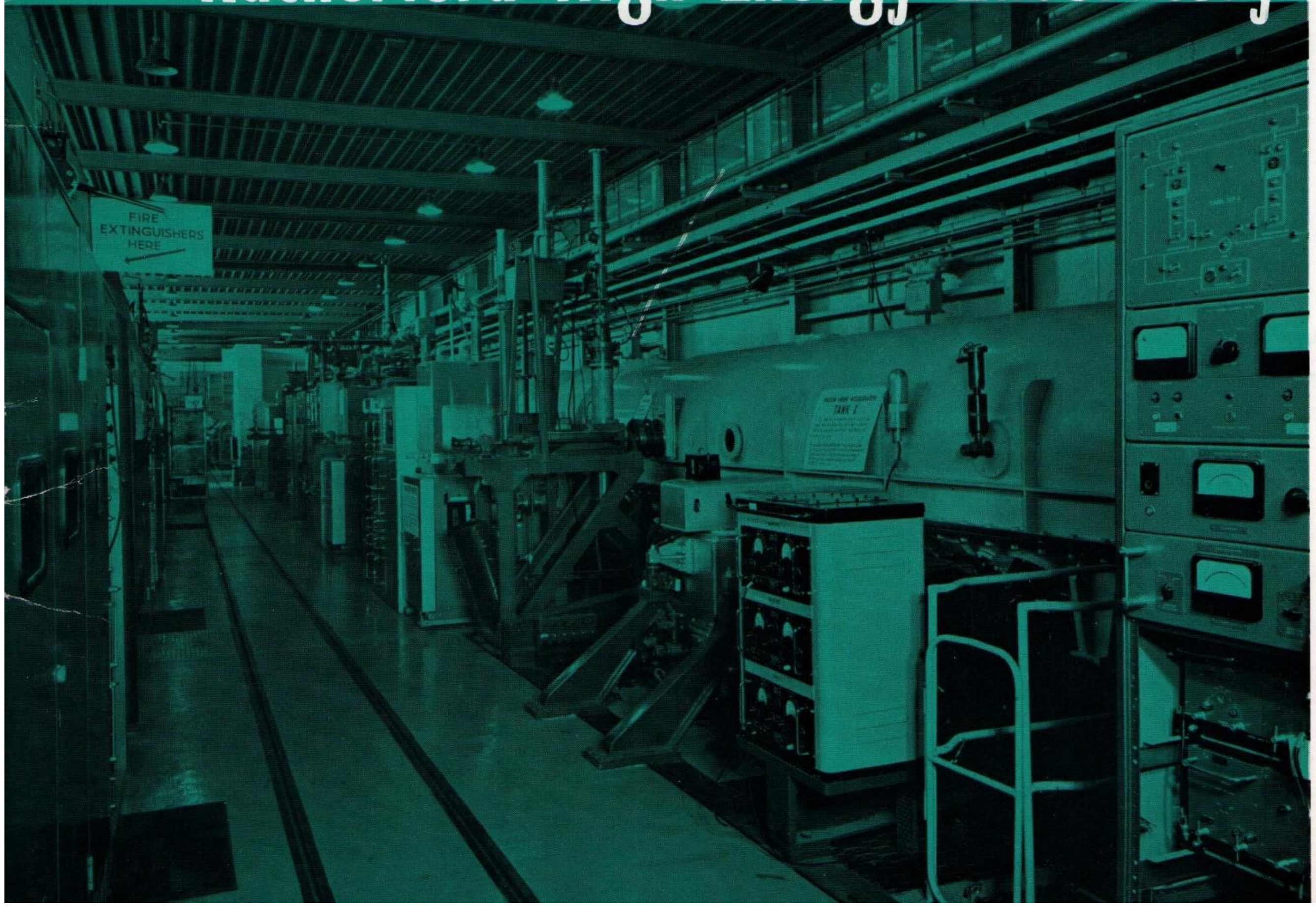
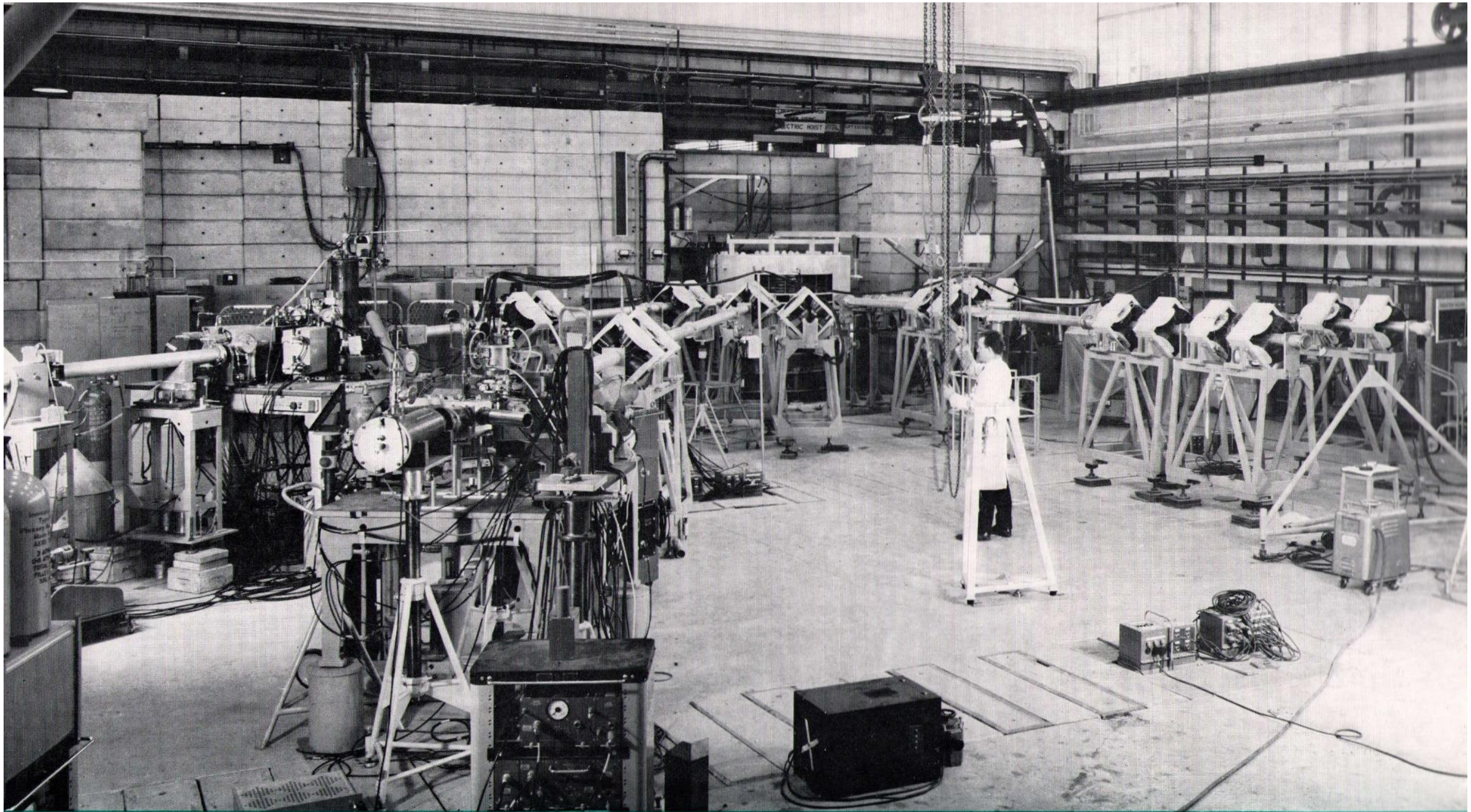
NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

