fallout, Hohenemser and his colleagues estimate that at most 25% of the volatile fission products in the reactor were released. A task force set up by the Department of Energy will examine the potential health impact of the Chernobyl accident.

Until data are available in usable form, some scientists have been running atmospheric-transport models to simulate the possible magnitude and extent of contamination from the reactor accident. Joseph Knox and his colleagues at Livermore, and, independently, Helen ApSimon and J. Wilson of Imperial College, London, have undertaken such simulations, using actual wind patterns for the days after the accident. Their efforts are very preliminary because there are few or no data describing the nature of the releases. The simulations must make assumptions about the probable inventory of radioactive fission products in the reactor, the fraction of the volatile fission products that may have escaped, the height to which they were carried by the heat and fire, the time over which that release occurred and the rate at which the radioisotopes are deposited on the ground. Thus the results could well be in error by an order of magnitude or more.

The Livermore simulation corresponds to a hypothetical total release of 40% of the core inventory of volatile radionuclides in the first day after the accident and an additional 10% spread out over the subsequent five days. It was assumed that the reactor had been operating at full power until just before the accident, in which case the core may have contained 80 megacuries of I^{131} and 6 MCi of Cs^{137}, among other fission products. The simulation does not include the effects of terrain or rainfall. The figure on page 19 shows contours predicted by the Livermore program for the time-integrated dose to the adult thyroid that a person would have received by the fifth day after the accident from inhaling the I^{131}. The dose values obtained from the model are high compared with measurements near Stockholm and in Poland, but agree with data taken off the coast of Sweden and in Italy, Knox says. The Imperial College simulation, which does include rainfall, assumes the accident released 21 MCi of I^{131} and 1.4 MCi of Cs^{137}.

The simulations of contamination from the Chernobyl plant have concentrated on I^{131} and Cs^{137} because they pose considerable health concern and are released in appreciable quantities. Iodine-131 is a beta emitter and has a halflife of only eight days, but it is taken up quickly into the thyroid once it is inhaled or ingested. Cesium-137 is a gamma emitter with a halflife of 30 years, so it can contaminate the ground for long periods.

Frank von Hippel (Princeton University) and Tom Cochran (Natural Resources Defense Council) have made[5] some very preliminary estimates of what the long-term health consequences of the Chernobyl accident would be if the doses were distributed as these simulations predict. They used the Imperial College maps to deduce the numbers of people possibly exposed to given levels of radiation. They then applied the so-called linear hypothesis—which assumes that the health effects of low doses of radiation can be extrapolated linearly from those seen at higher doses—and found that among the roughly 100 million exposed people in the western USSR and Eastern Europe there might be thousands to tens of thousands of tumor cases from I^{131} and cancers from Cs^{137}. About half of the Cs^{137} cancers, but only a few percent of the thyroid tumors, might be fatal. These fatality predictions result only from summing very small incremental cancer risks to individuals over very large numbers of people. Over the lifetimes of the exposed population, one might expect about 20 million cancer deaths from other causes. Von Hippel and Cochran caution that these are very uncertain, first-order estimates, which rest on the model simulations, assume a uniform population density and rely on a linear model of the dose–effect relationship.

Since the Chernobyl accident, many have spoken of the need for international communication and cooperation in matters of nuclear safety. In his speech of 14 May, Gorbachev stated his readiness to cooperate in such efforts, within the framework of the International Atomic Energy Agency. IAEA has scheduled a meeting of experts in Vienna for 25–29 August. At that time the Soviets have promised to give a post-accident briefing. The IAEA board of governors will meet 22–23 September, and a special session at the ministerial level will follow on 24–26 September. An IAEA spokesman told us they expect to strengthen an existing agreement on cooperation in matters of nuclear safety and expand it to cover all aspects from design to decommissioning. —Barbara Goss Levi

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Panel reaffirms high-field magnet choice for Supercollider

The Superconducting Super Collider, if it is built before the end of the century, will certainly be the largest scientific instrument in the world. But whether its circumference should be 100 miles, or a mere 50 miles, has been a bone of some contention. The design energy is not at issue: SSC is to be an ultra-high-energy proton–proton storage-ring collider with countercirculating beams of 20-TeV protons providing p–p collisions at 40 TeV in the center of mass. The radius of the gargantuan storage ring required to keep these protons going round in circles varies inversely as the strength of the superconducting bending magnets one chooses to make up the ring.

