AN INTERIM REPORT ON THE CONSTRUCTION OF THE LOS ALAMOS MESON PHYSICS FACILITY*

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ABSTRACT

A description of the progress which has been made on the construction of the project prior to September 1970 is given. Some of the principal technical and administrative problems are discussed.

Introduction

The Los Alamos Meson Physics Facility accelerator is about halfway through the construction cycle -- as measured from the first major release of construction funds for equipment in October of 1968 to the expected beam date of July 4, 1972. The major elements of the overall design have been frozen for several years and detailed design of accelerator components is practically complete.[1-7] A start has been made on construction of the buildings in the experimental areas; experimental area equipment design is proceeding and fabrication of some of these components has started.

Fortunately the release of funds and construction progress have been reasonably in accord with the anticipated schedule. The project has been carried on in a period which has been strongly inflationary; however, by some combination of good fortune and careful attention to final design we have managed to overcome most of the effects of inflation. The major exception was caused by a delay in fund release which resulted in an increase in authorized construction costs from 55 to 56 million dollars.

The scientific motivation for the project is the exploration of the physics and practical applications made accessible by intense beams of mesons and nucleons. This type of research started to receive serious attention in the early 1960's[8] and several proposals were made for intense meson sources or meson factories. Currently there are three accelerators in various stages of construction which will provide greatly increased intensity; these are TRIUMF at Vancouver, Canada, the Isochronous Ring Accelerator at Zurich, Switzerland, and LAMPF.

The energy and proton current for the three machines is:

	Average Proton Current (μA)	Maximum Energy (MeV)
TRIUMF	100	500
Zurich	100	560
LAMPF	1000	800

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Experimental programs at all three installations are scheduled to start in 1972 or 1973.

It appears feasible to attain our goal of an 800 MeV beam in July of 1972. Intermediate goals of a 100 MeV beam in mid-summer of 1971 and a 200 MeV beam sometime in the fall of 1971 are planned in order to check performance as construction proceeds. We believe that the experimental program will start about January of 1973, allowing six months after achievement of the 800 MeV beam to bring the project into the status of an operating facility.

It has been our experience that problems in two areas not commonly discussed at these conferences have been nearly as difficult as most of the usual technical problems These areas are the overall administration of the development and construction effort, and the necessity for optimizing the operation of the facility as a whole. After a review of the technical aspects of accelerator and experimental area construction, therefore, a few paragraphs will be devoted to these problems to perhaps open a more thorough discussion.

Accelerator Construction

The buildings housing the accelerator and its associated equipment are 96% complete; a view of the site as it appeared recently is shown in Fig. 1. Installation of accelerator components started in the injector building in the summer of 1969 and installation work is now proceeding in nearly all of the buildings associated with the accelerator.

The first Cockcroft-Walton and ion source system -- used for the H^+ beam -- became operational in June of 1970. The performance characteristics of this injector system will be given later in this conference.[9,10] Installation of a second Cockcroft-Walton machine to be used for H^- beams and development of the H^- ion source have begun. Room is also available in the injector building for the installation of a polarized proton source. The schedule for the polarized source depends on the availability of manpower and funds; a useful polarized proton beam will be available in 1973 at the earliest.

The first drift tube accelerator tank and the beam transport area which connects the various injectors to it are shown in Fig. 2. At this time, the only transport system in place is for the proton beam. This transport area also houses the buncher cavities used to improve the acceptance of the accelerator to the beam from the ion source. Currently, a single cavity buncher operating at the drift tube accelerator frequency has been installed and some testing started. More complicated buncher systems using two cavities will be tried in the future.

The first tank of the drift tube accelerator (0.75 MeV to 5.4 MeV energy) has been used since early in June of 1970 to accelerate protons to the design energy. This tank is similar to those used elsewhere; however, substantial departure from previous engineering practices have been necessary due to the eventual 12% duty factor requirement. The optimization of the behavior of this portion of the machine is quite important since it plays such a strong role in the behavior of the beam throughout the remainder of the accelerator. This optimization is the subject of an extensive testing program which will continue until the end of 1970; the results thus far will be described later in this conference.[11-14]

The other three tanks of the drift tube linac (5.4 to 41.3 MeV, 41.3 to 72.7 MeV and 72.7 to 100 MeV) are post-coupled[15] and, of course, also contain the necessary design feature for eventual 12% duty factor operation. The outer shells of the tanks three and four have recently been put in place and final assembly begun. Approximately 45% of the drift tube fabrication is now complete. The complete assembly of the drift tube portion of the accelerator should be finished in the spring of 1971.

