TWO SUPERCONDUCTING STORAGE RINGS - ISABELLE*

James R. Sanford†

At Brookhaven National Laboratory on Long Island the Department of Energy has under construction a high-energy, proton-proton colliding beam research facility called ISABELLE. Located in the northwest corner of the existing Brookhaven site (Fig. 1), two rings of magnets are contained within a common tunnel more than two miles in circumference. These two rings of magnets carry beams in opposite rotations, crisscrossing at six positions around the periphery. At these locations, head-on collisions occur between the proton beams, leading to center-of-mass energies up to 800 GeV. This paper summarizes the general features of the design and the status of the project at the present time. It brings up to date the results reported at the National Particle Accelerator Conference in March 1977. The most significant change since that time has been an upgrading of the energy of the overall facility, and acceptance of the project by the Department of Energy.

9-341-78

Fig. 1. Siting of ISABELLE

The major project highlights over the past two years are outlined in Fig. 2. Technical developments led to a reconfiguration of the machine for six intersection regions where full-scale high-energy physics experiments will be located. The money saved by this step, coupled with additional support, made it possible to raise the energy of the overall machine, compared to the 1976 design. Now it is proposed that each beam have an energy between 30 GeV and 400 GeV, therefore providing center-of-mass energies from 60 to 800 GeV. A proposal was prepared in 1977 reflecting the higher energy machine which was favorably received by the high-energy physics community and received the first priority recommendation at the Woods Hole Panel meeting of June 1977. This was followed shortly thereafter by the first Congressional action on the project -- bringing \$5 million in fiscal year 1978. The President recommended in January 1978 full authorization and requested \$23 million for the fiscal year 1979. Congress is currently considering these recommendations. Encouraged by the support of the Department of Energy and Congress, the project has been organized into five divisions with over 130 people assigned to the work at the present time. In parallel with this, the appropriate supporting documents such as the Environmental Impact Statement and

Management Plans have been prepared in cooperation with the Department of Energy. It is our expectation that with this work out of the way it will make it possible for ground to be broken for the project in October of this year.

9-572-78

ISABELLE HIGHLIGHTS OF PAST TWO YEARS

Reconfigured the Machine

8-4000, new injection scheme

Raised the Energy to 400 x 400 GeV

400 - 800 GeV in center-of-mass

Attracted Congressional and HEP Support

\$3 M in '78 and \$23 M in '79

Achieved DOE and Presidential Approval for FY 1979

Deposited full authorization and \$23 M in '79

Organized the Project, and Started Hiring

Five divisions and over 130 people

Tested Components, and Sub-systems

Magnets, cryogenics, half-cell

Reestimated Costs and Schedules

We can do the job for \$275 M

Started Detailed Design

Conventional construction with tunnel & library

Copied with the Bureaucracy

Environmental Impact Statement(s)

Management Plan

Management System

etc.

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor any of its employees, nor any of their contractors, subcontractors, or their employees, by legal warranty, or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that it would not infringe privately owned rights.

Fig. 2. Project highlights in the last two years.

Figure 3 shows the arrangement of the ISABELLE ring with respect to the AGS. The AGS, an existing 30 GeV proton accelerator, is routinely used for high-energy physics research. It provides more than 10^{13} protons per pulse every two seconds for use in the North and East Experimental Areas. It's fortunate that the AGS exists to be used as an injector for the machine. It is a reliable accelerator with a capable staff familiar with its idiosyncracies. For ISABELLE, it is proposed that a branch of the beam from the North Area be developed and the protons bent either to the right for the counter-clockwise rotation of beam, or to the left for the clockwise rotation of beam. The six intersection regions and experimental areas are indicated by the clock face designations, 2, 4, 6, 8, 10, and 12. Each of these areas is being developed with somewhat different characteristics in order to emphasize various experimental possibilities.

9-340-78

Fig. 3. ISABELLE layout with AGS in foreground.