Rutherford High Energy Laboratory



50 MeV Proton Linear Accelerator



Part of the experimental area showing the alternative beam pipes radiating from the bending magnet (top centre). The apparatus set up on the beam line in the near foreground was used in a measurement of (p-d) differential cross-sections with a liquid deuterium target.

The cover shows a general view of the main part of the P.L.A. installation with tank 1 in the right foreground.

50 MeV Proton Linear Accelerator

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 Rutherford High Energy Laboratory is the first establishment of the National Institute to be completed. Situated at Chilton and occupying a site of some 75 acres, the Laboratory is intended 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 (MeV) proton linear accelerator (P.L.A.) and a 7000 million electron volt proton synchrotron (NIMROD). The Laboratory also contains the necessary supporting facilities for conducting experimental work and can assist in the design, manufacture and installation of experimental equipment to user requirements.

The 50 MeV P.L.A. was the first accelerator at the Laboratory to become operational. It was designed by the United Kingdom Atomic Energy Authority, handed over to the Institute in 1959 and has been scheduled for experimental use since 1960. Except for maintenance periods, the machine is in operation 24 hours a day.

The P.L.A. is about 100 ft long; it consists of three cylindrical resonant cavities, placed end to end, into which pulses of protons are injected at 500 keV from a d.c. gun and accelerated successively to energies of 10, 30 and 50 MeV. Each resonator is contained in an evacuated tank and is excited into resonance at 200 Mc/s by a pulsed radio frequency power supply. A series of hollow cylindrical electrodes, known as drift tubes, are spaced at intervals down the axis of the resonator and it is in the gaps between successive drift tubes that the acceleration occurs.

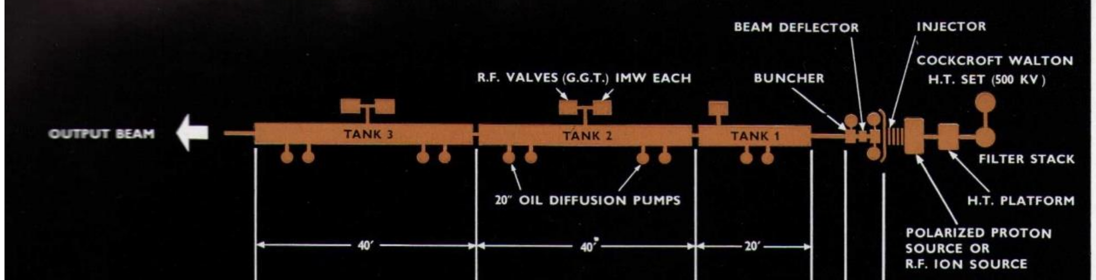
There are no extraction problems since the beam emerges directly from the end of the machine and passes through concrete shielding walls into the 7000 sq. ft experimental areas. Maximum efficiency in the use of the machine is gained by the provision of bending magnets which deflect the proton beam in a number of alternative directions, thus enabling many sets of experimental apparatus to be set up and left undisturbed.

Each beam pulse lasts 200 microseconds and the repetition rate is 50 pulses per second. In addition to performing experiments with 50 MeV protons, the machine has been designed so that 30 and 10 MeV protons can be used. It is also possible to accelerate protons with their axes of spin substantially aligned in a given direction; such 'polarized' beams enable the spin-dependent features of the complicated proton-nucleon and proton-nucleus interaction to be explored in more detail.

The unpolarized external proton current obtainable (typically 3 μA mean: $1{\cdot}8 \times 10^{13}$ protons/second) is many times greater than had been available previously with other accelerators in this energy range. Furthermore, the beam is well collimated and has a well-defined energy, giving the high resolution required in precise measurements. Should there be sufficient nuclear physics demand for beams of higher energy, the P.L.A. could be extended at any time by the addition of further sections.

The growing number of successfully completed experiments is evident from the many papers which have already been published by the participating scientists and by more than a dozen higher degrees which have now been awarded to members of the various experimental teams.

