ALTERNATING GRADIENT SYNCHROTRON PROJECT CONSTRUCTION COMPLETION REPORT

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BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, L.I., N.Y.

CONSTRUCTION COMPLETION REPORT

ALTERNATING GRADIENT SYNCHROTRON PROJECT

Associated Universities, Inc.

Brookhaven National Laboratory

Upton, New York

Under Prime Contract AT-30-2-GEN-16

with

United States Atomic Energy Commission - Brookhaven Office

Budget Project 05-1-54-Y-019-52

Work done under the auspices of the U.S. Atomic Energy Commission

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PART I - GENERAL INFORMATION

1. General Description of the Project

The Alternating Gradient Synchrotron Project consisted of the design and construction of a proton synchrotron capable of producing particles with energies of 33 Bev. The project was conceived as the largest proton accelerator technically and economically feasible, and was to be capable of producing particles with many times more energy than any proton accelerator heretofore constructed in the United States; the Bevatron at Berkeley being the nearest at an energy of 6 Bev. The project included the construction of the related facilities to house and operate the synchrotron.

The AGS is approximately 843 feet in diameter, one half mile in circumference and consists of 240 magnets of about 15 tons each, arranged in an underground tunnel, powered by dc rectified power from a 29000 KVA 12 phase, 5500 HP flywheel motor generator. A 50 Mev linear accelerator is provided for proton injection to the main ring.

In addition to the structures which house the linear accelerator and the main magnet ring there was provided: experimental space both indoors and outdoors; a service building housing the control room, water pumping equipment, the rf power amplifier, main power supply, and engineering and administrative offices; an equipment assembly building and a warehouse. Under the project an addition was made to the Central Steam Plant and extensions were made to the distribution systems for water, steam, electric power, storm drainage and other utilities as well as construction of necessary service roads.

The AGS Complex covers a site of approximately 50 acres at the northwest section of the developed area of the Brookhaven National Laboratory.

The Project also included, as one of the early phases, the design and construction of an "Electron Analogue" to test experimentally the dynamic behavior of strong focusing synchrotrons. This device was operated successfully and confirmed the basis of design for the Alternating Gradient Synchrotron as well as the CERN Proton Synchrotron. It was ultimately disassembled and shipped to the Oak Ridge National Laboratory.

2. Design Basis

a. Synchrotron

The Synchrotron design is based on the discovery of the alternating gradient ("strong") focusing principle which, by greatly reducing the amplitudes of particle oscillations, reduced the required cross sectional dimensions of the vacuum chamber with commensurate reduction of size of synchrotron magnets.

The final design specifications of the AGS were:

Type of Particles	Protons
Maximum Energy	33 Bev
Pulse Repetition Rate at Maximum Energy	2.4 Seconds
Beam Intensity (1961)	1×10^{10} per pulse approx.
(1964)	5×10^{10} per pulse approx.
Magnet - Focusing Type	Alternating Gradient
Orbital Radius	280 feet
Mean Radius	421.45 feet
Magnet Circumference (including straight sections)	2648 feet
Number of Magnets	240
Magnet Cross Section	33 X 39 inches
Magnet Weight - Steel Cores (Total)	4000 tons steel
Magnet Weight - Copper Coils (Total)	400 tons copper
Field at Injection	121 guass
Field - Maximum	13,000 gauss
Power Input - Maximum	33,000 kilowatts
Rise Time	1.2 seconds
Aperture Width	6 inches
Aperture Height	2.7 inches
Vacuum Chamber - Elliptical	7 X 3-1/4 inches
Vacuum Chamber - Operating Pressure	10^{-6} millimeters of mercury
Injection System	Linear Accelerator
Injection Energy	50 Mev
Injector Output	3 milliamperes
Acceleration System Frequency	1.4 to 4.5 megacycles/sec.
Accelerating Stations	12
Energy Gain, Average per Turn	90 Kev

Performance of the AGS has exceeded the "design intensity" by a factor of more than 20. with the attainment of more than 1×10^{12} protons per pulse in 1966.

b. Facilities

The facilities were designed to provide all of the features which the synchrotron design required. The use of an underground tunnel was dictated by the shielding requirements while the spacial concepts were based on movement and layout of equipment. The Service Building was designed to accommodate the initial operating crew and to house necessary machine support services. The experimental areas were designed on the basis of the known or predictable research requirements as they existed at the time. (Subsequent knowledge has led to alterations and additions to keep pace with technological advances as well as new experimental research developments.)

3. Important Dates

Summer 1952	Concept of Strong Focusing Principle developed
April 3, 1953	Tentative Proposal for 50 Bev AGS contained in BNL Budget Submission for FY 1954
August 21, 1953	Letter - BNL to T.H. Johnson proposing analogue
September 9, 1953	Letter - BNL to T.H. Johnson proposing 25 Bev AGS
September 9, 1953	Budget Data Sheets submitted for 25 Bev Synchrotron
December 23, 1953	Letter - E. L. VanHorn to BNL authorized construction of analogue
January, 1954	Authorization and funds allotted by Atomic Energy Commission
February 8, 1954	Letter - E.L. Van Horn to BNL authorized preliminary design of AGS
April 13, 1960	Linac proton beam accelerated to 50 Mev for first time
May 17, 1960	50 Mev proton beam injected into Synchrotron and successfully completed one turn around the ring
July 29, 1960	Proton beam accelerated through phase transition and accelerated to above 30 Bev. Research started
July 29, 1960	Beneficial Use
September 13, 1961	AGS Dedication
June 1964	Project completed

4. Other Significant Dates

Design - Synchrotron

February 8, 1954	BNL started Preliminary Design
February, 1956	BNL started Detailed Design
May, 1960	BNL completed Design

Design - Facilities

January, 1954	Architect - Engineer Seclection started
April, 1954	Architect - Engineer Selection completed
July 28, 1954	Architect - Engineer started design work
November, 1963	Architect - Engineer completed all design work

Construction - Synchrotron

February 8, 1954	Analogue Construction started
June, 1955	Analogue completed
March, 1958	Analogue Dismantled
March 8, 1956	Initial Procurement - Cockcroft Walton placed on order
March 18, 1957	Main Magnet Power Supply placed on order
July 3, 1957	Magnet Coils placed on order
July 25, 1957	Magnet Cores placed on order
August 19, 1957	Linac Tanks placed on order
December, 1957	Magnet Test Facility set up in Target Building
February 20, 1958	First Magnet Coils received
March, 1958	Assembly of Cockcroft-Walton in Linac Building started
April 24, 1958	First Magnet Core received
June, 1958	First Linac Tank received
July 22, 1958	Vacuum Chambers placed on order
October 1958	Started Installation of Main Magnet Power Supply
November, 1958	Main Magnet Power Supply received
November, 1958	Started Installation of Main Magnets in Ring

November, 1958	Placed first Linac Tank in position
February, 1959	Delivery of Vacuum Pumps started
February, 1959	Cockcroft-Walton operated at full voltage
April, 1959	Last Magnet Core delivered
April, 1959	Last Magnet Coil delivered
May, 1959	First Vacuum Chamber delivered
June, 1959	Main Magnet Power Supply powered
July, 1959	Installed first drift tube in Linac
August, 1959	Ring Magnets Pulsed
February, 1960	Thrust Bearing installed on Main Magnet Power Supply
April, 1960	Vacuum pumped on first Superperiod

Construction - Facilities

February 9, 1955	First procurement for Boiler House Extension
May 16, 1955	Steam Plant Addition started
July 28, 1955	First Procurement for Service Building
August 18, 1955	First Construction Contract for Service Building
October 3, 1955	Service Building and Utilities started
December 2, 1955	Steam Plant Addition placed in operation
January 30, 1956	Magnet Enclosure, Linac Building, Target Building - Clearing and Excavation started
February, 1956	Steam Plant Addition completed
April 23, 1956	Magnet Enclosure, Linac Building, Target Building - Pile Driving started
July 16, 1956	Magnet Enclosure, Linac Building, Target Building - Concrete Work started
October, 1956	Service Building occupied
January 8, 1957	Magnet Enclosure, Linac Building, Target Building - General Contract started
April, 1957	Service Building completed
July 29, 1957	Target Building Shielding placed under contract

October, 1957	Warehouse started
December, 1957	Target Building - Test Facility Occupied by BNL
January, 1958	Warehouse completed
February 14,1958	Linac Building Occupied by BNL
February 21, 1958	Service Building Foundation for Power Supply started
March 3, 1958	Target Building - All occupied by BNL
March 31, 1958	Magnet Enclosure Occupied by BNL
April, 1958	Service Building Foundation for Power Supply completed
April 23, 1958	Target Building Shielding erected in place
May 15, 1958	Service Building Power Room started
September, 1958	Magnet Enclosure, Linac Building, Target Building completed
February, 1959	Service Building Power Room completed
April, 1959	Service Building Office Wing started
January, 1960	Service Building Office Wing completed
August 11, 1960	East Experimental Building started
December 13, 1960	Service Building Laboratory Addition started
September, 1961	Service Building Laboratory Addition completed
September, 1961	East Experimental Building completed
November, 1962	Warehouse Addition started
June 25, 1963	Warehouse Addition completed
April, 1963	Equipment Assembly Building started
January 24, 1964	Equipment Assembly Building completed

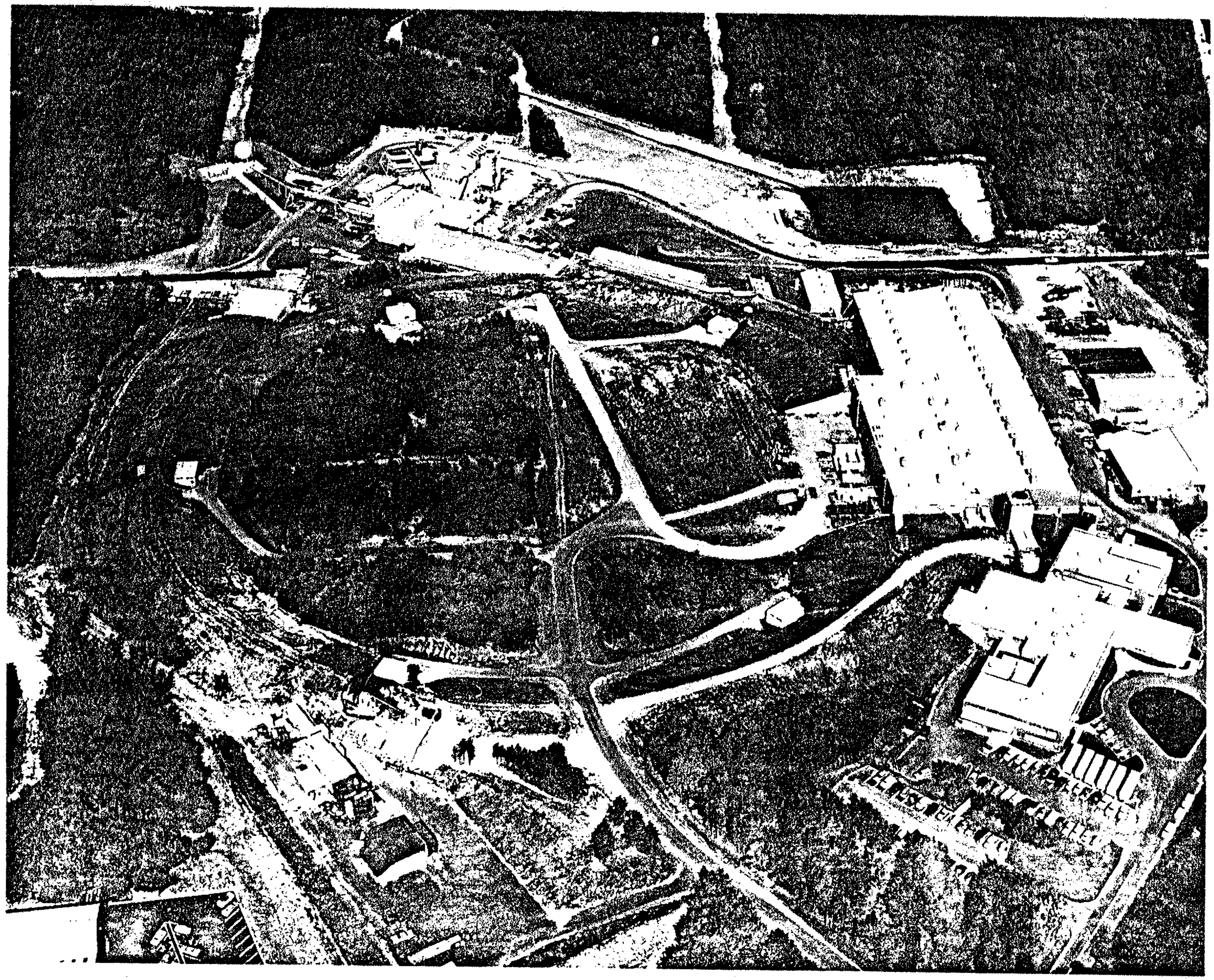


Figure 1
Aerial View of Alternating Gradient Synchrotron Complex

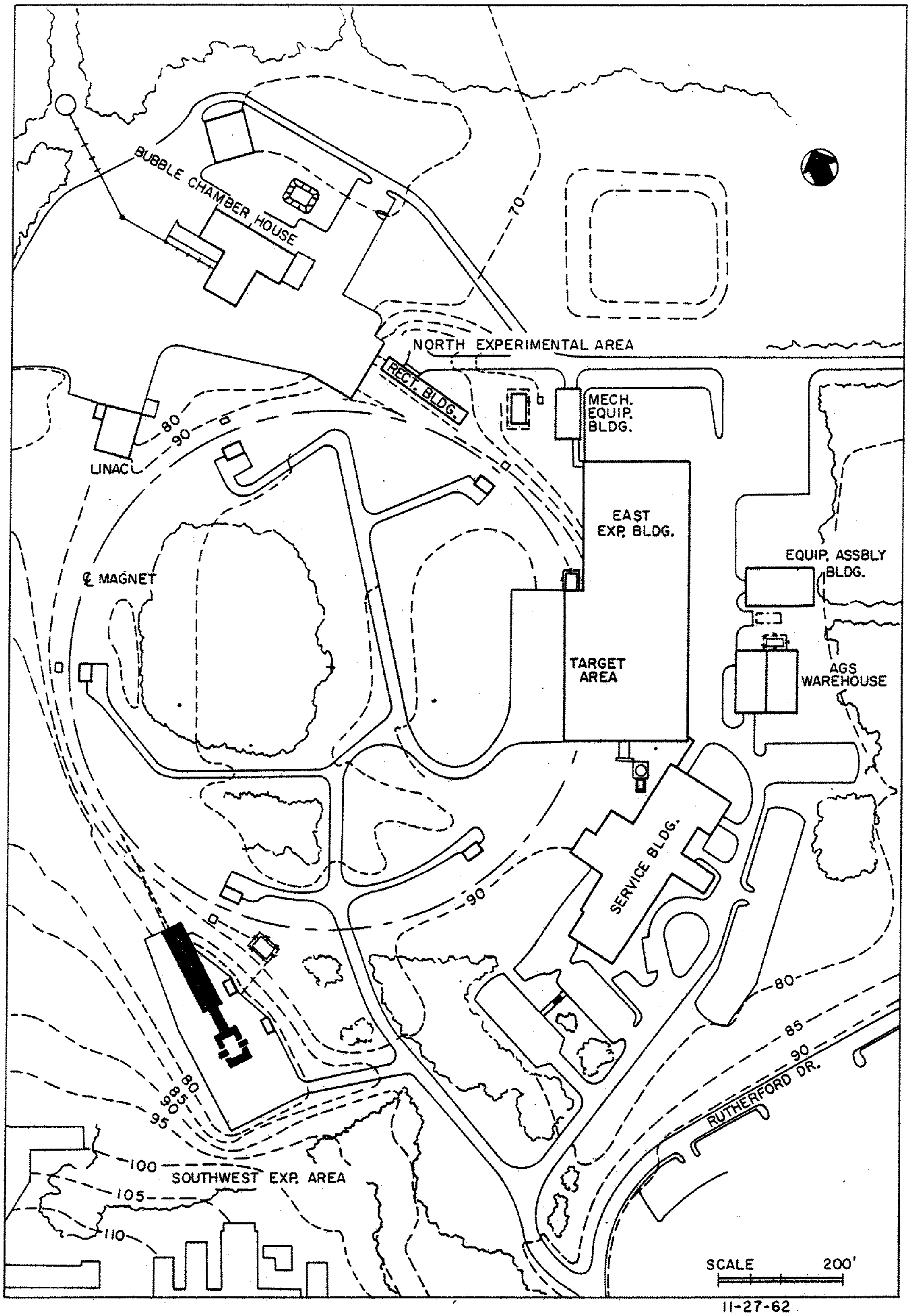


Figure 2
AGS Complex Plot Plan

6. Organization and Control of Project

The Alternating Gradient Synchrotron Project was set up under the Accelerator Development Department of the Brookhaven National Laboratory operated by Associated Universities, Inc. under Atomic Energy Commission Contract No. AT-30-2-GEN-16.

The Director of the Laboratory initially was named Department Chairman and a full time Deputy Chairman was named. The Deputy Chairman also acted as Project Engineer with two others named to assist him. A full time Construction Manager was appointed to the Project.

The Project functioned as a complete entity with unified management within the framework of the Brookhaven National Laboratory. Personnel were assigned from other Departments and Divisions of the Laboratory as necessary. Specialized procedures were established for the management of the business and construction activities of the Project. Separate accounting, purchsing, and materiel functions were established under the project.

The facilities were designed and their construction supervised by an Architect-Engineer selected by the Project. The construction of the facilities was accomplished under multiple contracts and/or purchase orders, generally of the lump sum type arrived at competitively.

The Synchrotron was designed by the Project staff and procured under multiple procurements of the fixed price type based on competitive bidding wherever feasible. In general, the synchrotron was assembled and tested by the Project staff supplemented as necessary by specialty contractors such as the rigging and heavy power installation of the Main Magnet Power Supply.

The Brookhaven Office of the Atomic Energy Commission exercised administrative control of the project through the Directive System whereby funds were authorized on a piecemeal basis as separate proposals were made for divisible portions of the project against the overall Budget Project No. 05-1-54-Y-019-52. The Manager of the Brookhaven Office appointed a Project Liason Engineer who maintained direct contact with the Project staff. It was established that there would be annual reestimates and reviews of the Project. The procedure proved to be successful in practice and served to keep the Commission informed at all times. Regular monthly progress and summary cost reports were prepared and issued.

Actual performance of the Architect-Engineer came under the supervision of the Construction Management Staff. The detailed plans and specifications were prepared by the A-E in its Boston, Mass. office after consultations and review with the Project Staff. Lists of bidders for advance procurements and construction contracts were prepared jointly. All bids were analyzed by the A-E and recommendations made to the Construction Manager. After review by the Project Staff, the necessary purchase orders and contracts were prepared by the Project and required approvals obtained. Under the terms of Brookhaven's prime Contract, all actions over $5,000 were approved by the Commission. The A-E had a field construction supervision force assigned to the site which was responsible for the hour by hour supervision and inspection of the work. This staff prepared the usual reports of job progress, checked for conformance to specifications, obtained the Project's comments on submittals, checked invoices for quantities and performed all the usual services of field supervision. Change orders were initiated by the field force and were negotiated with the assistance of the Project's Construction Management Staff.

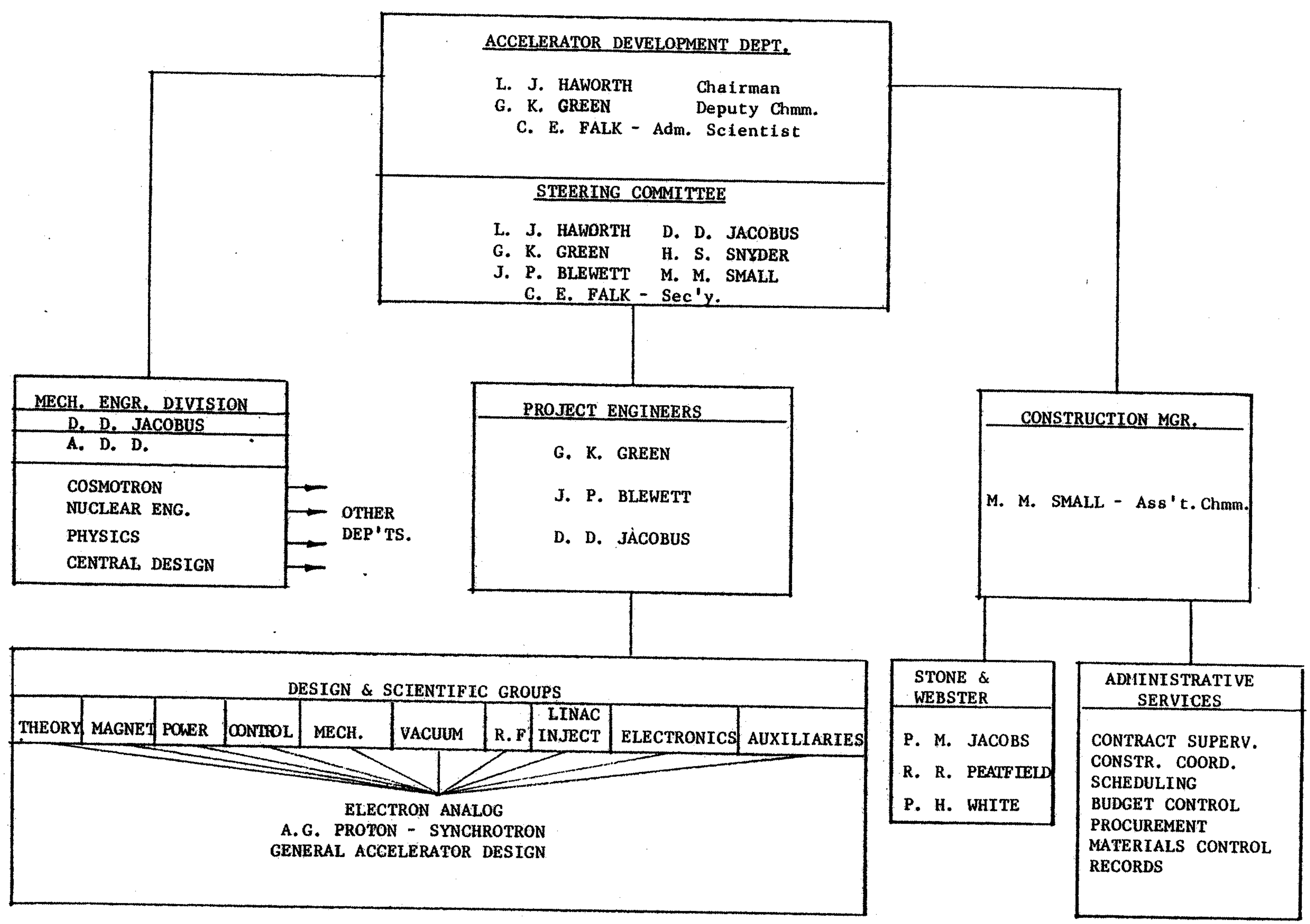
Actual performance of the Project design and assembly staff came under the supervision of the Project Engineer. This staff prepared the necessary designs, plans and specifications and assisted the Construction Management Staff in selecting vendors for procurement of equipment and material. Qualified members of this staff performed the necessary inspections at Vendor's plants and in some cases were in continuous residence at such plants. Final assembly and test were performed by this staff. The Construction Management Staff was responsible for the procurement actions and approvals.

Detailed cost records were kept by the Project and monthly cost reports were made internally as well as to the Commission. Periodic (generally yearly) re-evaluations of the entire Project were made and submitted to the Commission for appropriate action.

Towards the end of the project, the Project Staff was phased out of the Project into operational positions.

ALTERNATING GRADIENT SYNCHROTRON PROJECT

INITIAL ORGANIZATION



PART II - CONTRACT DATA

All work was performed under subcontracts of the operating contractor, Associated Universities, Inc., Prime Contract No. AT-30-2-GEN-16.

1. Architect-Engineer

a. Stone & Webster Engineering Corporation
49 Federal Street
Boston 7, Massachusetts

Subcontract No. S-259 (Portion allocable to this project only)

	Costs	Fee	Total
Title I	$173,078.	$31,000.	$204,078
Title II	652,075.	73,100.	725,175.
Title III	306,476.	23,900.	330,376.
Totals	$1,131,629.	$128,000.	$1,259,629.

Original Fees

Total estimate on which A-E provided services		$5,000,000.
Maximum allowable fee		
Negotiated fee	$95,000.	

Additional Fees

Estimate on which A-E provided services		$2,862,000.
Maximum allowable fee		
Negotiated fee	$33,000.	

Final cost of work on which A-E provided services $9,948,039.

Number of Title II Drawings 344

Cost per drawing $2,400.

Work started July 28, 1954

Work completed November 30, 1963

b. In addition to the above major Architect-Engineer contract, the following minor contracts were utilized:

1. Byrnes Associates
South Broadway
New York, New York

Purchase Order 56162 for engineering services for the office addition to the Service Building.

Lump Sum Amount $5,500.

Final cost of work on which A-E provided services 81,700.

Number of Title II drawings - 9
Cost per drawing 610.

Work started December 15, 1958
Work completed January 31, 1959

2. Sidney B. Bowne & Son
161 Willis Avenue
Mineola, New York

Subcontract CS-36 for engineering services for rework of three water wells.

Lump Sum Amount 1,000.

Final cost of work on which A-E provided services 41,029.

Work started December 1958

Work completed October 1,1960

3. Byrnes Associates
South Broadway
New York, New York

Purchase Order 56374 for engineering drafting for addition of Hydrogen Protection Systems to the Target Building

Final amount of order 7,666.

Final cost of work on which A-E provided services 145,882.

Number of Title II Drawings 7

Cost per drawing $1,090.

Work started January 15, 1960

Work completed March 18, 1960

2. <u>Construction Contracts</u>

(Major Contracts, over $250,000)

CS-11 - White Construction Co., Inc. $1,088,840.
95 Madison Avenue, New York, New York

General Contract for the Service Building and associated yard work.

Fixed Price

Work started September 30, 1955

Work completed February 5, 1957

CS-16 - White Construction Co., Inc. 887,241.
95 Madison Avenue, New York, New York

Structural concrete work and drainage for the Magnet Enclosure and Linac Tunnel.

Fixed Price

Work started September 23, 1956

Work completed March 19, 1957

CS-20 - Malan Construction Corporation 3,112,974.
2 Park Avenue, New York, New York

General Contract for Magnet Enclosure, Linac Building and Target Building.

Fixed Price

Work started February 20, 1957

Work completed May 29, 1958

CS-22 - Precast Building Sections, Inc. 831,107.
21 East 40th Street, New York, New York

Construction and Installation of High Density Shielding Blocks for the Target Building.

Fixed Price

Work started July 29, 1957

Work completed April 25, 1958

CS-49 - American Bridge Division - U.S. Steel Corp. $255,856
Statler Building, Boston, Massachusetts

Structural Steel for East Experimental Building and Laboratory Addition to Service Building

Fixed Unit Price

Work started June 1, 1960

Work completed January 24, 1961

CS-55 - Malan Construction Corporation 956,783.
2 Park Avenue, New York, New York

General Contract for East Experimental Building

Fixed Price

Work started September 20, 1960

Work completed November 1961

CS-56 - Anderson Construction Corporation 295,124.
Jericho Turnpike, Huntington Station, New York

General Contract for Laboratory Addition to Service Building

Fixed Price

Work started December 2, 1960

Work completed October 22, 1961

Total amount of all construction contracts $16,464,995.

(For complete listing see Appendix B)

3. Brookhaven National Laboratory Participation

	Salary, Wages, Ins. & Overhead	Material, Supplies, Equipment	Total
Engineering, Design and Inspection, G & A			
Title I (Including Analogue)	$730,691.	$446,070.	$1,176,761.
Title II(Including Analogue)	2,117,840.	436,923.	2,554,763.
Title III(Including Analogue)	462,971.	205,536.	668,507.
Totals	$3,311,502.	1,088,529.	4,400,031.
Construction (Including Analogue) (Does not include Cost of Buildings and Utilities, etc. designed by the A-E)	$2,338,523.	12,376,291.	14,714,814.

Note: The above costs include the Research & Development costs associated with the Project and should not be used for comparative purposes with later projects.

4. Other Contracts

(For listing see Appendix D)

5. Major Equipment Procurements

(Major Contracts over $250,000)

CS-19 - Westinghouse Electric Corporation $1,038,960.69
40 Wall Street, New York, New York

Fabrication of Main Magnet Power Supply

Fixed Price with Escalation

Work started March 18, 1957

Work completed December 21, 1960

CS-23 -	Baldwin-Lima-Hamilton Corporation Philadelphia, Pennsylvania	$3,110,303.00
	Fabrication of Main Magnet Cores	
	Fixed Price	
	Work started July 25, 1957	
	Work completed May, 18, 1959	
CS-26 -	National Electric Coil Company Columbus, Ohio	1,761,508.65
	Fabrication of Main Magnet Coils	
	Fixed Price	
	Work started July 8, 1957	
	Work completed May 7, 1959	

(For listing of all items over $10,000., see Appendix C)

PART III - GENERAL DESCRIPTION OF PROJECT

The Alternating Gradient Synchrotron Project comprised the design and construction of the Synchrotron and the structures to house it, together with support structures and experimental areas.

The feasibility of constructing a proton accelerator in the 30 Bev energy range was given great encouragement in the early 1950's with the development of the method of focusing by alternating gradients. As a consequence the Alternating Gradient Synchrotron was studied and a proposal made for its design and construction in 1953.

Early in 1954 funds were authorized for the construction of an electron analogue to confirm and extend the alternating gradient orbit dynamics. At the same time preliminary design studies were undertaken for the construction of the AGS. The electron analogue model study affirmed the alternating gradient principles as postulated and the project proceeded to its successful attainment of acceleration to 33 Bev in July of 1960.

The following pages describe the synchrotron and the facilities as finally constructed under the project. As with any major research apparatus, a continuing program of improvement is underway and some portions of the apparatus described herein have been modified in later years. At the same time the facilities described have been and are continuing to be expanded to keep pace with the expanding requirements of the research program.

PART IV - DESCRIPTION OF THE SYNCHROTRON

1. General Description

A description of the Synchrotron can best be made by first describing the general operation of the machine. This will be done by following the proton from source to target.

Protons are obtained from hydrogen gas which is supplied to an ion source at the Cockcroft-Walton generator in the Linac Building. Protons from the ionized gas in the ion source pass through a small orifice in the cathode and are then accelerated through 750 kilovolts by a Cockcroft-Walton generator. These protons then are accelerated from 750 kV to 50 MeV in the linear accelerator, or "Linac". In the Linac, the protons pass through 124 drift tubes of varying length and diameter placed along the axis of a copper-lined tank about 1 meter in diameter and 110 feet long. The tank is both a vacuum enclosure and a cavity resonator which will be driven at 200 megacycles per second so that accelerating electric fields appear between the drift tubes.

The protons are "bunched" in the beam like beads on a string, and the spacing of bunches increases with velocity through the linac. Each bunch experiences a forward or accelerating electric field in the gap between drift tubes. While the bunch is passing at constant velocity through the axial hole within the drift tube, the cavity oscillation passes through a complete period so that the bunch is again subjected to an accelerating field by the time it reaches the next gap. By proper choice of the voltages, tube lengths, and spacings, bunches are accelerated simultaneously at all gaps in the linac. The peak gap voltages vary from 116 kilovolts at the beginning to 890 kilovolts at the end; the cavity requires several megawatts of power at 200 megacycles per second during the acceleration. The oval shaping of the drift tubes, materially reduces the energy required to excite the electromagnetic oscillations within the cavity to given gap voltages and permits higher voltages to be used without electrical breakdown.

The beam is conducted from the linac into the main synchrotron ring through an elaborate injection system consisting of deflecting, focusing, and monitoring gear mounted on four floor-level pile caps. At injection into the ring, the beam is about 1.7 inches in diameter and comprises several milliamperes of protons with a total angular spread of 5 milliradians (diverging horizontally and converging vertically) and an energy spread of about .3 - .5 per cent.

In the Linac each proton passes each accelerating gap only once. By deflection into circular orbits, the protons may be made to pass many times through each acceleration station around the ring. The magnet arrangements for producing the circular orbits are discussed below.

There are 12 radio-frequency accelerating stations around the ring. Each station consists of a 20 KW power amplifier driving a pair of tunable ferrite loaded cavities. Each cavity has a gap across which the potentials are developed to add energy to the protons each time they pass through. To maintain a vacuum-tight system, the gaps consist of ceramic rings sealed into the cavity system. The voltage gain at each gap is about 4 kv per traversal. With 12 stations, and two gaps per station, the energy gain per revolution is about 96 Kev. On this basis, the protons must go around the ring about 300,000 times, or about 150,000 miles, to gain 30 Bev in energy.

As the energy increases, the velocity of the protons increases rapidly at first and then more slowly as the protons approach the velocity of light. As the velocity increases, the transit time of the protons around the ring decreases and the frequency at the accelerating stations must be increased so that the protons arrive at the gaps at the right phase to experience an accelerating force. The cavities are continuously tuned to resonate at the correct frequency by controlling the permeability of the ferrite rings with which the cavities are loaded. The magnetic permeability of a ferrite is a function of the degree of constant magnetization which may be impressed on it by a direct current. By an ingenious double-cavity arrangement, the direct-current saturating bias may be superimposed on the alternating radio-frequency currents in the cavity walls.

The cavities operate on the twelfth harmonic of the revolution frequency, which creates 12 equally spaced bunches of protons circulating around the ring during acceleration. Since the protons are accelerated from less than one-third of the velocity of light to within a fraction of a tenth of one per cent of light velocity, the frequency of the accelerating cavities increases during acceleration from 1.40 to 4.46 megacycles per second. To keep them in step, the power amplifiers for the 12 double cavities are driven from a common driving source. The exact frequency and phase of the driving source is governed by the revolution frequency and radial position of the proton bunches, as sensed electrically by suitably placed "pickup electrodes" within the vacuum chamber.

The magnets in the main ring perform two functions: guiding the proton beam into a circle and focusing the beam. The deflection of the protons is accomplished by the force exerted on a charged particle moving across a magnetic field. Careful pole shaping is required for the focusing function of the magnetic fields.

Each of the 240 magnets around the AGS ring will deflect the protons by about 1.5 degrees, or 360 degrees in all to complete the(nearly) circular path. The reference circle is 842.90 feet in diameter. The physical length of the magnets occupies about two-thirds of the circumference, the rest being available as straight sections between magnets for other equipment, such as acceleration stations and vacuum pumps, and equipment for injection, targeting and beam ejection.

An elliptical vacuum chamber just over 7 by 3-1/4 inches outside dimensions, is centered in the gap between the magnet poles on the "aperture center line". This line lies 5.25 inches from the open side of the poles, where their vertical separation is 3.500 inches. To prevent undue loss of protons by collision with residual air molecules, a pressure of about 10^{-6} millimeters of mercury is maintained in the vacuum chamber by means of 48 titanium getter-ion pumps distributed around the ring. The chamber is made of nonmagnetic Inconel X, 0.078 inches thick, which offers relatively high electrical resistance to eddy currents.

At any time during the accelerating cycle, targets may be inserted into the beam within the vacuum chamber. Thus secondary beams may be produced at several energies of the circulating proton beam. Techniques have also been developed to extract the circulating proton beam from the synchrotron. The ability to do multiple targeting and to extract the main beam points up the versatility of the AGS.

There now follows a description of the various systems which make up the Synchrotron.

2. Main Magnet Ring

The Magnet Ring

The magnets perform two functions: a) guiding the proton beam into a circle and b) focusing the beam.

The deflection of the protons into a circular path is accomplished by the force exerted on a charged particle moving across a magnetic field. This phenomenon is essentially three dimensional and awkward to describe by two dimensional diagrams. In the AGS, the magnetic field at the medium plane of the orbit (e.g., the plane of Figure 3) is directed vertically downward, from the zenith toward the center of the earth. The protons from the linac at the left of Figure 3 move southward, toward the bottom of the page, and being positively charged, they will experience a force toward the center or east which guides them into the ring.

As the direction of the horizontal velocity v of the charge c changes, the direction of the deflecting force, F=Bev, also changes so that F is always at right angles to both v and the vertical magnetic field B and toward the center. Note that this deflecting force does not change the speed or kinetic energy of a particle; it only changes the direction of its velocity.

Each of the 240 magnets around the AGS ring deflects the protons by about 1.50°, or 360° in all, to complete the (nearly) circular path. The reference circle is 842.90 feet in diameter. The physical length of the magnets occupies about two thirds of the circumference, the rest being available as straight sections between magnets for other equipment such as acceleration stations, vacuum pumps, injection, targeting and ejection apparatus.

A typical magnet cross section is shown in Figure 4 . It is a photograph of one of the laminations of which the magnet cores have been assembled. In "open" magnets, the gap shown at the left flares away from the "back leg" at the right. There are also "closed" magnets in which the gap has an identical contour but flares toward the back leg.

The careful pole shaping is required for the focusing function of the magnetic fields to be discussed later.

A nearly elliptical vacuum chamber, just over 7 X 3-1/4 inches inside is centered in the gap between the magnet poles on the "aperture centerline" which lies 5.25 inches from the open side of the poles where their vertical separation is 3.500 inches.

Magnets

Figure 5 shows an assembled magnet of the "closed"type with the magnetizing coils in place. Each of the four coil sections or "pancakes" consists of eight turns of extruded rectangular copper 1-19/32 inches wide and 7/8 inches high with a 3/8 inch diameter cooling water hole in the center and about 0.001 ohms resistance per pancake.

The closed magnet shown is 90 inches long and consists of about 2800 laminations of 0.031 inch steel plus one inch end plates. It is held together by the eight longitudinal straps which were welded to the outer periphery while the laminations were compressed by a force of 80 tons. The core shown weighs 15 tons, and the copper 3200 lbs. The laminations are insulated from one another by a coating of varnish to inhibit eddy currents. About 98% of the core volume is steel. This excellent stacking factor shows that the steel produced for the AGS magnets is unusually flat.

The 96 "closed" magnets are all 90 inches in length. There are two lengths of "open" magnets: 48 are 90 inches long and 96 are 75 inches long giving a total of 240 magnets in the three classes: A - "long open", B - "short open", and C - "long closed".

The flaring magnet gap illustrated in Figure 4 is essential to the alternating gradient strong focusing system. Exceptionally stringent mechanical tolerances and magnetic uniformity are required to hold the protons within the 7 X 3-1/4 inch vacuum chamber while they travel more than 150,000 miles. The roughly hyperbolic pole contour was held to $\pm$ 0.002 inches of the prescribed form by punching the 633,000 laminations with a very accurate carbide die. The blanks were reversed right to left by pairs before punching to compensate for residual variations in thickness from side to side. After punching and while stacking the magnets, every twenty laminations were turned over top to bottom in order to keep the gap contour symmetrical about the median plane through the gap. The latter procedure inverts the shearing direction in the punch and gives rise to the striped appearance of the core in Figure 5 . The tolerances on straightness of lamination stacking, placement on the ring, etc. are all of the order of $\pm$ 0.010 inches.

The magnets were placed by pairs on 120 large steel girders, some of which are visible on the right in Figure 6 . The ends of the girders are supported on piles. Each pile cap as seen in Figure 6 is mechanically separated from the tunnel floor and covers four 10 inch H section steel bearing piles driven about 50 feet into the sand. The pile caps are special low growth concrete developed by the National Bureau of Standards, having excellent dimensional stability.

There are 120 sets of four piles each and this foundation for the ring is considered to be exceptionally advantageous in view of the stability problems of strong focusing synchrotrons. Sand acts as an effective damper for earth tremors and eliminates dangers of faults occurring in local sub-strata with the accompanying physical shift of adjacent regions.

Focusing

The research usefulness of an accelerator depends on beam intensity as well as on the top energy achieved. It is not enough to accelerate an ideal particle on an ideal orbit. It is important to accelerate the greatest number of particles by returning those that depart from the ideal orbit back to that stable path before they strike the vacuum chamber walls.

One thinks of an actual particle as following a path which deviates radially and vertically from the ideal equilibrium orbit. Focusing forces are those which tend to deflect the particle toward the ideal orbit and the strength of these focusing forces may be described by the frequency with which they cause an actual particle to oscillate back and forth across the equilibrium orbit. In the older "weak focusing" machines, such as the Cosmotron and Bevatron in this country and the Synchrophasotron in Russia, these "betatron oscillations" take place less than once per revolution; in the AGS there are 8-3/4 such betatron oscillations in both the vertical and horizontal planes per revolution. For this reason the term "strong focusing" has been applied to alternating gradient machines.

The AGS magnets are arranged in twelve identical 30° superperiods of twenty magnets each. The arrangement within a supereriod is shown in Figure 7 in which the magnets may be numbered 1 to 20 counting in the direction of the proton beam from right to left. Magnets 1 through 10 are placed with their back legs outside the ring on five successive girders; magnets 11 through 20 are in the same sequence as magnets 1 through 10 but have their back legs inside the ring. There are ten foot straight sections between magnets at each back leg reversal; five foot straight sections for auxiliary equipment following magnets 3,5, 7,13, 15, and 17; and only two foot straight sections to accommodate coils, vacuum chamber junctions, etc. between the rest, as shown.

The sequences of 10 magnets with back legs all on the same side of the orbit leaves open access to the vacuum chamber on the other side. This greatly facilitates tangential injection and ejection of the beam as well as leaving paths for product particles ejected from targets suitable placed in ten foot straight sections. These advantages are the main reason for adopting a basic plan which alternates the position of the back leg rather than one with the back legs all on one side of the orbit.

The gaps of magnets labeled + in Figure 7 flare toward the outside of the ring, while those labeled - flare toward the inside, regardless of the position of the back legs. The + and - magnets alternate in pairs and four successive magnets constitute one alternating gradient period. Thus the gaps of the four short magnets adjoining each 10 foot straight section flare away from their back legs, which accounts for the 96 short open magnets of Class B. It can be seen that half of the magnets of each class are placed with their back legs inside the orbit, and the other half outside. By such means a maximum overall symmetry of the guiding and focusing fields is attained in spite of residual random variations between and within magnet classes.

Within the flaring gap of each magnet the strength of the vertical component of magnetic field decreases toward the open side of the gap. Consequently, the particles are deflected less strongly (larger radius of curvature of path) in the wide than in the narrow side of the gap. With large magnetic field gradients, a + magnet tends to defocus the beam in the horizontal direction, and conversely for a - magnet.

The essence of the alternating gradient discovery is that a regular succession of focusing and defocusing elements can produce a strong net focusing action. Both focusing and defocusing elements exert stronger forces the farther the particle is away from the equilibrium orbit. It turns out that, in focusing sections, the particles are, on the average, farther from the equilibrium orbit than in defocusing sections. Therefore a net focusing action results.

The nature of a quasi-static magnetic (or electric) field in free space is that the "curl" of the field is zero; that is, if the vertical upward component of the field increases as the reference point moves horizontally to the right, then its horizontal component to the right will increase just as fast as the reference point moves vertically upward. A consequence of this fact is that a + magnet, which defocuses the beam in the horizontal direction, will focus the beam in the vertical direction, and conversely. Thus, + magnets in Figure 7 focus in the vertical direction and - magnets defocus in the vertical direction. Alternating gradient focusing is thus provided in both the horizontal and vertical directions, and by providing the same amount of strong + and - focusing around the ring, the net alternating gradient focusing forces will be about the same in both the horizontal and vertical directions, that is, there will be nearly the same number (8-3/4) of betatron oscillations in one revolution both vertically and horizontally.

Magnet Steel

To insure that the various deflecting and focusing conditions be fulfilled uniformly all around the ring and at all times during the acceleration, the magnets must be magnetically as well as mechanically accurate.

An Electrical Grade M-36 steel was chosen containing about 1.80% of silicon and 0.03% carbon. Before the current is turned on for a pulse, the remanent field at the aperture centerline is about 15 gauss due to the remaining magnetization in the steel core from the previous pulse. The value of this remanent field depends mainly on the coercive force of the steel which averages around 0.77 oersted. As the pulse current rises, the injection field value of 120 gauss should be reached simultaneously in all magnets. The increase above remanence depends mainly on the gap size and shape but partly on the low field permeability of the steel which averages about 740 at 100 gauss.

During the main part of the cycle up to 10,000 gauss and more, the fields depend almost completely on the gap geometry because the permeability of the steel is very high. By 11 or 12 kologauss the saturation of the steel becomes noticeable, especially since the flux density in the pole tips near the closed part of the gap can exceed that at the aperture centerline by 50% or more. The onset of saturation distorts the field distribution, especially toward the closed side of the gap, and thus sets an upper limit to the proton energy that can be attained. An average permeability approaching 140 at 18,000 gauss is attained by the AGS steel.

The stringent AGS demands for magnetic uniformity around the ring and at all times during the rising pulse could not easily be met by commercially produced steel even with the special care used for the 4,000 tons of AGS steel. Two related problems are involved: (a) coercive force and low field permeability show standard deviations of 10% to 15% from the mean, and (b) both properties show an "aging" deterioration of 60% or more as determined by accelerated aging tests in which samples are subjected to 150°C for five days. It is assumed that it will take at least 20 years for the same aging to take place at room temperature. Fortunately the high field properties show no appreciable aging.

The first line of defense against these large variations in the steel has been to shuffle or interleave the steel for each of the three magnet classes according to a careful plan so that the steel from a given billet and rolling mill coil will appear in all magnets of a given class at the same relative position and for about the same number of laminations. This shuffling reduces the residual variations between magnets to less than 0.1%, even at injection, and will minimize them throughout the aging process extending over several decades.

In addition to these measures to insure uniformity, a number of provisions have been made for final trimming of the orbits in the machine. Figure 7 shows the position of pickup electrodes and quadrupole and sextupole magnets in each superperiod as well as the primary survey monuments. At each pickup electrode location, both the horizontal and vertical position of the beam can be monitored electrically, enough in all to diagnose various harmonic distortions of the equilibrium orbits. On the basis of such information, the correcting multipole magnets and certain low field air core windings located in two foot straight sections can be powered to hold the orbits near the center of the vacuum chamber during injection and acceleration and to compensate to a degree for field distortions due to magnet saturation near the end of acceleration.

Magnet Positioning

The magnets were positioned on the ring with reference to the primary survey monuments shown in Figure 7. Each primary monument is driven into the underlying sand and is mechanically separate from the tunnel base and ring piles. From each monument straight lines of sight are available within the tunnel walls to the two adjacent monuments on either side. By means of high precision survey techniques, distances between adjacent monuments have been determined to a thousandth of an inch and triangle closures to one third of a second. Periodic resurveys are carried out to monitor stability and possible soil movements. The magnets were erected by using a system of Invar length rods which fitted into hardened bushings on each end of a magnet and which carried a target at the other end whose position relative to a line of sight between adjacent monuments was measured with line of sight telescopes. The magnets were then adjusted radially until the out board target was on the line of sight plus or minus the known magnetic correction for each magnet unit.

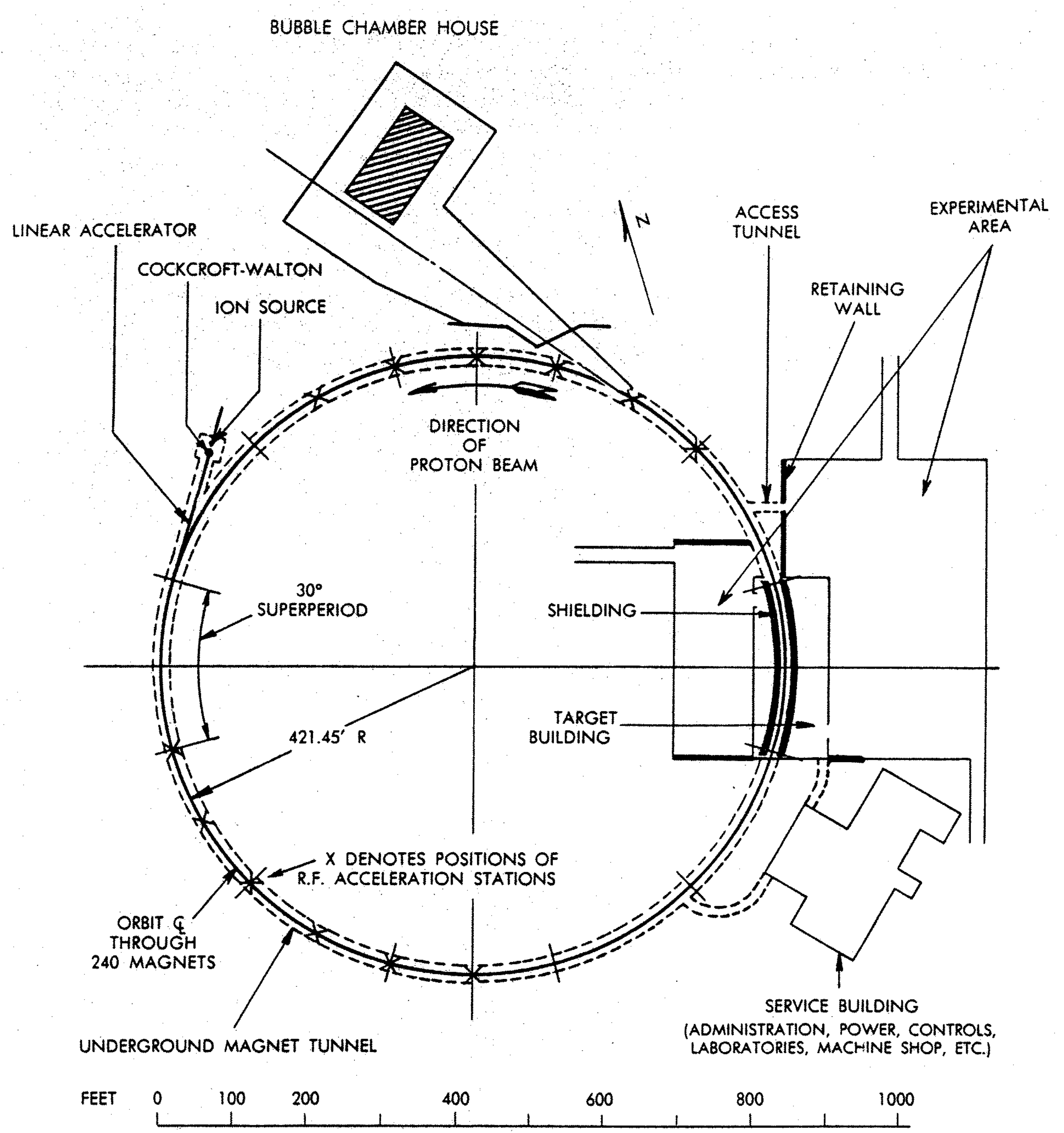


Figure 3
Plan of Brookhaven A.G.S. as of 1960

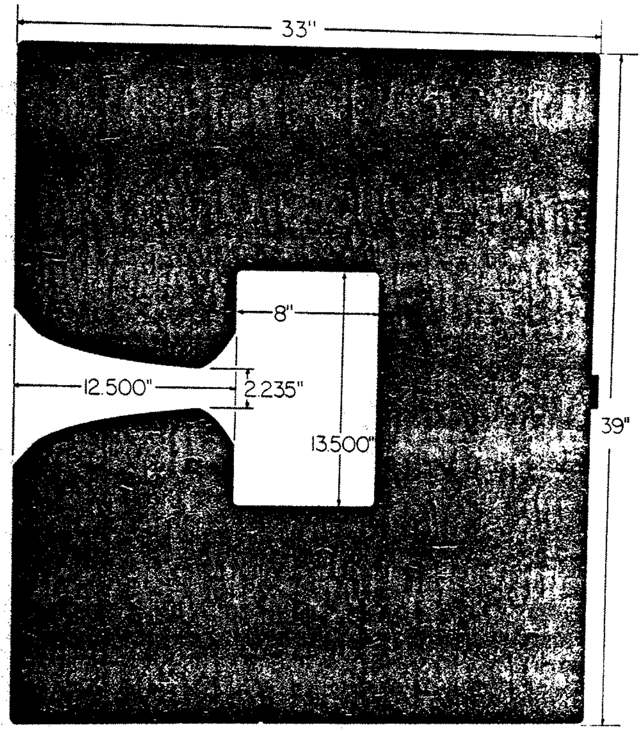


Figure 4
A.G.S. "Open" Magnet Lamination

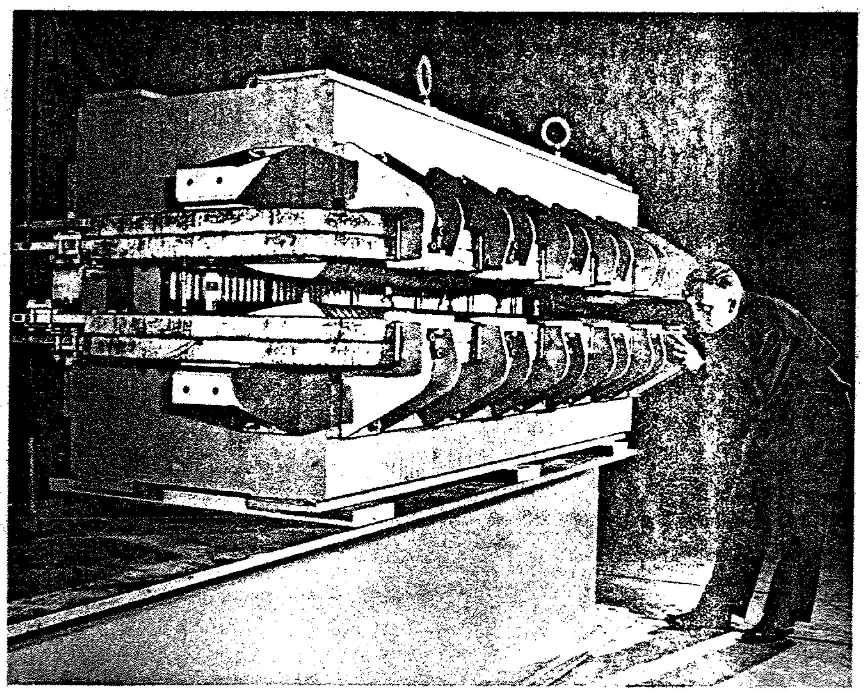


Figure 5
Assembled Closed Magnet with Coils in Place

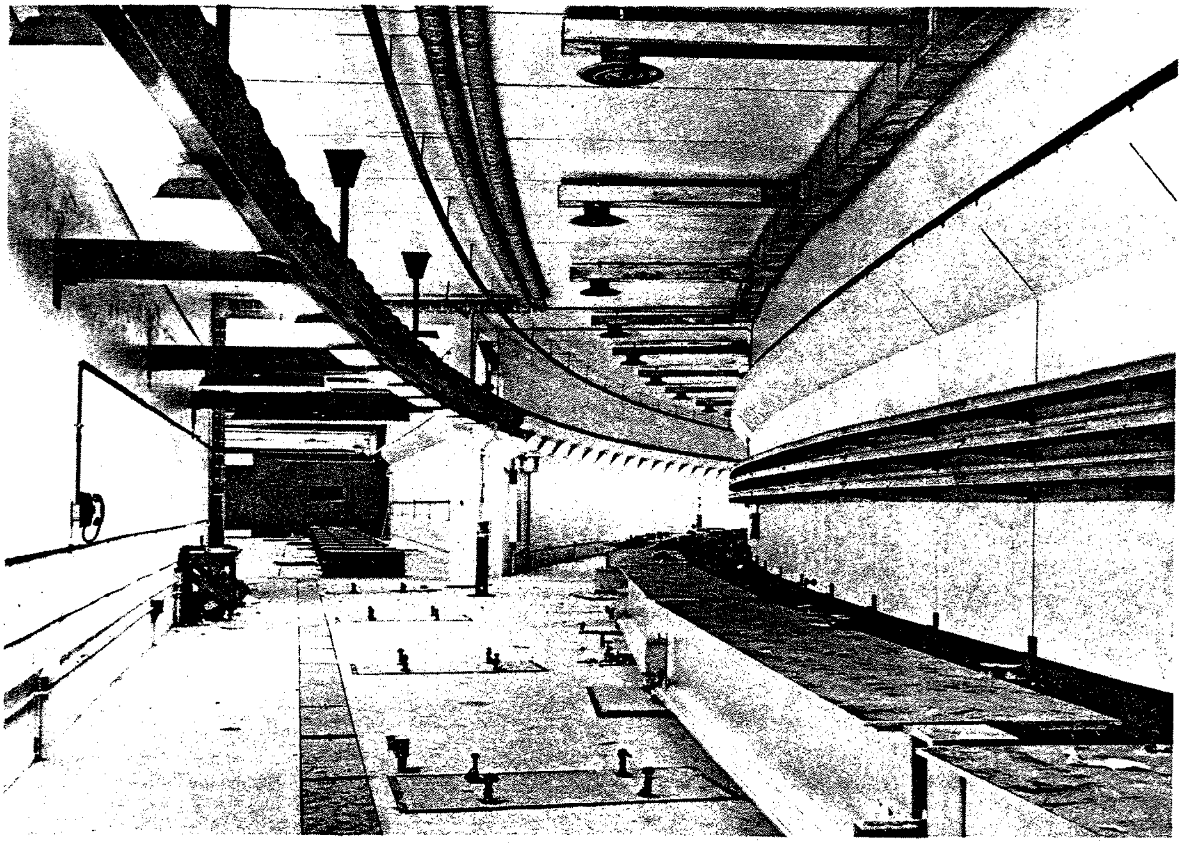


Figure 6
Conjunction of Linear Accelerator Tunnel and Main Ring

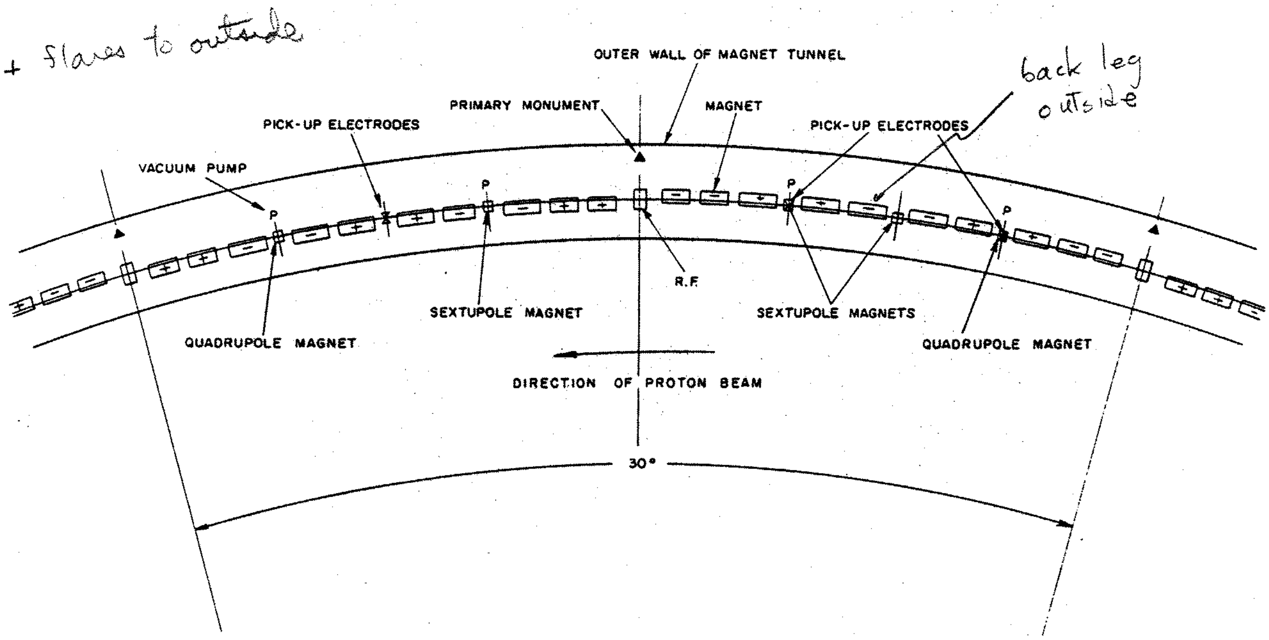


Figure 7
A.G.S. Superperiod

3. Power System

Main Magnet Power Supply

Design Parameters

The main magnet power supply of the AGS was specified as an a-c flywheel motor generator set supplying an ignitron power converter. This specification was based on years of successful operation of the Cosmotron with the same type of power supply. This type of power supply provides many advantages. The output is direct current and the high voltage provides a reasonable rate of rise of magnet flux and low enough d-c currents to keep the conductors of reasonable size. The ignitrons are capable of both rectification and inversion with very fast switching from one mode to the other. The flywheel is the least expensive means of storing the magnet energy derived from the decaying magnetic field. The a-c drive motor was specified as a wound rotor since it was the simplest and best adapted for speed control required during magnet pulsing. The a-c generator was proposed as a 12 phase synchronous generator matching the 12 phase converter and thus eliminating any rectifier transformers.