The rf power system[4] for the drift tube accelerator is essentially complete and testing has started. The system is similar to that used at BNL, ANL, and NAL but again, design has been complicated by the high duty factor requirement. A rather substantial amount of testing at high average power will be done during the next few months to uncover any remaining power dependent weaknesses in design. Experience is lacking on the use of these systems at full power in driving resonant loads. However, no major difficulties have been uncovered in the operation of tank 1.

The drift tube accelerator is followed by a transition region ~ 5 m in length. In this region will be placed diagnostic equipment for 100 MeV beam tests, a "bucket rotator" and a set of magnets which make the drift lengths different for the H^+ and H^- beams. The "bucket rotator" is a short section of the side coupled accelerator which is operated at such a phase that no net acceleration occurs; instead, the "bucket" in energy-phase space is rotated to provide a better match of the 100 MeV beam emittance to the acceptance of the side-coupled accelerator. The different drift lengths are necessary to obtain the proper phase for acceleration of both positive and negative beams in the side-coupled portion of the accelerator.

The side-coupled accelerator[2] accelerates the beam to 800 MeV. This portion of the machine is organized into 44 modules, each of which requires approximately 1 MW of drive power. Typically the energy gain per module is 16 MeV and the beam loading is 27%. Each module is divided into either two or four tanks separated by bridge couplers; these separations contain the quadrupole doublets needed for radial focusing. The final machine work, brazing and tuning of the side coupled accelerator sections is done at LASL;[16] the final machine work on the accelerator sections is 50% complete and brazing 40% complete. Some 20% of the side-coupled accelerator is in place in the accelerator channel and high power testing will begin in the late fall. A view of this portion of the beam channel is shown in Fig. 3.

The development of the 805 MHz power system involved the evaluation of several different power systems before the klystron was chosen.[5] The klystron remains the subject of a continuing development program.[17,18] The performance characteristics of the prototypes have been studied in detail and lifetime studies are well under way. The present situation is quite encouraging. The rf power—accelerator system has demonstrated a stability of better than ± ¼% in energy gain over many hours for the $\beta = 1$ structure in our electron prototype accelerator. The system stability for the lower β structure used in LAMPF[19] has been demonstrated to be better than a few percent and is the subject of continuing investigation. The klystron lifetime tests have accumulated over 22,000 h of high power operation on 10 different tubes without a tube failure; one tube has operated over 6,000 h. This is not enough experience to establish a measure of the lifetime but it definitely shows promise that klystron lifetime will at least be several thousand hours. Deliver of production klystrons has started; one of the prototype tubes is shown in its modulator in Fig. 4.

The control system for the accelerator is organized around an on-line digital computer. A prototype computer control system was developed in connection with our 25 MeV electron prototype accelerator; this prototype system evolved to the point where it could be used to sequence this machine on and off automatically or act as the link between the operator and the accelerator. The system for LAMPF will be similar but much larger, using about 6000 channels for data acquisition or control. The SEL-840MP computer to be used has passed its performance tests and has been installed in the operations building. The basic computer operating system is in use and programs are being written to do specific control tasks. We expect that this computer will be used to operate the injector this winter, portions of the drift-tube accelerator in the spring of 1971, and that it will be the dominant method of accelerator control during the 200 MeV tests in the fall of 1971. Some 30% of the local control hardware has been fabricated and installed.

Experimental Areas

A plan of the experimental area buildings is shown in Fig. 5 and a view of the present situation is shown in Fig. 6. The switchyard and area A will be finished first and the start of equipment installation is scheduled for the spring of 1971.

The buildings for Areas B and C should be available at the end of 1971. The switchyard is really a dual purpose area; it routes the proton beam to the desired experimental area and also houses the precision spectrometer (0.05% accuracy in momentum) which will be used to measure beam energy and changes in beam energy during the tune-up procedures. Experimental area A will house 3 target stations and the associated pion and muon channels. Area B will be a neutron research area; Area C will contain a high resolution spectrometer to be used for nuclear structure studies. This spectrometer is to have a resolution of 25 keV with a bending radius of 3½ m; procurement has started on the spectrometer magnet and coils.

Area D, (the National Defense Neutron Research Area), the Biomedical Facility and an Isotope Production Facility were not contained within the original scope of LAMPF. The schedule for full construction of these facilities is unknown but we hope they will become operational between 1973 and 1975.