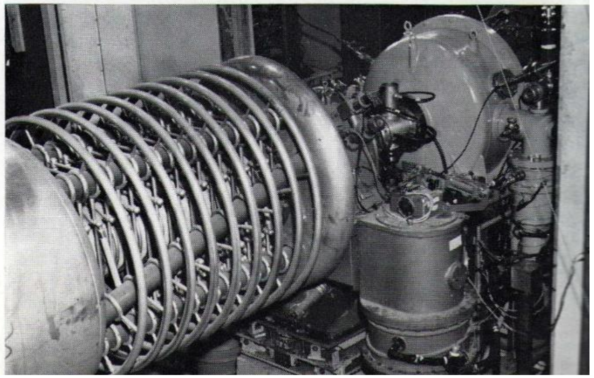
General Data

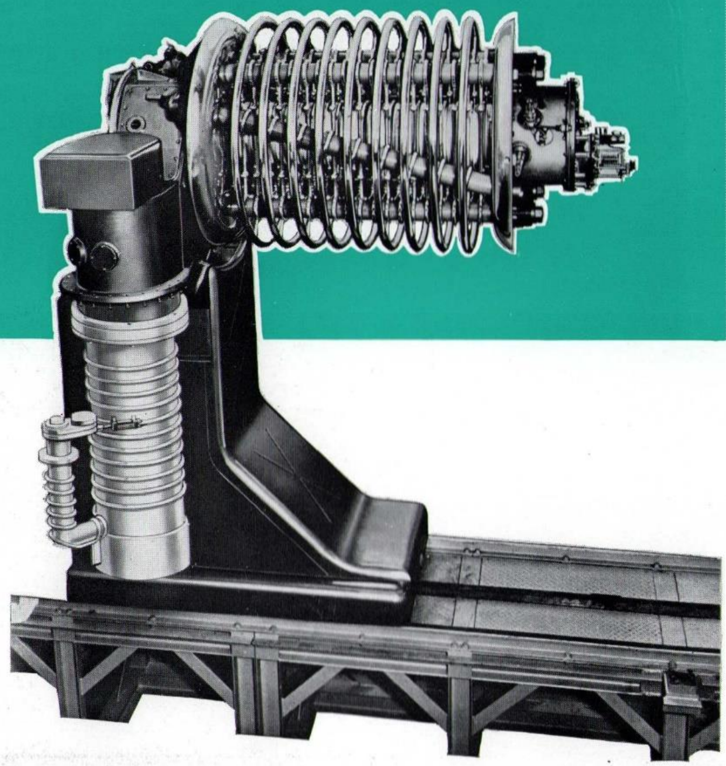


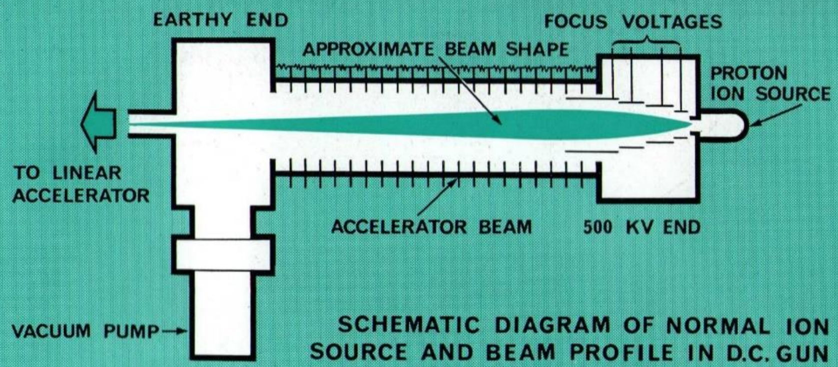
PROTON ENERGY (*approx*) (*Accelerating rate 1.7MeV/metre*)	50 MeV	30 MeV	10 MeV		½ MeV	
$\beta = \frac{\text{Speed of proton}}{\text{Speed of light}}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{7}$		$\frac{1}{30}$	
NO. OF DRIFT TUBES	26 + 2(½)	40 + 2(½)	41 + 2(½)			
BEAM APERTURE	1½"	1½"	¾" ½"			
FOCUSING	A.G. MAGNETIC QUADRUPOLES	A.G. MAGNETIC QUADRUPOLES	GRIDS			
R.F. PULSED POWER (*Peak*)	1400 kW	1200 kW	600 kW			Total 3·2 MW
(*Mean*)	28 kW	24 kW	12 kW			Total 64 kW
[*50 p.p.s. each* $\frac{1}{2500}$ *sec. long; 2% duty cycle for r.f. (400 µsec. pulses), 1% duty cycle for beam (200 µsec. pulses)*]						
BEAM CURRENT (*Peak*) *As % of injector output current*						
WITHOUT BUNCHER	1·3 to 2·0	1·3 to 2·0	1·3 to 2·0 Loss factor: 50—60		100	
WITH BUNCHER	2·6 to 5·0	2·6 to 5·0	2·6 to 5·0 Loss factor: 20—30		100	
Typical values						
WITHOUT BUNCHER	145 µA (1·45 µA mean)	145 µA	145 µA Loss factor: 55		8mA	
WITH BUNCHER	300 µA (3·0 µA mean)	300 µA	300 µA Loss factor: 27		8mA	
TIME OF FLIGHT	0·13 µsec.	0·20 µsec.	0·21 µsec.	0·15 µsec.		Total 0·705 µsecs. (with gaps between tanks)

Notes: 1. *Injector output current is usually within the range of 6-10 mA.*
2. *10 or 30 MeV beams may be coasted through tanks 2 and 3, or tank 3, respectively, without loss (after resetting of quadrupole focusing magnet total currents).*

(*113 r.f. cycles while particle traverses tanks 1, 2 and 3; plus 30 cycles between buncher and tank 1*).







