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LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California
LOS ALAMOS • NEW MEXICO

Quarterly Status Report on the
Medium-Energy Physics Program
for the Period Ending July 31, 1968

UNITED STATES
ATOMIC ENERGY COMMISSION
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Report distributed August 29, 1968

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I. SUMMARY

Accelerator Structures

The design of the 201.25-MHz drift tube linac tanks is complete; it will be given to potential vendors for quotation as soon as possible.

Working drawings for the first one-fifth of the side-coupled accelerator copper forgings have been completed and submitted to potential suppliers for quotation. A table of dimensions is being developed for the final accelerator cavities.

Work has been initiated on the instrumentation and layout of the beam diagnostics area located at the 100-MeV transition point. Some attention has been given to the possibility of simultaneous negative and positive beam acceleration; this would require an additional 8 cm path-length for the negative beam at the transition.

The Electron Prototype Accelerator (EPA) has been operated for a variety of experiments during this quarter. Considerable effort has gone into control system studies, with experience being gained on operation of the accelerator system through the computer operations console.

RF Power Systems

A third generation 7835 plate blocker design was successfully operated for ~ 100 h at 3-MW output, 6% duty factor (DF). Although this is too short a time to permit a meaningful evaluation, it would appear that a solution may have been found to the blocker problem which has plagued the 201.25-MHz test stand for the past year.

A twin-triode, 7835 modulator has been in operation for several months and has been found to be fully compatible with the operational parameters dictated by a 1-mA average beam, 6% DF. A twin-tetrode version will shortly be available for evaluation.

Litton klystron S/N-1 has now been operated satisfactorily for nearly 800 h.

Considerable attention has been paid to the problems associated with making measurements in the waveguide system over the required range of complex reflection factors. Encouraging progress was made toward developing hardware and techniques that will permit measurements from which system interactions can be understood.

Accelerator Control and Instrumentation

During this quarter the major areas of effort of the Instrumentation and Controls Group were in the computer control of the EPA, the continued development of computer system and operational programs, preliminary design of the Injector and Accelerator Module controls, and further design development of interface equipment and special instrumentation.

Preliminary design work was started on the final controls for the Injector system, the drift tube accelerator section, and 805-MHz section of LAMPF. As criteria became available, lists were developed to determine the channel capacity required in the final equipment.

Accelerator Physics

The dc accelerating column was completed and installed on the 200-keV test stand. Initial tests on the combined performance of the ion source and column indicate that the beam quality will be considerably better than is required for the injector transport system and the linac.

A superconducting quadrupole doublet is being fabricated. A facility is being set up at the EPA for irradiating samples of materials for magnets, in order to assess the effects of radiation damage.

Experimental Area

On April 26, 1968, the AEC Advisory Panel on Accelerator Radiation Safety (APARS) reviewed LAMPF plans and progress. The report of this panel was highly favorable and can be summarized by the following quotation: "The Committee was generally pleased with the Los Alamos presentation and felt that a very excellent

job had been done, and that this presentation was probably the best which we have seen and heard at any other accelerator site."

A large part of the effort on experimental area design was directed towards the development of a target test system, based on EPA, the layout of the beam switchyard, investigation of designs for the stopped muon and fast pion channels, and of the high-resolution spectrometer facility. Also considered was the possible addition of an H^- beam from the accelerator. Some effort also was devoted to preparations for the Study Group on physics applications of LAMPF.

LAMPF Scheduling and Facility Construction

LAMPF PERT activities have been applied to updating and improvement. Several normal modifications were made. The PERT COST feature was implemented, and studies were initiated to explore longer range improvement potentialities.

Construction is about 40% complete on the Equipment Test Laboratory Building, 10% on the Injector and the 201.25-MHz Sector Building, and 20% on the second phase of Site Utilities. An underground telephone cable has been installed to the site, and the construction has started on the 115 kV Substation. Design activities were directed toward completion of Title II documents for the 805-MHz Sector Buildings and of the criteria documents for a new structure called the Operations Building.

Physics Research

An experiment on the production of pions and heavier mesons in the reaction $p + p \rightarrow d + x$ was carried out at the Zero Gradient Synchrotron at the Argonne National Laboratory. This work was done in collaboration with physicists at the University of Chicago, ANL, Carleton University and the National Research Council of Canada, and Nagoya University, Japan. The pi-meson production data have been analyzed, and the analysis of the heavier meson production is proceeding.

Plans are under way to mount an experiment on the Berkeley 184-in. cyclotron for the purpose of measuring pion production cross sections at energies and angles required for design of LAMPF.

Publications

"Resonant Side-Coupled Cavity Electron Accelerators," Proc. Intern. Conf. on High Energy Accelerators, Cambridge, Mass., Sept. 1967. Cambridge Electron Accelerator, 1967. CEAL-2000, p. 466.

"Stabilization of the Drift Tube Linac by Operation in the P1/2 Cavity Mode," *ibid.*, Cambridge Electron Accelerator, 1967. CEAL-2000, p. 167.

"Los Alamos Meson Physics Facility (LAMPF). (Description in Tabular Format)," *ibid.*, Cambridge Electron Accelerator, 1967. CEAL-2000.

"Coupled Resonator Model for Standing Wave Accelerator Tanks," Rev. Sci. Instr., **38**, 1583 (1967).

"Experiments with Mesons at Energies Below 1 BeV: A Bibliography," LA-3946-MS.

II. ACCELERATOR STRUCTURES

Introduction

The Electron Prototype Accelerator (EPA) has been operated for a variety of experiments during this quarter. Considerable effort has gone into control system studies, with experience being gained on operation of the accelerator system through the computer operations console. Several irradiations for Mössbauer studies of iron radiation damage have been made at 600- μ A average current, 21-MeV output energy, with the runs lasting up to 7 h. Operation has proved to be extremely stable.

Working drawings for the first one-fifth of the side-coupled accelerator copper forgings have been completed and submitted to potential suppliers for quotation. A table of dimensions is being developed for the final accelerator cavities.

Additional measurements have been made on the post-coupled linac tank, to investigate the fields associated with excitation of the post resonance during the turn-on transient. The results agree qualitatively with the expected power-carrying function of the post excitation and agree with the coupled resonator predictions. Further study, including study of the coupled resonator model predictions with strong second-nearest-neighbor coupling, is in progress.

The design of the 201.25-MHz drift tube linac tanks has been completed and it will be given to potential vendors for quotation as soon as possible.

An optimized set of quadrupole focusing conditions has been determined for the drift tube linac using the PARMILA Program. Currents to the quadrupole magnets have been specified to yield these conditions.

Extensive testing of the new split-yoke quadrupole magnet design has indicated no difficulties associated with the design. Some difficulty has been experienced with the stem-to-body drift tube braze joint, but this should be solved by a simple design change.

Work has been initiated on the instrumentation and layout of the beam diagnostics area located at the 100-MeV transition point. Some attention has been given to the possibility of simultaneous negative and positive beam acceleration; this would require an additional 8 cm pathlength for the negative beam at the transition.

805-MHz Side-Coupled Structures (LAMPF)

Cavity Parameters

Graphic plots have been completed of cavity dimension for the segments and clamshells as a function of beta. These plots are being used to construct drawings for forging and machining work.

A computer program which tabulates the geometric and electromagnetic parameters of each tank in the linac is under construction.

Correlation of the empirical data on the electromagnetic behavior of the test cells with the theoretical results generated by the LALA phase of the program continues to be excellent.

Mechanical Engineering

OFHC copper forging drawings for the first eight modules (Tanks 1-32) of the 805-MHz segments, tank heads, and coupling-cavity clamshells have been completed and submitted to potential suppliers for quotation. These 3550 forgings represent ~21% of the total required for the side-coupled structure.

Purchase requests have been written for all of the bridge coupler OFHC copper tank cylinder forgings, cup head forgings, stainless steel investment cast rf window flanges, head nozzle stainless steel castings, and vacuum bellows for coupler tuning slugs.

Attachment of Cooling Tubes to the 805-MHz Tank Sections

Work has been continued on the development of equipment and techniques for soft-soldering cooling tubes to waveguide tank sections. Cooling tubes will be attached to Model N as a test of the soldering procedure. In preparation for this test, fixtures have been built which will support Model N

Fig. 1. Post coupler excitation.

Fig. 2. Partial mode spectrum.

Fig. 3. Post coupler excitation and drive position.

in a small oven. Flats have been milled along the length of Model N to minimize the gap between the rectangular copper tubes and the model.

Construction of the large oven for LAMPF is under way. This oven is designed to handle the longest LAMPF waveguide tank section, and will be installed in the Equipment Test Laboratory Building (ETLB).

Post-Coupled Linac Studies

Cavity Transient Response

Some qualitative measurements on post-coupler excitation during fill time of tank fields have been made on the 26-cell 5 to 30 MeV drift tube linac model. An electric probe was installed on three of the post couplers with the end of the probe very nearly flush with the face of the tab on the post coupler. These post couplers were installed in positions No. 3, 13, and 25. Figure 1 shows the excitation of post coupler No. 13 under the conditions of no end-cell tuning errors and an end-cell tuning error of 500 kHz. It will be noted that without end-cell errors the post coupler excitation is independent of the field level of the main cells, and depends only on the final equilibrium value. The frequency of the ringing at the beginning of the pulse is ~ 8 MHz. The frequency spacing between the operating mode and the nearest mode above and nearest measurable mode below is ~ 8 MHz as shown in Fig. 2. With end-cell tuning errors the post coupler signal has the same shape as the main cell signal.

Figure 3 shows the effect the position of the rf drive to the tank has upon the signal from the post couplers. On each picture the end-cells were adjusted to give the minimum steady state excitation signal from the post couplers. Here again, the 8-MHz ringing is evident on the signal from post coupler No. 13, but it does not show up on the signals from the post coupler at the ends of the tank (No. 3 and No. 25).

Drift Tube and Quadrupole Magnet Development

A prototype split yoke design was made for one of the Group I model quadrupole magnets. This design permits the leads to exit from the

magnet at the midpoint of the yoke instead of around the end of the yoke as in conventional designs. Two significant improvements are realized by this modification: one, the stem-to-body braze is greatly simplified and, two, the danger of shorts is eliminated where the leads bend around the end of the yoke.

Harmonic analysis measurements of the split-yoke and solid-yoke type magnets were compared. The new design actually exhibits a slight improvement in the quadrupole harmonic. The pole design is unchanged.

Since the main purpose of the yoke modification was to improve the final stem-to-body braze, parts from two earlier drift tube assemblies were combined and modified to expedite the braze study.

The magnet was brazed within the body and bore tube assembly. Leak checking at this point showed all six joints to be vacuum tight. The body assembly was then brazed to the stem assembly in an inverted position in an effort to prevent misalignment during the heat. The joint between the inner stem tube and the body leaked, although visual inspection indicated the alloy had wet properly and the joint appeared to be excellent.

The brazing temperature employed for this stem-to-body joint is too low to eliminate the formation of carbide precipitates from the stainless steel, consequently the stainless steel is flashed with nickel. This technique is highly dependent on the quality of the nickel flashing. Parts are now being fabricated for another brazing evaluation in which the stainless steel inner tube will be replaced with a copper tube; this should enhance the possibility of a successful stem-to-body furnace brazed joint. The single leak in the previous assembly occurred between the copper body and the stainless inner tube.

Drift Tube Quadrupole Magnet Field Surveys

Each of the six prototype quadrupole magnet designs for the 201.25-MHz linac was subjected to extensive field surveys on the new magnet measurement stand. Measurements were made at currents of 160%, and greater, than design

values. The purpose of these tests was to compare the analytically predicted parameters with the measured operation values and to determine effective length values for further PARMILA studies. These characteristics are compared in Table 1. In all cases the magnets proved to satisfy the design requirements and even the most marginal design (Model I) is capable of providing a 15% increase in gradient without saturating.

Rotating Coil Magnet Measuring Device

Work has been continued in testing and improving the rotating coil magnet measuring system, as well as in using this system for some quadrupole magnet testing. A low-frequency oscillation in the amplitude of the output harmonics is still being observed, primarily with the small-diameter coil assembly. It has been found that these effects are not a problem when using the larger coils so that the system is now ready for testing the larger quadrupole magnets.

A variable-frequency power source (power amplifier-signal generator system) has been assembled and used to power the drive motor. The amplitude of the modulation observed in the harmonic signals was reduced by operating at frequencies other than 60 Hz. This amplifier-signal generator system also isolates the drive motor of the rotating coil system from transients in the ac power line. An attempt is being made to eliminate this modulation problem for the smaller coils by replacing the drive motor with a more suitable type and installing a new flywheel.