The radioactivity which will be induced near the high power targets will require the use of remote manipulators and other techniques commonly used in "hot cells." It would have been inordinately expensive to outfit each of the high power target areas as a hot cell. Instead, a device called Merrimac[20] has been designed which contains the necessary hot cell features, yet it can be moved from target cell to target cell as needed. When Merrimac is in use on a target cell it effectively replaces the roof shielding of that cell.

One of the desired features in the experimental area is ability to make multiple simultaneous uses of the output of the accelerator. A major step in this direction was the decision to provide for simultaneous acceleration of 1 mA H^+ and 100 μA H^- beams. Areas B and C will be served by the H^- beam while area A will use the H^+ beam. In area A there will be three target stations each of which can provide a meson beam to two or more experimental setups. The beam remaining after passing through area A target cells can be used in Biomedical Facility and Isotope Production Facility. A beam deflection system which will provide 1 μsec pulses at the beginning and end of each macropulse will serve the National Defense Neutron Research Area.

Personnel, Funding, and Scheduling

One measure of the scope of a project is the number of people directly invloved with the project and the amount of money associated with their effort. Table I gives this information for LAMPF. The personnel figures are averaged over the fiscal year and show only those in the Los Alamos Scientific Laboratory directly assigned to this project and funded either by R&D or construction funds. This tabulation includes secretaries, technicians, and draftsmen but does not include machinists, and other support personnel such as buyers or craftsmen.

TABLE I

Fiscal Year	Personnel	R&D Funds (K$)	Construction Funds Released (K$)
1966	60	2,130	1,200
1967	95	2,855	3,000
1968	135	3,199	10,400
1969	165	3,682	18,700
1970	220	5,250	5,000
1971	255	6,250	6,400

The figures in the personnel column reflect our desire to maintain the staff at LASL at the minimum possible level. When need be, this staff has been augmented to a small extent by use of consultants and personnel temporarily available at other laboratories.

The details of the construction schedule are monitored through the use of a PERT system showing the schedules and correlation of some 5000 construction activities. In general, PERT has been worth the effort for the following reasons:

1. It's use has required project personnel to do a reasonable amount of planning about their activities and manpower needs.
2. It displays the major constraints placed on the various groups by the activities of other groups.
3. It measures periodically a group's actual progress versus anticipated progress.

4. It gives us some advance warning about errors in planning.

However, PERT does not provide a panacea for project planning and monitoring. Three major difficulties have been encountered:

1. It is difficult to strike a balance between necessary detail and trivia when networks are drawn.
2. It is impossible in a network of tractable size to show all of the interactions between the various activities on a complex project.
3. The line diagram which forms the basis of the PERT network is an oversimplification to the manner in which people actually perform their work.

These difficulties have been overcome by using common sense and treating PERT as a useful tool and not as the dominant method of project control.

System Problems

At this point in the construction of LAMPF the realistic evaluation of the remaining problems is a difficult thing; the situation is closely related to the proverbial difficulty of "I can't see the forest because of the trees." However, it does seem worthwhile to try to classify and discuss briefly the different types of problems in general terms. This discussion is limited to problems which are solvable within the project; it excludes those difficulties such as fund release, which are controlled by the outside world. Then, the problems seem to fall into three classes; 1) difficulties associated with fabrication and installation, 2) the reliability problem, and 3) system analysis.

The difficulties associated with fabrication and installation are the easiest to rectify in many respects. They seem to come, for the most part, from overly optimistic predictions about schedules. Items like, "Vendors are sure that they can easily deliver well in advance," "the installation work really won't take much time," and "checkout is easy," are typical of the pitfalls we encounter almost daily in one form or another. The solution seems to lie in a determined effort to obtain realistic estimates about schedules coupled with a continual monitoring of actual versus predicted performance. This at least permits replanning on a reasonably firm basis when things go wrong.

The reliability question is harder. It is an especially fundamental problem for this accelerator since all parts of the machine up to a given energy must be operating in order to achieve that beam energy. Our design has been made on a conservative basis insofar as component ratings are concerned. Further, we have taken some care to establish a rapid replacement capability for those components likely to have some appreciable wearout or failure rate. The validity of our design choices can only be determined by lengthy periods of operation. Life tests have already uncovered defective components and this kind of testing will continue at a high level during the remainder of the construction period.

