Magnet Failures Imperil New Accelerator

Designers didn't build an exact prototype magnet; with millions sunk in construction, they're still wondering if one can be built

Slowly taking shape at the Brookhaven National Laboratory on Long Island is a machine intended to be one of the most powerful in the history of U.S. particle physics. Known as Isabelle, the accelerator is slated for completion in 1986 at a cost of $423 million. Work at the construction site and nearby production areas, begun in 1978, currently draws on the expertise of 574 persons.

Despite the activity, the future of the Isabelle project is anything but promising. The project is teetering on the brink of a technological failure that would set the high energy physics program in the United States back by many years and might ultimately lend to closer supervision of the way in which projects such as Isabelle are planned and carried out.

Serious technical problems have delayed the construction of 1100 superconducting magnets. Blueprints show these magnets arranged in a circular tunnel more than 2 miles around, forming a magnetic prison that accelerates protons to nearly the speed of light and then smashes them together. Production of the magnets, however, is 1 year behind schedule and might fall 3 to 4 years behind if the magnet design, under development at Brookhaven since 1965, is abandoned. This is a distinct possibility, even though development of a new design and the resulting delay might increase the cost of Isabelle and cheat U.S. physicists out of an early chance to beat their European rivals in the race to discover new subatomic particles.

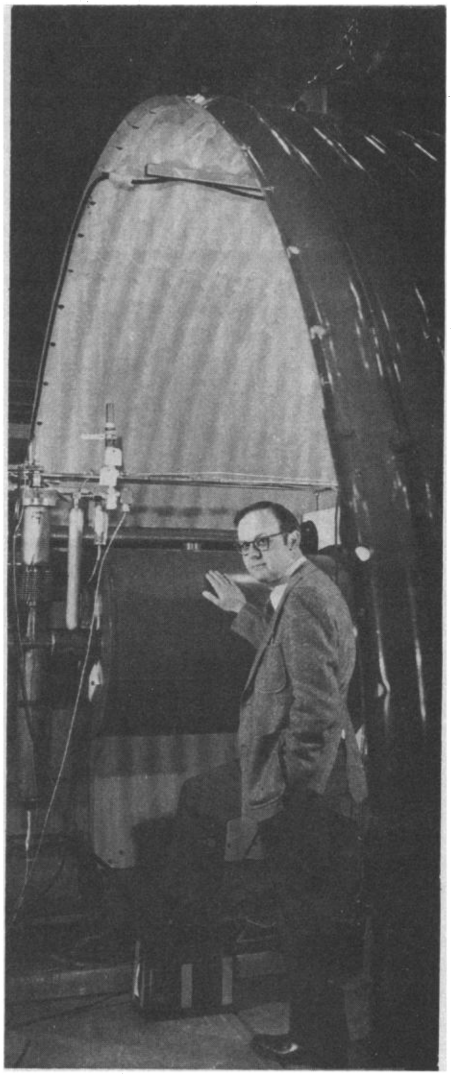
Under federal pressure, Brookhaven officials this spring called together a ten-person panel of scientists and engineers not directly connected with the Isabelle project to evaluate the magnet problems. In an 88-page report issued this fall, the panel recommended that Isabelle project engineers quickly evaluate four alternative magnet designs. In addition, the Department of Energy (DOE), which finances the Isabelle project, has given the Lawrence Berkeley Laboratory in California more than $1 million to assist Brookhaven in coming up with a better magnet idea.

The consequences of switching to a new design would be considerable. Since most of these designs call for more of the costly niobium-titanium wire that is used in the Isabelle magnets as a conductor, magnet prices could rise from $93 to $160 million. If Isabelle engineers develop weaker magnets that are easier to make, as some outside observers have suggested, the energy of Isabelle's proton beams would fall from 400 to around 300 billion electron volts (GeV), making the machine less attractive for performing experiments. For the project as a whole, all this adds up to a very uncertain future. "We'll eventually come up with something," says David Sutter of DOE's division of high energy physics, "as long as the physics community doesn't lose interest because of the delay, and as long as we don't get into a hassle with Congress about the increased funding."