One useful application of the rotating coil system was to verify that a change in the Alvarez quadrupole magnet design, in which the conductors were brought through the yoke (split-yoke design), did not impair the quality of the quadrupole magnetic field. A multipole spectrum of the total harmonic content for this split-yoke design is shown in Fig. 4. The upper and lower bounds of the cross-hatched areas on the histogram are the maximum and minimum values of a given harmonic amplitude. This variation is due to the low-frequency modulation previously described. The numbers above the histograms are the phases of the harmonics. A comparison of this spectrum with that

Table 1.
Comparison of Design & Measured Parameters

PARAMETER	Quadrupole Magnet Models											
	INITIAL		I		II		III		IV		V	
	D	M	D	M	D	M	D	M	D	M	D	M
Current (A)	462	460	702	700	474	475	314	310	454	450	408	408
Gradient B' (G/cm)	5493	5373	8335	7769	5632	5984	3725	3858	2444	2467	1007	1024
Strength (kG)	9.45	14.09	21.8	26.31	21.3	27.8	20.4	24.0	19.2	22.3	16.4	18.0
Magnet Length (cm)	1.722	-	2.616	-	3.777	-	5.482	-	7.876	-	16.286	-
Effective Length (cm)	-	2.621	-	3.379	-	4.624	-	6.223	-	9.086	-	17.52
Voltage (V)	1.42	1.40	2.38	2.37	1.80	2.10	1.38	1.42	2.05	2.11	2.77	2.87
Resistance (Ω)	.0031	.0030	.0034	.0034	.0038	.0044	.0044	.0046	.0045	.0047	.0068	.0070
Power (W)	656	643	1666	1660	853	1000	432	440	932	950	1129	1175

D = Design

M = Measured

Fig. 4. Integrated harmonic spectrum.

obtained from the older magnet (solid-yoke) design indicated that the split-yoke design has a little less harmonic content, presumably due to the larger yoke thickness employed. Thus, the quality of the fields was not impaired by this change.

Four-Foot Drift Tube Model (201 MHz)

The ceramic well type monitor loops were installed in the 4-ft drift tube model and have been found to be vacuum tight. These prototype loops, designed for use in LAMPF, will subsequently be evaluated for electrical malfunction under high-level rf power.

Silver-plated spring ring contactors have been installed in the tuning slug and the slug cycled over a small range near rated rf power and field levels without evidence of burning or sparking. The zirconium-copper wire has been received and will be wound into contact springs for evaluation as tuning slug rf contactors at high-level rf power.

Drawings of the latest tuning slug design incorporating a stepping motor drive are ~ 90% complete and most of the purchased items required for this slug have been received.

The water supply carts for the 4-ft model are being modified to provide parallel control systems for both power on and power off conditions. The new water control valve design with a stepping motor drive is nearing completion and will be evaluated in the parallel system arrangement.

The prototype post coupler which permits axial and rotary positioning under vacuum has been fabricated and installed. Axial positioning within 0.001 in. is possible throughout a 1-in. range of travel. Tab rotation is obtained by magnetic coupling through the vacuum shell using a portable electromagnet. This prototype post coupler has been operated at 200 kW peak power and 10% DF at three different positions with no evidence of sparking. Tests at higher power levels are planned.

Electron Prototype Accelerator

All eight thermistor flow switches installed in the EPA cooling system failed after ~ 30 days of operation. It appears that the epoxy material sealing the thermistors leaked, thus causing the leads to short out. Redesign of the flow switch using a different type of thermistor and low-melting-point solder is now in process.

Two refrigerant (Freon-12) cooling systems have been received and will be installed on the target area cold trap and vacuum pump.

Drift Tube Linac Resonance Control

A series of experiments is being designed which will involve digital as well as analog control of the 4-ft drift tube linac model. The aims of the experiments are as follows: (1) To try out the digital as well as the analog component of the resonance control scheme proposed for the drift tube linac portion of LAMPF. (2) To investigate if better control can be obtained when using the digital equipment to drive the valve motors directly, rather than when driving the set point of the analog equipment; the latter would then serve as backup. (3) To use the computer to modify the signals received from the 4-ft model so as to simulate control of the longer tanks of the actual linac more accurately than can be done with the 4-ft model alone.

The EPA control computer will be used. Connections to the computer will be made by way of the Module 1 interface unit. The analog controller units are being repackaged in a form which can be used on the LAMPF machine if desired.

Estimates of the characteristic thermal response times for the tank walls, the drift tubes, and the recirculating water loops for the LAMPF drift tube linac tanks are being calculated. The tank wall response times will not be greatly different from that of the 4-ft model.

Accelerator Physics Beam Dynamics Studies

Drift Tube Linac

After selecting the principal design parameters of the drift tube linac, which are determined primarily by the rf requirements, an optimum quadrupole focusing system must be designed. The quadrupole strengths must be selected within the limitations imposed by the size and shape of the drift tube shells which house the lenses. These strengths were chosen with the help of the stability diagram and by tracing particle trajectories through the machine to study the effects of varying the magnet strengths. Recently a series of such particle dynamics runs have been made using the PARMILA program.

Due to the linac geometry and space charge, the radial defocusing forces at low energies are the largest experienced by the beam. It is desirable, therefore, to have strong focusing lenses in this region. Since these magnets are necessarily short, their gradients must be high, and are limited by the ability to cool them sufficiently. Setting the first quadrupole gradient as high as possible, the beam is allowed to grow slightly through tank 1. Permitting beam growth conserves power and makes an easier task of beam matching between tanks 1 and 2, where the beam size is slightly larger.

The power required to maintain a given gradient for a larger quadrupole bore radius increases as the fourth power of the radius. Since the bore radius in tank 2 increases at cell No. 60, and it is desirable to maintain smoothly changing focal properties, there must be a considerable

Fig. 5 (below). Cell number between tanks or quadrupole groups.

Fig. 6 (above). Matching between tanks and quadrupole groups.

Fig. 7. Quadrupole gradients for the drift tube linac.

Fig. 8. Wavelengths of longitudinal and transverse oscillations in linac.

power increase at quadrupole No. 60. Considering the cooling capabilities of the system, this quadrupole is set as high as possible, whereas the rest of the magnets in tank 2 are set such that the beam grows slowly and smoothly.

In tanks 3 and 4, quadrupole magnets occur only in every other drift tube. Gradients for these magnets were chosen in order to produce a beam of approximately constant size through the two tanks while keeping powers at a low level. It is not necessary to expend the power required to reduce the beam size further.

Because of the fringe fields of each quadrupole, a particle will see a magnetic field over a distance that is longer than the actual length of the iron. The particle dynamics program, however, treats each magnet as though it produces a constant field over some effective length. A prototype magnet of each length group has been made, its field surveyed and effective length determined. These effective lengths, which are given in Table 1, were used in the present study.

Since the length of each magnet is different from $\beta\lambda/2$, the gradients were adjusted in such a way as to preserve the focal properties of the periodic system.

There exist discontinuities in the focal system at each change in magnet length, and each new tank, especially between tanks 2 and 3 where the periodicity of the focusing structure doubles. It was necessary to write a special program to "match" the beam through the discontinuities by adjusting the four adjacent quadrupole strengths.

The beam profile without matching is plotted in Fig. 5 and that with matching is shown in Fig. 6. Plots of the quadrupole strengths for (1) a system in which all magnets are of length $\beta\lambda/2$, and (2) the drift tube linac with matching between tanks and quadrupole groups are given in Fig. 7.

The wavelengths of the longitudinal λ_φ and transverse λ_t oscillations are shown in Fig. 8. The wavelengths are given in terms of numbers of cells as a function of cell number. There are about seven transverse oscillations in the drift tube linac; two are in the first tank, three in the second tank, and one in each of the last two tanks.

Split Phase Space Beams

One method proposed for providing multiple beams in the experimental area is to inject two (or more) beams into separate regions of the $x - x'$ phase space. If the transverse focusing and defocusing forces are sufficiently linear, the separate regions of the $x - x'$ phase space will retain their identity and can be made to come out of the linac with a clean separation between them. If this is the case, it would be possible to separate the beams by using a septum magnet, after which the beams could be transported to different experimental setups in a conventional manner.

Beam dynamics calculations indicate that this process does indeed work for beams of low intensity (1 mA during the pulse or 0.06 mA time average). At full intensity, however, space charge effects destroy the linearity of the transverse forces to such an extent that the separate regions in $x - x'$ phase space are no longer distinguishable. In spite of this result, the split beam approach will be developed in order to provide multiple beams at low intensity.

Stray Magnetic Fields

The effect of a stray magnetic field on the position of the beam in the linac has been analyzed. In a linac with no stray field, the axial ray is the equilibrium orbit. With the application of a uniform stray field, the equilibrium orbit is displaced until the focusing field just compensates the effect of the stray field.

In the drift tube linac, the effect of a stray field is of most concern in tanks 3 and 4, where the quadrupole magnets are limited to every other drift tube. In this region a stray field of 10 G will displace the equilibrium orbit (and the beam as a whole) a distance of 1 cm.

In the side coupled linac, the region of most concern is in sectors 33 through 104 where there are only two quadrupole doublets per module. In this region a stray field of 4 G will displace the beam by 1 cm.

A 1-cm displacement of the beam in either linac will impair its performance by either (1) producing beam loss or (2) greatly

reducing the tolerance on quadrupole magnet alignment. On the other hand, a 0.5-cm displacement should be acceptable.

Steering magnets can, of course, be employed to restore the beam to the axis of the linac. If both positive and negative beams are being accelerated, a stray magnetic field will displace the positive beam one way and the negative beam in the opposite direction. The steering magnetic fields that are required to bring the positive beam back to the axis will simultaneously bring the negative beam back.

Transition Region and 100-MeV Diagnostics Area

Design work has begun on the beam transport system for the 5-m long transition region between the drift tube structure and the side coupled structure. An innovation in this area has recently been proposed which will make it possible to accelerate both positive and negative proton beams through the entire facility; the problem is that if the side coupled structure is phased properly to accelerate the positive beam from the drift tube structure, it will be phased improperly for acceleration of the negative beam. This problem can be rectified by delaying the negative beam for half a cycle (0.625 nsec), and the proposal is to do this by diverting the negative beam through a path that is 8 cm longer than that for the positive beam.

This side-track for the negative beam amounts to a major complication in the design of the transition region. A set of magnets which will accomplish the task are shown in Fig. 9. The positive beam is deflected only a few degrees at each bend and passes through the "bucket rotator," which acts like a buncher to reduce the longitudinal extent of the beam bunches, and thereby improves the longitudinal acceptance of the positive beam in the side coupled structure. The negative beam is bent successively about 20° away from the axis, 40° towards the axis, and another 20° to replace the beam on the axis. This beam, too, should go through a "bucket rotator" but there is not room for one. The consequence of this is that a certain fraction of the negative beam may be unacceptable

Fig. 9. Magnet arrangement for negative beam sidetrack.

to the side coupled structure and might be lost. Since the negative beam will be a low-intensity beam, the loss of a small fraction at this point is considered acceptable. The optics of both beam paths are being studied with the TRANSPORT code.

III. RF POWER SYSTEMS

Introduction

Considerable effort was devoted to the problems associated with making measurements in the waveguide system over the required range of complex reflection factors. Encouraging progress was made toward developing hardware and techniques that will permit measurements from which system interactions can be understood.

Litton klystron S/N-1 has now been satisfactorily operated for nearly 800 h.

The first of five 1.25-MW klystrons contracted to Varian is expected to be delivered by mid-September for LASL evaluation.

All of the design work for the Experimental Test Laboratory Building (ETLB) test stands was completed. All major component procurement was initiated and/or completed.

A third generation 7835 plate blocker design was successfully operated for ~ 100 h at 3-MW output, 6% duty factor (DF). Although this is too short a time to permit a meaningful evaluation, it would appear that a solution may have been found to the blocker problem which has plagued the 201.25-MHz test stand for the past year.

A twin-triode, 7835 modulator has been in operation for several months; it has been found to be fully compatible with the operational parameters dictated by a 1-mA average beam, 6% DF. A twin-tetrode version will shortly be available for evaluation.

RF Control Studies

Overall System Design

A complete set of drafting procedures was compiled and is being evaluated by use on the ETLB installation.

An exercise of the wiring code on the 201.25-MHz test stand was completed, resulting in consistent terminology and some modifications. A second complete listing for this test stand is nearly completed, using the revised procedures. The code will then be used for the ETLB installation.

Frequency and Phase Reference Studies

The second unit of the new hybrid multiplier chain was completed and operated for some 550 h. An output amplifier was incorporated in this new design so that the output from the multiplier assembly is on the order of 5 W. This increase in output power raises the level in distribution lines well above any noise pickup that might occur in the transmission lines between the multipliers in the screen room and the amplifiers which are outside in the noise environment of the Mockup Building.

During this quarter a Hewlett-Packard Model 105AR Quartz Oscillator designed for the required frequency was received and placed in service as the driver for the multiplier chains. This provides a long-term stability of better than 5×10^{-10} . There is now an option of the extreme stability provided by the Hewlett-Packard reference or the old reference which is capable of 3×10^{-7} stability and can be varied or frequency modulated by about 70 kHz.