The problem termed system analysis, is one of the most interesting and challenging in view on our project. In order for this accelerator to operate to its fullest capabilities, the overall system must be optimized to a high degree yet measurement of many of the system parameters is a state-of-the-art effort. As an example, for several years we have been making detailed studies of the klystron's performance under various conditions. For the past 18 months this klystron work has been combined with a study of the operation of the side-coupled accelerator at high average powers and this combined study has led to a better understanding of cooling and tuning problems. In parallel with this work, several computer studies of the "turn-on problem" have addressed the question of how the accelerator fields should be initially set to the desired accuracy in phase and amplitude. In studying the turn-on problem, probable errors in measurement are assigned on the basis of the experience with the klystron-accelerator structure study. This sort of system study is further complicated by the large amount of data necessary to describe the problem; fortunately, we soon will have access to the control computer to aid in this type of exercise.

Conclusions

The construction of the Los Alamos Meson Physics Facility is proceeding at a satisfactory pace and it is realistic to expect an 800 MeV beam by July 1972, the scheduled date. The problems at the present time are a mixture of technical and administrative difficulties all of which appear to be under control. The most interesting problem in sight from the accelerator builder's point of view is the optimization of the performance of this complex accelerator system.

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Fig. 1 The Los Alamos Meson Physics Facility as it appeared in Sept. 1970. A wing of the Laboratory Office Building appears in the right foreground, the accelerator buildings attthe left and the framework for experimental area A in the background.