Heads are not exactly rolling, but the director of the Isabelle project, James R. Sanford, has been joined by a "technical director" who, in a newly created post, oversees magnet and accelerator design. This is Kjell Johnsen, a Norwegian physicist and a key figure in the development of the only machine similar to Isabelle, the 26-GeV Intersecting Storage Rings (ISR) run by CERN in Geneva, Switzerland. The ISR does not utilize superconducting magnets, but, at a less energetic level, uses conventional magnets to break apart protons in the same manner as proposed for Isabelle. This method uses colliding beams. One ring of magnets carrying protons is interlaced with a second ring, and proton collisions take place where the beams cross. The Europeans do not plan to build a machine in the energy range of Isabelle.

Johnsen, who took on the job in September, is weighing the risks and benefits of staying with the original magnet design or switching to an alternative. He is also waiting for the results of eleventh-hour research. To the old guard at Brookhaven, who, though discouraged, are trying to salvage the current design, this scramble for new ideas holds little promise. "Five years ago we had little models [of magnets] that were good enough to get us $300 million to start this thing," says William B. Sampson, a long-time magnet designer at Brookhaven. "Models always look good. So now it's tempting to say, oh, let's go ahead and try a new design. But in practice there are no guarantees."

Why the magnet problems? One reason is that in 1977, when the Isabelle project was approved, a prototype magnet for a 400-GeV version of Isabelle had not yet been made. The first one was not tested until 1979, long after funding and civil construction were well under way. What did exist in 1977 were "little mod-



Brookhaven National Laboratory Photo

Victim of a technical trick?

James R. Sanford, head of the project, poses in 1977 with a small model of an Isabelle magnet that showed false promise.

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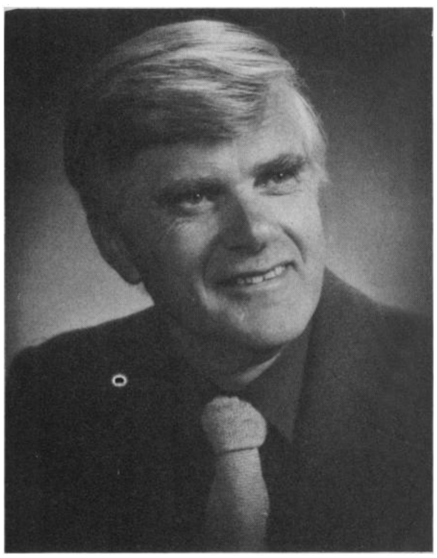
el" magnets for a smaller, 200-GeV version of Isabelle. These magnets (and one in particular, the Mark 5) worked at levels far above their ratings, and it was thought that they could easily be modified and strengthened so that a 400-GeV accelerator could be constructed. This feeling, held by people at Brookhaven and by members of the High Energy Physics Advisory Panel (HEPAP), a group of 15 U.S. physicists who advise DOE on the direction of the U.S. machine-building program, turned out to be wrong.

In fairness, it must be said that the broader origins of the problem go beyond any single technical oversight or even a single project. For one thing, superconducting magnets are at the cutting edge of accelerator technology and have yet to be successfully used anywhere in the world as the main magnets in an accelerator. Manufacturing them is more art than science. "It's one thing to knock off a half-dozen of them in the lab, using hand-tooled technician's tricks in every one," says a Brookhaven engineer. "It's quite another to bang them out like Cadillacs." Another problem is that the builders of the big machines cannot look to industry for much help because there is a dearth of expertise with superconducting magnets, in sharp contrast to industry's extensive experience with the fabrication of conventional magnets. Finally, the overriding priority of the U.S. high energy physics community during the past decade has been machine construction and use, with little concomitant emphasis on finding the best ways to carry out the construction. Even though conventional construction methods have been pushed closer and closer to their limit, few dollars have been spent on the exploration and development of new technologies. In short, the builders of particle accelerators have been living on borrowed time.



