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EARLY HISTORY OF THE 200-GeV ACCELERATOR

M. Stanley Livingston

June 18, 1968

Operated by Universities Research Association Inc. Under Contract with the United States Atomic Energy Commission

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Associate Director

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ORIGINS

The conceptual planning for an accelerator in the hundred-Gev energy range became possible with the discovery of the principle of alternating-gradient focusing[1] in 1952, which led to the design and construction of the 28-GeV "CPS" at CERN and the 33-GeV "AGS" at Brookhaven National Laboratory (BNL). Although these two accelerators represented the practical first steps toward exploiting the new principle, speculative thinking which was aimed at much higher energies started as early as 1952 in Brookhaven and included several other laboratories in the following years. At the University of California Radiation Laboratory in Berkeley, the design staff had been thinking for years about the next step beyond the 6-GeV bevatron. An early feasibility study of AG synchrotrons in the 100- to 150-GeV range was reported by Brobeck[2] in 1955. In 1956 a local "Accelerator-Building Committee" was formed consisting of E. M. McMillan, E. J. Lofgren, R. L. Thornton, W. M. Brobeck, L. Smith and D. L. Judd, which

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*This work was done under auspices of the U. S. Atomic Energy Commission.

coordinated the studies during the next five years. Activities during this period were summarized by Judd[3] in a report in 1960, including references to 47 Internal Memos and Engineering Notes.

This early planning was brought to wider attention in 1959 at a summer study of the Midwest Universities Research Association (MURA) group at Madison, Wisconsin, where questions were first raised and discussed publicly concerning the scientific need and feasibility of an accelerator for several-hundred-GeV energy. A memorandum on the concept was circulated that fall by Professor Matthew Sands,[4] then at California Institute of Technology (Caltech). It described a possible 300-GeV "Cascade Synchrotron" utilizing alternating-gradient focusing in the main ring, and using a smaller synchrotron as an injector. Sands stated later that he first heard of this concept from R. R. Wilson of Cornell University, now Director of the National Accelerator Laboratory. This discussion came at a time when the CPS at CERN was just being brought into operation and the AGS at Brookhaven was a year from completion. The concept of a much higher energy machine was exciting to scientists and stimulating to accelerator designers.

Many of those involved in the design planning recognized that such a large and costly accelerator might properly become the focus for an international laboratory, patterned after the successful European Laboratory CERN. Informal discussions were held at the Rochester High Energy Physics Conference in August 1960, with many foreign delegates in attendance.[5] On September 16, 1960, a meeting was held at the American Institute of Physics in New York between U. S. and Soviet physicists, at which it was agreed that both countries should explore further the feasibility and desirability of accelerators for energies above 200 GeV. Plans were made to report progress at the International Accelerator Conference scheduled for September, 1961, at Brookhaven.

During the early 1960's, three U. S. laboratories initiated design studies, at Brookhaven, Caltech and UCRL; a design group was started at CERN composed of experienced members of the CPS staff, and later events showed that preliminary studies were also underway in the USSR.

At Brookhaven, a group led by Dr. J. P. Blewett started thinking seriously about higher energy machines in 1960. They chose energies of 400, 700 and 1000 GeV for their initial study. A preliminary design report was issued in May, 1961, and the conclusions were revised during an extensive study carried on at Brookhaven during August, 1961. At that time, about 25 accelerator experts were assembled from nine centers in the U. S. and from CERN and the Rutherford Laboratory. The Report[6] of the Study Group published in late 1961 included both a preliminary design study and an analysis of experimental program requirements.

The Caltech group organized by Sands made a series of studies during 1960 and 1961, on such topics as the problem of injection from the smaller "booster" synchrotron into the large synchrotron, and issued several internal reports.[7] When it became clear that the University of California Radiation Laboratory and Brookhaven Laboratory were becoming involved in similar design thinking, a meeting was held at UCLA in December 1961 between members of the three groups. An agreement was reached in which UCRL would carry on the West Coast design efforts in the 100-300 GeV range and Brookhaven would explore the higher energy range. The Caltech effort was phased out in the following year.