A summary of design parameter is given below:

No load voltage, volts	5000
Full load voltage, volts	4800
Peak current - pulse, amperes	6550
Time of rectifying pulse, seconds	1.2
Peak power - momentary, kilowatts	31,000
Repetition rate, pulses per minute	20
Energy stored in rotating parts, megajoules	210
Energy stored in flywheel, megajoules	147
Energy stored during rectifying pulse, megajoules	17.5
Energy loss - resistance, rectifying pulse, megajoules	3.8
Energy loss - resistance, invert (estimated), megajoules	3.7
Total energy loss - resistance, megajoules	7.5
Energy returned to power supply terminals, megajoules	10
Average power for resistance loss 3 second repetition period, kilowatts	2500

To allow enough reserve capacity for possible changes in pulse requirements, the specifications required a peak current of 7000 amperes with a no-load voltage of 6250 volts and a regulation of 30%.

In addition, the entire motor-generator-flywheel set was specified to be mounted on one shaft. A study of the torsional oscillations of the shaft was required. The number of bearings was specified as four and the machines were to be self-cooled. A liquid rheostat was specified for speed control and starting. A dynamic brake system also utilizes the liquid rheostat for stopping. The initial inrush kva was to be limited to 3000 kva or less. All subsequent kva variations were to be limited to 1500 kva per second.

Detailed Description

The nameplate data for this motor-generator set is as follows:

Manufacturer: Westinghouse Electric Corporation

Motor: Wound rotor induction motor
5500 hp, 3 phase, 60 cycle, 13,800 volts
203 amperes, indoor, open-type, self-cooled
Class B insulation 50°C rise
Secondary volts = 3168, secondary amperes = 787
Speed = 846 rpm

Generator: Salient-ple a-c generator
29,000 kva, 12 phase, 0.95 power factor
2800/2300 volts, 1305 amp. for pulse rating at 36,000 kva
Indoor, open-type, class B insulation, 80°C rise
Exc. volts = 260, exc. amperes 226.5/578, 846 rpm

Flywheel: Solid plate, 9 foot diameter, 30-½" thick
98,500 lbs., WK^2 = 784,000 lb.-ft.^{2}

The wound rotor motor supplies the losses of the power supply and magnet system. With its adjustable secondary resistance, it is ideal for acceleration, braking, and for limiting power swings when the set is pulsed. Since the total flywheel-rotor system, which weighs 105 tons and has a WK^2 of 1,123,000 lb.-ft.^{2}, slows down only 3.5% on a pulse, only a small resistance need be inserted.

The liquid rheostat consists of three cylindrical electrolyte cells 20 inches in diameter, each consisting of a fixed electrode at the bottom and a moving electrode with a maximum permissible travel of 75 inches. The electrodes are moved during starting and braking by a pilot motor. During pulsing they are actuated by hydraulic cylinders. The control during pulsing is by a hydraulic servo system. The 105 ton rotating mass can be brought from 900 rpm to a full stop in one minute by dynamic braking.

The generator is a special 12-phase salient pole machine of the same type as those on the Cosmotron and Bevatron, and the same diameter but shorter length than one of the Bevatron generators. The quadruple wye winding was designed especially for use with two 6-phase double wye rectifiers shifted 30° to give 12-phase ripple. All four neutrals must be brought out of the machine. (The 16 terminals have a total of 24-1250 MCM, 7.5 kv cables attached.) Since the winding carries rectifier d-c current, it was designed to keep the net d-c current in each stator slot zero, and also to keep the net d-c current linking the rotor shaft zero.

It is desirable to minimize the harmonics in the output voltage of the power supply because of harmonics in the magnet flux affecting the particle beam. As a consequence the ignitrons are fired with "no delay" on rectify to minimize these harmonics. The commutating angle should also be a minimum. To accomplish this, the commutating reactance of the generator must be held as low as possible. The commutating reactance is a subtransient reactance involving only the phases undergoing commutation at the same time. The considerations of commutating reactance and of the d-c current in the generator winding, resulted in a design of the winding as integral-slot, full pitch, and with two of the wyes having reversed polarity with respect to the other two. A low resistance copper amortisseur winding connected between poles also reduces the commutating reactance. Unfortunately, the full pitch winding allows the 5th and 7th harmonics in the voltage wave to be quite large. However, by skewing the stator slots and chording the damper windings, the slot harmonics are eliminated.

The regulation of d-c output voltage is a function of the m-g set speed and the generator excitation. The generator excitation is supplied by an electronic exciter under the control of an electronic voltage regulator. The exciter is a phase controlled six phase sealed-tank mercury-arc rectifier rated at 100 kv continuous and 600 amperes peak at 260 volts. The performance specification on pulse control required that the open-circuit voltage on the generator just prior to the start of a pulse be adjustable and repeatable to within $\pm$ 0.25%. The full load voltage was required to be reproducible to within $\pm$ 1%. Finally, the excitation equipment was required to have 10% reserve capacity above the standard pulse, and a recovery time constant, after a pulse, of 0.2 seconds.

The main rectifier consists of two banks of 12 each of Westinghouse high voltage continuously pumped-type ignitron tanks, type 1PJ712 which have an inside diameter of 15 inches. Each of the two assemblies has its own vacuum and cooling water equipment. The rating of the complete rectifier is 7000 amperes with an open circuit voltage of 6250 volts. Each phase has two tanks in parallel for protection in the event of a misfire.

The electrical feeders which supply the equipment with 13,800, 480 and 120-208 volt power are protected by air circuit breakers set for correct thermal and short circuit protection. The control circuits operate from the 120 volt station battery which has low voltage protection and a warning bell. In case of power failure, the emergency generator will supply some components, such as the battery charger and the m-g set lubricating system.

If the power supply is in operation, the protective relays may operate the partial shut-down lock-out relay or the complete shut-down lock-out relay. The following faults will cause a partial shut-down:

Emergency crash button
Main rectifier over-temperature
Exciter rectifier over-temperature
Exciter breaker over-current
Main rectifier low water pressure
Exciter rectifier low water pressure
Firing tube grid bias under voltage
Generator field failure or under voltage
Vacuum protective relay
Main rectifier over-current
Generator over-voltage
Main rectifier arc through

The following faults will cause a complete shut-down:

Emergency crash button
Ground on d-c circuit
Bearing over-temperature
Low oil pressure
Motor over-current
Motor phase unbalance and low voltage
Battery low voltage

A partial shut-down shorts the magnet and removes generator field excitation. A complete shut-down in addition to the above, removes power from the drive motor. In addition, if the complete shut-down is caused by bearing trouble, the dynamic brake is automatically applied.

To limit fault current in case of an accidental ground, the power supply is grounded through a 100 ohm grounding resistor.

Other large components necessary for the operation of the main magnet power supply are the series inductor and the interphase transformers (IPT).

The interphase transformer critical load resistor draws 20 amperes from the power supply. This value is large enough to fully excite the interphase transformers so that the ignitron banks act as double wye banks rather than six-phase diametric banks. Each phase then conducts current for 120 degrees. The resistor bank is rated 25 amperes at 6000 volts.

The series inductor was designed to reduce the rate of rise of the magnet flux density from 13,000 gauss per second to about 3000 gauss per second during the first 100 milliseconds of the pulse. The reasons for this reduction in rate of rise of field were :

1. Reduction of field distortion by reducing eddy currents in the magnet steel, magnet coils, and vacuum chamber,

2. Reduction in azimuthal distortion of the field due to transients in the application of voltage pulse,

3. Increase in the time to reach and complete injection, thus making timing control circuits less critical.

In addition, the series inductor serves as a ripple filter at the beginning of the pulse. At the end of the pulse when the inductor is saturated and has a voltage drop of about 90 volts, it still has 10-15 millihenries of inductance. It can then be used as part of the electronic ripple filter for high fields.

The series inductor consists of a large laminated square U-shaped core with a top yoke separated by an air gap of about 3/16 of an inch on each side. There are two coils on each side of the core; each of these four coils is composed of 30 turns. The copper conductor is 1-3/4" x 1-19/32" with a 1/2" water hole in the center. The core weighs 67 tons while the coils weigh about 13 tons.

The foundation for the motor-generator-flywheel set was studied in considerable detail because of the large and continuous pounding at the feet of the generator stator. Due to the complete reversal of torque as the generator changes from generator action to motor action when the ignitrons change from rectify to invert, the foundation and anchor bolts are subjected to an impact load every three seconds.

The foundation must furnish the m-g set with a level, non-settling base so that the proper alignment of the bearings and stators can be maintained. It must resist any overturning moment of the torque reversal or possible short circuit condition without any damage to itself. It also must aid in damping out any vibrations which the pulsing of the m-g set might transmit through the ground which might disturb the magnet ring.

The possibility of mounting the entire 488,000 pound m-g set on an even greater mass of concrete and then shock mounting the entire structure was considered. Such a scheme was used on the m-g set at the CERN alternating gradient synchrotron at Geneva, Switzerland. However, even though this synchrotron is only slightly smaller than Brookhaven's, the m-g set it uses is considerably less in weight since its speed is 3000 rpm, compared to Brookhaven's 900 rpm. The generator, which supplies rectifier transformers, is three phase, and much smaller in diameter.

A vibrograph study of the Cosmotron power supply under full load pulsing showed that the vibrations were completely damped out at a distance of 75 feet from the m-g set. The design principle for the AGS foundation therefore was to make it solid, massive, and set it firmly on undisturbed earth.

The pulsing type of duty necessary to alternately store and withdraw energy from the synchrotron magnet causes torsional stress in the shaft of the m-g set as the torque reverses in a few milliseconds. The possibility of an ignitron arc-back would also cause similar stresses although they are not repetitive. However, Cosmotron experience has shown that arc-backs are extremely rare. The AGS ignitrons being identical should perform as well as Cosmotron experience would indicate. The repetitive nature of the pulsing torque reversal allows the possibility of resonant build-up of oscillation from one pulse to the next. The manufacturer made a study of shaft oscillations. The generator rotor, flywheel, motor rotor, and shaft are a three mass-two spring system. The results of sudden torsion forces produces oscillations with two natural frequencies. In the case of the Cosmotron, the motor was small enough to be neglected. The torsional oscillations can be reduced by two methods. The first and most effective is to invert one ignitron bank first, thus reversing the torque of only one half of the generator winding. The second ignitron bank is inverted at a time later by one half cycle of the natural shaft frequency. In the Cosmotron, where only one shaft section and one natural frequency was involved, this was done easily. On the AGS machine, with two natural modes of vibration, a computer study was made to determine the optimum time of delay. In addition to the two-step change over, a viscous type vibration damper is attached to the shaft. The vibration damper implements the two step change over during the "flat-top" mode of operation of the magnet cycle. (Instead of a sharp peak of current, the highest value will be held constant to form a "flat-top".) As a result, the second ignitron bank is inverted later and does not produce the cancelling torque pulse in time to reduce large initial oscillations. The vibration damper performs this function under these operating conditions.

The m-g sets on the Brookhaven synchrotrons will always be used on pulsing loads. As it does not take very long to build up millions of pulses, the shock to the shaft is always a grave concern. The recent interest on the part of manufacturers and public utilities in the brittle fracture of turbo-alternator shafts was noted. Since the original specifications did not call for ultrasonic testing of the shafts, Brookhaven requested the manufacturer to conduct a reflectoscope study of the Cosmotron and AGS shafts. The results indicated both machines were in excellent condition.

Significant Dates

a.	Specifications completed	August 1, 1956
b.	Order PS-19 placed	March 18, 1957
c.	Westinghouse equipment delivered	October 31, 1958
d.	M-G set pulsed for first time	August 20, 1959

Correcting Lens Power Supplies

Design Parameters

a. The motor-generator set shall consist of one motor and four generators on a single base.

b. The motor shall be a wound rotor induction motor of 300 hp 440 volts, 3 phase, 60 cycles.

c. The generators shall supply pulsed currents as required by the quadrupole and sextupole magnets.

d. The rate of rise of current for the quadrupole generators was specified as 5,000 amperes per second and 2,000 amperes per second for the sextupoles.

e. The motor-generator set shall have enough enertia that during a pulse the speed change shall not be more than 5%.

f. The generators shall have double field windings such that either winding can be used to excite the generator to either polarity. The field winding shall be made in six sections which may be connected in series, parallel or combination of series parallel.

g. The poles, pole shoes, interpoles, and yokes of each generator shall be laminated.

Description of Components

The design of the AGS main magnet provides the best compromise to give the widest constant field gradient between the poles of the magnet. However, at high fields the pole tips saturate, reducing the useable width of constant gradient. The multipole magnets are used to correct this. They are also used to obtain controlled bumps in the proton orbit to deflect the beam locally onto a target.

The multipole magnet power supply system is servoed such that the current in the magnets is constrained to follow a program which has been adjusted to match the cycling of the main magnet and to provide the required corrections. The components consist of a program generator with adjustments to provide a wide variety of functions such as one or two current slopes with or without flat top and with continuous control of amplitude and dissection. The program generator is connected to an error amplifier which drives two field exciters for bidirectional control. The field exciters are connected to two separate fields in the generator, the output of which feeds the load. In series with the generator output and the load, a current shunt is connected to provide a current signal which is fed back to the input of the error amplifier, and is compared to the output of the program generator. The resultant amplified error signal drives the generator to follow the selected program.

All of the equipment except for the motor-generator set was designed and fabricated by AGS personnel. Some redesign was necessary to meet new requirements and to improve system accuracy and stability. The apparatus performs adequately and its flexibility makes new changes and requirements easy to incorporate.

The quadrupole and sextupole m-g set consists of a motor-generator-flywheel set of one 300 hp wound rotor motor, two 500 kw d-c generators, two 300 kw d-c generators, and a 3,750 pound flywheel. The components are mounted on a common base, coupled together and run at a nominal 1200 rpm. The motor is started by a 5-step grid resistor rotor controller. The m-g set was installed in the AGS power room in an enclosed area under the RF balcony. Since the loads supplied by the generators were pulsed, the heat load in the enclosure was small, about 115 kw, and could be accommodated by 33 tons of air conditioning.

<u>Significant Dates</u>

a.	Specifications completed	March 5, 1959
b.	Purchase Order placed	May 11, 1959
c.	Witnessed factory test	September 16, 1959
d.	First run of m-g set at BNL	December 16, 1959

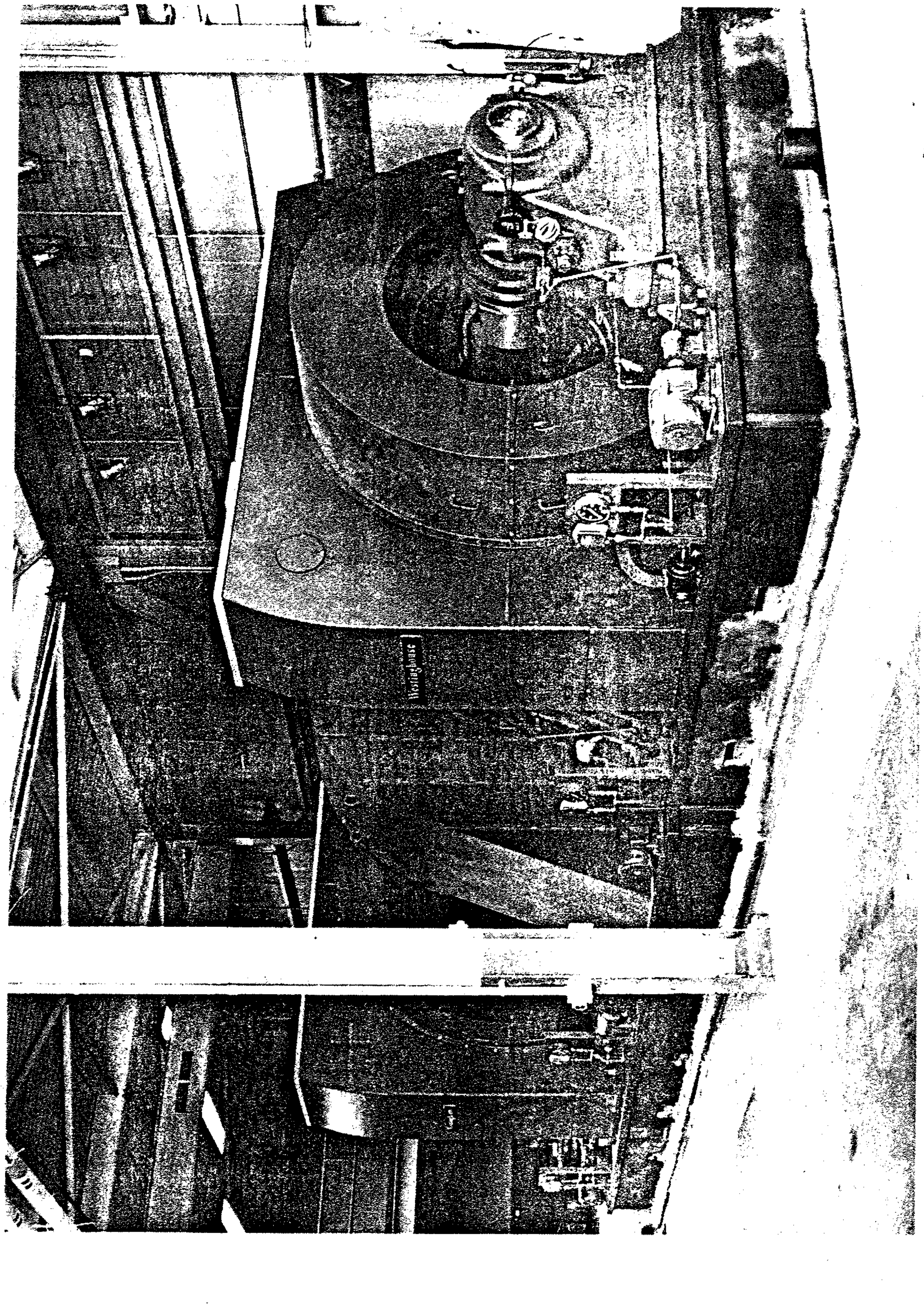


Figure 8
Main Motor Generator Flywheel Set

4. Vacuum System

General Description

The vacuum system of the Brookhaven AGS is in reality two separate systems. The main ring system is one entity and the linac system is another. While they both use the same type of pumps, the design parameters and problems are entirely separate.

In discussing the ring vacuum system, it will be necessary to discuss the chamber first and then the pumping devices. There are three types of chambers; those that fit into the main magnet gaps, those that fit the five-foot straight sections and those that fit the ten-foot straight sections. In addition, there are 144 expansion joints located more or less symmetrically around the ring to allow for curvature and expansion and contraction.

Vacuum Chamber

The main magnet vacuum chambers are roughly ten feet long flanged tubes, O-ring grooved, bolted construction. Their cross section shape is quasi-elliptical being 7-in. by 3-1/4-in. in dimension. The chamber material is Inconel-x. This material was chosen because of its high resistivity and consequent smaller eddy current loss and perturbation of the beam. The resistivity of Inconel-x is 120 microhms centimeters while stainless steel has a resistivity of only 80 microhms centimeters. The chamber wall thickness was chosen as .078-in. as an optimization of rigidity and aperture loss. The closed aperture magnets required that those vacuum chambers be slipped into position azimuthally rather than radially as with the open magnet sections. A split flange and collar accommodates this feature.

The five-foot straight sections are round stainless steel tubes. Stainless can be used here since these sections are not in the main magnetic field. These sections serve a dual purpose, the pickup electrodes are mounted inside and the section itself fits into either a quadrupole or sextupole magnet. Vacuum tight feedthroughs must be brought out of the flanges radially to accommodate the pickup electrode signals. These round chambers are custom rolled to produce a maximum I.D. aperture for the pickup electrode and a minimum O.D. for fitting inside the correcting magnet.

There are several types of ten-foot straight section vacuum chambers. One type is used to accommodate the rf cavity. The cavity accelerating gaps are formed by ceramic rings appropriately soldered to the vacuum chamber sections. The ceramics were first coated with a molymanganese by the manufacturer. The actual bracing was done under vacuum using BT solder but not titanium hydride flux. Other ten-foot straight sections are target boxes. These are usually rectangular boxes 10-ft.

long by 12-ft. square cross section. Various types of target operating devices are placed in these boxes and in order to bring the beam out, thin windows are installed on the sides of the box. These windows, of either aluminum or Mylar, run from .003-in. to .008-in.

Pumping Systems

The entire ring, some 2,600-ft. of vacuum chamber, was divided into 12 superperiods for reasons of beam dynamics. This division was also provident for vacuum design. Sectionalizing valves were placed at 12 places, roughly symmetrically around the ring. With few exceptions, therefore, the vacuum pumping system for one superperiod is very much like that for any other. A superperiod is approximately 220-ft. long and contains four high vacuum pumping stations at 55-ft. intervals. The required design pressure was 1×10^{-6} torr at the pumps with a maximum of 2×10^{-6} torr around the ring.

At first, conventional diffusion pumps were considered, four per superperiod for a total of forty-eight. However, during the years of 1956-1957 a new high vacuum pumping concept was developed into a commercial product. This was the getter-ion pump which used no boiling oil or mercury. Basically the pump has two pumping actions. First, titanium, a very reactive metal is evaporated onto the water cooled walls of the pump. Here, fresh, clean titanium combines chemically to form titanium hydride, oxide, nitride and carbide. Combining gases are the common constituents of air and are, therefore, effectively removed from the vacuum chamber. Once formed, these compounds are quite stable and the gases do not re-evolve. Argon is found in air in about a 1% concentration and titanium will not combine with argon. So another pumping mechanism must be used. This is done by emission of electrons from a hot filament, acceleration of these electrons through a grid and consequent ionization of argon atoms and other atoms as well. These ions so formed are positively charged and are driven by the positive grid voltage into the walls of the pump. The combination of both pumping processes produce a clean-dry vacuum, something that most accelerators up to now have not had. Another important feature of these new pumps is that they do not require a continuously operating fore-vacuum, thus dispensing with the noisy, oil-sealed mechanical pumps. The getter-ion pumps require a rough vacuum to get started but then the mechanical pumps may be shut off and wheeled away. Brookhaven pioneered the use of getter-ion pumps in place of diffusion pumps and every major accelerator since then has incorporated this new concept in its design.

The rough pump system is also a new development in concept. Most mechanical pumps do not pump below 10^{-3} torr. During the design study of the AGS, a new mechanical pump was introduced commercially. This was a vacuum adaptation of the Roots type lobe pump used in blower systems for many years. Brookhaven decided to use them for roughing out purposes and they have proven out excellently. These pumps consistently pump to 10^{-5} torr with the aid of a freon or liquid nitrogen baffle and they have become the workhorse of the entire complex. These Roots type pumps use no oil for sealing the high vacuum stage and thus produce a clean dry rough vacuum in order to start the getter-ion pumps discussed above. Most of the beam separator vacuum systems used in experimental beam work now use the Roots type pump exclusively because of its ability to handle a large throughput of gas at high pressure (about 10^{-3} torr) and still produce a clean-dry surface.

The linear accelerator presents a contrast in vacuum design to the ring. The ring is a long thin tube with very poor conductance, low volume and small surface area. The linac on the other hand is a long, large diameter tank, large volume, large conductance and large surface area. The linac is 110-ft. long roughly 3-ft. in diameter. It is a steel shell copper clad on the inside. It contains 128 drift tubes of copper suspended inside. This copper has an initial outgassing rate of 8×10^{-9} torr liters/sec/cm^2 in contrast to the inconel-x of the ring which has an outgassing rate of 1×10^{-9} torr liters/sec/cm^2. Since there are about 2×10^6 square centimeters of copper exposed to vacuum in the linac, the total gas load is $2 \times 10^6 \times 8 \times 10^{-9} = 16 \times 10^{-3}$ torr liters/sec. The design pressure desired was 1×10^{-6} torr so we required a pumping speed of 16,000 liters/sec. This is supplied by twenty getter-ion pumps of 1,500 liters/sec. each. However, each of these must pump through an rf orifice which cuts the pumping speed in half. Thus we end up with a total of 15,000 liters/sec. There are two pumping ports for each ten feet of linac tank. This makes 22 holes. Twenty of these holes are for the high vacuum pumps and two are for the roughing system. The roughing system consists of two sets of Roots type blowers backed by a small mechanical oil-sealed pump. The mechanical pumps are rated at 130 cubic feet per minute each. They are capable of reducing the pressure in the linac to 80 millimeters in twelve minutes. At this point the two small blowers start. These have a rating of 1,600 cubic feet per minute and reduce the pressure in the tank to 10 millimeters in 5 minutes more. Then the two huge blowers start. They are rated at 6,000 cubic feet per minute and pump the tank to 5×10^{-5} torr in eighteen minutes more. So, in thirty-five minutes the tank can be roughed out to the pressure at which the high vacuum pumps can be started.

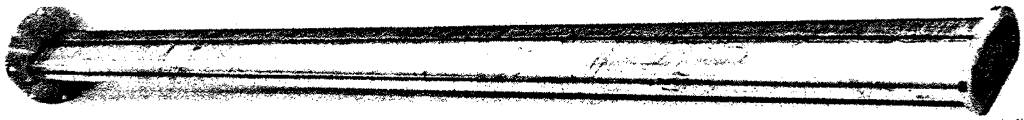


Figure 9
Main Vacuum Chamber

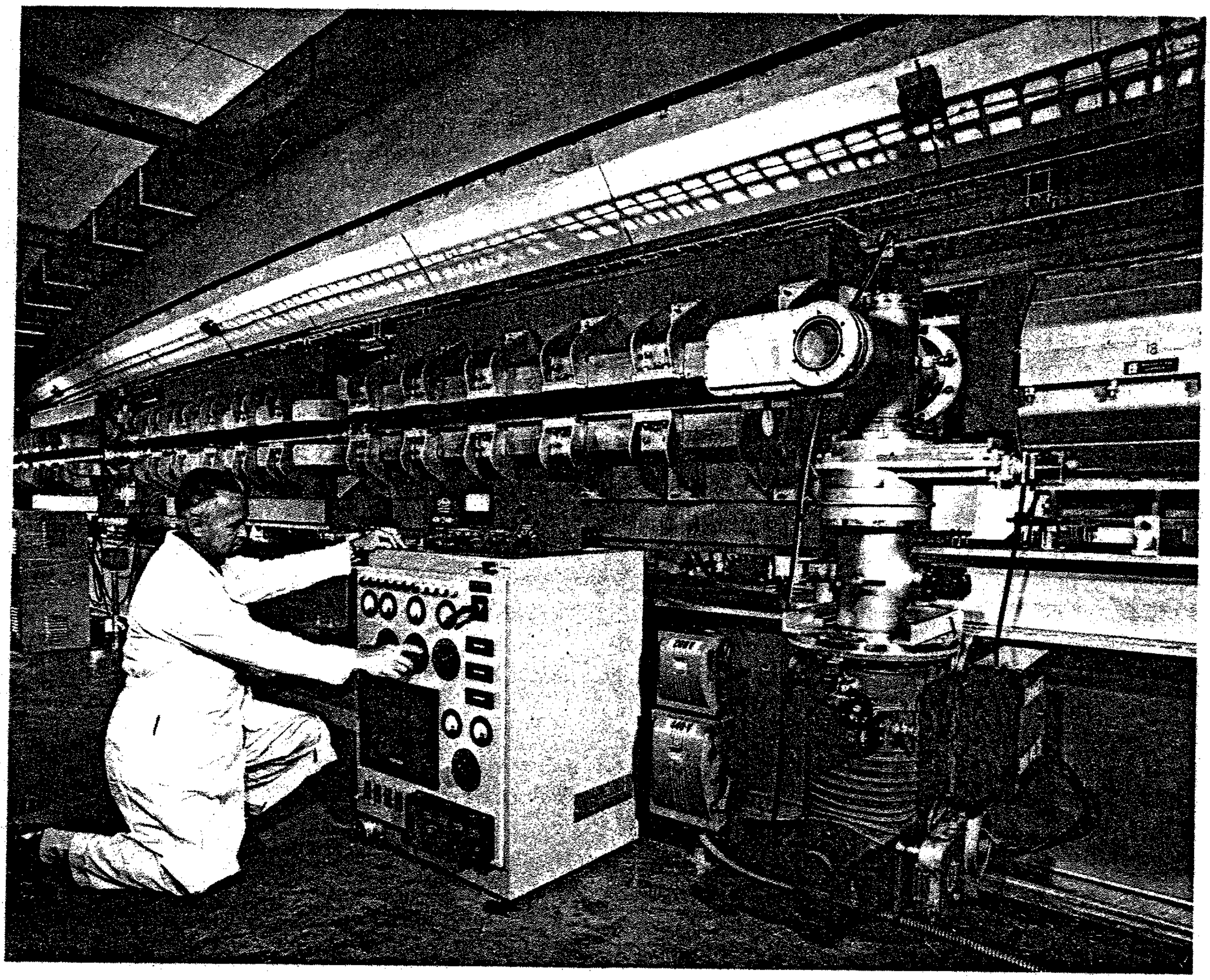


Figure 10
Evapor-Ion Pump and Control Console in Position in A.G.S. Ring

5. RF System

General Description

The proton beam in the AGS is accelerated to its final energy of 30 billion electron volts (Bev) by means of a radio frequency accelerating system. The particles are injected into the machine at an energy of 50 million electron volts (Mev) at which time they are traveling at one-third the velocity of light. At 30 Bev they are essentially moving with light velocity, necessitating an accelerating system which can stay in synchronism with the particles as their revolution frequency varies by a factor of three.

The frequency range covered is 1.40 mc/sec to 4.5 mc/sec. A low level rf system detects the correct frequency from the beam itself, corrects the phase so that the particles are accelerated properly and in turn drives a central driver amplifier. This unit is an eight stage broad band video amplifier capable of delivering an output of 80 Kw. This driver feeds twelve accelerating stations, each consisting of a 25 Kw push-pull amplifier and a tuned, ferrite loaded, accelerating cavity. The cavity is kept continuously tuned by means of a saturating current used to vary the ferrite permeability. The saturating supply utilizes a transistor amplifier capable of delivering and controlling 1000 amperes. It is a portion of a closed tuning loop which ensures that the load on the final amplifier is kept at resonance. Due to the frequency change by a factor of three to one, it was necessary to develop a means to correct for the incremental phase shift inherent in the thousands of feet of coaxial cable required for the system. In addition, amplifiers had to be built which would automatically tune to a desired varying frequency in the output of a mixer circuit where the sum frequency, difference frequency, and one of the input frequencies were all relatively close together.

The linear accelerator injector supplies protons to the AGS with an energy of 50 Mev. At this energy, the particles are traveling at one third the velocity of light (1/3C). The time required for one revolution in the 1/2 mile circumference is about 8 μ sec, corresponding to a fundamental rotation frequency of approximately 120 Kc/sec. 30 Bev protons travel essentially at the velocity of light, resulting in a final fundamental rotational frequency of about 360 Kcs.

Energy is imparted to the protons by means of a radio-frequency voltage. If we consider a proton approaching a pair of rings, energized by a dc potential, the proton would be accelerated between the rings but decelerated when approaching the positive ring and also when leaving the negative ring, a net effect of zero. Using an rf cavity, however, the proton can approach an accelerating gap in field free space and receive only a net acceleration.

Phase Stability

The mechanism of acceleration using an rf voltage is successful because of a phenomenon known as phase stability. Consider the sine wave shown in Figure 6. Let us assume the proton passes an accelerating gap at point 0_1, which we will designate "stable phase angle". It receives an energy increase equal to E sin 0_1. If for any reason the particle gains too much energy, two things happen: first, it goes faster requiring less time for one revolution; second, it will move in a path of a larger radius because of the decreased restraint of the magnetic field and require more time for one revolution. These two effects are in opposite directions but when the protons are moving at much less than light velocity, the first effect predominates due to the small radial excursions of the beam. The proton, which now requires less time for a revolution, reaches the accelerating gap earlier at 0_2, thus receiving an energy increase $E \sin 0_2 < E \sin 0_1$. The opposite phenomenon occurs for a particle which finds itself with less energy than normal. It now goes slower, arrives later and receives an energy increase $E \sin 0_3 > E \sin 0_1$. The result of these motions is an oscillation of the particles about a stable phase point 0_1 usually chosen as 30°. The dynamics of the entire machine is such as to cause the amplitude of these phase oscillations to decrease as the particles are accelerated.

Phase Transition

As the particles approach the velocity of light the first effect mentioned above decreases in importance and the radial effect, although small, predominates. The region where the two effects compensate each other is called phase transition and occurs in this machine at 7 Bev. At transition there is no phase stability but above this point the stable phase angle becomes 0_4. The reason for this is just the converse of the situation below transition. Now, a particle with too much energy arrives later at 0_5 and receives a smaller "kick". The accelerating system must therefore be able to jump the phase of the accelerating voltage 120° from 0_1 to 0_4 at the appropriate point in the cycle.

Selection of Operating Frequency

It is necessary that the rf accelerating voltage have the correct phase and amplitude when the proton passes the accelerating gap. The frequency of this voltage must be integrally related to the fundamental revolution frequency of 120-360 Kcs. Referring to Figure 11, it does not matter how many cycles of rf are between two successive transits of the accelerating gap, provided the phase and amplitude are correct during transit. The slope of the wave is greater, however, at higher harmonics which yields a greater restoring force for particles which deviate from the stable phase position. This provides more rapid damping of the phase oscillations.

In addition to the better damping characteristics, a choice of a higher harmonic of revolution frequency can be made to simplify the electronic problem to bring the frequency range into the video band, harmonics ranging from the eighth through the fifteenth could be selected. The AGS has a built-in numerology based on twelve uniform sections, and thus to best fit into this system, a twelfth harmonic acceleration was chosen, covering the frequency range from 1.40-4.46 mc/s.

If we have an rf system operating and a beam of protons is injected to fill up the entire ring, a twelfth harmonic voltage will accept twelve groups of protons centered at 0, in Figure 11, and reject the remainder. This leaves twelve circulating "bunches" trapped at the stable phase points. The synchronism of frequency to magnetic fields is very critical and a method of generating the correct frequency must be used which does not introduce appreciable errors into the frequency characteristic.

Bootstrapping

The way this has been accomplished in the AGS is by "bootstrapping". If we assume that the protons are bunched, then they are moving with the correct frequency. If we can detect these bunches then we have a correct frequency generator. An electrostatic induction electrode, consisting of a hollow cylinder through which the beam passes, picks up an induced charge each time a bunch passes through. Since we have twelve bunches, the fundamental frequency at this electrode is the proper twelfth harmonic which we require.

There still remains the problem of keeping the correct phase relationship between this detected signal and the accelerating voltage. This is complicated by the fact that the system requires several thousand feet of coaxial cable in the rf loop. As the frequency changes by 3:1, the differential phase shift of thousands of degrees must be compensated for in some monotonic fashion; any abrupt changes might perturb the beam enough to lose large numbers of protons.

Location of Accelerating Stations

With twelve bunches of protons circulating in the machine as many as twelve accelerating stations can be used, all at the same phase. If we wish to include stations which are phased 180° from each other, then we can have twenty-four symmetrical rf accelerators. A bunch which passes an in-phase station at the correct angle (0_1 in Figure 11) requires a time of travel to an out-of-phase station equivalent to 180° at which time the station energized at 180° is back into phase at 0_1, thus continuing to accelerate. The AGS uses 12 stations, six in phase and six 180° out of phase. This arrangement has been selected because certain portions of the machine must be left clear for targets and experimental purposes. The drive to the accelerating stations is push-pull and the method of obtaining the 180° is simply the reversal of the feed cables. The use of twelve stations lowers the voltage required at each station by a factor of twelve, or approximately 8 Kev of energy gain per station.

The Multiple Heterodyne System

The basic problem in the low level portion of the rf system consisted of finding a method to compensate for the differential phase shift in the cables and circuitry. The method which was evolved is what is designated a multiple heterodyne system. At the induction electrode which detects the beam, we could mix the rf signal of frequency f with a signal $f + f_k$ and take the difference - a constant frequency f_k. At the accelerating station we could remix the $f + f_k$ with f_k and extract the original frequency f. If the lengths of cable from the source $f + f_k$ to each position, the electrode and the accelerator were the same, we would be heterodyning up and down with signals at the same phase. The transfer over the long cables would be at constant frequency f_k with no differential phase shift. This system has the disadvantages of requiring either high level mixing at the accelerating stations or low level mixing with twelve multistage amplifiers. Also, performing the final mixing at twelve different places, presents the possibility of phase differences at each accelerating station.

Starting Oscillator

This system can be shown to be equivalent in behavior to the final system shown in the block diagram in Fig. 12. In the description of the system, it was assured that the beam was circulating in twelve bunches. In practice we must include a means of accomplishing this. For a given injected energy and a given machine diameter, the initial twelfth harmonic is calculable. A starting oscillator, running at the initial frequency and capable of being programmed with an f vs t characteristic to match the machine, is fed into the system. The oscillator runs normally at a frequency just below the required injection value, held by a discriminator and a servo loop. At the start of the magnet cycle, the servo is disabled and just prior to injection the oscillator program is initiated such that at injection the frequency is the correct value. The controlled cycle lasts about one millisecond. At this time the beam is bunched and an electronic switch transfers control to the beam signal from the induction electrode. The initial phase adjust, a manual control, ensures that the beam signal is in phase with the starting oscillator signal at switching time, since the starting oscillator is the independent signal.

Heterodyne Loop

The frequency $f + f_k$ is now developed by adding f to f_k in mixer one. f_k has been chosen as the standard IF frequency 455 Kcs. The frequency $f + f_k$ varies from 1.855 mcs to 4.905 mcs. This in turn feeds mixers two and three. Out of mixer two is selected the fixed frequency f_k. All required phase shifting is done in the constant frequency line at 455 Kcs. Mixer three then combines the constant frequency f_k with sum frequency $f + f_k$ to yield the original frequency f. If the line from mixer one to mixer two contains a phase shift element equivalent to all the phase shifts outside the loop, the incremental phase shift from the induction electrode to the accelerating station is zero.

The Self-tracking Amplifiers

In the outputs of the mixers one and three signals are present which are close together and for which we must have a method of selection. For this purpose the self-tracking amplifiers (STA) was developed. The amplifier consists of a tuned amplifier with a controlled resonant frequency. The inductive portion of the resonant load utilizes two similar ferrite cores with a figure eight rf winding, housed in a faraday shield covered with a dc saturating winding. A phase discriminator compares the phase of the anode signal to that of the grid signal which has been shifted 90°. The error signal controls a dc amplifier which drives the saturating winding on the inductance. In this manner the circuit is kept at resonance for the desired input frequency.

The mixers use balanced modulators which tend to cancel the two input frequencies and yield primarily the sum and difference frequencies. In mixer one the sum is 1.855 to 4.905 mc/s, and the difference is .945 to 3.995 mc/s. The desired frequency is the sum signal. By resonating the load to 1.80 mc/s in the unsaturated state, the only initial frequency to which the STA can lock is the sum at 1.855 mc/s. Once locked, it then tracks during the remainder of the cycle.

The output of mixer two is at constant frequency and the selection is accomplished by standard available methods. The most suitable one is the greatly overcoupled double tuned circuit which has an almost flat phase shift characteristic in the center of the pass band.

The third mixer has a sum output of 2.310 to 5.360 mc/s and a difference output of 1.40-4.45 mc/s, the desired signal. In this case the STA is initially set at 1.35 mc/s and locks in on the lower difference frequency where the Q of the ferrite is higher.

High Level Amplifiers

The output of this heterodyne system feeds an eight stage broad band video amplifier with an output of 80 KW (Figure 13). The stages, except for the input, are all double ended and in general ferrite chokes are used to impedance match and to provide good push-pull coupling. The output stage is a pair of 6398 triodes in grounded grid with a ferrite coupling choke to match the rf feed lines which go to each of the accelerating stations. The lines are 12 pairs of RG15/U 75 ohm cables driven in parallel, a net impedance of about 6 ohms each side. The required drive is roughly 750 volts peak. The cables are fed through solenoid operated vacuum switches which can disconnect any one of the accelerating stations from the drive. These cables must all be cut to the same electrical length. The physical length involved is 1400 feet and an actual length measurement would have been too inaccurate. For this reason, the lines were shorted at the end and resonated to give a straight line Lissajous pattern for voltage and current at the input. They were cut until they all had the same resonant frequency to better than one part in 20,000. Thus, the signals reaching the accelerating stations will all be at the same phase.

Accelerating Stations

The accelerating stations have three main components; a power amplifier, a saturating supply, and an accelerating cavity (Figures 14and 15). The power amplifier is a single stage grounded grid push-pull amplifier using two 3W5000F3 triodes. The high voltage anode supply for the 12 power amplifiers as well as for the main driver is supplied by a common 4200 volt 220 ampere dc power supply located in the AGS main power room. The power amplifiers, with this exception, are self-contained, each with its own bias supply, water cooling facilities and control.

Ferrite Cavities

The ferrite loaded cavity, Figures 16, 17 and 18, has two foreshortened push-pull quarter wave coaxial cavities in parallel. Each cavity pair contains 80 ferrite rings, 35 cm o.d., 20 cm i.d. and 2.1 cm thick, arranged in four groups of 20. The rings are interleaved with edge cooled copper plates to provide cooling, since under continuous operation, they can dissipate up to 25 Kw. The cavities are initially tuned at the lowest rf frequency with the addition of vacuum capacitors across the accelerating gaps. They are then tuned over the frequency range by dc saturation using a method essentially the same as that used in the self-tracking amplifiers.

It was necessary to balance the groups of 20 ferrite rings and each of the thousand rings used was individually tested at high rf flux density. The rings were then grouped into stacks of 20, each stack averaging the same permeability and the same losses at high rf flux density and zero saturation. This tends to balance each cavity and to make the total resonant impedance of all the cavities the same.

Cavity Tuning

The accelerating cavities are tuned by dc saturation. Figure 19 shows the method used. The rf fluxes in the two halves are in phase while the dc fluxes are out of phase. Therefore, the total rf induced in the dc is zero if everything is balanced and the rf and dc circuits are thus decoupled. Since the saturating winding is the same as the rf winding, it is a one turn structure and requires currents up to 1000 amperes, controllable to keep the load resonant. The saturating supply is a three stage transistor amplifier with one 10 ampere transistor driving ten in parallel, driving 100 in parallel. The final stage is connected as a grounded emitter. In each emitter is a small degenerative resistor of 1/8 ohm. The amplifier is driven from a phase discriminator sensing phase differences between anode and grid of the power amplifier. To increase the accuracy of the system, a frequency dependent program is added to the output of the phase discriminator. The required input to the saturating supply for correct tuning is approximately proportional to frequency. A linear frequency meter is therefore used to set the tuning to essentially the correct point.

The discriminator then provides the fine tuning. With this setup it is possible to turn on the system with full drive, at any point in the frequency cycle, and it will lock in without overloading the final amplifier tubes.

RF Shielding

There will be sensitive detection equipment continuously operating at the same frequency as the accelerating stations. For this reason every precaution has been taken to minimize leakage from the stations. Figure 13 shows the shield around the cavities. Each joint in both the P.A. and bias supply cubicles and in the cavity shield is closed with double strip metal gasketing. All input leads are brought in through filters and are run on shielded cables.

Amplitude Control

Amplitude control for the entire system will be obtained from a summing device which adds the amplitudes at each cavity and controls the main driver accordingly.

Radial Control

The final portion of the system is the one to control phase. The principle of phase stability ensures that particles will tend to oscillate about a given stable phase but does not designate the radius in the machine. If the particles are in an orbit centered close to the wall of the vacuum chamber, those with even small amplitudes of radial oscillation will hit the wall of the vacuum chamber, those with even small amplitudes of radial oscillation will hit the wall and be lost. To eliminate this, a sensing device which detects the radial position of the beam is used to adjust the phase. If we take a cylindrical tube with its axis centered on the beam orbit and cut it with a vertical diagonal slice, then the signals induced by protons at the center will be the same for both halves. The signal output of a difference amplifier would be zero. If the signal moves radially, the signal on one half increases and the other decreases, giving a net difference. This difference can be used as an error signal in the manner shown in the block diagram (Figure 12). The differences are taken and normalized to the sum signal. Synchronous detection is used to give an error signal which contains sense information for radial motion. This drives an electronic phase shifter in the constant frequency, f_k, line. This same channel also compensates for differences between the incremental phase shift in the entire loop as compared to that in the lump delay which we add between mixers two and three.

Earlier the phenomenon of phase transition was discussed and need for an additional 120° phase shift was indicated. This 120° phase shifter which can be added at transition, is cascaded with the variable phase shifter of the radial loop.

Transition presents one additional problem. The slope of the accelerating voltage wave is reversed above and below transition. If, below transition, an inward movement of the beam yielded a positive error signal, this signal would retard the phase to make the protons arrive later and receive more energy per turn. Above transition, however, retarding the phase would cause the beam to arrive later and receive less energy, thus giving a further inward movement. The sense of the radial correction must therefore be reversed at transition and an electronic reversing switch is used to accomplish this.

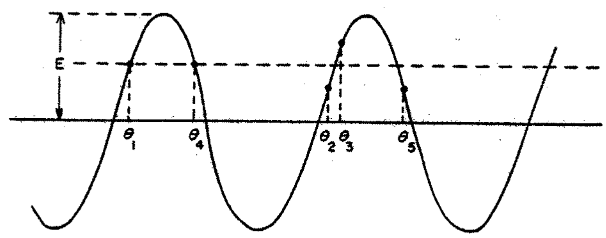


Figure 11
Positions of Stable Phase Angles

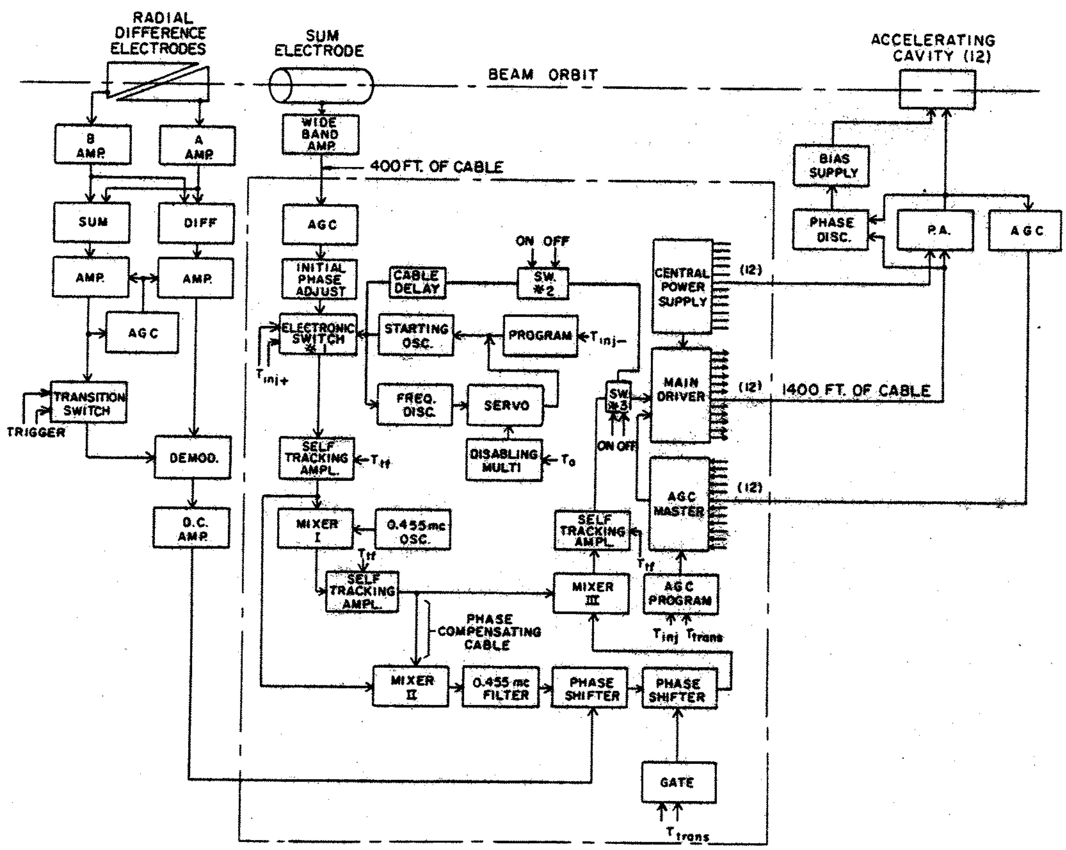


Figure 12
Block Diagram of RF System

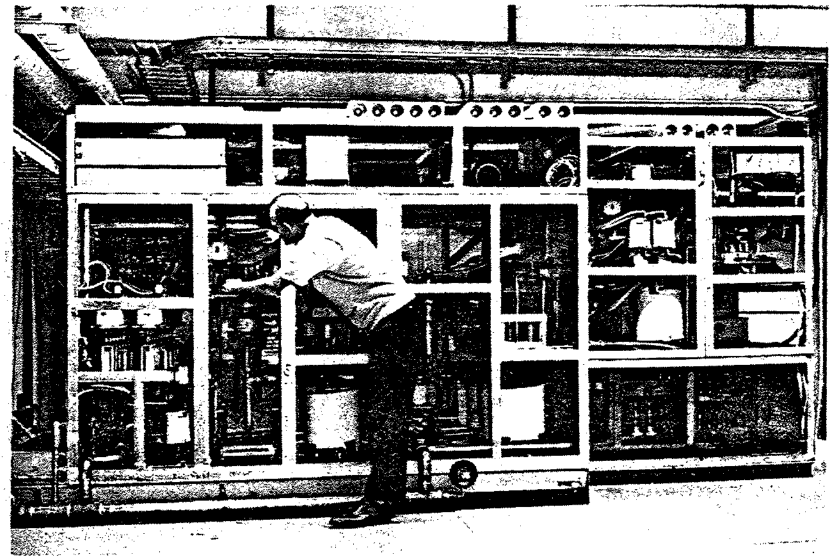


Figure 13
Main Driver Amplifier

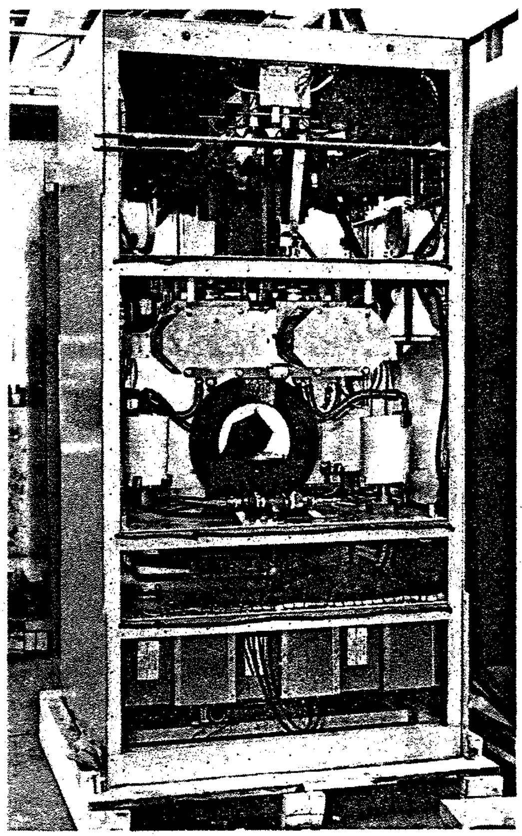


Figure 14
Power amplifier, rear view

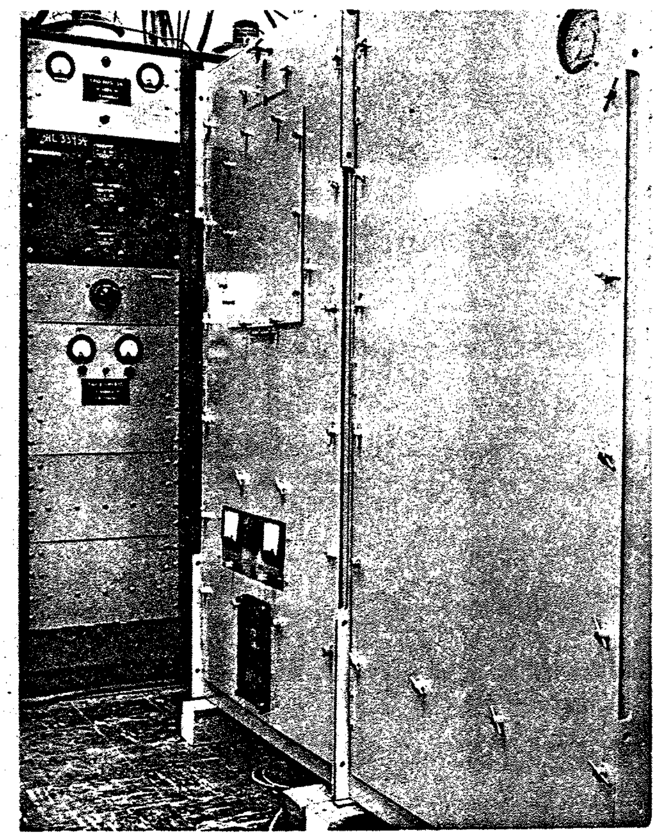


Figure 15
Front view, power amplifier and saturating supply

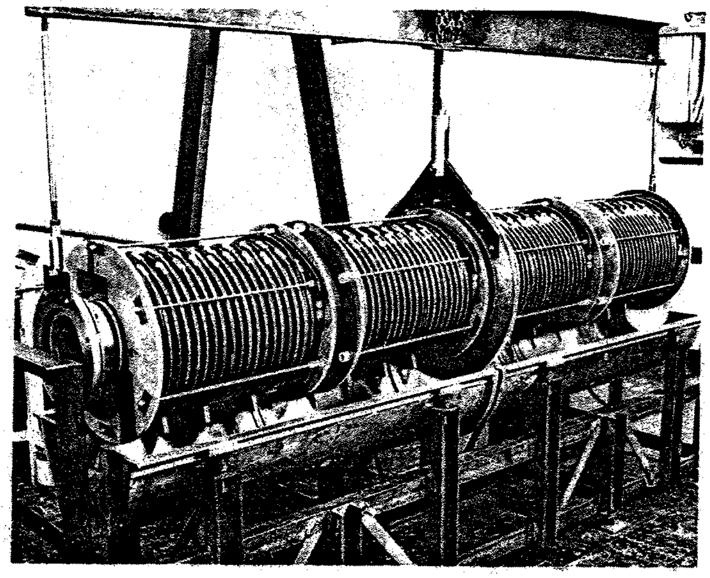


Figure 16
Accelerating cavity showing ferrite rings

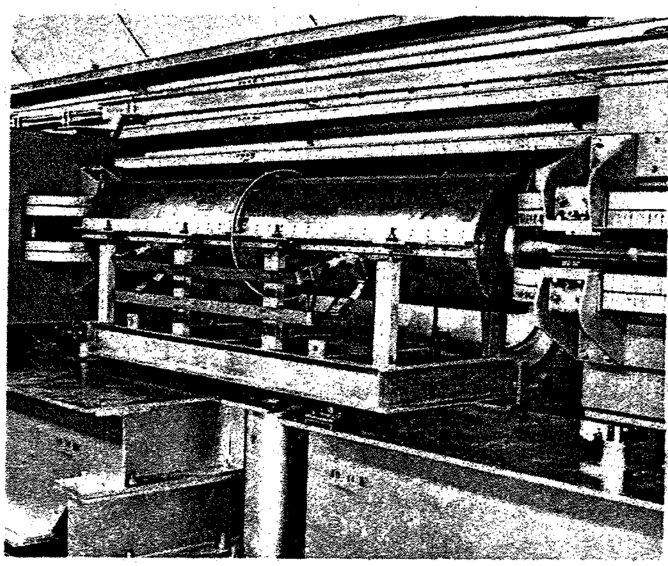


Figure 17
Unshielded cavity in position in the AGS

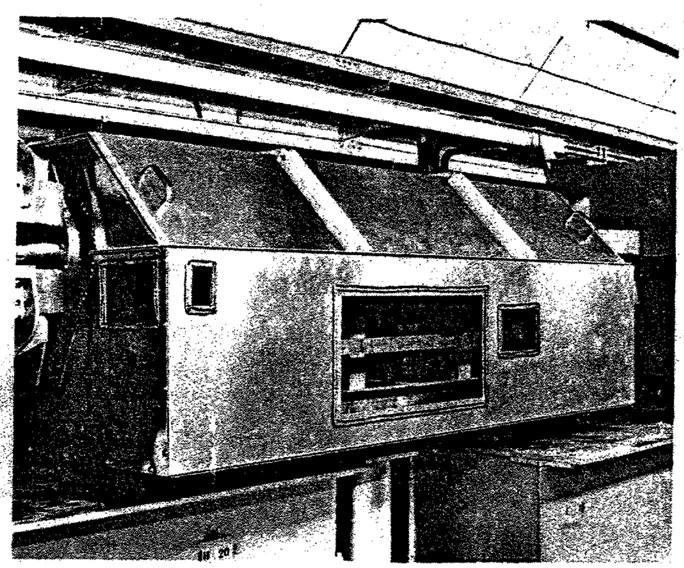


Figure 18
Cavity with RF shield installed

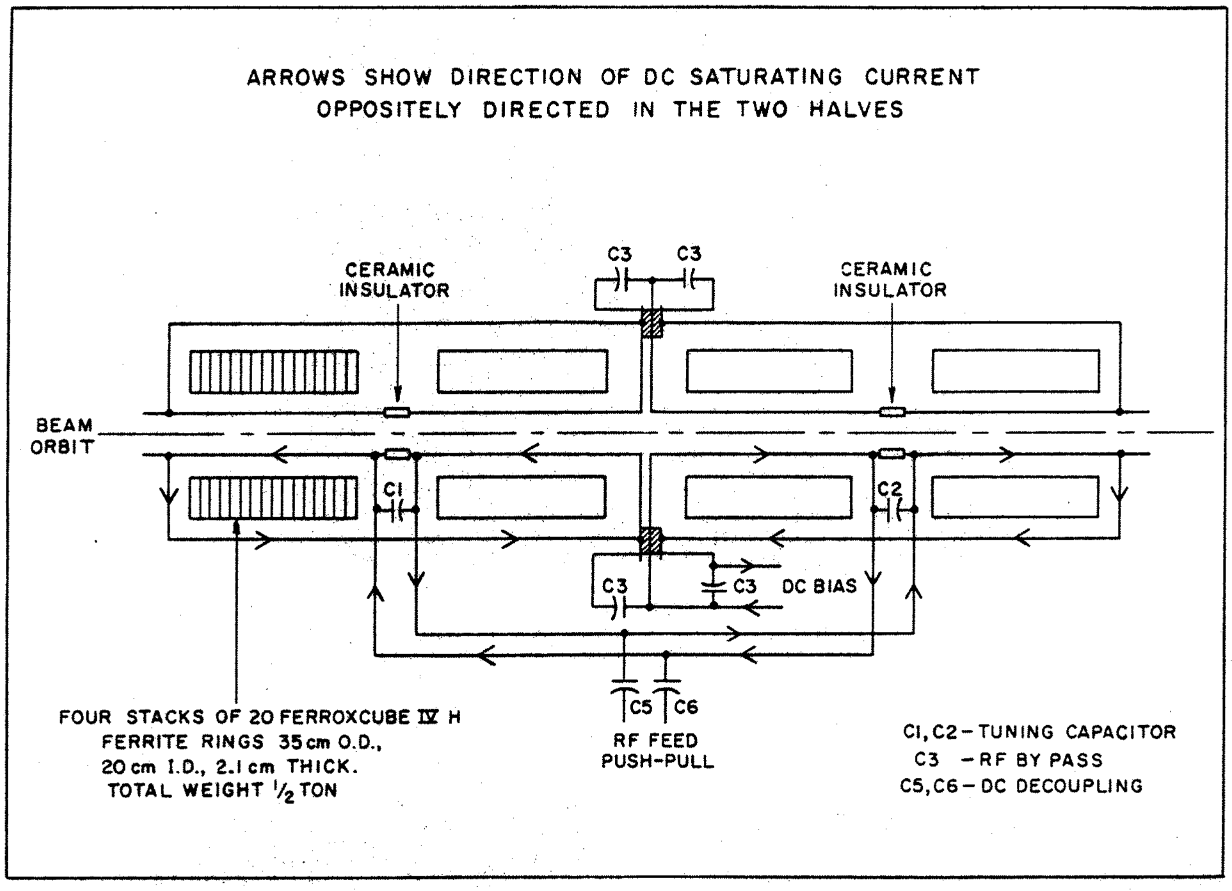


Figure 19
Cross section of Ferrite Loaded Accelerating Cavity

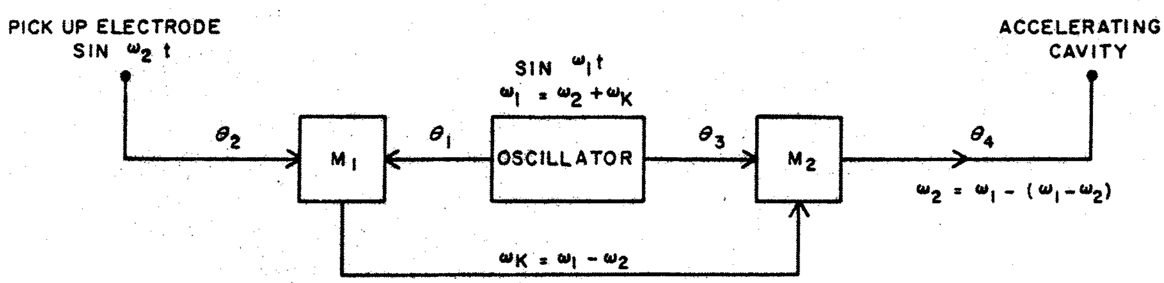


Figure 20
Simplified block diagram of multiple heterodyne system

6. Linear Accelerator Injection System

Introduction

Brookhaven experience with synchrotron magnets indicates that magnetic fields do not reach a sufficiently stable configuration for injection at fields less than about 100 gauss. At this field the injection energy is about 50 MeV. Although higher energies would be desirable, it was felt in 1953 that inflection into the synchrotron ring would present difficulties for energies much higher than 50 MeV (this problem has since been removed by the use of multiturn injection). For the above reasons, an injection energy of 50 MeV was chosen.

