NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

Rutherford High Energy Laboratory

NIRNS

7GeV Proton Synchrotron

INTRODUCTION

The National Institute for Research in Nuclear Science was formed in 1957 to provide facilities for research into high energy physics which would be available for common use by universities and similar institutions. The first laboratory of the National Institute is the Rutherford High Energy Laboratory situated at Chilton and occupying a site of some 75 acres. The Laboratory is being equipped to carry out research into the physics of the nucleus, and the structure and interactions of elementary particles. The main equipment of the Laboratory consists of two proton accelerators: a 50 million electron volt proton linear accelerator and a 7000 million electron volt proton synchrotron (NIMROD). The Laboratory will also contain supporting facilities for conducting experimental work.

The name NIMROD—("A mighty one in the earth"—Genesis 10, 8-2) has been given to the 7 GeV proton synchrotron at present under construction.

Injector

Energy of protons entering Linear Accelerator	0·6 MeV
Energy of protons entering Synchrotron	15 MeV
Lineac output current	5·20 mA
Lineac operating frequency	115 Mc/s
Estimated pulsed R.F. power dissipated	700 KW
Overall length of lineac	46 ft
Diameter of Lineac tank	8 ft
Number of pumps Mercury	4

Magnet Power Supply

Number of Motor-alternator-flywheel sets	2
Alternator ratings nominal	60 MVA
Alternator ratings maximum	79 MVA
Alternator ratings thermal	46 MVA
Weight of rotors	60 tons
Weight of stators	72 tons
Motor rating	5000 h.p.
Motor speed	970 r.p.m.
Flywheel diameter	10 ft 6 in
Flywheel weight	24 tons
Stored energy in flywheel at 1000 r.p.m.	500,000 h.p. sec
Speed reduction during pulse	4%

Magnet

Beam radius mean	77·5 ft
Magnetic field at injection	300 gauss
Peak magnetic field	14,000 gauss
Magnetic aperture 11 vertical 45 horizontal	
Number of magnet sectors	336
Weight of each magnet sector	19 tons
Number of turns in coil	42
Weight of magnet coil total	350 tons
Pulse rise time	0·7 sec
Pulse decay time	0·8 sec
Repitition rate of magnet pulse	26 pulses/min
Peak current in coil	9150 amps
Stored energy in magnet at peak field	40 megajoules
Number of protons accelerated	10^{12} per pulse

R.F. System

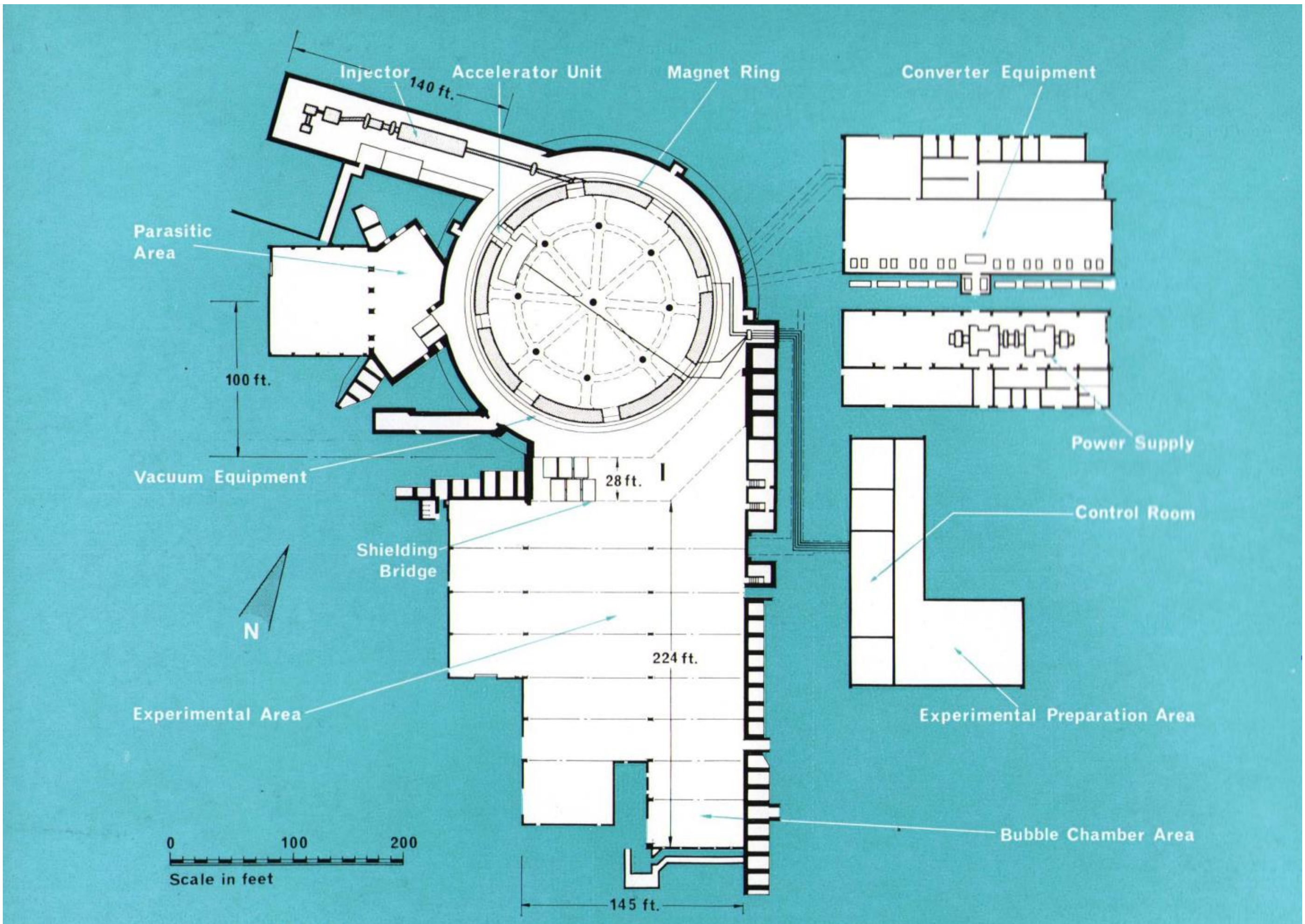
R.F. frequency at injection energy	1·4 Mc/s
R.F. frequency at peak energy	8 Mc/s
Weight of ferrite	12,000 lbs
Weight of cavity	10·5 tons
Peak R.F. volts per gap	7 KV
R F power dissipation	14 KW
Ferrite working temperature	25°C
D C bias winding ampere turns	6000