Last September the issue appeared to have been settled once and for all by the magnet-selection advisory panel headed by Frank Sciulli (Columbia). The Sciulli panel and its industrial consultants unanimously recommended the selection of the high-field "$\cos\theta$" magnet design developed by a Brookhaven–Fermilab–Berkeley collaboration (PHYSICS TODAY, December, page 59). With a field intensity of 6.6 tesla, these bending magnets would require an SSC circumference of 52 miles. A 3-tesla "superferric" magnet design, developed and championed by the Texas Accelerator Center, had emerged as the chief rival of the $\cos\theta$ design at the Sciulli-panel meetings. This presumably less expensive low-field magnet would require an SSC circumference of 100 miles, but its proponents argued that the additional civil-engineering cost of the longer tunnel would be more than offset by the savings in magnet fabrication. The Sciulli panel was not convinced that a superferric SSC would in fact be significantly cheaper. They opted for the high-field $\cos\theta$ magnets, which they felt were at a significantly more advanced state of development.

The calm that followed the selection of the high-field magnets was disturbed in April by a letter to DOE from Russ Huson and Peter McIntyre, the leaders of the Texas low-field-magnet effort, requesting that the SSC magnet-selection question be reopened in light of "a significant base of new information relevant to the design of the SSC" developed by the ongoing superferric R&D program at TAC. The superferric design, they argued, had been successfully "industrialized" with the production of a 28-meter prototype, "the longest superconducting magnet in the world," at General Dynamics. Industry is ready, the letter asserts, to begin full-scale production of the 4000 bending magnets needed for the SSC ring in about a year. "By contrast," Huson and McIntyre contended, "the high-field design has not yet been introduced to US industry."

Furthermore, the TAC letter argues, the tunneling-cost estimate used by the Sciulli panel was unnecessarily high. The lower the tunneling cost per foot, the more attractive, of course, is the low-field-magnet alternative. The letter contrasts the $873/foot "generic-site" estimate used by the Sciulli panel against a $345/foot estimate recently elicited by TAC for a specific site near Houston. "In the two principal categories of collider magnet system and collider system alone, we are prepared to demonstrate a cost savings of $700 million."

The SSC Central Design Group at Berkeley currently estimates the total cost of constructing the 52-mile SSC based on the high-field magnet design to be $3.01 billion (fiscal 1986 dollars). This figure does not include the detectors, computers, R&D or other "preoperational costs," which would add perhaps another billion dollars to the final reckoning. The cost of site acquisition, it is assumed, will be borne by the state that has the good fortune to be selected as the home of SSC.

In response to the letter from the TAC leadership, Alvin Trivelpiece, director of the DOE Office of Energy Research, asked the High Energy Physics Advisory Panel to convene a subpanel to reexamine the magnet-selection decision that had been taken last September. "Please review and evaluate the TAC claim," he charged HEPAP, "to determine if there is sufficient evidence to support their position that the superferric magnet is clearly superior to the cosθ magnet [and whether] HEPAP believes there are sufficient grounds to reconsider the September 1985 SSC magnet decision."

The HEPAP subpanel thus created met for four days in April and May, under the chairmanship of Burton Richter, director of the Stanford Linear Accelerator Center. The other members were Parke Rohrer, the tunneling expert who built the Fermilab tunnel; Herman Grunder, director of CEBAF, the nuclear-physics accelerator facility proposed for Newport News, Virginia; Fred Mills and Alvin Tollestrup (Fermilab); Richard Taylor (SLAC); and Sam Treiman (Princeton). Of the subpanel's seven members, three were chosen from a list submitted by the Texas petitioners. Sciulli was among the consultants to the subpanel.

TAC presented to the subpanel its new superferric-magnet results and its new tunneling-cost estimates. Representatives of the Central Design Group were present to uphold the case for the high-field cosθ magnets. The cosθ design is a "pure" superconducting magnet, with a field configuration determined almost entirely by its coil geometry. The iron in the structure has little effect on the shape of the field. Ideally one wants the bending-magnet field to be perfectly vertical and uniform over the entire cross section of the proton beam. The cosθ distribution of current-coil density—maximal in the horizontal plane and going to zero at top and bottom—is designed to approximate this ideal field.

The superferric design, on the other hand, is something of a hybrid between a superconducting and a conventional ferromagnet. Its field configuration is largely determined by its iron yoke, especially at the low field strengths at which it would run early in the acceleration cycle. The idea is that this mass of ferromagnetic material gives a boost to the field strength produced by the superconducting coils, permitting the construction of a relatively inexpensive 3-T magnet. To counteract field nonuniformities introduced by the saturation of the iron, the Texas magnet requires three separate coils of differing geometry, each rising to full current at a different time in the acceleration cycle.