The one that is currently under detailed design is the 6 o'clock area containing the so-called Wide-angle Hall. Because this region is near the injection and ejection segment of the main ring, it's appropriate to use this intersection region for the study of reaction phenomena

Manuscript received September 26, 1978

*Work performed under the auspices of the U.S. Department of Energy.

†Brookhaven National Laboratory, Upton, NY 11973

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

at very large transverse momentum to the colliding beams. At 4 o'clock an undeveloped experimental area will be built, one that can be completed when the first research results indicate the most profitable areas of emphasis. Between these halls is a service building containing the central refrigerator, power supplies for energizing the superconducting magnets, and power supplies for the rf system. In an attached building spanning the ring will be the control room and offices for the project. During the final construction and initial operation of the machine, this will be a very active region. There will be another undeveloped experimental area at 12 o'clock, and three more completely constructed. This brings the total to six.

The major features of ISABELLE that are important to take note of in an overall survey talk like this are indicated in Fig. 4. The beam is ejected from the AGS at 30 GeV, and several hundred pulses are used to fill up each of the two ISABELLE rings. This high intensity leads to a luminosity of 10^{32} to $10^{33}/\text{cm}^2/\text{sec}$, depending upon the mode of tuning. There are approximately 500 superconducting magnets in each ring. It's required that the dipoles operate at 50 kG in magnetic field intensity to produce a beam corresponding to 400 GeV. In order to operate these magnets at the peak performance, a single large cryogenic system providing 20,000 watts of coolant at 3.8 K, is located in the Service Building area. Elements of that cryogenic system are currently under design and will represent one of the largest such systems ever constructed. Each ring must have a central beam pipe with an exceptionally low vacuum. This is to reduce the loss of circulating beam and provide long beam lifetimes. Vacuum lower than 10^{-11} Torr have been achieved in the laboratory, and we expect to have a large scale system in operation early next year repeating that performance.

MAJOR FEATURES OF ISABELLE

TWO INTERLACED ACCELERATOR/STORAGE RINGS
Circumference = 3.8 km

INJECTION FROM THE AGS AT 30 GeV
 $\sim 10^{12}$ p/p for ~ 100 pulses

HIGH INTENSITY OF PROTONS - LUMINOSITY
8 amps - 1 of 10^{32} - $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$

HIGH CENTER OF MASS ENERGY
80 - 400 GeV

732 SUPERCONDUCTING DIPOLE MAGNETS
50 kG

352 SUPERCONDUCTING QUADRUPOLE MAGNETS
8.1 kG/cm

LARGE SCALE CRYOGENIC SYSTEM
20,000 watts at 3.8°K

DEMANDING SYSTEM PERFORMANCE
Vacuum $\sim 3 \times 10^{-11}$ Torr, Current Regulation $\sim 10^{-4}$

FLEXIBLE INTERACTION REGIONS
 ~ 0.5 m with 80 m of free space

SIX EXPERIMENTAL AREAS
four enclosed, two open

MODEST SITE DEVELOPMENT
adjacent to site services

Fig. 4. Major features of ISABELLE.

A cross section indicating magnets from the two rings within the tunnel is shown in Fig. 5. Here we see the superconducting magnets with the beam pipes 1.27 m above the floor. They are located side by side on a common stand, with the cryogenic supply and return gas headers in the ceiling. Each dipole vessel is 5 m long and about 60 cm in diameter. The magnetic field is created by NbTi superconducting wire woven into a braid. The braid is formed into two coils surrounding the

correction windings and beam pipe in a cosine theta distribution. The long coils are inserted into the iron that comprises the magnet circuit. The iron provides a restraining medium for the coils during operation. The iron is in turn supported within the vacuum dewar with appropriate layers of superconducting insulation surrounding the magnet. Full size units of these magnets have been assembled and tested. Figure 6 shows such an array, called the Half-Cell. Here two dipoles and a quadrupole were connected in series, both cryogenically and electrically, and pulsed repeatedly to over 40 kG. In the distance the cryogenic heat exchanger can be visualized. This is where the stream of helium gas is chilled by a bath of subcooled liquid helium. The magnets are in turn cooled by the subcooled supercritical helium gas. By this time more than 15 full-sized ISABELLE magnets will have been constructed. A snapshot of the present magnet situation can be visualized in Fig. 7.