Vacuum System

Beam aperture	$9\frac{1}{2}$ inches
Pressure in inner vessel	10^{-6} mm hg
Pressure in outer vessel	1 mm hg
Pumping volume of inner vessel	3500 cu ft
Number of pump units for inner vessel	40
Pump type	24 in oil diffusion
Vacuum vessel material	Epoxy glass laminate
Overall speed of diffusion pumps	200,000 litres/sec (approx)

General Parameters

Diameter of magnet building	200 ft
Weight of concrete in building	approx 100,000 tons
Radiation shielding wall thickness	30 ft of concrete (equivalent)
Roof thickness	16 ft of concrete (equivalent)
Distance travelled by particles during acceleration	100,000 miles

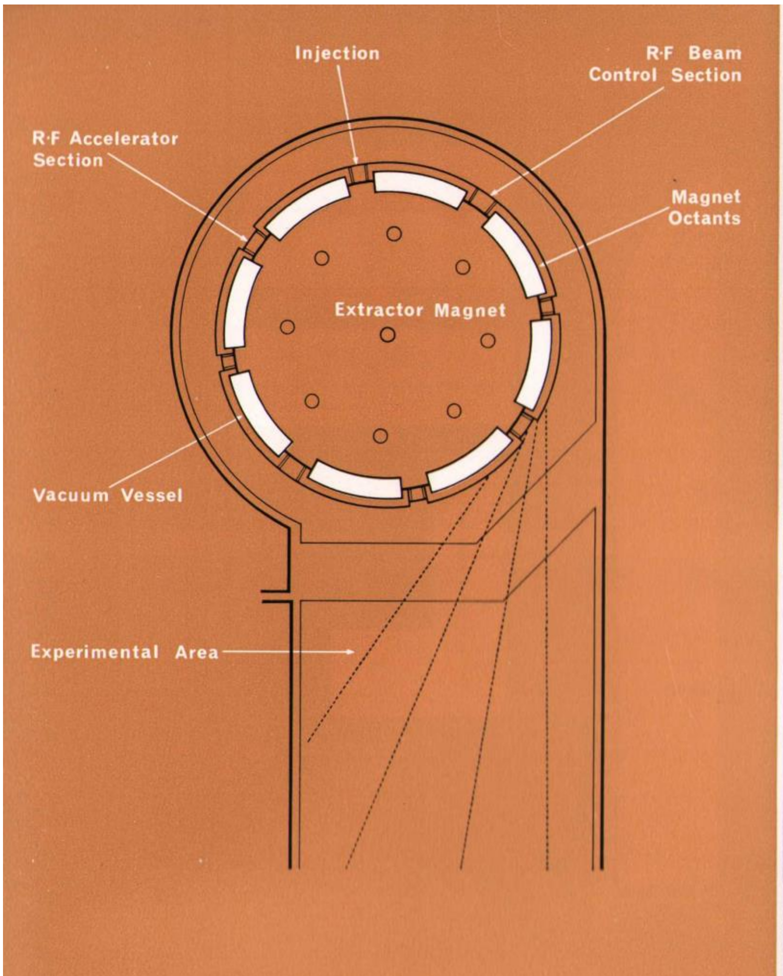


Nimrod Parameters

The main physical feature of NIMROD is a large ring-shaped electromagnet, 160 ft. in diameter, which weighs 7000 tons. A toroidal shaped evacuated chamber made from glass-fibre reinforced epoxy resin is situated between the poles of this magnet. A pulse of protons, given an initial acceleration to 15 MeV in a linear accelerator, is injected into this chamber and the protons are forced by the magnetic field into a circular orbit in which they receive an acceleration from a radio-frequency electric field once in each revolution. After approximately a million revolutions the protons reach their maximum energy; they are then either extracted from the vacuum chamber or allowed to bombard internal targets, the resulting secondary particles being channelled into an adjoining area where they will be used for experiments. During the acceleration period, lasting about three-quarters of a second, the magnetic field strength and the frequency of the electric accelerating field have both to be increased steadily to confine the proton orbits to the magnet ring, and in such a manner as to maintain the delicately balanced stability in the motion of the protons. The whole machine is housed in a semi-underground circular building of reinforced concrete 200 ft. in diameter with a 6 ft. concrete roof on which a 20 ft. layer of earth is placed as additional radiation shielding.

Heavy currents up to 10,000 A with an applied voltage up to 15 kV are needed to energise the electromagnet during the short acceleration time. The power supply used consists of a motor-alternator set, incorporating flywheels connected to the magnet through a bank of rectifiers. This equipment supplies direct current of gradually increasing strength during the $\frac{3}{4}$ sec acceleration period, and the current decays again to zero in a further 0·8 sec, ready for the next pulse. Energy is thus stored in the magnet during the current-rise period and is subsequently returned to the flywheels as the current is reduced again to zero. The amount of energy being shuttled to and fro amounts to some 40 megajoules. In this way, the flywheels act as a buffer between the load (the magnet windings) and the electrical supply.

The machine is designed to produce at least 10^{12} protons per pulse at a repetition rate of 28 pulses a minute. NIMROD will be used for fundamental research into the physics of elementary particles, in particular the unstable strange particles (hyperons and heavy mesons) and antiparticles.



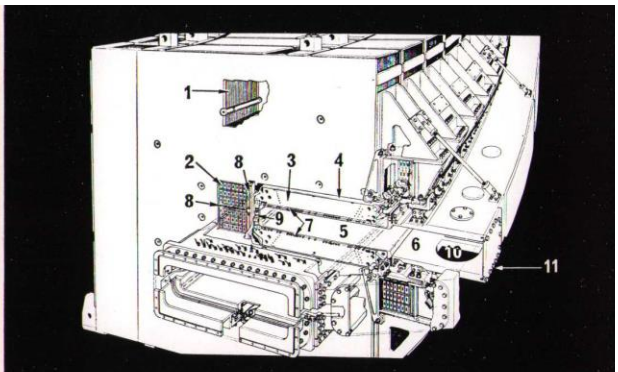
Magnet

The magnet comprises eight octants separated by straight field free spaces which accommodate the R.F. accelerating cavity, and various machine components. Each octant comprises 42 sectors the whole 336 sectors weighing 7,000 tons.

The $12\frac{1}{2}$ in. thickness of a sector is made up from about 46 plates of 1 per cent silicon steel. The plates are annealed and flattened, cleaned and coated with insulation. The sector is held together by bolts and some edge welding. Finally the C-gap is machined to the final dimension.