Protons for injection into the AGS are provided from a cold-cathode hydrogen-gas discharge. A preinjector then accelerates the protons to an energy of 750 keV. The 750-keV beam is then injected into a linear accelerator, where its energy is increased to 50 MeV.

The linear accelerator is a cylindrical structure which sustains a radio-frequency accelerating field. To tune the linear accelerator to the proper mode and establish the correct field pattern, various tuning devices and pickup probes are included in the structure. The over-all structure must be temperature-controlled to within $\pm$ 0.1°F.

The linear accelerator can only accept protons during part of the radio-frequency cycle. A buncher cavity is located between the preinjector and the linear accelerator; its function is to prebunch the proton beam to match the entrance requirements of the linear accelerator.

The beam is carried from the linac to the synchrotron through a variety of beam transport and observing gear and finally is deflected into the synchrotron orbit by an electrostatic field.

Preinjector

Ion Source

The "Penning Ionization Gauge" ion source consists in its simplest form of a cylindrical or ring anode with a cathode on either side. A magnetic field is introduced axially to increase electron path length. With a positive voltage on the anode with respect to the cathode, a cascade discharge is excited; electrons lost in the ionization process are replenished by secondary emission from the cold cathodes and ions lost at the cathodes are replaced by gas ionization. The oscillating electrons between the two cathodes are constrained in the radial direction by the axial magnetic field. It has been found that an oxide layer on the cathodes reduces the work function for electron emission and increases electron yield, resulting in lower operating voltages. Therefore aluminum is often used for the cold cathode because of its natural tendency to form an Al_2O_3 layer on its surface.

During operation, the oxide layer is gradually destroyed by ion bombardment. Periodic reoxidation of the cathodes is therefore necessary for optimum operation. A drawback of this type of ion source is that its steady performance is affected by the condition of the cathode. Immediately after oxidation of the cathodes performance is erratic with more pronounced tendencies for plasma oscillations; after about 200 hours of relatively steady operation with high discharge currents, the performance of the source tends to deteriorate again and reoxidation is necessary.

Cockcroft-Walton System

The high voltage set for the 750-keV preinjector is of conventional design and uses selenium rectifiers. It includes a five-stage voltage multiplier and a filter stack. The capacity in the filter stack is 8000 micromicrofarads; it is connected to the high voltage terminal of the voltage multiplier by a 5 megohm resistor. All of the necessary power supplies and auxiliaries for the ion source are mounted in a terminal of dimensions roughly 6 X 6 X 8 feet. A 10-kilowatt, 3-phase, 400-cycle generator in the ion source terminal is belt-driven by a motor at the base of the filter stack. The cascade transformer and filter stack, except for the ion source terminal, were designed and built by the Philips Company of Eindhoven, Holland. The filter stack and the cascade transformer are shown in Figures 21 and 22.

The ion source itself and the accelerating column are cantilevered from the grounded wall of the Cockcroft-Walton enclosure. The accelerating column consists of 72 ceramic rings cemented to accelerating electrodes. Voltage down the column is divided by a resistor string drawing about 1 milliampere.

The Linear Accelerator

The linear accelerator consists of a cavity about 33 meters long and 90 centimeters in diameter, excited in the TM_{010} mode. A general view of the linear accelerator looking from the low energy end is given in Fig. 23. To shield the protons from the field when it is in a decelerating phase, drift tubes are arranged along the axis of the cavity. Their length increases as the proton velocity increases. The first drift tube is about 2 inches long, corresponding to a proton velocity of about 0.04 times the velocity of light. At 50 MeV the proton velocity has reached 0.3 times the velocity of light and the corresponding drift tube length is about 14 inches.

Radiofrequency structure

The linac contains 124 drift tubes with a quadrupole focusing magnet located inside each drift tube. The drift tubes are supported inside the tank with two stems as shown in Figure 24.

From previous considerations, the lengths of the gaps and drift tubes were determined. It is now necessary to compute the shapes of the drift tubes so as to make the over-all rf structure resonate at 200 megacycles in a TM_{010} mode. The effects of the drift tube holes and support stems must also be included. A brief description of the design procedure is as follows:

(i) A field solution involving a finite number of cylindrical harmonics was first assumed and the solution divided into two parts: one for the region between the drift tubes and the second for the remaining volume.

(ii) From the boundary condition the coefficients of the assumed solutions were computed.

(iii) The shapes of the drift tubes were then computed by numerical integration.

The calculations were performed on the UNIVAC at New York University. To determine the accuracy of the computation, five drift tubes were modeled in a precision cavity, and the frequency error was found to be less than 0.5%. Measurements were made on the precision cavity to determine the frequency effects of the bore holes (the holes going through the drift tubes) and support stems.

To maintain a uniform electric field along the length of the linac, it is necessary that the over-all structure be locally tuned to exactly the same frequency. To tune the linac, 56 ball tuners are distributed along the length of the linac as shown in Figures 23 and 24. As the balls are moved radially in toward the center, the resonant frequency of the tank increases; the tuners have a total tuning range of approximately 300 kilocycles. These ball tuners are individually adjusted to correct local frequency errors.

Thermal gradients along the linac tank can detune the tank sufficiently to upset the uniformity of the field. Water tubes, welded to the outside of the linac, are used to control the temperature to $\pm$ 0.1°F.

Radiofrequency power

To power the linac, a pulse of rf having a peak power of 5 megawatts and a pulse length of 200 microseconds is required. After 175 microseconds, the electric fields in the linac have reached approximately 98% of their final value. A beam of protons having a pulse length of 7 microseconds is injected into the linac, which then accelerates the protons to an energy of 50 MeV. The repetition rate of the linac is 5 pps.

To supply the peak rf power, rf amplifiers using FTH 470 triodes (French Thomson-Houston) are used in a grounded grid circuit with coaxial plate and cathode resonators. Each amplifier is capable of supplying 2.5 megawatts of peak power. The outputs of two such amplifiers are combined in a waveguide hybrid junction. The output arm of the junction is a 9-inch coaxial line which is loop-coupled into the linac.

The anode voltage for the FTH tubes is supplied from a 200-microsecond storage line which is charged to 60 kilovolts and has a stored energy of 3,600 joules. A three-ball spark gap is used to trigger the storage line.

Mechanical design

The linac consists of a segmented cylinder which serves simultaneously as a vacuum envelope and rf cavity. This structure is supported on 10-inch "H" beam piles driven 50 feet into the ground; the piles are covered with concrete pile caps.

The tank supports on top of the concrete pile caps are constructed with linear bearings operating between a "V" and a flat on a support bar. The position of the tanks in a direction perpendicular to the axis (horizontal plane) is fixed by a key in the support bar. This type of construction allows for linear tank expansion while preserving alignment and also permits the removal and placement of a single tank without disturbance of adjacent ones and without affecting total alignment.

Each tank section is about 10 feet long and its wall is copper-clad steel with a 0.85-inch steel thickness and a 0.15-inch copper thickness. This copper-clad steel costs approximately as much as pure copper per unit weight. The advantage lies in the strength of the material. The great advantage of having a copper layer of this thickness is that machining directly into the copper is possible and also that edge connections can be made directly to the copper. Extensive use has been made of spring rings for electrical connections. These have proved to be very reliable in operation. They are used also for electrically connecting the individual linac tanks together. They are designed as follows: beryllium copper wire of 0.015-inch diameter is close wound on a 0.125-inch-diameter rod. After radial expansion the diameter is 0.140 inch. The spiral is then stretched so that the spacing between the wire is 0.015 inch. The groove to be used for this particular spring ring is 0.125-inch width by 0.125-inch depth.

Each linac tank is connected electrically to the next by means of spring rings, as mentioned above, positioned in the copper layer. The vacuum seal is made by "O" rings in the steel part of the wall. The heat dissipated in the tank wall is carried off in cooling tubes of square cross section welded to the tank.

The cooling system was designed for a 0.1°F maximum variation in tank wall temperature.

An indication of the accuracy with which the tanks are fabricated can be gained from the fact that with fixed settings of the ball tuners, each individual tank had a resonant frequency within the range of 200.0 to 200.5 Mc/sec. Each tank was checked with drift tubes and ball tuners in place. To make the resonant frequency equal for all tanks, a bar was placed in an axial direction 45 degrees below the horizontal plane. It was found that a frequency shift of about 0.5 Mc/sec. was obtained with a bar of cross section 1 inch by 2 inches. To equalize the resonant frequency, bars varying in thickness from 0 to 1 inch were needed. Therefore the design frequency was raised to 201.075 Mc/sec. to allow for bars with thicknesses between 1 and 2 inches.

The final resonant frequency is accomplished with the ball tuners; a 5-inch motion from "O" position of all ball tuners corresponds to a resonant frequency change of 0.2 Mc/sec.

The drift tubes in the linear accelerator are each supported by a vertical stem and a horizontal stem, which in turn are supported from the tank wall. Supporting fixtures provide the possibility of accurately positioning the drift tubes within the tank. In general the object was to hold alignment tolerances to within $\pm$ 0.001. The horizontal stem has on its supporting end a T-bar of which the axis, by means of jigs, is carefully aligned with the axis of the quadrupole.

The drift tube shape varies along the accelerator, being disc shaped at the 750-keV end with an axial thickness of $\cong$ 2 inches, and being ellipsoidal with axial length of $\cong$ 14 inches at the 50-MeV end. These drift tubes are made of copper and the stems are brazed to the body in a hydrogen atmosphere. Both stems are stainless steel with a surrounding copper cylinder.

After placing the quadrupoles in the drift tubes, the copper covers were soldered on with indium-tin solder. This type of joint was tested on a drift tube in an rf power model and found satisfactory. However, during operation in the linac some erosion took place in several of these joints resulting in a leak between the partially evacuated stem boxes and the high vacuum in the tank. A small amount of gas evolved might precipitate sparking and consequent deterioration of the leak. Presently, all repaired indium-tin joints are copper-plated with no recurrence of leaks in the copper-plated joints.

Beam Transport to Synchrotron

After leaving the linac the proton beam travels about 140 feet before it is inflected into the synchrotron. Its path is parallel to the final path in the inflector straight section, but displaced outward 3 inches. Before entering the inflector straight section, the beam passes close enough to three synchrotron magnets that it is influenced by their stray fields. As a result of this influence the beam enters the inflector straight section displaced by about 1.5 inch from the final orbit and at an angle of about 1.5 degrees to the final orbit. It is inflected onto the final orbit by the field of two electrodes 90 inches long and 6 inches apart. These plates are charged to about ± 80 kilovolts. After one complete revolution of the synchrotron has been injected, this voltage must be removed in a time that is short compared with the revolution period of about 7 microseconds. This is accomplished by short circuiting the inflector plates by triggered spark gaps. Beam transport equipment between the linac and the inflector includes two quadrupole triplet focusing lenses, vertical and horizontal steering magnets and viewing boxes. About midway along the beam transport path is an analyzer magnet which can bend the beam through an angle of 25 degrees to a detector where precise measurements can be made of its energy and energy spread.

A general view of the beam transport system, looking toward the linear accelerator, is given in Figure 25. The linear accelerator is concealed in this view by the shielding wall in the background of the picture.

Performance

Protons were accelerated to 50 MeV for the first time on April 13,1960. By April, 1961 the linac had accumulated a total running time of about 800 hours. The output current of the preinjector was between 15 and 20 milliamperes total current; the proton content was 55%. Using the prebuncher, about half of the injected protons could be accelerated, resulting in a linac output of 7 to 10 milliamperes. Energy spread was normally between 0.2 and 0.3 MeV. Beam emittance from the linac was about 6 mm-mrad.

Parameters

General

Linac Injection Energy .... 751.6 keV
AGS Injection Energy .... 50.84 MeV

Preaccelerator

Ratings of Philips set: Voltage .... 750 kV
Maximum continuous current .... 8 mA
Ripple .... 70 volts per milliampere

Floor level of preaccelerator pit .... 13' below main floor (57' elevation)
Ceiling level of preaccelerator pit .... 13' above main floor (83' elevation)
Inside dimensions of preaccelerator pit .... 20' in E-W direction
36'6" in N-S direction

Height of cascade transformer stack .... 13'10"
Base of transformer stack is 18" above pit floor
Dimensions of terminal on transformer stack: Height .... 2'
Width (E-W) .... 6'
Length (N-S) .... 9'10"
Clearances around terminal of transformer stack .... 8'8" to ceiling
7'1" to N wall
7' to E and W walls

Number of stages in transformer stack 5
Motor-generator set for input to transformer stack:
Input .... 10 kW, 440 V, 3 phase 60 cycles
Output .... 220 V, 500 cycles single phase

Distance from transformer terminal to filter terminal .... 5'11"

Resistors connecting transformer stack to filter stack:
5 megohms between terminals
20 megohms each at the 150 kV, 300 kV, 450 kV, and 600 kV points

Height of filter stack .... 12'
Base of filter stack is 18" above pit floor
Dimensions of terminal on filter stack: Height .... 6'
Width (E-W) .... 6'
Length (N-S) .... 7'8"
Clearances around filter terminal .... 6'6" to ceiling
6' to S wall
7' to E and W walls
Total capacity in filter stack .... 8000 μμF
Power available in filter terminal .... 10 kW, 3 phase at 400 cycles, 220 volts
(from 1800 rpm generator)

Length of accelerating column .... 6'
Aperture in accelerating tube .... 5.5"
Number of sections in accelerating tube 72

Linear Accelerator

Inside diameter .... 95 cm
Wall thickness .... 1.00" .... 0.85" of steel + 0.15" of copper
Number of pumping ports .... 2 per tank section
Number of pickup probes .... 6 per tank section (approx.)
Number of 5" ball tuners .... about 60
(about 10 in 1st section, 8 in second section .... 3 in last section)

Length of tank sections:	No. 1 .... 115.654"
	No. 2 .... 122.192"
	No. 3 .... 119.590"
	No. 4 .... 118.955"
	No. 5 .... 122.207"
	No. 6 .... 121.332"
	No. 7 .... 116.779"
	No. 8 .... 125.090"
	No. 9 .... 116.199"
	No. 10 .... 122.417"
	No. 11 .... 109.824"
	Total 1310.239" = 109' 2.239"

Number of drift tubes 124
(first is a half drift tube attached to the end wall of the tank)

Vertical drift tube stem diameter .... ½" stainless steel (+ copper cladding)
Horizontal drift tube stem diameters:
No. 2 through No. 29 .... 1" stainless steel (+ copper cladding)
No. 30 through No. 58 .... 1.25" stainless steel (+ copper cladding)
No. 59 through No. 124 .... 1.5" stainless steel (+ copper cladding)

Drift tube internal apertures:
No. 1 through No. 8 .... 0.5"
No. 9 through No. 18 .... 0.75"
No. 19 through No. 33 .... 1.0"
No. 34 through No. 124 .... 1.25"

Location of drift tubes:	No. 1 through No. 28 .... in tank section No. 1
	No. 29 through No. 45 .... in tank section No. 2
	No. 46 through No. 58 .... in tank section No. 3
	No. 59 through No. 69 .... in tank section No. 4
	No. 70 through No. 79 .... in tank section No. 5
	No. 80 through No. 88 .... in tank section No. 6
	No. 89 through No. 96 .... in tank section No. 7
	No. 97 through No. 104 .... in tank section No. 8
	No. 105 through No. 111 .... in tank section No. 9
	No. 112 through No. 118 .... in tank section No. 10
	No. 119 through No. 124 .... in tank section No. 11

Tolerance on drift tube alignment and position .... ± 0.005"

Estimated Q of linac structure 90,000

Estimated rf power dissipation .... 2.5 megawatts

Estimated stored energy .... 120 joules

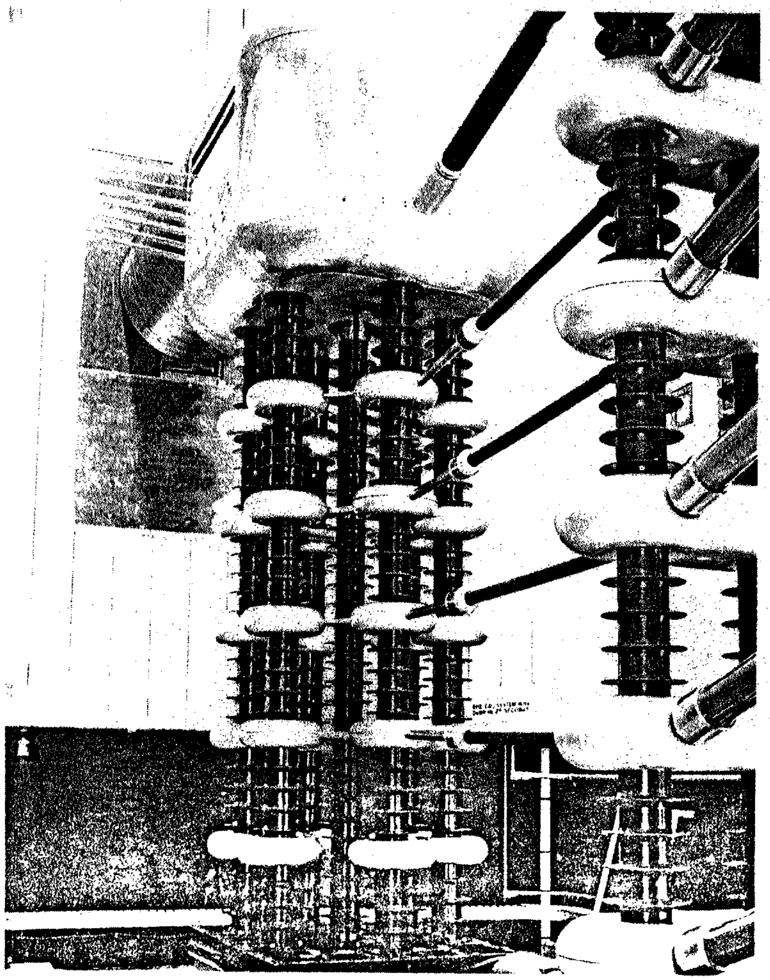


Figure 21
Cockcroft-Walton, filter stack, ion source terminal and accelerating column

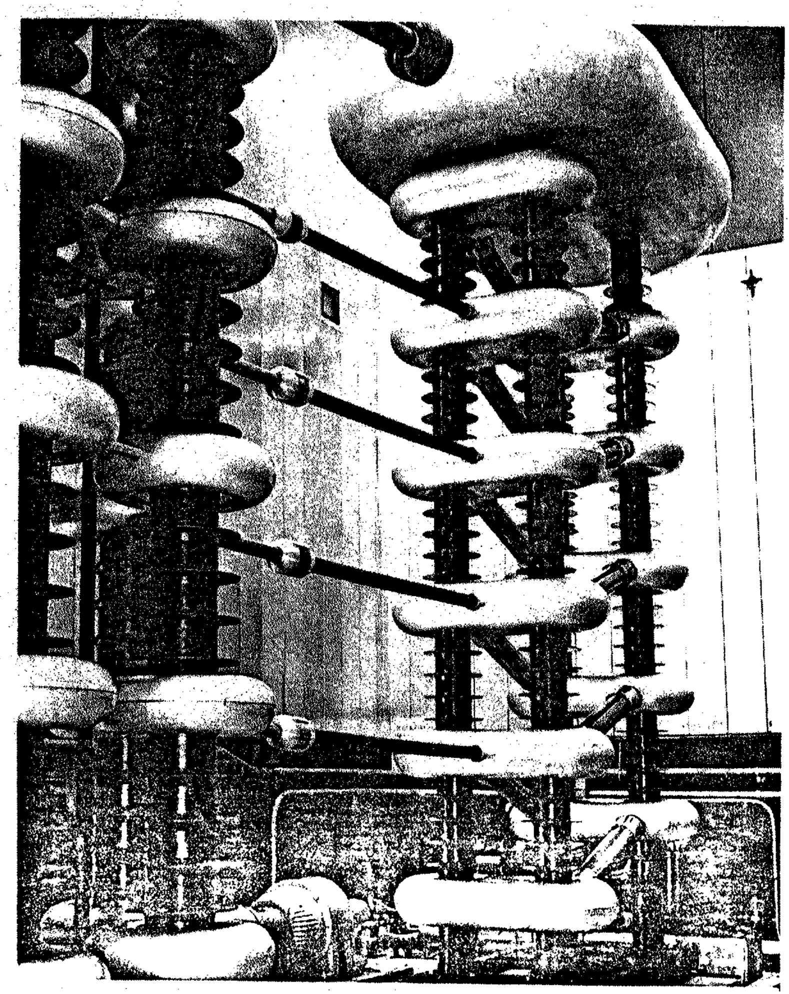


Figure 22
Cockcroft-Walton, filter stack and cascade transformer

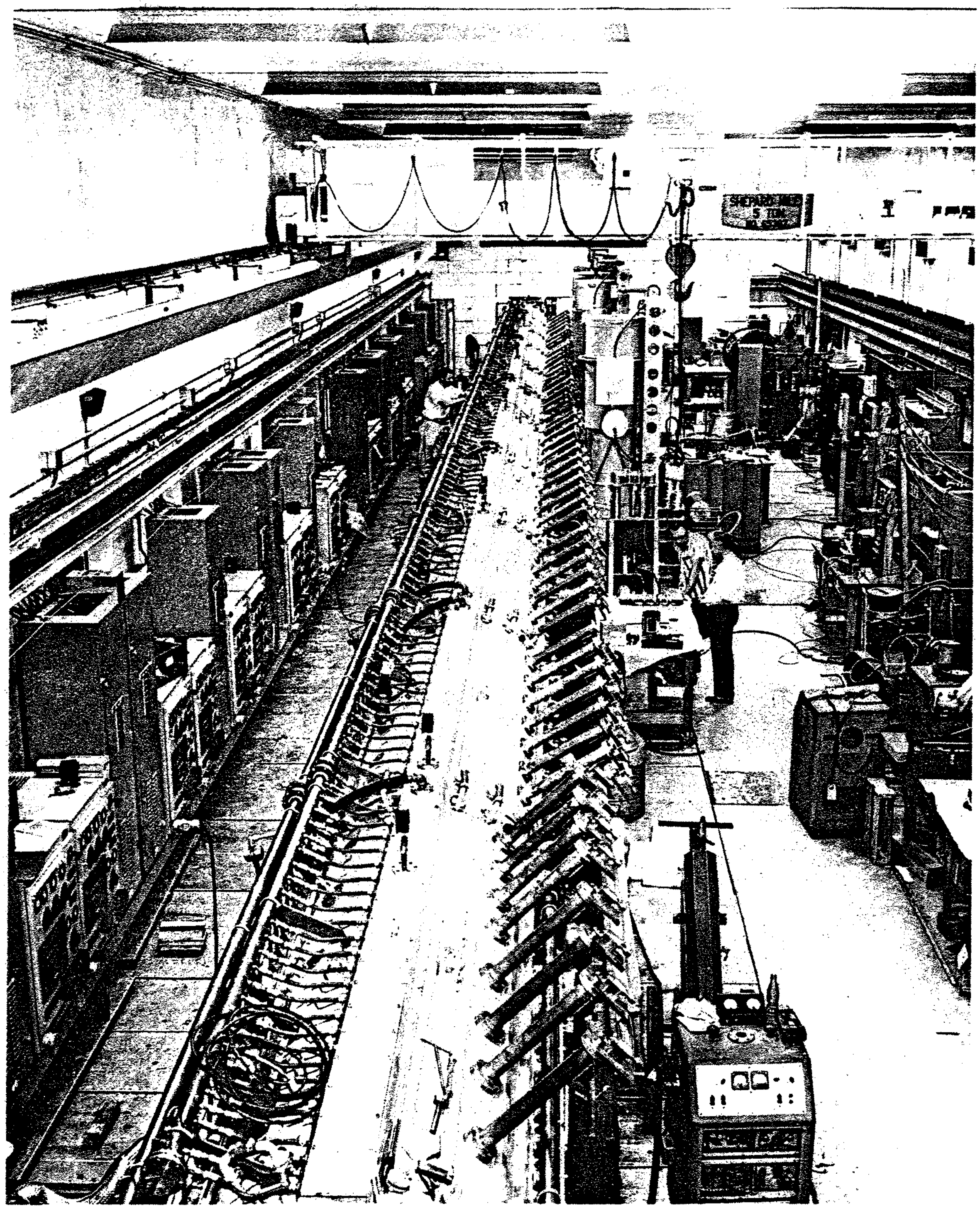


Figure 23
Linear Accelerator Tank Section looking toward High Energy end

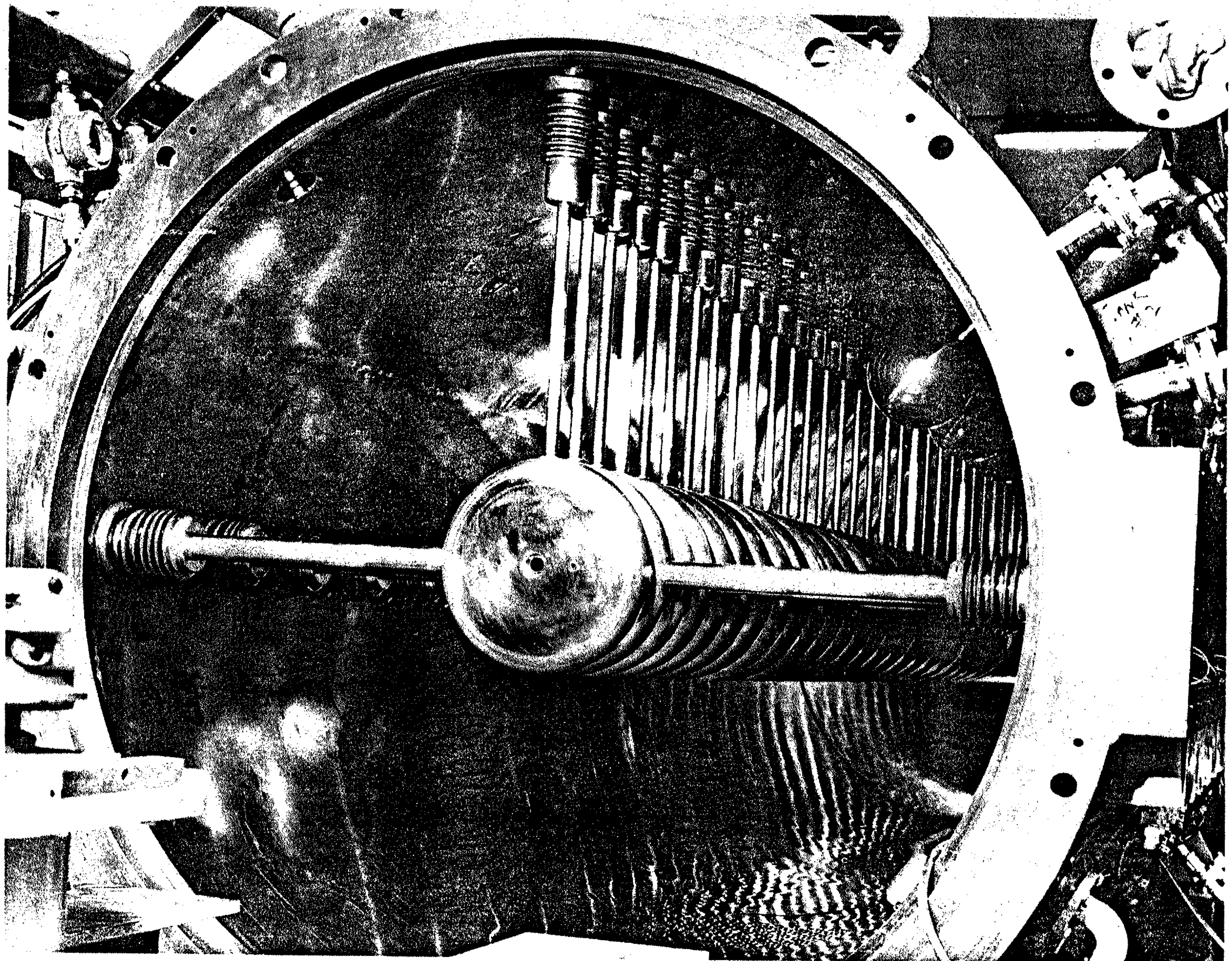


Figure 24
Interior of Linac Tank with Drift tubes in Place Low Energy end

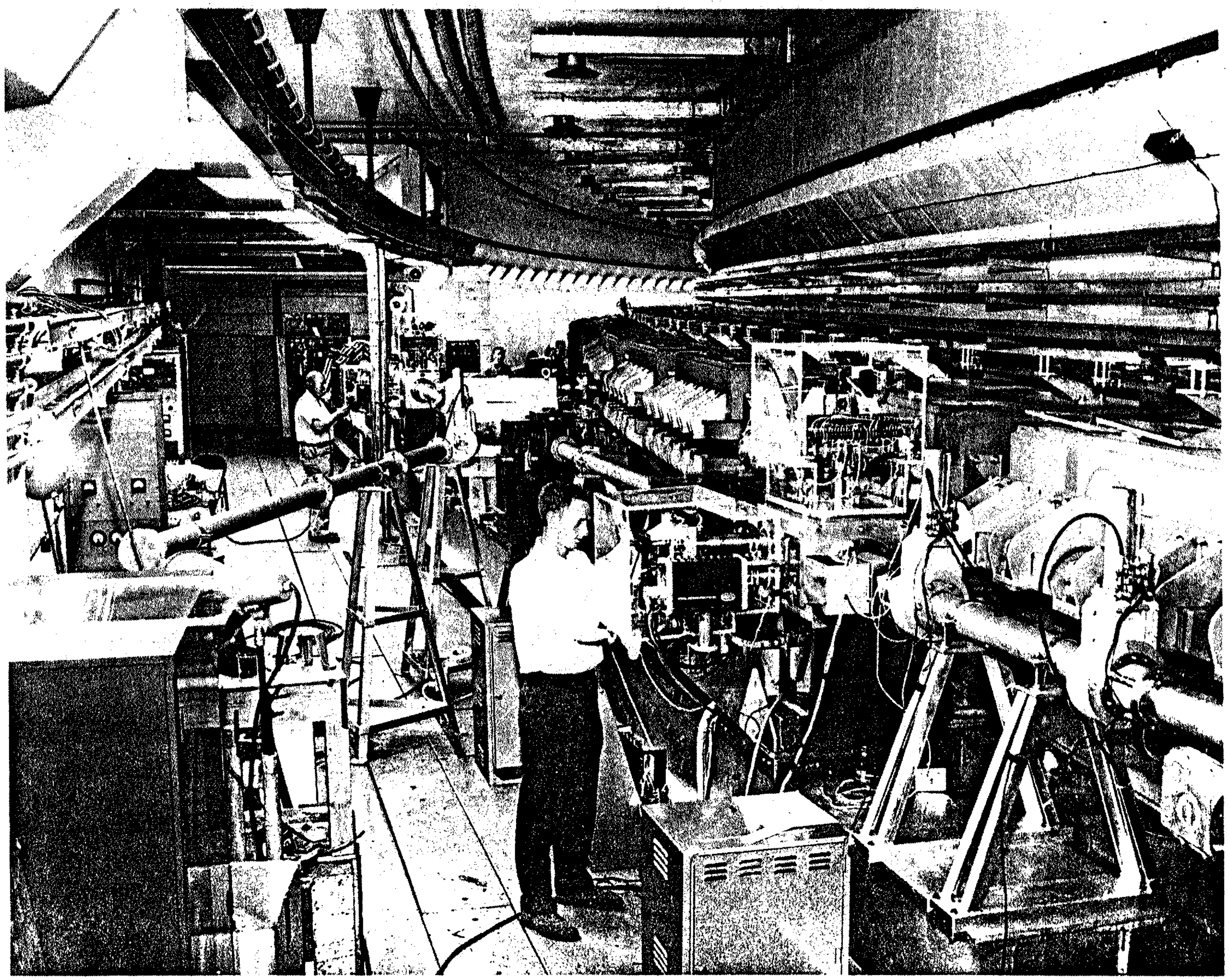


Figure 25
Linac Beam Transport System

7. Control Systems

Design Criteria

The objective of the control systems is to provide the means for the operation of the accelerator and its components in an orderly fashion both in terms of the individual component requirements and in terms of an overall integrated installation.

For the components themselves, the design of the controls is based on the nature and needs of the equipment involved and must provide the proper sequencing, interlocking and monitoring of the various sub-units within the component. Additionally, provisions must be included for equipment and personnel protection, for local and remote operation and for at least limited future modifications and additions. Insofar as possible, the control techniques and information display should be similar and consistent, since in the completed, operating machine, the same personnel operate and maintain all components. Wherever there is component interaction, appropriate cross-interlocking must be provided.

In that the entire accelerator consists of many components and sub-components, and that these units are separated by considerable distances, the remote control of these units must be integrated and systematized on the basis of overall accelerator functional operation. This is accomplished by organizing the controls, first into sub-control areas, and finally into a main control area. To provide a reasonable and manageable situation in the main control area, the accelerator control system must combine detailed component status and diagnostic information into meaningful summary indications. Similarly, master on-off switching must be included. Conversely, direct proton beam information, targeting controls and secondary beam spills must be available in detail in the main control area. For all of this, a wide assortment of instrumentation incorporating the latest techniques is required.

These general objectives and philosophies were used in the design of the control systems of the accelerator and its components. In the following, certain component control systems and certain installation details are described to indicate the means, methods and techniques for implementation of these objectives.

High Level RF Control System

As detailed elsewhere in this report, the high level rf system consists of:a common driver having a number of stages of amplification, and located in the power room; twelve stations, each with a final amplification stage located in the magnet enclosure; and a common anode power supply for the twelve stations and the four last stages of the common driver. In these high level electronic equipments, there is need for process sequencing both in the start-up and shut-down procedures. For protection of both equipment and personnel, full interlocking is required against failure or abnormal operation of the various sub-units within this system. In toto, this involves approximately 600 relays, power contactors and other electrical solenoid devices. As designed, developed and finally installed, the auxiliary function of all these units is controlled by a single on-off push-button station in the main control room. A second push-button station controls the application of all high voltages in the system. Summary status and malfunction information exist in the main control area to indicate the status of the overall system and to direct maintenance personnel to the area of difficulty in case of malfunction. At each area, detailed information for the equipment is provided.

To illustrate, a typical sequencing and interlocking operation of a final stage is outlined. Upon operation of the common push-button to start all auxiliary functions, an initiating circuit is established in each final stage amplifier. This circuit turns on the pumps and blowers and an automatic interlock by-pass is set up for a brief period to allow the various air and water flows to be established. If the flows are not established during the by-pass period, or, if the flows fail anytime following this period, the station is automatically turned off. Thus, if a hose breaks within the amplifier cabinet, water damage to equipment in the cabinet is kept to a minimum by turning off the water system automatically.

Once the flows are fully established, and assuming no overload conditions exist, filament time delay is instituted and the status, "Time Delay in Process" is indicated in the main control room. Upon completion of this time delay, permission circuits for application of high voltage are established, a "Ready" status is indicated in the main control room and the auxiliary on sequence is complete.

The common push-button for the high voltages can be operated to close the primary and output switches of the common power supply and the output switches of the common driver. Assuming no overload conditions to trip these circuits off, the final stage amplifier is now fully operational.

Because of potential parasitic oscillations in the common driver caused by inadequate loading, an interlock chain was included to prevent application of anode voltage to all parts of the system except when at least nine out of the twelve final stage amplifiers are in the "Ready" status, and further, are connected to the common driver. At any time, should the number of stations on line fall below nine, the common power supply is automatically turned off.

Upon normal shut-down, or under certain interlock trip-outs, the controls for each station are set for an after-cooling period. Under these conditions, all high voltage switches are opened and filament power removed. However, the water and air cooling is kept operational for the period of the after-cooling, subject to the air and water flow interlocks. During this time, the status "Time Delay in Process" is again indicated in the main control room.

A requirement of the system was to have the ability to either turn off only one or several particular stations, or to prevent one or several particular stations from being turned on with the common master push-buttons. For these purposes lockout switches, one for each station, exist in the main control room, to permit such combinations while maintaining the integrity of the operational requirements of the overall high level systems. For example, if such a lockout switch is used to turn a particular station off because of difficulties in the electronics, the feature of after-cooling is still maintained.

Vacuum Control Systems

As described elsewhere in this report, high vacuum is obtained by Evapor-Ion pumps in which titanium wire is fed to a post held at high temperature. Upon contact (or near contact) with the post, the titanium is heated to the boiling point, evaporates, and is deposited on the walls of the pump barrel to provide a coating for further adsorption of gases from the vacuum system.

Early in 1959, test operation of these pumps using commercial power and control units indicated a number of shortcomings of these units. Basically, it appeared that these commercial units were meant only for single pump, intermittent, attendant laboratory type operation, and as such was inadequate for the AGS. Accordingly, tests and measurements were made of the pumps' electrical characteristics so as to be able to specify the power supply requirements. Further, controls were redesigned in the light of the requirements of a multi-pump, continuously operating system. In the redesigned controls, techniques for sensing the feeding-evaporation process were developed and used to automatically turn off the pump upon malfunction. The net result was that, depending on the nature of the malfunction, proper operation of the pump usually could be reestablished in a few minutes by manual operation thus eliminating the need in most instances of removing the pump from the system.

The redesigned power and control system was drawn up with the specification that start-up of the pump required direct operator viewing of the evaporation process within the pump. Accordingly, remote start and stop provisions were included and only summary status information in the main control area for each pump was provided. However, locally a full set of operating controls, and status, metering, and detailed malfunction indications are included. Pumps are grouped by superperiods usually four in each, and each group is protected against poor vacuum by a common superperiod high vacuum gage. To allow for bringing a single pump into the main system, the controls provide for single pump, valved off operation using, temporarily, a local high vacuum gage for protection.

In that normally the titanium wire needs to be evaporated only approximately 10% of the time, automatic wire feed is provided using clock timers in which the duration of the wire feed as well as the interval between wire feeds can be set as needed. Here again, these automatic circuits are grouped by superperiod, thus allowing extra feed time on a superperiod basis if required.

As a further adjunct to the superperiod grouping of pumps, sectionalizing valves exist in the main chamber to provide segragation of the superperiods to ease maintenance work and to allow preservation of the vacuum in the remainder of the ring in the case of a vacuum failure in one particular area. As such, these valves are fully interlocked by the high vacuum gaging and further, are provided with manual switch control in the main control area.

Ionization gages were specified for both reading high vacuum and for high vacuum interlocking. A commercial power and control unit having automatic ranging was selected for these ionization gages. Again these units apparently were intended only for single unit local use. In this instance, modification of the commercial units provided the necessary remote operating features as well as improved supervised circuits necessary for a multi-unit installation. Included, for example, was the provision for remote direct reading of the ionization gage collector current using a low impedance spotlight galvanometer as giving a more accurate, and reliable measure of the vacuum conditions. These modifications as well as the basic unit requirements were drawn up as a specification and obtained from the vendor.

Where high voltages exist within the vacuum (e.g. rf accelerating gaps, inflector, etc.) and protection required to prevent arcing in the Geisler discharge region of vacuum, such interlocking was provided from the vacuum gaging system.

The same basic philosophies of control were applied for both the main ring and for the linac injection vacuum systems. In the latter area, in addition to the tank vacuum system, a separate system is used for pumping the drift tubes to the micron region. In this instance, to preserve the mechanical integrity of the drift tube assembly, it is required that the differential between the vacuum within the drift tube and in the tanks proper be held to set minimum values. Accordingly, interlocking and protective circuits were added to automatically limit these vacuum systems to these conditions.

Cooling System Controls

The control requirements for the major water-cooling and air-conditioning systems of the AGS were studied in detail, and generally pneumatic instrumentation and operation was selected as being the most advantageous. Detailed specifications for these devices were written and the material procured on a competitive basis. Additionally, interlock and alarm circuits were designed and installed together with a main control board in the mechanical equipment room of the service building.

Several of the proportional control loops had unusual characteristics and requirements which necessitated detailed analysis to insure satisfactory operation. For example, in the main magnet cooling loop, the transit time of the cooling water through the entire loop is about twenty minutes, whereas the response time to load changes was specified to be considerably less than this. This problem was solved by the use of an anticipator which essentially derived pre-information from the magnet pulsing control system.

The cooling loop for the linac tanks was specified to hold the temperature to $\pm$ 0.1 $^{\circ}$F. To accomplish this, a high gain control loop was required. However, such a loop could have a tendency to oscillate. A detailed analysis of this loop revealed that such tendencies, though marginal, could be controlled by first derivative type functions, and the instrumentation for this loop was so specified. Upon installation, this loop performed as designed.

The air conditioning system for the main control room upon installation, was found to oscillate over wide ranges. In this instance, the heat load and correspondingly the air change rate was large so that conventional air conditioning controllers were inadequate. By adding proper pneumatic lag elements, the oscillations ceased to exist and the system operated smoothly.

A temperature monitoring system for the magnet enclosure was requested. The expense for the equipment and installation of such a system was found to be high. An adequate and much less costly means was provided by connecting pressure switches to the 3 to 15 psi pneumatic control lines of the existing air conditioning control system. These switches were set to operate whenever the pressure went out of the normal control range which would include failure in the pneumatic lines themselves. These switches were connected to individual alarm annunciators in the mechanical equipment control room to alert maintenance personnel in the event of trouble.

Signal Cable System

During the one second beam acceleration period, many fast timing pulses are required throughout the accelerator. Some of these are derived from crystal controlled electronic clocks, others from varying parameters within the accelerator, and still others from various electronic delays and counters. All of these timing pulses are transmitted on coaxial cables having matched terminations. Coaxial cables are also used for the transmission of analogue signals.

As operating conditions of the accelerator change, variations in the interconnections of these cables are necessary. Therefore, a patching arrangement was designed and installed. It is much preferred to group cabling coming into the patching area according to the far end destination, whereas the actual patching groups should be according to function.

Because the signal cable system is common to many components of the accelerator, and is fundamental to the successful operation of the accelerator, the patch panel racks were located in the main control room and additionally serve as the distribution and collection point for all component cables. Five racks were assigned to this system including space for various electronic delay, counter and clock units. The physical arrangement as designed provided for extensive cross connections within the racks and grouping of the final patching on the front of the racks according to function. As installed, the front panels are neat, convenient to follow, with short one-for-one jumpers and devoid of a large tangle of long cables. However, interim cross connections can be made on the front for temporary or brief requirements and system testing and checking can be performed quickly in a straightforward manner.

Communications

Considering the distances involved, a necessary and vital adjunct to the successful operation of the accelerator is an adequate communications system for personnel use. For this purpose, a public address system and a private telephone system were provided.

The public address system has loudspeakers located throughout all operational areas of the accelerator and is used both to alert personnel in these areas concerning operational status and to serve as a paging means. To keep the number of announcements and pages to a minimum, the system is divided according to the areas involved, and the nature of the announcements. For example, the microphone at the linac console will drive loudspeakers only within the linac area, whereas the microphone at the main console will drive not only the same loudspeakers in the linac area, but also speakers in all areas of concern to the overall operation of the accelerator. Because of these various common and overlapping arrangements, nearly all of the electronics and relaying for the public address system is located in the main control room. As a secondary feature of this location, more rapid trouble-shooting of the system is possible and substitution and patching out is quite feasible.

As a method of supplementary information, an electronically generated, low level chime note corresponding to the beginning of each acceleration cycle is sent to all operational areas via the public address system.

For the private telephone system a sixteen pair cable is routed through all operational areas of the accelerator, and assorted types of terminal equipment are connected along these routes to these pairs (commonly referred to as channels) to serve basically for point to point communications. Ten of these channels are assigned for general use and are connected to each of approximately 175 stations strategically located throughout the accelerator complex. Selection of a particular channel is made by means of a selector switch at the station and as many as six telephones will operate satisfactorily on any one channel. Choice of a particular channel is made either by prearrangement by the personnel involved or by use of still another "call" channel which is normally held open in that only momentary switches are used for connection to this call channel. Operator type head sets with long coil cords are plugged into the station as required allowing maximum freedom to personnel in checking and testing equipment.

Other channels are assigned to an intercom type function. In the machine areas, conventional handset on hooks is permanently connected to these channels which terminate in one or another control area corresponding to the point of origination. In the control area, loudspeakers with amplifiers serve to alert the operators audibly to incoming calls. Use of control room handsets is then made to complete the call, and in this process, the amplifier is automatically disconnected. With this loudspeaker arrangement, it is intended that emergency calls can receive immediate attention.

Use is made of closed circuit television for viewing of beam observation flags which can be remotely positioned to intercept the proton beam. The materials used in these flags are selected so that they will fluoresce when struck by the protons. In the linac area, six observation points exist and television cameras at these points are permanently connected to the monitors in the linac control room. For the magnet enclosure area, it was anticipated that the needs and points of observation would vary. Therefore, four circuits were routed around the magnet enclosure with connections to junction boxes strategically located and arranged to permit connection of a television camera to the junction box. These circuits terminate in the main control room and allow the remote operation of the camera as well as positioning of the observation flag and its illumination.

Cable Trays and Control Cable

During the preliminary design stage, the technique of using open cable trays to support power, control and signal lines was selected for general use in the AGS. This technique has the advantages of flexibility and versatility as required for an accelerator, is economically preferable and results in minimum cable installation time. Having made this selection, the preliminary drawings for the accelerator buildings were examined in detail to determine the compatibility and maximum use of the advantages of a tray installation. Certain modifications and additions to the building design were found to be necessary and were incorporated in the final design and specification. The building construction contract included installation of a major portion of the cable tray system, about 10,000 linear feet in all. Additional trays were added as the needs became specific.

A survey of commercial multiconductor control cable revealed that generally, two classes were available. One was light weight construction with thin insulation and intended for communication and electronic installation. The other was a heavy duty type as used in power stations and certain industrial installations. It was anticipated that many control lines would be required in the final installation and that cable tray space might be a limiting factor. Accordingly, a complete cable specification was drawn using ASTM and IPCEA standards where applicable, for a composite cable assembly midway between the extremes noted. In brief, the specification called for No. 14AWG untinned stranded conductors insulated with 0.025 inches of polyethelene and covered with 0.005 inches of nylon for mechanical protection. The overall assembly, in varying numbers of conductors per cable was jacketed in 0.050 inches of polyvinylchloride. Approximately two and a half million conductor feet of this cable has been procured and installed.

Standard Parts

Because the control system must provide equipment and personnel protection, must monitor and interlock equipment failures, and in some instances, must control high power components, optimum reliability of the control devices used is required. During preliminary design, the market was surveyed in some detail, tests performed on devices where necessary and finally a listing of approximately 200 items made which was adopted as preferred standards in control circuit design. This list included small minimum-maximum quantities to be stocked at Brookhaven for emergency use, temporary or small installations and for spares. A secondary but important feature of this standard list was that the inventory of items was kept to reasonable levels and the number of small quantity purchase orders was reduced.

Main Control Room

During the preliminary building design, the details of equipment to be located in the main control room was either vague or unknown. Therefore, the size was specified based only on experience with other accelerators and anticipated needs for the AGS. As the equipment details became firm, the configuration within this room was detailed with emphasis on the functional operation of the accelerator. In particular, racks were assigned to certain functions, interwiring needs were estimated, and a cable tray system designed to be installed under a false floor. The false floor itself was then detailed, specifications written and material procured and installed.

The assortment of devices and equipment to be located on the main console was somewhat unusual and included switches, indicator lights, meters, electronic counters, television monitors and oscilloscopes. The commercially available console modules available at the time were not adaptable to this assortment. Therefore, a console was designed to meet these needs and constructed of open channel framing. In this design, features not available in commercial units were incorporated. Included was maximum utilization of available floor to ceiling height, minimum lost panel space from the framing and adaptability to both standard panel sizes and to bench type oscilloscopes.

8. Surveying

This section of the report outlines the highly precise surveying operations used in building the AGS and summarizes the alignment stability of the machine as measured by surveys made during five subsequent years.

Specifications for the Survey of the 33 Bev Synchrotron

The machine (Figure 26) required the location of some 240 magnets around a circle about 1/2 mile (807 meters) in circumference within one tenth millimeter (0.004 inch) of their specified positions in relation to each other. However, two diameters of the circle may vary as much as 1 cm (3/8 inch) without handicap to the machine, providing the change in the diameter is very gradual and not so placed as to set up oscillations in the ninth harmonic as the particles are accelerated to some 350,000 passages a second around the circle. The modifications of geodetic survey instruments and methods, including some special devices adopted to attain this specified precision are described in the following pages.

Plan of Survey and Preliminary Results

The machine was built in a tunnel in order to provide shielding from high energy radiation when the machine is in operation. The tunnel is approximately 6 meters (18 feet) wide. This width permitted the establishment of 24 equally spaced control survey stations around the circumference with each station intervisible with the first and second adjacent stations on each side of it. (Figure 27). This intervisibility permits the observation of closed triangles. Because of this intervisibility and the one centimeter tolerance in diameter of the circle, it was decided that the expense of radial tunnels for the direct measurement of radii of the circle would not be necessary.

Angle Measurements

All the angles between the intervisible stations are measured with 16 positions using a specially centered T3 theodolite and special targets (Figure 28). The centering ball on the theodolite and the base cylinder of the target plug fit the bushed hole whose center is the control station within 10 microns (.0004 inch). The centering of the ball on the theodolite and the centering of the target graduations on its base cylinder are within 10 microns (.0004 inch) tolerance also. The first set of discs were replaced with a second set of discs with holes offset to the amounts necessary to place the stations on the desired circle as computed from the first precise traverse. A second traverse using the offset discs proved the positions were within the specified tolerance.

For the angle measurements, a rejection limit of 3 sexigesimal seconds per single pointing and one second per triangle was adopted. Additional sets of 16 positions were taken in the few instances when these tolerances were not met. The average triangle closure was 0.33 sexigesimal seconds using tubes and 0.43 seconds later without tubes when the air conditioning of the tunnel was in stable operation. The 24 sided figure required an adjustment of 0.04 and 0.08 seconds respectively per interior angle to close the two traverses of the control monuments.

Tape Measurements

Each distance between adjacent and the next adjacent control monuments was measured with specially graduated steel tapes. The average temperature of the tapes was measured by the electric resistance method first developed by the National Physical Laboratory of Great Britain at Teddington. Tension was applied to the tapes by a standardized weight over a carefully selected ball bearing, balanced pulley. Eight readings were taken with each of two tapes (using forty power microscope): four with the weight raised and four with the weight lowered just prior to contact. The direction of current in the resistance apparatus was also reversed four times. Three tapes were used, the pairs being exchanged so that each tape was intercompared with each of the others for one-third of the measurements. The root mean square error of the tape measurements of the 112 foot (33 meter) interval between control stations is 17 microns (0.0007 inch). Figure 29 shows the forward contact and tension apparatus; Figure 30 the resistance measuring equipment.

A mean of 72 intercomparisons checked the calibration data given by the National Bureau of Standards within two thousandths of an inch for the 112 foot tapes and within five thousandths for the 222 foot tapes. All three 112 foot tapes agree with each other and apparently with their specified length as compared with the National Bureau of Standards within four thousandths of an inch although the Bureau of Standards Calibration Certificates estimate only that the precision of the calibration is within six thousandths. It is very gratifying to those interested in precise measurements that tapes of such high precision are available on special order.

Leveling

A tolerance of 25 thousandths of a millimeter (0.001 inch) in the relative vertical positions of the magnets was adopted. In order to attain this, a two second vial was exchanged for the ten second vial normally installed on the NIII Wild level. The lengths of foresights and backsights is kept equal by measurement. Sights are about 4 meters and seldom as much as 20 meters long. The closures of the leveling circuits around the half-mile ring have been five to twenty-nine thousandths of an inch (.12 - .75 mm) (Figure 31).

Final Alignment by Offset Radial Measurements

The preliminary setting of the magnet locating pins was done by means of taped distances and measured azimuths from the 24 control stations. The locating pins are adjustable radially. The final radial alignment was done by special invar tape offset rods calibrated to the specified radial distances (Figure 32). One end of these rods fits in sockets on top of the magnets; the other has an optical alignment target of the type used in the United States aircraft industry (Figure 33). The target end of the rod rolls on stands set along a specially graduated tape between the adjacent control stations. The radial displacement of each magnet socket from its specified position is measured by an alignment télescope optical micrometer to the nearest 25 microns (0.001 inch) (Figure 34 and 35). The invar tape offset bar arrangement permits considerable fluctuation of the temperature of the magnets without appreciably affecting the accuracy of the radial measurements.

Measurement Through Tubes

The air conditioning of the tunnel was not in stable operation when the first measurements between the control monuments were made. Rather than wait, it was decided to make both angle and distance measurements through pressboard tubes 12 inches in diameter, such as are commonly used for concrete column forms. The tubes were supported on lumber scaffolding on small trucks (Figure 36). The root mean square errors obtained with measurements through the tubes were about one fourth smaller than those obtained without tubes after the air conditioning had been stabilized within one degree centigrade. Such tubes probably offer a practicable means of measuring with tapes with similar precision when the wind is blowing moderately. A light breeze is sufficient to prevent such precision without them.

The adjustment of the machine to the required tolerances did not complete the survey task. The glacial moraine soil on which the machine is built is sensitive to changes in foundation loads. It settles as loads are added and rebounds when they are removed. The changes in elevation of the ring foundations from the initial adjustment of the machine in

January, 1960 to March, 1963 are shown in Figure 37. The changes in elevation correspond well with the variations in loads of shielding, excavations for construction of additional target areas, heavy experimental equipment, etc.

Figure 38 shows the differences in radial positions of the survey control stations and the magnets which occurred with the mechanical changes to adjacent equipment and with the removal of large quantities of earth near the north and southwest target areas adjacent to the machine. The machine was realigned to standard tolerances during September, 1962, but continuing changes in loading since then have already caused changes exceeding the survey tolerances several times, but not sufficient to require readjustment of the magnets except for a few places near large load changes(as of 1965).