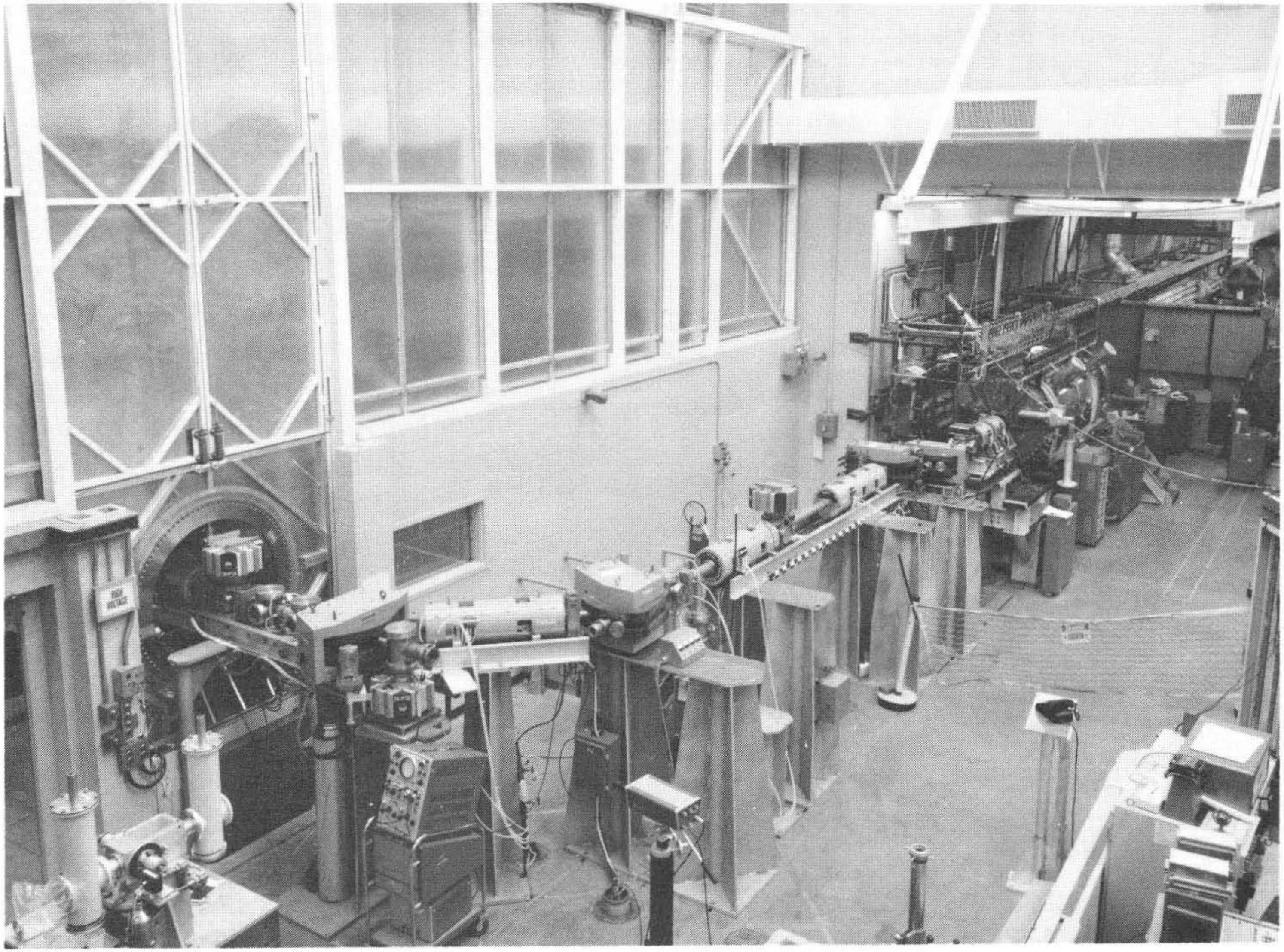

Fig. 2 The beam transport area connecting the H^+ injector system to the first tank of the drift tube accelerator. The Cockcroft-Walton machine is in the electrostatic enclosure at the left and the first tank of the accelerator is in the background.