In 1961, at the time of the agreement between UCRL, Caltech and Brookhaven referred to above, the status of UCRL studies was reported by Judd and Smith.[8] A summer study in 1961 explored problems of the experimental use of very high energy particles. In February 1962, the UCRL submitted a request to the U. S. Atomic Energy Commission for support of a design study in the 100- to 300-GeV energy range, and renewed the request in December 1962. The early concepts at UCRL were similar to those at Caltech and Brookhaven in that they involved a large ring of AG magnets for the main synchrotron, but initially they explored the possibility of using a 1- to 2-GeV proton linac as an injector into the main ring. The name of the University of California Laboratory was changed to Lawrence Radiation Laboratory (LRL) in 1959, in honor of Ernest O. Lawrence who died in 1958; E. M. McMillian became the new Director.

At the International Conference on High-Energy Particle Accelerators held at Brookhaven in September 1961, an extensive program was arranged for the exchange of information of designs of multi-hundred-GeV accelerators. Unfortunately, the USSR delegation did not attend so the exchange was incomplete. However, scientists from CERN and the European countries attended and described their existing designs; the three U. S. laboratories presented detailed status reports.

GOVERNMENT POLICY DEVELOPMENTS

The U. S. Atomic Energy Commission had been for years the primary source of supporting funds for construction of accelerator facilities and high-energy physics research in the United States. It was kept informed of the planning for higher energies in the several laboratories and encouraged the exchange of ideas with scientists abroad. In November, 1962, a special panel was appointed jointly by the General Advisory Committee of the AEC and the President's Scientific Advisory Committee to study the high-energy physics program and to recommend a program for the future. The Report[9] of this Panel (called the Ramsey Panel after the Chairman, Professor N. F. Ramsey of Harvard University) which was released on May 10, 1963, in addition to making general and extensive recommendations for support of the high-energy physics program, made several specific suggestions relating to the extension of accelerator facilities into the very-high-energy range. The panel proposed a two-step approach, starting with early authorization of the construction of a proton accelerator of about 200-GeV energy to be built by the Lawrence Radiation Laboratory and continued support of design studies at Brookhaven of a national accelerator in the 600- to 1000-GeV range to be authorized at a later date. The panel also suggested construction of proton-proton storage rings at the Brookhaven AGS as an intermediate step toward the study of higher energy interactions.

The recommendations of this panel justified the AEC in implementing the plans at LRL and Brookhaven. Both Laboratories were authorized to proceed with their design studies starting in April 1963.

EARLY DESIGN STUDIES

In the Lawrence Radiation Laboratory, the authorization of the 200-GeV design study in 1963 resulted in a major effort extending over four years, with an average professional staff of 35 persons. In December 1964, an Interim Report was presented to the AEC, followed by a Design Study[10] in two volumes in June 1965. The Design Study covered the scientific, technical and engineering features of the accelerator and the associated facilities, and included a cost estimate and time schedule for completion. The cost of the facility plus basic experimental equipment was estimated to be $350 million, with a continuing annual operations cost of $50 to $60 million.

The LRL Design Study was a description of a single integral design that was feasible, with realistic cost estimates. Although a fixed set of parameters was chosen, it was recognized that further development would be required. To make cost estimates meaningful a single site was selected, in the Sierra Nevada Foothills. Following publication of the Design Study and during the following year before the AEC announced the selection of a site for a 200-GeV accelerator, work continued on exploring possible improvements, optimizing parameters and refining cost estimates. A Summer Study was held in 1966 to explore further the instruments and facilities needed for experimental use. Some design and development work continued for two more years until the National Accelerator Laboratory was able to take over the work.

At Brookhaven, a Summer Study held in 1963 was attended by a large number of physicists and accelerator experts from this country and abroad. This study showed that there was considerably more interest in the super-energy project and in increasing the intensity of the existing AGS than in planning for a set of interlocking storage rings to utilize the 30-GeV protons for beam-beam interactions. A program was initiated, and soon authorized by the AEC, for conversion of the AGS to produce 10-times higher intensities. The design study for an accelerator in the 600- to 1000-GeV energy range continued, but at a considerably lower scale of effort than that at LRL. The emphasis was on analysis of feasibility and general parameters at these high energies, without much engineering detail of cost estimating. Exchange of ideas continued with design groups at LRL, CERN and in the USSR, with the possible goal of an international accelerator for this super-high-energy range.