3-653-78

Fig. 5. Sketch of magnets in the tunnel.

5-1413-77

Fig. 6. Photograph of Half-Cell.

9-574-78

MAGNET SITUATION

UNITS II & V	48 - 49 kG
UNITS VI & VII	40 - 41 kG
UNITS VIII - XI	"CONSTRUCTED"
UNIT IX	45 kG
UNIT XIV	BEING TESTED

GOOD RESETTING OF MAGNETIC FIELD AFTER QUENCH - 1 PART IN 10^5

CAREFUL MAGNETIC FIELD MEASUREMENTS ARE UNDER WAY

EXCELLENT CRYOGENIC PERFORMANCE ~ 4 W AT 4 K

Fig. 7. Magnet situation.

Early units operated exceedingly well and produced fields of nearly 50 kG under somewhat adverse conditions. Attempts to speed up the production process for magnets led to a setback in peak field performance. It appeared that too many short cuts were taken in the coil assembly and support of the superconducting braid. Because of this, lower fields were realized for several months. That tendency has been reversed, and recent data collected on magnet MK-IX has recovered the field capabilities that were earlier realized. All of these magnets exceeded the design value of 40 kG that was set for this series of magnets. The first of the magnets prepared for 50 kG performance is unit XIV, which is now being tested. Even here not all of the design changes have been incorporated in the magnets that will be used in the full cell, but we are closer to the final configuration. At present, orders have been placed with Westinghouse for the fabrication of 8 magnets in the Full-Cell using material provided by Airco, MCA, and IGC. These companies are providing braid made from 12 mil niobium-titanium wire. Each wire contains 500 filaments in a copper matrix. Approximately 100 such wires are woven into a braid which is 650 mil wide and 30 mil thick. This braid, produced in lengths of over one-half mile are used for the production of a full half coil. Two such coils are used in each magnet. Returning to the magnetic field results, unit IX had a uniform magnetic field with acceptable characteristics. These data will be reported on during the present conference. It was also gratifying to find that the magnet performance, as measured by the transfer function, was very close to the calculated value (12.46 G/A). Such agreement seems to be no small miracle in this business. Another aspect was the reproducibility of the magnetic field. In quench after quench, it was possible to return to the same field to about one part in 10^5 , considerably better than needed in routine operation of the machine. Currently, thorough magnetic field measurements are underway on units VI, IX, and XIV, and detailed results are reported elsewhere in this conference. Another gratifying feature of the present work was the greatly improved cryogenic performance demonstrated in MK-VI. This magnet cooled down quite rapidly, and heat input the low temperature coil and iron was about 4 watts at 4 K. This corresponds exactly with what had been calculated and is well within the design capabilities of the refrigerator. The secondary load, that is to say, the heat intercepted at the shield operating at 50 K is also within the design tolerance.

There are a number of other development activities underway in association with ISABELLE. Some of these are outlined in Fig. 8. The main objective of the cryogenics program has been to get the reduction of the heat losses as mentioned earlier. This has made it possible for the magnets that have been developed so far to be operated on the existing small capacity refrigerators. There are two additional refrigerator projects underway. One is a unit built by CVI that is on loan to the Laboratory. This refrigerator has recently been tested and provides 250 liters/h of liquid helium. It will be used to produce liquid for the production and testing of ISABELLE magnets and is called the PAT refrigerator. Another unit has been designed by Cryogenic Consultants, Inc. and the Brookhaven staff to be used for the forced flow cooling of magnets, such as the string of magnets for the Full-cell. This refrigerator uses screw compressors in the multiple stages. The final expansion steps to produce liquid uses gas bearing turboexpanders manufactured by L'Air Liquide in Europe. The refrigerators will provide 120 watts as well as 2.2 g/sec. Emphasis will be placed on studying the reliability of operation of both of these large refrigeration units.