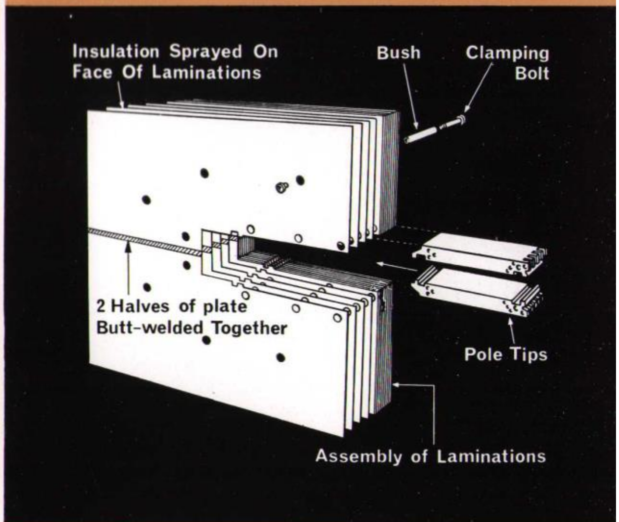
Each pole piece weighs 800 lb. and consists of a stack of about 450 steel laminations 0·020-0·030 in. thick. These accurately formed laminations are glued together with an epoxy resin—glass cloth adhesive to accurate finished dimensions. The pole pieces are produced in matched pairs to preserve magnetic symmetry.

Each magnet octant has its own 42 turn winding fabricated from 50 ft. lengths of extruded copper of section 1·375 x 2·625 in. The conductors are cooled by demineralised water pumped through a 0·2 sq in. hole in the centre. The windings of the octants are all connected in series and carry a peak current of 9,150 amps. The total power dissipation is 3 MW at the normal repetition rate of the machine. The weight of copper in the coils is about 350 tons.

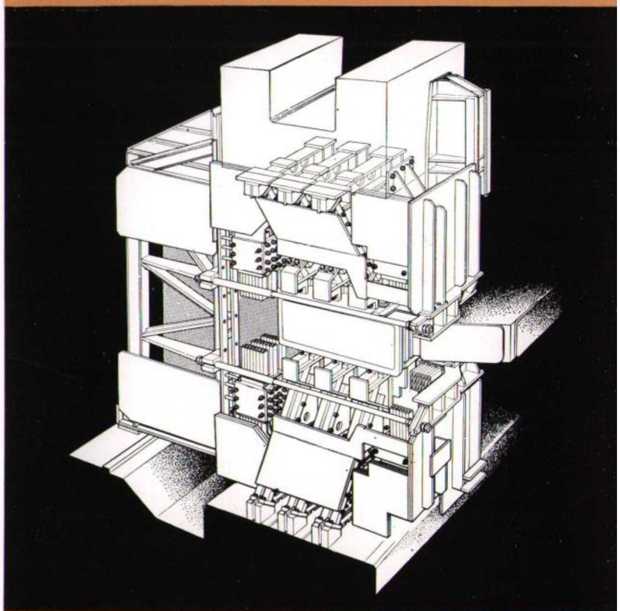


1 Magnet Sector
2 Magnet Coils
3 Pole Tips
4 Outer Vacuum Chamber
5 Inner Vacuum Chamber
6 Header Chamber
7 Pole Face Windings
8 Pressure Pads
9 Pole Tip Jacks
10 Main Pumping Port
11 Beam Exit Window