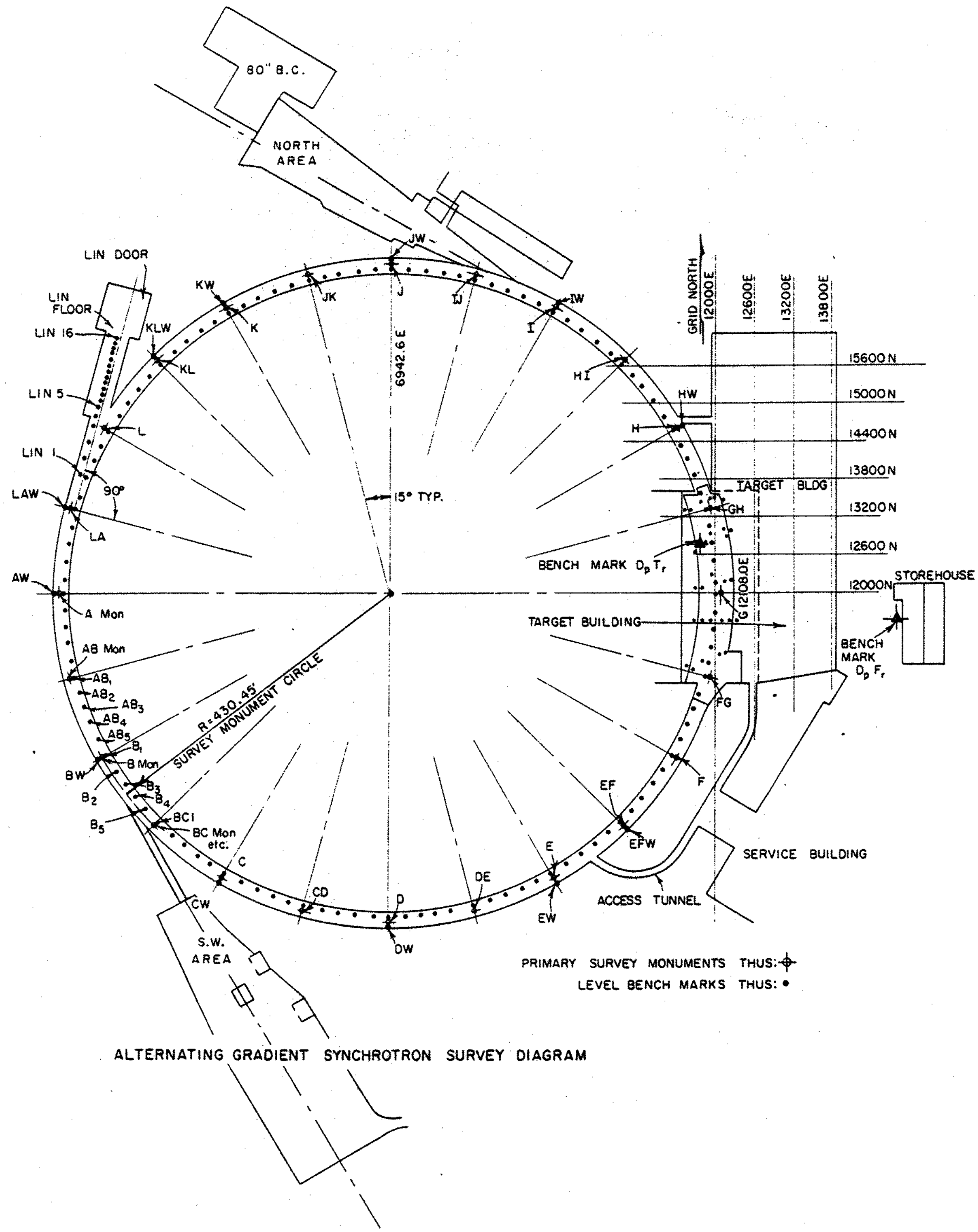
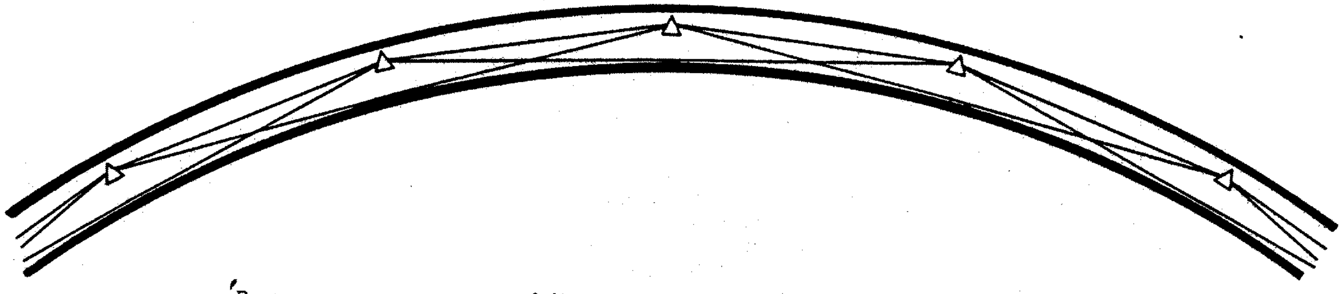


Figure 26
Alternating Gradient Synchrotron Survey Diagram



Root mean square error of distances - 17 microns for 33 meter interval
(0.0007 inch in 112 foot interval)
Average triangle closure using tubes 0.33 sexigesimal seconds
" " " without " 0.43 " "

Interior angle closure adjustment, 24 station figure: 0.04 second with tubes.
0.08 " without "

Figure 27
Diagram of distances and directions measured in tunnel Synchrotron Control Survey

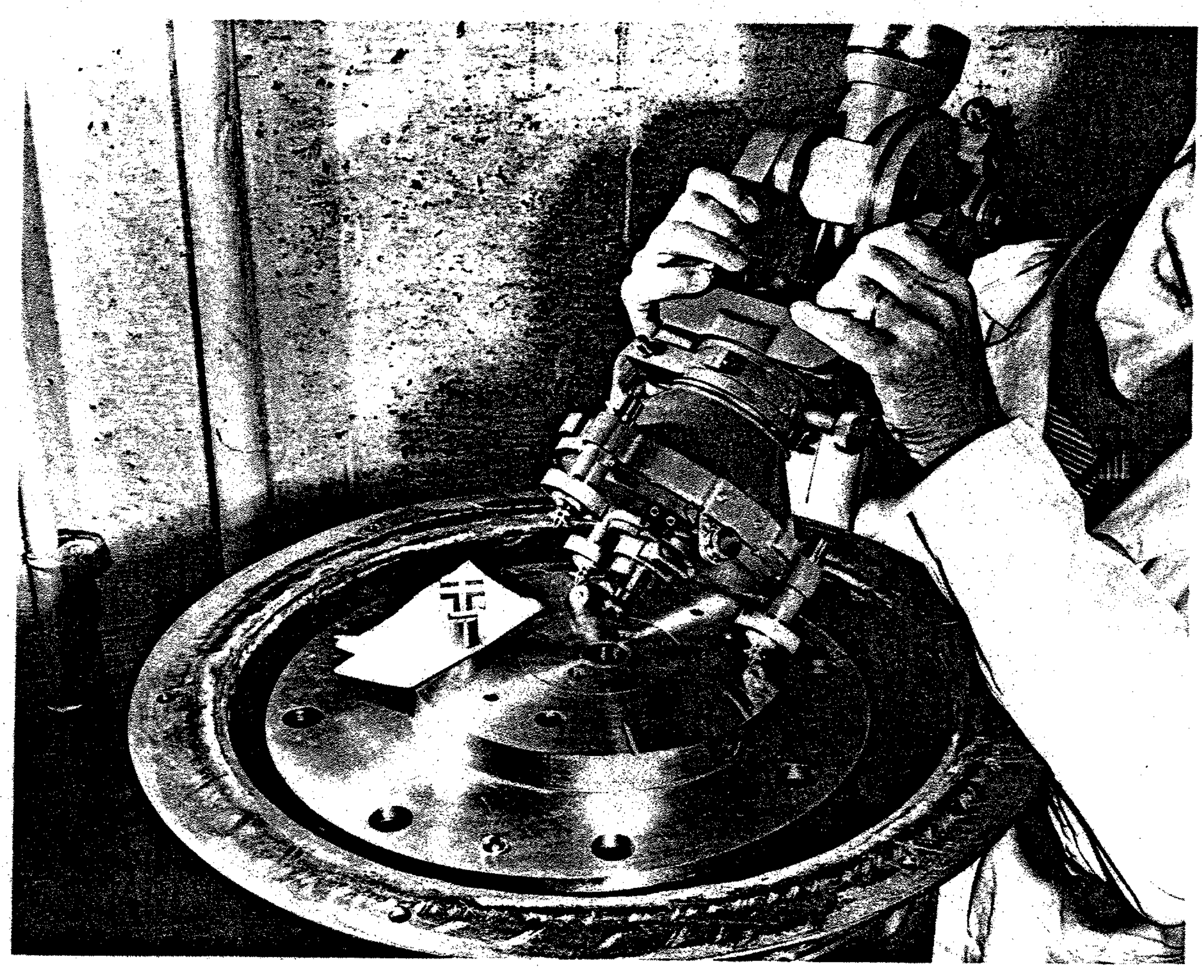


Figure 28
Centering Survey Theodolite on Primary Monument

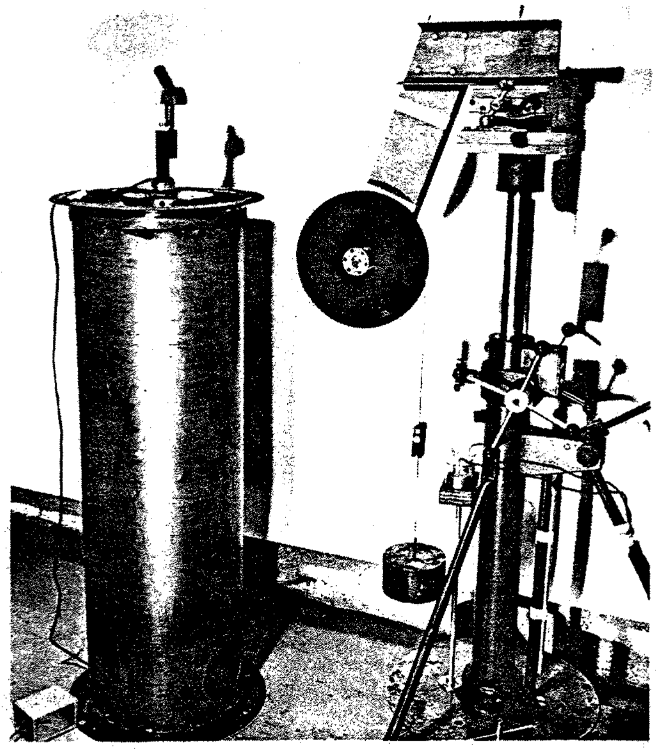


Figure 29
Survey Tape forward contact and tension apparatus

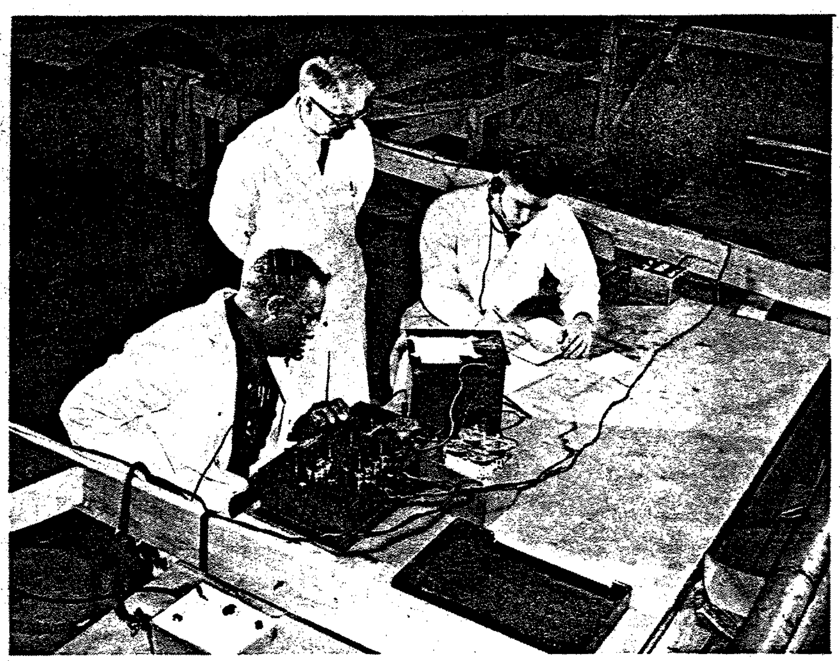


Figure 30
Survey Tape resistance measuring apparatus

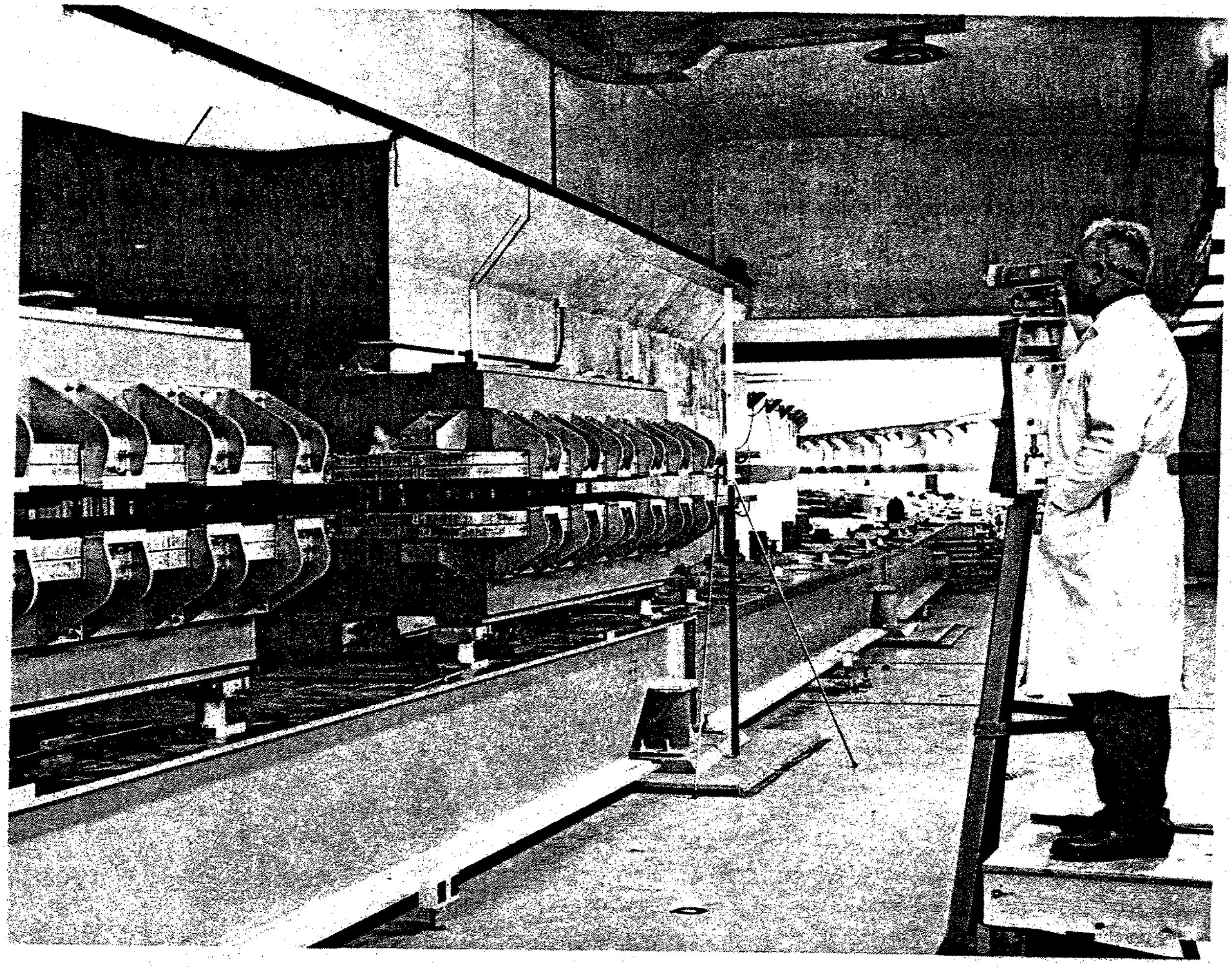


Figure 31
View of leveling survey

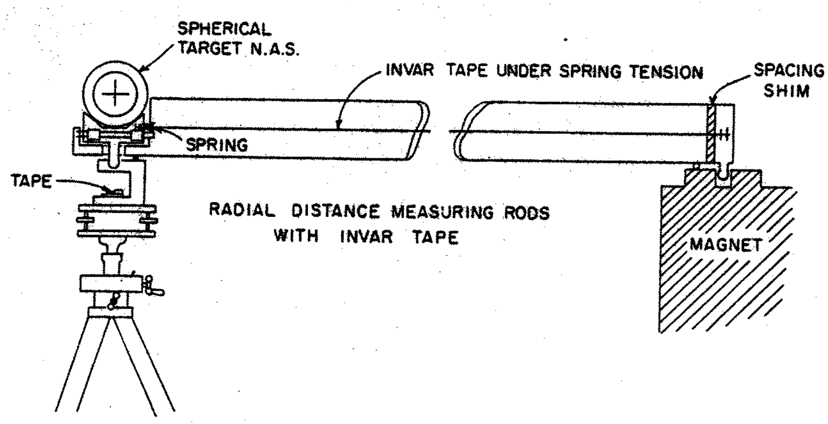


Figure 32
Radial Distance Offset Measuring Rod

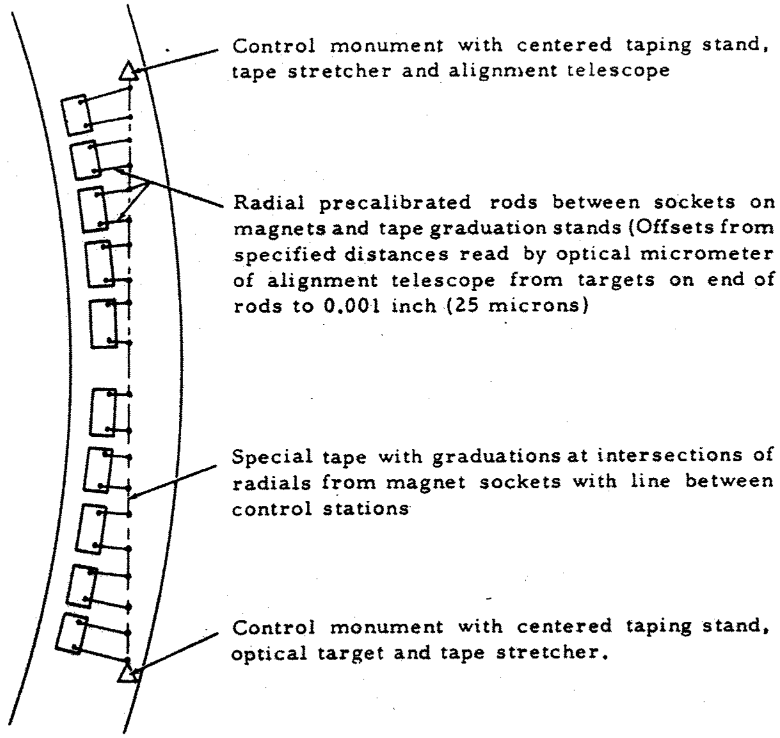


Figure 33
Radial Alignment of Magnets using invar tape offset rods

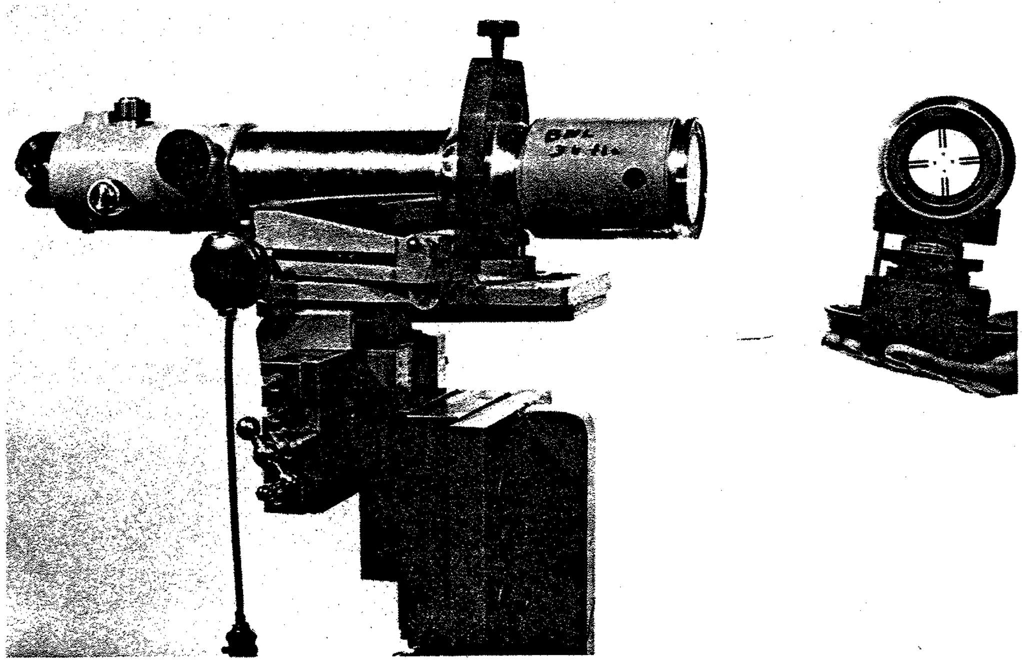


Figure 34
Alignment Telescope

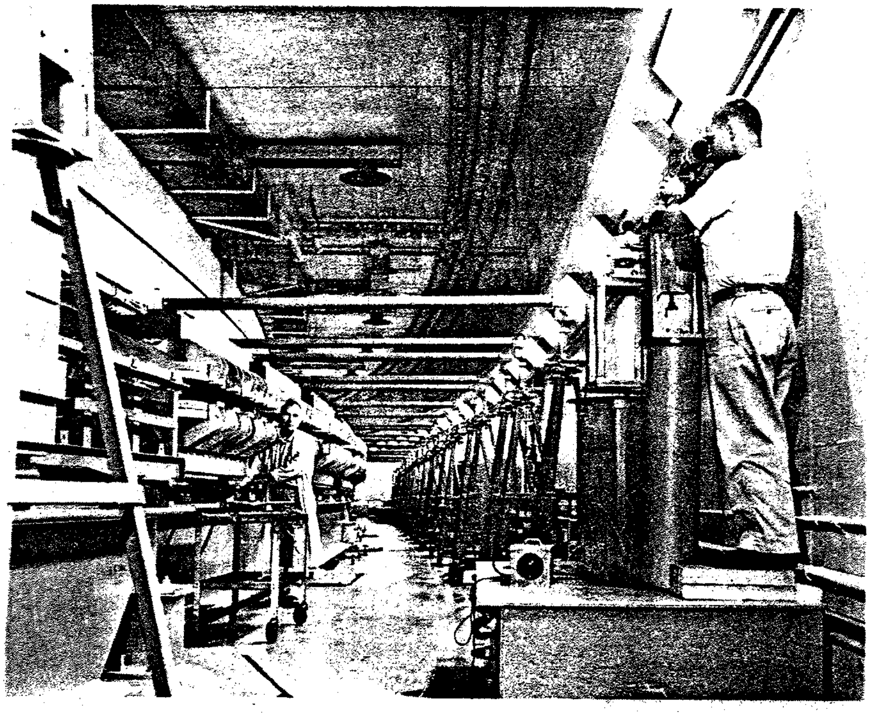


Figure 35
View of Offset Measuring Rods in use

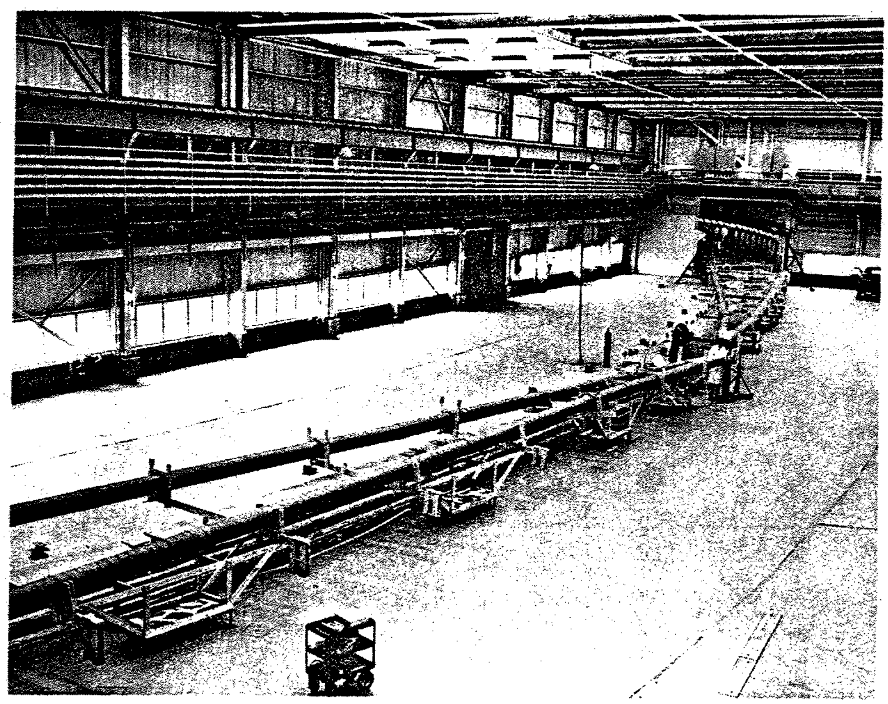


Figure 36
View of Pressboard tubes in use for initial survey of ring

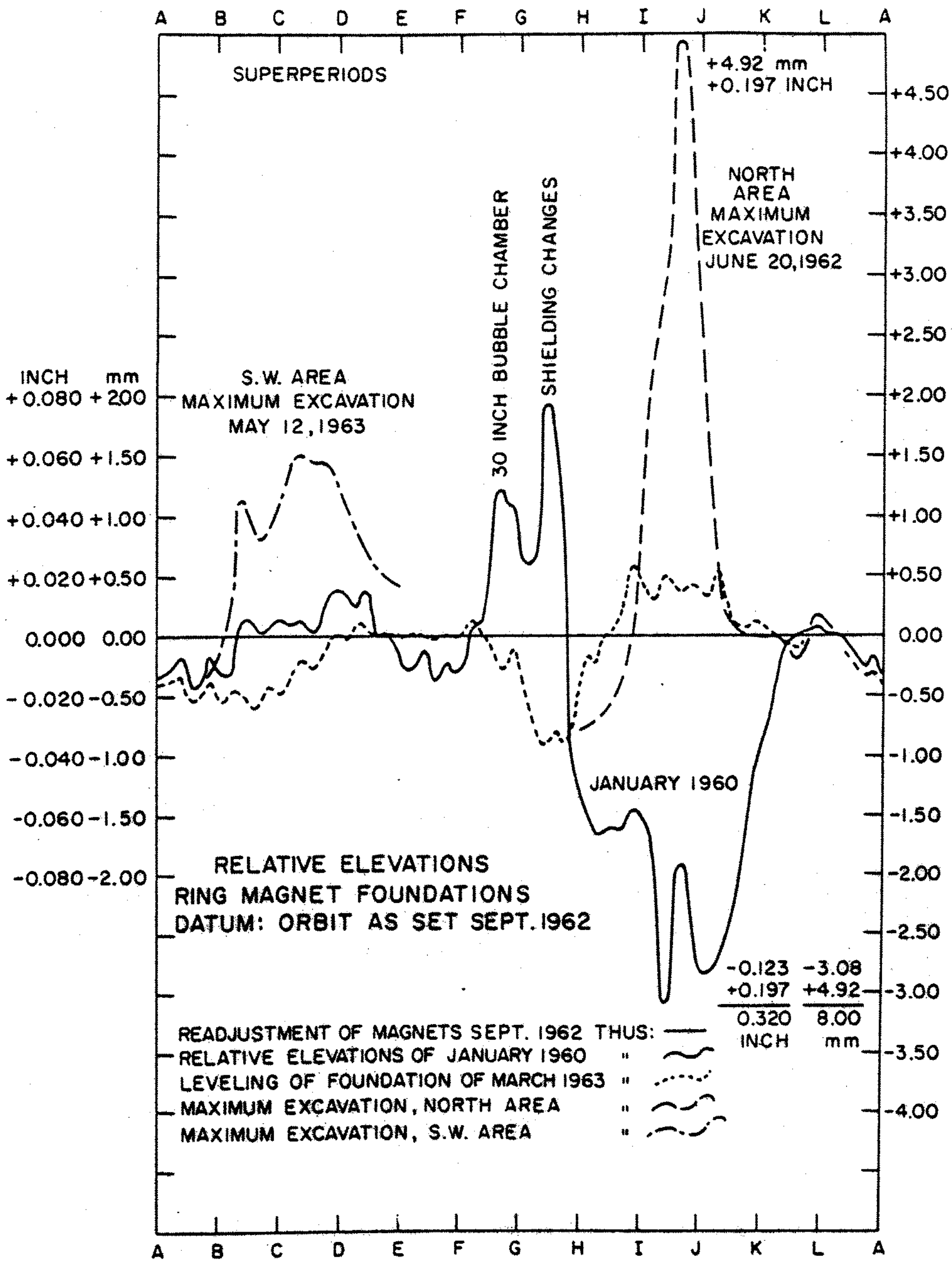


Figure 37
Relative elevations Ring Magnet Foundations

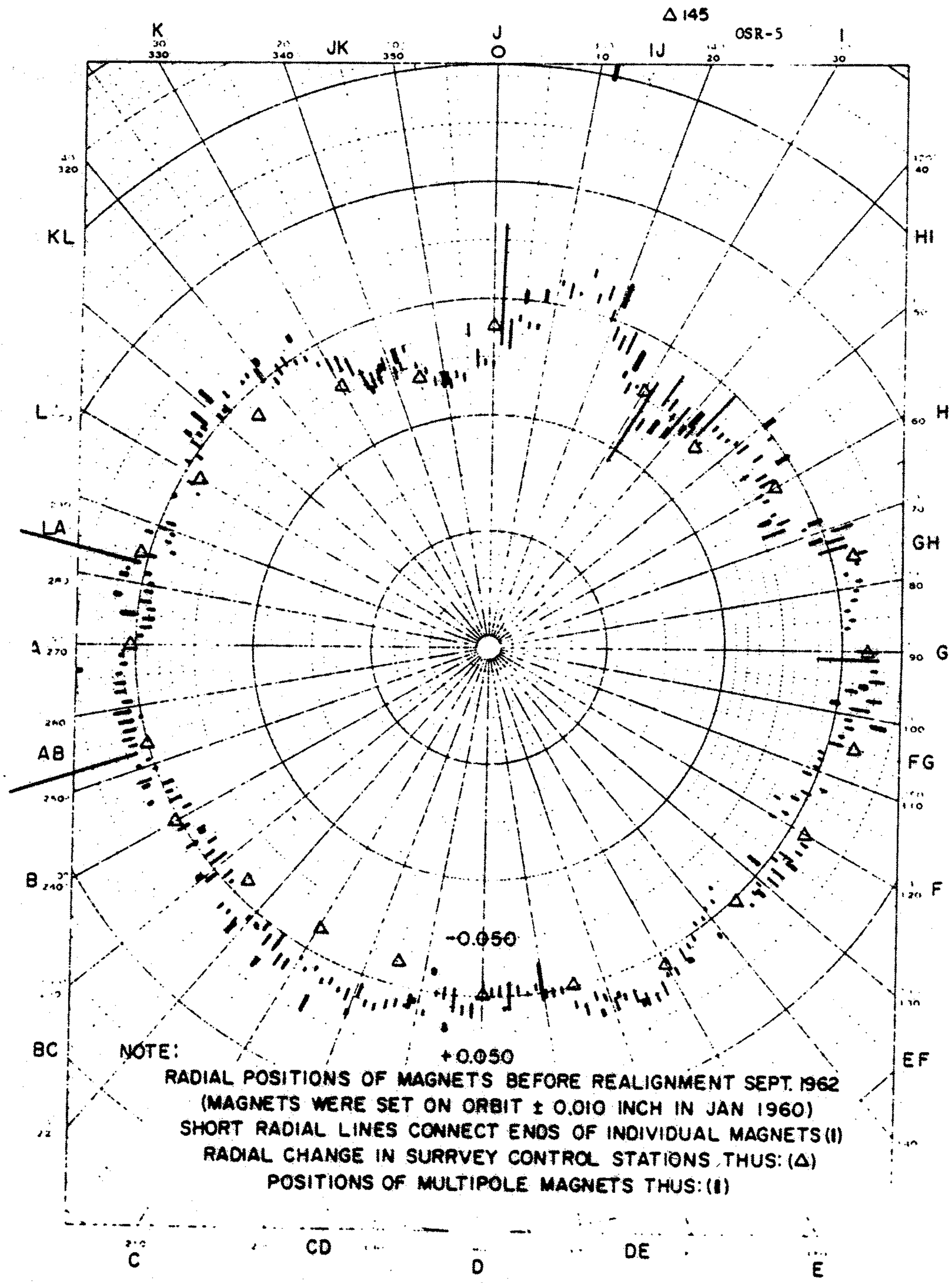


Figure 38
Radial positions of magnets before realignment Sept. 1962

9. Special Equipment

The project included the procurement of sufficient equipment for one experimental beam and its related shielding.

a. Magnets and Power Supplies for Beams

The experimental beam equipment consisted of representative sizes of bending and focusing electromagnetic lenses intended to afford the specific beam optics which any one of several possible particle beams might require. The project provided 10 quadrupole focusing magnets type 8Q48 and 4 bending magnets type 18D72 together with 10 solid state rectifier power supplies, 4 at 450 KW and 6 at 300 KW.

The quadrupole magnets are fabricated of punched steel laminations held together with welded straps. The bending magnets are fabricated of steel forgings machined to the desired size. Coils consist of water cooled copper conductors wound to the appropriate size, covered with insulating tape and impregnated with epoxy. Water cooling manifolds are mounted on the magnets. Ball pad jack assemblies are provided on stands of suitable height to support the magnets and to afford means of precise alignment.

The power supplies are designed to operate from the experimental power at 480 volts AC which is distributed around the experimental areas. The power supplies are of the air cooled dry rectifier type developed by Brookhaven National Laboratory. These units supply dc power for individual magnets and their output can be varied to fit the particular experiment.

Design parameters are as follows:

Output Power	300 Kw dc	450 Kw dc
Output Voltage	125 volts dc max.	125 volts dc max.
Output Current	2400 amperes	3600 amperes
Voltage Control Range	125 to 30 volts dc	125 to 30 volts dc

b. Shielding

High Density Concrete Shielding - 2900 tons consisting of the same modular sizes as procured for the Target Building and discussed under the Shielding Section of the Facilities part of this report.

Steel Shielding - 2400 tons consisting of surplus armor plate removed from Naval Vessels. This material was cut into 2 and 4 foot modular sizes with varying thicknesses and lengths as obtainable. Each plate was then drilled and tapped for insertion of eye bolts to provide means of lifting when the plates are to be stacked in the experimental areas.

10. Electron Analogue

The Electron Analogue was a device constructed to test experimentally the dynamic behavior of strong-focusing synchrotrons. It was hoped that this specialized accelerator would shed more light on three aspects of AGS operation: the locations, widths, and strengths of resonances; the feasibility of phase transition passage; and the effects of nonlinear fields. As the phase transition energy is a function of the mass of the accelerated particle, it was necessary to use electrons in the analogue in order to bring the phase transition energy down to a value which is relatively easy to achieve i.e. 2.75 Mev. The diameter of the analogue was made fairly large, 45 ft., in order to facilitate observation of electron pulses orbit by orbit. However, with this large radius of curvature and the low injection energy of 1 Mev, it would have been extremely difficult to construct precise magnetic guide lenses. Consequently, the strong-focusing lenses of the analogue are electrostatic.

This machine used a 2-Mev electron Van de Graaff as an injector and 80 electrostatic electrodes as guide and focusing lenses. A large number of quadrupole, sextupole, and octuple lenses were interjected along the electron path to make changes in the guide field possible. The lenses themselves were housed in 16 vacuum chambers which were connected by 7-inch flexible joints. Sixteen 10-inch mercury diffusion pumps were used to maintain the required pressure of about 5×10^{-7} mm of mercury. The electrons were accelerated from an initial energy of 1.5 Mev to a final energy of about 10 Mev by means of a single ferrite cavity. Phase transition occurs at 2.5 Mev. The diameter of the analogue is 45 ft. and its construction was undertaken in the Cosmotron test building.

Design Parameters for the Electron Analogue

Radius of curvature	15 ft.
Diameter	45 ft.
Guide electrode aperture	$(0.8 \text{ in.})^2$
Transition energy	2.5 Mev
Injection energy	1.0 Mev
Maximum energy	10.0 Mev
Field gradient index, n	225
Number of double unit cells	40
Rise time	$5\text{-}10 \times 10^{-3}$ sec
Rf frequency	7 mc
Energy gain per turn	$\sin \phi_0$ ev = 150 or 300 ev
Repetition rate	6/sec
Pressure	5 or 10×10^{-7} mm of Hg

Betatron oscillation frequency, v	6-3/4
Maximum possible change in betatron frequency, Δ v	1-1/2
Quadrupole lens aperture	$(1.2 \text{ in.})^2$
Sextupole lens aperture	$(1.2 \text{ in.})^2$

The analogue was constructed in 1954 and operated satisfactorily under dc conditions. Resonances and their characteristics were explored experimentally and were found to agree well with theoretical predictions.

Early analogue operations had shown that the locus of the equilibrium orbit was quite wobbly, a fact which contributed to the width of the resonance bands. Consequently, after the basic resonance location studies were finished, attempts were made to straighten out the equilibrium orbit by means of dipole "kicker" electrodes. Kickers were energized in groups with 6th-and 7th-order harmonic corrections because the largest disturbances occur in the neighborhood of the betatron oscillations at order 6-1/2. The corrections reduced the widths of the 6th and 7th integral resonances as much as 50%.

Once the resonance pattern had been established, experiments were started to study the excitation of the various resonances. Sloped voltage pulses were applied to quadrupole lenses when the machine was operating in the vicinity of a resonance. The resultant change in n would then carry the operating point through the resonance. As expected, it was impossible to carry the beam through integral resonances. Furthermore, total beam losses occurred nearly every time a sum resonance crossing was attempted. Other resonances and sub-resonances could be traversed rapidly with only small beam-intensity losses. At slower crossing rates losses were observed consistently at one-third integral resonances. Analysis showed that these losses were due to nonlinear field components introduced by the kicker electrodes which were actually quadrupoles connected to act as dipoles; their fields contained significant nonlinear components. The theoretical explanation was verified when augmented nonlinear field components considerably increased the one-third integral resonance losses.

After the resonance studies were completed, rf was applied to the accelerating cavity and the beam was accelerated up to phase transition energy. In December, 1955 phase transition was attempted under relatively unfavorable circumstances, without the utilization of the radial control circuit. The attempt was successful in that a large fraction of the electron beam was observed to go smoothly through phase transition. Subsequent refinement of control circuits made it possible to accelerate about half the injected beam through phase transition to an arbitrary cutoff energy of 6 Mev, which corresponds to several phase oscillations beyond the transition point.

In the spring of 1956, operation of the analogue became increasingly erratic. Orbit distortions indicated that the machine had become misaligned as a result of nearby earth-moving operations in connection with the construction of the Cosmotron beam-catcher dike, which started in early February. Consequently, the decision was made to open the vacuum tanks and resurvey the locations of the focusing lenses, and level and radial misalignments of as much as 0.050 in. and 0.020 in. respectively, were found in the machine. After realignment in level to ± 0.004 in. and in radius to ± 0.0025 in., which took a month, operational tests showed marked improvement in the performance of the analogue, and the experimental program was continued.

Attempts were made to determine experimentally the inherent nonlinearity of the analogue. This was accomplished by observing the changes in betatron oscillation frequencies with respect to changes in electron momentum. The betatron oscillation frequency was then made independent of momentum by introducing the necessary quadratic nonlinearities with sextupole correcting lenses.

In the analogue the electrons undergo only a few phase oscillations during their acceleration cycle. This is not the case in the AGS. It was, therefore, of interest to check whether repeated crossings of the higher-order resonances, caused by phase oscillations, will affect the beam stability. AGS phase oscillation conditions were simulated in the analogue by applying an ac field to one quadrupole lens . Observations made with unaccelerated beams showed that the small intensity losses were essentially independent both of sweeping frequency from 0.5 to 30 kc/sec and of the position of the operating point unless an integral stop band was encountered. An integral resonance or sum resonance invariably caused total beam loss.

At the end of FY 1956 the analogue was put on standby and in early 1958 it was disassembled and transferred to Oak Ridge.

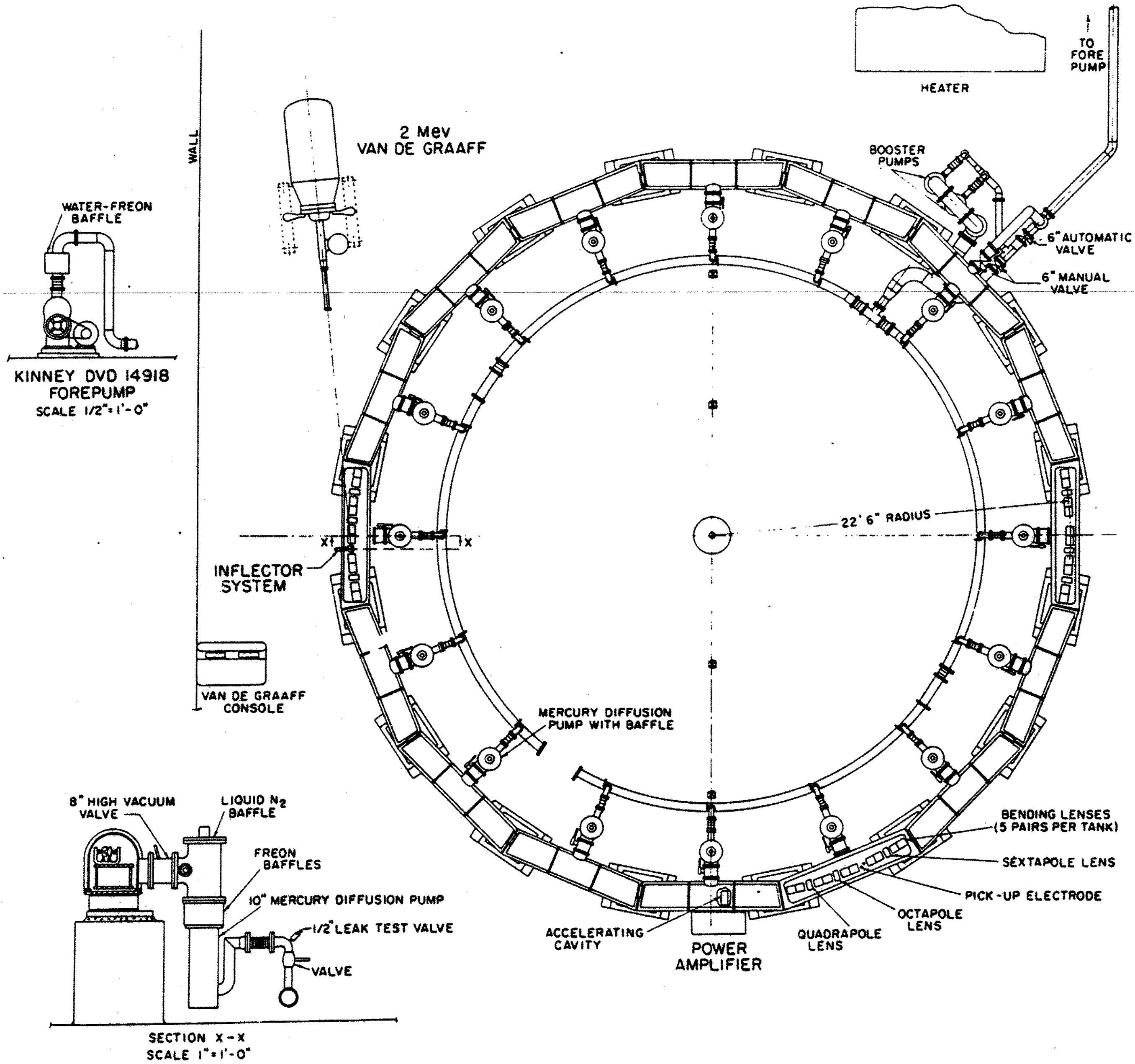


Figure 39
Schematic of electron analogue

PART V - DESCRIPTION OF THE FACILITIES

1. General Description

The plot plan shows the location of the various structures which were constructed. Detailed description of the various facilities follow. Briefly the buildings, structures and utilities which were constructed are:

Magnet Enclosure - A structural concrete building approximately 2400 feet long, 20 feet wide, 19'-6" high in a circle of 847 feet diameter buried underground with 10 feet of earth fill on top for radiation shielding. This structure houses the main magnet ring.

Target Building - A structural steel and metal sandwich panel building approximately 252 feet long, 100 feet wide, and 48 feet high. This structure houses a portion of the main magnet ring and experimental floor.

East Experimental Building - An "L" shaped structure, adjacent to the Target Building consisting of two bays, one bay 459 feet long by 100 feet wide, and 50 feet high and a second bay 205 feet long by 65 feet wide and 48 feet high.

Outdoor Experimental Area - On the West side of the Target Building an open paved area approximately 81 feet wide and 252 feet long.

Linac Building - Includes a structural concrete tunnel section connected to the Magnet enclosure approximately 130 feet long by 35 feet wide and 22 feet high and a structural steel metal sandwich panel building with a 14 foot deep pit for the Cockcroft Walton generator 74 feet long by 64 feet wide and 21 feet high. The linear accelerator is housed in the tunnel section and the control room and service facilities together with the Cockcroft Walton are housed in the building section.

Service Building - An irregular shaped building of structural steel and metal sandwich panels which is 348 feet long overall and 224 feet wide at the widest point. It includes 2 story office and laboratory space, a high bay assembly area, low bay mechanical room, and a high bay room for the main magnet power supply and RF driver. This building houses the main control room, the main magnet power supply, the RF driver, cooling water pumps, assembly spaces, administrative offices, drafting rooms, electronic shop, machine shop and other service functions.

Mechanical Equipment Building - A rigid frame prefabricated metal sandwich panel low bay building approximately 81 feet long by 40 feet wide and 18 feet high. This structure is located adjacent to the East Experimental Building and houses the helium compressors, air compressors and emergency generators which serve the experimental area.

Assembly Building - A rigid frame prefabricated metal sandwich panel high bay building approximately 100 feet long by 60 feet wide and 34 feet high located East of the drive which goes from the Service Building North to Fifth Avenue. It is used for assembly of scientific and experimental equipment.

Warehouse - A rigid frame, prefabricated, insulated metal panel building approximately 100 feet long by 100 feet wide and 18 feet high in two bays each 50 feet wide located East of the East Experimental Building.

Boiler House Addition - A structural steel, aluminum faced sandwich panel addition to a pre-existing building approximately 37 feet wide by 44 feet long and 31 feet high with a 19 feet x 26 feet x 13 feet high penthouse. The addition included the installation of a 60,000 lb. per hour oil fired steam generating unit.

Land Improvements - Clearing and grading of the site of the AGS complex; construction of service drives, roads and parking spaces; construction of a storm drainage system with a recharge basin.

The Site Utilities included the following:

Steam Distribution System - A 1,000 lineal feet extension to an underground steam distribution system.

Electrical Distribution System - The addition of 1,100 lineal feet of underground electrical duct and the installation of three 13.8 KV feeders, a total length of 14,200 lineal feet, in existing and new ducts from the Central Switch House to the AGS Complex.

Central Switchgear - The installation of breakers for the feeders serving the AGS Complex, at the Central Switch House.

Water Distribution System - The extension of the underground domestic water system to the site of the AGS Complex.

Sewer System - The addition of a pressure main and gravity line from the Service Building to an existing manhole in the central laboratory sewerage system.

2. Magnet Enclosure

General Description

The Magnet Enclosure consists of a reinforced concrete tunnel 18 ft. wide by 17 ft. - 9 in. high approximately 2,460 ft. in circular length with a mean diameter of 846.90 ft. It houses the proton accelerator which is essentially a series of large magnets together with radio frequency accelerators and vacuum pumping equipment.

The tunnel is buried under at least 10 ft. of earth and is fully air conditioned to assure controlled atmospheric conditions for the critical work involved during operations. It houses the piping and wiring required to service the enclosure and to operate the Synchrotron. In general, the service piping is located close to the floor and inside wall, parallel and adjacent to the magnets. A steel grating walkway, located over the piping, runs continuously around the tunnel and permits convenient access to the wireways which are bracketed from the wall of the tunnel. Cross trenches have been provided at frequent intervals in the floor slab to serve as raceways for the wiring, thus insuring additional flexibility of control. Between the magnets and the outside wall, an open corridor running continuously around the circumference of the tunnel, permits easy access to the magnets and provides a passageway for the use of equipment that may be required to service and maintain the accelerator.

Five 20 ft. by 28 ft. buildings, spaced inside the ring at 65 deg intervals, house the air handling equipment required to service the enclosure. Emergency exits from the tunnel have been provided by means of four escape hatches and two access tunnels on the outside of the ring. At two of the escape hatches, toilet facilities have been installed.

Additional services required for the operation of the accelerator are installed in the power and machine rooms of the Service Building, including the 5500 hp motor generator set, ignitrons, electrical switchgear, cubicles and console, machine cooling equipment, air compressors, and water chillers and pumps for air conditioning. Also located in the Service Building is the control room, in which is installed the main console and other equipment and wiring required for remote control of the accelerator.

A series of deep-seated survey monuments has been established at critical points around the ring to permit accurate alignment of the magnets.

To facilitate installation of magnets and other equipment and to expedite maintenance of the accelerator, a 20 ton overhead traveling crane with special controls has been installed. This crane travels completely around the ring, overlapping the travel of the crane in the Target Building.

Structural

This section describes the structural design of the tunnel, the magnet girder and supporting foundations, the air conditioning houses, escape hatches and toilets and special features such as access tunnels, utility trenches, walkways and survey monuments.

In general, the tunnel consists of a 2,460 ft. long reinforced concrete structure 18 ft. wide by 17 ft.-9 in. high with a mean diameter of 846.90 ft. The roof is 15 in. thick with walls that taper from 15 in. at the top to 12 in. at the bottom. The walls are supported on a continuous earth bearing footing 3 ft.-6 in. wide and 15 in. deep. Continuous concrete brackets, 12 ft.-6 in. above the tunnel floor, support an overhead traveling crane. Continuous inserts have been placed at regular intervals in the interior face of the roof slab and walls to provide a flexible means of support for such items as the main crane trolley, air conditioning ducts, light fixtures, wireway trays, the grating platform and other utilities.

The floor slab of the tunnel is 6 in. thick resting on compacted earth fill. It is isolated from the tunnel walls and other intercepting structures such as the pile caps and the survey monuments. At about 110 ft. intervals, cross trenches are provided in the floor slab to permit passing of utilities from one side of the tunnel to the other without obstructing the corridor which exists between the magnet girder and the outside wall of the tunnel.

In general, the service piping is located close to the floor, running continuously around the ring, between the magnet girder and the inside wall of the enclosure. A steel grating platform is located over this piping, approximately 2 ft.-1 in. above the floor, permitting convenient access to the wireways which are bracketed off the tunnel wall.

The 240 electromagnets which comprise the Synchrotron ring are supported by 120 steel box girders, each approximately 22 ft. long and 3 ft.-2 in. wide by 2 ft.-4 3/8 in. deep. Each girder has a fixed and hinged end, with the hinged end being provided with a dielectric joint. The girders are supported on a concrete capped cluster of four piles, located at each plus-minus magnet juncture. The pile caps are completely dampproofed and consist of a special controlled concrete mix designed to hold to a minimum any possible distortion after the Synchrotron is in operation. All piles are 10 in. BP42 lb. steel piles 50 ft. long.

Twenty-four survey monuments consisting of 20 ft. lengths of 8 in. ID steel pipe weighing 24.7 lb. per ft., are accurately located at 15 deg intervals around the enclosure to be used as a basis for setting the magnets and for maintaining their precise alignment. Each monument is isolated from the floor slab by an 18 in. diameter sleeve which is provided with a removable steel cover.

The Magnet Enclosure is interrupted or intersected by the Target Building, Linac Tunnel, two access tunnels, a utilities tunnel, four escape hatches, the inflector room and the concrete ducts from the air conditioning houses. A description of the structural design of the Target Building and the Linac Tunnel is given elsewhere in this report. Both access tunnels are 6 ft. wide by 8 ft. high with 12 in. reinforced concrete roofs, walls and mat. One tunnel starts from a point opposite Air Conditioning House E extending generally northeastward in a curved route to the assembly area in the Service Building. The other tunnel is located just north of the Target Building running in an easterly direction to the East Experimental Area.

A network of service tunnels extends from the control room and the power room in the Service Building to the Magnet Enclosure and the Target Building. In general, the utilities are bracketed from the walls or supported on racks in such a way as to be easily serviced from walking aisles.

In general, the four escape hatches consist of a reinforced concrete substructure extending from El. 70 ft.-0 in. to the ground surface, with a painted concrete block enclosure above the ground. The roof consists of a poured concrete slab with a 4-ply tar and marble chip surface. At the El. 70 ft.-0 in. level, escape hatches "B" and "C" cover an area 9 ft. by 10 ft. each and contain a drainage sump. Hatches "A" and "D" are 10 ft. by 16 ft. in size each and contain toilet facilities and a sewage ejector, as wellas a drainage sump. The toilet has a ceramic tile floor and cove base.

The inflector room is 10 ft. by 12 ft.-7 in. high in size and is located at the junction of the Linac Tunnel and the Magnet Enclosure. The walls and roof are of 12 in. reinforced concrete. The floor is of crushed stone. A 6 ft. by 7 ft. metalclad door separates the room from the tunnel.

The five air conditioning houses are 20 ft. by 28 ft.-6 in. by 12 ft. high and consist of 12 in. load bearing concrete block walls with a 3 in. deep steel roof deck supported on a steel frame and on the walls. The roof consists of 1 in. Fiberglas insulation and a 4-ply tar and marble chip surface. The sash and louver are of aluminum and the doors are industrial steel panel type. The floor is a reinforced concrete slab resting on earth and the block walls are supported by a continuous concrete grade beam and footing. From each building, three reinforced concrete air ducts enter the Magnet Enclosure tying into the air conditioning ducts which are suspended just below the roof of the Synchrotron Tunnel.

<u>Sanitary Plumbing</u>

The sanitary system in the Magnet Enclosure is designed to serve fixtures in toilet rooms in two escape hatches, and includes water coolers, service sinks and electric water heaters. Water for the plumbing fixtures is supplied from the domestic water main in the Magnet Enclosure. Sanitary waste from the fixtures flows to sewage ejectors which discharge to small local septic tanks discharging to large precast louvered cesspools.

Floor Drainage

This drainage system is divided into five independent sections approximately equal in length, with each section including two branches which drain to a centrally located sump. Each section is served by duplex sump pumps and discharge piping which connects with the yard piping system at points outside the wall of the structure. Piping installed in the air conditioning houses handles cooling coil wastes, which drain to bottomless sumps.

Domestic Water Service Piping

The domestic water service piping system is an extension from the domestic water header in the machine room of the Service Building. It runs through the utilities tunnel to the Magnet Enclosure, where it feeds a continuous loop which runs entirely around the enclosure, passing through the Target Building beneath the catwalk along the west wall. Connections from the loop serve toilet rooms in the Magnet Enclosure and hose outlets in the air conditioning houses. Other connections are installed for feeding vacuum pumps in the Magnet Enclosure. Valved outlets are provided at approximately 110 foot intervals along the main loop.

Heating System

Steam is furnished from the steam main in the Service Building with the piping, providing steam at 50 psi, extended to supply steam coils in the Air Conditioning houses for the Magnet Enclosure. A pressure reducing station at the Air Conditioning station reduces the pressure to 15 psi before the steam coil.

The Magnet Enclosure heating is provided by 10 Air Conditioning systems, with heating coils, located in five Air Conditioning houses around the enclosure. Unit heaters provide spot heating in the Air Conditioning houses. Condensate from the Air Conditioning houses is returned by condensate pumps to a receiver located in the machine room of the Service Building.

The route of the steam and condensate is from the Service Building through the utilities tunnel to the north end from which point one branch runs through the Target Building, thence underground to two Air Conditioning houses and the Linac Building. Another branch from the same point runs underground to the other three Air Conditioning houses.

Refrigeration System

Refrigeration equipment is provided for the air conditioning systems to cool well water sufficiently to maintain required temperatures and humidity. Water from the well water main is pumped by centrifugal chilled water pumps through water chillers and thence to the cooling coils in the air conditioning systems. The water returns from the coils through the condensers of the chillers, and thence flows to the mix-waste tank described later. Two package type chillers, located in the Service Building machine room, and having a capacity of approximately 75 tons each, serve the above system. A third chiller of the same capacity is available as a spare for either of the above, as well as for the smaller chiller serving the Service Building.

The chilled water piping system supplies approximately 375 gpm of water at 44° F to serve cooling coils in the air conditioning systems and a process heat exchanger in the Linac Building.

The chilled water distribution system includes supply and return piping which extends from the water chilling equipment located in the machine room of the Service Building. It runs through the utilities tunnel to the north end, from which point one branch runs through the Target Building under the catwalk along the west wall, and serves the air conditioning systems for the building, and continues counterclockwise around the Magnet Enclosure to serve two air conditioning houses. From the same point, another branch runs clockwise around the Magnet Enclosure to serve three air conditioning houses and the Linac Building. Branches from the piping through the Target Building run down the west wall columns, and thence through trenches and buried conduit to serve the air conditioning units in the shielded area.

Ventilation and Air Conditioning Systems

All principal process areas are fully air conditioned, the only exceptions being service rooms such as toilets, escape hatches, fan rooms, etc. The established year-round design conditions for air conditioned areas are 75° F dry bulb ± 2°F and maximum relative humidity 50 per cent.

The following systems are provided:

MS1-2 (A-E) and MR (A-E) - Magnet Enclosure Air Conditioning Supply and Return Systems

Ten similar supply and five similar return systems provide air conditioning for the Magnet Enclosure.

The fan and equipment for two supply systems and a common return system are located in each of five air conditioning houses.

Each supply system consists of field assembled equipment including fan, heating and cooling coils, automatic air filter and dampers with outside air intake, return inlet and supply duct work distribution with diffusers. The common return system for the two supply systems in each air conditioning house consists of a return air fan with connecting duct work to roof exhaust hood and intake plenum for the supply units. Each system is designated by the same letters as the air conditioning house in which it is located.

Each supply system handles approximately 9,300 cfm with provision for 100 per cent outside air, and serves a sector of the enclosure 65 deg in arc measurement, extending either clockwise or counterclockwise from the fan location. Each return system serves a sector of the enclosure 130 deg in arc measurement centered on the fan location. (Systems Nos. MS2A and MRA serve sectors 2-1/2 deg less in arc measurement than the other supply and return systems, respectively.)

MX1 (A,D) - Escape Hatch Toilet Exhaust Systems

Supply air for the toilet rooms is induced through door louvers and exhausted through the following fans and separate duct systems to roof hoods:

System	Cfm	Location
MX1A	160	Escape hatch A
MX1D	160	Escape hatch D

MX2 - Inflector Alcove Exhaust

This system is designed to exhaust approximately 1,050 cfm from the inflector alcove and consists of an exhaust fan located in the area with connecting discharge duct to above the ground level, terminating with discharge fitting.

MX3 - Access Tunnel Exhaust

This system is designed to exhaust 1,320 cfm from the Access Tunnel connecting the Service Building and Magnet Enclosure. The roof type exhaust fan is located on a concrete curb extending above the ground surface. Air is induced from the Magnet Enclosure.

Fire Detection Systems

All areas in the Magnet Enclosure, Target Building and Linac Building, except those for which CO_2 fire protecting systems are provided, are equipped with fire detection systems.

Two reporting zones are provided. One of these consists of seven separate detecting zones, four in the Target Building, one of which is an electric system for the Shielded Area, together with one adjacent detecting zone of the Magnet Enclosure north of the Target Building, and two adjacent zones of the Magnet Enclosure south of the Target Building. Each Magnet Enclosure detection zone includes air conditioning houses, escape hatch and toilet when they occur within the limits of the zone. Two of the pneumatic detecting zones in the Target Area extend into adjacent segments of the Magnet Enclosure in order to reduce the extent of the Magnet Enclosure zones. All above detecting zones report to a Master Box located adjacent to the S.E. door of the Target Building which relays to the Fire House.

The other reporting zone consists of four detecting zones, two in the Linac Building and Tunnel and two adjacent detecting zones in the Magnet Enclosure. These report to a Master Box located at the Linac Building which relays to the Fire House.

Detectors for each Magnet Enclosure zone are located in the Air Conditioning Houses, for each zone in the Linac area at the north wall of the Linac Building and for each zone of the Target Building at various locations within that building.

Manual fire alarm boxes are provided as follows: one in the Linac Building, one at each of the five escape points from the Magnet Enclosure, and four in the Target Building. They are connected to the same reporting zones as the detecting equipment in the areas in which they are located.

The fire detection system is of the Gamewell "Vigilarm" type. The system is of the temperature rate-of-rise, continuous pneumatic detection element, electrically supervised type, in which expansion of air in a copper tube is utilized to actuate electrical devices controlling the operation of the alarm system.

Operating on the rate-of-rise principle, the system operates when the rapidity of the temperature rise exceeds a predetermined rate, irrespective of the temperature prevailing within the area of the time an abnormal rise in temperature begins to occur.

The Magnet Enclosure is divided into five zones, each with its detector unit, manual alarm station and general alarm bell located in the several fan rooms around the Enclosure. Two of the detector units are connected to the Linac Building control cabinet and three of them are connected to the Target Building control cabinet.

Compressed Air System

The compressed air system includes two 50 cfm air compressors with after-coolers and receiver located in the machine room of the Service Building. Branch lines in the machine room serve the demineralizer, water treatment equipment, pneumatic control system and power room.

The main compressed air distribution system extends from the north wall of the Service Building through the utilities tunnel to the Magnet Enclosure where it feeds a continuous loop which runs entirely around the enclosure, passing through the Target Building beneath the catwalk along the west wall. Principal branches from the loop include one crossing in a trench to the Linac Tunnel and running the length of the tunnel to serve the Linac Building; one running through the shielded area of the Target Building, and one running through the equipment tunnel and thence along the east wall of the Target Building. Connections from the main loop or principal branches extend to air conditioning houses and fan rooms. Hose outlets are provided along the main loop and through the shielded area at each vacuum pump location. In the Target Building valved drops are installed at various columns.

Electrical System

The five air conditioning fan houses located around the Magnet Enclosure are used as electrical control and distribution points. They are known as fan houses A,B,C,D and E. Power feeds for these houses are covered under "Linac Building" and Target Building" with power supply coming from outdoor substations "D", "B" and "C".

For lighting purposes the Magnet Enclosure outside the Target Building is subdivided into 11 equal segments, each containing a lighting sub-station consisting of a 30 kva transformer and a 120/208 v lighting panel. The segment within the Target Building is divided into two halves, one fed from the building south lighting cabinet and the other fed from the north lighting cabinet. The supply to all these cabinets is covered under "Linac Building" - Substation "D" and "Target Building - Sub-stations "B" and "C".

Each Magnet Enclosure lighting panel contains two sections, the top section being either manually or remotely controlled and feeding all normal lighting, and the bottom section being manually controlled and feeding receptacles and vacuum system heaters. The lighting may be turned on or off at either the north or the south ends of the Target Building and at the Linac Building. All normal lighting is by rapid-start fluorescent tubes. There are 29 emergency incandescent light convenience outlet combinations spaced equally around the Magnet Enclosure, including the shielded portion in the Target Building and there are exit lights at the escape hatch positions. These emergency lights and exit lights are fed from a safety switch in the Service Building with the normal supply from substation "A", but will be automatically supplied from emergency engine-driven generator when the normal supply fails.

480 Volt 3 phase power is provided in the magnet enclosure for motors, controls, vacuum system motors and receptacles as well as for lighting transformers which also serve 120 volt receptacles, vacuum system heaters and fan house lights. Regulated 480 volt, 3 phase power is provided to RF system stations.

The interconnection of these systems is covered in more detail under the Linac Building and Target Building sections of this report.