Superconducting magnets of the cosθ design have been serving the high-energy-physics community well for some time now. Eight hundred of them form the four-mile-long Tevatron ring, which has been operating successfully at Fermilab since 1983. Such experience had weighed heavily in the Sciulli panel's selection. The superferric concept was much more of an unknown quantity. Huson takes exception to the invocation of the Tevatron on the side of his rival. The Tevatron magnets, he points out, operate with a maximum field intensity of 3.6 T, much closer to the TAC 3-T field than to the 6.6 T proposed for the SSC cosθ magnets. The enormous magnetic stresses that constitute a major challenge to magnet stability increase as the *square* of the field intensity, Huson reminds us. Therefore, he argues, it is unwarranted to extrapolate from the Tevatron fields, where all is well, to 6.6 T, where magnet stresses would be almost four times as severe.

Tollestrup, in response, points out that the Tevatron experience has shown that one can operate a high-energy accelerator with superconducting magnets whose field quality depends entirely on coil placement, and that these magnets can survive the hazards of heating and thus quenching by a megajoule of circulating beam that comes perilously close to the superconducting coils. These, he argues, are more crucial issues than is the problem of magnet forces.

The TAC representatives presented to the HEPAP subpanel their new measurements from the seven 1-meter-long magnets they had recently built, and from the 28-meter magnet assembled at General Dynamics. A full-length superferric magnet for SSC would be 35 meters long. The purpose of the one-meter program was to permit the timely testing of proposed design changes and to examine the random variability of field parameters from one magnet to the next in a less than perfect fabrication process.

Protons are to be injected into the main SSC ring at 1 TeV. As they are accelerated to 20 TeV, the bending magnets keep up by increasing their field intensities. It was apparent from the one-meter-magnet measurements presented by TAC that the field quality of the superferric magnets is best at intermediate field intensities, about 1.5 T. At injection, where the superferric magnets would run at 0.15 T, the performance of the magnets is described in the HEPAP subpanel's report as "poor." TAC proposed eventually to improve this low-field performance, which is plagued by the remanent field in the iron, by using iron of lower residual magnetization.

At 3 T, the high end of the acceleration cycle, where the field quality is very sensitive to coil-position errors and variations in saturation magnetization, the subpanel noted that the performance of the one-meter magnets degrades to about the level of the tolerance limits. Huson counters that the present cosθ magnets have similar tolerance problems. The subpanel also noted that the measurements were made in single-bore magnets. The two countercirculating proton beams, of course, require magnets of opposite polarity. The cosθ "one in one" design calls for two completely independent rings of magnets surrounding the two beam pipes. In the Texas design, by contrast, each pair of opposite-polarity magnets shares a common yoke and cryogenic system. Problems associated with this "two in one" configuration became evident in the dual-bore 28-meter-magnet measurements presented to the subpanel.

The cooling of the 28-meter superferric prototype to liquid-helium temperature is described by the subpanel report as a noteworthy accomplishment, for which "TAC is to be complimented." TAC presented field measurements from along two-thirds of this prodigious length for both bores at an intermediate field intensity of about 1.5 T, where the iron is in a linear region and the field quality should be at its best. Noting that the measured multipole coefficients of the upper-bore field indicated serious asymmetries not evident in the lower bore, the subpanel concluded that this discrepancy between the two beam pipes is "most probably due to a mechanical problem in mating the iron assemblies.... The [simultaneous] alignment of the fields in the two bores cannot be checked until any mechanical problems are cured." The subpanel also pointed out that one still has to measure the fields along the full length of the magnet, looking for unacceptable twists or bends. "This is a problem common to both designs," Huson asserts.

On the basis of its measurements on the short and long superferric prototypes, TAC proposed a number of design changes to overcome present deficiencies. In addition to using iron of lower coercive force and exercising greater control over fluctuation in the fabrication of iron laminations, the Texas group proposed moving the "trim-correction coil"—the last of the three coils to turn on during the acceleration cycle—to a different position in the magnet, where it would perform its wonted function of canceling undesirable multipole components without bucking the main bending field. Furthermore, TAC proposed to widen the magnet aperture somewhat, and to double the number of windings, reducing the coil current from 12 to 6 kiloamps. "We got hit for offering design changes," Huson told us. "But any magnet design, including the cosθ, would require similar changes before a final model is ready."

