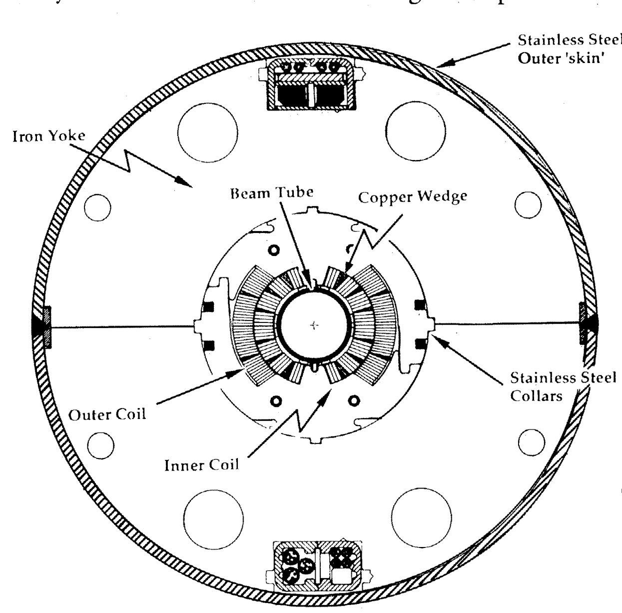
Indeed, the new SSC project management team being assembled by Schwitters may examine the merits of reducing the length of the 17-meter dipole magnets to about 6 meters, sources say. The shorter length might make magnet manufacturing and handling easier.

The question now facing Congress is whether to proceed with construction, or to wait and see if the magnets will have to undergo major design changes. The last thing SSC supporters want is for Congress to delay construction, as it did for fiscal year 1989. Raphael Kasper, incoming chief of staff for the SSC laboratory, says continued uncertainty about the country's commitment to the project will make it hard to recruit scientists and engineers.

Further delays also will hinder efforts to negotiate cooperative international agreements that could reduce U.S. outlays for the project by as much as $1 billion, says says Robert Diebold, director of DOE's SSC division. "I think we have shown that these magnets do work. We do have the proof-of-principle," says Diebold, arguing the Congress should push ahead with the SSC. What work remains to be done on the SSC magnets, he adds, "is just fine tuning."

Congress, however, may hesitate to accept 3 working magnets as a basis for allowing construction to proceed in 1990. Many legislators still remember the magnet problems that plagued Brookhaven's Isabelle accelerator (*Science*, 9 April 1982, p. 158) and the fact that the project was killed after $220 million was spent. Even more problematical, however, is the federal budget deficit and the desire of members to fund dozens of projects that are smaller than the super collider. Says an aide to one Republican member of the Senate Appropriations Committee, "right now no one wants to say 'no' and no one wants to say 'yes' to the SSC."

■ **Mark Crawford**



DOE/Central Design Group

SSC dipole magnet cross section