of his time is spent organizing conferences—two he has handled are the First International Congress on Aerospace Medicine, held in Amsterdam in 1970, and the United Nations Second World Food Congress held last year in The Hague—but he is not planning another at present.

The International Conference on Drug Education proved a bad trip for Claudius Chorus, Arthur Tongue, the NCCDE, and the participants. But each knew at least in part what risks he was taking. The innocent victim was the U.S. taxpayer, who in one form or another paid for or subsidized many of the conferees. The sum contributed to the Swiss balance of payments was not enormous—on the order of $36,000, assuming that the U.S. Treasury was the ultimate source of half the estimated $600 in conference expenses incurred by each of the 120 American participants. But even a glance at the "travel program" issued for the conference would perhaps have suggested the existence of more direct ways of contributing to the advance of knowledge.

—NICHOLAS WADE

RESEARCH NEWS

The Big Accelerators: A Progress Report

1) New Optimism at NAL: Problems Continue, but Research Is Under Way

In contrast to the dissatisfaction and bitterness of a year ago, there is an upbeat mood among physicists working with the world's largest accelerator at the National Accelerator Laboratory (NAL), near Batavia, Illinois, now that experiments are well under way and beginning to produce results. The accelerator itself has operated at energies up to 400 billion electron volts (Gev), a fivefold increase over earlier machines of the same type. While no startling new results have emerged from the first round of experiments, a number of important measurements have been made and more are expected in the coming year. Officials of NAL believe that the worst of a frustrating series of delays, equipment failures, and management problems are behind them. Nonetheless the facility is still far from complete. The accelerator does not yet operate at its full intended power, none of the three major experimental areas is complete, and a logjam of approved but not yet done experiments is causing problems for university physicists and other users of NAL.

Operation of the accelerator was delayed nearly a year until spring 1972 by magnet failures attributable to cracks in their insulation and, according to some physicists, to an inadequate amount of insulation. Magnets are still breaking down at the rate of about one a week, although use of a new insulating material, mica and resin instead of the earlier epoxy, seems to be gradually eliminating the problem; nearly half of the 1000 magnets in the accelerator's main ring have been replaced, some more than once. There have been difficulties with accelerating cavities, power supplies, and the equipment for extracting the beam of protons from the accelerator. In the first 10 months of 1973, unscheduled repairs closed down the accelerator for a total of 2514 hours, a period slightly longer than the operating time available for research. The accelerator, in short, has simply not worked very well in its initial year of operation.

The philosophy followed by NAL director Robert Wilson in building the accelerator included cutting corners whenever possible and generally following a tight design. This approach is given credit for getting the accelerator built quickly and within a stringent budget, and some difficulties in bringing such a complicated machine into service were expected. But some physicists now question whether a more conservative approach—such as that being followed in the construction of the new accelerator at the European Organization for Nuclear Research (CERN) (see accompanying article)—would really have required any more time or money. The problems at NAL appear to have been aggravated by what in retrospect were unrealistic promises about the performance of the accelerator. Plans to bring three major experimental areas into operation simultaneously have been hampered by the concentration of manpower on fixing the accelerator. Experimental physicists who hurried to prepare experiments for NAL have found themselves facing delays of 2 to 3 years, often at some cost to the individuals and institutions involved. Those who did set up the first round of experiments reported complaints ranging from irregular and often inadequate beam to a lack of technical support facilities and a shortage of housing. It has been, as one physicist put it, "not fun to do an experiment at NAL."

To their credit, the NAL management have been responsive to these complaints, according to experimenters contacted by *Science*, and conditions are improving. The reliability of the accelerator is reaching the point where it can be turned off and on without necessitating major adjustments. The average intensity has reached 5×10^{12} protons per pulse (5×10^{13} is ultimately hoped for), the beam is now being extracted from the accelerator with an efficiency of about 95 percent (99 percent efficiency will be needed to avoid radiation problems at the higher intensity), and a uniform pulse nearly 0.75 second in length is being delivered to experimental areas (a 1.0-second pulse is eventually promised). Directors have been appointed for each experimental area to facilitate the research efforts.

The experimental facility furthest along is the neutrino area, now nearly 90 percent complete. It includes a high energy neutrino beam and a muon beam. A variety of counters, spark chambers, and other electronic equipment has been used to detect particles from these beams and study their reactions. Also located in the neutrino area is a small bubble chamber 30 inches (76 cm) in diameter used to study strongly interacting particles. Nearly ready is a large bubble chamber that will be one of the major pieces of permanent experimental equipment at NAL (Fig. 1). The chamber, 15 feet (4.5 m) in diameter, is comparable to the Big European Bubble Chamber at CERN, but will have the capability of serving two different experiments simultaneously. Although the chamber will be primarily used for neutrino studies, experiments with mesons and other strongly interacting particles are planned as well. The bubble chamber is to be augmented by the addition of a muon detector nearby. Initially, hydrogen will be the target material in the chamber, but neon may be substituted to give a denser target if the intensity of the accelerator does not reach its intended level in the near future.