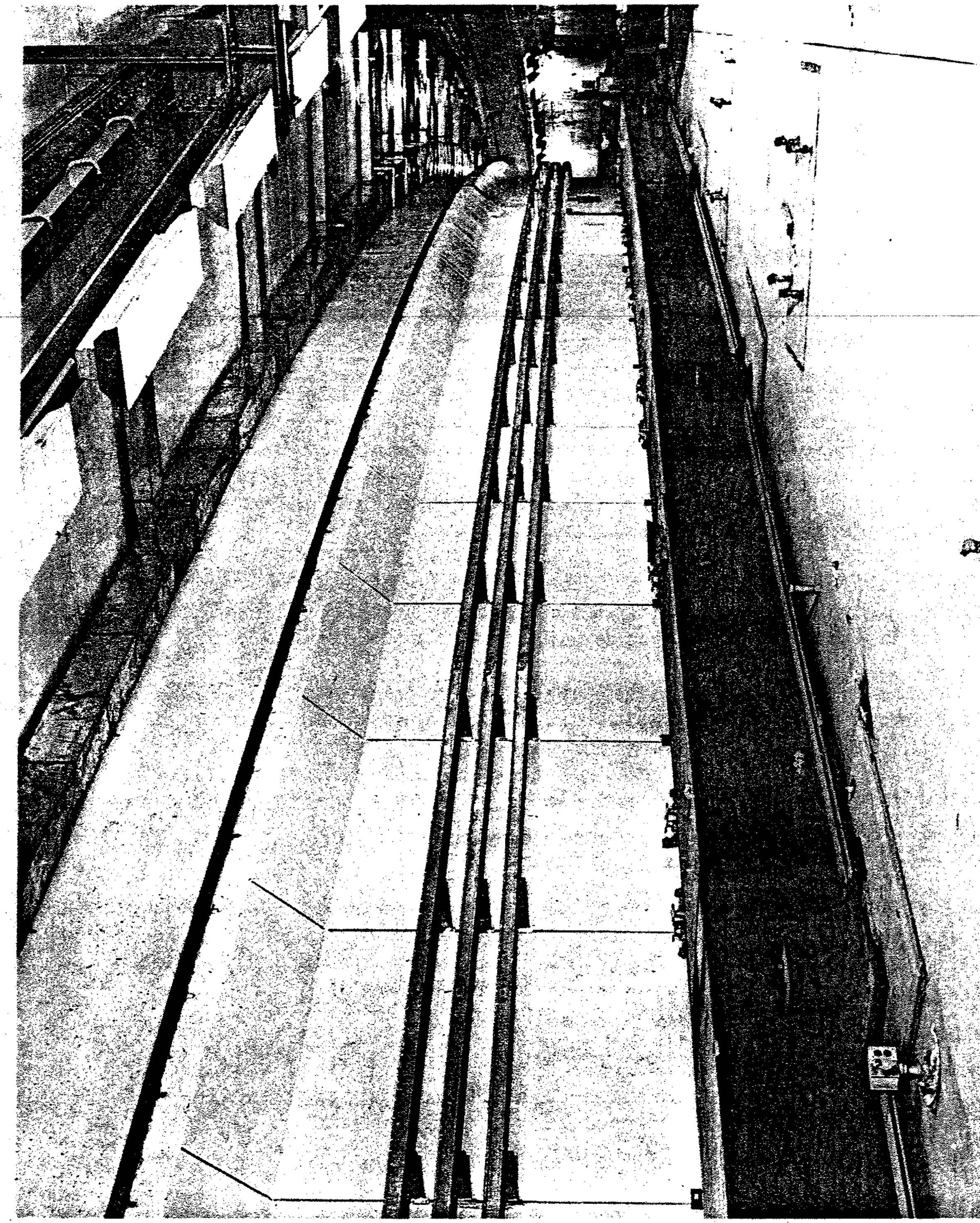


Figure 47
Main Magnet Ring Girders

3. Target Building

General Description

The Target Area, specifically designed to serve as an experimental testing area, consists of a Target Building and large open paved areas on each side of the building.

The Target Building is 100 ft. wide, 252 ft. long and 46 ft. high and intercepts a part of the magnet ring of the Synchrotron. To protect the personnel from the effects of radiation, a heavy concrete shield is placed around the magnets, forming a tunnel with a clear passageway 18 ft. wide by 10 ft. high. This protective cover is built up of removable blocks of "heavy" concrete which can be dismantled and set aside as required to suit the experiments that are to be conducted by the various agencies, either in the building or in the adjacent experimental areas.

To provide flexibility in setting up the experiments, all building service and electrical utilities and controls have been so laid out as to be easily accessible at all times. This was accomplished by means of an extensive grid of trenches in the floor and by means of exposed raceways on the building walls. Walkways, bracketed off the walls, provide easy access to the various utilities.

A 40 ton overhead traveling crane with special eddy current controls is provided to move the heavy concrete shielding blocks, magnets and other equipment that may be required for the tests.

The Target Building and adjacent section of the magnet enclosure are connected to the Service Building by an access tunnel through which equipment is transferred from the assembly area to the Target Building, and by a utilities tunnel through which are carried electrical and mechanical services and controls for the accelerator. Three large 12 ft. by 12 ft. rolling steel doors provide truck access directly into the building.

The building was initially fully air conditioned to assure controlled atmospheric conditions but this was abandoned when the East Experimental Building was appended. At the south end of the building are located two toilet rooms, one on each side of the shielded area.

The paved areas adjacent to and outside the Target Building, designated as Experimental Areas, are serviced by means of a system of utility trenches and electrical and water outlets strategically located so as to ensure flexibility in conducting experiments.

Structural

The Target Building is a 100 ft. by 252 ft. by 45 ft. high steel framed structure with exterior walls consisting of metal panels composed of fluted aluminum interior sheets with 1-1/2 in. Fiberglas insulation and a galvanized sheet metal backing. That portion of the wall which supports the protective earth shield is of reinforced concrete. The roof consists of a steel roof deck with 2 in. Fiberglas insulation, covered with a 4-ply tar and marble chip surface. Personnel doors are glazed hollow metal panel type and service doors are manually operated 12 ft. by 12 ft. rolling steel. All sash is of the aluminum projected type. Through the siding at El. 90 ft. are several openings to permit passage of cables to the experimental areas.

Inserts have been located on the faces and along the webs of columns and other critical surfaces so as to provide a flexible means of supporting wire trays, piping and other utilities all around the perimeter of the building. A continuous walkway, ranging in elevation from 87 ft. to 91 ft., has been provided for easy access to these services. Another walkway has been located at El. 106 ft.-3 in. to service the electrical and air conditioning equipment supported on platforms at that level.

A part of the Synchrotron ring passes through the Target Building requiring the use of heavy concrete shielding blocks to protect personnel. These blocks are supported by a 50 ft. wide by 4 ft. thick soil bearing mat designed to minimize the differential in deflections that might occur when the shielding blocks or magnets are dismantled and moved about. This mat is isolated from the 12 in. ground floor slab by a 1 in. Flexcell joint and from the magnet girder supports by means of 10 ft. long sheet piling which form a protective barrier 11 ft.-6 in. square around each cluster of piles.

In general, the utilities that travel along the building walls drop down along the columns to pits in the floor at the bases of the columns, thence through trenches in the 12 in. floor slab to the 4 ft. mat. At the junction of the slab and the mat, the utilities fan through a system of conduits that are embedded in the mat, coming up through the floor in the vicinity of the magnets.

At each pit near the bases of the columns an opening with a hinged cover has been installed through the grade beam making the utilities within the building accessible for tests being conducted in the open experimental areas on each side of the Target Building.

Sanitary Plumbing

The sanitary system in the Target Building is designed to serve fixtures in two toilet rooms, and includes water cooler and electric water heaters, and also two remote service sinks. Water is supplied from the domestic water mains passing through the Target Building. Sanitary waste from the west toilet joins in a common drain line with waste from the east toilet and flows by gravity to a sewage ejector which discharges to the Service Building. Remote service sinks drain to the floor drainage system.

Floor Drainage

The floor drainage system in the Target Building includes connections from floor and trench drains, equipment drains, cooling coil drains, and drains from remote service sinks. This system is divided into two sections of underfloor drain piping, discharging by gravity to yard storm sewers on the east and west sides of the building, respectively.

Roof Drainage

The roof drainage for the Target Building is handled by two groups of roof boxes and downspouts, one on the east and one on the west side of the building. All downspouts connect to short underfloor laterals which in turn connect to the yard storm sewers.

Domestic Water

Domestic water is serviced by a connection to the main loop in the magnet enclosure which passes through the Target Building along the west wall. Branches are provided to service the Synchrotron ring equipment-primarily vacuum pumps, - under the shielded area in this building. Branches also serve the toilet rooms and a branch is provided along the east wall of the building. Remote sinks, water coolers and hose outlets are serviced by these branches.

Heating System

Steam is furnished from the steam main which comes from the Service Building and passes through the Target Building to Air Conditioning houses which serve the Magnet Enclosure. A branch with a pressure reducing station to reduce the pressure from 50 psi to 15 psi supplies the air conditioning system and unit heaters.

The general heating in the Target Building is provided by two air conditioning systems with heating coils located in the truss space. Unit heaters provide spot heating at the large roll-up doors. Condensate is returned to a receiver in the Service Building.

Refrigeration System

A general description is included under the section which describes the Magnet Enclosure. The systems supplied in the Target Building follow.

Ventilation and Air Conditioning

Two similar supply systems located on a platform in the truss space provided air conditioning for the Target Building. Each supply system consists of field assembled equipment including fan, heating and cooling coils, automatic air filter and dampers with outside air intake, return and supply distribution duct work with diffusers. Each system handles approximately 31,750 cfm of supply air with provision for the introduction of up to 100 per cent outside air. The Target Building shielded area air conditioning system includes 15 unit air conditioners, consisting of fans and water-cooling coils under the shielding. The conditioners include no heating coils nor outside air connections and are supplied chilled water via under floor ducts.

Target Building exhaust systems are designed to exhaust air from the Target Building when excess fresh air is being supplied to the area, and each system includes four roof type exhaust fans installed on the roof of the building. The control of each of these systems is interlocked with their respective supply systems. Supply air for the toilet rooms is induced through door louvers and exhausted to the outside through a duct system and centrifugal fan connected to a wall hood. Utilities tunnel exhaust system is designed to exhaust 4,000 cfm from the utilities tunnel connecting the Service Building and the Magnet Enclosure. The roof type exhaust fan is located on a concrete curb on the roof of the tunnel. Air is induced from both the Magnet Enclosure and the machine room in the Service Building. Equipment tunnel exhaust system is designed to exhaust 2,200 cfm from the equipment tunnel connecting the Service and Target Buildings. The roof type exhaust fan is located on a concrete curb extending above the ground surface. Air is induced from the Target Building.

Fire Detection System

For a description of the overall zone arrangement, see Magnet Enclosure Section. The fire detection system for the Target Building is of the Gamewell "Vigilarm" type. The system uses temperature rate of rise continuous pneumatic detection elements.

The Target Building control cabinet, in addition to the three Magnet Enclosure zones, serves four protection zones in the Target Building and four manual alarm stations also in the Target Building. One of the protection zones in the Target Building which covers the shielded portion of the Magnet Enclosure passing through the Target Building is equipped with 22 thermostats for fire detection instead of the copper tubing tupe of detector. The Target Building control consists of the control cabinet, emergency power supply, 20-lamp annunciator, administration bell, trouble buzzer and a master fire alarm box. There are two general alarm bells in the Target Building. Wires are carried to the Service Building control room for duplicate lights on the 30-lamp master annunciator and an administration bell.

This system is tied into the general Laboratory alarm system which is monitored at the main Fire Headquarters.

Fire Protection System (Water)

The fire protection system in the Target Building includes hose reels, hose and valves along east and west walls of the building, complete with all distribution piping and necessary shutoff valves.

Hydrogen Protection

Approximately two years after the Target Building was occupied and when preparations were being made to accommodate the first experiments, a hydrogen protection system was installed. This protection system includes the following:

An Emergency Ventilation system which operates automatically whenever hydrogen gas is detected in the upper levels of the building or at any other location. A gas detection system actuates the system, or it may be actuated manually. When the system is actuated, pneumatically operated louvers in the perimeter of the building are opened, the pneumatic dampers in the ventilation system open and the eight Swartwout roof emergency ventilating fans are turned on. These fans were designed to exchange the air in the building within three minutes.

Local exhaust from shielded areas, or blockhouses is provided by means of portable fan equipment which can be connected to five permanent exhaust stacks located on the perimeter of the building. These stacks handle a normal flow of 2,000 cfm or an emergency flow of 12,000 cfm. The stacks have a 3 ft. diameter throat connection in the building and extend upwards to project above the roof and terminate in rotary roof ventilators. Flexible ducts connect the portable fans to the inlet flanges of the ducts.

Five emergency hydrogen pressure vent stations are installed around the perimeter of the building adjacent to the local air exhaust ventilating systems. These vents are used to exhaust gases from equipment containing hydrogen. A three inch vent exhausts normal "boil-off" from equipment and an eight inch line is provided to vent large quantities of gas in an emergency. The stacks are capable of exhausting 5,000 cu. ft. of hydrogen in 3 minutes and are designed to receive liquid hydrogen temperatures and 300 psi pressures. The three inch line can vent to the eight inch line via twin rupture discs in the event the smaller line cannot accommodate the volume of gas being released. These vents extend above the roof level of the building and are of copper alloy for low temperature service.

Compressed Air System

Compressed air is obtained from a loop which also services the Magnet Enclosure and is supplied compressed air from two compressors located in the Service Building.

Branches from the loop run through the shielded area of the Target Building and through the equipment tunnel and thence along the east wall of the Target Building. Connections from these branches extend to the Air Conditioning rooms in the truss space. Hose outlets are provided at vacuum pump locations and valved drops are installed at various columns.

Experimental Cooling Water System

This system provides cooling water for experimental magnets in the Target Building and is fed from supply pumps located in the Service Building machine room. Parallel supply and return mains run along the east, west, and north walls of the Target Building. At several columns, supply and return branches are installed. Some branches also extend beyond the building to flush hydrants in the outdoor experimental area.

Helium System

A high pressure helium distribution piping system is provided. It includes supply and return headers along the wall of the building with valved branches located at several columns. The supply header is capable of transporting 7 cfm of helium at 600 psi while the return line is suitable to handle helium at 20 psi.

Gas Detection System

The combustible gas alarm systems consist of gas analyzer units, diffusion type analyzer heads, air pumps, air flow meters, filters, purging valves, all interconnected to automatic relays designed to actuate various alarm and ventilating systems. Gas analyzer units are located in the air conditioning house and at the eight exhaust fans. Similar portable detection systems are provided for operation of the portable ventilating equipment serving the blockhouses and shielded areas.

Electrical

Two outdoor substations, lettered "B" and "C", located south and north of the Target Building, respectively, supply all Target Building service power and lighting and also part of the power and lighting for the Magnet Enclosure through three fan house distribution points.

Substation "B"

The south substation is supplied by an underground 13.8 kv, 3-conductor No. 2/0 paper insulated, lead covered cable of the 13.8 kv switchgear in the Service Building. The substation contains a 3-conductor pothead, a fused primary disconnecting switch, a 1,500 kva, 3 phase, 13.8 kv-480 v, delta-delta O.I.S.C. transformer and 480 v metal enclosed switchgear. Space and mounting brackets are provided for a future 3-conductor pothead to extend the circuit in the future. The primary disconnecting switch is capable of rupturing 125 per cent transformer full load current and is mechanically interlocked so that the primary compartment door cannot be opened when the switch is closed. The fuses have an interrupting capacity of at least 250,000 kva symmetrical.

The 480 v metal enclosed switchgear distributes power and lighting to part of the Target Building and part of the Magnet Enclosure through four 600 v, 1,600 amp, manually operated air curcuit breakers with an interrupting capacity of 60,000 amp at 480 v. They are equipped with instantaneous and long time magnetic overcurrent tripping devices. Provision is also made for shunt tripping and remote position indication. One spare cubicle is available for future installation of equipment Provision is made for locking circuit breakers in open position. The instrument compartment contains three potential transformers, three voltmeters, one ground alarm relay, three current transformers, one ammeter and an ammeter transfer switch.

Circuit B41 with circuit breaker set for 400 amp is connected to a 6-switch power panel at fan house "D". This panel supplies unregulated 480 v, 3 phase power for motors, controls, vacuum system motors and receptacles in fan house "D" and a portion of the Magnet Enclosure, as well as transformers for lighting panels which serve receptacles, vacuum system heaters, Magnet Enclosure lighting and fan house lighting. It also supplies regulated 480 v, 3 phase power to radio frequency stations "B", "C" and "CD" through a a 108 kva, 480 v, 3 phase induction voltage regulator.

Circuit B43 with circuit breaker set for 400 amp is connected to a 10-switch power panel at fan house "E". This panel supplies unregulated 480 v, 3 phase power for motors, controls, vacuum system motors, and receptacles in fan house "E" and a portion of the Magnet Enclosure, as well as transformers for lighting panels which serve receptacles, vacuum system heaters Magnet Enclosure lighting and fan house "E" lighting. It also supplies regulated 480 v, 3 phase power to radio frequency stations "E", "F" and "DE" through a 108 kva, 480 v, 3 phase induction voltage regulator.

Circuit B45 with circuit breaker set for 600 amp is connected to a 10-switch power panel in the Target Building south. This panel supplies building auxiliaries such as ventilation and roof fans, cranes and receptacles as well as transformer for lighting panel which serves receptacles, vacuum system heaters and Magnet Enclosure lighting. It also supplies 120/208 v, 3 phase, 4-wire regulated power through a 150 kva, 480-120/208 v dry type transformer and three 48 (through) kva single phase wye connected air-cooled induction voltage regulators, to a 12-switch regulated power panel which distributes to eight single phase, 3-wire, 120/208 v receptacles and two 3 phase, 4-wire, 120/208 v lighting panels, located throughout the Target Building. The panel also supplies one circuit to the A.G.S. warehouse.

Circuit B42 is a completely equipped spare circuit breaker set for 600 amp. There is space for a future circuit B44 circuit breaker.

Substation "C"

The north substation is supplied by an underground 13.8 kv, 3-conductor No. 2/0 paper insulated, lead covered cable from the 13.8 kv switchgear in the Service Building. The substation contains two 3-conductor potheads, one incoming and the other for extension to sub-station "D" at the Linac Building. It also contains a fused primary disconnecting switch, a 1,500 kva, 3 phase, 13.8 kv-480 v, delta-delta O.I.S.C. transformer and 480 v metal enclosed switchgear. Space and mounting brackets are provided for a future 3-conductor pothead to extend the circuit. The primary disconnecting switch is capable of rupturing 125 per cent transformer full load current and is mechanically interlocked so that the primary compartment door cannot be opened when the switch is closed. The fuses have an interrupting capacity of at least 250,000 kva symmetrical.

The 480 v metal enclosed switchgear distributes power and lighting to part of the Target Building and part of the Magnet Enclosure through three 600 v, 1,600 amp manually operated air circuit breakers with an interrupting capacity of 60,000 amp at 480 v. They are equipped with instantaneous and long time magnetic overcurrent tripping devices. Provision is also made for shunt tripping and remote position indication. Two spare cubicles are available for future installation of equipment. Provision is made for locking circuit breakers in open position. The instrument compartment contains three potential transformers, three voltmeters, one ground alarm relay, three current transformers, one ammeter and an ammeter transfer switch.

Circuit C41 with circuit breaker set for 400 amp is connected to a 6-switch power panel at fan house "A". This panel supplies unregulated 480 v, 3 phase power for motors, controls, vacuum system motors and receptacles in fan house "A" and a portion of the Magnet Enclosure, as well as transformers for lighting panels which serve receptacles, vacuum system heaters, Magnet Enclosure lighting and fan house lighting. The panel also supplies regulated 480 v, 3 phase power to radio frequency stations "H", "I" and "IJ" through a 108 kva, 480 v, 3 phase induction voltage regulator.

Circuit C45 with circuit breaker set for 600 amp is connected to a 10-switch power panel in the Target Building north. This panel supplies building auxiliaries such as ventilation and roof fans, cranes and receptacles, as well as transformer for lighting panel which serves receptacles, vacuum system heaters and Magnet Enclosure lighting. The panel also supplies 120/208 v, 3 phase, 4-wire regulated power through a 150 kva, 480-120/208 v dry type transformer and three 48 (through) kva single phase, wye connected air-cooled induction voltage regulators to a 16-switch regulated power panel CR451A which distributes to 11 single phase, 3-wire, 120/208 v receptacles and two 3 phase, 4-wire 120/208 v lighting panels located throughout the Target Building.

Circuit C42 is a completely equipped spare circuit breaker set for 600 amp. There is space for future circuits C43 and C44 circuit breakers.

Emergency Power

Four automatic transfer switches are installed at four contactor groups supplying roof exhaust fans for the Target Building. These exhaust fans are all started in an emergency, either by combustible gas detectors or by emergency push buttons around the building.

Emergency supply to these four automatic transfer switches is from a 350 kilowatt Diesel engine driven generator in the Mechanical Equipment Building. Three 500,000 cir mil cables are installed from the generator circuit breaker through the tray system in the East Experimental Building into the tray system in the Target Building to the emergency supply terminals of these automatic transfer switches through locally mounted fused disconnecting switches. These disconnecting switches are rated 200 amp with 125 amp current limiting fuses for the 150 amp transfer switches and 100 amp with 100 amp current limiting fuses for the 100 amp transfer switches. Control conductors are also installed from the transfer switches to the generator starting panel for starting the generator, should any of the four transfer switches lose its normal power.

Lighting

Fluorescent fixtures are provided for normal lighting except incandescent lights outdoors. Emergency lights, together with emergency receptacles, are fed from safety switch X-2 located in the Service Building which is normally energized from circuit 11 in substation "A" but is automatically fed from emergency engine-driven generator when the normal supply fails.

4. East Experimental Building

General Description

The East Experimental Building is actually an extension to the Target Building and is intended mainly to house an anticipated increase in number and size of experimental setups. Technological developments have resulted in experiments which require beam layouts up to several hundred feet in length, containing large numbers of analyzing, bending and focusing magnets, electrostatic beam separators, vast arrays of counters and large bubble chambers. These developments, plus the requirement of rapid movement of the experimental setups, made it economically essential that the entire area be sheltered and that it be accessible to heavy material handling equipment.

The East Experimental Building is an L-shaped structure occupying an area of approximately 60,000 sq. ft. In design and appearance, it is essentially the same as the existing Target Building except that sloping roofs have been provided to eliminate possible gas pockets inherent with flat roofs.

In this building, protection against the hazards of a major release of hydrogen gas or liquid has been provided by means of a gas alarm system, which sets in motion 30 large exhaust roof fans designed to make one complete air change every 3 min. Make-up air is furnished by means of a nearly continuous line of louvers around the building at floor level. These louvers are interlocked with the exhaust fans and will open automatically when the gas alarm is triggered.

Local air exhaust systems have been installed to provide normal and emergency ventilation for shielded equipment, block houses or bubble chamber canopies. These systems consist of a number of packaged ventilation units designed to exhaust air through flexible hoses leading to fixed stacks, which are located on the exterior walls and extend above the roof level.

In addition, bubble chambers and other equipment containing liquid hydrogen have been provided with a positive high pressure venting system leading to the outside of the building in case of failure to the primary container.

On the east wall of the building is located a two-story structure with a control room on the second floor and an operators' room and toilet on the first floor.

Two 40-ton overhead traveling cranes have been provided to handle the heavy concrete shielding blocks, magnets and other equipment required for the tests.

Structural

The East Experimental Building is an L-shaped, two-bay structure with a 46 ft.-6 in. eave height and bays measuring 100 ft. by 457 ft.and 64 ft. by 205 ft. It is a steel framed structure with exterior walls consisting of standard insulated fluted aluminum panels except where there are existing concrete retaining walls. The roof consists of a steel deck with 1-1/2 in. rigid type insulation mechanically fastened to the decking and applied over a standard Lexsuco vapor barrier. The roofing consists of a 4-ply, built-up roofing with a light colored marble chip surface. Personnel doors are glazed industrial steel panel type and there are six manually operated rolling steel doors, four of which are 12 ft. by 15 ft. high and the other two are 14 ft. by 15 ft. high. All sash is of the aluminum fixed type except at the control room where vented sash is used. The windows and doors are glazed with shatterproof and fire resistant plastic panes.

Inserts have been located on the faces and along the webs of columns and other critical surfaces so as to provide a flexible means of supporting wire trays, piping and other utilities all around the perimeter of the building. In general, these utilities drop down along the columns to headers a few feet from the floor or extend into the network of floor trenches in which headers are located at strategic points, reducing to a minimum the amount of cable or hoses lying exposed on the floor.

For further flexibility in setting up of experiments, each of the interior columns along the "A" line of the Experimental Building may be removed, provided the unsupported space at any time does not exceed 50 ft.

The ground floor slab, where it rests on the existing pavement, varies in thickness from 6 in. to 12 in. Elsewhere it rests on well compacted soil and has a minimum thickness of 12 in. The substructure is of reinforced concrete with spread footings designed for a maximum allowable soil pressure of 8,000 psf. The roof is designed for live load of 25 psf. An expansion joint was located approximately in the center of the building.

The structural steel is designed for not less than the minimum requirements of the AISC and reinforced concrete for not less than the minimum requirements of the ACI with an ultimate compressive stress at 28 days of not less than 3,000 psi.

Access to the adjacent Target Building is by means of two 12 ft. by 12 ft. rolling steel doors. Four 12 ft. by 15 ft. high and two 14 ft. by 15 ft. high rolling steel doors provide truck access directly into the building.

Sanitary Plumbing

Toilet fixtures are provided in a toilet room under the control room, also a water cooler and service sink just outside the room, and a kitchenette in the operators' room adjacent. Water is supplied from the domestic water distribution main and wastes flow to a sewage ejector which discharges to the yard system. Hot water is provided by an electrical water heater.

Floor Drainage

Floor drains are provided throughout the entire East Experimental Building serving both the floor itself, the service trenches which run across the building and the elevated platform at the south end. Drains, in general, flow to catch basins originally installed to drain the paved area on which the building is located and have been fitted with gastight covers. Catch basins drain to the yard storm sewer through existing branches.

Roof Drainage

Roof boxes are installed in all roof valleys of the East Experimental Building to receive storm drainage. Roof boxes serving the valley where the building joins the Target Building are physically located in the Target Building roof. Drainage from the southerly portion of the building runs to the yard catch basins, and from the northerly end of the building to the same sewers. All drainage flows to the basin north of Fifth Avenue.

Domestic Water Service Piping

The domestic water service piping system includes a distribution loop extending around the entire outside perimeter of the East Experimental Building. The loop is supplied from the domestic water service entrance and ties to the Target Building system at each end of that building. Water is supplied from the loop to the sanitary system, to safety showers at six small entrance doors, and to valved outlets on piping drops located frequently along the outside walls of both buildings.

Fire Protection

No water supplied fire protection has been provided.

Heating System

The heating system for the East Experimental and Mechanical Equipment Buildings is designed with additional capacity to provide for heating the Bubble Chamber Building. Steam enters from the underground conduit system at pit "E" and is reduced immediately from its distribution system pressure of 75-125 psi to 50 psi. The steam supply main extends through the truss space from the southeast corner to the northwest corner of the building, from which it continues through the passageway to the northeast corner of the Mechanical Equipment Building where it connects an underground conduit line running to the Bubble Chamber Building. The main supplies horizontal type unit heaters located along the outside walls of the building, projection type heaters at the truck doors, and pipe coils in the passageway. Steam is also supplied to coils in four ventilation supply units in the East Experimental Building.

Condensate from the unit heaters and heating coils in the East Experimental Building returns to a duplex pump and receiver set in pit "E", which discharges to the yard system.

Ventilation Systems

Normal gravity ventilation of the East Experimental Building for heat removal in the summer is accomplished by means of pneumatically operated louvers installed near the ground level in all available outside wall spaces for supply, and 15 Swartwout Airjectors equipped with pneumatic dampers and located on the roof ridges for exhaust. To offset infiltration and provide make-up for air exhausted by portable equipment, the gravity ventilation is supplemented by three unit ventilators supplying a total of 15,000 cfm of filtered and tempered fresh air to the area. One of these is located on the platform at the south end and two along the east wall. In addition, a unit ventilator in the control room supplies filtered and heated air for the control room and the areas beneath. A small vent set exhausts from the toilet room and the remainder of the air supplied flows through relief grilles to the main area.

An emergency exhaust system is provided for automatic operation whenever hydrogen gas is detected in the upper levels of the East Experimental Building in dangerous concentrations. A gas detection system, described elsewhere, is provided to actuate the system, or it may be actuated manually. System operation includes opening wide the pneumatically operated louvers in the side walls, if not already open; opening the pneumatic dampers in the throats of the Airjectors, if not already open; starting the fans in the Airjectors to change from normal to emergency capacity, and starting 15 Swartwout Whirlout fans to provide additional exhaust capacity. The Whirlout fans are located on the roof ridges alternately with the Airjectors and are equipped with self-operating dampers which open with fan operation and close when the fan stops.

To provide for local exhaust from shielded areas, or blockhouses by means of portable fan equipment, 10 local vent stacks are provided extending up the building wall with goosenecks above the roof level. Flexible ducts can connect between the portable fans and inlet flanges on the stacks.

Fire Detection Systems

A fire detection system connected to the existing Gamewell system serving the entire AGS Complex is provided for the East Experimental Building. It is divided into four major detecting zones for the open area, and one small zone for the control room and the areas beneath. Four manual stations are provided; one in the control room and three at exit doors. All zones and the manual stations report to a control panel in the Target Building, to the adjacent master box and thence to the firehouse. The annunciator is located on the east wall of the building and all stations operate individually or in groups to trip lights on the annunciator and the similar unit located in the Service Building.

Combustible Gas Detection Systems

The gas detection system for the East Experimental Building includes five gas analyzer cabinets and 20 intake tubes with filters. The cabinets are located in the control room and each is equipped with vacuum pump, four analyzer heads, flowmeters, purge valves and associated control relays for gas alarm transmission from four intakes. Relays energize coils in exhaust fan motor starters and solenoid valves in the pneumatic system controlling the damper motors. Gas intakes are located in the bases of all Airjectors and five of the Whirlout exhaust fans. Similar portable gas detection systems are provided for operation of the portable ventilation equipment serving the blockhouses and shielded areas.

Emergency Hydrogen Pressure Vents

Ten emergency hydrogen vent stations are installed, one adjacent to each local vent stack. Each station includes two parallel vent pipes, one 8 in. and one 3 in., extending up the outside of the building and terminating above the roof. Three pressure relief valves discharge to the 3 in. vent, while a twin rupture disc assembly is provided in the 8 in. vent, so that if the hydrogen flow cannot be dissipated by the 3 in. relief assembly, the rupture disc will burst. Hydrogen gas leaking from equipment is released outdoors. Portable piping connects between the protected equipment and the vent stations.

Experimental Magnet Cooling Water System

This system provides cooling water for the experimental magnets in the East Experimental Building. Water is taken from the mix-waste tank located behind the Service Building and pumped through the distribution system by two 550 gpm centrifugal pumps. The pumps are located on the platform at the south end of the building with a suction connection underground from a flange in the bottom of the mix-waste tank. The distribution system includes parallel supply and return mains running north along the "A" and "F" lines and interconnected at the "1" and "24" lines to form two complete loops, with valved supply and return drops down columns at frequent intervals. The piping is cross-connected to the similar system in the Target Building. The return piping loop is connected underground to the drain line from the mix-waste tank, with provision to prevent emptying the tank when the pumps are stopped. A by-pass with control valve between the return line and the suction from the tank regulates the temperature at the pump discharge, and another by-pass with control valve between the supply and return connections to the distribution loop regulates the pump discharge pressure.

Compressed Air System

Two motor driven air compressors with aftercoolers, dryers and receiver are installed in the Mechanical Equipment Building to supply air through the passageway to the East Experimental Building. A distribution loop is installed around the outside perimeter of the East Experimental Building with valved drops at columns at frequent intervals and cross-connections to the air piping in the Target Building. Connections to the pneumatic control systems are installed.

High Pressure Helium System

Two 125 scfm helium compressors, with aftercoolers, filters, storage tanks and gas bottle racks, are installed in the Mechanical Equipment Building, and circulate helium through the passageway to the East Experimental Building and is cross-connected to the high pressure helium headers in the Target Building. The supply and return headers parallel the compressed air piping with valved supply and return drops at similar locations. Gas storage is provided outdoors on the west side of the Mechanical Equipment Building.

Electrical

There are three electrical power systems:

480 v, 3 phase, 60 cycle normal power
480 v, 3 phase, 60 cycle emergency power
120/208 v, 60 cycle power and lighting

A peripheral cable tray system is provided in the East Experimental Building, consisting principally of 12 in. galvanized steel Globetray of the ladder type with 9 in. spacing and 9 in. radius fittings to carry cable for all building services with provision for experimental power cables. The tray system is also carried into the Mechanical Equipment Building for power feeds and control connections and connected to trays in the Target Building for power feeds and controls.

Supply for 480 v, 3 phase normal power service comes from substation "E". Two 500,000 cir mil cables per phase are connected by cable tray to a power distribution panel in the East Experimental Building. Branch circuits supply the following:

Lighting cabinets (480 v for mercury arc lamps)
45 kva, 480-120/208 v transformer for lighting
Condensate return pumps
Crane trolleys
Unit ventilators
300 kva, 480-120/208 v transformer for special experimental receptacle cabinets

The power distribution panel is a dead front 480 v, 600 amp, 3 phase, 3-wire panel, equipped with Westinghouse Electric Corporation "FDP" switches for branch circuits with current limiting fuses.

Two lighting cabinets serve the high bay mercury units in the East Experimental Building. They are 480 v, 225 amp, 3-wire, 3 phase, each provided with 16-20 amp, 2-pole Westinghouse "EH" circuit breakers.

A third lighting cabinet serves all other normal lighting, outdoor floodlighting, as well as the unit heater and projection heater fans in the East Experimental Building. It is a 225 amp, 3 phase, 4-wire, 120/208 v cabinet, supplied by a 45 kva transformer. It is provided with 16-20 amp, single pole; eight 30 amp, single pole; seven 20 amp, 3-pole and one 50 amp, 3-pole Westinghouse Type "QC" Quicklag circuit breakers.

Six of the 20 amp, 3-pole circuit breakers are supplied from the mains through an "ASCO" Bulletin 920, 3-pole, 100 amp contactor with 120 v operating coil. This contactor is controlled by a Sangamo Astronomic time switch, synchronous motor driven, with mechanical carry-over and a "hand-off-auto" selector switch, both installed adjacent to cabinet L-3. These circuits supply the outside floodlights. The other 20 amp, 3-pole circuit breaker serves the water heater.

The 50 amp, 3-pole circuit serves an electric range outlet in the operator's room.

Motor controls for condensate return pumps are fused safety switch combination starters with 120 v control transformer and "hand-off-auto" switch in the cover. Their automatic control is by two level float switches and Square D Company 9039 class automatic alternators.

Main Craneway conductors for both cranes are INSUL-8-CORP. No. 10-83-FS. They are supplied from the power distribution cabinet through individual 100 amp fused safety switches locally installed.

Motor controls for unit ventilator fans are fused safety switch combination starters with 120 v control transformer and "hand-off-auto" switch in the cover. Their automatic control is by thermostat.

Twenty special experimental receptacle cabinets are strategically located in the East Experimental Building to provide 3 phase, 120/208 v and single phase, 120 v power wherever needed. Each is provided with a Westinghouse 225 amp "K" main circuit breaker, a 5-wire, 3 phase, 30 amp Hubbelock receptacle with a 30 amp Hubbelock receptacle with a 30 amp Type "E" circuit breaker and five 50 amp, 3-wire, single phase Twist-lock receptacles, each with its 2-pole, 50 amp, Type "E" circuit breaker.

All five of the single phase receptacles in any one cabinet are connected to the same phase. There are seven cabinets connected to phase "A", seven connected to phase "B" and six connected to phase "C". These are installed alternately around the building.

These cabinets are supplied from the secondary of the 300 kva, 480-120/208 v transformer through three 1,000 amp Amptrap Type 5 A6Y1000 fuses. From the fuse cabinet, a set of four 1,000,000 cir mil cables is carried around the tray system in both directions. Four No. 4/0 cables are connected to these mains above each receptacle cabinet and are carried down to supply the cabinet in rigid conduit.

Two 100 hp cooling water pumps are installed at El. 91 ft.-0 in. at the south wall of the East Experimental Building. Power supply for these motors is from motor control center No. 2 in the machine room of the Service Building which receives its supply from circuit "A48" in substation "A-1500". For this purpose, two floor mounted fused switch combination starters are installed at the south end of motor control center No. 2 and supplied directly from the bus in motor control center No. 2 with 350,000 cir mil cable in conduit. These starters are of the automatic reduced voltage autotransformer closed transition type.

Motor leads are No. 2/0 run from the starters in rigid conduit overhead through the power room and out along the retaining wall into the southeast corner of the East Experimental Building to the pump motors. "Run-safe stop" selector switches are installed at the motors. In addition, control conduits, each containing seven No. 12 conductors, are run exposed overhead from the starters to the pump control room to connect to the Owner's control switches and indicating lights.

<u>Emergency Supply to Target Building</u>

Supply for 480 v, 3 phase emergency power service comes from circuit "3F44" in substation "3F2500" which is bifurcated into two 600 amp circuits using 600 amp, 3-pole current limiting fuses with one for the Mechanical

Equipment Building motor control center and one for the normal/emergency power to the East Experimental Building. Two 1,000,000 cir mil cables per phase are connected to the 600 amp Amptrap fuses and , thence, two 500,000 cir mil cables per phase to the normal/emergency transfer switch adjacent to the fuse cabinets.

The emergency supply comes from a 350 kw Diesel engine driven generator, installed in the Mechanical Equipment Building. This generator unit is fully equipped for automatic starting. Two 500,000 cir mil cables per phase are carried from the emergency generator through the cable tray system to the emergency supply terminals of the automatic transfer switch. Control conductors from the transfer switch are also carried through the tray system to the starting panel of the emergency generator to start it when the normal power source fails, and to stop it after the normal source is restored.

From the load terminals of the automatic transfer switch, two 500,000 cir mil cables per phase are carried in conduit to power distribution panel "RBT" at column F-16, which serves two sets of 30 amp, 480 v, 3 phase experimental power receptacles and lighting cabinet E-1.

Two 500,000 cir mil cables per phase are also connected to the load terminals of the automatic transfer switch and carried to the roof fan motor control center via cable tray.

Power distribution panel "RBT" is a dead front 480 v, 600 amp, 3 phase, 3-wire panel, equipped with Westinghouse "FDP" switches for branch circuits with current limiting fuses.

There are ten experimental power receptacles separately located in the East Experimental Building, five per branch circuit from power panel "RBT". Each consists of a Crouse-Hinds ARE3423, 480 v, 30 amp, 3-wire, 4-pole receptacle with spring door and a 600 v, 100 amp frame, 3-pole circuit breaker set for 30 amp trip. Three No. 1/0 cables per branch are carried from the power panel in the peripheral cable tray system with No. 10 taps brought down to the circuit breakers in conduit.

Lighting cabinet E-1 serves all emergency lights which consist of 100 w angle wall units around the inside of both the East Experimental Building and the Mechanical Equipment Building, above the fire alarm stations with red globes, and above the emergency showers at the exits with blue globes.

The cabinet is supplied from a 15 kva, 480-120/208 v dry type transformer with the 480 v feed coming from power panel "RBT".

The cabinet is rated 100 amp, 3 phase, 4-wire, 120/208 v and is provided with 16 single pole Westinghouse Type "QC" Quicklag, 20 amp circuit breakers.

The emergency motor control center is equipped with fused disconnecting switch combination starters to control the motors of 30 roof fans. Each is equipped with a control transformer, "run-stop" maintaining contact push buttom and a red and green indicating light. Each fan motor is provided with a "run-safe stop" selector switch at the motor, and this switch is monitored by the green indicating light in the control center.

The relay compartment of the control center is provided with General Electric Company "HEA" relays, timers and a control transformer so connected that, if combustible gas detectors in the control room operate or if any one of 16 emergency switches around the building is operated, a crash program will be initiated which will start all 30 roof fans, 10 at a time, and open all peripheral louvers around the building, as well as the dampers of 15 of the fans which are normally positioned for ventilation by a pneumatic system described elsewhere in this manual. The dampers on the other 15 fans open themselves when the fans operate.

The push buttons for operating the crash program are of the maintaining contact type. They are in watertight enclosures when located near the safety showers, and all others are in general purpose enclosures.

Motor controls for sewage ejection pumps are fused safety switch combination starters with 120 v control transformer and "hand-off-auto" switch in the cover. Their automatic control is by two level float switches and Square D 9039 class automatic alternators. A high level switch, Automatic Control Company Bulletin 7500, is connected to an alarm bell.

All 120 v, single phase lighting and power, with the exception of the special receptacle cabinets, are supplied from circuits in lighting cabinets.

There are 25 unit heaters in the East Experimental Building, six of the vertical discharge type over rolling doors with 1/2 hp fan motors, 13 of the horizontal discharge type with 1/4 hp fan motors, and six of the horizontal discharge type with 1/20 hp fan motors.

Each unit heater is supplied with a line type thermostat and a size 0 manual starter with thermal overcurrent protection.

These unit heater fans are all supplied from circuits in lighting cabinet L-3, separate 30 amp circuits for 1/2 hp motors and two per 20 amp circuit for 1/4 hp motors.

The toilet exhaust fan is rated 1/6 hp and is provided with a size 0 manual starter with thermal overcurrent protection and is supplied from a circuit in lighting cabinet L-3.

5. Outdoor Experimental Areas

The outdoor experimental area consists of a paved yard 81 feet by 252 feet on the West side of the Target Building inside the ring. A service road leads into the area.

Paving consists of a 4 inch broken stone base on a compacted sub-base with a 2 inch bituminous concrete wearing surface.

Drainage is provided and connects to the storm drains which feed into the settling basin North of Fifth Avenue.

Two sets of underground electrical ducts extend from the Target Building to manholes in the area. These are provided for extension of temporary power feeds to experimental equipment as required.

As part of the experimental cooling water system, there are also supply and return water lines connected to two flush hydrants set below grade in manholes in the area.

6. Linac Building

General Description

The Linac Building houses the 50 mev linear accelerator designed to inject particles into the main Synchrotron. The structure consists of two parts: a reinforced concrete tunnel section 130 ft. in length by 32 ft. inside width, which houses the Linac radio frequency power equipment, power amplifiers, vacuum pumps, and focusing equipment; and a 71 ft. long by 62 ft. wide headhouse which contains a special metal lined enclosure for the 800 kev Cockcroft-Walton ion source equipment, the control room, electronics test room, laboratory and experimental area, clean room, mechanical equipment rooms, and toilet facilities.

Special features include a 10 ton overhead traveling crane that extends throughout the length of the tunnel and headhouse; the 36 ft. by 20 ft. by 27 ft. high aluminum lined, projection free enclosure to shield the Cockcroft-Walton equipment mentioned above and an extensive covered trench system to distribute services. The headhouse and tunnel are fully air conditioned to assure controlled atmospheric conditions.

Structural

The Linac Building consists of a 71 ft. by 62 ft. by 20 ft. high headhouse and a 32 ft. by 18 ft.-10 in. high tunnel. The headhouse is a steel framed structure with exterior walls consisting of metal panels composed of fluted aluminum exterior sheets with 1-1/2 in. Fiberglas insulation and a galvanized sheet metal backing. The personnel door is glazed hollow metal panel type. Sash is aluminum projected type. That portion of the wall which supports the protective earth cover is of reinforced concrete. The roof consists of a steel roof deck with 1 in. Fiberglas insulation, covered with a 4-ply tar and marble chip surface. In general, the ground floor and supported floor slabs are of reinforced concrete, with a monolithic finish. In the control room a raceway for utilities is provided under the floor by the use of a supported removable steel decking, covered with a resilient tile finish. The toilet room has a ceramic tile floor and cove base.

In this building is located a concrete pit 20 ft. by 36 ft. by 13 ft. deep, which, together with a 20 ft. by 36 ft. by 13 ft. high metal enclosure, houses the Cockcroft Walton ion source equipment. The interior of the enclosure is smoothly lined with aluminum wall panels, avoiding all sharp projections to prevent arcing induced by the extremely high voltage inherent with the machine. Entrance to the pit is by means of a stairway from the control room. A large 7 ft. by 9 ft. window between the control room and the enclosure permits observation of the machine. Removable panels in the roof of the enclosure are provided so as to allow the crane hook to enter and remove the machine or any elements requiring service. The substructure of the building is of reinforced concrete, with spread footings resting on specially compacted fill. A 12 ft. by 12 ft. rolling steel door on the north side of the building provides access to the road leading to Fifth Avenue.

The Linac Tunnel extends southerly 130 ft. ± from the headhouse to a point where it intersects the Magnet Enclosure. The structure has a 20 in. thick roof slab and walls which taper from 20 in. at the top to 12 in. at the bottom. The walls are supported by continuous soil bearing footings 4 ft.-6 in. by 15 in. deep on one side and 5 ft. by 15 in. deep on the other. Continuous concrete brackets on each wall, 14 ft. above the floor slab, support the 10 ton overhead traveling crane. Continuous inserts have been spaced at regular intervals in the inside face of the roof slab and walls to provide a flexible means of supporting air conditioning ducts, crane trolley, wireways, piping and other miscellaneous utilities.

The floor consists of a 6 in. reinforced concrete slab resting on compacted fill. Approximately half of the floor area has been dropped 2 ft. to act as an areaway for distributing services. This area is covered with removable steel floor decking. Additional trenches are cut through the remaining slab to permit extension of utilities from one wall to the other.

The Linac tube and inflection equipment is supported at approximate 10 ft. intervals by a concrete capped cluster of two 50 ft. long 10 in. BP42 lb. steel piles. The pile caps consist of a concrete mix specially designed to keep to a minimum any possible distortion of the cap after the Linac is in operation. Each cap is completely dampproofed and isolated from the floor slab by 2 in. of Fiberglas.

Sanitary Plumbing

The sanitary system in the Linac Building is designed to serve four fixtures in a toilet room, and includes service sink, electric water heater and water cooler, and a sink in the clean room. Water is supplied from the domestic water main in the Linac Tunnel. Sanitary waste flows by gravity to a septic tank and cesspools in the yard.

Floor Drainage

The underfloor drainage system serving the Linac Tunnel and Building includes floor drains, trench drains, equipment drains and cooling coil drains from the second floor. The system drains to a sump in the toilet room where duplex sump pumps are installed to discharge to the yard storm drain line. A small sump collects drainage from the generator pit, with a single pump discharging to the main system.

Roof Drainage

The roof drainage system for the Linac Building includes roof boxes and downspouts serving roof area and connecting to underfloor piping through which drainage flows by gravity to the yard storm drain lines.

Domestic Water

Domestic water is supplied by a connection to the main loop in the magnet enclosure which is in turn fed from a header in the Service Building. The branch crosses the Magnet Enclosure in a trench to the Linac Tunnel and runs the length of the tunnel to serve the Linac Building. It is connected to the toilet rooms and hose outlets as well as a heat exchanger in the Linac Building.

Heating System

Steam is furnished from the steam main servicing the Magnet Enclosure Air Conditioning houses at 50 psi and reduced to 15 psi at a pressure reducing station in the building. The general heating in the building is provided by four air conditioning systems, with heating coils, located in two fan rooms on the second floor of the building. Unit heaters provide spot heating at the large door.

Condensate from the unit heaters and air conditioning system is returned by condensate pumps to the receiver located in the Service Building.

Refrigeration System

A general description is included under the section which describes the Magnet Enclosure.

Ventilation/Air Conditioning

The Linac Building control room air conditioning supply and return system provides air conditioning for the control room on El. 70 ft. and is designed to supply approximately 3,270 cfm of a filtered and conditioned mixture of outside and recirculated air with provision for 100 per cent outside air. The Linac Building generator room air conditioning supply and return system provides air conditioning for the generator room and is designed to supply approximately 2,730 cfm of a filtered and conditioned mixture of outside and recirculated air with provision for 100 per cent outside air. The Linac Tunnel air conditioning supply and return system provides air conditioning for the Linac Tunnel and is designed to supply approximately 11,700 cfm of a filtered and conditioned mixture of outside and recirculated air with provision for 100 per cent outside air. The Linac Building miscellaneous areas air conditioning supply system provides air conditioning for the live storage and laboratory, and the operations room at El. 80 ft. and the test bay and shop, the clean room, toilet and electronics laboratory at El. 70 ft. The system is designed to supply approximately 7,700 cfm of outside and recirculated air with provision for 100 per cent outside air. No return air fan is provided for this system. The field assembled equipment is located in the fan rooms at El. 80 ft. and consists of the supply fan, heating and cooling coils, automatic air filter, dampers and supply and return duct work. Supply air for the toilet room at El. 70 ft. is partly induced through a door louver and exhausted through an exhaust fan with connecting duct work to and including a wall hood. Supply air for the clean room is partly induced through a door louver and exhausted to the outside through a hood above the sink with a wall mounted propeller type fan and self-closing louver type damper.

Fire Detection System

For a description of the overall zone arrangement, see Magnet Enclosure Section. The fire detection system for the Linac Building is of the Gamewell "Vigilarm" type. The system uses the temperature rate-of-rise, continuous pneumatic detection element.

The Linac Building control cabinet, in addition to the two Magnet Enclosure zones, serves two protection zones in the Linac Building and Tunnel, one manual alarm station and two CO_2 switch devices on the same circuit. The control group consists of the control cabinet, emergency power supply, 10-lamp annunciator, administration bell, trouble buzzer and a master fire alarm box. There is also a general alarm bell in the Linac Building. Wires are carried to the Service Building control room for duplicate lights on the 30-lamp master annunciator and bell.

The system is tied into the general Laboratory alarm system which is monitored at the main Fire Headquarters.

CO_2 Fire Protection System

A Kidde carbon dioxide fire extinguishing system is provided, including two separate batteries of CO_2 cylinders, one of which provides complete automatic protection for the Cockcroft Walton enclosure in the Linac Building, and the other for miscellaneous oil baths in the Linac Tunnel and Linac Building, and the Inflector Alcove in the Magnet Enclosure.

The CO_2 cylinder batteries are located at El. 80 ft. in the northwest corner of the Live Storage and Laboratory. The larger battery consists of 14-75 lb. carbon dioxide cylinders assembled in two banks in an angle iron framework with wire mesh enclosure, gate and padlock. The battery is arranged to permit cylinders being weighed without removal from the framework and without putting the system out of service. The smaller battery is similar and consists of two 75 lb. cylinders.

The discharge manifolds at the cylinders are arranged to permit actuation by thermostats in the Cockcroft Walton Enclosure to open the 14 cylinders, and actuation by the thermostat in the inflector alcove or by any future thermostat in the oil bath areas to open the two cylinders.

Both the Cockcroft Walton Enclosure and the Inflector Alcove are provided with fixed temperature thermostat detection and actuating devices, those in the Cockcroft Walton Enclosure being recessed in the ceiling of the room.

Two cylinders in the larger battery, and one cylinder in the smaller battery are equipped with electric control heads which are actuated by the appropriate thermostats. Actuation of the initial CO_2 cylinder discharge head by a thermostat detector will develop the necessary pressure in the discharge manifold to trip the discharge heads of all cylinders in the bank.

In addition, operation of the thermostat in the Inflector Alcove will open a divisional valve in the CO_2 main outside the alcove. Similar valves to be installed in the future will control flow to miscellaneous hazards.

Pressure operated trips are provided to release self-closing door mechanisms in the Inflector Alcove, and to close all exhaust and supply dampers. Pressure operated switches are provided to open the circuits of the exhaust fan motor in the Inflector Alcove and the supply and return fan and oil pump motors in the Cockcroft Walton Enclosure. Upon actuation of the system all control functions are simultaneous with no appreciable time lag.

Two independent circuit closing contacts are provided to be operated by sensing elements when either system is discharged, with wiring between these contacts and alarm and annunciator equipment.

Electrical System

Electric power and light is supplied to the Linac Building and part of the Magnet Enclosure by an underground 13.8 kv paper insulated lead covered cable from the 13.8 kv switchgear in the Service Building. This 3-conductor No. 2/0 cable is tapped at outdoor unit substation "C" with potheads located outside the Target Building enroute to outdoor unit substation "D" outside the Linac Building.

Substation "D" contains a 3-conductor pothead, a fused primary disconnecting switch, a 1,000 kva, 3 phase, 13.8 kv-480 v delta-delta O.I.S.C. transformer and 480 v metal enclosed switchgear. Space and mounting brackets are provided for a future 3-conductor pothead to extend circuit No. 911-14-2 in the future. The primary disconnecting switch is capable of rupturing

125 per cent full load current and is mechanically interlocked so that the primary compartment door cannot be opened when the switch is closed. The fuses have an interrupting capacity of at least 250,000 kva symmetrical.

The 480 v metal enclosed switchgear distributes 480 v power to the Linac Building and part of the Magnet Enclosure through four 600 v, 600 amp, manually operated air circuit breakers, with an interrupting capacity of 35,000 amp at 480 v. They are equipped with instantaneous and long time magnetic overcurrent tripping devices. Provision is also made for shunt tripping and remote position indication. One spare cubicle with circuit breaker completely wired is provided and two spare cubicles are available for future installation of equipment. Provision is made for locking circuit breakers in open position. The instrument compartment contains three potential transformers, three voltmeters, one ground alarm relay, three current transformers, one ammeter and an ammeter transfer switch.

Circuit D41 with circuit breaker set for 600 amp supplies a 12-switch power panel in fan house "B". This panel supplies unregulated 480 v, 3 phase power for motors, controls, vacuum system motors and receptacles in the Magnet Enclosure as well as lighting transformers for lighting cabinets which serve receptacles, vacuum system heaters, Magnet Enclosure lighting and fan house lighting. It also supplies regulated 480 v, 3 phase power to radio frequency stations "K," "L" and "JK," through a 108 kva, 480 v, 3 phase induction voltage regulator.

Circuit D42 is an equipped spare.

Circuit D43 with circuit breaker set for 400 amp supplies an 8-switch power panel in fan house "C". This panel supplies unregulated 480 v, 3 phase power for motors, controls, vacuum system motors and receptacles in the Magnet Enclosure, as well as lighting transformers for lighting cabinets which serve receptacles, vacuum system heaters, Magnet Enclosure lighting and fan house lighting.

Circuit D44 with circuit breaker set for 300 amp supplies regulated 120/208 v power to small motor and receptacle loads in the Linac Building via a 225 kva, 3 phase, 480-120/208 v dry type transformer and three single phase wye connected 90 (through) kva, 120 v self-air-cooled induction voltage regulators. This regulated supply is distributed via power panels located at the Linac Tunnel, 1st floor headhouse and 2nd floor headhouse.

Circuit D45 with circuit breaker set for 600 amp supplies unregulated power for the Linac Building through an 8-switch power panel for such requirements as the machine shop, the Linac crane, the Magnet Enclosure crane, vacuum system and temperature control motors, ventilation fans, building lighting and other process and building service requirements.

Lighting

Fluorescent fixtures are provided for normal lighting except incandescent fixtures in the Linac Area, test bay and shop and electronics laboratory.

Emergency and exit lights, as well as emergency 120 v receptacles, are fed from safety switch "X-2" located in the Service Building which is normally energized from circuit 11 in substation "A" but will be automatically fed from emergency engine-driven generator when the normal supply fails.

7. Service Building

General Description

The function of the Service Building is to house personnel and to provide adequate work areas and equipment to operate and maintain the accelerator. The Service Building is composed of a power room, machine room, assembly area, machine shop and a laboratory and office area. In general, all offices and laboratories are air conditioned and all other areas provided with adequate ventilation. Fluorescent lighting is used throughout and convenience and power outlets supplied as required.

The power room is approximately 20 ft. high with floor area of about 7,000 sq. ft. It houses power and electronic equipment required for the accelerator and includes such equipment as the motor generator set, ignitrons, main switchgear and control center. The motor generator set is ventilated by a separately housed fresh air system.

The machine room is adjacent to the power room and is approximately 15 ft. high with a floor area of about 3,500 sq. ft. This room houses the cooling equipment for the AGS magnet, the main steam line control valves, sewer ejection pumps, compressors and related equipment for servicing both the AGS and the Service Building itself.

The machine shop, approximately 15 ft. high with a floor area of about 3,500 sq. ft., contains standard machine shop equipment, a welding shop and a superintendent's office.

The assembly area is approximately 24 ft. high with a floor area of about 5,000 sq. ft. and it includes a 30 ton overhead traveling crane. Direct access to the Target Building and the magnet enclosure is attained by means of concrete underground tunnels. Magnet assemblies and testing, target setups, r-f repair, cloud chamber setups, and many other experimental and operational devices will be assembled in this room. Floor rings have been located near columns to act as anchors for skidding equipment along the floor.

The remainder of the building consists of two stories with a 12 ft. height between floors. This section of the building consists of the stockroom, drafting room, dark room, library, chemistry laboratory, control room and operations office, conference rooms, general offices, electronics shop and laboratory and physics research laboratories. On the concrete platform adjacent to the stockroom are located a levelator to facilitate loading operations and a storage area for bottle gas. Except for the stockroom, this section of the building is air conditioned with supplementary heating by means of radiation at the exterior walls.

To house the air conditioning equipment, penthouses have been provided on the machine shop roof beside the office area and on the machine room roof adjacent to the physics laboratory.

The Laboratory Addition to the Service Building provides additional laboratory space and facilities required for the preparation of electronic equipment, counters and other small experimental gear. This extension is a two-story structure approximately 50 ft. wide by 96 ft. long and includes the addition of 13 laboratories, three offices, one shop storage room, one toilet and the relocation of the stock room and levelator. In addition to the usual building services for the addition, the scope of work includes the air conditioning of the existing machine shop, assembly area and that area formerly occupied by the stock room. To house the new equipment required for the combined air conditioning job, a 24 ft. by 24 ft. by 9 ft. high enclosure was added on top of the existing roof of the Service Building.

The office wing extension to the Service Building provides additional offices for the department staff. This extension is a two-story structure approximately 32 ft. wide by 48 ft. long and 24 ft. high. It provides eight additional offices on each of two floors.

Structural

The Service Building is a structural steel framed structure with exterior walls consisting of metal panels composed of fluted aluminum exterior sheets with 1-1/2 in. Fiberglas insulation and galvanized sheet metal backing. That portion of the exterior wall which supports the protective earth shield is of reinforced concrete. The roof consists of a steel roof deck with 1 in. Fiberglas insulation, covered with a 4-ply tar and marble chip surface. Supported floors are composed of steel floor decking with concrete fill and asphalt tile floor finish. The ground floor is a poured concrete slab resting on soil with a painted concrete surface in all areas except in the laboratory and office area where asphalt tile is used. Personnel doors are hollow metal panel type with louvered and glazed panels. Service doors are rolling steel type. All sash is of the aluminum projected type, provided with venetian blinds in those areas exposed to direct sunlight.

All interior walls consist of painted cinder block. Stairs and landings are of the pan type with concrete fill and abrasive nosing in treads and at landings. A suspended T-type acoustic ceiling is provided for the main lobby, library and for the conference, control, operation and drafting rooms. All toilets have ceramic tile floors and 6 ft. glazed tile dadoes.

The substructure is of reinforced concrete with spread footings designed for a maximum allowable soil pressure of 16,000 psf. The roof is designed for a live load of 25 psf and the supported floors for a live load of 100 to 150 psf.

To protect personnel, a shield of earth and concrete with a minimum thickness of 50 ft. is provided between the Service Building and the Target Building and the accelerator tunnel.

Structural steel is designed for not less than the minimum requirements of the AISC. Reinforced concrete is designed for not less than the minimum requirements of the ACI with ultimate compressive stress of 28 days test of not less than 2,500 psi.

The power room includes the foundations for the motor generator set and emergency generator, foundations and pits for the ignitrons, service trenches and supports for the electrical cubicles and equipment, mezzanine floor, oil tank pit, sump for liquid rheostat and the additional work required to ventilate the motor generator set.

The foundation for the motor generator set consists of a 19 ft.-8 in. by 43 ft.-8 in. by 13 ft. deep reinforced concrete soil bearing structure. To resist the heavy repetitive pulsating forces and an occasional jolt due to generator short circuit, both of which are inherent with this type of machine, it was decided to design a massive foundation, the inertia of which would limit motion. Actually, the foundation weighs 1,460 kips, approximately three times the weight of the motor generator set and seven times the weight of the rotating mass. A special feature of the design was the use of long, high tension steel bolts, anchored deep into the bottom mat, to transfer these forces to the concrete support.

The remaining foundations, trenches and pits are routine in type of construction except for the following items : trench covers, in general, consist of grating with a 1/8 in. steel plate welded to the top of the grating; the use of inserts spaced vertically at regular intervals on the trench and pit walls; and the use of an epoxy synthetic resin paint to protect the interior surface of the liquid rheostat sump from the corrosive effects of the caustic in the liquid.

The additional work required to ventilate the motor generator set includes an 18 ft. by 34 ft. by 12 ft.-6 in. high lean-to type extension to the Service Building at the 21 column line to serve as a fan house. It consists of a steel framed structure, with siding, louvers and doors that match the existing Service Building. On the roof of the Service Building, directly above the motor generator set, a 5 ft.-5 in. by 50 ft. aluminum exhaust hood has been installed.