Brookhaven National Laboratory Photo

Can this man save Isabelle?

A Norwegian, Kjell Johnsen was hired in 1980 to help get the bugs out of Isabelle.

The ultimate irony in all this is that the headlong push for construction with untested magnet designs, intended to quicken the pace of research, has resulted in just the opposite. In order to finance eleventh-hour research on superconducting magnets, officials at Brookhaven are dipping into funds for the operation of existing big machines, such as Brookhaven's Alernating Gradient Synchrotron. This shuffling of funds has also become a necessity at the Fermi National Accelerator Laboratory in Batavia, Illinois, which is having similar problems with superconductivity. At a cost of $6.5 million, Fermilab built 130 superconducting magnets as part of its effort to develop mass production techniques for a device called the energy doubler. Unfortunately, none of these were acceptable for use in the accelerator. Many went up in smoke.

What makes the Isabelle episode all the more significant is that during the past decade in the United States the big accelerators have been built with speed, economy, and style. For example, it was initially thought that construction of Fermilab would take about 6 years. Under the direction of Robert W. Wilson, most of the machine was built in 4 years and considerably on budget, the federal government receiving in 1972 a refund of $7 million. This made Wilson a congressional favorite and helped pave the way for other projects. In 1979, a $78 million machine was completed in California ahead of schedule and under budget (*Science*, 28 September 1979, p. 1361). Isabelle, of course, was envisioned as pushing this remarkable track record forward. What impact the current difficulties will have on congressional goodwill and long-range funding of the U.S. program remains to be seen.

Not long ago, superconducting magnets for particle accelerators looked like a promising idea. These magnets offer no resistance to the flow of a steady electric current. Once a stable current is started in such a magnet, which is cooled to near absolute zero, it flows without stopping. For particle accelerators, this could add up to substantial savings because the magnets use huge amounts of electricity. Fermilab says the use of super-conducting magnets might cut $5 million from its annual $8 million electric bill.

Making the magnets perform in the real world is another question. One difficulty is that superconducting magnets tend to return to the normal, resistive state with the least provocation—as when currents are unevenly increased or when the tremendous forces in a magnet cause a slight inelastic motion of, say, a wire, resulting in the generation of heat and the loss of superconductivity. This sudden return to resistance is called quenching. The 200-GeV design of Isabelle called for magnets with a strength of 4 teslas. For the 400-GeV version of Isabelle, the magnets had to reach a strength of 5 teslas. This relatively small increase in field strength resulted in a doubling of the forces within the magnet, pushing the magnets to their design limits and making them more likely to quench.

In 1979, when the first Isabelle magnets started rolling off the production line, tests quickly showed that full strength could only be achieved by an arduous method called training. The current is increased little by little, and each time, the threshold at which a quench occurs is slightly raised. To achieve the 5-tesla strength, however, more than 100 quenches were often required, a process that takes at least a week. This was an impossible situation, since the manufacture of 1100 magnets during a projected 3-year period required the production of one magnet a day. In addition, tests showed that the quality of the magnetic field was not suitable for use in a particle accelerator.