A second set of driveline amplifiers is now in service. The original string of amplifiers used four stages to attain 500 W, but improvements in amplifier design and the higher output from the multipliers now gives the required 500-W output with only three stages. This second set of amplifiers is scheduled for installation in the ETLB late in 1968. The first four amplifiers all

have over 3000 h service with only one failure which involved a filament contact that lost tension due to heating and annealing.

RF Phase and Amplitude Control Studies

Data were obtained on the Electron Prototype Accelerator (EPA) system using the computer-based collection and reduction system described in the preceding quarterly report (LA-3946-MS). Analysis of the results indicates that the method holds great promise for making measurements from which the system interactions can be understood.

The major difficulty in making these and other types of measurements in the waveguide system is the lack of a waveguide directional coupler whose behavior is consistent over the range of complex reflection factors involved. Considerable effort was spent on this problem during the quarter, and encouraging progress made. A four-probe coupler with $\lambda_g/4$ probe spacing and $5\lambda_g/4$ external phasing stubs was constructed and tested. The directivity of this coupler was at least 30 dB and agreement with slotted line measurements to VSWR's of about 3:1 was quite good. It was found that an exact $(2n + 1)\lambda_g/4$ spacing was not optimum due to geometrical and physical realities; modifications are in progress to optimize this coupler. A four-hole version of a conventional side-coupled waveguide coupler is also under development.

Theoretical explorations of the problem resulted in increased understanding of the effects of nonideal components on measurements involving both the verification of coupler performance and their use in making the system measurements described above. Several alternative methods for measuring coupler parameters and for externally tuning the coupler outputs for maximum directivity were developed and will be used in future measurements.

An attempt to resolve the remaining discrepancies between the slotted line and the four-probe coupler led to a detailed investigation

Fig. 10. Pure time delay (or transport lag) in the EPA system.

of the slotted line, and it was found that significant uncertainties were introduced by this device. The major problem appears to be the effect of the slot ends; they are essentially square and the line is not long enough to allow measurement of a full pattern in an undistorted region. A design for a longer line with attention to end effects, slot radiation, probe capacitance, and other details was worked out and construction of a new line will begin during the next quarter. An accurate slotted line is believed essential in that it is inherently more straightforward to construct than a coupler and thus can serve as a reference for comparison. The slotted line is, however, cumbersome for rapid measurements where the coupler can be used to advantage.

Preliminary measurements were made of EPA system frequency responses, rise times, and other characteristics. Final measurements in this area also await the development of a good waveguide directional coupler. EPA system time delays were measured by several different methods, with good correlation; the results are shown in Fig. 10. In this figure, T_0 to T_4 are the time delays in the major components; other delays noted are for cables and waveguide runs.

A study of phase shifters was initiated to find an improved design which will provide better linearity at higher power levels. Commercial shifters now in use are limited to 100 mW input for reasonably linear characteristics. This low input is attenuated by the insertion loss of the

device, making the output level marginal for drive requirements of the interface amplifiers. At this time there are two lines of investigation which appear promising; one involves time delay techniques and the other involves a four-port triplate coupler with tuned terminations at two of the ports. The latter approach is an extension of that used in the commercial shifters presently on hand.

A motorized amplitude controller set-point potentiometer and remotely resettable logic were added to the 1.25-MW klystron system. The complete EPA rf system can now be brought to full operation under computer control.

Logic and Protective Circuitry

Circuitry was developed and tested to interface fault-protection-logic fault signals and reset commands to the computer.

Recent problems with ignitron breakdown in the 201.25-MHz amplifier crowbar resulted in a considerable effort to isolate the cause. The present solution appears to be to limit peak ignitron current to ~ 8000 A. Poor Klystron life resulted in the replacement of that component with a high-voltage Silicon Controlled Rectifier (SCR). The SCR is limited by di/dt ratings in the application. A new "regenerative gate" SCR capable of passing $600 \text{ A}/\mu\text{sec}$ di/dt transient will be investigated for this ignitron-triggering application.

Several crowbar trigger chassis were constructed by an outside vendor, using LASL drawings and components, for the 805-MHz ETLB systems. The work was done without a prototype; and so required very detailed diagrams to be supplied concerning wiring layout, etc. This will not be done again, since the extra paperwork involved more effort than building a prototype. Moreover, since a prototype was not first built and tested at LASL, several electrical problems were not found until delivery.

The crowbar using the modified Sherwood spark gap was installed as a permanent part of the 805-MHz, 1-MW klystron test stand to replace the marginal commercial unit that had been used for several months. Prototype trigger and logic chassis will complete this crowbar modification program.

805-MHz Power Amplifiers

1.25-MW Klystron Program

Klystron S/N-1 has now been run in excess of 798 h and performance is satisfactory. Operation has been primarily to provide power for the EPA and to make certain experiments related to amplitude and phase control.

The blocking oscillator modulator circuit mentioned in the last report was completed and operated satisfactorily at a DF of 6%. Design theory and data on this regenerative modulator have been tabulated and will be issued shortly in report form. In addition to further work on this circuit, the original modulator circuit is being tested with a 14-mil transformer core substituted for the previous 2-mil core. If the 14-mil core is satisfactory, the circuit cost will be reduced by \$700.

Work has been continued on modification of klystron test stand components to make them more reliable or more nearly prototype. The high-voltage capacitor room and crowbar were completely rebuilt and the entire assembly tested to 100 kV in anticipation of receiving new higher voltage klystrons from Varian. A new 100-kV voltage divider accurate to 0.01% was received and tested. The filament time delay chassis was rebuilt using an Agastat time delay to replace a Cramer device. A cheat switch and warning light were added to make completion of the interlock chain simple, without the danger of damaging the time delay. A single power supply and pulser chassis was built to take the place of separate pulser and power supply packages. A meter relay was added to monitor plate current of the modulator tube for protection against bias failure.

Varian estimates that their first tube will go on the pumps around mid-August, and it should be delivered at LASL about Sept. 15, 1968.

The loan of a magnet assembly is being negotiated with Litton Industries so that Litton's S/N-2 can be put into service.

Preliminary design was completed of slow controls and ac distribution for the ETLB klystrons. Long lead-time items were ordered and preliminary schematics and parts lists were completed.

The theoretical investigation was expanded in the following areas. A ballistic code was written and tested to analyze the axially symmetric multicavity klystron. The error accumulation and propagation were investigated for several numerical integration procedures, and it was concluded that the Runge-Kutta methods are best. An output gap subroutine is being written to study the energy conversion process under large signal conditions. A space charge code was written to calculate the appropriate Green's functions for the radial geometry. These functions will be used to calculate the axial space charge forces in the main program.

Experimental Crossed-Field Amplifier (CFA) Program

The two-stage, 1.25-MW, 805-MHz Amplitron (QKS1493) S/N-2 which failed last fall was repaired by Raytheon and returned to LASL. The failure was due to a leak near the vacuum pump. The repaired tube still showed signs of being a virtual leaker although the vacuum was good enough for test purposes.

S/N-2 was installed in the test stand along with the modified electromagnet system described in LA-3884-MS. The immediate effect of these modifications, which improved the uniformity of the magnetic field about the centerlines of each Amplitron stage, was to widen the dynamic operating range. Thus, mode changing of the CFA could be achieved with ease by voltage control alone, making the operation of the tube easier than before. Nevertheless, S/N-2 did not perform well. Tests were made with E-H and double stub tuners in both the input and output lines and with the tube run in both the forward and reverse directions, with appropriate reversals of the magnetic fields. Of chief concern was the rf spectrum of the output signal which was sampled with a spectrum analyzer.

The design changes incorporated into S/N-2 indeed eliminated the 950 and 1050-MHz resonances (back-wall modes) which plagued S/N-1. However, the normal mode excitation of the 750-MHz resonance persisted. It was possible by experimenting with shunting bars to alter the magnetic field between input and output parts so

that the feed-forward mechanism which drove the resonance was reduced. This allowed the spurious 750-MHz signal to be decreased to 1% (-20 dB, power) of the 805-MHz carrier signal. But this could be done with one stage only. No amount of such experimentation produced equivalent results with the second stage. The spectrum analysis data was provided to Raytheon to aid in the design of the forthcoming single-stage, 1.25-MW Amplitron.

The testing of the experimental CFA which was begun at the end of the preceding quarter has been continued. An accurate scan of the operating frequency range (700-900 MHz) was conducted for three test cathodes: the 6-cm platinum plated cathode and two beryllium cathodes of 4.5 cm and 3.6 cm diameters. The tube continues to amplify at near (depending on the cathode diameter) the three frequencies the cold-probe results indicated it should, namely 715, 826, and 851 MHz. The frequency at which the tube amplifies is also affected by the klystron tuning and drive level; this suggests bad matching between the external circuit and the slow-wave structure. The most powerful rf generation is near 815 MHz. Various power gains were achieved, the highest being 15 dB with the 4.5-cm beryllium cathode. However, at the frequency where this was achieved (847 MHz), the rf power level was very low.

Difficulty in measuring rf power output is due to the very low DF (0.15%) at which the tube must be run because it has no effective cooling system. Early speculations that the cold-emission of the Pt-plated cathode might be inadequate were dispelled when the operating region around 851 MHz was thoroughly explored. Currents drawn from the modulator during the dc pulse ran as high as 25 A at an applied voltage of 30 kV, representing 650-kW peak power delivered to the tube.

To measure rf power generation in this region, the DF was run out to 3% briefly and the flow rate in the water load reduced from its normal 6 gpm to 1 gpm. It was found that peak rf power generation did not occur at peak modulator current, but rather at a current of 3.7 A. Here, with a dc voltage of 20.2 kV, 21.9 kW of peak power were produced at a circuit efficiency of

about 29.3%. Although this power level is still low and the efficiency poor for a CFA, the dynamic range in dc electric field and magnetic field were quite large and the tube responded like a typical CFA.

In an effort to increase the rf power generation of the experimental CFA, modifications are being made to the input and output waveguide sections. Long tapers are being fabricated to improve matching from the main waveguide to the slow-wave structure cavities. At the cavity end of the taper, a thin iris is installed which can be enlarged if test results so indicate. In addition, coupling between cavities has been increased by drilling slots down the sides of the cavities, thus allowing the H-field to couple between cells more readily. These coupling slots have the effect of moving the π -mode resonance into the 805-MHz region, as indicated by the cold-probe model.

The general shape of the dispersion characteristic is in agreement with that predicted by an equivalent circuit analysis of a resonant ring of parallel LC resonators coupled to each other through the anode-cathode interelectrode capacitance and a mutual coupling factor. The equivalent circuit model also accounts for the observed change in resonant frequencies with cathode diameter as attributable to the change in this interelectrode capacitance.

201.25-MHz Amplifier Program

Encouraging progress was seen during this quarter in the performance of improved components. The new machined aluminum output cavity continued to operate very satisfactorily. The new water-cooled input cavity center conductor was installed; it lowered the difference in temperature between the lower and upper sections of the amplifier cavity from 45 to 20°F. A ceramic output cavity pressure window was installed and run with varying degrees of success. There are none of the disturbing temperature effects encountered with the rexolite window, but there have been some discrepancies in the rf efficiency data from day to day that have not as yet been explained. The teflon filament insulator in

the cavity was replaced with one of G-10 fiber glass, thereby eliminating water seepage problems around the filament leads.

A new teflon insulated upper blocker received from Continental Electronics has now been in service for enough time to be very encouraging. There have been no high-voltage arcs due to insufficient creepage paths and no apparent corona damage to the teflon dielectric. It appears that a solution may have been found to the blocker problem which has plagued the program for the past year.

The prototype 14-in. coaxial line was placed in service and tests run to evaluate its performance. It was necessary to eliminate the disk-shaped rexolite center conductor supports in order to cut down the line losses. Work is presently under way to design new lightweight supports which should have negligible effects upon line impedance and losses.

The fabrication contract with EG&G was used to construct a prototype set of power supplies for the 201.25-MHz Intermediate Power Amplifier (IPA). These were received and placed in service in the test stand. The test stand is now an essentially prototype unit as far as peripheral power supplies and control systems are concerned.

Experiments were run to determine the extent to which the output power of the 7835 could be modulated by modulating the drive into its cathode. It was found that it was possible to modulate about 25% below saturation before instability resulted. This controllable range limit is, however, uncomfortably close to that required to cope with beam loading (21%).

Experiments were also made to determine if both the IPA and the 7835 power amplifier could be operated from the same energy storage bank and the same hard-tube modulator. It was found that this technique is possible if trailing-edge shaping is used on the IPA drive pulse so as to keep the drive on slightly longer than the 7835 plate current. By using this technique operation is stable, but without it, i. e., letting 7835 drive and plate current turn off simultaneously, the 7835 oscillates at 2800 MHz. Although such a configuration results in a simpler system as well as easing the dynamic

range required of the modulator, the addition of the pulse-shaping circuitry does result in a significant, but not intolerable, degradation in the modulator response time. At the moment the technique as well as the drive modulator have been dropped from active consideration in view of the excellent performance of the twin-triode modulator presently in use.