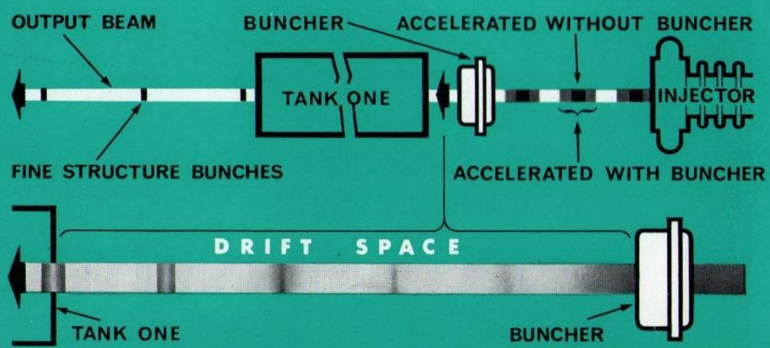
SCHEMATIC DIAGRAM OF NORMAL ION SOURCE AND BEAM PROFILE IN D.C. GUN

Injector

The injector comprises a source of protons (either a r.f. ion source or a polarized proton source) and a 500 kV d.c. gun, which provides the initial acceleration. A Cockcroft-Walton generator supplies this voltage, which is fed to the ion source end of the accelerating column via a smoothing stack and a high-voltage platform containing the power supplies and controls for the ion source and focusing electrodes. The unpolarized source consists of a Pyrex tube, inside which a discharge is maintained in hydrogen gas, at a pressure of 30 microns, by a 20 Mc/s r.f. field. The molecular hydrogen is dissociated into atomic hydrogen and subsequently ionized to produce protons, which are extracted from the discharge in the form of a beam by applying a high-voltage pulse ($\backsim$7 kV) to a suitable electrode. The accelerating column has a uniform potential gradient produced by a large number of intermediate electrodes and an external potential divider. The column is supported as a cantilever from the earthy end and it can be adjusted in position by remote control to align the beam to the axis of the main sections of the machine.

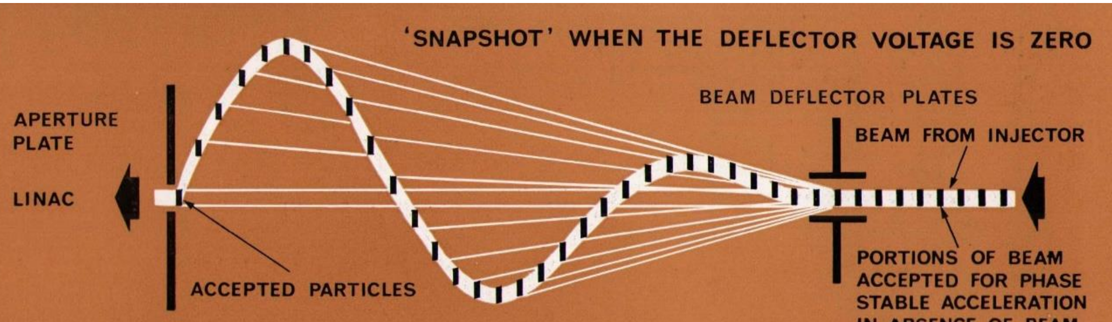
Left Injector room, with polarized proton source bun and d.c. gun in background.

Below, left. D.C. gun and low energy drift space, showing buncher assembly.



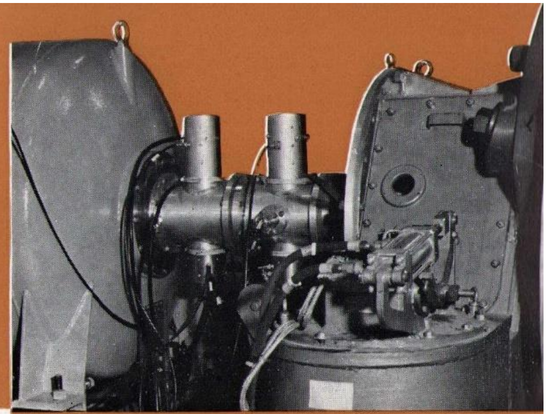
Buncher

Less than one-quarter of a continuous proton beam can be accepted for stable acceleration in tank 1. The buncher provides a means whereby many more protons can be made to arrive at the entrance to tank 1 at the most favourable times for acceleration and can consequently increase the accelerated beam intensity by a factor of nearly 3. It consists of a single gap r.f. cavity (located between the injector and tank 1) which is supplied with the requisite amplitude and phase of r.f. power from tank 1. The protons are velocity modulated in the buncher and, after traversing a drift space, they become grouped in bunches around the acceptance phase range of tank 1. The lower diagram shows the density distribution of protons in the beam between the buncher and tank 1 at a given instant of time.



Beam Deflector (T.O.F.)

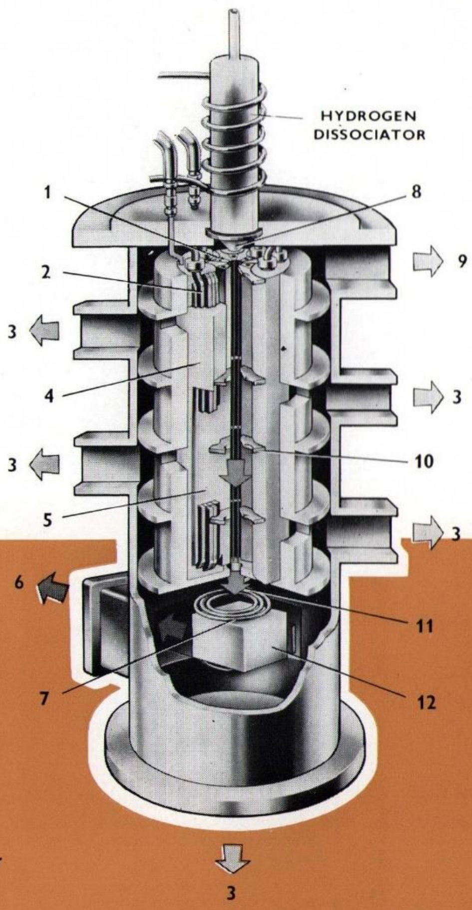
In many nuclear physics experiments particle velocity measurement by the time of flight method is desirable but the normal time spacing ($t = 5 \times 10^{-9}$ second) of the fine structure bunches in the P.L.A. beam is too short. A r.f. electric field deflection system has been provided between the injector and the buncher to produce longer time intervals between bunches by deflecting the 500 keV proton beam across an aperture before injection into tank 1. The frequencies of the deflecting voltages available are sub-harmonics of 202·5 Mc/s and their phases are locked to that of the r.f. power in tank 1 so that the deflection process, in effect, allows only every nth bunch of the normal proton beam to be accelerated. The bunch separation time is thus increased to $n \times t$, where n can be 3, 6, 9, 18 or 36.