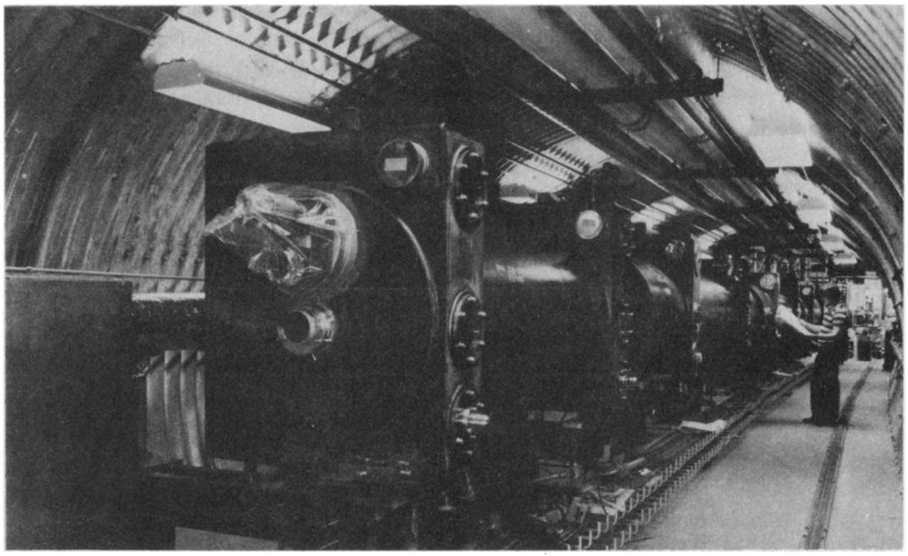
The need for a large-scale research program into the development of superconducting magnets was realized as far back as 1971. In that year, Bruce Cork of the Lawrence Berkeley Laboratory headed a HEPAP panel that recommended such a national effort. Most HEPAP members, who wanted funds to go to construction, opposed such a program, although DOE officials at the time lobbied on its behalf. A stalemate existed until July 1974. Following preliminary studies, a project known as the Experimental Superconducting Accelerator Ring (ESCAR) was funded that year at Lawrence Berkeley to explore magnet design. ESCAR was originally expected to take about $2^1/_2$ years. But the funds came more slowly than expected, partially due to pressure from the rest of the high energy physics community. They wanted funds for construction and were prepared to use threats and resignations to obtain them. In the fall of 1977, for instance, Wilson wrote to DOE Secretary James Schlesinger, saying he would not continue as director of Fermilab unless a project to double the accelerator's energy through the use of superconducting magnets was given $30 million. This, he said, was needed to meet competition from a new European accelerator. When in the spring of 1978 it became clear that Fermilab would not receive the full amount, Wilson quit, much to the alarm of those in Washington who considered him a master builder.

However, the pressure applied by Wilson helped to bring about considerable changes. In June 1978, with $7 million spent and the project only half completed, ESCAR was canceled, and that fall the construction funds rushed in, not only $15 million for Fermilab's superconducting doubler project, but money for the beginning of construction on Isabelle. In October 1978, just days after the start of the fiscal year, ground for Isabelle was broken.

At the time ESCAR was canceled, DOE and Lawrence Berkeley officials agreed the project was moving too slowly and that results would arrive too late to be useful in the full-scale superconducting projects then getting under way at Brookhaven and Fermilab. Hindsight has proved everyone wrong.

Another reason that ESCAR was abandoned was the apparent success at Brookhaven. Much of this centered on the Mark 5, a magnet that by virtue of the quirks of manufacture turned out to be superior. The first magnets of the Mark series were meant to reach a field strength of 4 teslas and were cooled with liquid helium. But with the fabrication of Mark 5 in December 1975, helium in a supercritical state was used to cool the magnet to temperatures below those obtainable with liquid helium, from 4.5 to 3.8 K. The results, as Sampson recalls, were "magnificent." By the spring of 1976, the Mark 5 was operating at a strength of 4.8 teslas, well above its design limits. "There was every indication that 5 teslas was not out of the ball park," says Sampson. Infused with technological enthusiasm, the design group during the summer of 1976 assembled a full-scale mock-up of a section of the proposed 200-GeV Isabelle project. The Mark 5 was included in this demonstration, which was arranged for the benefit of visiting DOE administrators and HEPAP dignitaries. With a bicentennial flourish, the magnets were painted red, white, and blue.