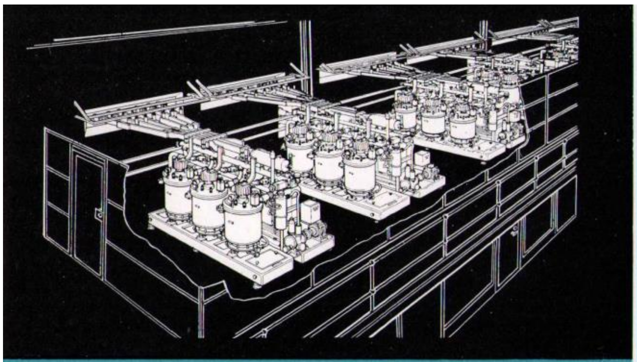
CROSS SECTION THROUGH 7 GEV MAGNET OCTANT



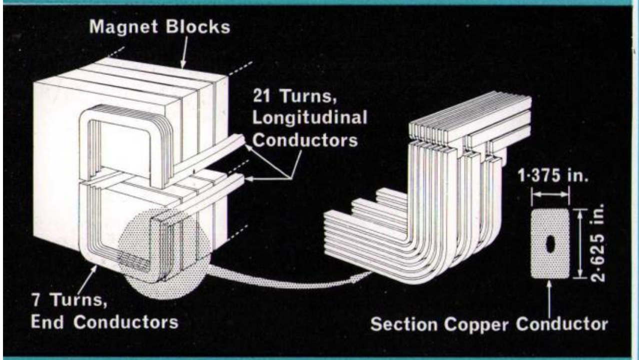
7 GEV MAGNET SECTOR ASSEMBLY



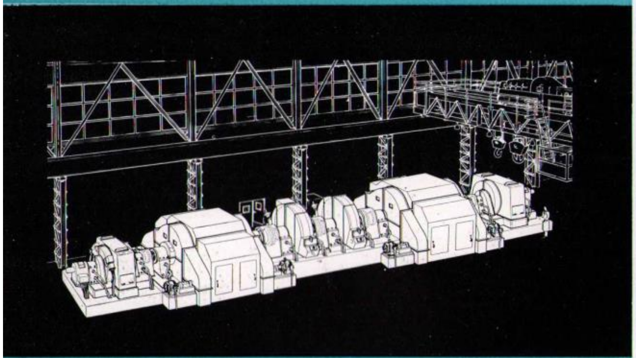
OCTANT END STRUCTURES



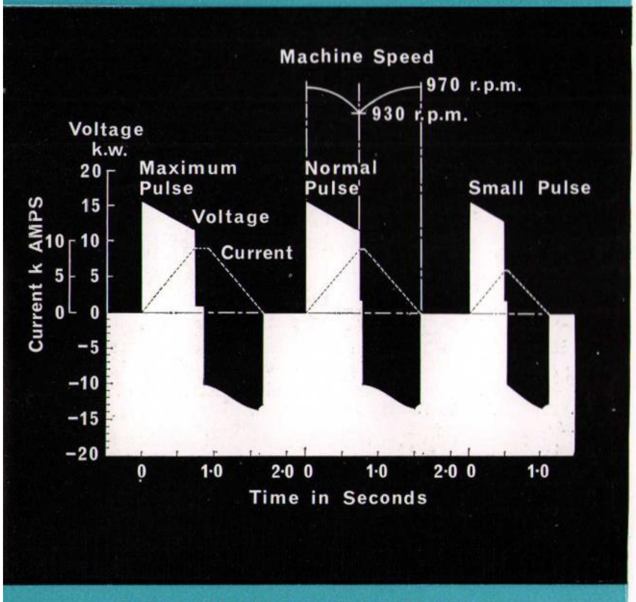
RECTIFIER INSTALLATION



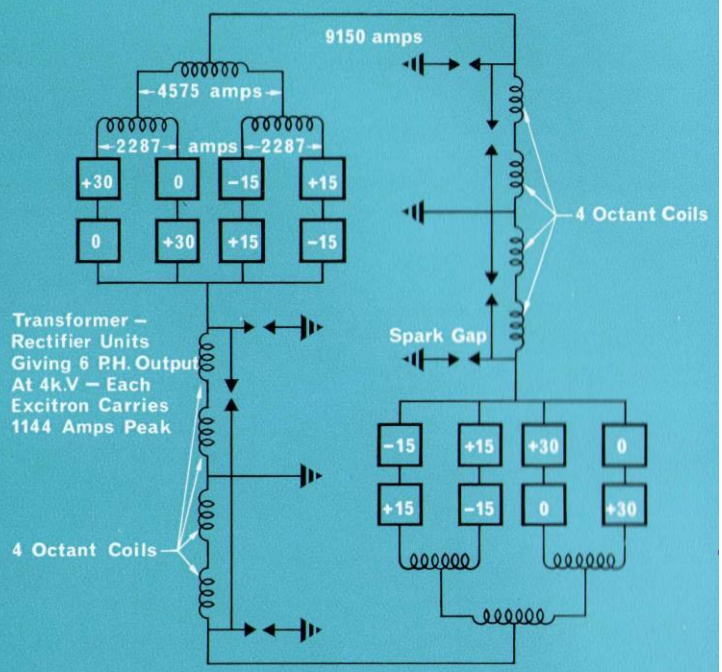
COIL LOCATION ON MAGNET BLOCKS



MOTOR ALTERNATOR SET



PULSE SHAPES, MAGNET POWER PLANT



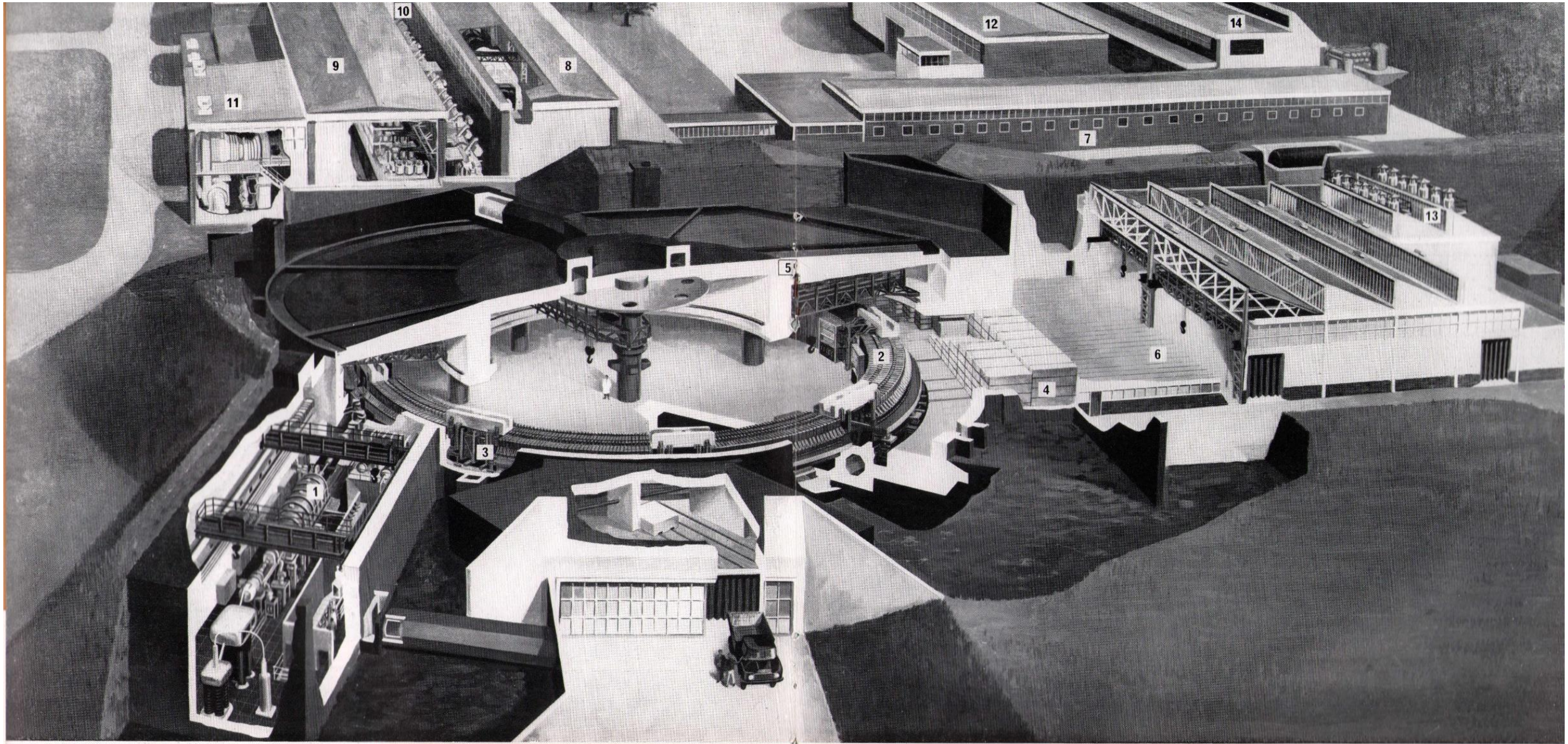
Magnet Power Supplies

The magnet coil demands large pulses of direct current which is generated by an A.C. induction motor driven flywheel-alternator set giving direct current through grid controlled rectifiers.

The plant comprises two 5,100 h.p. 50 c/s 1000 r.p.m. slipring induction motors with rotor resistance control driving two flywheels and two 60 MW salient pole alternators on a common shaft.

The alternators feed the large electromagnet via phase multiplying transformers and 96 single anode grid controlled mercury arc rectifiers to give pulses up to 10,525 amps at 15·5 kV D.C., the total peak output of the alternators being 180 MVA, the energy supplied mainly from the flywheels with rise time of 0·8 seconds. During the decay period the rectifier groups are inverted and the magnet energy is restored to the flywheels via the alternators which act as motors.

The foundation problem is relieved by supporting the massive reinforced concrete machine block on steel springs.



7 GeV PROTON SYNCHROTRON

1 **Injector.** This unit does the initial acceleration of the protons up to 15 MeV energy level.

2 **Electro magnet.** The large magnet guides and focusses the protons to an orbit of constant radius.

3 **R.F. System.** The radio-frequency accelerating unit gives the protons a 5-7 KeV kick on each orbit.