Sanitary Plumbing

The plumbing system serves three toilet rooms on the first floor, two on the second floor, one toilet in the machine room area, two janitors closets, drinking water coolers, and laboratory sinks. The domestic water line from the yard supplies water to all fixtures and also to the air conditioning water chilling equipment. Hot water is provided from a steam heated 530 gal. storage tank. Hot water from the storage tank is circulated by means of a hot water circulator. The domestic water lines are designed for extension to other parts of the project.

Soil and waste from fixtures gravitates through underfloor piping to a duplex sewage ejector in the machine room. The ejector discharges by pressure to the yard sanitary sewer system. The welding shop sink waste discharges to the floor drainage system. Waste from laboratories and the toilet room at the south end flow to a duplex sewage ejector in a pit in the main first floor corridor. Discharge from the ejector flows under pressure through a force main which connects to the discharge piping from the large sewage ejector in the machine room. Hot water is provided by a connection from the central hot water storage tank in the machine room. A branch domestic water line supplies water for initial filling and make-up to the chilled water system.

Roof Drainage

Roof boxes and canopy drains are provided to receive storm drainage from all roofs and canopies. The drainage flows through a system of under-roof collectors and downspouts which connect to hub inlets in the first floor drainage piping.

Floor Drainage

A drainage system below the ground floor receives storm drainage from the roof drainage system and water from floor drains and from pump base drains and drip pan drains in the air conditioning equipment room. It also receives wastes from the drip pans in all the fan coil units in the first and second floor areas of the extension. In general, second floor units are grouped to drain through common risers. Separate underfloor branches connect to these risers and also pick up the first floor unit drainage.

A floor and equipment drainage system serves the machine room, assembly area, machine shop, and air conditioning rooms, and also receives flow from the roof drainage system. One section of the system discharges to the yard storm sewer at the south wall of the machine room, the other at the west wall of the machine shop.

Domestic Water

Miscellaneous branches from the domestic water main in the machine room provide for connections to the chiller discharge header, the air compressor aftercoolers and the demineralizing equipment. An additional branch to the power room provides for connections to the emergency generator and miscellaneous equipment.

Gas, Oxygen and Acetylene Piping

Oxygen and acetylene are piped to the welding bench from cylinders and manifolds outside the west wall of the machine shop. Gas from the same location is piped to the welding bench, chemistry laboratory and electronics shop.

Heating Systems - Original Building

Steam at 75-125 psi from the yard supply line is reduced in two steps to 15 psi gage to serve the Service Building heating systems, steam coils for ventilation and air conditioning systems and the domestic hot water storage tank.

Unit ventilators with heating coils are provided in the machine shop, assembly area and machine room. Propeller type unit heaters are provided in the power room, main air conditioning fan room, welding shop and stockroom. A finned steam radiator is provided in the small air conditioning fan room. A blast heating coil is provided in the power room ventilation supply system. Steam coils in the air conditioning systems provide for air tempering in winter and reheat for humidity control in summer.

A forced hot water system utilizing finned radiation is provided for perimeter heating of office and laboratory areas. This system is supplied with a circulating pump from a hot water converter operating on 15 psi gage steam.

Condensate from all heating equipment will gravitate to a duplex condensate pump and receiver unit in the machine room, and will thence discharge to the yard return line. The condensate equipment is sized to receive condensate from other parts of the project.

Refrigeration System - Original Building

Refrigeration equipment is provided for the air conditioning systems to cool well water or domestic water sufficiently to maintain required temperatures and humidity. Water is pumped by centrifugal chilled water pumps from the well water or domestic water main through a water chiller, and thence to the cooling coils in the air conditioning systems, returning through the condenser of the refrigerating equipment and wasting to the storm sewer system.

Ventilation and Air Conditioning Systems - Original Building

Control Room air conditioning supply system supplies approximately 6,320 cfm of filtered and conditioned mixture of outside and recirculated air to the control room. Physics area air conditioning supply system supplies approximately 19,450 cfm of filtered and conditioned mixture of outside and recirculated air to physics room 110, instrument room office area 218 and physics rooms 219, 220, 221, 222 and 223. Electronics area air conditioning supply system supplies approximately 9,330 cfm of filtered and conditioned air to laboratories 102, 103, 104 and 105 and electronics shop. Fan, coils, filter and dampers are located in fan room A. Southeast and Southwest offices air conditioning supply system supplies approximately 8,420 cfm of filtered and conditioned air to lobby, offices 106 and 201 to 213 inclusive. Northeast offices air conditioning supply system supplies approximately 3,850 cfm of filtered and conditioned air to offices 107 and 108, conference room 109, operation office, and offices 214, 215, 216 and 217. Equipment comprising fan, coils, filter and dampers are located in fan room B. Drafting and Conference room air conditioning supply system supplies approximately 6,580 cfm of filtered and conditioned air to drafting room, ozalid room, counting room, chemistry laboratory, library, conference rooms and dark room. Fan, coils, filter and dampers are located in fan room A.

Power Room supply ventilation system supplies a mixture of outside and recirculated air to the power room by air handling equipment including fan, heating coil, dampers, filter, outside air intake, return inlet and supply duct with ceiling diffusers. Machine Room supply system provides a total of 5,400 cfm supply ventilation air to the machine room on the first floor by air handling units including fan, heating coil, dampers, outside air intake, return inlet and supply duct with discharge outlets. Control Room return and exhaust system exhausts air from the control room to permit supply system to operate with fresh air when conditions are desirable. The fan is connected in the return air duct. Automatic dampers enable return air to be exhausted or recirculated. The equipment is located in fan room B. Physics Area exhaust system with fan and automatic dampers exhausts air from the physics area to permit the system to operate with fresh air when conditions are desirable. The fan is mounted on the roof. Electronics Area exhaust system with fan and automatic dampers exhausts air from the electronics area, permitting System to operate with fresh air when conditions are desirable. The fan is mounted on the roof. Dark Room exhaust system exhausts air from the dark room. The fan is mounted at the ceiling and discharges by duct work to a roof hood. Conference Room exhaust systems include two 1,350 cfm fans exhausting air respectively from two conference rooms. Each fan is mounted on the roof and is provided with self-acting shutters. Ozalid Room exhaust systems include a propeller type exhaust fan with self-acting shutter discharging through the north wall to atmosphere and an exhaust duct to an outlet above the roof connected to the ozalid machine exhaust. Three 7,500 cfm roof type exhaust fans exhaust air from the power room. One 3,000 cfm roof type exhaust fan exhausts air from the motor generator set enclosure. Flushing exhaust ventilation for the machine room and fan room "B", is provided by a fan mounted on the roof. Two systems,one of 1,755 cfm and one of 120 cfm are provided to exhaust from the toilet rooms through fans and ducts to roof hoods. A propeller fan with self-acting shutter will exhaust air from an exhaust hood above the welding shop bench through the north wall to atmosphere.

Heating, Ventilating and Air Conditioning - Laboratory Addition

General

The entire Laboratory Addition is air conditioned, with the exception of the stock room and the air conditioning equipment room which are heated by steam unit heaters. In addition, air conditioning is provided for the machine shop and assembly area. A steam fired absorption type water chiller provides chilled water for all air conditioning requirements. The laboratories and offices are equipped with fan coil units without outside air connections. The units are supplied through a 3-pipe system with chilled water from the water chiller and hot water from a steam heated converter. Outside air for these areas is supplied by a central air handling system equipped with chilled water cooling and steam heating coils. Air handling units supplied with chilled water and steam are located in the machine shop and assembly area.

Steam and Condensate Piping

Steam for the Laboratory Addition is supplied from the 50 psi main in the machine room and runs to a pressure reducing station in the equipment room. Steam is supplied at 15 psi from the reducing station to the preheat and reheat coils in the outside air system, to the hot water converter, to three steam unit heaters and, after reduction to 12 psi, to the absorption type water chiller. Condensate is returned from all the above items to an existing condensate line in the machine room, whence it flows to the main condensate tank. Steam and condensate piping is connected to the new air conditioning units in the machine shop and assembly area.

Chilled and Hot Water Piping

The chilled water piping system includes two 120 gpm chilled water pumps, one (P1) to serve the addition to the laboratory and one (P2) to serve the machine shop and assembly area. The hot water piping system includes one 60 gpm hot water pump (P3) which serves the addition to the laboratory only.

Pump P1 takes suction from a mixed chilled water-hot water common return from the fan coil units, discharges through the cooler of the absorption unit, and thence to the cooling coil in the ventilation system where a 3-way valve bypass controls the quantity passing through the coil. From the cooling coil, the chilled water discharges to distribution piping which supplies the fan coil units. A circulating bypass line from the outlet of the cooling coil permits a varying quantity of water to flow direct to the pump suction without passing through the fan coil units. Bypass flow is regulated by a modulating pressure control valve to provide for pump operation at constant pressure. Maximum quantity through the entire fan coil system is 90 gpm.

Pump P3 takes suction from the same common return serving pump P1 and discharges through the steam heated converter to distribution piping supplying the fan coil units. A circulating bypass line from the outlet of the converter permits a varying quantity of water to flow direct to the pump suction without passing through the fan coil units. Bypass flow is regulated in a similar manner to the control of the flow through the chilled water bypass. Maximum quantity through the entire fan coil system is 45 gpm.

The proportioning control of the chilled and hot water flow through the fan coil units is as described hereinafter. The piping systems are reverse return design, supplying all units in parallel, with a common branch line from each unit collected to a common return main which connects to the suction of pumps P1 and P3.

Pump P2 discharges through the cooler in parallel with pump P1 and thence to the cooling coils in the new air handling units in the machine shop and assembly area which are equipped with 3-way bypass valves. From the coils, the water returns to the suction of the pump. Cross-connections are provided so that pump P2 can serve as a spare for pump P1 in an emergency.

Condenser Water Piping

The condensing water piping system includes one 290 gpm pump (P4) which serves as a booster and provides for recirculation of condensing water at light loads. The pump takes suction from an extension of the well water piping from the machine room (or alternately from the domestic water service) and discharges through the absorber and condenser in series and thence to waste. Recirculation from the waste line through a bypass to the pump suction is controlled by throttling valves on the supply line ahead of the bypass which are actuated by water temperature at the condenser inlet.

Ventilation and Air Conditioning Systems

Ventilation and air conditioning systems are provided for the various building areas in accordance with the following description:

Interior zone air conditioning system supplies 5,400 cfm of conditioned 100 per cent outdoor air from central station equipment located in the equipment room through a system of duct work to the interior zone, which in general extends outward to about 12 ft. from all exterior exposures on both first and second floors. The system is designed to supply the ventilation requirement and humidity control for the entire Laboratory Addition and also to provide year-round cooling or tempering of the air supply for the interior zone. The system includes centrifugal fans, preheat steam coil, blow-through cooling and heating coils, filters, and controls. The system is also arranged to provide chilled water for the perimeter system described below when outdoor air conditions permit. Chilled water circulation will be maintained through the air coils on a year-round basis and cooling of the water with simultaneous heating of the air will occur.

Perimeter fan coil unit system is a 3-pipe fan coil system providing heating and cooling to the perimeter zone of the Laboratory Addition and to certain interior rooms in the building. The perimeter zone, in general, extends inward about 12 ft. from all exterior exposures on both the first and second floors. The system utilizes vertical floor mounted fan coil units located, where possible, beneath the windows. The units are supplied with either chilled water or hot water, as determined by a room thermostat which controls a modulating sequencing water valve. The system provides true room control in that a source of either heating or cooling automatically controlled is available in each office and laboratory all year round.

Machine Shop system supplies 8,600 cfm of conditioned air to the machine shop by means of a ceiling type air conditioning unit located in the area served. The unit provides a minimum of 3,150 cfm of outdoor air under normal conditions and can be used to provide 100 per cent outdoor air when conditions are favorable. Of the normal fresh air quantity added to the area, 2,240 cfm serves as make-up for that exhausted through the stock room and the remainder will offset infiltration. During full fresh air operation, the surplus air is removed by the existing exhaust fan. Air is distributed through duct work and ceiling diffusers.

Assembly area system supplies a total of 10,200 cfm of conditioned air to the assembly area by means of two 5,100 cfm vertical air conditioning units, each one centrally located at opposite ends of the area. Each unit normally supplies 1,125 cfm of outdoor air for ventilation and to offset infiltration and can be used to provide 100 per cent outdoor air when conditions are favorable. During full fresh air operation, the surplus air is removed by the existing exhaust fans. Air is distributed through duct work and ceiling diffusers.

Interior zone exhaust system utilizes a roof exhaust fan, located above the second floor corridor, to exhaust 2,900 cfm from the interior zone, 900 cfm from the first floor electronics laboratory through a relief duct connecting the laboratory with the second floor corridor, and 2,000 cfm from the offices and laboratories on the second floor. Electronics Laboratory exhaust system utilizes two wall mounted, propeller type exhaust fans in the first floor electronics laboratory to provide emergency exhaust by discharging 4,300 cfm to atmosphere. The fans are interlocked with the roof type exhaust fan in the interior zone exhaust system so that when they operate, the roof fan is shut down. The air flow through the relief duct is reversed and a major portion of the conditioned air supply to both floors is flushed through the electronics laboratory. Miscellaneous exhaust equipment includes a roof type fan to exhaust from the second floor toilet and from interior laboratories on the first floor, another roof type fan to exhaust from the air conditioning equipment room and a propeller type fan to exhaust from the stock room. A propeller type fan ventilates the shop storage area.

Heating, Ventilating and Air Conditioning - Office Wing Addition

General

The entire office wing is heated and cooled with a two pipe system designed to supply hot water or chilled water to individual room "Unitrane" Conditioners.

Heating

Steam is furnished from the 15 psig steam main in the machine room to serve the addition. Heating is by a forced hot water system utilizing a coil in the individual room air conditioners and controlled automatically by a three way valve operated by a thermostat, to provide varying temperature of blended water in the coils to maintain the desired temperature corresponding to the outdoor temperature. This system is supplied from a hot water converter operating on 15 psig steam by means of a circulating pump.

Chilled Water

Chilled water is obtained from the original building system and serves closed cooling coils in the conditioning units. A separate pump in the system takes suction from the chiller discharge header, discharging to the water coils. Chilled water from the coils discharges to the condenser header of the water chilling equipment.

Ventilation

The individual room "Unitrane" conditioners supply a mixture of outside and recirculated air to each room. Separate air intakes are provided through the outside wall directly to the unit located in the center of the outside wall.

Motor Generator Set Ventilation System

The motor generator set in the power room is designed for air cooling, having fans built integral with the unit which force a total of 105,000 cfm through the various housings of the set. Air enters the housings axially and discharges through openings in the top, with 35,000 cfm for the motor, 60,000 cfm for the generator, and 10,000 cfm for the flywheel. The expected temperature rise is approximately 35°F.

To provide clean air for the motor generator set, and also to avoid unsatisfactory temperature conditions in the room in cold weather, a supply ventilation system is provided of 105,000 cfm capacity. Fans and filters are located in a fan house adjacent to the area, and air is drawn in through hoods in the east wall of the house and discharged direct through the opposite wall. A duct work connection for partial recirculation is provided for two of the three fans and omitted for the most southerly unit. This assumes that under full load operation three fans will be required at all outside temperatures of 75°F and above, but that at outside temperatures of 65°F (which has been selected as the minimum fan discharge temperature) or below, two fans will provide adequate supply. At reduced load operation and outside temperature of 65°F or less, one fan will at times be adequate. Maximum recirculation requirement is computed to be about 56,000 cfm, the proportion being determined by the relation between machine loading and outside temperature and controlled by intake and return air dampers responsive to fan discharge temperature. The surplus heated air accumulating in the upper levels of the area will be relieved by gravity through a large hooded roof opening. Manual dampers in this opening can be closed during machine shutdown.

Fire Detection System

The fire detection system consists of two sections, one section serving the control room with adjoining cable vault and the other serving the power room. A separate zone is provided for each area. The equipment is "Rate of Rise" detector equipment, consisting of circuits of 0.08 in. OD copper tubing connected to two automatic fire detectors having two opposing diaphragms with platinum electrical contacts. The closed circuit electrically supervised control panel may be actuated by the detectors, or by any of six manual alarm stations, or by alarm switches at the two sprinkler risers. The system operates on 120 v a-c power and incorporates emergency power for use in event of power failure. The system signals to the annunciator panel in the control room and includes an alarm bell and trouble bell.

The existing Gamewell fire detection system was extended to serve all areas in the Laboratory Addition which are not protected by sprinklers. There are two major detecting zones, one for first floor areas and one for second floor areas. Manual alarm stations at the stairway, the two zones and the sprinkler alarm valve all report back to the master box in the front entrance lobby and thence to the fire station. Equipment is connected to the annunciator.

Sprinkler and Fire Protection Systems

Spray type sprinkler systems provide protection to all areas not served by detection system. Two sprinkler risers are provided, one at the west end of the main building corridor, and the other in the southwest corner of the machine room. The two systems are tied together with a valved cross connection. Hose cabinets hose racks, hose and valves are also provided at strategic locations.

Fire protection in the Laboratory Addition includes a riser serving the west end of the building near the entrance door at the south end of the corridor in the addition. Sprinklers protect the toilet room, air conditioning equipment room, stock room and stair wells and are connected to the west end system. Hose stations were installed in the stock room and the first and second floor corridors.

Electrical

Electrical power and light for this building is supplied via underground 13.8 kv paper insulated, lead covered, neoprene jacketed cable from switchgear panel No. 14 in the Temple Place Substation. This feeder enters the Service Building in the power room and is separated into two subfeeders, each controlled by its own 13.8 kv metalclad air circuit breaker located adjacent to column f/18. One of these subfeeders, controlled by the southerly breaker, feeds two unit substations. Each of these substations has a primary compartment with fused switches, mechanically interlocked so that the compartment door cannot be opened until the primary switch is open. The primary subfeeder loops in and out of the 1,500 kva, 480 v, 3 phase substation A1 and into the 500 kva 120/208v, 3 phase, 4-wire substation A2.

The 480 v, metal enclosed switchgear is in the machine room, throat-connected to the outdoor OISC transformer, and supplies the 480 v power to the building through three 60,000 amp (I.C. at 480 v) manually operated air circuit breakers. One spare breaker and space for two future manually operated and for two future electrically operated breakers are provided. The instrument compartment contains three potential transformers, three voltmeters, ground alarm relay, three current transformers, one ammeter and an ammeter transfer switch.

Power for the 480 v system is distributed locally from Motor Control Center No. 1 in the machine room, Power Panel No. 42 in the machine shop and Power Panel No. 43 in the assembly area. Receptacles for 480 v power, 30 amp, 3-wire,4-pole are located at strategic locations in the building. Feed for the 30T crane is taken from Power Panel No. 43 through a 200 amp unfused safety switch at floor level, connected to open wire main runway conductors in the assembly area. All other 480 v equipment is listed in the "Schedule of Motors and Control on 3 Phase, 480 V System", included as part of the equipment data portion of this manual.

To provide distribution and control for the motor drivers for pumps and compressors installed in the machine room, cubicle sections are installed on both ends of M.C.C. 1 with the bus connected to them. An additional Motor Control Center is installed south of M.C.C. 1 and in line with it against the west side of the 18 wall. This is known as Motor Control Center No. 2. It is supplied from the Service Building 480 v unit substation by two 3 in. conduits, each with three 500,000 cir mil insulated cables, connected to circuit breaker No. 48.

The 120/208 v metal enclosed switchgear is in the machine room, throat-connected to the outdoor OISC transformer, and supplies the 120/208 v system in the building through seven 50,000 amp (I.C. at 240 v) manually operated air circuit breakers. One spare breaker and space for three future manually operated breakers are provided. The instrument compartment contains one voltmeter and voltmeter transfer switch, three current transformers, one ammeter and one ammeter transfer switch.

Lighting at 120 v and power for the 120/208 v system is distributed locally from lighting panels and power panels located at load centers throughout the building. Regulated 120 v, single phase power is available in the control room and physics laboratory through three 48 (through) kva, 10 per cent buck or boost, single phase air-cooled induction voltage regulators, connected in wye on the 120/208 v, three phase system. Regulated, 15 amp, 120 v, 3-wire duplex receptacles are located in the control room and physics labs, 1 ft. above the floor. Unregulated 15 amp, 120 v, 3-wire duplex receptacles are located in other parts of the building 3 ft. above the floor. Unregulated 20 amp, 120 v, 3-wire twist-lock receptacles are located in the electronic shop at the ceiling for supply drops to benches. Unregulated 30 amp, 120/208 v, 3-wire, 4-pole receptacles are located at strategic locations throughout the building.

Fluorescent lighting with slimline lamps is provided for normal lighting, except for isolated locations in the air conditioning fan houses where incandescent lighting is used. Emergency and exit lighting as well as emergency 120 v receptacles are fed through an emergency lighting panel which will later be supplied by an emergency source. The yard area adjacent to three sides of the building is floodlighted with two 500 w and 11 - 1,000 w lamps located on the building walls and controlled with astronomic time switches.

Electrical power and lighting for the Laboratory Addition consists of supplying similar facilities for the laboratories and offices as those provided for the original Service Building, plus service to the air conditioning room located on the roof of the original building and three air conditioning units, two in the assembly room and one in the machine shop.

Lighting and Power Supply

The 480 v, 3 phase, 60 cycle supply is from a former spare 200 amp circuit in existing power panel 43, except that the supply for air conditioning units in the assembly area and machine shop is from power panel 42, circuit 1.

The 200 amp circuit from power panel 43 is carried by three No. 4/0 cables in conduit to the new 480 v power panel 43A in the air conditioning equipment room. Power panel 43A serves air conditioning equipment, hot and cold circulating water pumps, primary air fan, roof exhaust fan, sewage ejector pumps and 480 v power panel 43B in the electronics laboratory.

The 120/208 v, 3 phase, 60 cycle supply is from a 600 amp manually operated air circuit breaker installed in a spare space of lighting unit substation "A". This circuit is carried by four 300,000 cir mil cables in conduit to junction boxes for taps to lighting panels, power panel and electronics laboratory receptacle panel.

Grounding

The grounding system was extended to cover the building addition, with two more driven ground rods. A 1 in. by 1/8 in. copper bar connected to the grounding system is installed all the way around the electronics laboratory below the windows on the outside wall and 4 ft. above the floor on the inside walls. This ground loop is not closed. On the second floor a ground bar is similarly installed enclosing the building addition in such a manner that every laboratory has a ground bar on at least one wall. This loop is not closed.

Lighting

Fluorescent lighting with Slimline lamps is provided for normal lighting, except under air ducts in the air conditioning equipment room where incandescent lights are used. All emergency lights are incandescent as are outside floodlights and lights above outside doors.

Power Room

A cable trench and underground conduit system are provided for cable connections to the alternator and all other Westinghouse Electric Corporation equipment used for magnet power supply. The trench is carried into the machine room on the west for additional 480 v supply cables and is carried through the east wall of the power room to serve the interphase transformers outdoors.

A gasoline engine driven emergency lighting generator is provided in the southwest corner of the power room. It is rated at 125 kva, 3 phase, 60 cycles, 125/216 v. The emergency circuits are fed through safety switches X-1, X-2 and X-3 to the Linac Building, Magnet Enclosure, Target Building and Service Building and are normally fed from a tap off circuit 11 through a 200 amp fusible safety switch near column "17-f" above Gr. 74.0 ft. When this normal supply fails, the engine driven generator is started and as soon as rated voltage is established, the automatic transfer switch will transfer the supply of the emergency circuits to this generator. On restoration of normal supply voltage with a slight time delay, the automatic transfer switch will transfer back to normal position. Subsequent shutting down of the engine driven generator will be manual by push button at the generator. A complete list of engine driven generator auxiliaries together with automatic

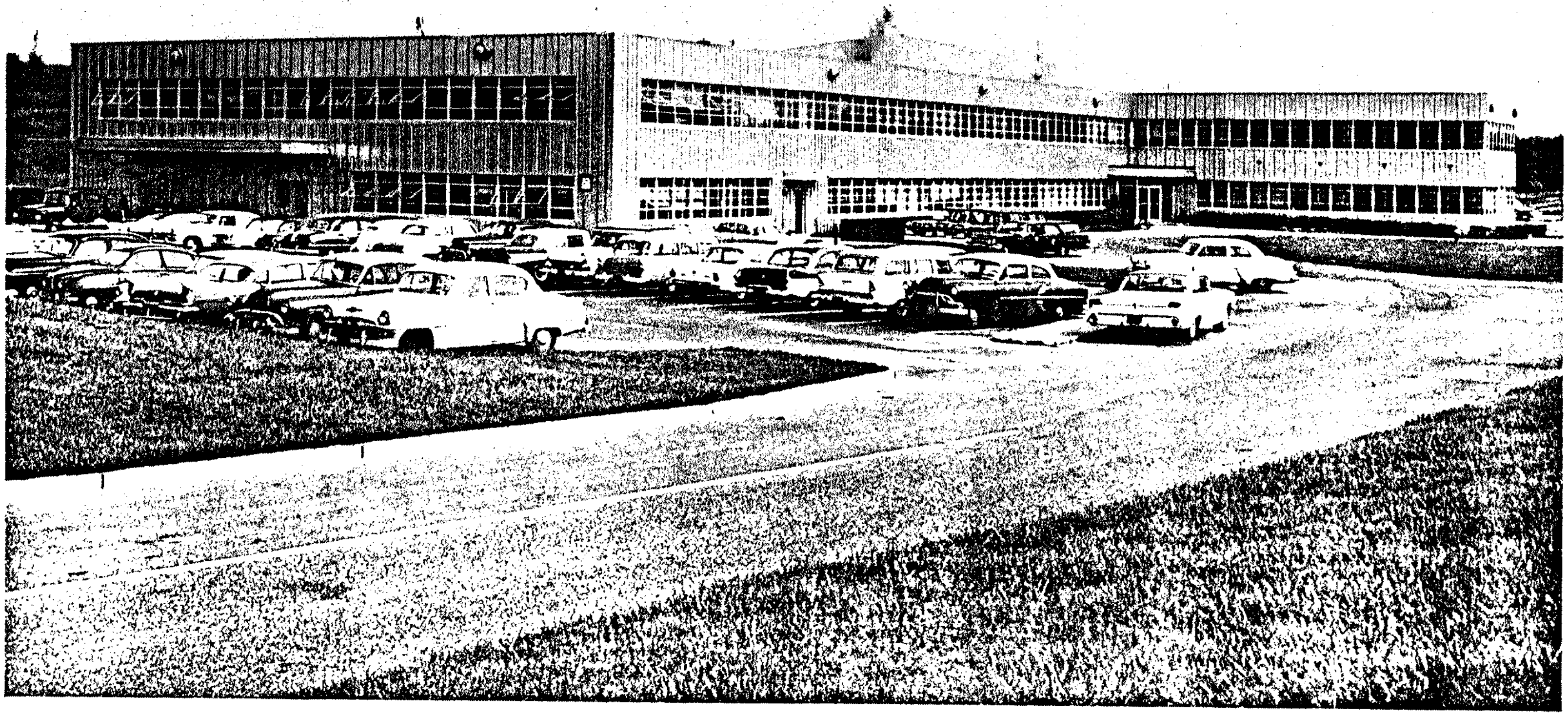


Figure 72
Exterior view of Service Building-Looking North

8. Support Structures

a. Mechanical Equipment Building

General Description

The Mechanical Equipment Building is located to the north and west of the Experimental Building and connected to it by means of a passageway. The building occupies an area of 3,200 sq. ft. and houses emergency generator sets, vacuum pumps, air compressors and helium compressors. Access to the building is by means of a 12 ft. by 13 ft. high overhead door leading to Fifth Avenue. The passageway is also used to support electrical and mechanical services running between the two buildings.

Structural

The Mechanical Equipment Building consists of a 40 ft. by 80 ft. prefabricated structure, with insulated fluted aluminum walls and roof. The inner face of the roof insulation is covered with a vinyl vapor seal; the wall insulation, with a galvanized steel inner sheet. Sixteen translucent Fiberglas panels serve as skylights on the roof. Sash is of aluminum, commercial projected type, with ventilated sections swinging out. The personnel doors are industrial steel, hollow metal, full flush doors. The 12 ft. by 13 ft. high door is an aluminum sectional, upward-acting overhead type door. The floor slab, grade beam and column footings are of reinforced concrete. The basis of design for the building and the foundations is the same as for the Experimental Building except that the maximum allowable soil pressure is 4,000 psf.

The covered passageway from the Mechanical Equipment Building to the Experimental Building is similar in materials and workmanship to the Mechanical Equipment Building.

Floor Drainage

Floor drains are provided which tie into a branch of the storm drainage system which comes from the West Experimental Area and discharges into the settling basin north of Fifth Avenue.

Roof Drainage

Roof drainage runs off to the ground east and west of the building.

Domestic Water

A branch extends from the yard system into the building and connections are made to various equipment stems.

Heating System

Steam is supplied from the East Experimental Building and extends through this building and thence underground to the Bubble Chamber Building. Horizontal type unit heaters are provided along the outside walls.

Condensate from the passageway and the building returns to an auxiliary pump and receiver set in the corner of the building which discharges to an overhead line to the East Experimental Building. This same pump receives condensate from the Bubble Chamber Building.

Ventilation

Roof ventilation and ventilated sash are provided.

Fire Detection System

A fire detection system is connected to the other Gamewell systems which serve the AGS Complex. It consists of one detecting zone and two manual stations which report via the control panel in the Target Building to an adjacent master box and thence to the firehouse. A drop is also provided on the annunciator in the Service Building.

Installed Equipment

For a description of the Helium Compressors, Air Compressors, and Emergency Generators installed in this building, see appropriate sections under the East Experimental Building where the complete systems are described.

Electrical

Supply for 480 v, 3 phase normal power service comes from circuit "3F44" in substation "3F2500" which is bifurcated into two 600 amp circuits utilizing 600 amp 3-pole current limiting fuses with one for the Mechanical Equipment Building and one for the normal/emergency power to East Experimental (see page 14). Two 1,000,000 cir mil cables per phase are connected to the 600 amp Amptrap fuses and, thence, two 500,000 cir mil cables per phase by cable tray through the East Experimental Building to the motor control center in the Mechanical Equipment Building. This motor control center is Type "C" in which all motor and control connections are carried to terminal blocks in a top compartment for external connection and serves the following:

Helium compressors
Air compressors
A 30 amp, 480 v, 3 phase power receptacle
Condensate return pumps
Lighting cabinet L-4

Motor controls for the Helium compressors are fused disconnecting switch combination across the line starters with "hand-off" selector switches and red and green indicating lights with control transformers and control relays, all incorporated in the motor control center. Space is provided to add equipment for autotransformer reduced voltage starting if it is found to be necessary.

Motor controls for the Air compressors are fused disconnecting switch combination starters with "hand-off-auto" selector switches and red and green indicating lights with control transformers, all incorporated in the motor control center. External automatic controls are provided by the compressor manufacturer.

480 v, 3 phase power receptacle is a Crouse-Hinds Company ARE3423, 30 amp, 3-wire, 4-pole, Style 2, with spring door. It is supplied from a 30 amp fused disconnecting switch in the motor control center.

Motor controls for the condensate return pump are fused disconnecting switch combination starters with "hand-off-auto" selector switches and red and green indicating lights with control transformers, all incorporated in the motor control center. Automatic control is by two level float switches and Square D 9039 class automatic alternators.

Lighting cabinet L-4 is supplied from a 15 kva, 480-120/208 v, dry type transformer which is supplied from a 30 amp fused disconnecting switch in the motor control center.

The cabinet supplies lighting in the Mechanical Equipment Building and connecting passageway to the East Experimental Building, instrument air dryer, unit heater fans, convenience outlets, ventilating fans and a PH-3 projection heater fan.

The cabinet is 100 amp, 3 phase, 4-wire, 120/208 v, with 20-20 amp, single pole Westinghouse Type "QC: Quicklag circuit breakers.

There are four horizontal discharge unit heaters with 1/20 hp fan motors, and one vertical discharge heater over the rolling door with a 1/2 hp fan motor. These are each provided with a line type thermostat and size 0 manual starter with thermal overcurrent protection.

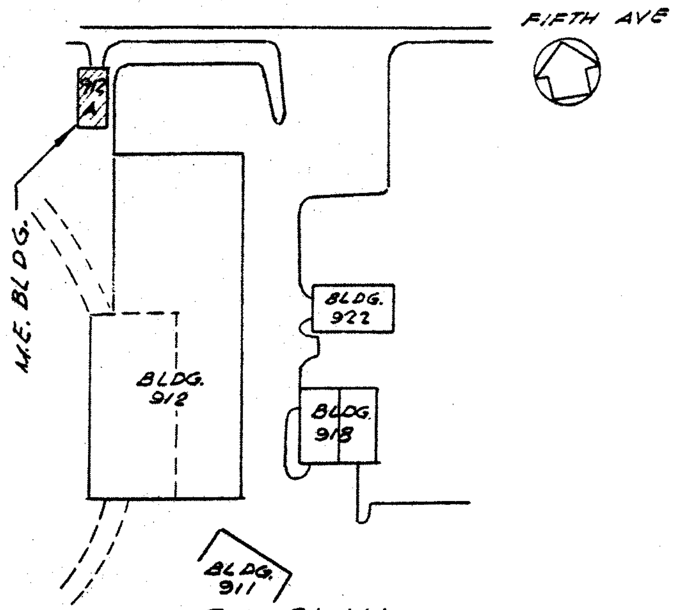
There are four roof fans which are provided with size 0 manual starters with thermal overcurrent protection.

These are all fed from circuits in lighting cabinet L-4 as also are the battery chargers for Diesel engine generators and the instrument air dryer.

Lighting

8 ft fluorescent fixtures with two 96 in. Slimline lamps are provided, supplied from circuits in lighting cabinet L-4. Lighting is designed for 40 ft-c.

The passageway between the two buildings is provided with ceiling units with 100 w incandescent lamps, also supplied from lighting cabinet L-4.



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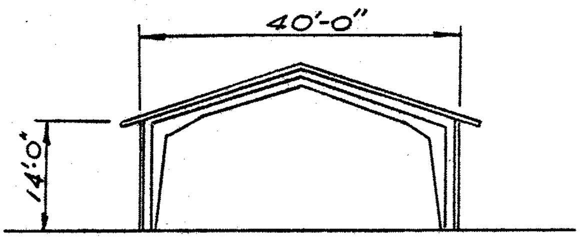
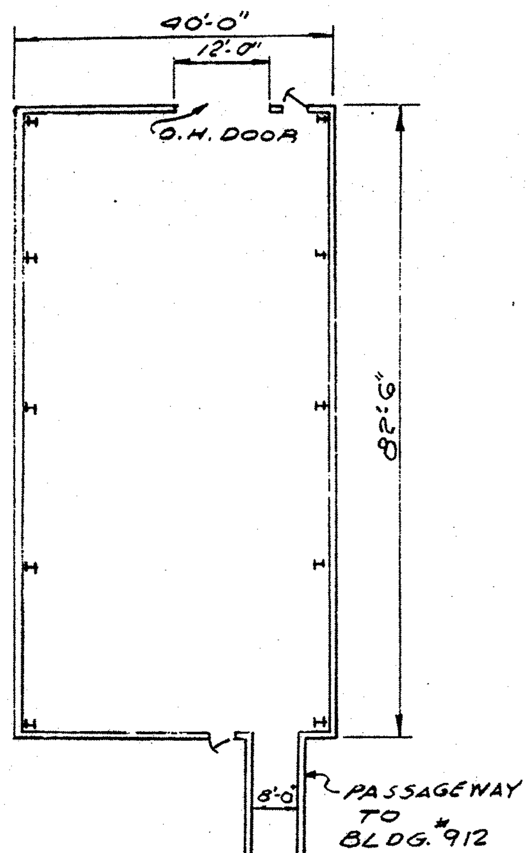


ELEVATION



PLAN

M.E. BUILDING
BLDG. 912A
FIG. 73

b. Assembly Building

General Description

The Scientific Assembly Building is intended to provide space for the assembly and testing of scientific apparatus required in the research program associated with the synchrotron. This equipment includes beam separators, power supplies, small size magnets, and other particle beam transport components.

Structural

The Building is approximately 60 x 100 ft. with an approximate 20 ft. eave height and includes a 20-ton gantry crane. It is located east of the paving which extends along the east side of the Experimental Building.

The Building is of a conventional prefabricated type as manufactured by Parkersburg. It consists of rigid frame bents which in turn carry a conventional girt and purlin arrangement to support siding and roofing materials.

The concrete floor slab is 6 inches thick reinforced with wire mesh and has imbedded in it crane rails to carry the gantry crane.

The roof consists of 1-1/2 inch Fiberglas insulation with a vinyl vapor seal on the interior face stretched over the roof purlins and covered with .032 inch thick aluminum ribbed panels. The side and end walls are constructed with a galvanized metal liner, 1-1/2 inch thick Fiberglas insulation covered with 0.040 inch thick aluminum outer sheet.

Windows consist of projected sash. Personnel doors of hollow metal are provided. A 12 x 14 ft. roll-up door for truck access is provided at the west end of the building.

The crane is a 20-ton deck leg gantry type having a 45 foot span and 16 feet clear under the hook all pendant operated at the floor level.

Sanitary Plumbing

No sanitary facilities are incorporated.

Floor Drainage

A system of floor drains are incorporated for waste of cooling water, etc. tied to the yard west of the building.

Ventilation

Ventilation is provided by four 16 in. diameter standard gravity type ventilators with manual chain operated dampers.

Heating

Heating is furnished by six 20 kw electric unit heaters mounted overhead clear of the gantry crane.

Fire Detection

Fire detection consists of self-supervised fixed temperature rate of rise detector units mounted overhead. The usual alarm, control box and manual pull box are provided. The system is tied into the Laboratory alarm system which is monitored at the central fire headquarters.

Fire Protection

Fire protection is provided with a number of CO_2 fire extinguishers strategically located.

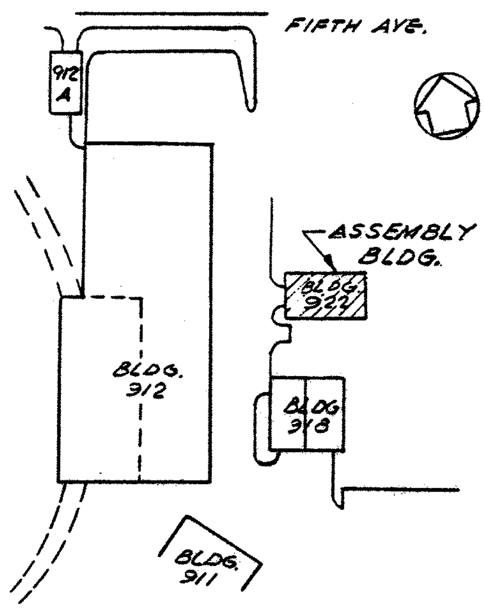
Electrical

Electrical power is supplied from a separate air circuit breaker located in substation E which is located immediately adjacent to the south of the building. 480 volt power is brought underground into the building where it is distributed to a 225 kva dry type transformer for normal 120/208 volt building services.

480 volt power for experimental equipment is distributed to two three-phase power distribution boxes. 480 volt power is also extended to an overhead craneway conductor for the gentry crane.

Special 120/208 receptacle panels are provided in the building for normal operating and equipment test purposes.

Lighting is provided by High Bay mercury vapor type located overhead. High intensity outdoor flood lights are provided on the north face of the building to light a paved storage yard located there.



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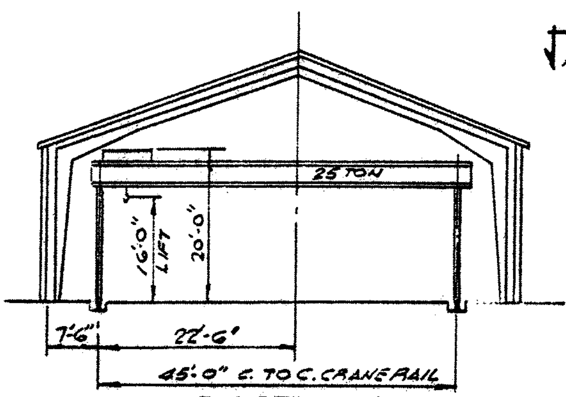
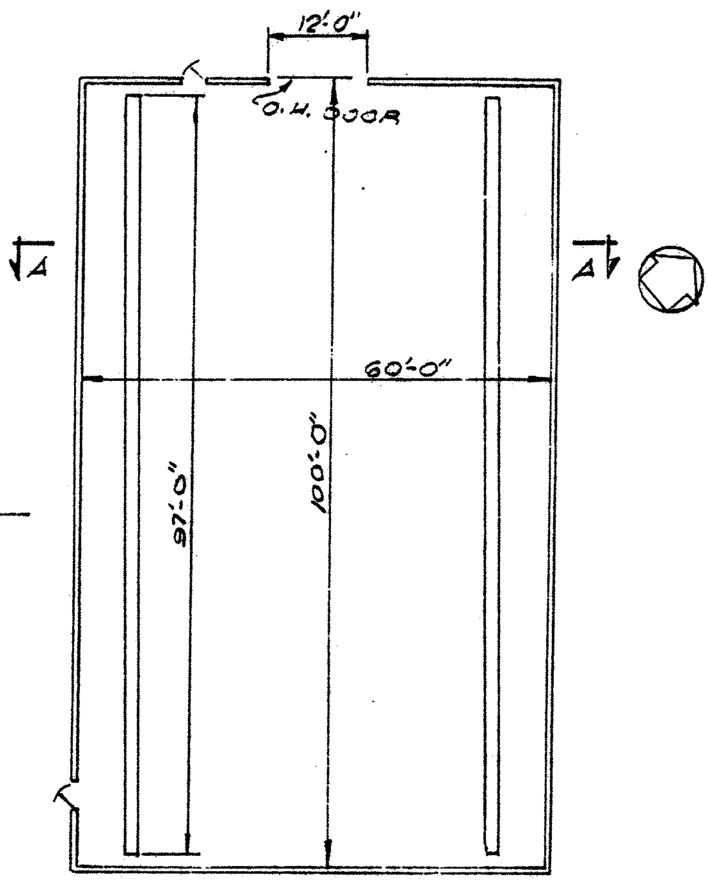


SECTION A-A



PLAN

ASSEMBLY BLDG.
BLDG. 922

FIG. 74

c. Warehouse

General Description

During the early phases of the Project a warehouse was erected east of the Target Building and the outdoor paved area. This building was required for receipt and warehousing of equipment and materials used on the project. Subsequently, as the project neared its completion, the warehouse was expanded to handle the storage of jigs and fixtures, spare parts and equipment required for the efficient operation of the Synchrotron.

Structural

The building is approximately 100 ft. x 100 ft. with a 14 ft. eave height. It consists of two 50 ft. wide rigid frame prefabricated structures of the Stran Steel type. Rigid frame bents support conventional girts and purlins which in turn support the siding and roofing materials.

The concrete floor slab is 4 in. thick wire mesh reinforced concrete slab on grade. A concrete loading platform at tail gate height is provided on the west side.

A one-ton monorail is provided in one bay hung from the building frame.

The roof consists of 1-1/2 in. thick Fiberglas insulation covered on one side with an aluminized vapor seal stretched over the roof purlins and covered with 0.032" thick aluminum ribbed panels. The side and end walls are of similar construction.

Windows are of the commercial projected type. A sliding door 12 x 11 ft. is provided at the loading platform and two 12 x 12 ft. overhead doors are provided at the north end for equipment handling vehicles access at grade.

Sanitary Plumbing

No sanitary or water facilities are provided.

Roof Drainage

Conventional eave, valley gutters and down spouts discharging at grade were provided.

Ventilation

Ventilation was provided by adjustable louvers installed in each end gable and operated from the floor.

Heating

Heating is provided by eight 15 kw electric unit heaters hung from the roof purlins.

Fire Detection

Fire detection consists of self-supervised fixed temperature detector units mounted overhead. The usual alarm, control box and manual pull box are provided. The system is tied into the Laboratory alarm systems which is monitored at the central fire headquarters.

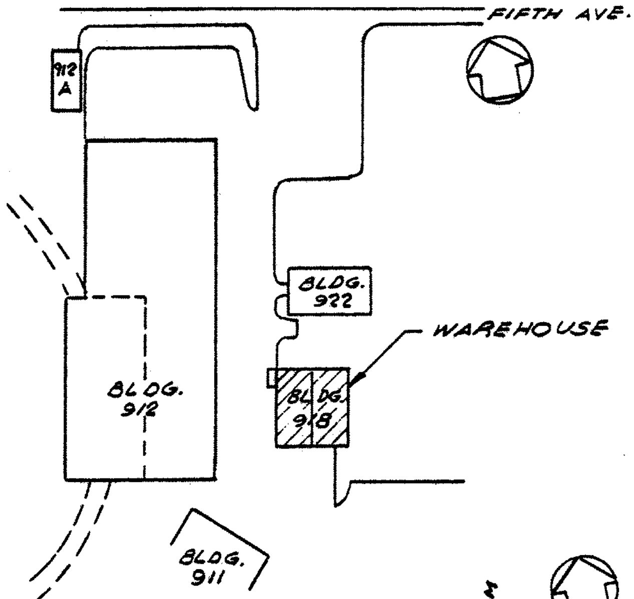
Fire Protection

Fire protection is provided with a number of CO_2 fire extinguishers strategically located.

Electrical

Electrical power for heating, lighting and convenience outlets is provided by an underground 480 volt power line from the 480 volt panel in the south end of the Target Building. A 30 KVA and a 7.5 KVA dry type transformer is installed in the warehouse for 120/208 v building services.

Lighting is furnished by fluorescent fixtures hung from the roof purlins.



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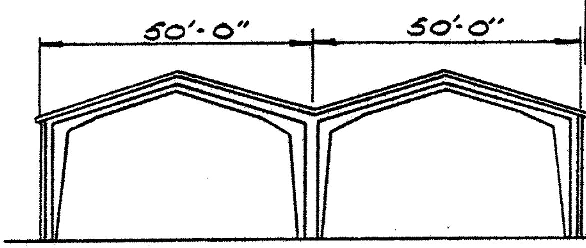
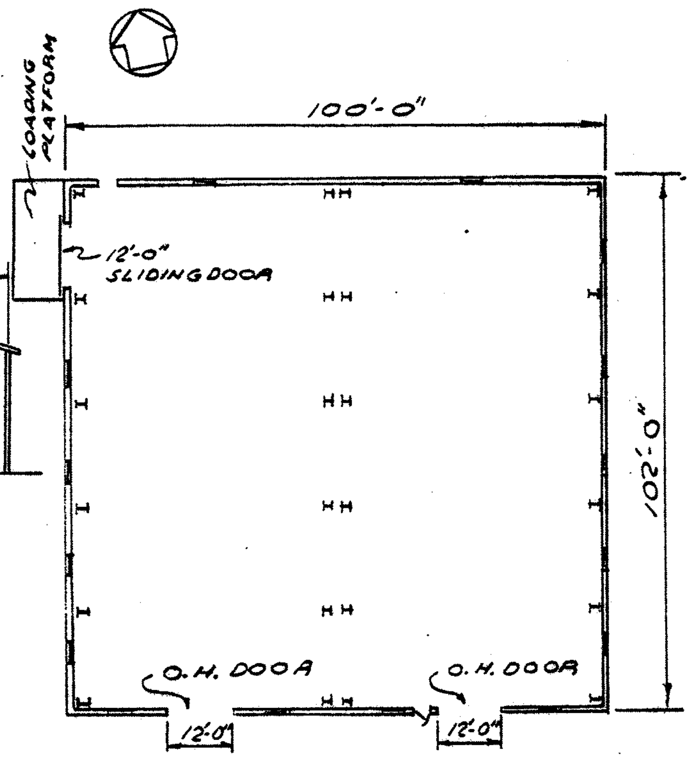


ELEVATION



PLAN

AGS WAREHOUSE
BLDG. # 918

FIG. 75

9. Boiler House Addition and Equipment

General Description

The existing boiler house, known as Building No. 610, is located in the eastern section of the Brookhaven National Laboratory property and contained two 20,000 lb. per hr. oil-fired, 125 psi saturated steam generating units. The extension comprises a 60,000 lb. per hr. oil-fired steam generating unit and auxiliary equipment installed in an extension of the building to the south which is provided with a temporary south wall to permit future extension to accommodate a second 60,000 lb. per hr. unit. The various auxiliaries, other than the draft fans, are sized to serve this second unit as well as the present 60,000 lb. per hr. unit.

Fuel oil, Bunker "C" grade, is used exclusively at the plant and is usually delivered by truck to two 10,000 gal. day tanks from supplier's tank storage facilities not far from the laboratory. A railroad siding is located adjacent to the boiler house, however, from which oil can be delivered out of tank cars to the day tanks or to a 200,000 gal. storage tank by means of oil transfer pumps housed in a shack alongside the track. Both the storage and day tanks are fitted with immersion type suction heaters through which the fuel oil is drawn by a pump and secondary heater set located within the building to serve the existing two boilers. The extension provides an additional suction heater connected externally to the large storage tank and an additional pump and secondary heater set located within the extension of the building to serve the present and future 60,000 lb. per hr. units.

The steam output of the boiler house is used principally for building heating with some special process uses and is conveyed to the load center, about one-half mile away, through an existing 10 in. steam main which is estimated to have adequate capacity to handle the present and future requirements of the laboratory with the present operating pressure of 125 psi at the plant.

Condensate returns are collected into a 4 in. line which previously entered a return tank for delivery to the existing deaerator serving boilers 1 and 2. With the present extension these returns are diverted to a new return tank from which the older tank level is maintained to satisfy the feed water requirements of the older units while make-up for the entire plant from the laboratory city water system is introduced to maintain level in the new tank which supplies Unit 3 directly.

The laboratory receives electric power from the Long Island Lighting Co. through a single 66 kv feeder and this is stepped down to the 13.8 kv laboratory underground distribution voltage in a substation and switch-house adjoining the boiler house to the east. A 1,000 kva, 13.8/480 v transformer in the substation supplies the boiler house. Extension of this 480 v station service supply to the auxiliary drive motors of the new boiler is effected through an existing spare feeder air circuit breaker in the existing metalclad switchgear.

The heat balance and auxiliary drives are similar in principal to these features on the existing boilers with normal drives generally by electric motors, as being more economical than steam drives in this type of plant, but in case of an emergency interruption to the power supply, turbine driven auxiliaries may be used. The deaerator operates from the 5 psi auxiliary exhaust header and, since some steam is always required, the forced draft fan is provided with a turbine drive only. The induced draft fan is fitted with dual motor and turbine drive, both of which may be employed to share the load if desired for heat balance purposes. A pressure reducing valve serves to supply from the main steam header any deficit of deaerator steam. In the case of the condensate return pumps, two full sized units are installed, one being motor driven and the other turbine driven. A similar arrangement is planned for the future in the case of the boiler feed pumps, but initially the motor driven pump is fitted with a half capacity impeller to improve efficiency when operating with one boiler only. The motor, however, is sized for the future full capacity impeller. The instrument air compressors are both motor driven as one of these may be supplied with power in an emergency from an existing 50 kw gasoline driven engine.

Arrangement of Equipment

The arrangement of equipment in the plant extension is shown on the drawing of Machine Location Plans and Sections. An effort was made in the design of the extension to confine the cross sectional dimensions to agree with those of the existing plant and this objective was met with the exception that it was found necessary to provide a penthouse for the induced draft fan above the rear of the boiler bay. The cross sectional width is thus 37 ft. and the height about 31 ft. with the first bay of 20 ft. length housing the deaerator and most of the auxiliary equipment and the second bay of 24 ft. length housing the boiler, draft fans and instrument air compressors. The main floor is at Gr.78 and a mezzanine floor is provided at Gr. 92 to support the deaerator, condensate return tank and the continuous blowdown equipment.

The condensate return pumps and the boiler feed pumps are located below the deaerator on the main floor together with the fuel oil pump and heater set, boiler gage board and instrument air receiver. Electrical contactors for the motor driven auxiliaries are mounted at this grade along the rear wall of this bay.

As previously mentioned, the induced draft fan is located in a penthouse above the rear of the boiler and supports a venturi type stack extending 30 ft. above the plant roof. The forced draft fan is located on the main floor at the rear of the boiler discharging downward into passages under the furnace floor which convey the air to the wind box at the boiler front. This fan is fitted with an inlet duct leading from an opening in the upper part of the rear wall of the plant with interlocked dampers permitting the use of outside or inside air in any desired proportion. The fan thus assists in ventilation of the building and additional ventilation is secured by means of a roof fan mounted above the deaerator, movable sash at some of the windows and a gravity ventilator in the penthouse roof.

Two instrument air compressors are located on the main floor level at the rear of the boiler and a group of chemical feed tanks and pumps is similarly located in the existing portion of the plant behind boilers 1 and 2.

The existing building is of steel frame construction with cement lime brick walls, precast concrete roof decking and reinforced concrete spread footings. The extension is of similar design except that the walls are of insulated steel-backed aluminum siding.

Structural

The approximate dimensions of the new extension are 37 ft. wide by 44 ft. long with a 19 ft. by 26 ft. penthouse. The building is 31 ft. high from the ground floor to the main roof deck and the penthouse is 13 ft. high. The substructure is of reinforced concrete with spread footings designed for a maximum allowable soil pressure of 16,000 psf. The building consists of a steel frame structure with exterior walls of H. H. Robertson's M-Panel, made up of fluted aluminum exterior sheets, 1-1/2 in. Fiberglas insulation and galvanized sheet metal backing. The roof is of tar and gravel on 1 in. insulation over a precast concrete plank roof decking designed for a live load of 30 psf. Sash is of aluminum and the doors are hollow metal.

The induced draft fan floor beams are encased in concrete to minimize the effect of vibration from the fan. The floor supporting the deaerator is of reinforced concrete and the steel framing is designed to support a live load of 125 psf plus the equipment load.

All platforms are constructed with structural channel stringers, pipe handrail and grating surfaces. The stair treads are of "Feralun".

Structural steel is designed for not less than the minimum requirements of AISC. Reinforced concrete is designed for not less than the minimum requirements of the ACI with ultimate compressive stress at 28 days test of not less than 2,500 psi.

Floor and Roof Drainage

A combined system of floor and roof drainage is provided, including roof boxes and downspouts connecting to underfloor piping serving floor and equipment drains. All drainage from the new extension flows to the storm sewer handling floor and roof drainage from the existing boiler house, and this sewer is diverted to a manhole in the Brookhaven sanitary sewer system.

Ventilation

To supplement in warm weather the ventilation provided by the forced draft fan, a roof type exhaust fan is provided over the deaerator bay. This fan will draw in 24,500 cfm of outside air through low level windows and discharge to atmosphere above the roof. A gravity roof ventilator is provided for the induced draft fan room.

Electrical

The normal incandescent lighting system for the Boiler House Extension is fed from the existing lighting transformers through a new branch breaker in the existing distribution cabinet to a new lighting cabinet "D" located on the "a" line wall between columns 4 and 5. Duplex convenience outlets are provided 3 ft.-6 in. above grade on the three floor elevations 78 ft., 92 ft. and 109 ft. supplied from the same lighting cabinet "D". Emergency incandescent lighting is installed at strategic locations via circuits from existing emergency lighting cabinet "BE" using spare breakers.

120 v single phase power is supplied through a new branch breaker in the existing distribution cabinet and new manual starters to seven fractional horsepower motors for the chemical water treating pumps and agitators.

480 v, 3 phase power is supplied from the existing 1,000 kva station service transformer through an existing spare breaker in metalclad switchgear via a new 500,000 cir mil feeder to the starter group on the "b" line wall between columns 4 and 5. Seven motor driven auxiliaries including two 7-1/2 hp air compressors are normally supplied over this feeder. The two air compressors supplying control air have a manual throwover switch to connect these compressors to the emergency 480 v, 3 phase supply which is fed by an existing 50 kw engine driven emergency generator. A temperature switch in the air line leaving the aftercooler of each air compressor shuts down the compressor motor on high air temperature as may occur upon failure of cooling water supply.

125 v d-c supply is furnished to the annunciator, alarm bell and two solenoid valves from the existing station battery through a spare breaker in the existing direct panel. The induced draft fan is driven by an

electric motor and a steam turbine on the same shaft. A differential pressure switch across the fan closes upon low differential pressure and energizes the two solenoids, tripping the fuel to the boiler and steam to the forced draft fan when the induced draft fan shuts down. This protects the furnace from overpressure and guards against fuel injection with insufficient air supply.

Conduit installation is rigid steel, zinc coated. Wire and cable have oil base insulation.

Fuel Oil System

The 60,000 lb. per hr. boiler has a nominal 2-hour capacity rating of 66,000 lb. per hr. and the fuel oil required at this load is 4,510 lb. per hr. equivalent to about 550 gal. per hr. The fuel oil suction heater is designed for a capacity of 1,400 gal. per hr., thus providing for the present and future 60,000 lb. per hr. boilers plus a margin. This heater is designed on the basis of an oil side fouling factor of .005 to heat the rated capacity of oil from 50°F to 120°F employing 100 psi saturated steam. An oil temperature regulating valve is installed in the steam line to the heater to reduce the heater shell steam pressure at reduced flow rates.

The fuel oil pump and heater set was furnished under the boiler contract and includes a 600 gal. per hr. motor driven pump and associated secondary heater designed to raise the oil temperature from 100°F to 250°F using 100 psi saturated steam and a steam driven pump of the same capacity with associated secondary heater identical to that of the motor driven pump. This set is complete with temperature control regulator and discharge trap on each heater, suction and discharged oil strainers of duplex type, pressure gages and thermometers and devices for maintaining a constant oil discharge pressure of 140 psi by spilling excess oil to a recirculating line. This equipment is all factory assembled and mounted on a steel base plate having space for future installation of an additional motor driven pump and associated heater to serve the future boiler unit, the steam driven pump and heater thus serving as a spare for either unit.

The boiler is fitted with four atomizing steam oil burners with appropriate control valves as further described under the combustion control system. Although the existing boilers have been operating with mechanical atomizing burners at 250 psi oil pressure, these burners are being converted to steam atomizing type and accordingly the lower pressure oil of the new unit can be used, if desired, on the older boilers. A 3/4 in. tie line is provided for this purpose.

Saturated steam at 100 psi pressure has a temperature of about 350°F which is rather high for fuel oil due to the risk of carbonization. Accordingly care should be exercised to see that steam is manually shut off from the heaters when there is no oil flow. The possibility of using a pressure reducing valve and relief valves and designing the heaters to operate on 25 psi steam was considered but not adopted because of the added equipment costs and the fact that operating experience has been satisfactory with the 100 psi steam in the existing plant.

Draft System

The combustion control system is arranged so that the furnace draft is controlled by the forced draft fan while the induced draft fan capacity follows the fuel demand. The capacity of the forced draft fan is varied by speed control, effected by throttling the steam flow to the fan drive turbine, with supplementary control at low loads afforded by manual repositioning of the fan inlet damper. The induced draft fan operates essentially at constant speed because of the motor drive so that its capacity is varied by throttling on the boiler outlet damper. An additional damper at the fan inlet may be repositioned manually to reduce capacity at low loads if this becomes necessary. This fan also has a built-in by-pass damper but it is not expected that this damper will be used in ordinary operation. The manufacturer suggests it be moved to the open position if the fan must be operated on cold air; however, cold air operation should be avoided in general as this type of fan tends to overload the driving motor when handling cold air.

Steam Systems

The 60,000 lb. per hr. steam generating unit is connected through an 8 in. nonreturn valve and steam lead to an extension of the existing 10 in. main steam header. A 4 in. auxiliary steam supply header furnishes steam to the various drive turbines in the plant and to the fuel oil system at full line pressure and through a pressure reducing valve to maintain 5 psi pressure in the auxiliary exhaust header which supplies the deaerator. A 4 in. by 6 in. safety valve serves to discharge to atmosphere any excess steam from the exhaust header in the event the turbine driven auxiliaries have to be operated to an extent exceeding the steam requirements of the deaerator. A safety valve is also provided at each auxiliary turbine exhaust before the exhaust valve.

Condensate Return and Make-Up Systems

A 2,500 gal. condensate return tank is provided into which all condensate returning to the plant is taken and from the bottom of which there are three separate 4 in. lines with shut-off valves at the tank. Two of these lines run respectively to the motor driven and turbine driven condensate return pumps which discharge to the deaerator while the third line runs to the 6 in. boiler feed pump suction line thus serving to by-pass the deaerator. This arrangement provides for replacement of these lines individually without interruption to operation if this becomes necessary as a result of corrosion from the condensate before deaeration. From the deaerator by-pass line a 2-1/2 in. tie supplies condensate to the existing condensate return tank so that the existing boilers in this way obtain their feed water from the new return tank. A level control on the new tank serves to introduce all make-up required by the plant and this is obtained from the laboratory city water system being first passed through the blowdown heat exchanger. The laboratory city water is derived from three wells on the property, one of which is located inside the existing boiler house. This water has a fairly constant temperature of about 52°F and is discharged from the well pump at about 75 psi pressure. A meter is installed to measure the portion used for make-up.