Duly impressed, HEPAP the next summer recommended that Isabelle be funded and that the machine's proposed power be increased to 400 GeV. This meant that the length of the 200-GeV prototype magnets would need to be increased a couple of feet and the bore slightly increased as well. Given the good results with Mark 5, such a program was deemed quite reasonable.



Brookhaven National Laboratory Photo

Mock-up of the Isabelle tunnel

The string of 1100 superconducting magnets is slated to extend more than 2 miles. A single magnet is a little less than 16 feet long and weighs about 7 tons.

One administrative indication that technical difficulties with the magnets were not expected was the choice of Isabelle's director. Sanford came to the Isabelle project from Fermilab, where he had been director of the experimental planning section. Says one Brookhaven physicist: "Jim's the first to admit that he doesn't know a great deal about magnets. At least he didn't when he first came."

In late 1978, still without a magnet having been made to the new specifications, administrators at Brookhaven contracted with a division of Westinghouse in Pittsburgh to wind the coils for the magnets, which would then be assembled on Long Island. In early 1979, the first magnets of the new design were assembled at Brookhaven and tested. They easily reached a field strength of 4 teslas, but that was about it. Further increases required heroic efforts at training. It also became clear that the new magnet design often resulted in damage to the coil when the magnet quenched. The Westinghouse contract was canceled after the production of 12 magnets.

That is about where the situation stands today. Magnet production has been suspended, and no new contract has been let. Civil construction continues. Research into magnet design proceeds at breakneck pace, the number of people in the magnet program at Brookhaven having been increased in the past 2 years almost fourfold, up to 130. Performance of the magnets is getting better, but they still are not suitable for use in the accelerator. In the laboratories and administrative offices there is a feeling of unbelief among the workers, as though they all have been the victims of a technological trick. Remarks one engineer: "George Vineyard [the director of Brookhaven] keeps plaintively saying, 'If Mark 5 did it, the others should.' " This summer, Mark 5 was pulled out of retirement and retested to see if it had all been a dream. It worked better than ever, and nobody is sure exactly why it is such an excellent magnet.

Though it probably comes too late, the problems at Brookhaven and Fermilab are starting to change old notions of how to plan for future accelerators. It is finally being realized that more across-the-board research into accelerator design is needed, probably at the expense of the U.S. construction program. In the first such report* written since the Cork report of 1971, a recent HEPAP panel, chaired by Maury Tigner of Cornell University, recommended that "we tax the short-range program for the sake of assuring the health of the field in the rather far future." Rather modestly, the report recommended that funds for long-range research be increased from the current $3 million a year to $8 million. DOE says it would like to take this advice to heart, but that magnet research has laid claim to all available funds. "Because of magnet difficulties," says Sutter, "all R & D funds are grandfathered for at least the next 4 years." U.S. dollars for accelera-

**Report of the Subpanel on Accelerator Research and Development of the High Energy Physics Advisory Panel* (DOE/ER-0067, National Technical Information Service, Springfield, Va., 1980).

tor R & D currently stand at an all-time high of $28 million, most of it going for short-range magnet research. For Brookhaven alone, an additional $5 million is slated for next year.

Outside supervision of the whole planning and funding process has recently been suggested in a report† by the Government Accounting Office (GAO) because, according to the report, without it "the physics community has emphasized construction while other key program elements such as long-range accelerator R & D, accelerator utilization, and experimental research support have suffered." GAO recommends that the President's Office of Science and Technology Policy take on this task.