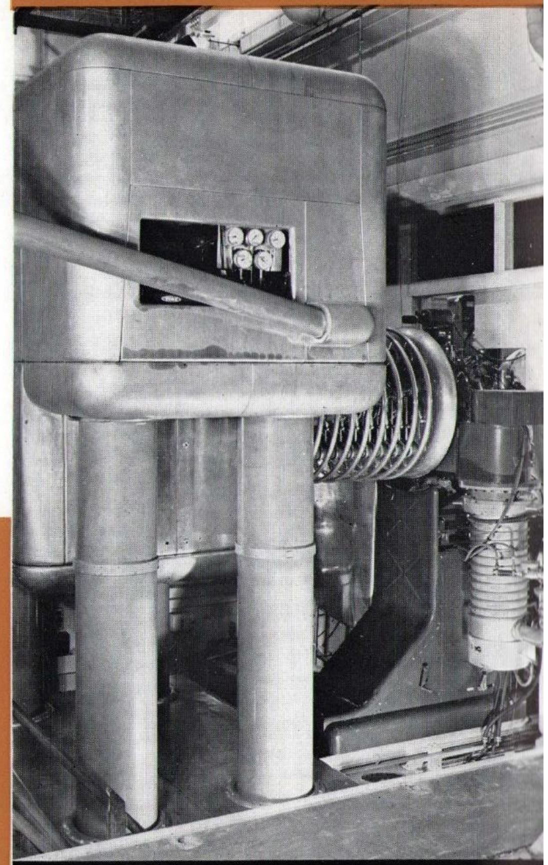
Deflector electrode assembly between injector and buncher

Polarized Proton Source

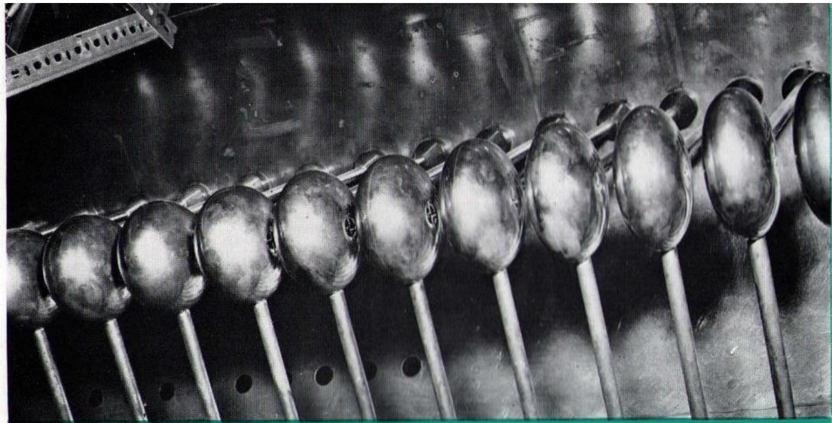
Since nuclear forces are known to be spin dependent, the production of a comparatively intense, strongly polarized, proton beam by the P.L.A. is a very useful facility. A special source provides the polarized proton beam for injection into the machine. The direction of polarization is controllable and is maintained throughout the acceleration. The P.P.S. uses the strong, non-uniform, field of a sextupole magnet to separate positive and negative magnetic moment atoms of hydrogen produced in a r.f. discharge dissociator. The negative magnetic moment atomic beam is ionized by electron bombardment in a weak magnetic field, where the protons in the atoms are theoretically 50% polarized. The resulting free protons, which retain their polarization, are extracted by an electric field and pass down the d.c. accelerating column in the normal way. Intensities in excess of 10^8 protons per second have been obtained at the experiment with 40% polarization.

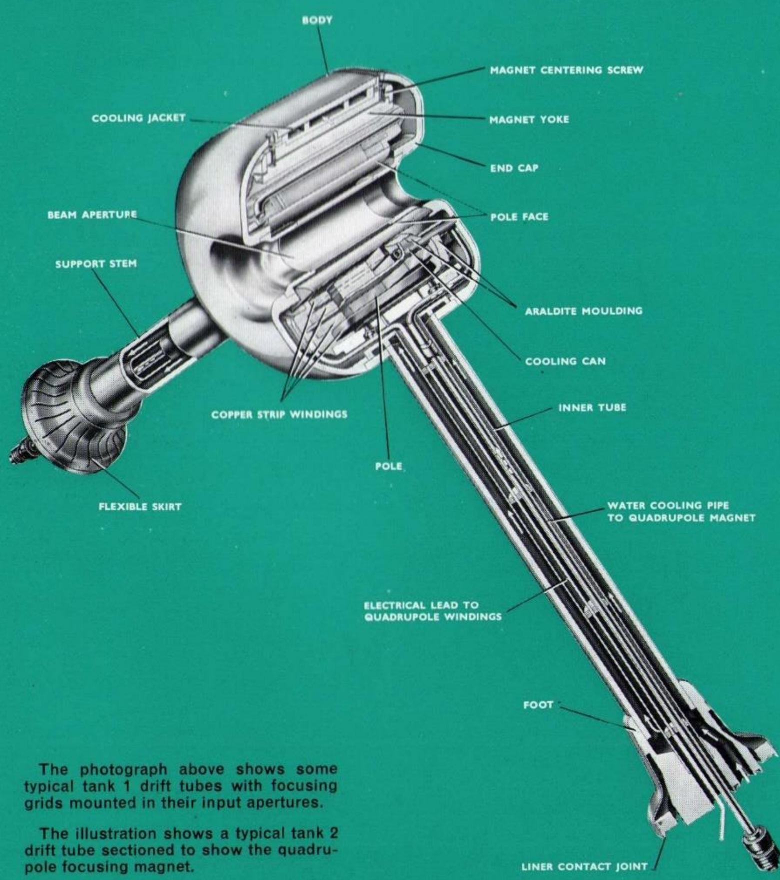


1 Top of sextupole magnet	7 Helmholtz coil
2 Magnet windings	8 Glass collimator nozzle
3 Diffusion pump	9 Booster pump
4 Araldite vacuum casing	10 Web plates
5 Magnet pole piece	11 Atomic hydrogen beam
6 Polarized proton beam	12 Electron bombardment ionizer