201.25-MHz Modulator Program

In addition to the modulator oriented experiments mentioned above, work has been continued on the twin-triode modulator using the ITT 7560 tubes as well as on the twin-tetrode unit using Eimac 4CW250,000 tubes. About 60 h at high DF have been logged on the 7560 modulator with no apparent degradation in the grid emission characteristics. Except for occasional internal tube arcs these tubes have operated very satisfactorily. The tetrode modulator is not yet finished due to delays in receiving transformers, but it should be ready to test very shortly.

A prototype modulator for the two 175-kW amplifiers of module one was completed. This unit, utilizing video drive to an Eimac 4CW100,000D tetrode, performed very well in all tests to date and should be the final design.

A 4616 screen-grid modulator was constructed to meet full prototype requirements and is now being used in the test stand. The circuit will also be used as a deck amplifier in several high-voltage modulator configurations. The modulator incorporates a chassis design that combines quick access to components and excellent shielding.

High-Voltage Power Supplies

Purchase orders have been placed for all power supply components for the ETLB. The voltage regulator and transformer/rectifier unit is being procured from General Electric. Two vacuum breakers are being procured from Trayer Engineering Corporation. Delivery of the breakers is expected in Dec. 1968. The voltage regulator and transformer/rectifier unit should be delivered in Feb. 1969.

One of the vacuum breakers, along with an existing voltage regulator and transformer/rectifier unit, should be available for installation by the end of the year. This will provide power for one klystron. The second power supply should be available for installation early in March 1969. The second supply will be capable of powering three klystrons.

The energy storage capacitors required for the ETLB have been received.

Traveling Wave Resonant Ring

Work was begun on the 1.25-MW traveling wave resonant ring which will be used as a high-power testing device. The source of power will be a 100-kW klystron which was modified to the one-tube modulator configuration used for the larger klystron. A crossguide coupling was constructed with a removable 9-in. square coupling plate at the junction of the two waveguides. This coupling plate will facilitate the testing of various methods of coupling the klystron power into the ring.

The first coupling plate had two $1\frac{15}{16}$ -in. holes diagonally spaced 5 in. on centers. Test on this configuration indicated a coupling of ~ 39 dB and a directivity of about 6 dB. A new coupling plate was made utilizing the Moreno crossguide configuration of two crossed slots in place of the holes in the first plate. These crossed slots are $\frac{1}{4}$ -guide wavelength apart on centers. Test on this coupler resulted in ~ -27 dB of coupling and 12.5 dB of directivity. The data indicate that a spacing greater than $\frac{1}{4}$ -guide wavelength will result in better directivity.

Cooling Water System Design

The final drawings of the 805-MHz rf water console for the ETLB were completed and a purchase request written for three units. This final design incorporates changes such as replacing Shur-Flo flow switches in orifice flange bypass systems with the McDonald FS1 flow switch. The Shur-Flo switch is not satisfactory in this application because it has a higher pressure drop

at rated flow than the orifice plate does. Also it was previously thought that for interlock certainty two Shur-Flo units would be installed in series in those circuits not having orifice plates and the associated Barton flow meters. Here again the high pressure drop across the Shur-Flo would not allow this. Instead a single unit will be used with the possibility of installing a McDonald unit in series in the future if it becomes necessary. Another significant change was the removal of the throttling valve handles from the console front. Doors on the console will be used for access to valve adjustment in the final design.

IV. ACCELERATOR CONTROL AND INSTRUMENTATION

Introduction

During this quarter the major areas of effort of the Instrumentation and Controls Group were in the computer control of the Electron Prototype Accelerator (EPA), the continued development of computer system and operational programs, preliminary design of the Injector and Accelerator Module controls, and further design development of interface equipment and special instrumentation.

Further progress in the computer control of the EPA was made with the addition of two master control programs to handle the turn-on and shut-down of the machine. Numerous other programs were added to the system. Additional operating experience was gained from frequent turn-on and beam steering exercises. The interface hardware operated with greater reliability during this period.

The design and construction of local control and interface equipment for the computer control of the Ion Source Test Stand has provided a means to test the use of various control system building blocks in an actual application. This includes the packaging of controls on a modular basis and the wiring of these controls in a LAMPF standard rack using standard terminations and wiring techniques.

Preliminary design work was started on the final controls for the Injector System, the drift tube accelerator section, and the 805-MHz section of LAMPF. As criteria became available, channel lists were developed to determine the channel capacity required in the final equipment. Special interface and instrumentation problems were also studied.

Considerable progress was made in the development of the designs of the interface equipment and the analog data acquisition system which will lead to final prototype design, fabrication, and test. The logic design of the Remote Information and Control Equipment (RICE) has been simplified while maintaining the overall system capability. The incorporation of the Module Interface Unit into the RICE I/O unit has been both an economical and technical success. Prototype versions of the

analog data acquisition system have performed satisfactorily during initial tests.

EPA Computer Control System

Introduction

The computer control system for the EPA is an experimental prototype of the control system for the LAMPF accelerator. It is being used to develop programs to operate an accelerator, to evaluate equipment which interfaces between the accelerator and the computer, and to design an accelerator operator's console.

Control Computer

Several pieces of computer equipment required attention during this past quarter. The disk had an access overshoot problem which was overcome by logic modification. The high-speed paper tape reader required a replacement part plus some tune-up of the electronics. The display scope high-voltage power supply started arcing because of a combination of dust and high humidity. The problem was cured by cleaning, and this procedure was added to the maintenance schedule. An intermittent short in the computer mainframe associated with unit code 12 was diagnosed and corrected.

The digital clock and calendar peripheral units to be used by the new executive program were completed and installed. The first attempt at installation created a timing problem between the disk and the main frame which was resolved by moving the clock and calendar units to new locations on the I/O cable. The units are currently undergoing tests by the programmers prior to putting them on-line.

Programming

Further progress in implementing computer control of EPA was made with the completion of two master control programs to handle the turn-on and shutdown of the machine. Each program is conversational in that it asks the operator what subsystems are to be sequenced. Special accelerator states such as Standby, Ready for Beam, Low Beam On, and Access can be specified

with a single operator response. All of the appropriate interlocking is built into the control programs. The progress of these programs can be monitored on the display scope where a graphical display indicates the status of EPA by brightening the labels associated with summary data channels. The operator can control the status of the accelerator by selecting desired options with the light pen.

Work continued on the beam steering program. The beam centering algorithm was optimized until it could center the beam in either of the first two current monitors in 3 min or less. Further increases in speed are possible only through the use of machine language programs. The optimization effort was temporarily shelved in favor of generalizing the program to handle bipolar magnet power supplies so that it could steer the beam through the whole accelerator. This task was completed satisfactorily and the final remaining goal is to devise a procedure to maximize the beam current by adjusting the focus magnets.

The addition of an analog command channel to control the rf power output of the 1.25-MW klystron made it possible for the computer to condition the cavities for rf power. A program to do this job was written and tested successfully.

All the programs cited above were written in a special control language which is understood by an interpreter program that makes the computer control system perform like a powerful multi-processor. Several new instructions were added to the language this quarter. One group facilitates communications between the interpreter and the system programs whereas another group provides for easier operator intervention via the light pen. A program to assemble interpreter programs was written for the CDC-6600. It augments the one already available on the control computer. •

A number of major improvements were made in the system programs. For example, the Disk Driver was replaced by a version which allows reading of the whole disk and writing on all but the parameter library. This will ease the problem of communications between application programs. A new analog command program was added along

with a modified Computer Interface Unit (CIU) Driver. These make it possible to have one analog command in execution in each module rather than a single analog command active in the whole accelerator. The binary command program was altered so that it formats the ten command bits from the latest data in the data bank rather than relying on a previously stored bit pattern. Not only does this eliminate the problem of locking up the system; but it also makes it easier to handle reset channels.

A scope processor - a set of programs to facilitate preparation of scope displays - was completed and documented. Channel labels can be revised on-line as the result of a newly completed program. Finally, the core memory allocation scheme was converted to half-map pages so that it is now possible to have an extra program or two in memory at a given time.

Two new programs to facilitate direct digital control of the water cooling system for the 4-ft drift tube model were defined. Their completion is subject to installation of several new data and command channels. A new capability, a "quick-look" display, is being developed to support these and other on-line experiments. At the completion of a run in which data are recorded by either the slow or fast recorder programs, the operator will have the option of specifying plots of $f(t)$ vs t or $f(t)$ vs $g(t)$ where time is the parameter. Portions of the display can be expanded to provide more detail. The more interesting displays can be printed on the line printer. This package does not compete with the programs for the CDC-6600 and SC-4020 in the central computer facility but rather augments them by giving the operator an indication of the success of the experiment before the machine is shut down or some of the equipment is dismantled.

The problem of converting readings from nonlinear channels to engineering units is nearing resolution. It now appears that all of the calibration curves can be fitted to a satisfactory degree of accuracy by third-order polynomials. A program was written to evaluate the four coefficients of the polynomial from a given set of calibration data. After the operator has had the

opportunity to check the goodness of the fit, the program stores the coefficients in a table appropriate to the channel so that other programs can have access to them. In particular, the line-by-line display program was modified so that it now displays analog data in engineering units.

A program to service the electronic keyboard was written and tested. Final integration into the system must await arrival of the keyboard. In anticipation of the new alphanumeric channel designations, a program was written to convert all channel numbers for the Ion Source Test Stand to a format compatible with the present three-digit operator channel numbers.

Work has been started on a group of interlock programs which are intended to tell the operator why a given operation failed, within the limits of the data available to the computer. In effect, the whole hardware interlock scheme for EPA will be stored on the disk so that various programs can trace the source of a fault.

Work has been continued on System II to replace the present operating system. The last major problem to be solved is the so-called "deadly embrace" in which a group of programs tie up memory by mutually preventing each other from going to a successful completion. Despite this problem, the system is ready for the first group of operation programs and work on these was initiated. A new initializing program for System II was completed. It facilitates writing new system programs on the disk in a form which makes them relocatable on a map.

EPA Control Equipment

The prototype CIU has been in service for ~18 months. This unit enables the computer to communicate with any of the three module control units. During this time it has experienced three failures requiring a total of 9 h to diagnose and repair. This gives an availability of 99.93%. Based on 1150 active logic elements, the mean time between failure per element is $\sim 3 \times 10^6$ h.

Three modules of interface equipment were operated continuously this quarter; there were two malfunctions resulting from hardware failures.

A logic gate failed and a dirty contact on a printed circuit board caused a fault. This constitutes $\sim 2.6 \times 10^6$ active component hours between failures. Such a failure rate is comparable to that being experienced on logic hardware other than the module interface equipment. The effective failure rate for LAMPF is expected to be reduced somewhat by making use of the normal accelerator down time to detect and replace marginal components.

The manual control system which provides local controls for the EPA operated essentially trouble free during the quarter.

The major portion of the target area instrumentation for EPA has been installed and it should be operational very soon. The instrumentation provides for measurement of water temperature at five locations, water pressure at three locations plus overpressure interlock indication, water flow rate at four locations, control of target positions, and water flow to three targets and a beam stop. Interlocks are also provided to shut off the beam and target water and to close the fast-acting vacuum valves in case of a target failure. The electronics for the turbine flow meters and the thermistor temperature sensors was designed, built, and tested.

Ion Source Test Stand

The Ion Source Test Stand (ISTS) is being instrumented for computer control to provide a test vehicle for new control equipment developed as a result of operating experience with the EPA. The ISTS will be integrated as the fourth module on the EPA computer control system.

The equipment for computer control of the ISTS was designed and fabricated. Installation of the equipment is about 60% complete, with another month needed for full completion. The interface equipment is ready to be installed in the racks in operational form. This equipment consists of a RICE, RICE I/O, Analog Data System (ADS), and associated power supplies. The RICE is based on the original design but was fabricated by Data Technology with diode-transistor logic. The RICE I/O represents a new

design; it is wired for 24 binary commands, 24 binary data indications (expandable to 96), and 10 analog commands (expandable to 30). The ADS is based on Redcor multiplexers and a Raytheon analog-to-digital converter. A number of minor problems were encountered in the checkout of this item when it was connected to the new RICE and RICE I/O, but they were corrected and the units appear to operate together satisfactorily.

Several data channels in the ADS are reserved for actual on-line evaluation of the Redcor equipment. Three full-scale channels and three zero-channels will be used to determine gain and zero drift due to temperature variations and long-term variations. The computer will log these channel values on a periodic basis. The results of this drift study will help in the final design for the system to be used on the accelerator.

Accelerator Controls

Injector

The controls design for the Injector system progressed slowly because the persons involved have been active in other areas, primarily computerizing the control of the ISTS. Preliminary designs of the control panels for the Injector and the beam transport magnet systems were developed. The design and breadboarding of the Manual Head Control Unit (MHC) were completed and fabrication of the MHC is now in progress.