At the CERN Laboratory in Geneva, a group of the design experts who had completed the CPS started a design study in 1961 with alternate initial goals of 150- and 300-GeV accelerators, and continued for the next three years. By the time the U. S. planning began to focus around 200-GeV energy, the CERN planning concentrated on the 300-GeV machine. A design study[11] was published in 1964 and a proposal was submitted to the CERN Council for further planning and negotiation between the member States. A Committee appointed by the Council initiated studies of possible sites in Western Europe.

During these years, a series of meetings took place between members of the LRL, BNL and CERN design groups, at approximately 6-month intervals, at which design concepts were exchanged and possible international collaboration was discussed. Exchange visits of extended duration by group members to the other laboratories maintained continuity in this collaborative effort.

The general conclusion from these design studies was that the basic principle of the AG proton synchrotron could be extended with certainty to the 200- to 300-GeV range or even higher, and that the peak energy would be set only by economic considerations. At these energies, the large orbits and use of high injection energy lead to high intensities, of the order of 10^{13} protons per second, and beam power approaching 1 megawatt. The estimated costs in this energy range were found to be nearly proportional to energy, with an approximate unit cost of $100 million per 100 GeV.

SCIENTIFIC JUSTIFICATION AND GOVERNMENT POLICY

The studies at Brookhaven and LRL also included analyses of the feasibility of beam-separation and detection equipment in the 100-GeV energy range, and thorough surveys of the purposes of high-energy physics and theoretical justifications for higher energies. In December 1964, a Brookhaven Report[12] edited by L. C. L. Yuan was published, presenting statements by about 25 leading theoretical scientists in the field. These statements were unanimously favorable, and even urgent, in their advocacy of the need for new accelerators in the higher energy range.

In the Spring of 1964, the National Academy of Sciences-National Research Council established a Physics Survey Committee under the chairmanship of Dr. George E. Pake, to study future requirements in relation to national needs in physics and other fields of science. A Subpanel on Elementary Particle Physics, Robert Walker, Chairman, brought in a report which was basically in accord with the conclusions of the Ramsey Panel but recommended that future high-energy accelerators be considered national rather than regional facilities. The Report of the Pake Committee was instrumental in developing national policy in the field of high-energy physics. It was available in draft form to the LRL Advisory Committee (see below) and to the Atomic Energy Commission; it provided basic recommendations for a study paper within the AEC setting forth policy. The most significant result, as far as the early history of the 200-GeV accelerator is concerned, was the statement that future high-energy accelerators be national rather than regional facilities, with the implication that the choice of site was an important aspect of this function.

In subsequent actions the Atomic Energy Commission turned down the MURA proposal for a regional fixed-field AG accelerator in the Midwest designed to produce extremely high beam intensities at less than 100-GeV energy. The LRL proposal for a 200-GeV machine to be located near and operated by the University of California was reconsidered, in light of its significance as a national facility with the location to be determined by the needs of all high-energy scientists in the country.

In 1963 the Lawrence Radiation Laboratory had set up a scientific policy Advisory Committee, with the approval of the AEC, consisting of senior scientists and administrators having a broad national distribution, to consider methods by which the 200-GeV Laboratory could become a nationally available facility. The report of this Advisory Committee, was available in draft form in late 1964 and was published in Congressional Hearings[13] in early 1965. This report recommended a joint venture in which the Laboratory would supply the staff for the design and construction phase, and after completion the operation of the Laboratory would become the responsibility of a "National Corporation." Dr. McMillan, Director of LRL, was in agreement in principle, but further negotiations were terminated by initiation of a site-selection survey by the AEC and the disbanding of the Advisory Committee.

A study paper on "Policy for National Action in the Field of High Energy Physics" was prepared by staff members of the Research Division of the U. S. Atomic Energy Commission dated February 1965. This became the basis for a U. S. Joint Committee Print[14] published in February 1965. This policy statement reviewed the progress in high-energy physics and high-energy accelerators, summarized the needs for higher energy and higher intensity, and made specific recommendations for Government action. In particular, it recognized the need for new high-energy facilities for the large number of user scientists within universities, and suggested that the orgainzation and location of future facilities be planned to serve the entire national community of high-energy physicists. It also recommended a two-step approach to an energy of the order of 1000 GeV, starting with a 200-GeV Machine similar to that under design at the Lawrence Radiation Laboratory.