In 1966, an observer said that the process whereby a federal agency asks groups of high energy physicists how to dispose of the public purse is like "asking a hungry cat to make recommendations about the disposition of some cream." In recent years, U.S. budgetary strictures have set a $300-million-a-year limit on the appetites of high energy physicists. Problems such as those with Isabelle point out the necessity of keeping a close watch not only on how much money is spent but also on how it is spent, lest the hungry cats spill what little cream is left. Whether the current difficulties will lead to reform in the long-range planning of and research for particle accelerators remains to be seen. As does the more immediate question of whether increased research for Isabelle this late will be able to extricate her from what appear to be intractable problems.—WILLIAM J. BROAD

†*Increasing Costs, Competition May Hinder U.S. Position of Leadership in High Energy Physics* (EMD-80-58, Government Printing Office, Washington, D.C., 1980)

Gene Goldrush Splits Harvard, Worries Brokers

Many Harvard faculty oppose a plan for the university to enter the gene splicing business; brokers see danger signals

"The whole matter violates the role of the university in our society so extensively and so terribly that I don't see how anything can come of it. The university would no longer be a nonprofit organization. It would mean that in everything we do, in our laboratories, in our scholarship, we are joining with the university to make a profit."

That is the reaction of one member of the Harvard faculty, biologist Woodland Hastings, to the proposal by Harvard president Derek Bok that the university should establish and hold part interest in a gene splicing company. Hastings' reaction seems to represent the majority view among the Harvard faculty, though maybe not among the administration. Ten of the 17 members of his subdepartment have subscribed to a letter he has written asking Bok to drop the plan, and others are making their own protests.

The Harvard faculty was invited by Bok last month to debate the general pros and cons of the university becoming directly involved in a gene splicing venture. What prompted the debate is a specific proposal from Harvard biologist Mark Ptashne that the university join him in setting up a gene splicing company. Bok has to make a decision by the end of the month, however, apparently before the debate can be concluded.

Universities already have numerous commercial involvements, ranging from investments to patents and licensing agreements, consulting and other business activity by faculty. What makes the Bok proposal apparently unique is that Harvard would be involved with members of its own faculty in a commercial enterprise.

The main outlines of discussion about the issue are clear enough. On the one hand, as the alluring example of Genentech makes clear, Harvard could hit the big time by taking an equity position in a gene splicing company operating under the Harvard coat of arms. On the other hand, ciritcs argue, such an involvement could compromise academic freedom, distort the direction of research, influence hiring and promotion, and discredit the impartiality of Harvard faculty when they speak out on matters of public interest.

Ironically, Ptashne's purpose in asking his university to be a partner was to avoid some of the disadvantages inherent in setting up a private company. Ptashne was not available for comment, but he is said to believe that Harvard's involvement might avoid the secrecy and other perils of commercialization, as well as giving the university a fairer share in the profits on inventions made in its laboratories. When faculty members form their own companies, as in the cases of Genentech and Biogen, their institutions gain little. A leading figure in Biogen is Ptashne's colleague and sometimes competitor, Walter Gilbert.

According to a discussion memorandum prepared by Harvard general counsel Daniel Steiner, the first advantage of such an arrangement is that the university would make money. Further, Harvard's participation would, in his view, help ensure that the faculty's attention was not diverted from their research and teaching duties, and prevent excessive secrecy.

Daniel Branton is one faculty member who thinks the proposal deserves a hearing. "I don't see why suitable rules cannot be worked out whereby the integrity of the university is maintained," he says. Others are more doubtful. "There are clear problems of conflict of interest in hiring. What do we do with a good but not outstanding professor who is making a lot of money for the university?" wonders Otto Solbrig, a member of the faculty council.

Solbrig also worries that a direct commercial involvement by Harvard would confuse its image in the public eye: "When we speak out for or against such things as nuclear power or air pollution we are listened to, in part, because people see us as members of an institution which is impartial. I think this technology [genetic engineering] will have good and bad impacts on society. If I speak about it, will people believe me? They will say, 'Universities are just like industry, they have an interest in it.' "

Another critic of the gene splicing company idea is historian of science Everett Mendelsohn. Creation of such a company would create an unprecedented kind of feedback into the university which "almost certainly would distort the direction of research," says Mendelsohn. He foresees problems of secrecy arising between faculty members com-