201.25-MHz Modules

Design of the controls for the drift tube accelerator has been hampered by difficulties in establishing the areas of responsibility of the various contributing groups and in developing a control philosophy acceptable to all parties. Tentative decisions were reached in this matter so that work can begin as soon as the system parameters are defined. In the meantime, specification of the controls for the vacuum system for this portion of the accelerator has been completed and the design of the associated hardware will begin in the near future.

The water temperature control system for maintaining resonance in the 4-ft drift tube

model is being linked to the EPA control computer system. It is expected that this will give greater flexibility in the control experiments than is now possible with the analog controller alone. The experiment requires five analog command channels, eight analog data channels, six binary command channels, and 15 binary data channels. The connection to the computer is through the Module 1 Interface Unit. Capabilities of the system include computer control of the set point potentiometers used to obtain error signals, computer operation of water valves and heaters, and simultaneous operation of the digital and analog controllers. Design of the system was completed and bids received for fabrication of the necessary local control modules. Cables were run from the mockup building to the 201.25-MHz test area, and installation and checkout of the hardware are essentially complete.

805-MHz Modules

Discussions concerning system requirements for the 805-MHz portion of the accelerator culminated in the following channel capacities for a typical four-tank module: 59 binary data indications, 39 binary commands, 14 analog commands (pulse motors), 48 analog data measurements, and seven video signals. Detailed channel lists for a typical module were compiled, and the associated costs were estimated. Completion of this exercise makes it possible to proceed with wire scheduling and to settle design details in the RICE I/O and ADS.

Inquiry specifications for the steering magnet power supplies were written and submitted to various manufacturers for information on price and approach. The specifications call for a basic power supply with four separately regulated and controlled current outputs (for two steering pairs). This power supply is to be bipolar so that there is a smooth transition when going from positive through zero to negative currents. One potential vendor has indicated that power supplies of this type can be delivered for a cost that appears reasonable.

An inquiry specification for the focus magnet power supplies is being generated. All of

the hardware necessary for the binary interface between the equipment and the computer is to be incorporated in the supply. It appears that each of these power supplies --one per tank in the 805-MHz portion--will be required to deliver about 4 kW of power to the magnet. For cooling estimates, assuming a 66% efficiency in the power supply, there will be about 8 kW of power dissipated as heat in the racks of a four-tank module from this source alone. This raises doubt concerning the adequacy of the proposed rack cooling capacity, namely, 1500 W per rack.

The interface problem between the Beam Position Monitoring (BPM) equipment and the RICE I/O was resolved. In the new design the RICE I/O supplies channel select commands to the BPM equipment to choose the particular position monitoring station desired. In this way the multiplexer, which is an integral part of the BPM equipment, is treated as an additional section of the analog data portion of RICE I/O. This approach not only simplifies programming, but also eliminates some binary hardware.

Interface Equipment

Remote Information and Control Equipment (RICE Mark II)

The RICE functions in each module as a computer-controlled multiplexer. The Mark II unit, an improved version of the original RICE, was completed during the last quarter. It was constructed from a commercial line of logic cards. This unit, including the data transmitter and receiver, has undergone a complete evaluation using a newly constructed RICE Exerciser (REX). The RICE I/O and ADS for the RICE Mark II are not yet complete; however, the system was coupled to similar units which had been constructed for the ISTS I/O and operated in a satisfactory manner. Operation of the complete prototype system will continue throughout the next quarter as the final form of the LAMPF data system takes shape.

RICE Mark II-B

The Mark II-B model of the RICE should be the final LAMPF design, even to the details of packaging. It has one innovation resulting from

operating experience on the RICE Mark II, namely, it recognizes five distinct operation or function codes, rather than the present three. The new function codes are video select, binary command, analog command, binary data take, and analog data take. This approach allows the RICE to run in an open-loop mode, requiring no feedback of control information from RICE I/O, and thus avoids potential equipment lockups. The effective channel capacity will be increased to 127 per command and data take function.

RICE Interface Unit (RIU)

Work was started on a prototype RIU, which is a second generation of the CIU. This version will be built to verify current design ideas for the LAMPF RIU. The prototype unit will operate with the SEL 810A computer and will drive a RICE in the Klystron Test Stand, plus a second RICE located in the laboratory. It will utilize all design features planned for the LAMPF RIU, but will be scaled down from an 80-module capacity to four.

The prototype RIU design and breadboarding were completed. Fabrication of the power supply chassis was completed, and wire lists and layouts of the logic chassis are under way. Design was started on a Driver/Terminator chassis which will interface the prototype RIU with the computer.

RICE Input/Output

A new RICE I/O was designed for the ISTS and its improved performance has done a great deal to crystallize the conceptual design of the RICE I/O system for LAMPF. Incorporation of the functions of the Module Interface Unit into the I/O unit has been an economical and technical success. The final design and packaging phase has been entered and will be completed when the channel lists for the machine have stabilized.

Analog Data System (ADS)

Two approaches to the ADS were developed. One utilizes sample and hold circuits on each channel and has the advantage of yielding time-correlated data, whereas the other is a

standard low-level multiplex system. It was decided that time correlated data were not a requirement for LAMPF and that if additional costs would be incurred, the approach should be dropped. Hence, the Redcor low-level multiplexer approach is being pursued. The 10-channel model has performed well in the ISTS data system. The company has announced that they plan to produce a 16-channel low-level differential multiplex module for about the same price quoted in 1967 for the 10-channel unit. This module will be available in late August. The 16-channel module offers several improved features over the old unit and will be evaluated when it becomes available.

Some time was spent investigating the possibility of using reed relays in a multiplexer. The cost of such a system is somewhat less than the old 10-channel Redcor version but will be about comparable to the new 16-channel Redcor unit. Relay multiplexers are much slower than the FET (Redcor) type but offer some distinct advantages, e. g. ,high common mode rejection, low contact resistances, etc. No firm decision has yet been reached on this matter.

Local Controls

The concept of packaging local controls in quickly replaceable modules is being tested in the mockup program. So far the approach has been very useful in the EPA and its use is being extended to the ISTS and to the temperature control instrumentation for the 4-ft drift tube model. It is expected that this approach to local controls will be reviewed and evaluated in the near future with an aim toward making it the standard technique for LAMPF.

Distributed Operational Systems

Timing System

The LAMPF Timing System Specification was completed and issued for review. A new prototype of this system is scheduled for the mockup program. It will include the entire central logic and counting system designed to interface with the computer through a console interface unit. The output drivers will be abbreviated to handle only those modules in the mockup program.

Fast Protect System

The transmission system for the fast protect system is being evaluated to determine if the signal rise time is adequate. A change in cable type or cable compensation may be required. A solid-state relay has been evaluated and found to be acceptable for fast data input to the computer for those systems using the fast protect system.

Radiation Safety

The Rad-safe system planned for LAMPF was completely reviewed, revised somewhat, and recosted. Work with LASL Health Division personnel on instrumentation problems and radiation surveys has been continued.

Auxiliary Systems

TV System

The closed-circuit TV system planned for LAMPF was reviewed, revised, and recosted.

An experimental evaluation of an 1100 line/scan system, as proposed for observation of the data display scopes in the Central Control Room (CCR), showed that satisfactory results could be obtained over 3000 ft of RG-11 cable without the use of line equalizers. Maladjustment of the camera was required, however. Hence operation would not be satisfactory for other distances with the same maladjustments, and a compensated distribution system of some sort will be required.

The poor reliability of the Insul-8 Vicon camera system in use in the mockup program was traced to a number of causes. The principal one was overheating of the main power supply. A ventilation scheme was designed and installed, thereby eliminating the heat problem. The remaining problems were traced to faulty components, erroneous departures of the wiring from the schematic, and poor original circuit design. Most of the correction work is now complete.

Video System

The LAMPF Video System will be structured on a sector basis, there being a total of nine sectors and two beam areas. At each sector a capacity of 12 channels per module will be

provided. Any of the signals can be patched manually into any of four cables running back to the CCR. Thus, a total of four simultaneous signals from each sector are available in the CCR. These signals terminate in a 44-point patch panel so that the operator can select any number of the 44 possible traces for display depending on the number of scopes available.

The following step response specifications are planned for the video system: (a) rise time (10% - 90% of steady state value) 70-80 nsec; (b) overshoot ≤ 0.5 db; and (c) droop $\leq 0.5\%$ for a 1-msec pulse. To meet these specifications it will be necessary to design preemphasis filters for the driving end of the cable. A study was made of the amount of compensation necessary, and it was concluded that a balanced system was highly preferable to a single-ended system. Moreover, RG-22B/U with center conductors twisted offers a high level of immunity to crosstalk in addition to a high level of rejection to extraneous electric and magnetic fields.

A set of bridged-T filters was built to check the theoretical calculations for the system response. From this experimental study it appears that two-section cascaded Bridged-T filters could be made to give adequate preemphasis over the whole range of cable lengths required for LAMPF. A computer program which will design a set of preemphasis filters for lengths of RG-22B/U ranging from 100 to 3000 ft is now in the checkout stage.

Miscellaneous

Channel Engineering

The LAMPF Device Designation System was rewritten and expanded to fill more adequately the need in the many areas involved in the accelerator construction. The device and channel lists generated from this system have proved most useful in identifying the various system requirements. These lists have undergone extensive revision and updating from time to time as the final engineering of the system has progressed.

Wire and Terminations

Trunk cable installation for the Injector Building was designed and coded into computer cards. This initial installation is composed of 39 runs of 27-pair cable for a total of 1053 individually shielded pairs which run from the beam transport service area to the cable room below the Injector Control Room. This package of cables could be installed immediately upon occupancy of the Injector Building or even before if the AEC should negotiate an addendum to the contract with the building contractor. The necessary cable for this project is on order and will be on hand about Sept. 15, 1968.

Wire lists were prepared for the ISTS. These lists describe the wiring inside the ISTS rack and its connections to the outside. The ISTS rack was wired from the coded card listings. A summary document was issued covering the wiring and termination scheme and procedures as presently evolved.

Light Links

The first phase of the tests on the linear light link was completed. The transmission distance was ~ 10 ft. Rise times of the order of 70 - 100 nsec were recorded with an overshoot of $\sim 20\%$. The criteria for linearity were determined by observance of triangular waveforms on an oscilloscope. These criteria were felt to be adequate because the light link will be used for transmission of video waveforms.

Details of the mechanical housing are currently being worked out. Final electronic design will be completed in the coming quarter.

Combustion Product Detector Tests

Fire detectors in the LAMPF beam channel must operate for a long period of time in a high-level radiation environment. A few smoke detector tests have been made by industry using x-ray environments which do not simulate the LAMPF environment. Therefore a test program was

started to determine if such detectors will work in a high radiation field and if they will survive the neutron fluxes expected when LAMPF is in operation.

Three samples of each of six brands of combustion product detectors are to be tested. The test will be an operating test in the radiation environment provided by EPA. A simulated fire, generated by overheating insulated wire, will be located so as to provide the same smoke to all the detectors. The fire detectors will be located on the ceiling at the target end of EPA.

Fabrication of the smoke generator was completed. The design provides for remote starting of three fires without reloading.

Preliminary measurements were made of the radiation levels at the ceiling grid. The gamma level was found to be uniform within $\pm 23\%$ from the mean values and the neutron level uniform to $\pm 9.5\%$. The average gamma/neutron dose-rate ratio was 2.8×10^4 . The data were determined using the Tube Forest as a target; this is primarily a water target. A new target is planned which should increase the neutron flux about a factor of 100 and improve the gamma/neutron ratio by a factor of 10. It will employ a Ta target being developed as the gamma producer and a block of high-Z material, such as tungsten, for the gamma-neutron conversion.

Standards

Standards were written and distributed covering time delay relays, meter relays, connectors, switches and indicator lights, rack and J-box terminals, a revised panel light color standard, the LAMPF wiring and termination record system, chassis and panel layout practices, drafting symbols, and pulse motor connectors.

Evaluations were made on various brands of crimp-type coax connectors, H.V. connectors for ion pumps, hand crimp tools for ring, spade and "Faston" terminals, and edgewise meters. Drawings of the LAMPF Standard rack were obtained for distribution.

V. ACCELERATOR PHYSICS

Introduction

The dc accelerating column was completed and installed on the 200-keV test stand. Initial tests on the combined performance of the ion source and column indicate that the beam quality will be considerably better than is required for the injector transport system and the linac.

A rotating wheel beam scanner was installed on the Electron Prototype Accelerator (EPA) and used to determine the profile of the electron beam.

A superconducting quadrupole doublet is being fabricated. A facility is being set up at the EPA for irradiating samples of materials for magnets, in order to assess the effects of radiation damage.

A study has been carried out of the acceleration of H^- ions in LAMPF. The indications are that this is a practical possibility and would allow more simultaneous users of the facility.