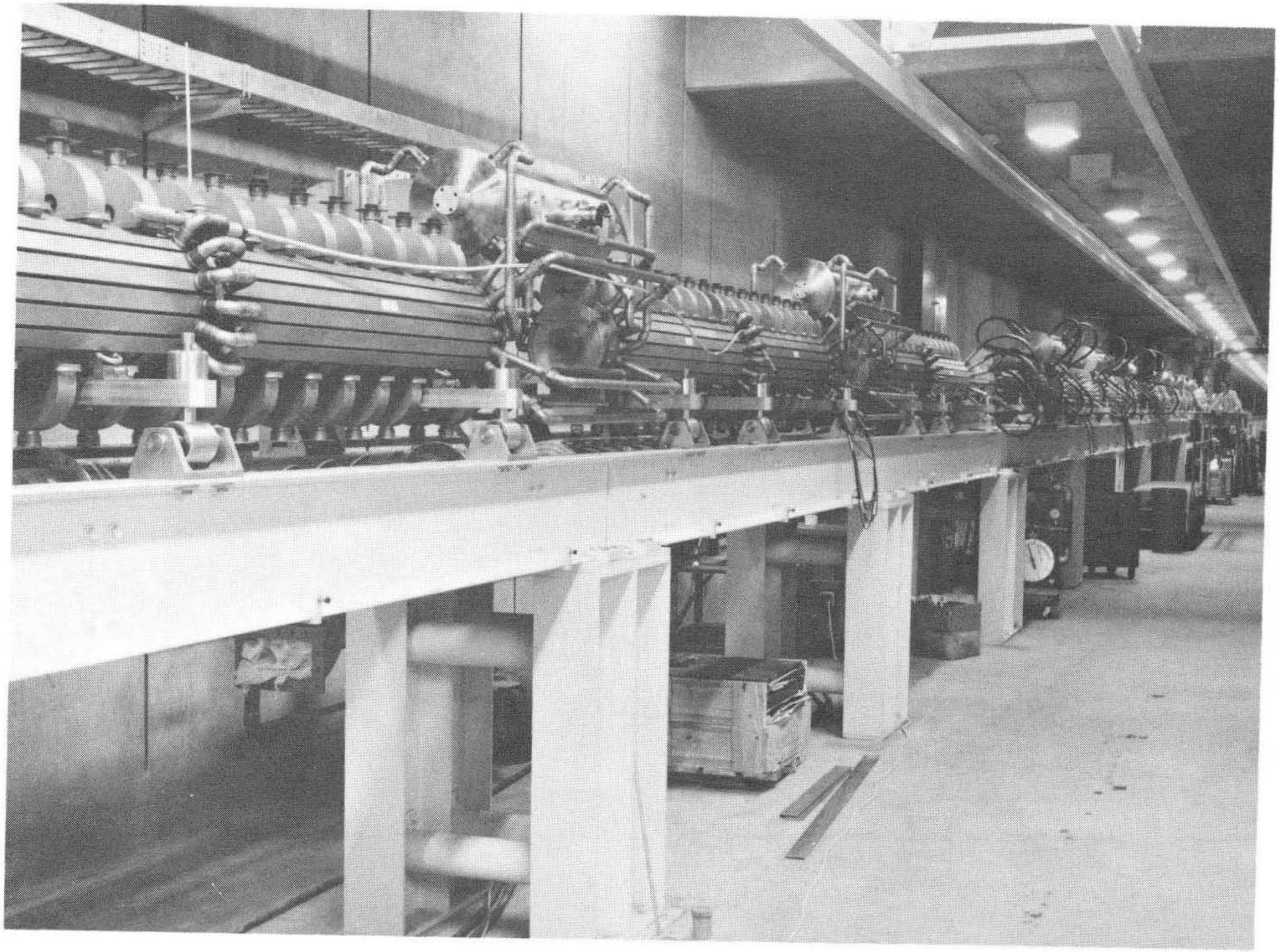

Fig. 3 The side coupled accelerator during installation. The coupling cells are seen at the top and bottom of the structure; the bridge couplers used to introduce power and provide beam linesspace for the focusing quadrupole doublets are at the top of this structure.

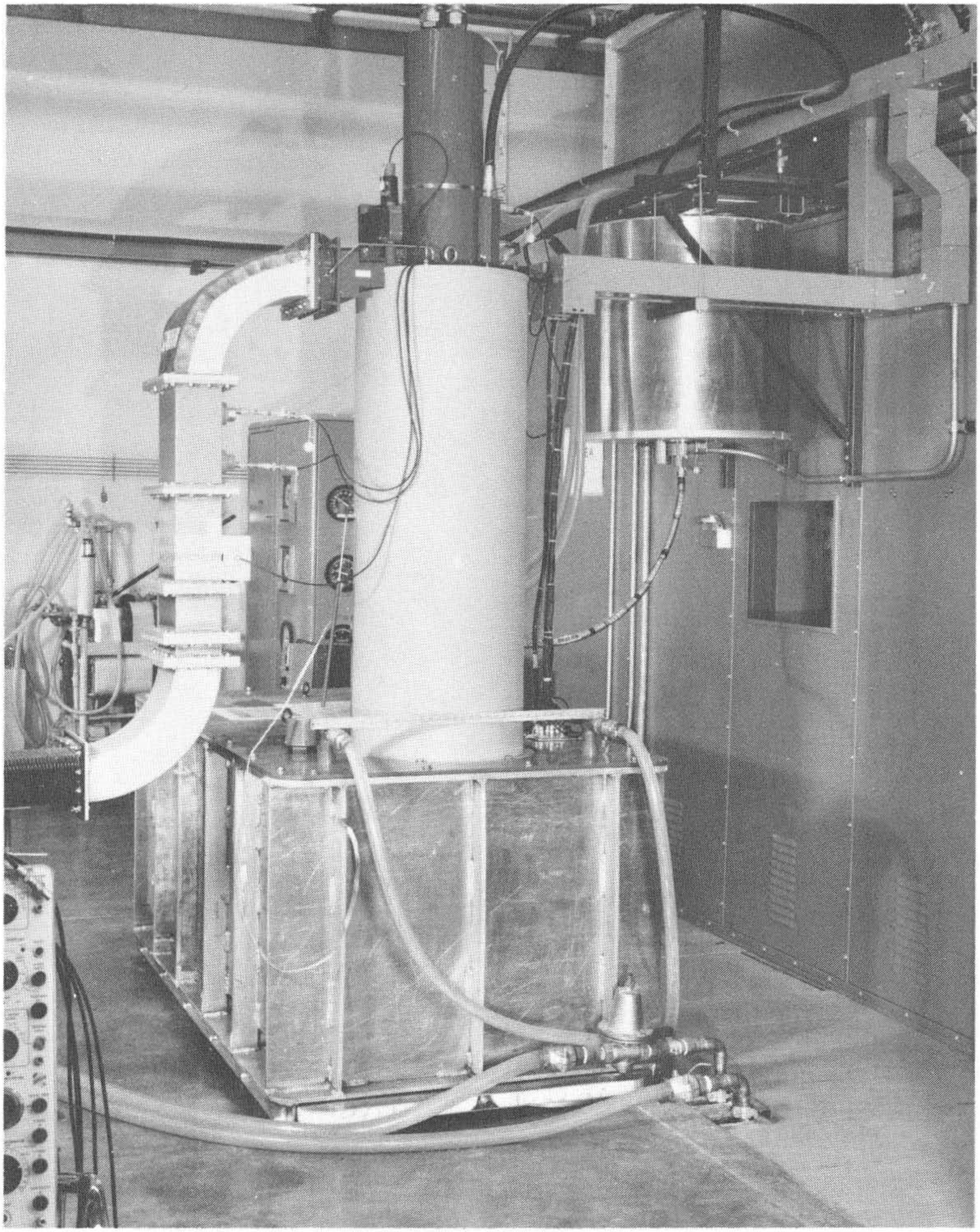

Fig. 4 A prototype 1¼ MW 805 MHz klystron in its modulator. The tube has a modulating anode which is controlled by the equipment in the oil-filled modulator tank on which the tube and associated electromagnet rests.