Conclusion. "TAC has done some interesting work... since the magnet selection decision was made last September," concludes the subpanel report, which was released in May. "However, we conclude that their claim to do the job better, cheaper and faster with superferric magnets is not borne out by the information supplied.... [Their] magnet R&D program is still about two years behind the high-field magnet program. The TAC magnet is not ready for industrialization.... Superferric magnet costs cannot be estimated with confidence at the present stage.... We do not believe the new information warrants reexamination of the magnet selection."

The subpanel also discussed extensively tunneling and other magnet-related conventional costs. Tunneling cost per foot is sensitively dependent on geological and labor issues. The subpanel found itself "faced with the vexing problem" of evaluating the TAC claim of substantial savings with a larger SSC ring without having a specific site to consider. Site selection, should that happy day ever come, will of course be a delicately political issue. Under the ground rules that require the Central Design Group, for the time being, to base its estimates solely on the generic site, "the proponents of any specific site will always have the advantage," Tollestrup told us.

It was finally concluded that the difference in tunneling-cost estimates between TAC and CDG rested entirely on different assumptions about geology and labor costs between the generic site and the atypically favorable sites considered by TAC. When the same site was considered, both estimating programs yielded almost identical costs per foot. A hundred-mile tunnel also requires more electrical-utility installation than does a tunnel half as long. TAC had originally argued that the more modest requirements of the low-field magnets would go a long way toward equalizing utility installation costs. It was finally agreed, however, that the superferric low-field design would cost a significant $30 million more for electrical installation.

'Taking all together,' Richter and his fellow panelists conclude, "we believe there is no convincing evidence that warrants reconsideration of the recommendations of the Magnet Selection Advisory Panel.... We believe that superferric magnet technology *could*, in time, be developed as the basis for a successful project on the SSC scale. However, the preponderant... opinion is that the high-field technology currently being pursued by the SSC Central Design Group represents the surer and more promising pathway for SSC.... Although the leadership... has to be open at all times to new (even if discordant) possibilities, it also has to lead and therefore *choose*. We believe, on all the available evidence, that the choice was soundly based, and that the important thing now is to get on with the work."

Though he "strongly disagrees" with the subpanel's evaluation of the new data, Huson agrees wholeheartedly that the overriding issue is "building an SSC in this country." To that end, TAC has now stopped all work on the superferric design and joined in the common effort to complete the development of the high-field magnets.

Meanwhile the SSC program goes on apace. Since last September, the CDG has assembled and tested several 4.5-meter high-field magnets, with notable improvements in field quality. The first full-length (17-meter) prototype high-field magnet has just been assembled at Fermilab, its magnetic components having been built at Brookhaven. The goal is to have four full-length prototype cosθ magnets by October.

The Central Design Group's *Conceptual Design Report* for the high-field SSC was published in April and subjected to an extensive review by DOE. The report of the DOE review committee, headed by Edward Temple, director of the Office of Energy Research's Division of Construction, Environment and Safety, has now been made public. It concludes that the CDG's conceptual design "is technically feasible and properly scoped to meet the requirements of the US high-energy physics program... from the mid-1990s well into the next century." The review committee further finds that the CDG's $3.01 billion cost estimate "is credible and consistent with the scope of the project." Finally, the committee "was impressed with the extent, the quality and the depth of the work accomplished by the CDG and laboratory and industrial participants."

In response to last year's suggestion by Leon Lederman, director of Fermilab, that one might save a considerable sum by making SSC a proton–*antiproton* ring, requiring only a single ring of magnets, the CDG asked Barry Barish (Caltech) to head a panel of uncommitted experts to look into Lederman's proposal. The report of Barish's committee was released last month. The group concludes that a p–$\bar{p}$ collider could not possibly have the same luminosity as a p–p machine with present technology, but that the loss of luminosity may be no worse than a factor of ten. Some theorists think such a tenfold event-rate reduction would be very serious for the observation of rare processes. But on the other hand, there might be some compensatory gain from the predominance of quark–antiquark collisions in a p–$\bar{p}$ collider.

With regard to costs, Barish and his colleagues conclude that one would not save much more than $200 million by eliminating the second proton ring, essentially because an antiproton beam would require an elaborate $\bar{p}$-source system, an additional accumulator ring and a larger beam aperture. Furthermore, the report concludes, "Judging from the CERN experience... $\bar{p}$p is at least a factor of two worse than pp in reliability of performance."

In the light of the Temple review DOE must now decide what to recommend for the fiscal 1988 budget. The proposed DOE budget goes to the White House Office of Management and Budget toward the end of summer. The most optimistic scenario, from the point of view of the high-energy-physics community, would be a DOE decision to go ahead with SSC construction in fiscal 1988.

—Bertram Schwarzschild □