Beam Diagnostics

Rotating Wheel Beam Scanner

The rotating wheel beam scanner has now been installed on the EPA and has been used to determine the beam profiles of the accelerated beam. Figure 11 is a picture of the scanner installed on the EPA. The mechanical difficulties previously reported have now been corrected, and the rotational stability of the wheel is adequate.

Beam profiles of the EPA beam have been observed for several operating conditions up to full beam power. A typical beam profile pattern is presented in Fig. 12 for a 20-MeV, 3-mA peak electron beam. The left half of the picture is the horizontal beam scan whereas the right half is the vertical scan. The beam samples are 0.050 in. apart and so the beam has a diameter of 1.1 cm. The horizontal scan shows some asymmetry, but it is observed to change as the phase of the scanning wheel is changed with the same beam conditions; consequently, it is at least in part due to instrumental difficulties, presumably to

Fig. 11. The rotating wheel beam scanner.

Fig. 12. Beam profile pattern obtained with rotating wheel scanner.

misalignment of the horizontal scanning wires. No such asymmetries have been observed for the vertical scans. A calibration of the position of scanning wires will be carried out prior to final alignment and installation on the EPA and any misalignments will be corrected then.

The beam profile in Fig. 12 indicates that this beam consists of a central core superimposed on a more diffuse distribution. Assuming the current density to be characterized by a Gaussian distribution, the observed beam profiles imply a standard deviation in this distribution of 0.3 R or 0.17 cm. Thus, the beam scanner can be used, subject to certain assumptions, to provide information concerning the current density distribution of the beam as well as for its usual beam diagnostic functions of determining beam shape and position.

Beam Profile Monitor

Profiles of the EPA 20-MeV 0.5-mA-average beam have been observed at $\sim 5 \times 10^{-5}$ torr with the gas ionization profile monitor. Attempts to shield from the high ambient radiation were only partially successful, and so the device will be moved upstream from the target area to improve lifetime of components and to reduce the background of radiation-induced illumination of the CRT face.

Superconducting Quadrupole Development

All materials have been received for the two superconducting quadrupoles and preliminary tests are being conducted on the superconducting wire prior to winding. Final machining is now being performed on one set of the aluminum coil forms. The coil forms and superconducting wire for the dipole correction coils have been ordered.

Several thousand feet of copper wire, of the same diameter as the superconducting wire and having the same Nomex braid insulation, have been received. This wire will be used for hand winding to determine the best packing arrangement for the insulation. The copper wire will also be used for some preliminary work with a coil-winding machine. Preliminary testing of the quadrupoles will begin shortly.

Beam transport magnets in the experimental area at LAMPF will be exposed to relatively high radiation levels. As there are no data available on the effects of radiation on niobium-titanium superconductors, a research program is being initiated on radiation effects on such materials. Superconducting beam transport magnets will probably remain at liquid helium temperatures for extended running periods and it is known that some microscopic defects in the superconductors which have a short anneal time at room temperatures will persist at 4.2°K. For this reason the irradiation will be in liquid helium.

Superconducting ribbon for a 100-kG magnet for measuring B-I curves (critical current as a function of applied field) before and after irradiation and a helium dewar for the irradiation are being ordered.

Injector Program

Cockcroft-Walton (C-W) Power Supply

Recent progress reports from Haefely & Co. indicate that much of the design work on the C-W unit has been completed, including the rectifier stack, damping resistor, equipment stack, bleeder resistor, measuring resistor, bouncer rectifier, power rack, and plate power supply. Presently under design are the following units: power distribution rack, control rack, and stabilization rack. Already manufactured are components of the isolating power drive system, bleeder potentiometer, stabilizing system, and the rectifier stack, as well as the support frame for the equipment dome and the anode power supply. Under construction are the motor generator set, the equipment stack and rectifier stack domes, and various high-voltage shields. It is now anticipated that the C-W unit will be ready for factory testing in early October and that final delivery will be made early in 1969.

Accelerating Column

Much of the work this quarter was conducted on the partial column oriented vertically as shown in Fig. 19 of LA-3948-MS. Additional large corona rings of 1½-in. diam polished aluminum tubing were installed at all of the 50-kV bleeder resistor terminals to minimize the corona discharge. It also was found necessary to cover the inside of the expanded metal isolating cage with a fine-mesh copper screen to further reduce the discharge. Final voltage tests were conducted at 200 kV and 5 psig of SF₆ in the high-pressure jacket, although a maximum voltage of 215 kV had been obtained. During this test, totaling 4 h, the average sparking rate was about two per hour, and the present interpretation is that all the breakdowns are due to the marginal voltage characteristics of the bleeder resistors. The design voltage of the column is 192 kV, but until the resistor string can be redesigned, operation of the column will be limited to voltages in the range 160 to 190 kV. Although the discharge is dramatic in appearance, no apparent damage can be found on the polished surfaces at the points of discharge.

Fig. 13. Corona discharge from end of a partial column bleeder resistor.

Fig. 14. High-voltage surface breakdown along a partial column bleeder resistor.

Fig. 15. Steps in the modification of the bleeder resistors.

Extensive high-voltage tests on the bleeder resistors showed they were marginal for this application. Problems of poor end contacts, corona from the sharp end configuration (Fig. 13), and surface dielectric breakdown (Fig. 14) were encountered. Performance of the individual resistors was substantially improved by several modifications, although the column performance with these improved resistors remains marginal at 200 kV. The poor end contact was caused by either a resinous insulating coating covering part of the fixed platinum ends (this was scraped off with

a scalpel) or by the insulating epoxy sleeve covering the resistors projecting slightly beyond the platinum ends (this was corrected by brass washers small enough to fit inside the epoxy sleeve and make contact with platinum ends).

Corona discharge from the ends of the resistor was eliminated by filling the space between the epoxy sleeve and the terminal with RTV-732 Silastic. Figure 15 shows the resistor as unmodified on the left, as fitted with a brass washer and Silastic band in the center, and as completely assembled with the corona terminals on the right. Dielectric breakdown along the surface of the epoxy sleeve was substantially improved by scraping off foreign material under the stereomicroscope and by rounding off all sharp epoxy edges caused by the mold. Q-Dope was then painted on the epoxy sleeve.

Although the modified resistors appear to be performing well at present, the factor of safety provided is not sufficient, as indicated by occasional sparking at 200 kV. Before modification, the resistors broke down at voltages varying from 30 to 60 kV; after modification, all resistors were tested for 12 min at 60 kV. However, as the resistors will be operated at 50 kV for long periods of time, perhaps days, design of a new resistor string is being pursued, each resistor being 60% longer and of high wattage rating. Because of the increased length, the dielectric stress will be reduced. These resistors will be slant-mounted between adjacent corona rings.

The partial column, shown in Fig. 16, was originally patterned, insofar as the outer pressure jacket was concerned, after one designed and tested by MURA. The original design of the partial column called for an acrylic pressure jacket capable of withstanding a pressure of 90 psig. This was not economically practical as the wall thickness demanded for such a large cylinder was too great. In order to reduce appreciably the SF_6 pressure required, an early program was instituted for finding the approximate location of the equipotential surfaces by field patterns obtained from two-dimensional conducting paper field plots. In this manner, the spider connections from the inner column to the outer pressure jacket

Fig. 16. Drawing of partial column showing location of spider connections with pressure jacket.

Fig. 17. Computer output for the potential field pattern of the partial column.

can be placed on equipotential surfaces to minimize corona stresses. As a result of this study, the design pressure was reduced to ~ 30 psig, a much more practical value.

The high-voltage tests on the partial column were conducted with various pressures of SF_6 . At 200 kV on the column, corona discharge on the spiders did not appear until the pressure was reduced to slightly less than 2 psig, and the location of the corona was accurately predicted from the field plots. An even more careful study will undoubtedly allow the design pressure to be

reduced to 0 psig, a most desirable condition. With this in mind, and the detailed design of the full column imminent, a program for studying the potential configuration in three-dimensional detail was undertaken.

The program of calculations for determining the field pattern for a symmetrical system was initiated using a LASL computer program LAPLACE. A typical output is shown in Fig. 17 which adequately approximates the geometry and representative equipotential lines of the partial column. On those boundary surfaces for which the potential is not specified, the potential gradient is required to have a zero normal derivative. In the present form of the code, the problem is treated in a two-dimensional plane geometry approximation, but the code is now being generalized to treat the actual three-dimensional case with cylindrical symmetry. The results obtained with the two-dimensional computer code agree with the conducting paper field plots.

Ion-Source Test Stand (ISTS)

The principal activity with the ISTS has been the installation and testing of the second ion source. This source is adjustable to accommodate variable extraction cup depths, and has been engineered to be compatible with the 200-kV partial column, which is now added to the test stand. In the course of installing and testing this source, several variations in the cup and plasma aperture configuration were tried. The aim was to improve the emittance of the beam at the designed extraction voltage and rated (Child-Langmuir) extracted current. The tests were made with a single extractor electrode (25 kV) even though the lens effects of the electrode interferes with the formation of a flat plasma surface. Significant improvements in the best obtainable emittance were not noted, and the better emittances were realized with values of extractor voltages and extracted currents differing up to 25% from the expected values. In order to understand these effects, tests will be continued using the multi-electrode partial column, where the lens effect of the last electrode will be completely decoupled from the plasma surface by the intervening electrodes.

The Child-Langmuir Law is usually derived for the extracted current containing only one type of particle. The duoplasmatron, however, produces a significant amount of both H^+ and H_2^+ (and sometimes a much smaller amount of H_3^+), both being extracted as beam current. One measurement indicated that approximately equal numbers of H^+ and H_2^+ ions are extracted from the ion source under conditions of good emittance. This effect has been analyzed as follows: An extracted beam is constituted of singly-charged particles of masses m_1 and m_2 . If a uniform radial current density distribution is assumed, the charge density, ρ , at the position z is given by

$$\rho = \frac{I_1}{\pi R^2 \dot{z}_1} + \frac{I_2}{\pi R^2 \dot{z}_2},$$

where $\dot{z}_1$ and $\dot{z}_2$ are the time derivatives giving the velocities of the particles m_1 and m_2 , respectively. For one dimension, i. e., for a cylindrical beam, Poisson's equation becomes

$$\frac{\partial^2 V}{\partial z^2} = -\frac{\rho}{\epsilon} = -\frac{(I_1 m_1^{\frac{1}{2}} + I_2 m_2^{\frac{1}{2}})}{\sqrt{2} \epsilon \cdot V^{\frac{1}{2}} \cdot \pi R^2},$$

where ϵ is the dielectric constant for free space and $\dot{z}_1$ and $\dot{z}_2$ have been expressed in terms of the particle energy, V . The solution to this equation, shown in Fig. 18, gives a modified extraction current, I_{ex} , which would be expected from a mixture of H^+ and H_2^+ ions, and an extraction voltage of 25 kV. Thus,

$$I_{ex} = I_1 + I_2 = I_{TH} \left[a + (1-a)(m_2/m_1)^{\frac{1}{2}} \right]^{-1},$$

where a is the percentage of current of mass m_1 , and I_{TH} is the Child-Langmuir current for mass m_1 only. It is evident that for 50% proton beam, the expected extracted current should be only 41.5 mA for the present ion source. This would give a proton current of 20.75 mA instead of the previously expected 25 mA.

Fig. 18. Extraction current as a function of percent proton current in ion source.

It was immediately recognized from the foregoing theoretical derivation that, although the total current variation for various mixtures of H^+ and H_2^+ was not very great, current variation for a mixture of e^- and H^- is very large, because of the large mass ratio $(m_2/m_1)^{1/2}$. In this case the total current becomes a very sensitive measure of the amount of H^- ions contained in a beam of e^- extracted in a Child-Langmuir configuration. (The importance of H^- extraction is discussed elsewhere in this report.) The curve for e^- and H^- extracted current is shown in Fig. 19. To test the H^- content of the plasma in the expansion cup of the ion source, the polarity of the extractor electrode was reversed, and a capacitor was added to the supply to provide for very high instantaneous electron currents. As expected, the measured current was very high and indicated that the H^- ion content of the beam represented less than 1% of the current. Attempts to sweep the electrons magnetically out of the beam in order to measure the remaining H^- ion current also indicated a nonmeasurable amount of H^- . Neither was a good

Fig. 19. Total extracted negative current as a function of percent electron contamination.

measure of H^- ion content of the plasma because the very large electron current (~ 2 A) extracted from the plasma completely destroyed the plasma extraction surface, as evidenced by the extremely poor quality beam.

200-kV Test Stand

Prior to the assembly of the modified ion source, partial column, and diagnostic dome to the test stand, each of these major components underwent environmental tests. Tests performed on the ion source and partial column have been described in some of the previous paragraphs. The dome (Fig. 20 of LA-3948-MS) was moved to the isolated confines of the ion-source test facility and high-voltage tests have been carried out. The dome was tested in place on the test stand up to 250 kV, and only minor problems were encountered with corona-induced high-voltage breakdowns around two of the supporting legs. Suitable modifications of the front legs and addition of corona rings solved the problem. The isolating transformer which will power all the

Fig. 20. Accelerating column and equipment dome attached to ion source test stand.

diagnostic apparatus in the dome was tested successfully at 225 kV.