On March 2-5, 1965, Hearings on the High Energy Research Program were held before the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy. Many scientists from Government laboratories and from universities were called as witnesses to present their views on the program. The Lawrence Radiation Laboratory and Brookhaven Laboratory design studies were reported and summaries were entered in the testimony. High-energy physicists described the scientific justification, and Yuan's collection[12] of essays by theoretical scientists was presented. AEC and other Government officials presented program plans and budget estimates for the future. A full report of the Hearings was published.[13]

A group of leading scientists of the National Academy of Sciences had independently been considering the problems of management of large scientific facilities which could make them available nationally. These discussions led in January 1965 to a tentative organization of University Presidents with an initial membership from 25 leading universities distributed across the U. S. which had departments active in the physical sciences. The conception evolved out of analogy with the Associated Universities, Inc. (AUI) which was formed just at the end of World War II among the northeastern universities to sponsor and operate the Brookhaven National Laboratory. The function and purpose of this group of university presidents was also discussed at the Hearings.

A general conclusion from these Hearings was that the scientists had made a strong case. Government officials seemed persuaded that a national facility for research in the multi-hundred-GeV range was well justified.

UNIVERSITIES RESEARCH ASSOCIATION

The Universities Research Association (URA) was organized as a result of a meeting held in Washington at the National Academy of Sciences in June, 1965, of the presidents of 34 universities distributed throughout the United States which have research programs in the physical sciences.

The purpose was to provide university backing and support with a broad national basis to the planning and management of the proposed 200-GeV accelerator and the subsequent research program. Dr. Frederick Seitz, President of the National Academy of Sciences, acted as coordinator of scientific opinion in the universities in calling this meeting.

The URA is incorporated in the District of Columbia and maintains its principal office there. The Council of Presidents of the member universities meets about once a year. Active management of the Association is placed in a Board of Trustees elected by the Council of Presidents. The trustees include a representative from each of 15 regional groups of universities and 6 trustees at large to represent the public interest.

The first Chairman of the Council of Presidents was President Gaylord Harnwell of the University of Pennsylvania. The Chairman of the Board of Trustees was Professor H. D. Smyth of Princeton University, and the first President was President Emeritus J. C. Warner of Carnegie Insititue of Technology, who in 1966 was succeeded as President of URA by Professor Norman F. Ramsey of Harvard University. Dr. Frederick Seitz was elected Vice President, Mr. Leonard L. Bacon, Secretary, and Mr. G. Donald Meid, Treasurer/Controller until he was succeeded by Captain Robert A. Williams in 1967.

The URA offered its services to the Atomic Energy Commission as a management organization to contract with the AEC and to operate the

200-GeV facility. The URA was not involved in selection of the site for the Laboratory, but indicated willingness to undertake construction and operation at any site selected by the Federal Government. Each member university agreed to contribute up to $100,000 to URA if and when called upon by the Trustees, primarily for the expenses of organization and operation of URA. By January, 1968, with the election of additional universities, the number had grown to 48.

SELECTION OF THE SITE

The choice of Weston, Illinois, (near Chicago) as the site for the 200-GeV Laboratory was made by the Atomic Energy Commission after extensive site selection studies.[15]

The search for the site started in April, 1965, when the AEC issued a press release inviting statements of interest in proposing sites for this new scientific facility. A total of 125 proposals were ultimately received relating to more than 200 different site locations, including one or more from each of 48 states. By September, 1965, the Commission was able to reduce this list to a total of 85 relating to 148 sites. During November the Commission sent 8 teams headed by senior AEC staff members to visit all 85 proposers and to seek additional data.

The National Academy of Sciences was requested by the AEC to enlist a Site Evaluation Committee composed of eminent scientists to review and evaluate the site proposals and make recommendations to the

AEC. The Chairman of this Committee was Dr. E. R. Piore. The NAS Site Evaluation Committee visited and studied the proposed sites which met the basic selection criteria, and in March, 1966, issued a report to the Commission recommending six sites.

As a part of the final evaluation effort, three Commissioners visited each of the six sites recommended by the NAS Committee. The Commission announced its unanimous decision for the site at Weston, Illinois on December 16, 1966.

As might be expected, the selection of a site was not popular with proponents of many other sites, and was the subject for considerable discussion in the Congress and in Joint Committee Hearings.[15] Much of this discussion centered on the problems of the availability of open housing in the Chicago suburban area, raised by the National Committee against Discrimination in Housing and other Civil Rights groups. In the testimony, the State of Illinois was called upon to enact fair housing legislation, and suburban communities were importuned to the same effect. In partial answer, the Commission made clear its basic adherence to a policy of nondiscrimination.