The condensate return pumps discharge through a level control valve to the deaerator which is fitted with an internal vent condenser and mounted on a horizontal storage tank 6 ft. in diameter by approximately 21 ft. long having a capacity of 2,500 gal. to the normal level 9 in. above the center line. The storage tank is equipped with an overflow control valve arranged to open when the storage tank level rises 1-1/2 ft. above the normal point. This valve is located near the end of the overflow line just before it discharges into the blow-off tank so that flashing will not occur ahead of the valve and limit its capacity. In the event of failure of the normal condensate supply to the deaerator, an emergency low level control mounted 18 in. below the center line of the storage tank will serve to introduce make-up water directly to the vent condenser inlet.

The boiler feed pumps take suction from the deaerator storage tank and discharge to the boiler drum through a Copes Flowmatic type level regulator. Each pump has a recirculating line with pressure breakdown orifice which should be kept open when the pump is running to insure that the flow through the pump cannot be reduced below a safe value.

Chemical Feed and Continuous Blowdown Systems

General

Chemical feed and continuous blowdown systems are provided to take care of the present extension and the two existing boilers, as the latter had been operated with intermittent blowdown only and with a briquette chemical feed system. It is anticipated that design margins in this equipment may provide sufficient capacity to take care of a future boiler also, but if experience should indicate otherwise, it would not be difficult to modify the critical parts of the system accordingly.

Sulfite and Caustic Feed System

Provision is made to feed continuously sodium sulfite and caustic solution to the feed water at the outlets of the deaerating heaters to scavenge traces of oxygen not removed by mechanical deaeration and to adjust pH of feed water to afford maximum protection to the feed water piping system, respectively. The equipment consists of one 100 gal. dissolving feed tank complete with dissolving basket and doughnut float to minimize contact of air with the solution, recirculating pump for mixing the solution and two controlled volume pumps each with capacity ranging from .36 to 3.6 gal.per hr.

Phosphate Feed System

The phosphate feed system provides equipment for delivering sodium metaphosphate to the boiler drums to precipitate hardness present in the feed water and prevent scaling of heating surfaces. The sludge formed is removed from the boiler by continuous blowdown. The equipment consists of a 150 gal. phosphate dissolving tank complete with stainless steel wire dissolving basket and motor driven propeller type agitator and three controlled volume pumps, each with capacity ranging from .6 to 6.0 gal per hr.

Continuous Blowdown System

The continuous blowdown system consists of a single flash tank, arranged to discharge flash steam into the 5 psi exhaust header, and into which a line is run from each boiler drum through a flow control valve. These valves may be set accurately to adjust the blowdown rate in accordance with daily boiler water analyses so that the concentration of solids is held to the desired values.

Instruments and Control Systems

The boiler unit is furnished with a complete Bailey Meter Co. combustion control system employing pneumatic control units and including a control board upon which are mounted various operating instruments as well as the control units and the manual-automatic selector valves for the principal controls.

For supply of compressed air to the above pneumatic control systems as well as to the combustion control system of boilers 1 and 2, two motor driven air compressors are provided. Each compressor has a capacity of 28.2 cfm of free air at 100 psi pressure, which should provide the requirements of the plant including one future boiler unit. The size of the compressor was limited to permit the unit to be supplied from the gasoline engine generator during emergency loss of normal electric supply to the station. Accordingly there is a full spare compressor installed and a receiver of about 65 cu. ft. volume is provided which will supply the control air needs for a period of four or five minutes giving time to start the spare unit or the engine driven generator as required.

10. Land Improvements

Approximately 25 acres of land were cleared for the site of the AGS Complex. General excavation of the topsoil and clearing of the area was accomplished in the early stages of the project and finally the disturbed areas were graded and seeded.

Access to the area consists of two main roads from Fifth Avenue, and one road from Rutherford Drive. One of the roads from Fifth Avenue leads to the Linac Building while a second road leads to the East Experimental area, the Target Building and the Service Building with a connection to Rutherford and Cornell Avenue. A branch from the latter road leads into a network of roads within the ring which lead to the West Experimental area and the five air conditioning houses. Another service drive extends west from Upton Road to the two well houses situated in that area.

Parking areas are provided at the Service Building and the Linac Building.

All roads and parking spaces are paved with 4 inch broken stone base on a compacted sand sub-base with a 2 inch bituminous concrete wearing surface. The secondary roads leading to the well houses and air conditioning houses consist of a 2 inch limestone screening on a compacted sand sub-base with a 1-1/2 inch bituminous concrete wearing surface.

At the north and south ends of the Target Building,retaining walls are constructed to support the protective earth fill over the Magnet Tunnel enclosure and behind the Service Building. These walls varied in height up to a miximum of 27 feet immediately adjacent to the Target Building and there was a total of 490 feet constructed.

The storm drainage system includes underground drains to carry surface run-off as well as roof drainage from the various buildings. The system discharges into a large settling basin constructed north of Fifth Avenue. This basin is approximately 160 feet by 185 feet and 20 feet deep. At the Linac the storm drainage is carried off in an existing storm drain which serves the Cosmotron and extends north of Fifth Avenue.

11. Site Utilities

a. Steam Distribution

Steam is supplied to the Complex via a connection to an existing underground steam main which runs along Cornell Avenue and to the Reactor Building, 703, from the central steam plant.

The steam main consists of a 6 inch supply and 3 inch condensate return ric-wil system connected to Manhole No. 12 southwest of Building No. 703 extending northerly to the Service Building. Steam is supplied at 125 psi and is reduced in pressure reducing stations at the buildings.

From the Service Building, steam is distributed as outlined in various sections of this report concerning the individual structures.

b. Electrical Distribution

The Alternating Gradient Synchrotron Project initially installed two 13.8 kv feeders from the Central Switch House to the site of the Project. Subsequently near the close of the Project an additional feeder was installed as one half of a loop feed to the site of the Project and another project - the 80" Bubble Chamber Building.

One of the initial feeders was connected to two breakers at the Service Building. One of these is for a secondary feeder which goes to the RF Power Supply, Substation D at the Linac, and Substation C which feeds the north end of the Target Building and one half of its experimental power loads. The other branch is connected to Substation A which feeds the Service Building.

The second primary feeder was connected to a breaker supplied with the Main Magnet Power Supply. A branch was provided for a secondary feeder to Substation B which feeds the south half of the Target Building and one half of its experimental power loads.

The additional feeder, provided in the latter stages of the project, is connected with a feeder supplied under another project to form a loop which feeds Substation E, east of the East Experimental Building, Substations F_1, F_2, F_3, located northwest of the East Experimental Building, and Substation G, Substation H and the 80" Bubble Chamber Rectifier at the 80" Bubble Chamber Building. The Substations at E, F_1, F_2 and F_3 serve the East Experimental Building with its experimental power loads as well as the Conjunction Area.

All of the 13.8 kv feeders consisted of 3 conductor shielded impregnated paper insulated lead covered, neoprene jacketed cable. The initial feeders used 500,000 cir. mil. conductors and the third feeder used 750,000 cir. mil. conductors. The initial feeders were installed in an existing underground duct bank from the Central Switch House along Cornell Avenue. A new duct bank of 4 ducts was constructed from Cornell Avenue to the Service Building as part of the project. The Third feeder, which was part of the loop system discussed earlier, was installed in existing ducts to the immediate vicinity of the substations where short branches were constructed to tie in the substation and loop switched by means of G & W RALP switches at each of the substations connected.

Under the project the following power was installed:

Main Magnet Power Supply	4000 KVA
RF Power	1000
Substation A	2000
Substation B	1500
Substation B'	2000
Substation C	1500
Substation C'	2000
Substation D	1000
Substation E	2500
Substation F_1	2500
Substation F_2	2500
Substation F_3	2500
Substation G	2500
	27,500 KVA

Note:

Most of these substations were subsequently modified by the addition of cooling fans to obtain higher ratings.

Costs of the substations are included with the various structures which they are related to, not as part of the electrical distribution system.

The Brookhaven National Laboratory has an existing 2400 volt overhead distribution system which services much of the central area. Under the Project this system was extended north along Upton Road to the location of AGS Well No. 1 thence west along the service drive to AGS Well Nos. 2 and 3 to supply power for the pumping equipment.

This extension included wood poles, solid conductor, and step down transformers, from 2400 to 480 volts, located at each well house. Three 25 kva pole mounted transformers were installed at each well house.

c. Central Switchgear

The Brookhaven National Laboratory receives power from the utility, Long Island Lighting Company, via an overhead 69 kv line. The primary is stepped down to 13.8 kv, at the central substation, for distribution underground to the various laboratory facilities.

The Alternating Gradient Synchrotron Project included the installation of two 1200 amp 13.8 kv circuit breakers for two feeders and an enclosure for a new buss connecting switch arranged for a 2000 amp, 13.8 kv incoming breaker in the Central Switch House located on Railroad Avenue.

d. Water Distribution

The yard domestic water system is an extension of existing domestic water piping from the 10 inch loop surrounding the Reactor Building No. 703 to a connection with the existing 8 inch line adjacent to the Waste Concentration Plant Building No. 811. An 8 inch branch extends from this loop to Fifth Avenue and extends to the Linac Building. Another branch extends from this latter line to the West Experimental Area. The system includes branches serving: yard hydrants, building sprinkler systems where installed, and general domestic service.

Fire hydrants are installed adjacent to all major structures except the air conditioning houses.

e. Sewer System

The sanitary sewer system receives waste pumped by sewage ejector pumps in a pressure sewer running from the Service Building in a northeasterly direction to a new manhole No. 4 and a gravity sewer running east from that manhole to connect to the BNL existing sewerage network at manhole No. 203 which is located between Fourth and Fifth Avenues west of Railroad Avenue.

Sewage from the Service Building, Target Building and East Experimental Building is pumped into this system. Sewage from the Magnet Enclosure toilet rooms and the Linac Building is handled by septic tanks and cesspools at each separate location and the costs are included with the appropriate building structure.

f. Telephone System

Telephone service is supplied by a direct burial cable which runs from an existing manhole at Cornell Avenue to a telephone room in the Service Building. This cable consists of 150 pair. From the Service Building, various branches extend through the buildings and Magnet Enclosure.

12. Magnet Cooling Water System

Well Water System

The well water system is designed to supply a maximum of 2,200 gpm of well water for miscellaneous cooling uses throughout the project. The system is fed by three wells located along an east-west axis with the nearest well just east of Upton Road and the other two wells 500 ft. and 1,000 ft. to the west, respectively. The well water supply runs underground to the machine room of the Service Building, where approximately 1,400 gpm passes through the magnet cooling system heat exchanger. Approximately 800 gpm under maximum conditions flows through a pressure reducing valve to the chilled water pump suction header whence it enters the chilled water and power room systems. Minor branches provide for supply to the general water treating equipment, to the demineralizing equipment, and to the aftercoolers of the air compressors. Meters are provided in the main near the service entrance to the building, and in the branch to the pump suction headers. The former meter regulates the rate of chemical feed from the water treating equipment into the well water supply main.

A two-compartment tank is installed outside of the Service Building just north of the machine room. This tank is supported above a concrete-walled enlargement of the utilities tunnel provided for all piping connections to nozzles in the tank bottom, and its elevation is such that the bottom of the tank is at the approximate grade of the machine room roof. Water from the well water system after passing through the magnet cooling system heat exchanger enters the larger, or mix, compartment of the tank; in like manner the water from the chilled water system enters this compartment after passing through the condensers of the package chillers. Water from the mix compartment supplies the suction of the experimental magnet system, from which it eventually discharges to the smaller, or waste, compartment; this compartment also receives return water from the power room system. Surplus water from the mix compartment flows over a weir into the waste compartment from whence all water drains through a long underground line to the diffusion basin 3,000 ft. east of the project. An emergency overflow from the waste compartment discharges to the main project storm sewer. An additional nozzle and piping connection to the waste compartment provides for transfer of waste water from the Cosmotron to the diffusion basin.

Wells

The three wells are each of the shallow well type and were originally sunk to a total depth of approximately 200 feet below grade. Subsequently these wells were reworked to obtain water from a higher strata where the iron content of the water was less.

Well No. 1 has a 14" casing with 20 ft. of 10" stainless steel screen set with its bottom 119 ft. below grade. This well produces 700 gpm. Pump is 5-stage, single speed, deep water turbine type with a 40 horsepower electric motor.

Well No. 2 has a 14" casing with 20 ft. of 10" stainless steel screen set with its bottom at 119 ft. below grade. This well produces 950 gpm. Pump is a 4-stage two-speed deep well turbine type with a 75/33 horsepower electric motor.

Well No. 3 has a 14" casing with 20 ft. of 10" stainless steel screen set with its bottom at 102 ft. below grade. This well produces 700 gpm. Pump is a 5-stage single speed deep well turbine type with a 40 horsepower electric motor.

The total capacity of the system with more than one well pumping is 1,750 gpm.

Well Pump Houses

Three pump houses have been constructed to house the wells and equipment.

These pump houses are 10 ft. by 18 ft. by 8 ft. deep with approximately 2 ft. - 6 in. of the main structure above ground level. The exposed section consists of a concrete block access bulkhead and a 6 ft. square hatchway in the roof of the structure through which the pump or other equipment may be removed as required for maintenance purposes. In each side wall, immediately above the ground, are located eight aluminum ventilated sashes.

Except for the bulkhead, the structure is of reinforced concrete. The hatchway cover is metalclad wood and the roof consists of built-up roofing on a concrete slab.

Mix and Waste Tank Chamber and Support

The mix and waste tank is located close to the "m 17" column line of the Service Building at the junction of the utilities tunnel and the "m" line wall of the Service Building. The bottom of the tank rests on a concrete mat at El. 97 ft., 18 in. higher than the top slab of the chamber below. The entire structure is of reinforced concrete and rests on specially compacted fill. The mat supporting the tank is 10 in. thick and has a diameter of 20 ft. -8 in. The chamber is approximately 20 ft. by 20 ft. by 13 ft. deep and opens into the utilities tunnel on the east side. Access to the chamber is by means of a 2 ft.-6 in. by 3 ft. manhole at El. 96 ft.-6 in.

Settling Basin for Magnet Cooling Water

The settling basin for the magnet cooling water is divided into two 100 ft. by 165 ft. sections to permit cleaning of one while the other is in operation. The bottom of the basin is at El. 56 ft. and the top at El. 68 ft. The concrete headwork at the point of discharge is specifically designed to direct the water into either section of the basin and to reduce to a minimum erosion to the side banks or bottom of the basin. At the upper end, a concrete gutter has been provided to permit surface water to enter the basin without eroding the bank and for the same reason a 30 in. overflow pipe was installed at the lower end of the basin to act as a spillway.

Magnet Cooling System

The magnet cooling system provides cooling water for 240 main magnets, miscellaneous quadrupole and sextupole magnets, and 12 power amplifier units, all located in the Magnet Enclosure or the shielded area in the Target Building.

The system is designed as a closed reverse return system, and constructed entirely of aluminum with deionized water being continuously recirculated. Chemically treated well water as a coolant is supplied to a heat exchanger located in the machine room of the Service Building. Two main circulating pumps are also located in the machine room together with control valves and water demineralizing equipment. A by-pass with 3-way valve and orifice is installed across the heat exchanger for control of supply water temperature, and a by-pass with control valve is installed between the discharge and suction mains to limit pressure differential across the main magnet headers. Orifice flanges are provided to receive flow measuring equipment. Thermometers and gages are installed as required, also wells and tappings for temperature control elements and pressure switches.

The circulating pumps are equipped with recirculation by-passes, and the pump discharge valves have monitor switches to prevent starting with the valves open.

Demineralizing equipment is provided and connected to the system by a shunt piping circuit. This equipment will be used initially for filling the system and has capacity for continuously maintaining the system at specified purity during operation, with intermittent periods for regeneration.

The supply lines pass through the utilities tunnel, drop to the enclosure level, and thence extend completely around the Magnet Enclosure in a clockwise direction, passing finally through the Target Building and terminating in the Magnet Enclsoure, near the point where the drop to the enclosure level occurs. The return line starts at approximately the same point, extends around the Magnet Enclosure in a clockwise direction as far as the north end of the Target Building, where it rises to pass through the Target Building longitudinally at the truss level and thence through the utilities tunnel to the north wall of the Service Building. A spur return line starts at the north end of the Target Building, runs through the shielded area and rises at the south end of the building to join the return main. A cross connection between the end of the supply main and the beginning of the return main with normally closed valve is provided for flushing. An expansion tank is provided at the high point in the system.

Valved branch connections are installed on both mains for all branch connections for main magnets, quadrupole and sextupole magnets and power amplifier units.

Additional branches from mains in the machine room provide for supply and return of water from the magnet cooling system to RF equipment in the power room.

Experimental Magnet Cooling System

This system provides cooling water for experimental magnets in the Target Building, East Experimental Building or in the yard experimental area. The system is designed to supply well water as a coolant with three main circulating pumps located in the machine room of the Service Building taking suction from the mix compartment of the mix waste tank. The system includes parallel supply and return mains running through the utilities tunnel, with supply and return branches running through the equipment tunnel and along the east and north walls of the Target Building, and directly along the west wall, and valved supply and return drops at various columns along these walls. At several columns, supply and return branches extend underground and terminate at flush hydrants scattered around the yard. A pair of branch connections from the equipment tunnel pass underground, and terminate in a pair of valved connections in the Magnet Enclosure south of the Target Building.

The return main from the utilities tunnel connects to the waste compartment of the mix-waste tank. A by-pass with 3-way valve is installed between the supply and return connections to the tank to regulate temperature at the pump suction. A by-pass with control valve is installed between the supply and return connections to the utilities tunnel to regulate pressure differential. Thermometers and gages are installed as required, also wells and taps for temperature control element and pressure switches. The two large circulating pumps are provided with recirculation by-passes, and their discharge valves shall have monitor switches to prevent starting of pumps with valves open.

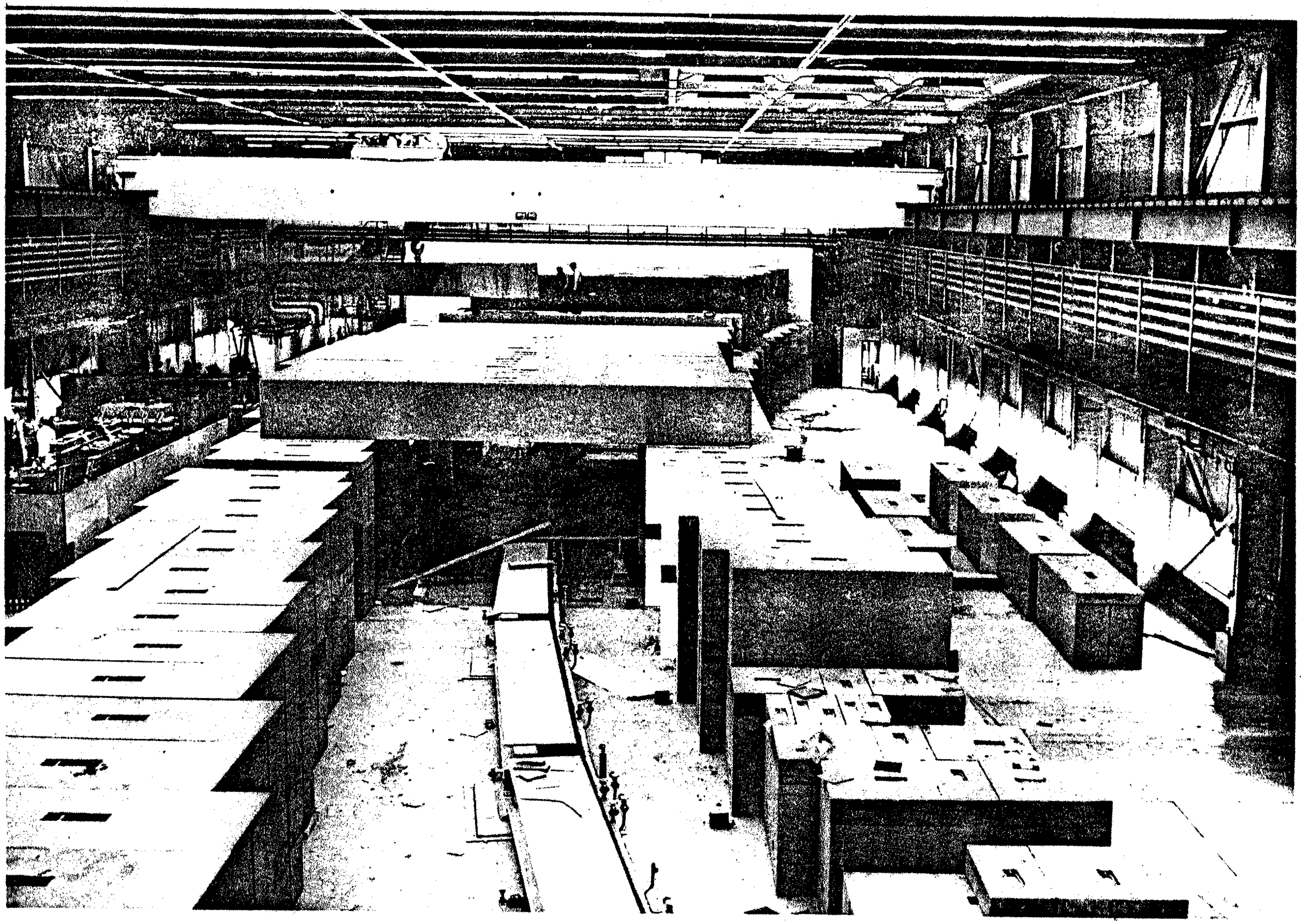


Figure 80
Shielding Block Installation In Target Building

14. Summary of Building Areas and Cubes

		Gross Square Feet		Gross Cubic Feet
Magnet Enclosure		54,920		1,032,680
Tunnel	50,290		974,150	
Air Conditioning Houses	3,350		43,550	
Service Tunnels to Service Bldg.	1,280		14,980	
Target Building		32,450		1,315,290
Building	28,690		1,280,000	
Tunnels for Utilities to Service Building	3,760		35,290	
East Experimental Building		60,000		2,977,060
Linac Building		11,630		211,130
Building	7,130		112,240	
Tunnel	4,500		98,890	
Service Building		62,840		915,700
Mechanical Equipment Building		3,500		59,080
Assembly Building		6,000		153,000
Warehouse		10,220		185,640
Boiler House Addition		2,240		44,430

PART VI - COST DATA

1. Budget History

Schedule 44 Data Sheet - September 9, 1953

Project scoped for a 25 Bev accelerator at a cost of $20,000,000.

Project completion date July, 1959.

Stated that upon completion it was intended to modify the accelerator to obtain 35 Bev from one to two years later.

Schedule 44 Data Sheet - July 18, 1955

Project scoped for a 33 Bev accelerator at a cost of $23,632,000. plus contingency for a total project of $26,000,000.

Project completion date July, 1960.

Schedule 44 Data Sheet - July 1, 1957

Project scope unchanged.

Project cost revised because of price changes to a cost of $26,826,000. plus contingency for a total project of $29,000,000.

Schedule 44 Data Sheet - May 21, 1958

Project scope unchanged.

Project cost revised because of: necessity to carry the personnel to July of 1960, actual price experience and the estimate for beam handling equipment. Estimated cost was $28,690,000. plus contingency for a total project of $29,361,000.

Letter of January 14, 1960 from L. J. Haworth to E. L. Van Horn
Stated that project as scoped to date could be completed at a cost of $28,220,000.

Project scope revised to include a covered Experimental Area, Laboratory Wing for the Service Building, Hydrogen Protection for the Target Building.

Project cost revised to $30,483,000. plus contingency for a total cost of $30,800,000. (AEC used an estimated cost of $30,935,000.)

Offsetting adjustments of $450,000. deductions in funds requested for Accelerator Additions and Modifications as well as Capital Equipment were also made.

On July 28, 1960 the Synchrotron accelerated proton to the design energy.

All costs were accumulated in June, 1964.

Total project cost	$30,605,290.

COMPARISON OF BUDGET ESTIMATES

DIRECT CONSTRUCTION COSTS	1954 (25 Bev)	1955 (33 Bev)	1956	1957	1958	1959 (33 Bev with Scope change)	FINAL
Magnet	3833	6472	6943	6810	6822	6497	6462
Power	1064	1381	1547	1946	2279	2089	1858
Vacuum System	684	649	967	1007	1053	896	897
R.F. System	994	1043	1015	971	965	1066	1065
Injection System	1557	1969	1840	2106	2150	2314	2486
Controls	792	804	651	602	645	650	540
Special Equipment - Shielding	300	540	820	886	987	1075	1039
Magnets & Power	325	325	325	325	540	540	510
Magnet Enclosure	1560	2229	2134	2361	2369	2348	2321
Target Building	575 (2)	723	1195	1177	1185	1385	1451
Experimental Area	465 (2)	229	156	132	257	1856	1918
Linac Building	180	366	460	516	528	527	531
Service Building	1810	1245	1125	1145	1268	1542	1574
Utilities & Land Improvements	750	878	722	740	741	774	844
Machine Cooling	250	343	475	675	705	785	737
Analogue	520	620	606	606	606	464	464
Buildings &Utilities - General	49	54	54	54	73	40	244
TOTAL	15,708	19,870	21,035	22,059	23,173	24,848	24,939
INDIRECT CONSTRUCTION COSTS							
A. Engineering Des. & Constr. Superv.							
Analogue Title II	100	68	68	68	68	68	68
Preliminary - AGS	735	949	894	894	894	894	894
Detailed - AGS	770	786	1333	1507	2123	2153	2128
Preliminary - A/E	50	220	225	225	205	204	204
Detailed - A/E	330	512	522	522	542	710	732
Construction - A/E	75 (1)	253	261	261	261	306	330
SUB-TOTAL	2060	2788	3303	3477	4093	4335	4356
B. General & Administrative							
Analogue Title III	71	50	50	50	50	50	50
Preliminary	175	231	282	283	283	283	283
Detailed	275	217	223	213	349	356	358
Construction	701	476	700	743	742	611	618
SUB-TOTAL	1222	974	1255	1289	1424	1300	1309
TOTAL	3282	3762	4558	4746	5517	5635	5666
TOTAL DIRECT & INDIRECT	18,990	23,632	25,590	26,826	28,690	30,483	30,605
Contingency	1010	2368	1638	2030	671	452	-
TOTAL PROJECT	20,000	26,000	27,228	28,856	29,361	30,935	30,605
Man Years	556	582-3/4	537-3/4	634	710½		695

Notes: (1) Only inspection, Buildings included Superv.
(2) Est. for Cranes, Local Substation, Heavy Power Distribution in 1954 est. only.

FINAL SUMMARY COST REPORT
PROJECT #05-1-54-Y-019-52
ALTERNATING GRADIENT SYNCHROTRON-BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN OFFICE
March 12, 1964

	COSTS INCURRED		
	Material & Contractors	Labor	Total
DIRECT CONSTRUCTION COSTS			
Magnet	5,921,322.	540,203.	6,461,525.
Power	1,599,609.	258,120.	1,857,729.
Vacuum System	785,820.	111,222.	897,042.
R.F. System	812,141.	252,474.	1,064,615.
Injection System	1,681,062.	804,653.	2,485,715.
Controls	394,359.	145,747.	540,106.
Special Equipment-Shielding	1,039,269.	--	1,039,269.
Magnets & Power	509,674.	--	509,674.
Magnet Enclosure	2,320,582.	--	2,320,582.
Target Building	1,450,519.	--	1,450,519.
Experimental Area	1,917,609.	--	1,917,609.
Linac Building	531,024.	--	531,024.
Service Building	1,574,466.	--	1,574,466.
Utilities & Land Improvements	844,359.	--	844,359.
Machine Cooling	736,709.	--	736,709.
Analogue	269,472.	194,213.	463,685.
Buildings & Utilities - General	212,611.	31,891.	244,502.
TOTAL	22,600,607.	2,338,523.	24,939,130.
INDIRECT CONSTRUCTION COSTS			
A. Engineering Des. & Constr. Superv.			
Analogue	4,269.	63,696.	67,965.
Preliminary - AGS	330,848.	536,152.	894,000.
Detailed - AGS	365,744.	1,762,709.	2,128,453.
Preliminary - A/E	204,078.	--	204,078.
Detailed - A/E	731,675.	--	731,675.
Construction - A/E	330,376.	--	330,376.
SUB-TOTAL	1,966,990.	2,389,557.	4,356,547.
B. General & Administrative			
Analogue	790.	49,567.	50,357.
Preliminary	115,222.	167,539.	282,761.
Detailed	66,910.	291,435.	358,345.
Construction	204,746.	413,404.	618,150.
SUB-TOTAL	387,668.	921,945.	1,309,613.
TOTAL	2,354,658.	3,311,502.	5,666,160.
TOTAL DIRECT & INDIRECT	24,955,265.	5,650,025.	30,605,290.

REPRESENTATIVE UNIT COSTS IN TERMS OF INSTALLED TOTAL COSTS BY MAJOR MACHINE CATEGORIES (Includes Spares)

	DOLLARS	DIVIDED BY UNITS	UNIT COSTS
Entire Project	$30,605,290.	33 Bev.	= $927,000./Bev.
Magnets-Main magnets with coils, mtg. hdw. in place	6,087,900.	÷ 246 magnets	= $24,700/Magnet in place
Correcting Magnets	373,600	÷ 62 Units	= $ 6,000/Magnet in place
Power - Main Magnets	1,627,900.	÷ 36,000 kva	= $ 45.00/kva
Main Magnets		÷ 240 magnets	or$6,790/Magnet
Correcting Magnets	229,800.	÷ 1,600 kw	= $144./kw
Correcting Magnets		÷ 60 magnets	= $3,840/Magnet
Vacuum System			
Vacuum Chamber	289,600.	÷ 2648 lin.ft.	= $109./ft.
Vacuum Pumping System with Controls	607,400.	÷ 2648 lin.ft.	= $229./ft.
Vacuum Pumping System		÷ 48 no. of stas	= $12,650./Station
R.F. System			
Power Amplifiers with Cavities & Low Level and Controls	936,800.	÷ 12 stations	= $75,000/Station
		÷ approx.100 Kev/turn	=$9400/kev/Turn
Pickup & Viewing Electrodes	127,800.	÷ 36 positions	= $3,550/Position
Injection System (Linac)			
Ion Source & Pre Accelerator	306,600.	÷ 750 Kev	= $410./Kev
Accel. Tank & Drift Tubes	787,500	÷ 110 lin.ft.	= $7,150./ft.
		124 drift tubes	$6,350./drift tube
Accelerating Section incl. Accel. Tank, Drift tubes, RF, Water, Vacuum, Test Equipment	1,707,100.	÷ 50 Mev	= $34,140./Mev
Injection & Inflector Array	347,900.		= (each)
Total Injection System with Controls	2,485,700.	÷ 50 Mev	= $49,710./Mev
Controls			
Controls - Central	457,600.		= (each)
Communications	82,500.	÷ 98,900 sq.ft. of Bldg. area served	= 84¢/sq.ft.
Machine Cooling including wells	736,700.	÷ 4,000 kw*	= $184./kw
		÷ 2,200 gpm	= $335./gpm
		÷16,000 kw	= $46./kw

*Approx. AGS Dissipative load. Total load including experimental load is approx. 16,000 KW

ANALYSIS OF COSTS

ENGINEERING

	Material & Contracts	BNL Labor	Total
Construction Costs			
Synchrotron	12,171,347	2,306,633	14,477,980
Building and Utilities	10,429,260	31,890	10,461,150
Total	22,600,607	2,338,523	24,939,130
Engineering, Design and Inspection			
Synchrotron	700,861	2,389,557	3,090,418
Building and Utilities	1,266,129	-	1,266,129
Total	1,966,690	2,389,557	4,356,547
Project General & Administrative	387,668	921,945	1,309,613
Total Project			30,605,290

E, D, I & A

A/E Costs	1,266,129	=	12.1% of Buildings Costs
BNL Costs	3,090,418	=	21.4% of Synchrotron Costs
		=	12.4% of All Construction Costs
BNL Project G&A	1,309,613	=	9.0% of Synchrotron Costs
		=	5.2% of All Construction Costs
BNL Costs & Project G&A	4,400,031	=	30.4% of Synchrotron Costs
		=	17.6% of All Construction Costs
Total E,D,I & A	5,666,160	=	22.8% of All Construction Costs

Note: BNL Incremental Overhead included in all BNL Labor above (i.e. Construction and EDI&A) amounts to $742,985 = 15.1% of All Salary Wage & Insurance

= $1070 per man year

ANALYSIS OF COSTS
SYNCHROTRON
MAIN MAGNET SYSTEM

	Material & Contracts	Labor	Total
Total Costs	$5,921,322.	$540,203.	$6,461,525.
Sub Costs			
General	2,100.	1,600.	3,700.
Magnetic Measurements	80,900.	147,500.	228,400.
Main Magnet Coil & Bussing	1,988,400.	25,400.	2,013,800.
Main Magnet & Fittings	3,396,200.	151,900.	3,548,200.
Correcting Magnets	320,500.	53,100.	373,600.
Magnet Steel Testing	600.	600.	1,200.
Test Equipment	41,200.	--	41,200.
Surveying	73,600.	138,200.	211,800.
Controls (Local)	17,700.	21,900.	39,600.

Material & Contracts

General - Misc. Chew Up Material

Magnetic Measurements - Detailed magnetic field measurements on each of 246 magnets to ascertain final positioning for arrangement in the ring. $930/magnet

Approximate costs

Main Magnet Coil & Bussing			
Coils - 4 per magnet 984 total Procurement Cost	$1,761,500.	=	$1,795./each $7,170/magnet
Bussing - 2,648 Lineal ft. of ring	95,700.	=	$36./lin. ft.
Coil Covers	26,800.	=	$109./magnet
Bus Covers	17,100.	=	$6./ft. of ring
Water Manifolds Connections	6,700.	=	$28./magnet
Power Cabling (Installed) from Power Room to Ring	36,900.	=	$177./magnet
Misc. Small parts, fittings, etc.	43,700.	=	
Main Magnet & Fittings			
Magnets 246 total = 3500 tons Procurement Cost	$3,110,300.	=	$12,680./magnet $888./ton
Fittings for Mounting Coils etc.	117,000.	=	$476./magnet
Ball Pads & Leveling Jacks	97,800.	=	$400./magnet
Water Manifolds	15,400.	=	$62./magnet
Misc. - Back leg windings, shims, etc.	55,800.	=	$226./magnet

Material & Contracts - continued

Correcting Magnets				
25 Quadrupoles	Procurement Costs	$110,100.	=	$4,450. each
37 Sextupoles		140,200.	=	3,800. each
Water Connections (62)		3,200.	=	52./magnet
Median Plane Kickers (96)		6,100.	=	63./each
62 Magnet Support Structures		24,500.	=	395./magnet
Power Connections (62)		6,700.	=	110./magnet
End Covers (67)		14,200.	=	210./magnet
Misc. (62)		15,500.	=	250./magnet
Test Equipment				
Long term Capital Equipment - Procurement Cost		41,200.		
Surveying				
Jigs, fixtures & Misc. Supplies		48,800.		
Contract Labor (U.S. Coast & Geodetic)		24,800.		
Controls				
Current Markers		17,700.		

ANALYSIS OF COSTS

SYNCHROTRON

POWER SYSTEM

	Material and Contracts	Labor	Total
Total Costs	$1,599,609.	258,120.	1,857,729
Sub Costs			
General	9,100.	27,500.	36,600.
Main Magnet Power Supply	1,355,500.	150,100.	1,505,600.
Correcting Magnets Power Supply	218,900.	10,900.	229,800.
Magnet Prototype & Exp. Power Supply	600.		600.
Special Power Systems		300.	300.
Cooling Systems	14,400.	68,600.	83,000.
Test Equipment	900.		900.
Controls	200.	700.	900.

Material & Contracts

General - Misc. Chew Up	9,100.	
Main Magnet Power Supply		
Main Power Supply 36,000 KVA	$1,039,000. =	$28.9/kva
Main Power Supply Series Inductor	129,800.	
Main Power Supply Loading Resistor	4,400.	
Main Power Supply Installation-Rigging & Mechanical	43,200.	
Main Power Supply Installation-Electrical	81,800.	
Misc. & Spares	57,300.	
Correcting Magnets Power Supply		
Cabling around ring for 24 Quads & 36 Sextupoles(Mat'l only)	47,700.	
Power Supply-double ended 1600 KW DC	135,800. =	$85./KW
Power Supply-Installation-Rigging & Mechanical	5,000.	
Misc. parts, controls, electrical hook up(material)	30,400.	
Cooling Systems		
Misc. Materials for Main Magnet Cooling Supply Systems	14,400.	

ANALYSIS OF COSTS

SYNCHROTRON

VACUUM SYSTEM

	Material and Contracts	Labor	Total
Total Costs	$785,820.	$111,222.	$897,042
Sub Costs			
General	1,400.	12,600.	14,000.
Vacuum Chamber	254,900.	20,700.	275,600.
Pumping System	379,900.	47,000.	426,900.
Controls	149,600.	30,900.	180,500.

Material and Contracts
General - Misc. Chew Up

Vacuum Chamber			
246 Magnet Chambers		153,500.	
78 Straight Sections 5 ft. long		16,300.	
12 Straight Sections 10 ft. long		2,700.	
Supports for Chambers		16,100.	
150 Exp. Joints		24,800.	
"O" Rings		6,100.	
Port boxes and Viewing Ports		9,400.	
Sectionalizing Valves		2,800.	
Misc.		23,200.	
Total Cost for 2648 lineal ft.	=	$254,900	= $96./ft.
Vacuum Pumping System - Ring			
58 Evapor ion pumps (48 + 10 spares)		172,800.	
Evapor ion pumps Spare Parts		22,500.	
Roughing Pumps		64,300.	
Valving		26,000.	
48 Pumping Station boxes and hardware		42,900.	
Misc. Material, Spares, Interconnections		51,400.	
Total Cost for 48 Pumping Stations (less controls)		$379,900.	= $7,920./Station
Controls			
48 Pumping Station Controls		149,600.	= $3,120./Station

ANALYSIS OF COSTS
SYNCHROTRON

RF SYSTEM

	Material and Contracts	Labor	Total
Total Costs	$812,141.	$252,474.	$1,064,615.
Sub Costs			
General	200.	300.	500.
Frequency Control	400.		400.
Power Amplifiers	481,000.	96,300.	578,300.
Cavities	226,100.	53,300.	279,400.
Low Level R F	9,500.	18,600.	28,100.
Pick Up and Viewing Electrodes	71,400.	56,400.	127,800.
Saturating Supply	200.		200.
Controls	23,300.	26,600.	49,900.

Material and Contracts

General - Misc. Chew Up

Frequency Control - Most costs in with other items.

Power Amplifiers (12 Stations @ 8000 volts per station) plus 1 spare		
Control DC Power Supply incl. Installation	85,500.	
RF Driver	66,400.	
Cabling to Power Supplies 13 Units	12,900.	= $1,000/Station
13 Power Amplifiers (12 + 1 spare)	263,400.	= $20,200/Station
Miscellaneous	52,800.	= $4,070/Station
Cavities (12 + 1 spare)		
Ferrite Rings	110,000.	= $8,460/Station
Balance of Assemblies	116,100.	= $8,930/Station
Low Level RF		
12 Stations	9,500.	= $800./Station
Pick up and Viewing Electrodes	71,400.	
36 Positions plus 2 spares		= $1,900/Station

ANALYSIS OF COSTS
SYNCHROTRON
INJECTION SYSTEM

	Material and Contracts	Labor	Total
Total Costs	$1,681,062.	$804,653.	$2,485,715.
Sub Costs			
General	11,700.	25,600.	38,300.
Ion Source & Pre Accelerator	172,600.	134,000.	306,600.
Accel. Tube and Focus Magnets	539,700.	247,800.	787,500.
R.F. System	453,500.	164,500.	618,000.
Vacuum System	166,900.	58,700.	225,600.
Inflector	238,200.	109,700.	347,900.
Water System	17,700.	4,900.	22,600.
Test Equipment	15,100.		15,100.
Controls	64,600.	59,500.	124,100.

Material and Contracts	
General - Misc. Chew Up Material	
Ion Source & Pre Accelerator	
Cockcroft Walton 750 KV Generator	$57,000.
Cockcroft Walton Installation incl.rails,power,gen.	6,700.
Vacuum Equipment 2 ea. Evapor Ion & 3 mech.	12,100.
Ion Source & Balance of Equipment	96,800.
Accelerator Tanks & Focusing Magnets & Drift Tubes	
Linac Tanks 11 Sections including Supports	192,000.
Ball tuners - 58 ea. (2 spares)	15,300.
124 Drift tubes with power supplies,quad.Mag.water conn.	332,400.
RF System	
Klystron Failure	82,000.
4 FTH Cavities with Triodes + 3 spare Triodes (Procurement)	123,100.
Pulsed Amplifier	24,900.
Misc. Hardware, Components, etc.	223,500.
Vacuum System	
Mechanical Pumps 12 each	40,400.
Evapor-Ion Pumps 17 each	53,800.
Piping, valves, etc.	72,700.
Injection & Inflector System	
Evapor Ion Pumps 3 each	8,400.
9 Magnets, Stands, Support Girders	44,600.
3 ea. Viewing Boxes	19,200.
Vacuum Chamber & Special Section at Conjunction to Ring	16,300.
Misc. including inflector & assoc. power supply	149,700.
Water System	
Misc. Piping connections, flow meters, valves, controls	17,700.
Test Equipment	
Long term Capital Equipment-Procurement Cost	15,100.
Controls	
Evapor Ion Pump Controls	37,000.
Misc. Parts for Controls and Console	27,600.

ANALYSIS OF COSTS

SYNCHROTRON

CONTROLS

	Material and Contracts	Labor	Total
Total Costs	$394,359.	$145,747.	$540,106.
Sub Costs			
General Controls	346,900.	110,700.	457,600.
Communications	47,500.	35,000.	82,500.
Material and Contracts			
General Controls			
Cable, control multi-conductor & coaxial	81,900.		
Cable Tray	7,600.		
Closed Television Equipment for Viewing	22,000.		
Misc. Equipment etc.& Installation Costs	235,400.		
Communications			
Telephone & P.A. System Equipment	47,500.		

ANALYSIS OF COSTS

SPECIAL EQUIPMENT

SHIELDING

	Material and Contracts	Labor	Total
Total Costs	$1,039,269.	-	$1,039,269.
Sub Costs			
Target Building Shielding	841,400.	-	841,400.
Other Shielding	197,900.	-	197,900.

Material and Contracts Breakdown

Target Building - Shielding 14,788 tons Concrete	841,400.	= $57./Ton
Other Shielding		
Linac-200 tons Concrete	16,300.	= $81./Ton
Beam Paths 2740 Tons Concrete	147,000.	= $53.60/Ton
2400 Tons Steel (Surplus Armor Plate)	34,600.	= $14.80/Ton (See note)

Note: Transfer of Armor Plate at No Cost - Costs shown are for shipping and rework.

ANALYSIS OF COSTS

SPECIAL EQUIPMENT

MAGNETS & POWER

	Material and Contracts		Labor	Total
Total Costs	$509,674.		$ --	$509,674.
Material and Contracts - Breakdown				
6 ea. Power Supplies @ 300 kw	130,500.	=	21,750/Power Supply	
4 ea. Power Supplies @ 450 kw	119,200.	=	29,800/Power Supply	
4 ea. Bending Magnets 18 D 72	121,950.	=	30,500/Magnet	
2 ea. Quadrupole Magnets 12 Q 30	35,800.	=	17,900/Magnet	
8 ea. Long Quadrupole Magnet 8 Q 48	100,400	=	12,550/Magnet	

ANALYSIS OF COSTS

BUILDINGS AND UTILITIES

		Total Cost
Magnet Enclosure		2,320,582.
Magnet Foundations includes: Piles, Pile Driving, Girders Pile Caps, Setting Girders, Linac for Ring & Linac	397,628.	
Crane - 20 Ton Bridge Crane	23,410.	
Magnet Ring Tunnel includes: Tunnel, Access Tunnels, Escape Hatches, Air Conditioning Houses, Unit Costs 2,405 lineal ft. @ $790/ft. 54,920 square ft. @ 34.59/sq.ft. 1,032,680 cubic ft. @ 1.84/cu. ft.	1,899,544.	
Target Building		1,450,519.
Crane - 40 Ton Bridge Crane	59,364.	
Building includes: Building, Substation B, Sub- station C, Service Tunnels, H_2 Protection, Unit Costs 32,450 sq. ft. @ 42.87/sq. ft. 1,315,290 cu. ft. @ 1.06/ cu. ft.	1,391,155.	
Experimental Area		1,917,608.
West Experimental Outdoor Area - includes paving, Underground ducts Unit Costs 2,265 sq. yds. @ 7.99/sq. yd.	18,100.	
Cranes - 2 each @ 40 Ton	103,885.	
East Experimental Building includes: Helium System complete with Compressors etc., Emergency Generators, Air Compressors and MC Centers. Substations E,F_1, F_2 and F_3 Unit Costs 60,000 square feet @ 28.88/sq. ft. 2,977,060 cubic feet @ 0.58/cu. ft.	1,732,968.	
Mechanical Equipment Building exclusive of Helium Compressors, Emergency Generators, Air Compressors & MC Centers Unit Costs 3,500 square feet @ 17.90/sq. ft. 59,080 cubic feet @ 1.06/cu. ft.	62,655.	

ANALYSIS OF COSTS

BUILDINGS AND UTILITIES

		Total Cost
Linac Building		$ 531,024
Crane - 10 Ton	18,650	
Building - includes: Building, Tunnel, Substation D Unit Costs 11,630 sq. ft. @ 44.06/sq. ft. 211,130 cu. ft. @ 2.43/cu. ft.	512,374	
Service Building		1,574,466
Crane - 30 Tons	25,022	
Building - includes: Building, Motor Generator Foundations Substation A Unit Costs 62,840 sq. ft. @ 24.65/sq. ft. 915,700 cu. ft. @ 1.69/cu. ft.	1,549,444	
Boiler House Building (Total cost of Building including amount charged to Medical Research Center - $15,000 = $74,147) Unit Costs 2,240 sq. ft. @ 33.10/sq. ft. 44,430 cu. ft. @ 1.67/cu. ft.		59,147
Boiler House Equipment (Total cost including amount charged to Medical Research Center Project - $35,000 = $173,849) 60,000 lb per hour		138,849
Land Improvements		354,038
Clearing, Grading, Seeding	72,414	
Drainage Basin	18,800	
Storm Sewers	62,984	
Roads, Paving, Parking Lots	83,840	
Retaining Walls	101,400	
Septic Tanks & Cesspools at Escape Hatches and Linac	14,600	

ANALYSIS OF COSTS

BUILDINGS AND UTILITIES

	Total Cost
Steam Distribution 1000 lineal feet 6" Steam Main and 3" Condensate Return	35,090.
Electric Distribution 14,200 lineal feet, 13.8 kva 500 & 750 MCM P&L Cable 1,100 lineal feet underground duct and manholes	187,600.
Central Switchgear 2 each 1200 Amp 500 MVA Breakers	19,638.
Water Distribution 3200 feet 8" transite 700 feet 6" transite pipe with fire hydrants.	43,305.
Sewer Distribution 900 feet 6" x 8" Transite and VT pipe with manholes	4,270.
Communications 1,000 Lineal feet 150 pair telephone cable	2,420.
Machine Cooling Water Systems Includes: 3 Wells, Well Pump Houses, Well Water Supply line. Magnet Cooling Water System, Experimental cooling water system in Target Building and Outdoor Experimental Area. Mix waste tank, water discharge line to Recharge Basin & Recharge Basin.	736,709.

ANALYSIS OF COSTS

BUILDINGS AND UTILITIES

		Total Cost
Building & Utilities General		$244,502.
General - Buildings Misc. costs, telephone, supplies, construction photos, electrical labor	49,400.	
Warehouse Unit Costs 10,220 sq. ft. @ 6.65/sq.ft. 185,640 cu. ft. @ 0.37/cu.ft.	68,000.	
Equipment Assembly Building		
Crane - 20 Ton Gantry	25,865	
Building Unit Costs 6000 sq. ft. @ 16.87/sq. ft. 153,000 cu. ft. @ 0.66/cu. ft.	101,235	

ANALYSIS OF COSTS

ANALOGUE

	Material and Contracts	Labor	Total
Total Costs	$412,172.	$194,213.	$606,385.
(Include $142,700 for material transferred to Oak Ridge and credited against Project)			(142,700)
Net Total Cost			$463,685.

A.C.S. PROJECT
(FINAL) SUMMARY STATEMENT

February 28, 1964

	PRELIMINARY DESIGN			DETAILED DESIGN			CONSTRUCTION			TOTAL
	Salaries, Wages, Insurance G & A	M&S Travel, Sub-Contrs. SH. Services	Total	Salaries, Wages Insurance G & A	M&S Travel Sub-Contrs. SH. Services	Total	Salaries, Wages Insurance G & A	M&S Travel Sub-Contrs. SH. Services	Total	EXPENSE
A.G.S.										
Magnet	206,533.53	132,280.59	338,814.12	417,240.26	148,732.58	565,972.84	540,203.34	5,921,321.88	6,461,525.22	7,366,312.18
Power	43,476.56	15,666.77	59,143.33	119,509.45	6,075.52	125,584.97	258,120.16	1,599,608.43	1,857,728.59	2,042,456.89
Vacuum System	20,092.38	29,429.76	49,522.14	99,529.48	47,461.30	146.990.78	111,221.88	785,820.61	897,042.49	1,093,555.41
R.F. System	69,723.52	61,988.64	131,712.16	267,547.00	50,348.15	317,895.15	252,473.97	812,140.96	1,064,614.93	1,514,222.24
Injection System	199,159.78	74,931.41	274,091.19	704,356.8	94,713.82	799,070.64	804,653.45	1,681,061.23	2,485,714.68	3,558,876.51
Controls	8,097.45	60.45	8,157.90	116,846.61	1,768.76	118,615.37	145,746.82	394,359.11	540,105.93	666,879.20
Special Equipment				3,968.87	4,968.62	8,937.49		707,561.33	707,561.33	716,498.82
General	167,538.90	115,222.41	282,761.31	291,435.38	66,909.71	358,345.09	413,404.46	204,746.30	618,150.76	1,259,257.16
Bldgs., Util.& Land Impr. Gen'l	16,068.98	16,490.74	32,559.72	33,710.22	11,675.87	45,386.09	31,890.55	212,611.02	244,501.57	322,447.38
Sub Total	730,691.10	446,070.77	1,176,761.87	2,054,144.09	432,654.33	2,486,798.42	2,557,714.63	12,319,230.87	14,876,945.50	18,540,505.79
A/E		204,077.97	204,077.97		731,675.40	731,675.40		330,376.08	330,376.08	1,266,129.45
Bldgs., Util.& Land Improvements:										
Magnet Enclosure										
Target Building								2,320,581.88	2,320,581.88	2,320,581.88
Experimental Area								1,450,519.21	1,450,519.21	1,450,519.21
Linac Building								1,917,608.51	1,917,608.51	1,917,608.51
Service Building								531,024.17	531,024.17	531,024.17
Gen'l Util.& Land Improvements								1,574,466.12	1,574,466.12	1,574,466.12
Boiler House Bldg.										
Boiler House Equipment								59,147.19	59,147.19	59,147.19
Land Improvements								138,849.12	138,849.12	138,849.12
Steam Distribution								354,038.83	354,038.83	354,038.83
Electrical Distribution								35,090.00	35,090.00	35,090.00
Central Switchgear								187,600.07	187,600.07	187,600.07
Water Distribution								19,638.36	19,638.36	19,638.36
Sewer Distribution								43,305.60	43,305.60	43,305.60
Communications								4,270.00	4,270.00	4,270.00
Magnet Cooling								2,420.00	2,420.00	2,420.00
Shielding - Target Building								736,709.01	736,709.01	736,709.01
Sub-Total								841,381.85	841,381.85	841,381.85
								10,216,649.92	10,216,649.92	10,216,649.92
Analogue				63,695.55	4,268.72	67,964.27	243,779.63	270,261.81	514,041.44	582,005.71
Contingency										
TOTAL	730,691.10	650,148.74	1,380,839.84	2,117,839.64	1,168,598.45	3,286,438.09	2,801,494.26	23,136,518.68	25,938,012.94	30,605,290.87

A. G. S. PROJECT - STATEMENT OF EXPENSE

February 28, 1964

PRELIMINARY DESIGN

A/C		Salaries, Wages Insurance Expense	General & Administrative Expense	S.W.I. & G & A Expense	Shared Services Expense	Travel Expense	M & S Sub-Contract Expense	Sh.Services, Travel, M&S Sub-Contracts Expense	Total Expense	Combined Total
79301	Magnet & Coils - General	53,228.06	23,382.13		12,827.22	697.28	18,047.64		108,182.33	
79311	Magnetic Measurements	74,041.01	12,047.59		2,856.37		13,746.56		102,691.53	
79321	Magnet Models	35,571.64	6,063.72	206,533.53	5,868.55	883.15	56,100.17	132,280.59	104,487.23	338,814.12
79331	Main Magnet Coil & Busing	1,358.34	250.57			17.00	17.25		1,643.16	
79341	Main Magnet & Fittings	139.75	22.33				53.15		215.23	
79361	Magnet Steel Testing	367.94	60.45			213.77	24.52		666.68	
79390	Test Equipment						20,927.96		20,927.96	
79401	Power - General	17,309.00	2,761.51	43,476.56		233.48	108.14	15,666.77	20,412.13	59,143.33
79431	Model, Proto & Exper.Pow.Supp.	20,130.88	3,275.17		758.13	1.50	14,565.52		38,731.20	
79501	Vacuum System - General	9,545.80	1,588.28		1,462.20	117.61	585.84		13,299.73	
79511	Vacuum Chamber	7,809.92	1,148.38	20,092.38	2,609.31	14.44	12,759.49	29,429.76	24,341.54	49,522.14
79590	Test Equipment						11,880.87		11,880.87	
79601	R.F. System - General	10,684.35	3,693.31		200.13	5.70	389.10		14,972.59	
79621	Power Amplifiers	26,509.41	4,116.33		331.26		1,100.06		32,057.06	
79625	Power Amps - Power Supply			69,723.52			11,976.32	61,988.64	11,976.32	131,712.16
79626	Power Amps - Prototype				976.43		15,600.36		16,576.79	
79631	Cavities	21,344.36	3,375.76		1,186.10	36.50	25,521.20		51,463.92	
79690	Test Equipment						4,665.48		4,665.48	
79701	Injection System - General	48,432.21	12,099.33		4,642.19	178.79	9,555.44		74,907.96	
79711	Ion Source & Preaccelerator	15,475.47	2,495.88		1,523.20	83.59	5,177.95		24,756.09	
79721	Test Accel.Tube & Assoc. Equip.	38,190.88	6,191.24	199,159.78	7,939.89		24,213.88	74,931.41	76,535.89	274,091.19
79731	Accel.Tubes & Focus Magnets	44,935.88	7,334.45		650.01	40.76	7,323.80		60,284.90	
79741 & 9	R.F. System (for final install)	20,789.41	3,215.03		517.39	63.11	8,850.77		33,435.71	
79790	Test Equipment						4,170.64		4,170.64	
79901	Controls - General	6,944.15	1,153.30	8,097.45		34.74	25.71	60.45	8,157.90	8,157.90
79990	Test Equipment									
79045	Analogue - Operations	31,139.23	5,059.42		1,941.60	12.04	21,716.66		59,868.95	
79049	General - Theoretical	5,909.15	1,032.35			33.56	31,053.69		38,028.75	
79051	- Administrative	103,844.23	20,265.47	167,538.90	5,203.38	4,696.21	270.23	115,222.41	134,279.52	282,761.31
79070	- Temp.Construction		289.05		1,861.63		19,990.93		22,141.61	
79085	- Small Tools						15,359.89		15,359.89	
79090	- Equipment						13,082.59		13,082.59	
79101	Bldgs.,Util.& Land Impr-General	14,075.48	1,993.50	16,068.98	8,892.96	2,501.87	5,095.91	16,490.74	32,559.72	32,559.72
79101	A/E Contract						204,077.97	204,077.97	204,077.97	204,077.97
	TOTAL	607,776.55	122,914.55	730,691.10	62,247.95	9,865.10	578,035.69	650,148.74	1,380,839.84	1,380,839.84

DETAILED DESIGN

A. G. S. PROJECT - STATEMENT OF EXPENSE

February 28, 1964

A/C		Salaries, Wages Insurance Expense	General & Administrative Expense	S.W.I. & G & A Expense	Shared Services Expense	Travel Expense	M & S Sub-Contracts Expense	Sh. Services, Travel, M & S Sub-Contracts Expense	Total Expense	Combined Total
79302	Magnet & Coils - General	99,160.64	14,353.51		157.20	531.41	1,778.93		115,981.69	
79312	Magnetic Measurements	145,982.57	23,123.66		3,501.60	.50	19,845.07		192,453.40	
79322	Magnet Models	46,355.72	7,179.72		3,430.60	479.63	106,324.17		163,769.84	
79332	Main Magnet Coil & Busing	13,026.48	1,844.45		859.20	1,052.11	767.27		17,549.51	
79342	Main Magnet & Fittings	1,364.70	213.44	417,240.20	33.60	1,930.41	470.10	148,732.58	4,012.25	565,972.84
79352	Correcting Magnets	47,186.40	6,296.70		667.80		1,055.58		55,206.48	
79362	Magnet Steel Testing	7,908.34	1,247.41		17.90	78.56	1,281.11		10,533.32	
79392	Test Equipment	-	-				4,149.55		4,149.55	
79394	Controls	1,785.13	211.39				320.28		2,316.80	
79402	Power - General	73,399.35	10,876.74			252.69	25.07		84,553.85	
79412	Main Magnet-Power Supply	8,538.41	1,149.70			495.63	677.01		10,860.75	
79422	Corr. Mag. -Power Supply	-	-			97.32	61.22		158.54	
79432	Mag.,Proto.& Exper. Power Supply	14,524.55	2,299.80	119,509.45	2,430.60		1,730.18	6,075.52	20,985.13	125,584.97
79442	Special Power System	47.95	7.75				3.76		59.46	
79452	Cooling Systems	7,278.57	1,119.78			231.12	70.92		8,700.39	
79494	Controls	237.90	28.95				-		266.85	
79502	Vacuum System - General	38,612.80	5,867.58		595.20	834.49	3,164.43		49,074.50	
79512	Vacuum Chamber	25,611.97	3,876.88		2,562.90	1,048.51	14,267.46		47,367.72	
79522	Vacuum Pumping System	20,282.35	3,167.98	99,529.48	268.80	141.53	18,365.02	47,461.30	42,225.68	146,990.78
79592	Test Equipment	-	-		-	-	5,459.29		5,459.29	
79594	Controls	1,879.66	230.26		16.80	9.50	727.37		2,863.59	
79602	R.F. System - General	3,412.94	443.76		27.20		709.33		4,593.23	
79612	Frequency Control System	274.78	40.24				6.65		321.67	
79622	Power Amplifiers	91,821.15	13,700.22		4.20	162.05	13,304.57		118,992.19	
79627	Power Amps. - Power Supply	-	-				1,204.83		1,204.83	
79628	Power Amps. - Prototype	-	-		21.60	1.40	9,578.34		9,601.34	
79632	Cavities	52,959.34	8,133.25	267,547.00	79.20	2,515.44	4,638.84	50,348.15	68,326.07	317,895.15
79634	Cavities - Prototype	4,913.08	756.32		1,790.40		3,756.58		11,216.38	
79642	Low Level - R.F.	31,769.21	4,221.07			262.67	1,598.42		37,851.37	
79652	Pickup & Viewing Electrodes	41,445.26	5,997.73		111.40		3,388.91		50,943.30	
79662	Saturating Supply	5,991.18	860.91				5,595.92		12,448.01	
79692	Test Equipment	-	-				1,234.79		1,234.79	
79694	Controls	713.81	92.75				355.41		1,161.97	
79702	Injection System - General	55,603.08	8,247.04		450.20	432.45	428.64		65,161.41	
79712	Ion Source & Preaccelerator	60,283.84	9,026.53		2,466.40		3,123.43		74,894.20	
79722	Test Accel.Sect & Assoc.Equip	143,219.36	22,429.94		8,664.20	217.12	41,812.69		216,343.31	
79732	Accel.Tube & Focus Magnets	129,059.63	19,355.37		2,864.81	630.06	14,384.52		166,294.39	
79742	R.F. System (for final install)	94,990.20	13,851.31	704,356.82	185.40	6,276.17	6,279.74		121,582.82	
79752	Vacuum (for final install)	9,892.78	1,303.89				81.75	94,713.82	11,278.42	799,070.64
79762	Inflector System	114,790.41	15,010.98		44.40		5,830.26		135,676.05	
79772	Water System	5,769.39	678.34			294.35	-		6,742.08	
79792	Test Equipment	-	-				249.79		249.79	
79794	Controls	747.80	96.93				3.44		848.17	
79812	Special Equipment - Shielding	-	-		27.20		1,425.00		1,452.20	
79822	Experimental Magnets	3,557.93	410.94	3,968.87			3,146.81		7,115.68	
79842	Ejection	-	-				369.61	4,968.62	369.61	8,937.49
79902	Controls - General	95,577.91	13,635.91	116,846.61		358.15	430.17		110,002.14	
79912	Communications	6,691.58	941.21				980.44	1,768.76	8,613.23	118,615.37
79048	General - Theoretical	7,086.14	1,089.60		1,413.28	71.92	15,591.47			
79052	Administrative	246,995.10	36,264.54	291,435.38	21,080.61	10,271.97	(3,030.09)		311,582.13	
79086	Small Tools	-	-				13,017.31	66,909.71	13,017.31	358,345.09
79092	Test Equipment	-	-				8,493.24		8,493.24	
79102	Bldgs. Util.& Land Imprs.-General	30,878.33	2,831.89	33,710.22	2,313.40	872.03	7,990.44	11,675.87	45,386.09	45,386.09
79102	A/E Contract	-	-				731,675.40	731,675.40	731,675.40	731,675.40
	Analogue	43,686.45	20,009.10	63,695.55	3,627.75	-	640.97	4,268.72	67,964.27	67,964.27
	TOTAL	1,835,314.17	282,525.47	2,117,839.64	60,207.85	29,549.19	1,078,841.41	1,168,598.45	3,286,438.09	3,286,438.09