Figure 20 shows the accelerating column and equipment dome attached to the ISTS. In this configuration, the column was tested for vacuum leaks, SF_6 leaks, and high-voltage characteristics. The highest voltage obtained before breakdown, after some preliminary adjustments of corona shields, was 215 kV. However, until a more reliable bleeder resistor string is fabricated, the voltage will be limited to operating values of 160-190 kV.

The initial test of the partial column produced a total current of 26 mA with 149 kV in the column. For the existing geometry, assuming 50% H^+ in the beam, the current expected theoretically is 24.3 mA. No attempt was made to vary the ion source parameters to obtain a minimum emittance; however, a rough estimate of the normalized emittance (phase space area $\times \gamma\beta/\pi$) is 0.094 cm-mrad.

The apparatus which will eventually be used in the dome to test the quadrupole triplet (or quadruplet) beam transport system are in various stages of design, testing, and construction. The construction of the quadruplet and beam tube hardware is under way, and the remaining beam transport system and the diagnostic test chamber are being detailed. Magnetic field surveys and multipole analysis have been run on all the quadrupole magnets. Preliminary alignment tests have been

carried out with the transport magnets mounted on the rail support system inside the dome.

Polarized Ion Source

The initial design for a liquid helium cryopump test stand is now complete and detailing is under way. The test stand will be used primarily to study the hydrogen gas pumping problem associated with the production of polarized protons. The knowledge gained from this activity also will be very useful in designing the gas pumping system for the H^- ion source. The plans for a laboratory area to accommodate this work are complete but construction work has not yet started.

A preliminary survey has been conducted on the requirements of the experimenters wanting to use the polarized beam from the LAMPF. The findings of this survey are discussed in detail in an internal report.¹ In general, most of the requirements can easily be met by an already developed polarized ion source. The major exception is the requirement of a certain type of experiments for polarized beams of 10-30 μA average intensity. This represents an increased current of two orders of magnitude. Some recent advances, however, give indications that at least one order of magnitude increase may be attained within the next few years at other laboratories.

Injector Control

Several panel layouts for the injector control console have been made to see that all appropriate controls and metering are sufficiently compact and convenient. These panels include the control for the startup of the Injector A C-W power supply and the ion source, and for the adjustment of the currents for the focusing magnets in the beam transport system. In general, master on and reset controls will be used whenever possible on the console, leaving individual reset controls at the unit location on the secondary racks.

The vacuum pressure interlock system will be derived from a single ionization gauge located in each section of the transport system which can be isolated by vacuum valves. Individual pump power supplies will be used, and they will be of the automatic-on type with manually resettable

overload protection. A single digital voltmeter will be provided for each of the four transport system magnet control panels. Fine control only will be provided for the bending magnets in order to obtain the necessary 0.01% precision, widely variable excitation not being required.

Accelerating H^- Ions

Accelerating H^- ions along with H^+ ions by the LAMPE accelerator² raises the intriguing possibility of separating a low-intensity beam from a high-intensity beam during each macropulse output of the accelerator. Such a process would allow two experimental areas to be run simultaneously. In one area, a high-intensity beam of H^+ would be used for forming various secondary meson beams; in the other area, a low-intensity beam of H^- would be used to form H^+ and neutrons for direct experimental use. The H^- ion has no advantage over H^+ as a nuclear probe but because the second electron is so loosely bound (0.75 eV) it is easily stripped off, providing means of extremely fine collimation and thus high-energy resolution in an H^- spectrometer type experiment. Also, a potentially accurate and simple method of determining beam energy would be to measure the stripped electron energy (435 keV for the 800-MeV ion and 54 keV for the 100-MeV ion).

Positive and negative beams could be simultaneously accelerated on alternate half-cycles of the 200- and 800-MHz linac frequencies. A bending magnet at the end of the linac can separate H^- ions from H^+ ions. One requirement is a 180° phase shift (8-cm increase in path length) for the H^- ion at the 200 to 800-MHz transition in order to place both H^+ and H^- ions in the acceleration phase of the 800-MHz cavities (see p. 11). To avoid the 8-cm increase in path length for the H^- ions at the transition, the H^- ions can be stripped to H^+ at the transition. A more difficult separation would then have to be made at the 800-MeV level by a rf deflector.

An alternative method of producing a split beam at the end of the linac would be to accelerate only H^- ions. This would require a 20-mA H^- ion source (not yet realized, but in the realm of possibility). At the 800-MeV level partial stripping

Fig. 21. Hydrogen gas consumption as function of extracted beam current and system pressure in H^- ion source.

could be effected by either a thin target or gas canal, giving H^+ , H^0 , and H^- beams.

To accelerate the H^- ions to the injection energy, namely, 750 keV, the C-W would have to be operated in the reverse polarity mode. This presents no problem. The most intense ion source reported in the literature^{3,4} for producing H^- ions is that built by Ehlers with the following claimed characteristics:

Extraction energy	150 keV, maximum
Beam energy spread	< 500 eV
Beam intensity, continuous	2.0 mA
Beam emittance at 150 keV	~ 6 cm-mrad
Beam diameter at exit	~ 1 cm.

As with a polarized source, the main problem with such a source would be control of the tremendous hydrogen gas consumption. In Fig. 21 the hydrogen flow is shown on the lower curve as a function of the beam current extracted, and in the upper curve as a function of the system pressure. The practical limit for using vac-ion pumps would be a pressure of 10^{-5} torr, corresponding to ~400 μ A of H^- beam. A demand for higher

Fig. 22. H^- lifetime as a function of electric field environment.

Fig. 23. H^- lifetime as a function of magnetic field environment.

currents would require a pumping system of large volume, either cryopumping, Ti sublimation pumping, or an oil or mercury cold-trapped system.

The H^- beam will be lost if the extra electron is lost. This can happen by collisions with residual gas or by electrical or magnetic field stripping. Measurements have been made near 2.4 MV/cm on the UCLA cyclotron⁵ H^- beam and

Fig. 24. Contribution to loss of H^- in various regions of the accelerator as a function of nitrogen gas pressure.

Fig. 25. Beam composition as a function of target thickness.

near 4 MV/cm with a D^- beam at the HILAC.⁶ These are shown in Fig. 22, together with the predicted curve.⁷ As LAMPF accelerating fields are around 1 MV/m and the rf magnetic fields are about $1/c$ times this, these accelerating fields do not significantly dissociate H^- ions. In Fig. 23, the results of Fig. 22 have been transformed into constant lifetime curves for energy vs magnetic fields. There is probably a factor of three uncertainty in the lifetimes. A deflecting magnet for the 800-MeV beam should be limited to 5 kG, corresponding to a radius of curvature of 10 m.

Stripping by residual gas atoms is less serious than electric stripping since the cross sections are inversely proportional to energy. Assuming a constant pressure and constant

Fig. 26. Preliminary layout of magnets for the beam switchyard.

acceleration in the linac, the fraction of H^- lost is

$$f_N = 0.86 \times 10^3 P \ln (T_f/T_i),$$

where T_f, T_i are the final and initial energies, and P is the pressure in torr units. For $P = 2 \times 10^{-7}$ torr, $f_N \approx 0.1\%$ loss in the linac portion of the machine. Thus, gas stripping does not appear to be a problem, particularly since the losses are concentrated at the lower energies. Figure 24 shows the contribution to the loss by various regions of the accelerator, indicating the greater contribution to the loss from the injector transport region.

Intentional stripping of the H^- for generating H^+ beams at either the 100-MeV level or at 800 MeV can be accomplished by a thin target or gas canal. For acceleration without a path length difference at 100 MeV, complete stripping is required. A three component beam will be produced by stripping, and the composition vs stripper thickness is given in Fig. 25. For a 99+% H^+ beam about 20 thicknesses in $(1/\sigma_{10})$ units, where σ_{10} is the H^- stripping cross section) is required. It is of interest to note that a substantial fraction (60%) of the H^- beam could be converted to H^0 . If a high-intensity beam of H^- were accelerated, a gas canal could be used to produce low-intensity H^+ and H^0 beams.

There are no fundamental reasons why H^- ions cannot be accelerated in the LAMPF machine, either independently of or concurrently with a H^+ beam. However, such operation would possibly require a redesigned injector transport system, a reliable H^- source, a H^- beam phase shifter at 100 MeV, 800-MeV stripper target design, and experimental area beam transport switchyard designed for handling H^+ , H^0 , and H^- beams. To produce H^+ beams of high intensity from a H^- beam does not appear to be too appealing, as the present H^- source capability for reliable low-emittance operation appears to be only a few mA. Simultaneous steering of H^- and H^+ beams through the linac portion of the machine is of great importance, and needs detailed investigation.

Beam Switchyard

A preliminary design study for the LAMPF beam switchyard was completed. The goal of the study was to work out the optical properties of a system which can provide beam simultaneously in three experimental areas. The system provides a high intensity H^+ beam in Area A and provides lower intensity H^- beams to Area B and the high-resolution spectrometer.

The layout of the magnet system is shown in Fig. 26. Two different techniques were used to accomplish the switching. The first switch consists of a dc magnetic field which separates the H^+ and H^- beams. The second switch is a septum magnet which further separates the H^- beam by the split phase space technique.

The optical properties required of the system were as follows: (1) achromaticity at each target and switch; (2) a waist with size adjustable from $0.1 \times 0.1 \text{ cm}^2$ to $10.0 \times 10.0 \text{ cm}^2$ at the first target in Area B; (3) a waist with size $\leq 0.05 \text{ cm}$ in the vertical plane and a divergence of $\leq 2 \text{ mrad}$ in the horizontal plane at the entrance to the High Resolution Spectrometer Facility; (4) reasonable beam size in all magnets. All of these requirements were met satisfactorily.

A further study will now be undertaken to design a more flexible system which also includes beam diagnostics. This system will include provision for switching the beam on a pulse-to-pulse basis and for a 3- μsec fraction of the normal macropulse.

References

1. "Polarized Ion Source Requirements," C. R. Emigh and R. R. Stevens, Jr., MP-4/CRE, RRS-1, July 1968.
2. "On the Feasibility of H^- Ion Acceleration by LAMPF," P. Allison and C. R. Emigh, MP-4/PWA, CRE-1, July 1968.
3. K. W. Ehlers, Nuc. Instr. Meth. 32, 309 (1965).
4. K. W. Ehlers, B. F. Gavin, and E. L. Hubbard, *ibid.*, 22, 87 (1963).
5. T. A. Cahill, J. R. Richardson, and J. W. Verba, *ibid.*, 39, 278 (1966).
6. S. Kaplan, G. Pavlikas, and R. Pyle, Phys. Rev. 131, 2574 (1963).
7. From D. L. Judd, Nuc. Instr. Meth. 18,19, 70 (1962).

VI. EXPERIMENTAL AREA

Introduction

During the early part of this past quarter the design and R&D effort on the experimental areas was concentrated on the consolidation of studies and information for presentation and discussion at the Users Group Meeting on June 20, 1968.

Target, remote-handling, shielding, and residual radiation studies have been continued and progress has been made. The review by the Advisory Panel on Accelerator Radiation Safety (APARS) was highly favorable, with the exception of a few recommendations which will involve some redefinition of access and radiation survey procedures.

Investigations have been continued with preliminary designs of beam transport systems of the main beam channels and of secondary channels. The possible addition of an H^- beam from the accelerator, as discussed earlier in this report, will have a major effect on the part of the experimental area where such a beam would be used. Design emphasis is being continued on the main beam transport systems, particularly in the switchyard area.

Facility Planning

Since the configuration of Beam Area A does not appear to be affected by the additional beam possibilities, preparation of design criteria for this area is continuing. Area A will provide three target cells in tandem along Beam A where the 800-MeV, 1-mA proton beam will be used. These target cells will be designed for progressively increased target losses with the last cell capable of acting as a full beam stop. A remote beam stop is planned to avoid background problems in Area A. The three target cells and Beam Area A will accommodate eight to ten pion and muon secondary channels. The area will be served by two 30-ton bridge cranes and will be designed for hydrogen use.

Massive stacked shielding is required along the main beam line through Beam Area A.

Deformation studies of the subgrade material under this heavy shielding load have been completed.¹ Based on an estimated weight of 26,000 tons distributed over an area of 50 x 180 ft, the maximum deformation is 0.32 in. This will occur within weeks of the application of the weight. After the initial deformation no substantial further deformation or "creep" is anticipated. Similar studies were completed on results of moving Merrimac, the remote maintenance machine, and of opening the heavy shield doors above the target cells. Subgrade deformation studies also indicate that loading on the experimental floor of 8000 lb/ft² over a 40 x 40 ft area will result in a maximum deformation of 0.54 in. Of this deformation ~ 20% will be permanent.