In the Hearings, the AEC proposed a reduced-scope accelerator dictated by the Bureau of the Budget for budgetary reasons. In this reduced scope, the energy was to be retained at 200 GeV, but the intensity could be decreased to about one-tenth that of the LRL design and the number of experimental target stations reduced. An initial cost figure of about $240 million was suggested, with additional funds to be provided later to recover the original scope. Other discussion covered the importance of providing options for future development to still higher energies and intensities and further experimental facilities. The organization for management of a 200-BeV facility was again discussed with relation to the Universities Research Association which had been formed for this purpose.

The general result of these hearings was Congressional authorization for the AEC to proceed with the planning for a 200-GeV accelerator, but at a lower initial cost. The first step was the execution on January 5, 1967, of a letter contract with the URA to initiate a design study to accomplish this purpose. This letter contract was replaced by a definitive contract on January 23, 1968. In February, 1967, Captain Bradley Bennett was appointed Assistant to the President of URA and subsequently was elected Vice-President for Administration. The URA's first offices were in the National Academy of Sciences Building, and in October, 1967, they were moved to the Joseph Henry Building at 2100 Pennsylvania Avenue, N. W., Washington, D. C.

ESTABLISHMENT OF THE NATIONAL ACCELERATOR LABORATORY

Following the selection of the Weston site by the Atomic Energy Commissioners, the URA moved promptly to select a Director and initiate activities. The first scientist asked to direct the design study declined, and professor Robert Rathbum Wilson of Cornell University was offered the position of Director of the "National Accelerator Laboratory." He announced his intention to prepare a design within one year that would give full intensity, an option for higher energy and at a cost not exceeding $240 million, but he required significant concessions of authority from the AEC and URA and a fast time schedule for construction, namely, five years. These were acceptable. Wilson accepted the position as Director on March 7, 1967; he took up the position full-time on June 15, when he moved to Chicago.

President Ramsey called a meeting of potential scientific users of the 200-GeV accelerator for April 7-8, 1967, at the Argonne National Laboratory, at which time announcements of the organization of the new National Accelerator Laboratory and the appointment of the Director were made. A URA Report[16] summarized the scientific papers presented at the meeting. Dr. Wilson used this opportunity to call a special meeting of accelerator designers and experts attending the larger meeting, at which preliminary plans were discussed and a summer design program was announced to start on June 15 in the Chicago area.

In April, a preliminary contract for A/E (architectural-engineering) services was signed with the firm of "DUSAF,"* and their engineers started meeting with the Director and his associates. They were asked to perform site surveys and make preliminary site plans. Also in April,

*DUSAF is formed by four architectural and engineering firms: Daniel, Mann, Johnson, Mendenhall, The Office of Max O. Urbahn, Seelye, Stevenson, Value and Knecht, and George A. Fuller Company.

arrangements were made for temporary office space in the Executive Office Plaze at 1301 West 22nd Street, Oak Brook, Illinois.

By May 1, a number of scientific and administrative staff menbers had been recruited and had accepted appointments, in most cases to start at some later date. These included: E. L. Goldwasser (University of Illinois), Deputy Director, F. T. Cole (LRL), A. L. Read (Cornell), J. DeWire (Cornell), M. S. Livingston (CEA), D. E. Young (University of Wisconsin), C. D. Curtis (University of Wisconsin), Mr. Donald Getz and several other administrative staff members.

Meetings of the URA Trustees, a Scientific Advisory Committee appointed by the Director, with representatives of DUSAF, and with accelerator design experts from many laboratories, were held at an increasing rate during the spring of 1967. The AEC took a leading role in planning and in clearing away administrative problems, and their representatives attended all planning meetings and discussions. All obstacles were cleared away, offices for the design group were prepared, contracts for financial support by URA and by the AEC were formally signed, and commitments were obtained from accelerator scientists from many sources to attend and contribute to the Summer Program to start on June 15, at the Oak Brook design headquarters.