ISABELLE DEVELOPMENT PROGRAM

SUPERCONDUCTING MAGNETS
 RAD UNITS
 FULL-CELL ISA UNITS
 OTHER DEVELOPMENTS
 REFRIGERATOR
 CRYOGENICS
 VACUUM SYSTEM
 POWER SUPPLIES
 INSTRUMENTATION
 CONTROL SYSTEMS
 RADIO-FREQUENCY SYSTEMS
 INJECTION/EJECTION SYSTEM
 EXPERIMENTAL UTILIZATION
 DETECTOR RAD
 COMPUTING
 APPARATUS DEVELOPMENT

Fig. 8. ISABELLE development program.

Although not listed on this slide, a considerable amount of effort has gone into the developing of plans for the production of the ISABELLE magnets. The objective is to have the subcomponents manufactured in industry and assembled at Brookhaven. In this way it is expected that the necessary quality control can be exercised during the assembly and testing of the units. Other ISABELLE activities concern the development of sophisticated detectors to be used in the experimental apparatus. This will lead in time to the specification and design of large detector arrays. These arrays will undoubtedly be used in conjunction with superconducting magnets for momentum resolution of charged particles produced from the high energy collisions. It's expected that at future meetings one will be able to talk about the design of the complicated magnets to be used in the experimental regions.

Returning to the design of the accelerator itself, Fig. 9 illustrates the way that the dipoles and quadrupoles are arrayed in a segment of the main ring. Each

7-892-78

Fig. 9. Sextant layout.

sextant contains nine cells of magnets where a cell contains six bending magnets and two quadrupoles. As the array approaches an intersection region, the cell structure gets modified in such a way as to bring the beams into collision at the center of the experimental hall.

To accomplish this a matching section is provided where the quadrupoles are adjusted to provide accurate beam properties at the collision point. This drawing also helps to illustrate the approximate size of an experimental hall. Shown here is one that might be used for a very large detector. It is roughly 60 meters long, and 16 meters wide by 16 meters high. Within this space the experimental apparatus will be constructed to be used for the study of the particle collisions. An artist's concept of this experimental hall is shown in Fig. 10. Here the beams are shown entering from the left and going into the center of a large detector. The detector is housed within the earth and concrete shielded bunker. During routine operation, none of the experimenters are located within the building, but are in a utility building outside the shielded experimental hall. The entire region is serviced by a 40-ton traveling crane which will allow the detector to be taken apart in a modular manner. This illustrates one of the four such experimental halls around the ring. Two others, as mentioned earlier, will be incomplete and temporarily shielded using existing concrete blocks.

Fig. 10. Architect's rendering of experimental area.

The project staff prepared the current proposal late last year. Subsequent to that and following the presentation of the President's budget for fiscal 1979, we were informed that a seven-year construction period is foreseen for the project, rather than a five as proposed by Brookhaven. This required a reestimation of the overall cost of the project, including appropriate allowances for escalation and contingency. Figure 11 shows the results of this April cost analysis. In storage rings the largest part of the cost is associated with the accelerator components. About half

ISABELLE Cost Estimate (April, 1979) (480 x 480 GeV) (in thousands of dollars)		
Accelerator Components		128,570
Ring Magnets and Power Supplies	72,740	
Refrigeration System	19,860	
Control System	7,810	
Vacuum System	9,570	
Injection System	6,940	
RF System	6,920	
Other Items	5,730	
Conventional Construction		51,430
Beam Enclosures	12,450	
Experimental Areas	8,800	
Service Buildings	4,100	
Site and Utilities	6,330	
Architect/Engineer		4,730
ERIA	27,170	
	Subtotal	191,520
Contingency		36,000
Escalation		46,250
	Total	273,770