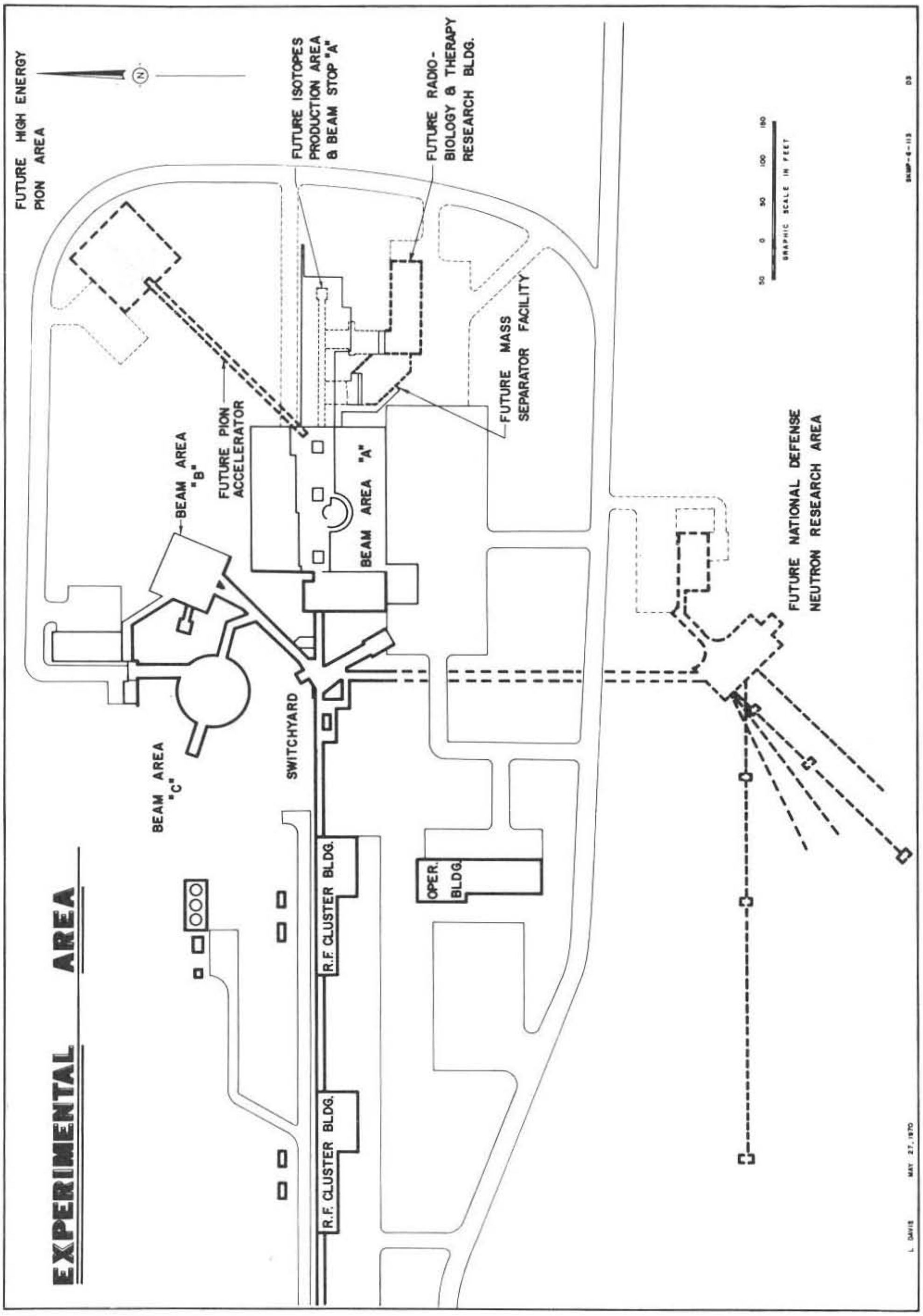

Fig. 5 Plan view of the experimental area.