Summer Program of 1967

The purpose of the Summer Program was to develop concepts for a new design for 200 GeV, significantly simpler and of lower costs than the LRL Design Study. The leader in this conceptual study was the new Director, Professor R. R. Wilson, who brought to bear his recent experience in building the Cornell 10-GeV AG electron synchrotron at a lower unit-cost than previous electron synchrotrons of this type. Some of these simpler and lower-cost concepts became part of the new design from the start, such as the compact magnet structure which embodies a girder-type support in its construction, and the minimal size magnet tunnel enclosure. Other simplifying concepts were provided by visiting accelerator experts and scientists. The theme of the study became a search for new and different solutions to design problems with the emphasis on reduction of cost without excessive loss of quality or reliability. Several of these alternative solutions were presented and developed by visitors from LRL; the LRL design group had several months lead in searching for cost reductions following the AEC requirement of a reduced-scope accelerator which had been discussed in the Hearings[15] in February 1967.

The Design Program started on June 15, 1967, with 20 accelerator scientists attending the first week, including Drs. Wilson and Goldwasser. Additional members arrived later and others came for a few weeks, with an average attendance of about 25. Nearly half of those attending ultimately accepted appointments at the NAL and joined the staff. A list is attached*

*See Appendix I.

of the names and affiliations of 62 persons involved in the study, during the summer and fall, with starting dates for those who joined the NAL staff.

The most significant of the features considered and ultimately accepted in the new design deserve to be identified individually:

1. Option for higher energy: Well before the Congressional Hearings in January-February 1967, it was becoming evident that the two-step program (for a 200-GeV machine to be followed by an "800"-GeV machine) might postpone too long the attainment of truly higher energies. Many scientists began to regret their commitment to 200 GeV and wish for higher energies. Also, the reduced scope specified by the AEC required re-thinking about the energy limitations of a synchrotron formed of a ring of magnets limited by saturation of the iron. An LRL concept consisted of filling half the ring with magnets, to reduce initial cost, with an initial operating energy which could be increased later by adding the other magnets; it was called the "expanditron" in laboratory slang. The individuals involved at LRL were Garren, Lambertson, Lofgren, and Smith.[17] Prior to the Summer Program, this concept was modified to consider use of a large orbit filled with magnets but initially powered at half-field to reduce cost, with additional power supplies to be added later; this procedure would minimize the down-time for such a conversion. Dr. Wilson adopted this concept and extended it to imply a 200-GeV start capable of future expansion to 400 GeV or even to 500 GeV. It was

discussed with enthusiasm as early as January, 1967, in local groups and at URA meetings. Wilson hoped that this option for higher energy could be included within the $240 million budget.

2. Separated Function Magnets: AG accelerator designers had long known of the option of separating the bending and focusing functions of the AG magnets in the main ring. For the large orbit (1 kilometer radius) required for 400 GeV, the focusing properties could be provided by relatively short and widely-spaced quadrupole magnets, allowing most of the orbit to be filled with bending magnets having uniform and very high fields, flat poles and simplified construction. Such bending magnets could follow the design concepts of the Cornell magnets, which were formed of die-stamped laminations (for precision) mounted and aligned in self-supporting girders.

3. Magnet Power from AC Mains: Previous large accelerators have used a motor-flywheel-generator system on a single shaft to provide energy storage for the magnet excitation cycle, which extends over several seconds and in which the peak power greatly exceeds the average power. Generator breakdowns due to the pulsed load have resulted in long-term repairs in essentially all of these earlier accelerators. During such a breakdown at the Nimron 7-GeV accelerator at the Rutherford Laboratory, a method of powering the magnet directly from the ac mains was used to get back into operation at reduced power. This principle was studied by engineers attending the Summer Program, with the result

that plans were made to take the magnet power directly from the mains through transformers and rectifiers controlled to produce the desired time cycle, and with lumped circuit elements switched in or out to correct for power factor variations during the cycle. The Commonwealth Edison engineers have accepted this technique for handling the magnet power cycle, in principle.

4. Minimum Magnet Enclosure: Experience at CEA, Cornell and other labs using small AG magnets has increased confidence that installation and maintenance of magnets and other components can be accomplished without an overhead crane. Maintenance planning at NAL involves the installation or substitution of complete magnet or component units, using special handling vehicles. The desire to minimize maintenance time in the enclosure and to reduce radiation exposure, resulted in limiting the amount of equipment requiring maintenance in the tunnel. These factors contributed to justify a simply-constructed and minimun size tunnel, formed of precast concrete sections. The cost savings in design estimates were considerable.