4 **Shielding Wall.** This comprises a 30 ft. thick wall of transportable concrete blocks.

5 **Shielding.** The synchrotron is enclosed in a shield of concrete with additional earth shielding on the roof and around the sides.

6 **Experimental Area.** Beams of protons are admitted through collimating channels in the 30 ft. concrete wall into this area where the research equipment will be set up.

7 **Control Room.** Contains all the instruments relative to the operation of NIMROD.

8 **Alternator House.** The rotating plant comprises two 60 MVA, 1,000 rev/min alternators and two 24 ton flywheels driven by two 5,100 h.p. induction motors.

9 **Converter House.** Contains the 96 water cooled single anode, grid controlled mercury arc converters.

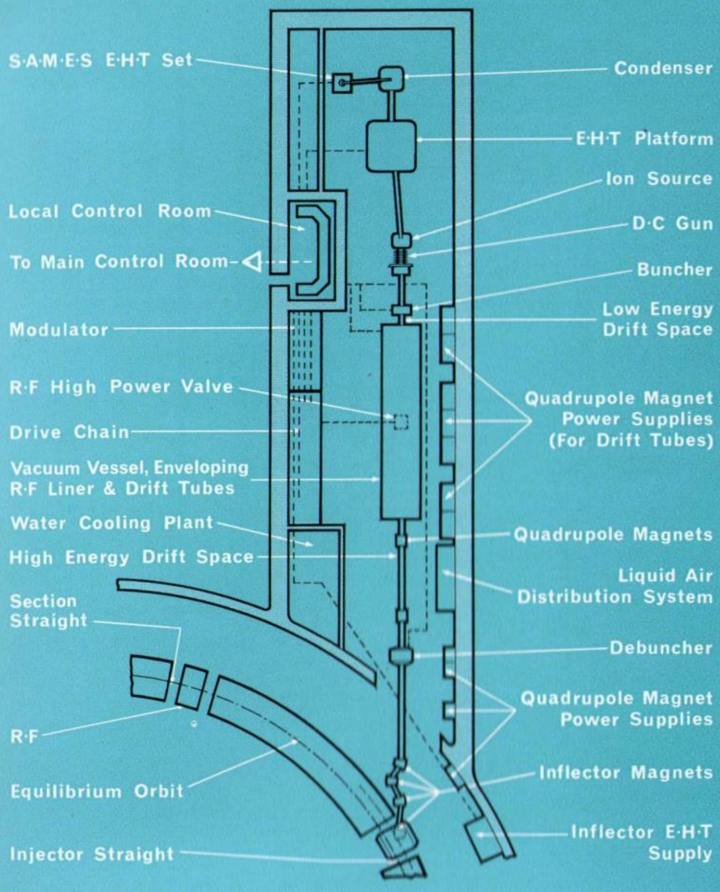
10 **Transformer Yard.** Eight 12 MVA phase splitting transformers.

11 **Plant Room.** Contains the air-conditioning plant for the Magnet Room.

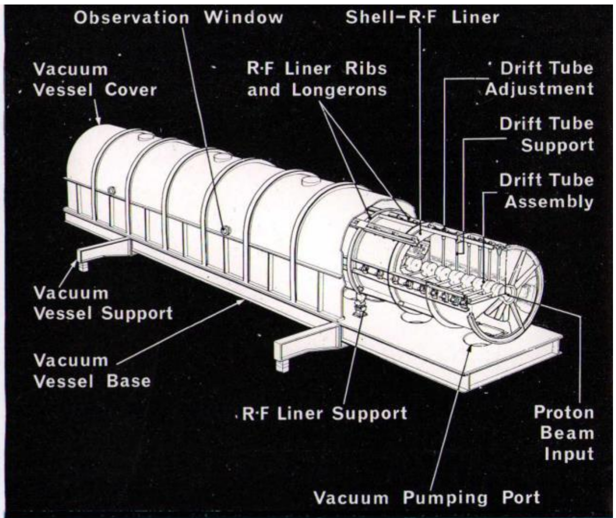
12 **Preparation Room.** Used for preparatory work in connection with experiments.

13 **Bubble Chamber.** A chamber containing liquid hydrogen used for the study of collisions between nuclear particles.

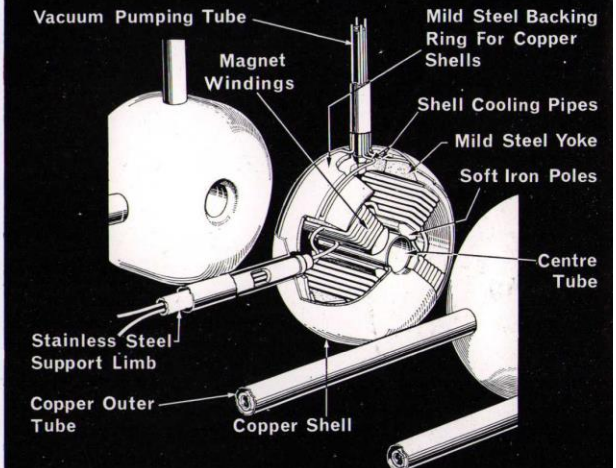
14 **Plant Room.** For housing plant and equipment for use with the Bubble Chamber.



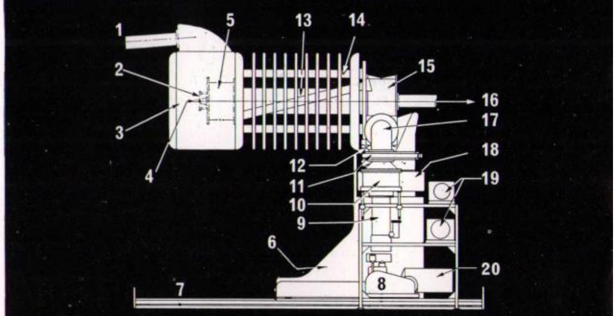
Injector



LINEAR ACCELERATOR



DRIFT TUBE



1 Tube From E·H·T Platform Carrying Electric Cable & Hydrogen Supply Pipe
2 Ion Source
3 Bun Casing
4 Hydrogen Inlet Into Ion Source
5 Focussing System
6 Light Alloy Fairings
7 Support Stand Rails
8 Backing Pump
9 Cold Trap
10 Diffusion Pump
11 Shut-Off Valve
12 Elevating Screw
13 Accelerating Column
14 Fibre Glass Tie Rods
15 Vacuum Manifold
16 Beam Path
17 Vacuum Elbow
18 Support Stand
19 Refrigerators
20 Compressed Air Cylinder