Fig. 11. Cost summary.

of the cost of ISABELLE is in those elements, of which the superconducting magnets and refrigeration system dominate the expenditures. The conventional construction is less formidable because it is localized at the six experimental regions and does not require future

growth such as is associated with a fixed target accelerator. The cost of the project is about \$191 million with additional allowances for contingency and escalation, bringing the bottom line number to \$275 million over the seven-year time span. Key elements in that time span are indicated on the time line (Fig. 12) developed for ISABELLE. Assuming that project authorization comes in a few weeks, that is to say near the beginning of fiscal year 1979, we will expect to have the magnet factory operational about a year later. The conventional construction will move ahead, so that a place exists to begin installing magnets shortly thereafter. The conventional construction will be complete in fiscal year 1983, just about the time when we reach the mid point of magnet production. Beam installation will keep on going, concluding in fiscal year 1985, after which we will start beam injection and collision of the circulating beams. We are eagerly looking for ways to speeding up this schedule, and if the available money can be augmented in fiscal year 1980 and 1981, we would expect to shorten the construction period correspondingly.

TIMELINE FOR ISABELLE

9-569-78

Fig. 12. Timeline for ISABELLE.

In conclusion I would like to summarize some of the history of the project and what we are now doing in detail. As seen in Fig. 13, there have a series of workshops studying the aspects of the accelerator and experimental use in some detail. Several proposals have

HISTORY OF THE PROJECT, CURRENT STATUS, FUTURE PLANS

9-573-78

SUMMER STUDIES OR WORKSHOPS SINCE 1975

THIS NUMBER: JULY 17 TO 18

PROPOSALS PREPARED IN 1975, 1976, 1977 AND 1978

LAST PUBLISHED IN JANUARY 1979

DOE PROVIDED FUNDS FOR ACCELERATOR R&D AND CP&D

JANUARY 85 MILLION/YEAR, AND TWO ALLOCATIONS FOR \$1.7 MILLION

WE ARE SEEKING FULL DOE AND CONGRESSIONAL SUPPORT

AUTHORIZATION IN FY '79, \$5 MILLION IN FY '78, AND \$25 MILLION IN FY '79

BROOKHAVEN IS READY TO INITIATE CONSTRUCTION IN FY 1979

\$275 MILLION AND 7 YEARS TO COMPLETION

IN THE MEANTIME, THE FOLLOWING ACTIVITIES ARE UNDERWAY:

- CONTINUE TO REEVALUATE PEOPLE
- DO DETAILED DESIGN OF FACILITY
- PREPARE THE ACE AS AN EXHIBITOR
- PREPARE PROTOTYPE TESTS, AND PLAN FOR PRODUCTION
- DEVELOP EXHIBIT, AND LET CONTRACTS
- HAVE JOURNAL IMAGING IN OCTOBER

Fig. 13. Current status and future plans.

been prepared, the last one a few months ago. The Department of Energy has provided construction planning and design funds for this work, and Congress authorized \$5 million in fiscal year 1978. We are expecting \$23 million in fiscal year 1979, the first year that sees authorization for us to proceed with the project. We are hiring many people for the project, many of whom are now involved in the detailed design, later in the production and installation of components. Our colleagues in the AGS are preparing that machine as an injector and helping to determine how the two injection lines must be built for bringing the beam to ISABELLE. Meanwhile the prototype magnets are being perfected and plans made for the production. Contracts are now being let with industry for coil fabrication, vacuum vessels, instrumentation, etc., and we expect to have the pipe line filled up in the next six months. An exciting event will take place for us next month when we expect to break ground for the start of construction of the machine. From then on we'll work very actively to achieve the high energy objectives for the accelerator shown on Fig. 14. Here we hope to take the jump of more than a factor of 10 in available center-of-mass energy over the only existing proton storage ring, the ISR at CERN. All of us on the staff of ISABELLE are looking forward to doing physics research with this new facility in the mid 1980's.

Fig. 14. Energy step.