A. G. S. PROJECT - STATEMENT OF EXPENSE

CONSTRUCTION

February 28, 1964

A/C		Salaries, Wages Insurance Expense	General & Administrative Expense	S.W.I. & G & A Expense	Shared Services Expense	Travel Expense	M & S Sub-Contract Expense	Sh. Services, Travel, M&S Sub-Contracts Expense	Total Expense	Combined Total
79303	Magnet & Coils - General	1,355.93	202.67		892.54	801.47	445.76		3,698.37	
79313	Magnetic Measurements	129,585.86	17,913.95		13,634.40	8.27	67,274.80		228,417.28	
79333	Main Magnet Coil & Busing	22,535.02	2,822.85		113.40	9,221.22	1,979,051.16		2,013,743.65	
79343	Main Magnet & Fittings	134,203.30	17,708.04		6,455.40	15,771.63	3,374,016.52		3,548,154.89	
79353	Correcting Magnets	47,570.01	5,565.24	540,203.34	563.60	376.73	319,606.81	5,921,321.88	373,682.39	6,461,525.22
79363	Magnet Steel Testing	552.33	72.87				657.26		1,282.46	
79393	Test Equipment						41,187.26		41,187.26	
79395	Surveying	121,891.16	16,328.22		8,037.53	436.24	65,085.76		211,778.91	
79397	Controls	19,696.88	2,199.01		235.80		17,448.32		39,580.01	
79403	Power - General	24,459.59	3,006.79		215.60	26.91	8,887.01		36,595.90	
79413	Main Magnet - Power Supply	133,488.27	16,606.42		3,830.70	4,908.27	1,346,761.75		1,505,595.41	
79423	Corr. Magnet - Power Supply	9,755.15	1,166.90		1,758.20	201.93	216,954.92		229,837.10	
79433	Mag., Proto. & Exper. Power Supply						560.55		560.55	
79443	Special Power Systems	270.04	28.92	258,120.16			32.33	1,599,608.43	331.29	1,857,728.59
79453	Cooling Systems	60,799.56	7,787.59		1,662.12	5.60	12,759.01		83,013.88	
79493	Test Equipment						882.04		882.04	
79497	Controls	665.48	85.45				161.49		912.42	
79503	Vacuum System - General	11,212.00	1,334.76			220.26	1,254.71		14,021.73	
79513	Vacuum Chamber	18,493.38	2,190.09	111,221.88	6,017.09	2,226.10	246,613.82		275,540.48	
79523	Vacuum Pumping System	42,021.21	5,033.15		993.60	314.72	378,570.82	785,820.61	426,933.50	897,042.49
79597	Controls	27,715.37	3,221.92		603.00	58.98	148,947.51		180,546.78	
79603	R.F. System - General	313.43	39.60				184.33		537.36	
79613	Frequency Control System				12.00		400.08		412.08	
79623	Power Amplifiers	86,894.93	10,371.08		2,957.60	1,319.36	476,760.86		578,303.83	
79633	Cavities	47,172.93	6,102.27	252,473.97	2,746.00	1,117.58	222,270.15		279,408.93	
79643	Low Level - R.F.	16,607.19	1,948.70				9,474.32	812,140.96	28,030.21	1,064,614.93
79653	Pickup & Viewing Electrodes	50,145.68	6,208.79		5,676.00	13.60	65,709.22		127,753.29	
79663	Saturating Supply	30.14	3.60				219.16		252.90	
79697	Controls	23,879.47	2,756.16		174.00		23,106.70		49,916.33	
79703	Injection System - General	23,045.79	2,598.80		1,564.40		11,081.92		38,290.91	
79713	Ion Source & Preaccelerator	118,602.03	15,438.46		14,689.00	96.25	157,733.39		306,599.13	
79733	Accel. Tube & Focus Magnets	221,773.83	25,948.92		46,035.60	5,690.79	488,010.68		787,459.82	
79743	R. F. System (for final install)	146,903.57	17,637.58	804,653.45	9,871.00	2,009.63	441,652.01		618,073.79	
79753	Vacuum (for final install)	52,610.31	6,126.43		1,231.40	183.78	165,504.81	1,681,061.23	225,656.73	2,485,714.68
79763	Inflector System	97,936.72	11,713.11		20,596.50	409.48	217,204.34		347,860.15	
79773	Water System	4,395.12	514.86		637.00	16.36	17,072.70		22,636.04	
79793	Test Equipment						15,144.87		15,144.87	
79797	Controls	53,426.52	5,981.40		2,655.60		61,969.72		124,033.24	
79813	Special Equipment - Shielding				3,359.00		194,528.04	197,887.04	197,887.04	197,887.04
79823	Experimental Magnets				1,263.00		508,411.29	509,674.29	509,674.29	509,674.29

A. G. S. PROJECT - STATEMENT OF EXPENSE

CONSTRUCTION - contined

February 28, 1964

A/C		Salaries, Wages Insurance Expense	General & Administrative Expense	S.W.I. & G & A Expense	Shared Services Expense	Travel Expense	M & S Sub-Contract Expense	Sh. Services Travel, M&S Sub-Contracts Expense	Total Expense	Combined Total
79903	Controls - General	99,757.91	10,989.10	145,746.82	60,699.35	59.79	286,074.22		457,580.37	
79913	Communications	31,488.07	3,511.74		5,980.00	567.00	40,978.75	394,359.11	82,525.56	540,105.93
79053	General - Administrative	365,593.23	45,744.95		36,157.10	414.51	34,731.46		482,641.25	
79073	Construction	630.54	89.65		1,227.20		1,321.72		3,269.11	
79087	Construction Tools & Equipment			413,404.46			19,099.10		19,099.10	
79093	Installed Equipment						111,795.21	204,746.00	111,795.21	618,150.76
79047	Analogue Disassembly	1,149.19	196.90				-		1,346.09	
79074	Warehouse Building						67,976.04	67,976.04	67,976.04	67,976.04
79075	Equipment Assembly Building						127,092.35	127,092.35	127,092.35	127,092.35
79103	Bldgs, Util.& Land Impr.-General	28,472.62	3,417.93	31,890.55	4,014.73	745.90	12,782.00	17,542.63	49,433.18	49,433.18
79103	A/E. Contract						330,376.08	330,376.08	330,376.08	330,376.08
79113	Magnet Enclosure				2,514.40		2,318,067.48	2,320,581.88	2,320,581.88	2,320,581.88
79123	Target Area				3,845.60		1,446,673.61	1,450,519.00	1,450,519.21	1,450,519.21
79133	Experimental Area				4,683.40		1,912,925.11	1,917,608.51	1,917,608.51	1,917,608.51
79143	Linac Building				1,940.55		529,083.62	531,024.17	531,024.17	531,024.17
79153	Service Building				6,648.44		1,567,817.68	1,574,466.12	1,574,466.12	1,574,466.12
79183	Boiler House Building				394.81		58,752.38	59,147.19	59,147.19	59,147.19
79193	Boiler House Equipment				20.50		138,828.62	138,849.12	138,849.12	138,849.12
79203	Yard Work				19,154.80		334,884.03	354,038.83	354,038.83	354,038.83
79213	Steam Distribution						35,090.00	35,090.00	35,090.00	35,090.00
79223	Electrical Distribution						187,600.07	187,600.07	187,600.07	187,600.07
79233	Central Switchgear						19,638.36	19,638.36	19,638.36	19,638.36
79243	Water Distribution					5.60	43,300.00	43,305.60	43,305.60	43,305.60
79253	Sewer Distribution						4,270.00	4,270.00	4,270.00	4,270.00
79263	Communications						2,420.00	2,420.00	2,420.00	2,420.00
79273	Magnet Cooling				4,894.50		731,814.51	736,809.01	736,709.01	736,809.01
79283	Shielding - Target Bldg.				1,878.80		839,503.05	841,381.85	841,381.85	841,381.85
	Analogue	186,849.25	56,930.38	243,779.63	44,601.45	830.73	224,829.63	270,261.81	514,041.44	514,041.44
	TOTAL	2,463,949.01	337,545.25	2,801,494.26	357,136.71	48,058.69	22,731,323.28	23,136,518.68	25,938,012.94	25,938,012.94

Notes:

(1) Salaries, Wages, Insurance, G&A - G&A Includes Project General and Administrative and BNL incremental overhead prorated by $ to each account.

(2) Shared Services - Labor cost incurred by use of BNL service groups such as Riggers, Laborers, Central Machinists, etc.

(3) Systems - Item of General - Costs of miscellaneous supplies not directly chargeable to sub-accounts.

SCHEDULE OF

COMMITMENTS AND EXPENSE

ACTUAL
(in 1000 Dollars)

Fiscal Year	Preliminary Design Commitments	Preliminary Design Expense	Detailed Design Commitments	Detailed Design Expense	Construction Commitments	Construction Expense	Total Commitments	Total Expense
1954	180	149	72	72	372	214	624	435
1955	682	626	371	95	669	447	1,722	1,168
1956	537	592	550	494	2,048	1,396	3,135	2,482
1957	3	11	832	1,120	11,217	3,353	12,052	4,484
1958	(20)	-	617	633	1,780	5,174	2,377	5,807
1959	(1)	3	405	421	3,431	7,711	3,835	8,135
1960	-	-	371	257	3,182	3,494	3,553	3,751
1961		-	60	179	2,229	2,566	2,289	2,745
1962		-	4	11	767	1,237	771	1,248
1963		-	5	4	191	272	196	276
1964		-	(1)	-	52	74	51	74
	1,381	1,381	3,286	3,286	25,938	25,938	30,605	30,605

PART VII - PERFORMANCE DATA

1. Factors Affecting Progress and Costs

As already shown, there were two major factors which affected the overall progress and cost of the project. The first was the decision in 1955 to eliminate the two step plan to achieve a 33 Bev Accelerator by first constructing a 25 Bev Accelerator and then to modify it at a later date to obtain higher energies. The second major factor was the decision in late 1959 - early 1960 to increase the scope by adding a large enclosed experimental area where originally only outdoor areas had been provided.

Studies undertaken in 1954 resulted in an increase in the aperture of the magnets as well as an increased cross section. These changes which were required for technical considerations resulted in almost doubling the amount of steel required and a commensurate increase in the estimate.

The cost of the magnet power supply increased due to the larger core section of the magnets as well as due to a change in the repetition rate for magnet pulsing from 12 to 20 times per minute. The estimate also proved to be somewhat low both for the main power supply and the auxiliaries.

The original conception of the vacuum chamber changed due to the larger aperture which was selected as well as magnetic measurements which were undertaken with various designs. As a result, the cost of the vacuum system was materially affected.

The cost of the injection system showed a substantial increase over the original estimate. This was due in part to poor estimating arising from lack of experience on a structure of this complexity - principally of the linear accelerator section itself and the inflector.

The original estimates for the amount of shielding required proved to be entirely too little both for the machine itself and for the one external beam provided under the project. Subsequent study and the increase in length of the Target Building, where the ring is shielded by moveable high density concrete shielding, substantially increased the amount of shielding and the costs. The quantities increased from 4900 tons to 20,100 tons.

The design of an experimental beam for an accelerator operating at the energies of the AGS was not undertaken for the initial estimates. As the project developed and experimental requirements became better defined, the beam transport equipment which was necessary for the first beam, increased in amount and showed a commensurate increase in cost.

The Magnet Enclosure as originally conceived was increased in cross-section which resulted in an increase in costs. The cost of the precise foundations for the magnet supporting system was underestimated.

The Target Building increased in length in order to better accomodate emergent beams and due to the increased shielding requirements it also increased in height. A further factor which affected its ultimate costs was the advances made in research technology which resulted in the development of hydrogen bubble chambers. The use of these devices was almost unknown in 1954 but by the time the accelerator was nearly completed, their use was clear and extensive provisions were added as part of the expanded 1960 scope to accommodate the explosive gas hazards.

The Experimental Areas as originally conceived were limited to paved areas outside the Target Building. As part of the expanded scope in 1960 a whole new structure was added to this project. This building was a direct result of the advancements made in research technology and the increased complexity of beam transport and particle detection devices.

The Linac Building doubled in size over the original concept in order to accommodate the linear accelerator whose complexity was considerably underestimated originally. As the design of the linear accelerator proceeded and the special requirements for its auxiliaries could be fully established, the size of the building had to increase.

The principal increase in the Service Building from the 1955 estimates was an increase in scope for additional laboratory space which was included in the expanded scope for the whole project outlined in early 1960.

The machine cooling system was originally estimated for a 2000 KW cooling load but ultimately the loads increased to upwards of 4000 KW which had a proportionate effect on costs. This was ascribed to the increased magnet apertures, greater complexity of the accelerator auxiliaries and the importance of maintaining dimensional stability of the ring. Hence very stringent temperature controls were instituted.

The costs of the architect-engineer effort increased only about one-third as much as the increase in the cost of the structures and shielding over the 1955 estimate. To some extent this was because of the fact that little additional costs were incurred with an increase in the shielding quantity.

The estimated costs for design of the machine systems by the Brookhaven staff increased over those shown originally because of higher pay scales due to wage escalations as well as a 25% increase in the total man-years of effort, some of which is attributable to the decision to proceed with the full energy accelerator rather than the two step program which included estimates of manpower for the first step only in the original proposal.

It is of interest to note that during the period of the main building construction effort, i.e. 1954 to 1958, the Engineering News Record Construction Cost Index rose from December, 1953 at 713 to December, 1957 at 888 or 24% and the Building Cost Index for the same dates rose from 507 to 591 or 17%.

Further, the costs of machinery, parts and electrical equipment cost index as reported by Marshall & Stevens, Inc. for the period from 1954 to 1960 rose from an index of 194.6 to 252.1 or 29-1/2% for a yearly average of 4.2%.

It is also of interest to note that during the period from 1954 to 1960 there was considerable escalation in basic wages. At Brookhaven National Laboratory the average annual salary for all employees increased 47-1/2% over the 1954 rate.

The progress of the project was extended by the factors discussed above in two ways. The original proposal in 1953 contemplated that the synchrotron would require 5 to 6 years for construction and predicted that it could be completed in FY 1959 with beam testing to continue in FY 1960. This was later revised (May, 1958) to indicate that full acceleration would be attained in the summer of 1960. This delay was attributed to the inability to recruit qualified personnel for design effort, the diversion of key personnel for rework of the Cosmotron, and the underestimate of the complexity of auxiliary and supporting equipment. Another factor not previously mentioned was the failure of a subcontractor to develop a Klystron for use in the Linac RF system which forced the redesign of the system to accept a triode of foreign origin which was being developed for the CERN synchrotron. This resulted in some delays in the Linac completion.

In spite of these factors, acceleration to design energy was obtained in July, 1960.

Completion of all the buildings and facilities as originally conceived was accomplished by the time acceleration was obtained. Nonetheless the overall project completion was extended by the revised scope, previously discussed, which added additional structures to the project scope in January, 1960.

SCHEDULE OF MANPOWER

A. BNL PERSONNEL ASSIGNED DIRECTLY TO PROJECT

Fiscal Year	Man Months by Category of Personnel					Man Months by Category of Effort			
	Scientific & Professional	Design	Technical	Administrative	Total	Preliminary Design	Detailed Design	Construction	Total
1954	138	22	101	32	293	155	64	74	293
1955	309	101	340	139	889	516	36	338	889
1956	261	143	376	178	958	536	393	29	958
1957	302	165.5	394.5	183	1045	-	1003	42	1045
1958	365	167	562	204	1298	-	831	467	1298
1959	389	216	916	228	1749	-	542	1207	1749
1960	396	187	1012	244	1839	-	276	1563	1839
1961	36.5	29	179	43.5	288	-	39	249	288
1962	-	-	-	-	-	-	-	-	-
1963	-	-	-	-	-	-	-	-	-
Total Man Months	2,196.5	1,030.5	3,880.5	1,251.5	8,359	1,207	3,184	3,969	8,359
Total Man Years	183	86	323	104	696	100	265	331	696

B. ARCHITECT ENGINEER

Fiscal Year	Man Months
1954	-
1955	34
1956	142
1957	275
1958	124
1959	18
1960	56
1961	5
1962	-
1963	-
1964	-
Total	654

C. CONSTRUCTION CONTRACTORS

Fiscal Year	Man Months
1954	-
1955	155
1956	502
1957	1,430
1958	1,094
1959	142
1960	54
1961	603
1962	142
1963	16
1964	11
Total	4,149

SCHEDULE OF PROGRESS

1954 Month End.	Preliminary Design Schedule	Preliminary Design Actual	Detailed Design Schedule	Detailed Design Actual	Construction Schedule	Construction Actual	
1/30	Started		Started				
2							
3							
4							
5							
6							
7	not		not				
8	reported		reported				
9							
10			6.5	7.0	2.6	2.3	
11			7.1	7.1	3.0	2.6	
12			7.1	7.1	3.2	3.0	
1955							
1			7.9	7.8	3.5	3.5	
2			8.1	8.0	3.6	3.6	
3			10.7	10.7	3.8	3.8	
4			13.6	13.7	3.8	3.8	
5			16.4	15.8	3.8	3.8	
6			19.2	18.5	3.9	3.9	
7			20.6	21.4	4.2	4.2	
8			21.4	21.4	3.9	3.9	
9			21.4	21.4	4.2	4.1	
10			21.4	21.4	4.4	4.6	
11			21.4	21.4	4.5	5.2	
12			21.4	21.4	4.7	5.7	
1956							
1			21.7	21.7	6.0	6.0	
2	Completed						
3				23.0	7.0	7.2	
4			30.0	30.0	9.1	8.8	
5			34.3	34.3	10.3	9.9	
6			62.5	46.0	10.0	11.4	
7				60.6		12.3	
8				65.6		13.0	
9				69.2		14.5	
10			63.0	63.0	13.4	13.4	Revised
11			68.0	68.0	14.4	15.0	Schedules
12			71.0	70.0	15.5	14.9	
1957							
1			73.0	70.2	17.0	15.0	
2			79.0	76.0	18.0	16.4	
3			89.0	79.0	20.0	17.3	
4			93.0	82.0	21.0	20.4	
5			94.0	84.0	24.0	20.9	
6			94.0	84.0	26.8	23.0	
7			81.0	81.0	24.0	24.0	Revised Schedules
8			84.0	84.0	26.6	26.2	
9			87.0	88.5	29.1	28.7	
10			90.0	90.5	32.0	30.8	
11			93.0	90.0	34.0	32.3	
12			96.0	91.5	36.5	32.8	

SCHEDULE OF PROGRESS - continued

1958 Month End.	Preliminary Design Schedule	Preliminary Design Actual	Detailed Design Schedule	Detailed Design Actual	Construction Schedule	Construction Actual	
1			97.0	93.5	39.0	35.0	
2			98.0	93.7	42.1	35.3	
3			98.5	94.6	44.2	39.2	
4			99.0	94.7	46.3	40.5	
5			99.5	94.8	49.8	42.1	
6			80.0	80.0	42.2	42.2	Revised
7			81.0	80.8	44.0	42.5	Schedules
8			83.0	82.0	48.0	45.2	
9			84.0	83.5	51.5	47.0	
10			85.0	84.7	54.5	50.6	
11			86.0	85.8	57.5	55.2	
12			87.3	86.8	60.5	58.1	
1959							
1			88.3	87.8	64.0	62.6	
2			89.0	89.2	68.0	65.0	
3			90.0	89.6	72.0	67.9	
4			91.0	89.6	75.0	74.3	
5			91.5	91.7	78.0	73.2	
6			92.0	91.8	81.0	76.7	
7			92.5	92.5	83.0	80.2	
8			93.5	93.8	85.0	81.9	
9			94.5	94.8	87.0	82.0	
10			95.3	95.1	89.0	83.2	
11			95.5	95.3	90.1	85.1	
12			96.0		93.0	85.4	
1960							
1			97.0		95.0		
2			97.5	96.2	96.0	88.0	
3			98.5		97.0		
4			93.9	92.6	84.7	84.7	Revised Schedule
5			94.5	94.3	85.2	85.2	for Scope Change
6			96.0	96.6	85.5	87.7	
7			97.2	98.6	85.6	85.6	
8			98.8	98.8	86.0	85.6	
9			99.2	99.2	86.8	86.7	
10			100.0	99.4	87.9	87.4	
11				99.6	88.6	88.3	
12				99.8	89.2	88.8	
1961							
1				100.0	90.2	90.0	
2					91.0	90.0	
3					92.5	91.8	
4					92.8	93.2	
5					95.5	94.5	
6					97.0	95.3	
7					96.9	96.1	
8					98.0	96.5	
9					98.0	97.0	
10					98.0	97.5	
11					98.2	98.0	
12					98.3	98.1	

SCHEDULE OF PROGRESS - continued

1962 Month End.	Preliminary Design Schedule	Preliminary Design Actual	Detailed Design Schedule	Detailed Design Actual	Construction Schedule	Construction Actual	
1					98.4	98.2	
2					98.4	97.8	
3					97.0	97.0	Schedules
4					97.3	97.3	Revised
5					97.4	97.4	
6					98.7	98.7	
7					98.8	98.8	
8					99.4	99.4	
9					99.4	99.4	(last AEC report)
10						99.4	Assembly Bldg.
11						99.4	& Warehouse
12						99 4	not started.
1963							
1						99.4	
2						99.5	
3						99.5	
4						99.5	
5						99.5	
6						99.6	
7						99.6	
8						99.7	
9						99.7	
10						99.8	
11						99.8	
12						99.9	
1964							
1						100.0	

PART VIII - RELATED PROJECTS

1. 80" Bubble Chamber Building Project

   Budget Project No. 05-1-61-F-001-52

2. Accelerator and Reactor Additions and Modifications

   Budget Projects (several) FY 1960 to FY 1965

APPENDIX A

ARCHITECT-ENGINEER CONTRACTS AND PURCHASE ORDERS

Contract No.	Contractor & Address	Contract For	Work Started	Work Completed	Amount of Contract
CS-36	Sidney B. Bowne & Son 161 Willis Ave., Mineola, N.Y.	Engineering Services Contract	December 1958	October 1, 1960	$ 1,000.00
P.O. 56162	Byrne Associates So. Broadway, New York 4, N.Y.	Engineering Services For Addition to Service Building	December 15, 1958	January 31, 1958	5,500.00
S-259	Stone & Webster Engineering Corp. Boston, Massachusetts	Engineering Services Contract	July 28, 1954	November 30, 1963	1,259,629.45

APPENDIX B

CONSTRUCTION CONTRACTS

Contract No.	Contractor & Address	Contract For	Work Started	Work Completed	Amount of Contract
CS- 1	Combustion Engineering, Inc. 200 Madison Ave., N.Y. 16, N.Y.	Steam Generator Unit for Boiler House Extension	February 1955	October 19, 1955	$ 70,679.77
CS- 2	Belmont Iron Works 22nd St. & Washington Ave. Philadelphia, Pa.	Structural Steel for Boiler House Extension	June 15, 1955	June 29, 1955	11,321.90
CS- 3	A. Munder & Sons 28-10 38th Ave., L.I.C., N.Y.	Install Exterior Wall Panels Boiler House Extension	May 20, 1955	October 19, 1955	8,695.00
CS- 4	Anderson Construction Company 615 Jericho Turnpike Huntington Station, N. Y.	Completion of all architectural and structural work for Boiler House Extension	Aug. 30, 1955	February 10, 1956	37,691.29
CS- 5	Charles A. Mulligan, Inc. 11 First Ave., Central Islip, NY	Electrical work for Boiler House Extension	May 10, 1955	October 2, 1955	10,399.00
CS- 6	Eugene J. Brandt & Co., Inc. 847 Eleventh Ave., N.Y. 19, N.Y.	Piping for Boiler House Extension	July 21, 1955	December 9, 1955	51,361.15
CS- 8	Richmond Asbestos Co. 54-18 43rd St. Maspeth, N.Y.	Heat Insulating Material for Boiler House Extension	October 21, 1955	January 15, 1956	8,089.51
CS- 9	South Shore Contracting & Dredging Corp., 100 West Ave., Patchogue NY	Clearing and Rough Grading for Service Building Area	August 28, 1955	October 29, 1955	8,972.55
CS-10	Spencer, White & Prentis, Inc. 10 E. 40th St. N.Y. 16, N.Y.	Driving Structural H-Beam Piles	Sept. 6, 1955	Sept. 24, 1955	9,003.22
CS-11	White Construction Co., Inc. 95 Madison Ave., N.Y., N.Y.	Service Building & Associated Yard Work	Sept. 30, 1955	February 5, 1957	1,088,840.13
CS-12	Roreck Construction Co., Inc. 162 Central Ave., Bethpage, N.Y.	Clearing, Stripping and Rough Grading	January 27, 1956	March 27, 1956	31,674.50
CS-13	Belmont Iron Works 22nd & Washington Ave. Phila.,Pa.	Structural Steel for Target & Linac Buildings	March 15, 1956	June 11, 1957	199,609.46
CS-14	Western Foundation Corporation 2 Park Avenue, N.Y. 16, N.Y.	Pile Driving	April 23, 1956	June 20, 1956	59,846.38
CS-15	Mike Stiriz, Inc. 537 E. Main St., Patchogue, N.Y.	Time & Material Work	April 26, 1956	August 31, 1957	3,880.14
CS-16	White Construction Co., Inc. 95 Madison Ave., N.Y., N.Y.	Concrete Work & Drainage for Magnet Enclosure & Linac Tunnel	Sept. 23, 1956	March 19, 1957	887,241.60
CS-17	Cross Island Electric Contracting Marine St., Farmingdale, N.Y.	Electrical Work to relocate Machine Shop in Service Building	October 1, 1956	December 9, 1956	5,342.66

Contract No.	Contractor & Address	Contract For	Work Started	Work Completed	Amount of Contract
CS-18	L & E Electric 222 Cedar Avenue, Patchogue, N.Y.	Electrical Work to Install Feeders in Service Building	October 22, 1956	November 4, 1956	$ 1,240.00
CS-20	Malan Construction Corporation 2 Park Avenue, New York	General Contract for Magnet Enclosure, etc.	February 20, 1957	May 29, 1958	3,112,974.00
CS-21	D. E. Electric Company, Inc. 82 Chestnut St., Rockville Center NY	Installation of Power Feeders for Magnet & Vacuum Testing	February 4, 1957	February 10, 1957	2,946.00
CS-22	Precast Building Sections, Inc. 21 E. 40th St., N.Y. 16, N.Y.	Target Building-Shielding for AGS	July 29, 1957	April 25, 1958	831,107.17
CS-24	Fred. S. Robbins, Inc. P.O. Box 67, Babylon, N.Y.	Install Cold Water & Drain Lines Assembly Area - Service Bldg.	February 25, 1957	March 8, 1957	1,204.00
CS-25	John H. Reetz, Inc. Marine Street, Farmingdale, NY	Acoustical Ceilings for Rooms 107 and 211	March 2, 1957	March 27, 1957	600.00
CS-27	Lee Dennison, Inc. Port Jefferson Station, N.Y.	AGS Warehouse	October 5, 1957	February 28, 1958	27,525.50
CS-28	C. W. Lauman & Company, Inc. Bethpage, N.Y.	Wells and Well Pumping Equipment	April 23, 1957	May 24, 1958	80,465.75
CS-29	Mike Stiriz, Inc. 537 E. Main St., Patchogue, N.Y.	Clearing, Grading & Concrete Work for Magnet Cooling Water Settling Basin	May 15, 1957	December 10, 1957	17,980.00
CS-31	Phillip Formel Company 45 East Putnam Ave., Greenwich, Conn.	Concrete Foundation for Main Magnet Power Supply Generator Set	February 17, 1958	April 30, 1958	32,447.00
CS-32	L. A. Wenger Contracting Co., Inc. 87 W. Merrick Rd., Amityville, N.Y.	Completion of Power Room for AGS	April 25, 1958	December 30, 1958	98,622.00
CS-34	D. E. Electric Company, Inc. 82 Chestnut St., Rockville Center, NY	Electrical Power & Control Installation for Linac, etc.	May 4, 1958	August 10, 1958	7,276.00
CS-35	Traynor & Hansen Corporation 19-02 38th St. L.I.C., N.Y.	Rigging & Millwrighting for Main Magnet Power Supply	October 19, 1958	May 15, 1959	39,000.00
CS-37	Charles A. Mulligan 11 First Ave., Central Islip, NY	Completion of Main Magnet Power Supply Installation and Main Power Cables	February 9, 1959	August 9, 1959	99,869.48
CS-38	Layne - New York Company, Inc. 150 Denton Ave, New Hyde Park, N.Y.	Testing and Rehabilitation of Well	February 18, 1959	May 15, 1959	14,596.00
CS-39	L. A. Wenger Contracting Co., Inc. 93 W. Merrick Rd. Amityville, N.Y.	Extension of Existing Service Bldg.	April 15, 1959	December 16, 1959	81,700.00
CS-40	L. A. Wenger Contracting Co., Inc. 93 W. Merrick Rd. Amityville, N.Y.	Miscellaneous Concrete Work and Series Inductor Foundation	May 1, 1959	August 19, 1959	3,345.00

Contract No.	Contractor & Address	Contract For	Work Started	Work Completed	Amount of Contract
CS-41	Layne - New York Company, Inc. 150 Denton Ave., New Hyde Park, N.Y.	Rehabilitation of Wells - AGS 2 and AGS 3	May 10, 1959	September 3, 1960	$ 21,683.00
CS-42	Virginia Metal Products, Inc. 355 Lexington Ave., N.Y., N.Y.	Demountable Partition to Enclose M-G Set in Power Room	May 16, 1959	August 12, 1959	7,164.00
CS-43	Traynor & Hansen Corporation 19-02 38th Street, L.I.C., N.Y.	Rigging of Series Inductor	July 7, 1959	August 5, 1959	4,200.00
CS-44	Anderson Construction Co., Inc. 687 Jericho Turnpike East Huntington Station, N.Y.	Foundation for Correcting Magnets M-G Set, etc.	Sept. 26, 1959	November 4, 1959	4,510.00
CS-45	Traynor & Hansen Corporation 19-02 38th St. L.I.C., N.Y.	Load, Haul and Set in Place, Power Supply for Correcting Magnets	Oct. 12, 1959	November 4, 1959	3,800.00
CS-46	Layne- New York, Inc. 150 Denton Ave., New Hyde Park, NY	Construction of Test Well	Feb. 12, 1960	June 4, 1960	4,750.00
CS-47	Virginia Metal Products, Inc. 355 Lexington Ave., N.Y. 17, N.Y.	Demountable Partition to Enclose Corr. Magnet Power Supply M-G Set	Feb. 7, 1960	June 8, 1960	3,439.00
CS-48	Bel Air Industries, Inc. Green Spring Drive, Timonium, Md.	Install (2) Removable Floor Systems	May 10, 1960	June 28, 1960	7,033.76
CS-49	American Bridge Div.-U.S. Steel Corp. 1413 Statler Office Building Boston 16, Massachusetts	Structural Steel Framing for East Experimental Building & Laboratory Addition to Service Building	June 1, 1960	January 24, 1961	255,856.13
CS-50	The Brandt Corporation 50-20 25th St. L.I.C., N.Y.	Install Component Equipment for Hydrogen Protection-Target Bldg.	June 12, 1960	March 23, 1961	108,824.00
CS-51	Carl E. Holgren, Inc. 16 Prospect Court, Freeport, N.Y.	Piping, Fittings & Valves for Magnet Cooling Water Systems	June 29, 1960	October 26, 1960	7,652.00
CS-52	Charles A. Mulligan 11 First Ave. Central Islip, N.Y.	Hydrogen Protection & Experimental Power Distribution - Target Bldg.	July 11, 1960	November 22, 1960	37,058.37
CS-53	Bowman Steel Corporation P.O. Box 2129, Pittsburgh Pa.	Metal Exterior Walls and Steel Roof Decking for East Experimental Bldg.	July 20, 1960	February 11, 1961	87,644.27
CS-54	Anderson Construction Co., Inc. 801 Jericho Turnpike East Huntington Station, N.Y.	Concrete Foundations for East Experimental Building	August 1, 1960	November 15, 1960	46,300.57
CS-55	Malan Construction Corporation 2 Park Avenue, New York 16, N.Y.	General Contract for East Experimental Building	Sept. 20, 1960	November, 1961	956,783.95
CS-56	Anderson Construction Co., Inc. 801 Jericho Turnpike East Huntington Station, N. Y.	Laboratory Addition to Service Building	December 2, 1960	October 22, 1961	295,124.77

Contract No.	Contractor & Address	Contract For	Work Started	Work Completed	Amount of Contract
CS-61	Carrier Air Conditioning Company 385 Madison Ave. New York, N.Y.	Absorption Refrigeration Machine for Laboratory Addition to Service Bldg.	Feb. 10, 1961	September 13, 1962	$ 18,336.00
CS-62	Jukar Construction Corporation 53 Chambers St. New York 7, N.Y.	Access Road to Ring and Electrical Ducts	April 17, 1961	May 10, 1963	34,695.00
CS-65	M. K. Lacey & Company, Inc. 6 Redington St., Bayshore, N.Y.	Electrical Utility Work for East Experimental Building	July 24, 1961	May 29, 1962	89,091.30
CS-66	S & S Air Conditioning Corp. 396 West John St., Hicksville NY	Install (3) M-G Sets in Mechanical Equipment Building	July 25, 1961	October 11, 1961	9,888.00
CS-67	Guldi Electric Construction Co., Inc. 124 Hazelwood Ave. Westhampton Beach N.Y.	Install 1,500 ft. of Control Cable Tray	Sept. 12, 1961	October 3, 1961	1,570.00
CS-68	S & S Air Conditioning Corp. 396 W. John St. Hicksville, NY	Fabricate & Install Dampers in Exhaust Fan Curbs-Target Bldg.	Sept. 28, 1961	November 19, 1963(terminated)	2,520.00
CS-69	J. J. Haggerty, Incorporated Rogers Ave., Westhampton, N.Y.	Pave Area from Existing Paved Area to Nitrogen Tank	Sept. 19, 1961	Sept. 29, 1961	250.00
CS-70	White Construction Co., Inc. 305 East 45th St. N.Y. 17, N.Y.	Completion of Conjunction Section and Associated Yard Work	Nov. 30, 1961	December 17, 1962	63,500.00
CS-71	Metal Wall Corporation 47-21 35th St., L.I.C., N.Y.	Removable Type Steel Partions with Doors and Glazing-E. Experimental Building	Dec. 15, 1961	January 26, 1962	2,836.00
CS-72	I.M. Solomon Company, Inc. 396 W. John St. Hicksville, N.Y.	Revise Condenser Water Piping for Refrigeration Machine Lab Addition Air Conditioning Room	Jan. 8, 1962	March 14, 1962	2,800.00
CS-88	Anchor Steel Structures 1433-38th St. Brooklyn, N.Y.	Prefabricated Addition to A.G.S. Warehouse	October 5, 1962	March 25, 1963	26,152.00
CS-95	Fellow Brown Contracting Corp. 1472 Broadway, New York	Prefabricated Scientific Assembly Building	April 10, 1963	August 14, 1963	68,900.00
CS-100	Alcap Electric Corporation 308 Old Country Road, Mineola, NY	Electrical Installation in New Addition to AGS Warehouse	May 15, 1963	June 25, 1963	4,444.00
004994	Wes Sheet Metal 74-80 Marine St. Farmingdale, NY	Install (8) Pneumatically Operated Dampers in Exhaust Fan Curbs Target Building	August 28, 1963	October 31, 1963	2,900.00

Contract No.	Contractor & Address	Contract For	Work Started	Work Completed	Amount of Contract
004996	Charles A. Mulligan 1 Rossmore Street, Central Islip, NY	Electrical Installation for Scientific Assembly Bldg.	September 6, 1963	January 24, 1964	$ 28,125.00
022763	Palomar Building Corp. 11 Jericho Turnpike, Woodbury, NY	Fill in Concrete Trenches for Gantry Crane Rails Bldg. 922	March 3, 1964	March 6, 1964	330.00
S-260	Fred S. Robbins	Vac. Pump Cooling for Electron Analogue	August, 1954	October, 1954	11,800.00

APPENDIX C

MAJOR PROCUREMENTS - SYNCHROTRON PURCHASE ORDERS

Purchase Order No.	Vendor and Address	Purchase Order For	Work Started	Work Completed	Amount of Purchase Order
PS-58	Phillips Electronics 100 E. 42nd St. New York, N.Y.	800 Kilovolt DC Supply for Proton Injector	March 8, 1956	October 15, 1958	$ 55,591.06
PS-66	Harrington-Wilson Brown Corp. 25 Beechwood Ave., Mt. Vernon, NY	1 Milling Machine	March 13, 1956	December 11, 1956	10,545.00
PS-99	General Electric Company 570 Lexington Ave., New York, NY	13 Indoor Inductrols	October 5, 1956	May 15, 1957	17,811.00
PS-119	The Trane Company 250 E. 43rd St. New York, NY	Water Chiller Equipment	February 25, 1957	June 17, 1958	34,491.00
PS-138	Ferroxcube Corp. of America Saugerties, New York	1000 Ferrite Rings	May 28, 1957	August 20, 1958	110,000.00
PS-154	Thomas A. Edison, Inc. 51 Lakeside Ave. W. Orange, N.J.	Quadrupole Focusing Magnets	July 17, 1957	June 11, 1959	14,938.50
PS-156	A. O. Smith Corporation 250 Park Ave., New York, N.Y.	1 Heat Exchanger with Tubes	July 17, 1957	May 12, 1958	22,295.00
PS-158	Lukenweld, Div. of Luken Steel Co. Coatesville, Pa.	Linear Accelerator Tanks and End Plates	August 19, 1957	May 12, 1959	177,280.00
PS-221	Consolidated Electrodynamics Corp. 33 Great Neck Rd., Great Neck, NY	Evapor-Ion Pumps	November 26, 1957	September 4, 1958	21,700.00
PS-243	Kidde Precision Tool Corporation Locust Ave., Roseland, N.J.	Aluminum Machined Castings	December 30, 1957	June 30, 1958	62,172.55
PS-245	Maple Machine Works 297 Moffitt Blvd. Islip, N.Y.	Stainless Steel Plates & Brackets	December 30, 1957	June 25, 1958	22,590.75
PS-247	Carter Milchman & Frank 36 Hudson St., New York, N.Y.	Stainless Steel Washers, Nuts & Bolts	December 30, 1957	June 26, 1958	11,199.73
PS-264	Philadelphia Bronze & Brass Corp. 22nd & Master Sts., Philadelphia, Pa.	Copper Forgings	January 15, 1958	February 21, 1958	25,027.75
PS-279	Aerocraft, Inc. 41 Degnon Blvd., Bayshore, N.Y.	Cooling Plates	February 3, 1958	November 20, 1958	10,700.00
PS-287	Duff-Norton Company 250 Park Ave., New York, N.Y.	Magnet Leveling Jacks	February 10, 1958	October 2, 1958	57,789.60
PS-295	Maple Machine Works 297 Moffitt Blvd., Islip, N.Y.	Linac Tank Support Assemblies	February 26, 1958	April 18, 1958	13,636.20

Purchase Order No.	Vendor and Address	Purchase Order For	Work Started	Work Completed	Amount of Purchase Order
PS-296	Kenick Manufacturing Company 54 Allen Blvd., Farmingdale, New York	Hydraulic Ball Pad Assemblies	February 26, 1958	January 26, 1959	$ 29,432.80
PS-317	Levinthal Electronic Products Stanford Industrial Park, Palo Alto California	Pulsed Radio FM Amplifier	March 11, 1958	January 13, 1960	24,900.00
PS-320	Taylor Instrument Company 45 Rockefeller Plaza, N. Y.	Instrumentation for Water Cooling System	April 4, 1958	May 3, 1960	12,667.85
PS-330	Compaignie Francaise Thomson-Houston 173 Boulevard Haussman, Paris, France	Power Triodes, Cavities and Associated Components	March 24, 1958	January 7, 1959	85,840.00
PS-380	Moloney Electric Company 310 Northern Blvd. Great Neck, N.Y.	1 Central DC Power Supply	May 7, 1958	April 21, 1959	63,348.00
PS-426	Consolidated Electrodynamics Corp. 33 Great Neck Rd., Great Neck, N.Y.	70 Evapor-Ion Pumps	June 5, 1958	March 15, 1960	197,443.00
PS-500	Youngstown Welding and Engineering Co. Youngstown, Ohio, 3700 Oakwood Ave.	Magnet Vacuum Chamber Sections	July 22, 1958	July 21, 1959	153,460.38
PS-519	Albert & J.R. Anderson 289 "A" St., Boston, Mass.	Receptacles and Plugs	August 4, 1958	November 7, 1958	11,297.50
PS-542	Elliott Corporation 271 Church St., New York, N.Y.	Bus Bar Segments	August 13, 1958	March 24, 1959	76,836.00
PS-596	Cleveland Diesel Engine Div. General Motors 2160 W. 106th St. Cleveland, Ohio	Ferrite Cavity Assemblies	August 29, 1958	March 10, 1959	49,160.00
PS-611	Flexonics Corporation 980 De Hart Pl., Elizabeth, N.J.	Expansion Joints	September 8, 1958	February 29, 1959	24,754.50
PS-633	Consolidated Electrodynamics 33 Great Neck Rd. Great Neck, N.Y.	Heraeus Pumps & Vacuum Pump	September 16, 1958	February 24, 1960	74,989.47
PS-665	Cole Engineering, Watkins Ave. & Banta Pl., Fairlawn, New Jersey	Front & Rear Bus Bar Brackets	September 29, 1958	January 21, 1959	10,867.25
PS-695	Westinghouse Electric Corporation 40 Wall St. New York, N.Y.	Saturating Inductor	October 15, 1958	July 17, 1959	130,207.00
PS-758	Elliott Company 271 Church St. New York, N.Y.	25 Quadrupole Magnets with Coils	November 14, 1958	October 15, 1959	110,294.00
PS-759	Rome Cable Corporation 60 E. 42nd St., New York, N.Y.	Cable	November 17, 1958	June 30, 1960	123,173.19

Purchase Order No.	Vendor and Address	Purchase Order For	Work Started	Work Completed	Amount of Purchase Order
PS-826	Vacuum Research Company 420 Market St., San Francisco, California	Vacuum Valves	December 8, 1958	March 23, 1959	$ 13,536.00
PS-829	Regent Controls, Inc. Harvard Ave., Stamford, Conn.	Control Cubicles for Evapor-Ion Vacuum Pumps	December 15, 1958	August 4, 1960	60,986.38
PS-830	General Electric Company 570 Lexington Ave., New York, NY	Over current Relays & Transfer Switches	December 16, 1958	February 26, 1959	22,780.00
PS-832	Kuslansky Electric Supply Co. 629 Broadway, Brooklyn, N.Y.	Time Delay Relays	December 16, 1958	January 22, 1959	10,956.16
PS-848	South Bay Electrical Supply Co. 288 Medford Ave., Patchogue, N.Y.	Mechanical Drop Enunciators	December 16, 1958	February 10, 1959	14,044.80
PS-917	N.R.C. Equipment Corporation 160 Charlemont St., Newton Highlands, Massachusetts	Pneumatic Valves	January 21, 1959	June 15, 1959	30,869.91
PS-934	The Globe Company 4000 So. Princeton Ave., Chicago, Ill	Globe Tray Items	January 26, 1959	March 25, 1959	20,248.57
PS-939	General Electric Company N.Y. Serv. Shop, 6001 Tonnelle Ave. North Bergen, N.J.	Identical Sextupole Correcting Magnets	January 29, 1959	February 2, 1960	140,118.00
PS-941	International Tel & Tel Corp. Components Div., P.O. Box 412 Clifton, N.J.	Triode Tubes & Water Jackets	February 6, 1959	August 14, 1959	11,773.04
PS-1036	Agawam Aircraft Products Sag Harbor, N.Y.	Complete Ball Tuner Assemblies	March 9, 1959	June 29, 1959	14,842.00
PS-1087	General Electric Co., Technical Prod. Div. Electronics Park Syracuse, N.Y.	Power Amplifier Cubicles & Saturation - Timing Supply Cubicles	March 24, 1959	December 14, 1959	218,994.49
PS-1107	High Voltage Engineering Corp. 7 University Rd., Cambridge, Mass.	Ionization Vacuum Gages	March 27, 1959	July 27, 1959	14,125.00
PS-1207	General Electric Company 570 Lexington Ave., New York, N.Y.	Motor Generator Set with Flywheel	April 23, 1959	October 15, 1959	135,772.00
PS-1450	Consolidated Electrodynamics 1775 Mt. Read Blvd. Rochester, NY	Filaments, Bellows, Flanges and Terminals	July 7, 1959	January 27, 1960	10,221.50
PS-1464	National Electric Coil Co. Columbus, Ohio	Injection Quadrupole Magnets	August 5, 1959	February 9, 1960	29,783.04
PS-1510	E. W. Bliss Company 1375 Raff Rd., Canton, Ohio	Five Foot Straight Sections	August 6, 1959	May 26, 1960	16,335.00

Purchase Order No.	Vendor and Address	Purchase Order For	Work Started	Work Completed	Amount of Purchase Order
PS-1570	Compaignie Francaise Thomson-Houston 173 Boulevard Haussman, Paris, France	Vacuum Tubes for Linac RF	August 7, 1959	March 11, 1960	12,480.00
PS-1626	Fiberglass Products Engineering Co. 17 Mechanic St., Norwalk, Conn.	Magnet Buss Coil Connection Covers	September 8, 1959	March 16, 1960	17,104.05
PS-1627	Aero-Nautical, Inc. 97 Garfield Ave., Copiague, N.Y.	Magnet Coil Covers	August 24, 1959	February 2, 1960	17,591.00
PS-1663	Cole Engineering Incorporated Watkins Ave. Banta Pl., Fairlawn,NJ	Quadrupole & Sextupole Magnet Support Girders & Frames	September 3, 1959	November 10, 1959	24,898.50
PS-1807	Agawam Aircraft Products Sag Harbor, N.Y.	High Energy Viewing Boxes	October 16, 1959	January 28, 1960	19,499.53
PS-1822	Youngstown Welding & Engineering Co. 3700 Oakwood Ave. Youngstown, Ohio	Vacuum Pumping Stations	October 20, 1959	April 7, 1960	37,381.50
PS-2353	Tektronix,Inc. 840 Willis Ave., Albertson, N.Y.	Oscilloscope & Preamplifiers	April 22, 1960	December 20, 1960	30,365.00
PS-2391	Air & Refrigeration Corp. 439 Madison Ave., New York, N.Y.	Hydrogen Exhaust Fans	March 30, 1960	August 28, 1960	13,828.40
PS-2506	General Precision Laboratory, Inc. 63 Bedford Road, Pleasantville, NY	Closed Circuit TV Equipment	April 29, 1960	November 8, 1960	16,715.10
PS-2831	W. M. Welsh Manufacturing Company Chicago, Ill., 1515 Sedgewick St.	3 Turbo Molecular Vacuum Pumps	October 6, 1960	December 20, 1960	18,050.00
PS-2978	Thomson Electric Company, Inc. 50 Rockefeller Plaza, New York NY	1 Cavity and Components to operate triode	December 22, 1960	December 11, 1961	14,810.00
PS-3100	Acme Electric Cuba, New York	10 Magnet Power Supply Modules	October 27, 1961	October 18, 1962	229,767.00
PS-3117	Aerocraft, Incorporated 41 Degnon Blvd. Bayshore, N.Y.	30 Ball Pad Jack Assemblies	December 20, 1961	June 2, 1962	12,300.00
PS-3118	General Applied Science Laboratory Merrick & Stewart Ave., Westbury, NY	56 Power Supplies	January 15, 1962	June 8, 1962	15,300.00
PS-3130	General Cable Corporation Ames Court, Plainview, N.Y.	Control Cable	June 28, 1962	October 4, 1962	14,804.25
57421	National Electric Coil 800 King St., Columbus, Ohio	4 18D72 Bending Magnet Coil Assemblies	July 18, 1961	June 27, 1962	41,531.00
57431	Bethlehem Steel Co., Inc. 375 Park Ave. New York, N.Y.	4 18D72 Bending Magnet Core Assemblies	July 20, 1961	January 31, 1962	74,628.58

Purchase Order No.	Vendor and Address	Purchase Order For	Work Started	Work Completed	Amount of Purchase Order
C11812	Aerocraft, Inc. 41 Degnon Blvd., Bayshore, N.Y.	8 8" Quadrupole Mag. Hardware Ass'ys 2 12"Quadrupole Mag. Hardware Ass'ys	May 10, 1962	September 6, 1962	$ 13,827.59
C11140	Elliott Company 385 Madison Ave., New York 17, N.Y.	8 8x48 Exp. Quad. Magnets 2 12x30 " " "	November 22, 1961	June 15, 1962	99,788.00
14239	Allis Chalmers Mfg. Co. 100 Church St. New York, N.Y.	1 6' 3" AGS Mechanical Prototype Magnetic Core	April 26, 1956	October 3, 1956	15,400.00
15829	Westinghouse Electric Corporation 40 Wall St. New York 5, N.Y.	1 6' 3" AGS Magnet Core	June 25, 1956	January 16, 1957	56,856.00
56940	Consolidated Vacuum Corporation 1775 Mt. Read Blvd. Rochester, NY	4 Evapor-Ion Pumps without Control Center	March 22, 1961	June 30, 1961	14,000.00
57223	Regent Controls Harvard Ave., Stamford, Conn.	7 Control Cubicles	May 11, 1961	August 22, 1961	14,640.57
20907	Moloney Electric c/o Pacent Engineering Corp. 310 N. Blvd., Great Neck, N.Y.	1 Bifilar Pulse Transformer	October 18, 1956	October 9, 1957	13,500.00
57183	White Construction Co., Inc. 95 Madison Ave., New York, N.Y.	2,740 Short Tons of Reinforced High Density Shielding Blocks	May 4, 1961	September 29, 1961	147,000.00
3080	Heintz Mfg. Company Front St. & Olney Ave. Phila. 20 Pa.	17 Laminated Assemblies	July 27, 1955	March 2, 1956	28,802.57
86455	Ferroxcube Corporation 125 E. Bridge St. P.O.Box 359 Saugerties, New York	40 Circular Rings of Ferrite	August 10, 1954	January 24, 1956	12,555.00
80948	Manhasset Machine Shop 259 E. 2nd St. Mineola, N.Y.	Bending Lens Assemblies	May 5, 1954	November 10, 1954	19,125.50
81693	Pusey & Jones Corporation Wilmington 99, Delaware	Lens Supporting Girders	March 23, 1954	August 5, 1954	15,763.00
82620	L.O. Koven & Brothers Inc. 154 Ogden Ave. Jersey City 7 N.J.	Vacuum Chambers & Base Plates	April 8, 1954	September 29, 1954	37,837.00
82950	Consolidated Vacuum Corporation Rochester 3, New York	16 Pumping Systems	April 14, 1954	November 3, 1954	40,112.00
77800	High Voltage Engineering 7 University Rd., Cambridge 38, Mass.	1 Van de Graaff Electro Accelerator	December 28, 1953	May 14, 1954	66,031.00

APPENDIX C

LIST OF MAJOR PROCUREMENTS
BUILDINGS AND UTILITIES

Purchase Order No.	Vendor and Address	Purchase Order For	Work Started	Work Completed	Amount of Purchase Order
PS-32	General Electric Company 570 Lexington Ave., New York, N.Y.	1 Metal Clad Switch Gear	August 8, 1955	August 7, 1956	$ 15,795.00
PS-36	Shaw Box Crane & Hoist Muskegon, Michigan	30 Ton Overhead Crane	September 7, 1955	January 24, 1956	25,022.00
PS-38	General Electric Company 570 Lexington Ave. New York, NY	1 Metal Clad Switch Gear	September 12, 1955	June 29, 1956	17,675.15
PS-41	General Electric Company 570 Lexington Ave. New York, NY	2 Unit Substations	October 17, 1955	June 6, 1956	39,659.00
PS-52	United States Steel Corporation 71 Broadway, New York, N.Y.	540 Tons Steel Bearing Piles	January 3, 1956	May 28, 1956	54,540.00
PS-76	Whiting Corporation 30 Church St., New York, N.Y.	1 - 40 ton Overhead Traveling Crane 1 - 5 ton Auxiliary Hoist	May 3, 1956	April 24, 1957	59,364.39
PS-79	Shepherd Niles Crane & Hoist 50 Church St., New York, NY	1 - 20 ton Magnet Crane 1 - 10 ton Linac Crane	May 23, 1956	August 26, 1958	42,060.00
PS-80	Feedrail Corporation 470 Statler Building, Boston, Mass.	Crane Runway Conductors	May 25, 1956	November 21, 1956	11,952.00
PS-83	Alco Products Incorporated 30 Church St., New York, N.Y.	Magnet Girders & Survey Pedestals	July 9, 1956	August 8, 1957	140,790.00
PS-95	Westinghouse Electric Corporation 40 Wall St., New York, N.Y.	3 Unit Substations	August 30, 1956	August 19, 1957	69,037.00
PS-1904	J. J. Haggerty, Inc. West Hampton Beach, N.Y.	High Density Concrete Shielding	November 9, 1959	January 22, 1960	11,400.00
PS-2390	Swartwout Fabricators 103 Park Ave., New York, NY	Roof Ventilators	March 30, 1960	November 1, 1960	13,600.00
PS-2500	Westinghouse Electric Corp. 40 Wall St., New York, N.Y.	Outdoor Unit Substations	May 2, 1960	October 29, 1960	39,985.00
PS-2572	Davis Instrument Div. of Davis Emergency Equipment Co. 47 Halleck St., Newark, N.J.	Gas Detectors	May 16, 1960	May 1, 1961	29,225.00
PS-2647	Gardner-Denver Company 700 Huyler St. Teterboro, N.J.	Helium Compressors	June 22, 1960	August 14, 1961	20,742.00
PS-2650	Whiting Corporation 980 Worcester St. Wellesley Hills, Massachusetts	2 - 40 Ton Overhead Traveling Cranes	June 27, 1960	June 26, 1961	103,885.00

LIST OF MAJOR PROCUREMENTS
BUILDINGS AND UTILITIES - continued

Purchase Order No.	Vendor and Address	Purchase Order For	Work Started	Work Completed	Amount of Purchase Order
PS-2777	Louver-Lite Corporation 19-41 46th Street, L.I.C., N.Y.	Louvers & Aluminum Tee Bars	August 30, 1960	April 5, 1961	$ 14,000.00
PS-2833	Fairbanks Morse & Company 19-01 Route 208, Fairlawn, N.J.	1 Engine Generator Set	November 1, 1960	January 30, 1961	12,934.00
PS-2885	Swartwout Fabricators 103 Park Ave., New York, N.Y.	Roof type fans	October 19, 1960	June 2, 1961	48,560.00
PS-3022	Griffin Equipment Corporation 880 E. 141st St. New York, N.Y.	Diesel Engine Generator Sets	March 17, 1961	June 29, 1961	53,988.25
PS-3040	Pennsylvania Transformer Div. McGraw Edison Co., 25 Broad St. N.Y.	Substations E, F & G	April 10, 1961	October 27, 1961	91,316.00
PS-3146	Manning Maxwell & Moore 161 East 42nd St. New York, N.Y.	1 Deck Leg Gantry Crane	January 15, 1963	May 9, 1963	25,865.00

APPENDIX C

MAJOR PROCUREMENTS - SYNCHROTRON CONTRACTS

Contract No.	Contractor & Address	Contract For	Work Started	Work Completed	Amount of Contract
CS-19	Westinghouse Electric Corporation 40 Wall St., New York 5, N. Y.	Fixed Price Agreement for Main Magnet Power Supply	March 18, 1957	Comp.Del. 12/1/58 Final Accept.12/21/60	$1,039,027.83
CS-23	Baldwin Lima Hamilton Corporation Eddystone Div. Philadelphia 42, Pa.	Main Magnet Cores for the AGS	July 25, 1957	May 18, 1959	3,110,303.00
CS-26	National Electric Coil Company Columbus 16, Ohio	Magnet Exciting Coils for AGS	July 8, 1957	May 7, 1959	1,761,508.65
CS-33	Perlman Manufacturing & Heat Treating 75 State St. Westbury, New York	Furnace Facilities to Braze Linear Accelerator Drift Tubes	May 2, 1958	July 29, 1959	36,414.00

APPENDIX D

OTHER CONTRACTS

Contract No.	Contractor & Address	Contract For	Work Started	Work Completed	Amount of Contract
Univac	Univac Monthly Charges		June, 1954	November. 1957	$ 54,308.13
A/F 30 (602) (1526)	U. S. Air Force Contract	Klystrons	March, 1956	December, 1959	81,796.71

APPENDIX E

BIBLIOGRAPHY

Beth, R. A., Lasky, C, "The Brookhaven Alternating Gradient Synchrotron" Paper printed in Science, December 5, 1958 Vol. 128

Blewttt, J.P., "The Brookhaven Alternating Gradient Synchrotron" Paper printed in the 1960 IRE National Convention Record.

Reading, O. S., "Alignment Stability of the 33-Bev Synchrotron at BNL 1959-1963, Accelerator Department", Internal Report OSR-5 dated July 15, 1964.

Shelton, E. E, "Electric Power for the Alternating Gradient Synchrotron at BNL", AIEE Conference Paper 59-1279 delivered at AIEE Fall General Meeting October 11-16, 1959 Chicago, Ill.

Gould, C. L., "Vacuum System for a 25 Bev Particle Accelerator" Paper presented at First International Congress on Vacuum Techniques, Brussels, Belgium June 12, 1958.

Plotkin, M., "Radio Frequency Accelerating System for the Brookhaven Alternating Gradient Synchrotron", Paper printed in the 1960 IRE National Convention Record.

Giordano, S., "The Linear Accelerator Injector for the AGS", Paper printed in the 1960 IRE National Convention Record.

Lancaster, J. H., "Alternating Gradient Synchrotron Summary Foundation Report", Accelerator Department Internal Report JHL-3 dated July 24, 1956.

Lancaster, J. H., "Design and Procurement of the High Density Concrete Shield", Accelerator Department Internal Report JHL-5 dated April 9, 1957.

Lancaster, J. H., "Long Term Vertical Pile Load Tests", Accelerator Department Internal Report JHL-6 dated January 22, 1958.

Lancaster, J.H., "Low Volume Change Concrete Studies", Accelerator Department Internal Report JHL-7 dated January 22, 1958.

Stone & Webster Engineering Corp., "Report on Foundation Design Alternating Gradient Synchrotron", Internal Report dated January 29, 1958.

Stone & Webster Engineering Corp., "Construction Report - High Density Concrete Shielding Blocks", Internal Report - Job Number 9213.19 dated July, 1958.

Stone & Webster Engineering Corp., Manual of Plant Equipment - Several for the buildings and utilities.