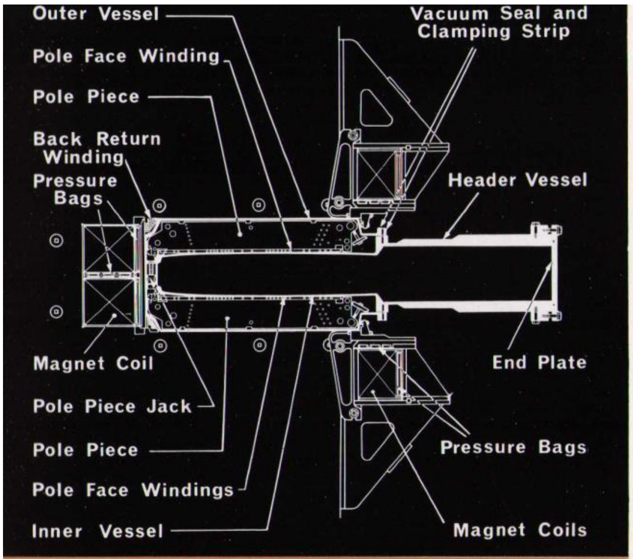
D. C. GUN SUPPORT STAND & VACUUM EQUIPMENT

The injector is a 15 million electron volt (15 MeV) linear accelerator, designed to provide a high intensity beam of protons for injection into the 7 GeV (7,000 MeV) synchrotron.

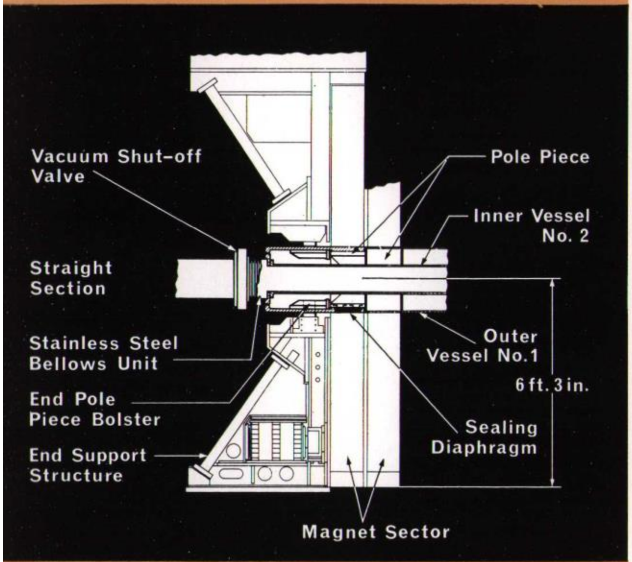
The origin of the proton beam is the ion source, where hydrogen gas at low pressure is ionised in a discharge induced by a Radio Frequency field. Pulses of proton beam are then extracted and accelerated to an energy of 0·6 MeV. This comprises the ION GUN or PRE-INJECTOR.

The beam next enters the LINEAR ACCELERATOR which is essentially a highly evacuated, cylindrical copper cavity, 44 ft. long by 5 ft. 6 in. dia. This cavity is resonated by a 115 Mc/s R.F. source, producing an alternating axial electrical field. The protons passing along the axis of the cylinder are shielded from the decelerating parts of this field by a series of DRIFT TUBES. Each drift tube contains a four-pole focussing magnet to prevent loss of proton beam by excessive expansion during acceleration. Since pulses of up to 0·002 seconds long at intervals of about two seconds are required by the synchrotron, the accelerating cavity is pulsed by about one Megawatt of R.F. power when required.

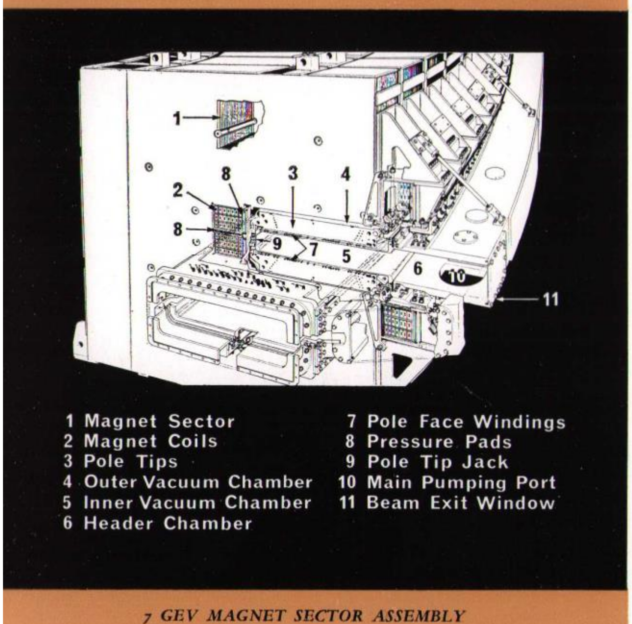
The 15 MeV proton beam is introduced into the main magnet ring by means of a 25° deflection system, consisting of four bending magnets followed by an electrostatic deflector.