5. Magnet Foundations: Confidence has increased among AG accelerator designers that beam apertures can be considerably smaller than those in existing machines, with the consequence of smaller cross-section magnets and lighter weight units. Experience with electron synchrotrons such as CEA and DESY justifies this confidence, and has also demonstrated the ease with which magnet alignment can be handled by using information

from beam-position monitors. These results justified the concept of eliminating magnet foundation piers and mounting the magnet directly on the slab-floor of the tunnel enclosure. Although there were many critics from outside the NAL group, this concept prevailed. Design cost savings were significant. In justification for this decision, a technique of using stretched wires with current sensors for magnet position surveys was proposed, to back-up beam position alignment techniques if required.

6. Increased Rise-Time in Magnet Cycle: The radio-frequency system designs initiated at LRL have been developed to provide the rf systems for the booster and the main ring at NAL. However, the LRL time cycle for acceleration resulted in relatively high rf power requirements. Accordingly, the acceleration time was increased to reduce volts-per-turn and peak rf power, with corresponding cost savings, although with a small reduction in repetition rate.

7. Fast-Cycling Booster: A significant development at LRL during their design study for 200 GeV was to adopt the concept of a booster synchrotron as an injector, rather than a multi-GeV linac, and to operate it at a fast cycling rate so successive booster pulses could be used to fill completely the main ring. This concept was also adopted at NAL, and the fast-cycling booster (15 cps) became the favored system for injection. A sequence of 13 pulses (0.8 sec) is used to fill the main ring, providing 13-times the intensity in the booster. The result is a

high-intensity circulating beam in the main ring, at the cost of a slightly reduced cyclic repetition rate.

8. Long Straight Sections: The need for relatively longer straight sections for ejection of emergent beams was obvious at the start of the design study. This was accomplished by adopting the technique proposed by Collins (at BNL Summer Study in 1963) of using matching quadrupoles at the ends of the straight sections, and was modified by Garren to give still better characteristics. Six such long straights were chosen for ejection, injection and for future options.

9. Vertical Injection: The magnet design using compact structures with small vertical height above the beam offered an opportunity of injecting the beam from the linac into the booster in the vertical rather than the horizontal plane. The same concept was adopted for ejection from the booster and injection into the main ring. Orbit analysis showed that such vertical injection gave somewhat larger beam acceptance values. It also provided greater design flexibility for the injection-ejection magnets and freed the accelerator from the location of sensitive components in the radial plane where radioactivity might become a problem.

10. Single Emergent Proton Beam: Planning for the scientific use of the high-energy protons paralleled accelerator design during the summer. A number of the summer visitors were experimentalists with an interest in planning experimental facilities. The concept of utilizing a single emergent beam, with switching magnets to utilize 3 or more

target stations, was originally introduced as a means of reducing initial costs. However, as the study progressed, excellent reasons were developed to justify such a single emergent beam as the total external-beam facility. Transportation and communication become simpler, and ejection efficiency can be made higher, with one extended beam path rather than several spaced widely around the ring.

11. Options for the Future: It is essential to provide options open for the development of further experimental facilities, including a storage ring. The location of the main ring on the site, and the arrangement of unallocated straight sections were planned to provide future opportunities to install beam bypass sections and either small-or large-diameter storage rings.

A private memorandum on the Summer Program prepared by Dr. A. van Steenbergen in September, gives a more detailed report of some of the discussions and decisions made during the study.

By September 15 most of the basic concepts of the new design had been crystallized, at least in principle. Preliminary descriptions and cost estimates were prepared and circulated to critics in other laboratories; several discussion sessions were held at which criticisms were considered and changes made when they proved valid. A number of critics remained unsatisfied, but no alternate concepts were proposed which would not significantly increase the estimated costs. As Director, Wilson made a sequence of basic decisions freezing one-by-one the major concepts and parameters. As the visitors from other laboratories left and returned to their home bases, NAL staff members were enlisted and joined the continuing staff. The total staff at the design headquarters did not drop below the 25 averaged during the Design Program.

Preparation of the Design Report

The activities initiated during the Summer Study continued through the fall, with increasing emphasis on more detailed designs, improved parameters and cost estimates. The Laboratory organization took form and a variety of business and clerical staff were added. A Machine Shop was initiated and installed in quarters in Downers Grove (5 miles); additional space was leased in the Executive Plaza Building. The professional staff grew to 30 by December 30, with 8 more appointments to start soon after the first of the year. The total Laboratory staff, including offers outstanding, was 90 on December 30.