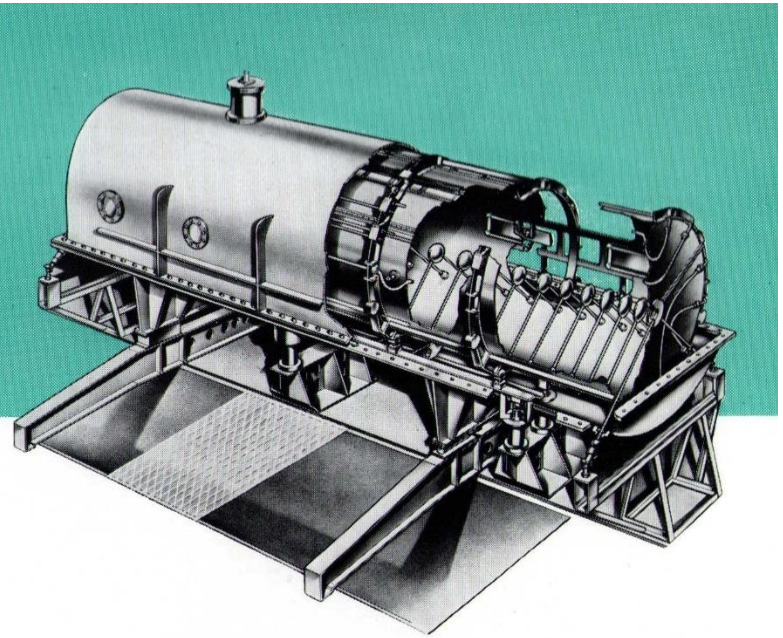
General view of polarized proton source assembly





The photograph above shows some typical tank 1 drift tubes with focusing grids mounted in their input apertures.

The illustration shows a typical tank 2 drift tube sectioned to show the quadrupole focusing magnet.



Tank One

The three main sections of the P.L.A. are very similar in design. Thus, tank 1 has a steel vacuum vessel (the top of which may be removed) containing a 4 ft 6 in diameter cylindrical copper resonator (also with a removable lid) which is independently supported from the foundations by pillars passing through holes in the vacuum envelope (metallic bellows complete the vacuum seal). Forty-one drift tubes, mounted on twin radial stems, are spaced along the axis of the resonator. Both resonator and drift tubes are water cooled, the temperature being stabilized at 38° C (100° F). The very high Q (∽80,000) resonator is maintained on tune by automatic control of tuner plates.

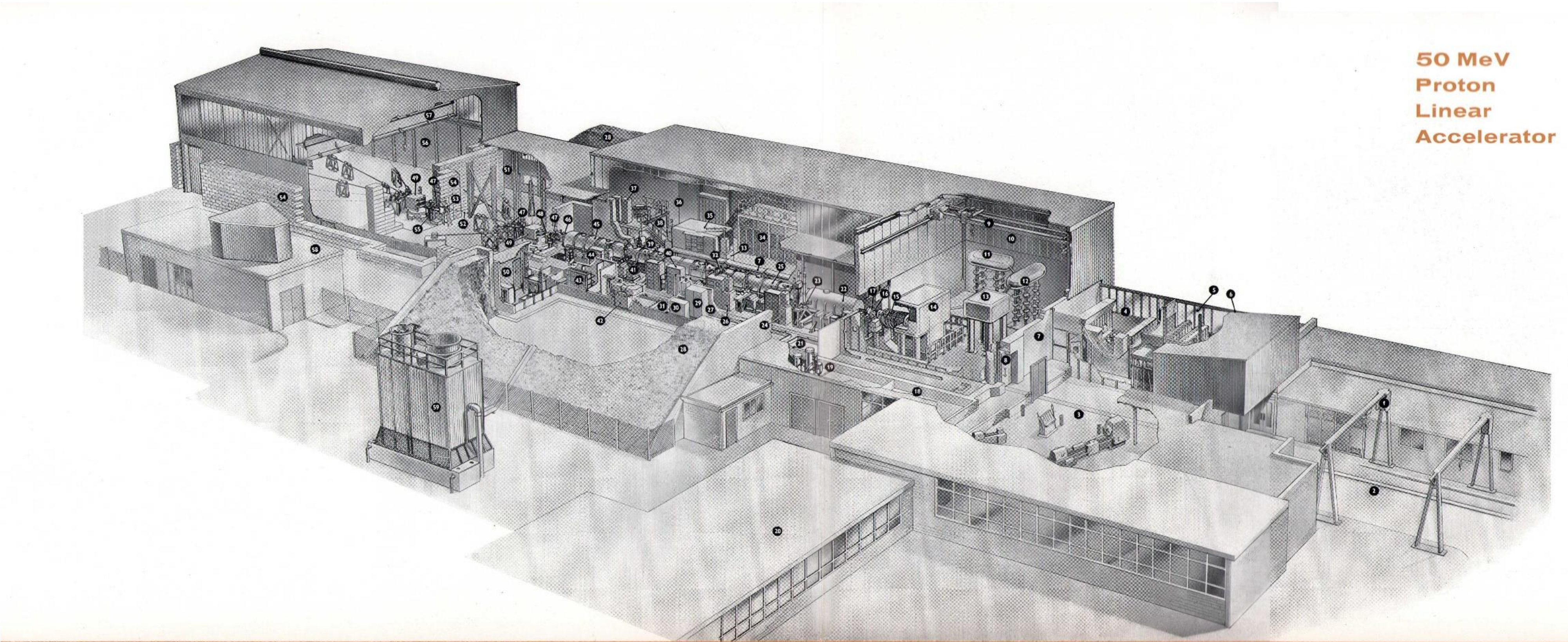
(NOTE. Alternate drift tubes are omitted in the illustration above).