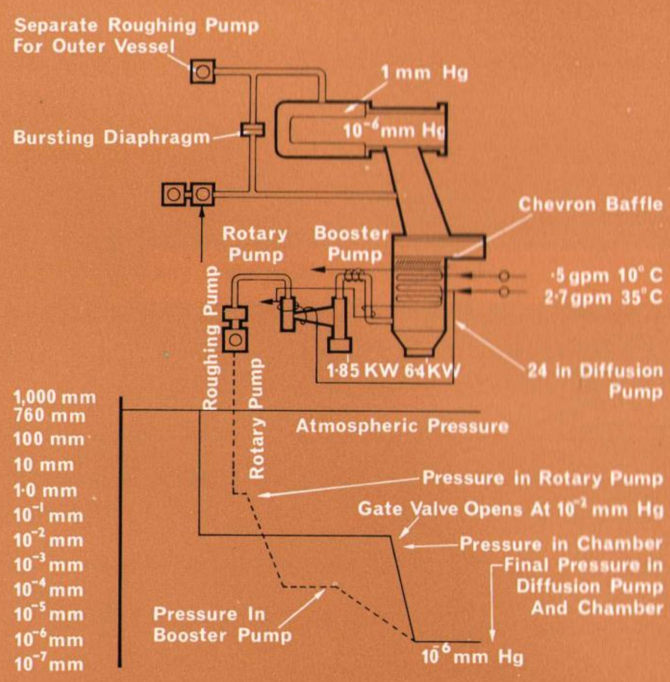
VACUUM VESSEL & SUPPORT SYSTEM



OCTANT END STRUCTURE



7 GEV MAGNET SECTOR ASSEMBLY



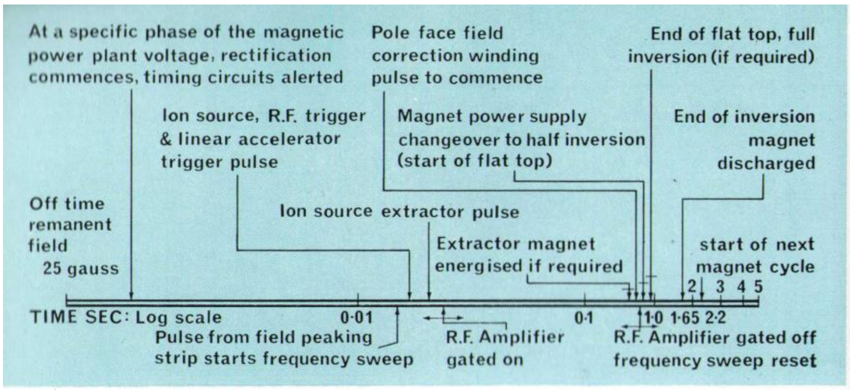
Vacuum System

The vacuum chamber comprises eight double walled vessels of glass reinforced epoxy resin each the whole length of an octant. An outer vessel with thin walls is sandwiched between the poles and yoke of each magnet octant. An inner vessel of similar length is placed within the octant gap and evacuated to 10^{-6} mm. of mercury while the space between the two vessels is evacuated to about 10^{-2} mm. of mercury. Thus the magnet structure supports practically all the atmospheric load and the inner high vacuum vessel has only a small differential pressure to withstand.

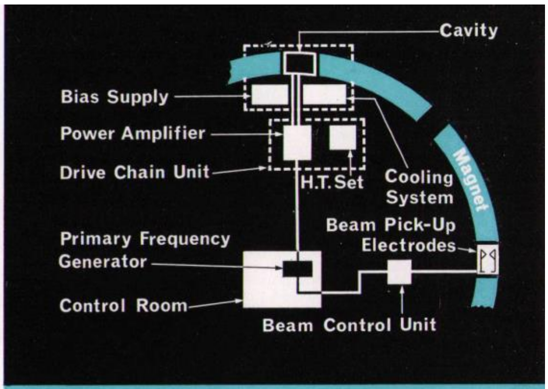
The inner vessels are evacuated by a total of forty 24 in. diameter oil diffusion pumps which exhaust the vessel via a substantial header chamber of similar construction to the main vessels.

The gaps between octants are bridged by single walled vessels, incorporating expansion bellows and shut-off valves, allowing a clear high vacuum path measuring at least 9½ in. vertically and 36 in. radially, round the ring in which the protons can travel.

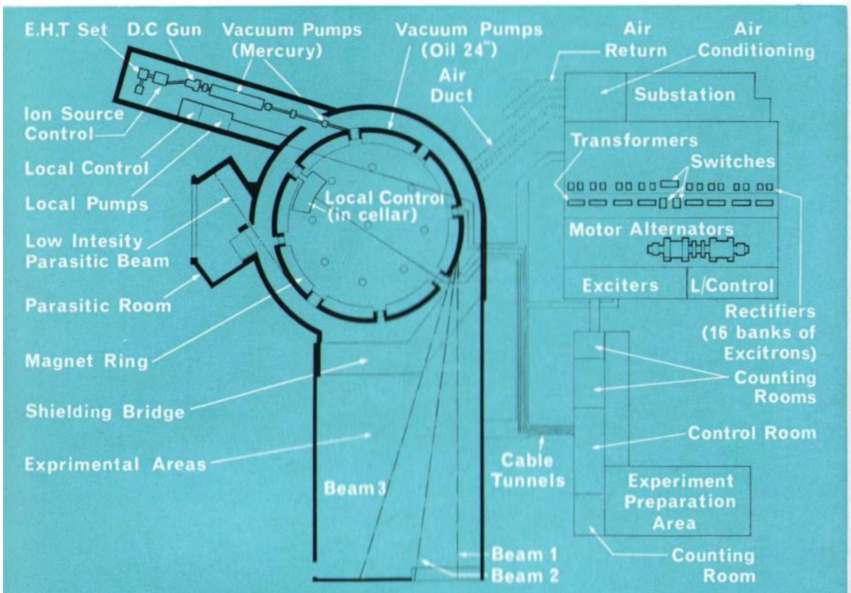
Accelerator and Control Systems

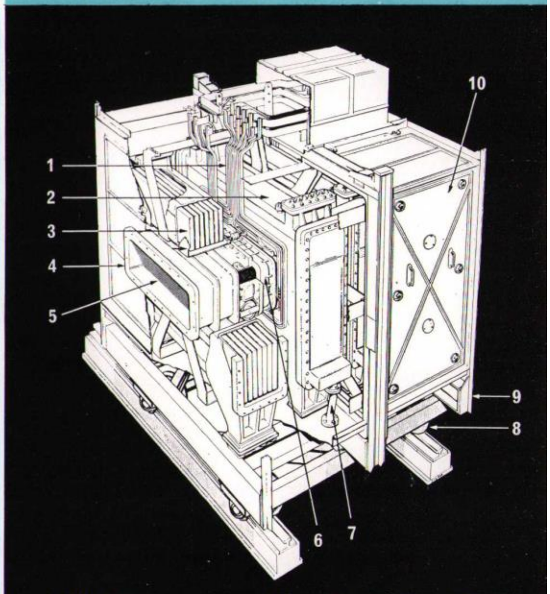


CONTROL SYSTEM: SEQUENTIAL CONTROL



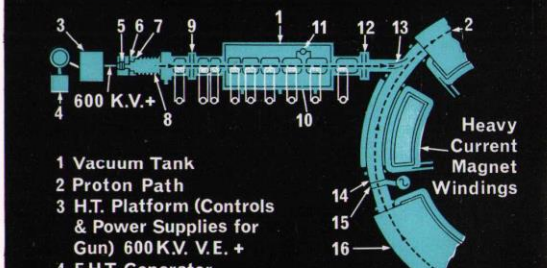
DIAGRAMMATIC LAYOUT OF ACCELERATING UNIT





1 Windings
2 Cooling Jackets
3 Ferrite Frames
4 Vacuum Vessel
5 Proton Beam Path
6 Insulator (One of Two)
7 Coolant Oil Inlet
8 Trolley
9 Base Unit
10 Cavity Shell