A second experimental facility at NAL is the meson area. This facility is restricted to experiments involving particles of energies no higher than 300 Gev. Protons from the accelerator are directed against targets to produce a variety of secondary beams for experimental use. Three beams of charged particles—protons and pions—and a neutron beam are now available. Among the experimental equipment being prepared for use with these beams is a large spectrometer.

The third and least developed experimental facility at NAL is the proton area. Here high energy protons from the accelerator are being used directly in two experiments. A photon beam is also under construction. No large detectors or other major experimental equipment have yet been planned for the facility.

In addition to the three external experimental areas, experiments are conducted at a station within the main ring of the accelerator. This internal target area has the advantage of permitting lengthy exposures to the proton beam, but the disadvantages that everything must be handled remotely and that repairs or adjustments to equipment can only be made when the accelerator is turned off.

Despite the problems with the accelerator and the incomplete state of development of the experimental areas, data are being taken in more than a dozen experiments and a number of results have been published. Some of the results are disappointing to physicists who hoped that NAL would dramatically clear up some of high energy physics' outstanding puzzles. Efforts to establish the physical existence of two useful theoretical constructs, the quark and the magnetic monopole, were unsuccessful; preliminary searches at the new range of energies available at NAL gave no evidence of either hypothetical particle. Another search—for the intermediate vector meson, a particle postulated as a go-between in interactions involving the weak nuclear force—is still under way.

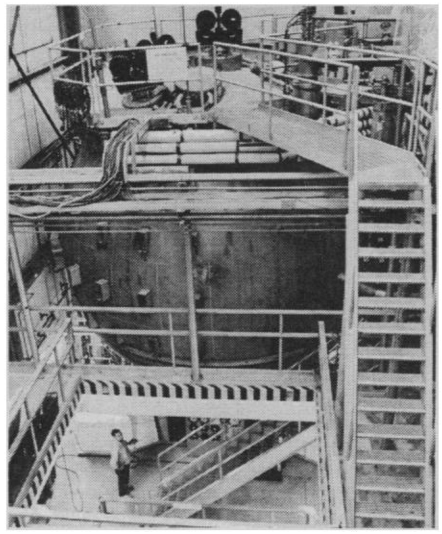

Fig. 1. The large bubble chamber at NAL. A huge piston keeps liquid hydrogen in the chamber under pressure. During experiments, the piston expands the liquid rapidly to create bubbles in the fluid and make visible the paths of high energy particles passing through the chamber. This facility and a similar chamber at CERN contain the largest superconducting magnets ever built. The magnetic field diverts charged particles within the chamber to allow measurement of their momentum. [Source: National Accelerator Laboratory]

If exotic particle hunts proved unsuccessful, more prosaic efforts had better luck. Experiments with the small bubble chamber in the neutrino area gave useful if not definitive measures of the strong nuclear force at high energies. The preliminary survey of reaction probabilities for protons at 100, 200, 300, and 400 Gev begins to fill in the gap between previous measurements up to 76 Gev (in the U.S.S.R.) and the recent measurement at 2000 Gev with the intersecting storage rings (ISR) at CERN. A related experiment was conducted in the internal target area by a joint U.S.–U.S.S.R. team. Their measurements of proton-proton elastic scattering imply that the reaction probability of protons continues to increase at higher energies, a finding consistent with the ISR result. More detailed measurements of reaction probabilities and their extension to particles other than protons are expected in the next year.

Studies of the weak nuclear force have also been begun at NAL—primarily neutrino experiments. The first results announced included a tentative confirmation of the CERN discovery of neutral current reactions with neutrinos. More elaborate studies of this phenomenon are in progress. Among the first experiments in the large bubble chamber will be measurements of neutrino reaction probabilities at high energies.

Many of the experiments of the past year and many of those now in progress at NAL are exploratory in nature. In the absence of any striking new discoveries, however, more quantitative measurements of a variety of phenomena are planned. Much work to complete the experimental areas and to improve the quality of the particle beams delivered to them also remains to be done. Operation at 400 Gev is by no means routine yet; the utility that supplies electricity to NAL is concerned about voltage fluctuations on its power lines at that energy, and NAL plans to install larger transformer and capacitor banks to control the fluctuations. There appears to be a good chance that the accelerator can eventually operate at energies as high as 450 Gev.