The arrangement of Beam Area B is now being reviewed for the proposed H⁻ beam, as described in the preceding section. Beam Line B will still be capable of handling the full beam when Beam Area A is not operating.

Studies have been carried out for siting a pulsed reactor facility near the LAMPF experimental area and to provide a pulsed proton beam to the reactor.

Design criteria for the Operations Building are being completed. The building is to be located about 200 ft west of Beam Area A and will provide limited office space, health physics space, a machine shop, and electronic and mechanical stock areas to support the experimental area. An electronic shop and conference space are provided to support the control center and the experimental area.

Shielding and Residual Radiation

In the review report by the APARS, exception was taken to the 100 mR/h level of radiation, which is estimated to exist 1 h after beam turn off in the beam channel, as a reasonable working environment for maintenance. The APARS recommendation of 25 mR/h based on experience at other installations will be complied with by delaying access as is necessary if a reduction of beam spill is not possible. A preliminary report on residual radiation has been completed and is available for distribution.

The construction of multitable, multi-group cross section sets for iron and magnetite concrete is in progress. The cross section sets will be used in the analysis of the experimental area shielding by means of the DTF IV type transport code.

A recomputation of the beam channel shielding in spherical geometry produced approximately the same results as the cylindrical calculation reported last quarter. A slab geometry calculation has not yet produced meaningful results.

Targets

The first full-scale test of the target water cooling system was performed recently. After several false starts including vacuum and electrical troubles and the repair of a defective water pump, the target system was run with a beam from EPA. A computer record of the beam power deposited in a graphite beam stop indicated a peak power deposition of 13.3 kW. More beam power will be needed to complete the target studies.

The beam plumbing in the target area is being rearranged to provide a better definition of the beam incident on the targets. The beam collimator and beam scanner are being interchanged in position and several inserts for the collimator are being constructed. Water cooling will be provided for the beam plumbing near the target box to minimize the effects of gamma heating.

Remote Handling

As part of the feasibility study for the LAMPF Merrimac concept of remote handling, tests were made on commercial roller assemblies to determine their ability to carry the weight of the shielding doors, the quality of plate required for ways, and the force necessary to move the load. A Hillman 5X express roller appeared to be in as-new condition after carrying 75 tons ~ 1000 ft and 92 tons 80 ft. The door requirement is for each roller to carry 60 tons for a distance of 10 ft. Commercial, unspecified boilerplate is sufficient for roller ways. The plate has a scale which flakes off during use into mounds which are hard to roll over. Sandblasting reduces the scaling,

but the sandblasted surface must then be rolled flat at a reduced roller loading. The rollers and ways will continue to scale and this should be wiped off. The way cleaning presents no problem with the present door design because the rollers are placed in their slot through the shielding only when needed. The slot can therefore be swabbed out. Forces of about 45-lb push/ton-roller appear to be adequate.

An internal report (MP-6/MW-2) on the Merrimac concept of remote handling and related schemes has been prepared and is available for distribution.

Primary and Secondary Beam Transport

A significant perturbation to the previous concepts of primary beam transport occurred during the past quarter because of a revived interest in allowing for multiple primary beam use. Preliminary switchyard designs (see Fig. 26) now exist for a primary beam transport system which could provide for the use at 120 cps of a 1-mA average H^+ beam in Beam Area A, a 100- μ A average H^- beam along Beam Line B, and a 3- μ sec pulsed H^+ beam to be transported to a pulsed reactor facility. The primary beam transport through Beam Area A will be reviewed. A report (MP-6/RRS-1) has been written describing one approach to the transport of the residual primary beam from the last Beam Area A target to a beam stop.

Several experiments now under consideration for LAMPF will require a very short beam pulse. Beam pulse lengths ranging from a single micropulse to 3 μ sec have been requested. In order to allow these experiments to run and at the same time allow conventional experiments to have close to the 1 mA promised, it is necessary for the beam switchyard to include a fast pulsed deflector.

Some conceptual design work on such a device has been started. The system has two basic elements: an injector current programmer and a delay line pulsed magnet. The latter is a ferrite magnet effectively wound with a single turn. Capacitors are connected between this turn and ground so that the magnet winding becomes a lumped element transmission line. When this line

is terminated in its characteristic impedance, it presents a resistive load to its driving source. This load can be driven by a rectangular wave form pulse, and but for the propagation delay of the transmission line, the magnetic field will follow the wave form. The ferrite rise time of the lumped element magnet line as well as the rise time of the source line within the pulse generator will also contribute to the fill time and decay time of the magnet.

The injector must be programmed to shut off the beam during the magnet fill and decay time ($\sim 0.3 \mu$ sec each) and to deliver full beam current in a pulse of the desired width during the time the magnet is at its steady field. Thus the injector program supplies the accurate timing required.

In this study the magnet was asked to provide a 2° deflection of the 800-MeV proton beam. A possible (unoptimized) set of magnet parameters are given below.

Field Strength	2 kG
Length	0.92 m
Width	0.05 m
Gap	0.02 m
Total L	3.0 μ H
Total C	0.03 μ F
Z_o	10 Ω
Propagation time	0.3 μ sec
Exciting current	3.2×10^3 A.

Assuming 3 μ sec/pulse and a repetition frequency of 120/sec, the average power is 3.6×10^4 W, which must be supplied at 64 kV. The parameters listed here seem to be technically feasible. They are similar to those of delay line magnets in use at other laboratories.

A design proposal for the stopped muon channel is being completed and an internal report will be written. Some of the characteristics of the channel are as follows:

Design energy - variable	100 to 200 MeV/c
Pion acceptance solid angle	11 msr
Flux of pions at channel end	$1.6 \times 10^9 \text{ sec}^{-1}$
Flux of forward muons for a 1 mA proton beam on Cu target 6 cm long	$2.8 \times 10^8 \text{ sec}^{-1}$ 40° production angle
Momentum spread of pions at channel end	$\pm 11\%$

Momentum spread of muons $\pm 11\%$
at channel end

Channel configuration: $Q_1 Q_1 B Q_1 Q_1$
 $B Q_2 Q_2 Q_2 Q_2$

Q_1 is an 8 in. quadrupole 20 in. long, 18 kW each;
 Q_2 is an 11 in. quadrupole 20 in. long, 25 kW each;
B is a $6\frac{1}{2}$ in. x 26 in. bending magnet, 30° bending
angle, 90 kW each. The total power consumption
of the channel is 400 kW at 100 MeV (200 MeV/c).

The code TRANSPORT from SLAC has
been modified for use on the CDC-6600 system at
LASL. Several first and second order corrections
have now been included and the code has been tested.
TRANSPORT finds many important uses in primary
and secondary beam channel design and in the
design of experiments.

Reference

1. M. D. Keller, LASL Engineering Report
ENG-1 Rp-9.

VII. LAMPF SCHEDULING AND FACILITY CONSTRUCTION

Introduction

LAMPF PERT activities have been applied
to updating and improvement. Several normal
modifications were made. The PERT COST
feature was implemented, and studies were initiated
to explore longer range improvement poten-
tialities.

Construction is about 40% complete on
the Equipment Test Laboratory Building, 10% on
the Injector and the 201.25-MHz Sector Building,
and 20% on the second phase of Site Utilities. An
underground telephone cable has been installed to
the site, and the construction has started on the
115 kV Substation. Design activities were directed
toward completion of Title II documents for the
805-MHz Sector Buildings and of the criteria
documents for a new structure called the Opera-
tions Building.

Accelerator Scheduling

Integrated LAMPF PERT printouts were
utilized as described in the preceding report
(LA-3948-MS). In this period, efforts were
devoted to updating and improving the system.

Normal modification activity included the
correction of numerous logic difficulties in four
of the subnets. Temporary substitution of a
summary network for the experimental area was
made until a new detailed breakdown can be
derived from the summer planning work. Manpower
leveling is currently being applied to the control
system subnet, and it is anticipated that extensive
changes will result.

Significant upgrading of the scheduling
program was achieved by implementing the PERT
COST options. This was made possible by addition
of a manpower rate table and of equipment and
building costs. Appropriate fund holds had to be
inserted in the FUND subnet to reflect the
obligational authority limitations experienced so
as to obtain the correct Earliest Expected Dates
for fund-constrained activities and milestones.

Several studies were initiated to explore possible methods of improving the network planning for LAMPF. The experimental subnet, XNET, is being used to find means of inserting extra-divisional manpower and detailed-level equipment costs. Other experiments are in progress which attempt to employ the MASK feature of the PERT program in order to obtain reports specialized for procurement activities. Because of some of the limitations encountered in the PERT system, the investigation of alternative programs, such as the CDC-6600, was initiated. To be feasible for LAMPF application, a new program would have to offer significant output data improvement and would have to be capable of being substituted for PERT with a negligible perturbation to the project planning activity.

LAMPF Site and Building Activities

Equipment Test Laboratory Building (ETLB)

Construction of the ETLB is now about 40% complete. Because of impedance of the start by the weather and delays in delivery of steel framing, this is about 10% behind schedule. However, from conferences with the contractor, it has been concluded that current expediting of equipment procurement will permit a closer approach to the scheduled completion. The steel framing, roof decking, and floors are now all in place; only a small portion of the roofing and metal siding remains to be installed. Plumbing and conduits have been placed in the joist spaces and are being extended as the present interior partition work progresses. Brazing furnace installation drawings and specifications are being prepared for negotiation with the building prime contractor, J. R. Brennan Construction Co.

Accelerator Building Activities

The George Rutherford Co. is ahead of scheduled construction on the Injector and 201, 25-MHz Sector Building. This package is now about 10% complete with the excavation work done and concrete pouring in progress on the Injector Building sub-basement and Beam Channel floors and walls. Plans and specifications were completed

and issued for procurement of the Faraday Cage which will house the first high-intensity C-W injector. Bid opening for this government furnished equipment will be held at the outset of the next report period.

As previously reported, new conceptual layouts were being developed for the 805-MHz Accelerator Buildings. The primary difference between these and previous designs was the clustering together of rf power sources into seven structures. At the beginning of this period the A-E (Giffels and Rosetti) was instructed to proceed with detailed design. An interim review of these plans was made on June 24-25, 1968, and the final design was then authorized. Review of Title II plans and specifications is scheduled for early in the next period.

Another previously reported modification in site layout was the relocation of the accelerator control facility to the proximity of the experimental area. The experimental service areas, previously located in the Experimental Building, were added to the control space requirements to form a 2-level, 17,000 ft² structure now called the Operations Building. Use-pattern studies of accelerator operation periods indicated that the control and close experimental support functions tended to have the same "center of gravity" and that the center was as close to the experimental areas as potential facility expansion would permit. Concept review sessions were held on the June 24-25 and July 24, 1968. The completed criteria package for this building will be available for A-E negotiations early in the next period.

Utility Work

Mountain States Telephone installed a 600-pair direct-burial cable to the LAMPF site during this period.

On May 2, 1968, bids were opened for the second phase of site utility work. This package consists of site water storage tank, fire pumphouse, sewage lagoons and extensions of the site water, sewage and gas piping systems. The A-E estimate for the work was \$281,500; the low and successful bidder was the Powers Construction

Corp. of Albuquerque at \$257,220. Notice to proceed was issued to the contractor on May 23 and the job is now about 20% complete. Work in progress includes grading of the sewage lagoons, trenching and laying of water and sewer lines, compaction of service roads, and placement of the storage tank foundation.

As previously reported, the original \$906,000 low bid for the 115 kV substation by Gardner-Zemke Co. and Beaty Electric was canceled because of restrictions on obligational authority. Subsequently, the AEC was authorized to construct a new Eastern Technical Area Terminal Station for LASL. The latter facility permitted a reduction in scope for the LAMPF substation. As a consequence, Uhl and Lopez Engineering redesigned and reissued plans and specifications to prospective bidders on May 22. The low bidder was the same joint venture as before at a price of \$662,000 compared with the redesigned estimate of \$690,000. The preconstruction conference was held July 16, and the grade line staking has now been completed.

A new proposal was submitted by the New Mexico Public Service Co. together with the Bureau of Reclamation for supply of LAMPF electric power. The AEC selection panel held a review meeting on June 10 and subsequently issued a letter asking for clarifications and additional information from the proposers. The response has been received and is being reviewed. Completion of this activity will be dependent upon the success of future negotiations.

VIII. PHYSICS RESEARCH

An experiment on the production of pions and heavier mesons in the reaction $p + p \rightarrow d + x$ was carried out at the Zero Gradient Synchrotron at the Argonne National Laboratory. This work was done in collaboration with physicists at the University of Chicago, ANL, Carleton University and the National Research Council of Canada, and Nagoya University, Japan. The pi-meson production data have been analyzed, and the analysis of the heavier meson production is proceeding.

Plans are under way to mount an experiment on the Berkeley 184-in. cyclotron for the purpose of measuring pion-production cross sections at energies and angles required for design of the LAMPF facility.