R. F. CAVITY



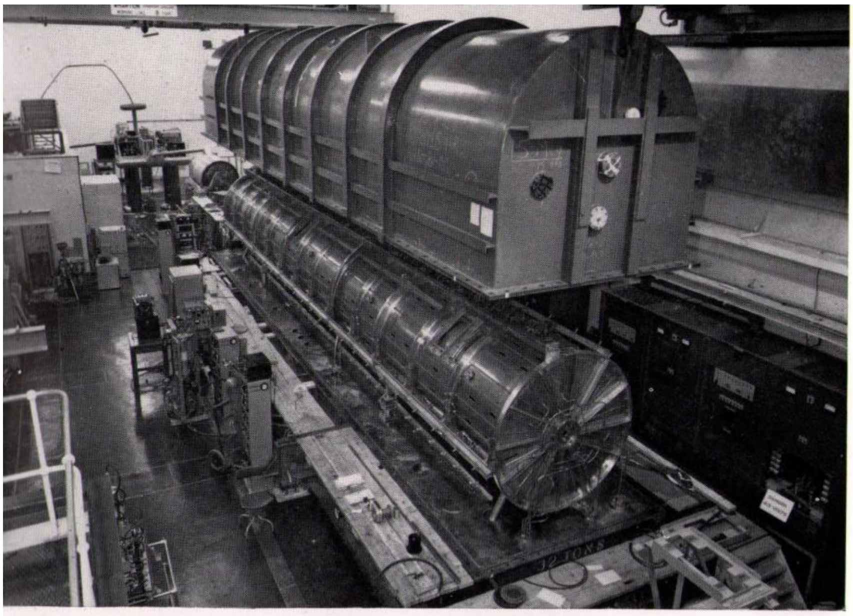
1 Vacuum Tank
2 Proton Path
3 H.T. Platform (Controls & Power Supplies for Gun) 600 K.V. V.E. +
4 E.H.T. Generator
5 Ion Source & R.F. Coil
6 Extraction Electrodes
7 Focussing Electrodes
8 Potential Electrodes
9 Buncher
10 Drift Tubes Housing Quadrupole Focussing Magnets
11 R.F. Resonator
12 Debuncher
13 Inflector Electrodes
14 Vacuum Tank (Annular)
15 R.F. Accelerating Cavity. (In One Position On Orbit)
16 Magnet Sector

OUTLINE OF OPERATION

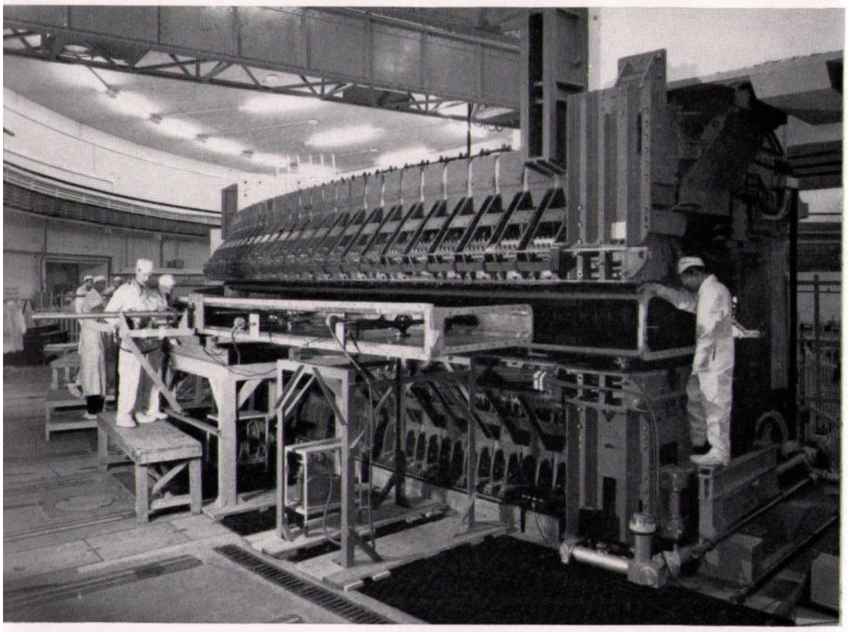
THE ACCELERATING DEVICE comprises a primary frequency generator, a bias supply, a beam control unit and an accelerator unit. The accelerator unit is fundamentally part of the main vacuum system the flanges of the vacuum vessel located within the R.F. unit actually acting as electrodes for beam accelerating purposes. The cavity will be excited by a variable frequency oscillator whose frequency must vary from 1·4 to 8 Mc/s between beam injection and extraction. The peak voltage across each insulator will rise to 7 kV. The frequency control of the cavity is obtained by magnetically biasing the ferrite cores by a direct current which changes the incremental inductance of the circuit. These cores are of a picture frame type and are produced by bonding sintered blocks with an epoxy resin cement. Some 12,000 lb of ferrite is used.

THE CONTROL SYSTEM of the proton synchrotron has the duty of maintaining at the preselected value during successive pulses, all critical variables associated with the equipment. It must also maintain the proper sequence of events and ensure the correct relative values of the variables during a pulse as acceleration takes place and be capable of extension to experimental apparatus.

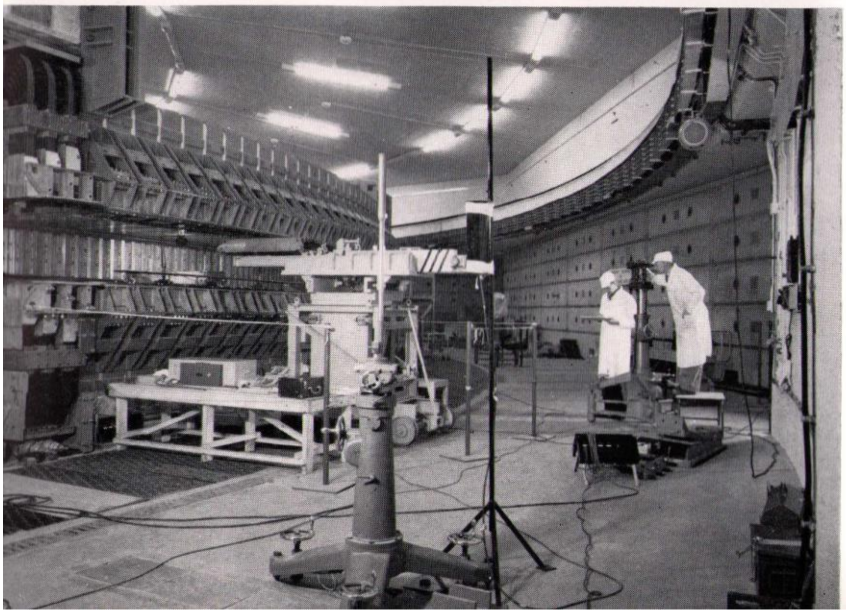
The control room will accommodate all the important instruments relative to the operation of the plant and the control and protection of personnel. The complete plant has been interlocked in the interests of general and radiological safety and strict control will be maintained over traffic of personnel into areas of excessive radiation.



View of the Injector showing the vacuum tank being lowered on to the R.F. liner



Installing an inner vacuum vessel into a magnet octant



Checking the alignment of the magnet pole pieces

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