An initial deadline for the Laboratory was preparation of the AEC Construction Data Sheet (Schedule 44), to be submitted by October 15, 1967. This represented the final and complete cost estimate for construction. It was prepared and submitted on time, with a total construction cost estimate of $242 million which the AEC changed and rounded off to $250 million, as a result of schedule revisions required by budgetary limitations.

The final product of the design program was a Design Report to the AEC presenting the results of the study, detailed parameters and justifications, and a cost estimate. The original date for this report requested by the AEC Research Division was December 15, at which time a preliminary copy was delivered to them. The final copy of the 200-BeV Accelerator Parameters and Specifications[18] was completed and delivered before January 15, 1968. This Design Report was submitted to the Joint Committee on Atomic Energy, and incorporated in the AEC Authorizing Legislation for FY 1969, published in a U. S. Government Print[19] in February 1968. The Bill authorizing construction of the 200-GeV accelerator was passed by the U. S. Congress and signed by the President on April 19, 1968.

APPENDIX I. PARTICIPANTS IN THE 200-GeV ACCELERATOR PROGRAM: SUMMER AND FALL, 1967

	Affiliation on 1/1/68 (and origin)	Starting date, NAL
Directorate:		
Wilson, R. R. (Dir.)	NAL (Cornell)	6/15/67
Goldwasser, E. L. (Dep.)	NAL (Illinois)	7/1/67
Livingston, M. S. (Assoc.)	NAL (CEA)	10/1/67
Collins, T. L. (Accel. Div.)	NAL (CEA)	1/1/68
Cole, F. T. (Asst.)	NAL (LRL)	8/1/67
Getz, Donald (Asst.)	NAL (ANL)	6/1/67
Scientists:		
Awschalom, M.	NAL (PPA)	1/1/68
Billinge, R.	NAL (Ruth)	1/29/68
Blewett, M. L.	ANL	
Blosser, H. G.	Mich. St.	
Courant, E. D.	BNL	
Curtis, C. D.	NAL (Wisc)	7/1/67
DeWire, J. W.	NAL (Cornell)	9/1/67
Foss, M.	Carneg-Mellon	
Fregeau, J. H.	NSF	
Garren, A. A.	NAL (LRL)	10/1/67
Hubbard, F. L.	NAL (LRL)	1/5/68
Jones, L. W.	Michigan	
Koester, L. J.	Illinois	
Livdahl, P. V.	NAL (ANL)	11/1/67
Malamud, E.	NAL (UCLA)	1/1/68
Mallory, K. B.	SLAC	
Maschke, A. W.	NAL (BNL)	7/9/67
Meyer, D. I.	Michigan	
Montague, R. W.	CERN	
Peterson, J. M.	LRL	
Read, A. L.	NAL (Cornell)	6/15/67
Reardon, P. J.	MIT	
Reich, H.	CERN	
Roberts, A.	NAL (ANL)	1/1/68
Sands, M. W.	SLAC	
Sanford, J.	BNL	

Serber, R.	Columbia	
Sessler, A. M.	LRL	
Smith, L.	NAL (LRL)	1/12/68
Snowdon, S. C.	NAL (Wisc)	11/1/67
Symon, K. R.	Wisconsin	
Teng, L. C.	NAL (ANL)	9/1/67
Thomas, R.	Rutherford	
van Steenbergen, A.	NAL (BNL)	11/15/67
Walker, T. G.	Rutherford	
Yamada, R.	Tokyo	3/1/68
Young, D. E.	NAL (Wisc)	5/22/67
Yuan, L. C. L.	BNL	
38	16	

Engineers:

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Dols, C. G.	LRL	
Dorst, J. H.	LRL	
Juergens, R. C.	NAL (ANL)	12/1/67
Katz, J. F.	LRL	
Kerns, Q. A.	NAL (LRL)	10/1/67
Kilpatrick, R. A.	LRL	
O'Meara, J. E.	NAL (Wisc)	7/1/67
Owen, C. W.	NAL (Wisc)	6/15/67
Palmer, M.	NAL (Wisc)	8/1/67
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Tusting, R. F.	LRL	
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63-total   30-NAL staff

Other, short-term visitors to the Summer Study - 70.

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