More ambitious plans for NAL's future also exist. It is characteristic of Wilson's style that, even in the face of difficulties in bringing the accelerator into service as a useful experimental tool, he has a group working on means to more than double the energy of the machine. The key to this would be a ring of superconducting magnets, installed in the same tunnel as the existing accelerator. The "energy doubler," as presently conceived, would take protons from the existing machine and accelerate them to energies as high as 1000 Gev. Reliable superconducting magnets have yet to be developed, a fact that was the basis for eliminating them from the design for the CERN accelerator. But optimism has prevailed and prototype superconducting magnets are under construction. And with the first round of experiments nearing completion and new ones starting up, even the experimenters appear to agree that physics at NAL is at long last in high gear.—ALLEN L. HAMMOND

2) Construction at CERN: Superconducting Concept Discarded

Geneva. The decision nearly 3 years ago to build a huge proton accelerator here adjacent to the existing facilities of the European Organization for Nuclear Research (CERN) resolved an impasse that had threatened to block the project altogether. The Geneva site not only proved a politically acceptable compromise between competing locations in the major European countries, especially Germany and France, but also won favor with government budget makers with a promise of substantially lower costs. European high energy physicists were pleased with the choice, because it offered the prospect of an earlier start on research than would have been possible if a completely separate laboratory had to be built. Now, 10 years after the project was first proposed, construction of the accelerator that is to guarantee the future vitality of European high energy physics and of CERN itself is at last well under way. And while it will come into operation well after the comparable U.S. machine already in use at the National Accelerator Laboratory (NAL) near Batavia, Illinois, the European effort may profit from NAL's experience.

Two recent decisions—that the accelerator will use conventional rather than superconducting magnets, and that it will nonetheless have the capability of producing protons with energies of 400 billion electron volts (Gev) right from the beginning—have resolved the last major questions about the design of the European facility. Originally only half of a full complement of conventional magnets was ordered, and these were to have been distributed around the 6.9-kilometer circumference of the accelerator according to a "missing magnet" design that left open the possibility of incorporating superconducting magnets at a later date. But anticipated difficulties with the reproducibility and reliability of pulsed superconducting magnets and the certainty of high costs and long delays in obtaining such magnets commercially led to the abandonment of the plan. Conventional magnets, on the other hand, have turned out to be inexpensive enough for a full set to be purchased within the budget agreed on for the machine.

Some physicists at CERN believe that in forgoing superconducting magnets Europe missed a chance to develop an important new technology. "It was a conservative decision, like all decisions at CERN," one researcher put it. Most of those contacted by *Science*, however, agree with the view that conventional magnets were the only real choice. But the conservative style of CERN as a whole and what some physicists see as a tendency to build overelaborate machines are criticisms frequently voiced by those concerned with pursuing as vigorous a research program as possible. The high salaries, relative to what many CERN scientists could earn in their home countries, and the pleasant ambience of work here have led to an extremely low turnover in staff, with the result that stagnation is beginning to be a problem. The new accelerator itself—unlike the NAL machine—does not represent a significant advance in accelerator technology, but its designers hope thereby to avoid the equipment problems that have plagued their American colleagues. With construction of the accelerator moving ahead and planning for experimental areas actively in progress, there is an air of enthusiasm at CERN.

Construction is proceeding rapidly

Fig. 1. Aerial view of the Rhone valley near Geneva, Switzerland, looking south into France. The heavily developed triangle of land in the center of the photo is the site of Laboratory I at CERN, including the 28-Gev proton synchrotron, the intersecting storage rings, and associated experimental areas. The dashed lines indicate the location of the new 400-Gev accelerator now under construction. Protons will be initially accelerated to 10 Gev in the small synchrotron, injected into the larger machine where they will move in a clockwise direction around the ring, and then directed either toward the west experimental area (at the tip of the triangle in Laboratory I) or toward the north experimental area at the bottom of the picture. The location of the buildings that will house Laboratory II are also indicated near the north experimental area. The French-Swiss border runs diagonally across the main ring of the accelerator. The international character of the site is further emphasized by the arrangements for utilities: cooling water for the facility will be piped from Lake Leman in Switzerland, and electric power will come from the French power grid. [Source: European Organization for Nuclear Research]

on a site that lies across the French-Swiss border (Fig. 1). That the accelerator could be built at all in this growing suburban area is due to an accident of political geography—the French customs station was located in a small nearby village and not on the border itself, leaving an undeveloped no-man's-land that is the present site. The slope of the land, a lack of stability in the surface soils, and a desire to preserve the site (much of it productive farmland) as unspoiled as possible dictated that the accelerator be housed in a relatively deep tunnel—50 meters below the surface at some points. The tunnel, now nearing the halfway mark, is being dug by an American-made boring machine that is guided by laser beams along a precomputed geodesic path at a speed of about 20 m per day. Digging is expected to be completed by September 1974, with construction of the accelerator itself scheduled to be completed in late 1975. Considering the size of the project, it is an ambitious schedule.