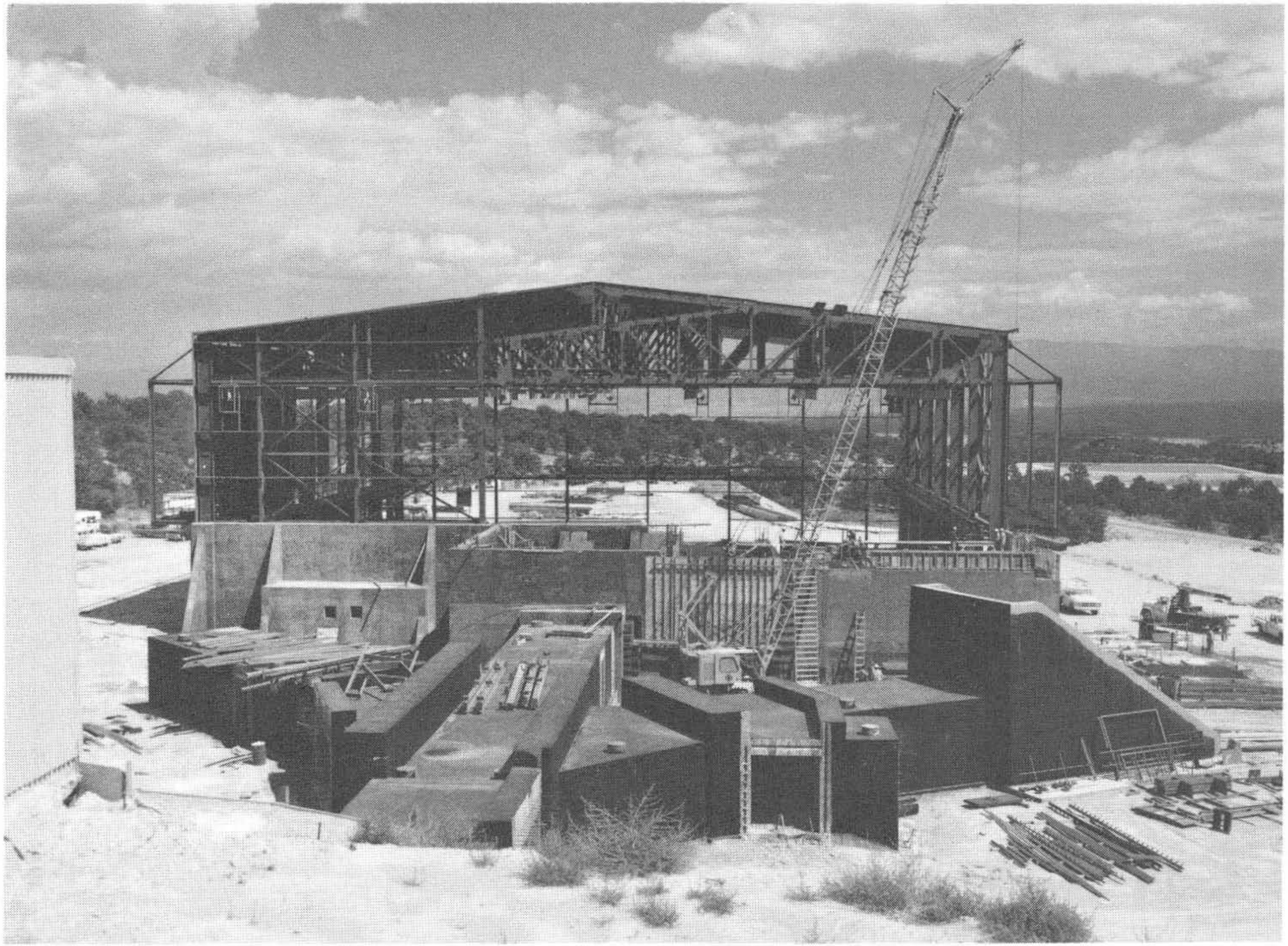

Fig. 6 Experimental area A as seen from the west in September 1970.

DISCUSSION

J. P. Blewett (BNL): Are H^+ and H^- ions accelerated simultaneously?

D. C. Hagerman (LASL): Yes. They go to different areas. The H^- ions are stripped after deflection and go to Area C. The H^+ ions go straight ahead to Area A.