Drift Tubes

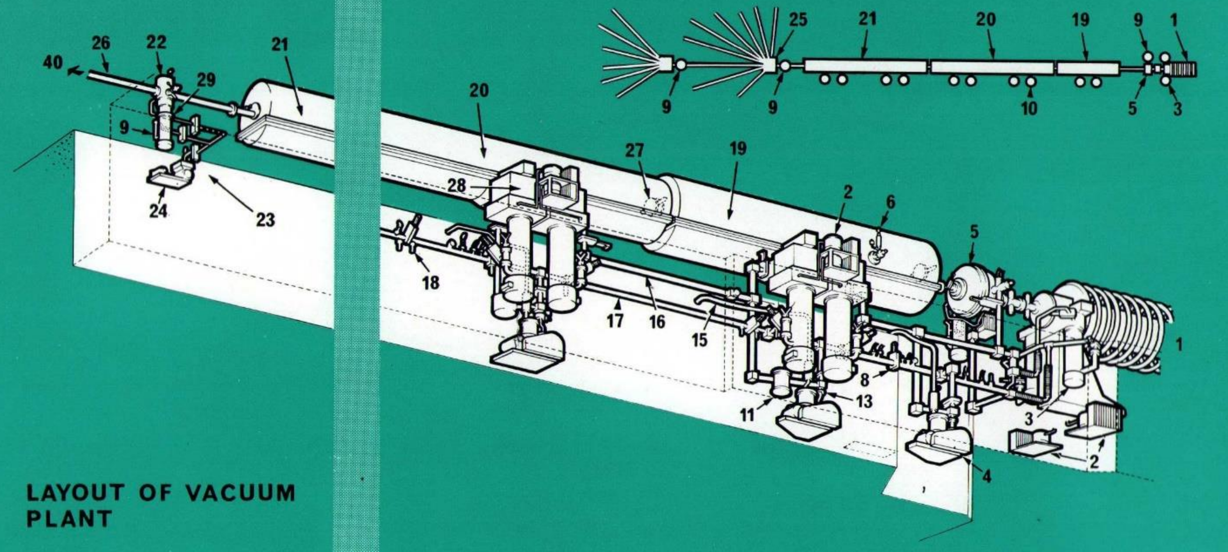
Proceeding along the machine each drift tube (D.T.) is made slightly longer than, and is spaced a little further away from, the previous one so that the accelerating electric fields in the gaps between the D.T.'s are synchronized with the increasing velocity of the protons.

Tank 1 D.T.'s are fitted with grids, which produce a weak focusing effect, while in tanks 2 and 3 the D.T.'s contain quadrupole electromagnets, which produce a strong focusing effect (by the principle of alternating gradient focusing). D.T. alignment, which is particularly important in tanks 2 and 3, is carried out optically.

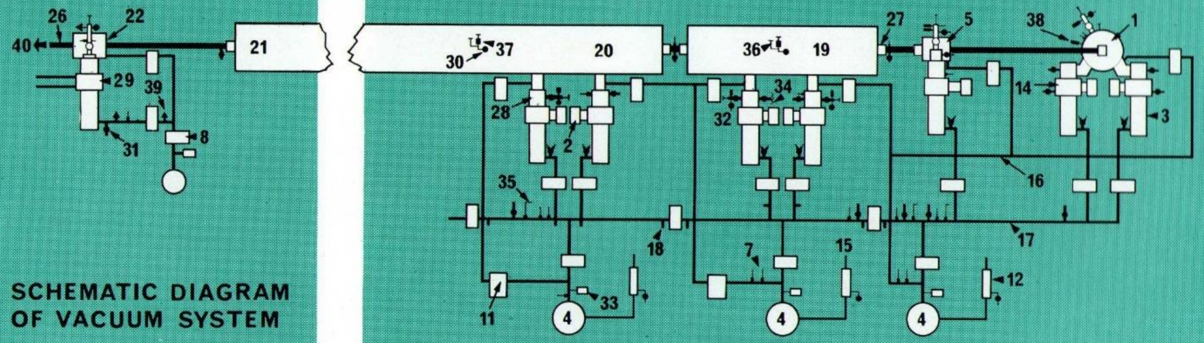
50 MeV Proton Linear Accelerator



1. Unloading gantry
2. Railway
3. Workshop
4. Control room
5. Counting room No. 1
6. Counting room No. 2
7. Concrete shielding wall
8. Concrete doors
9. 1½ ton crane.
10. Injector room
11. Cockcroft-Walton high voltage generator
12. Filter stack
13. Ion source power supply platform
14. Polarized proton source bun
15. Injector column
16. Beam deflecting electrodes (T.O.F.)
17. Buncher
18. Laboratory workshop
19. Water softening plant room
20. Crew room
21. Modulator cubicles
22. Tank 1
23. Tank r. f. feed line
24. Valve A cubicle (Tank 1 main r. f. amplifier)
25. Tank 2
26. Valve C cubicle (Tank 2 main r. f. amplifier)
27. R.F. drive
28. Earth bank shielding
29. Valve B cubicle (High power r. f. drive amplifier)
30. Foster regulator
31. R.F power dividing network
32. R.F. power combining bridge
33. Valve E (Tank 3 main r. f. amplifier)
34. Power supplies for beam transport system
35. Tank 3 r. f. amplifier cubicle for valves E and F
36. Auxiliary plant room
37. Bending magnet supply stabiliser
38. Valve F (Tank 3 main r. f. amplifier)
39. Generator supplying bending magnet
40. Local control racks
41. Vacuum pumping unit
42. Modulator cooling refrigerator
43. Pulse forming network
44. Valve D cubicle (Tank 2 main r. f. amplifier)
45. Tank 3
46. Beam monitor
47. Beam focusing quadrupoles
48. High speed shut-off valve and vacuum pump
49. Beam bending magnet
50. Modulator E.H.T. supply transformer
51. Experimental area No. 1
52. Beam transport pipes
53. Beam stop
54. Concrete block wall
55. Vacuum pumping unit
56. Experimental area No. 2
57. 10 ton crane
58. Pump house
59. Cooling towers