If no problems arise, experiments could begin in 1976. Indeed, because of the presence of experimental equipment originally built for use with the existing 28-Gev proton synchrotron at CERN, rather more sophisticated experiments will be possible than usually are with new accelerators. Two experimental areas are foreseen.

The west area will contain both neutrino experiments and experiments with hadronic (strongly interacting) particles. Two types of hadron beams will be available: those produced by allowing protons to collide with a target and then separating the resulting secondary particles into beams of kaons, pions, or antiprotons with radio-frequency electromagnetic fields (called RF-separated beams); and the initial proton beams themselves, which can be used to generate still other secondary beams within the experimental area. The RF-separated beams of the energies anticipated are unique to CERN and will allow great specificity for certain kinds of investigations. Because of radiation problems and the limited amount of shielding available in the small experimental area, it is expected that hadron beams in the west area will be limited to energies of 200 Gev or less.

The radiation problems arising from a weakly interacting neutrino beam are less severe. Because of the great interest in neutrino investigations (*Science*, 26 October 1973, p. 372), the full 400 Gev of the machine will be used in producing a neutrino beam. The higher energy will necessitate a more powerful system for extracting protons from the accelerator to the west area than that needed for the hadron beams alone, as well as a considerable quantity of expensive iron shielding (instead of earth) to stop particles other than neutrinos in the short distance between the target where neutrinos are produced and the experimental area. The iron shielding is expected, however, to yield as a benefit a more intensive neutrino beam than would otherwise be possible (four times the intensity of the NAL neutrino beam).

Sophisticated Experimental Equipment

A wide variety of particle detectors, already in operation at CERN, will also be available for use with the new accelerator. The west area will have, among other equipment, the Big European Bubble Chamber (BEBC), the large Omega detector, several smaller detectors, and possibly a second bubble chamber known as Gargamelle. The BEBC detector measures about 3.7 m across and is comparable to a similar bubble chamber being completed at NAL. It will be augmented by a muon detector and several electronic sensors and will be used both for neutrino studies and for experiments with the RF-separated meson beams. Gargamelle is a smaller heavy liquid chamber not presently located in the west area, but—thanks to a large and vocal group of Gargamelle proponents—there is considerable discussion of moving it into the path of the neutrino beam behind BEBC.

Neutrino experiments for the new accelerator have so far received the most thought, and planning for them is furthest along, but several hadron experiments with electronic counters are also expected to be included in the first round of experiments. One fixed installation of this type will be the Omega detector, which includes a large superconducting magnet, and Cerenkov counters and an array of spark chambers and acts like a spectrometer—essentially the electronic equivalent of a bubble chamber.

The north experimental area will not be completed until 1978, and consequently its detailed design is yet to come. The master plan for the area envisions that it will make use of the full energy of which the accelerator is capable. No bubble chambers or neutrino experiments are to be included in this area, however. Present plans are that four secondary beams would be provided to a close-in zone devoted largely to hadron experiments, and that a high energy muon beam as well as a proton beam would be channeled to a second and more distant experimental zone.

Overall, the new accelerator shapes up as an impressive research tool. Its intended peak energy, 400 Gev, and intensity, 10^{13} protons per pulse, are comparable to those achieved at NAL. Indeed, if CERN lives up to its reputation of building machines capable of reaching design specifications in daily operation, the new accelerator will prove superior to that at NAL in some respects—perhaps not surprisingly, since NAL was the pioneering facility. But the CERN facility will also come into operation 4 to 5 years after NAL—nearly half the "interesting" lifetime of most high energy physics installations —which raises the question of whether there will be significant investigations left for it to pursue.

It seems likely that if there are dramatic new phenomena such as quarks or magnetic monopoles to be discovered in the energy range accessible with these huge accelerators, they will be found at NAL. But if physics in the 400-Gev range turns out to require the unraveling of countless details and the careful spectroscopy that characterized investigations at lower energies, then CERN will be in a good position to make important contributions. In either case, experiments of a different character than those now being conducted at NAL—second-generation experiments rather than exploratory studies—will probably be the main task for the CERN accelerator.

In studying particle physics in the 30-Gev range, physicists found it valuable to have two different laboratories pursuing the same questions, and much the same justification is given for the present generation of large accelerators. Certainly the two laboratories reflect different philosophies—the pioneering if risk-laden approach at NAL and the conservative but thorough one at CERN. This diversity will undoubtedly stand high energy physics in good stead in years to come.—ALLEN L. HAMMOND