LAYOUT OF VACUUM PLANT



SCHEMATIC DIAGRAM OF VACUUM SYSTEM

1. INJECTOR
2. REFRIGERATOR
3. 16" DIFFUSION PUMP
4. KINNEY PUMP
5. BUNCHER
6. IONISATION GAUGE
7. THERMOCOUPLE
8. SLUICE VALVE
9. 6" DIFFUSION PUMP
10. 20" DIFFUSION PUMP
11. CO_2 COLD TRAP
12. CONDENSATION TRAP
13. AIR INLET VALVE
14. REFRIGERATED CHEVRON BAFFLE
15. KINNEY EXHAUST
16. ROUGHING LINE
17. BACKING LINE
18. OIL TRAP
19. TANK 1
20. TANK 2
21. TANK 3
22. HIGH SPEED SHUT-OFF VALVE
23. BEAM PIPE PUMPING SYSTEM
24. BACKING PUMP
25. BEAM BENDING MAGNET
26. BEAM PIPE
27. INTER TANK SHUT-OFF VALVE (V4)
28. GATE VALVE (V3)
29. CHILLED WATER COOLED CHEVRON BAFFLE
30. LARGE MANUAL VALVE
31. ½" VALVE
32. SMALL AIR INLET VALVE
33. SOLENOID OPERATED AIR INLET VALVE
34. FILTER
35. DISCHARGE TUBE
36. IONISATION GAUGE (UNTRAPPED)
37. IONISATION GAUGE (TRAPPED)
38. PHILIPS IONISATION GAUGE
39. PIRANI GAUGE HEAD
40. TO EXPERIMENTAL AREAS

Vacuum System

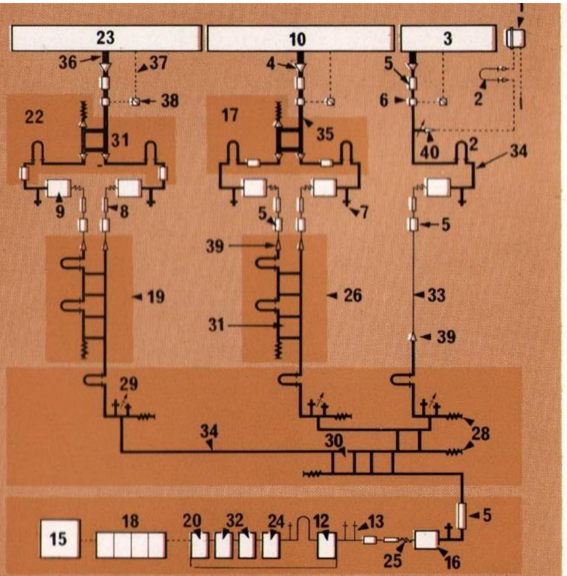
In order to avoid r.f. breakdown, beam scattering and beam energy loss it is necessary to provide a vacuum of about 5×10^{-6} torr in the main tanks and buncher. Oil diffusion pumps (fitted with refrigerated chevron baffles) are used throughout; two 20 in. pumps are provided on the 20 ft long tank 1 and four pumps on each of the 40 ft long tanks 2 and 3. The buncher has a 6 in. pump, while the injector has two 16 in. ones, which are required to handle the large throughput of gas from the ion source. One mechanical backing (and roughing) pump is provided for each pair of diffusion pumps. The whole system is fully interlocked and automatic in operation.

Separate pumping equipment is provided for the beam pipes and a high-speed shut-off valve protects the main machine from the effects of any catastrophic vacuum failure in the beam pipe system.

R.F. System

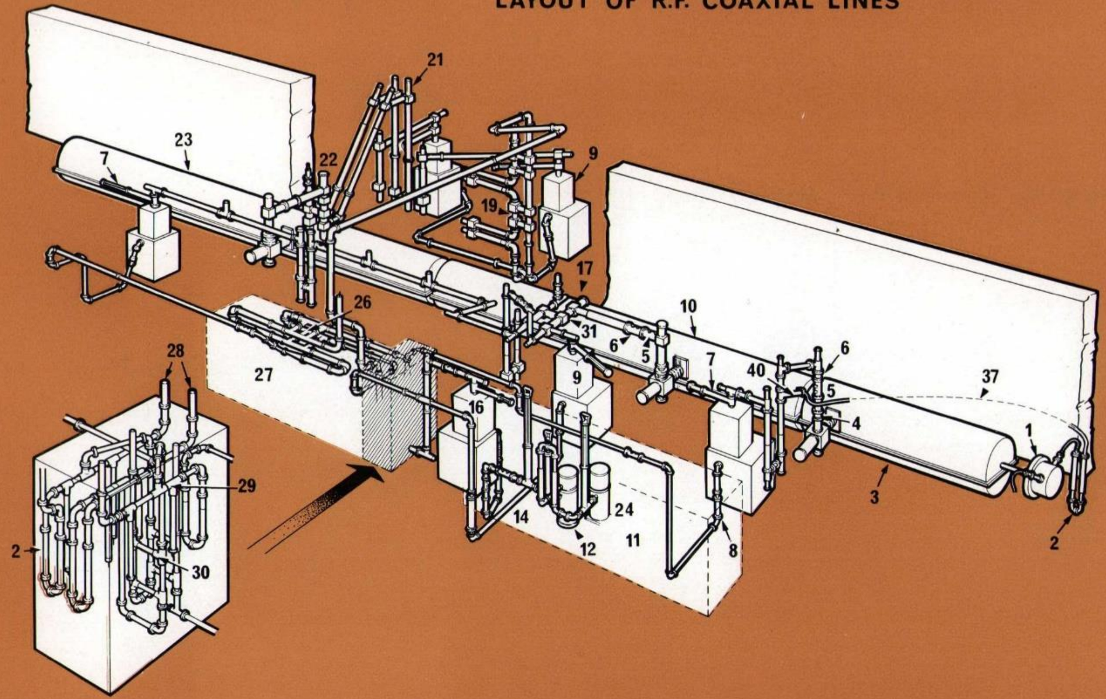
A very high-power pulsed r.f. signal (400 μs pulses, 50 pulses/second) must be fed into each of the main resonators. The total power of 3·2 MW is generated in five demountable grounded grid triode (G.G.T.) valves. One valve feeds tank 1, while two in parallel are required to feed each of tanks 2 and 3. All are driven by a common drive chain, starting from a 2·5 Mc/s crystal-controlled oscillator, the output of which is multiplied in frequency to 202·5 Mc/s and amplified in power level to 65 kW (under pulsed conditions at the higher power levels). Finally, one more G.G.T. valve raises the peak power level to 600 kW. The drive power is distributed to the final amplifiers by a complex network of 50 ohm coaxial lines. The outputs of the parallel valves on tanks 2 and 3 are similarly combined in coaxial line bridge circuits. Each tank is fed through a coaxial line vacuum window to a coupling loop in the resonator.

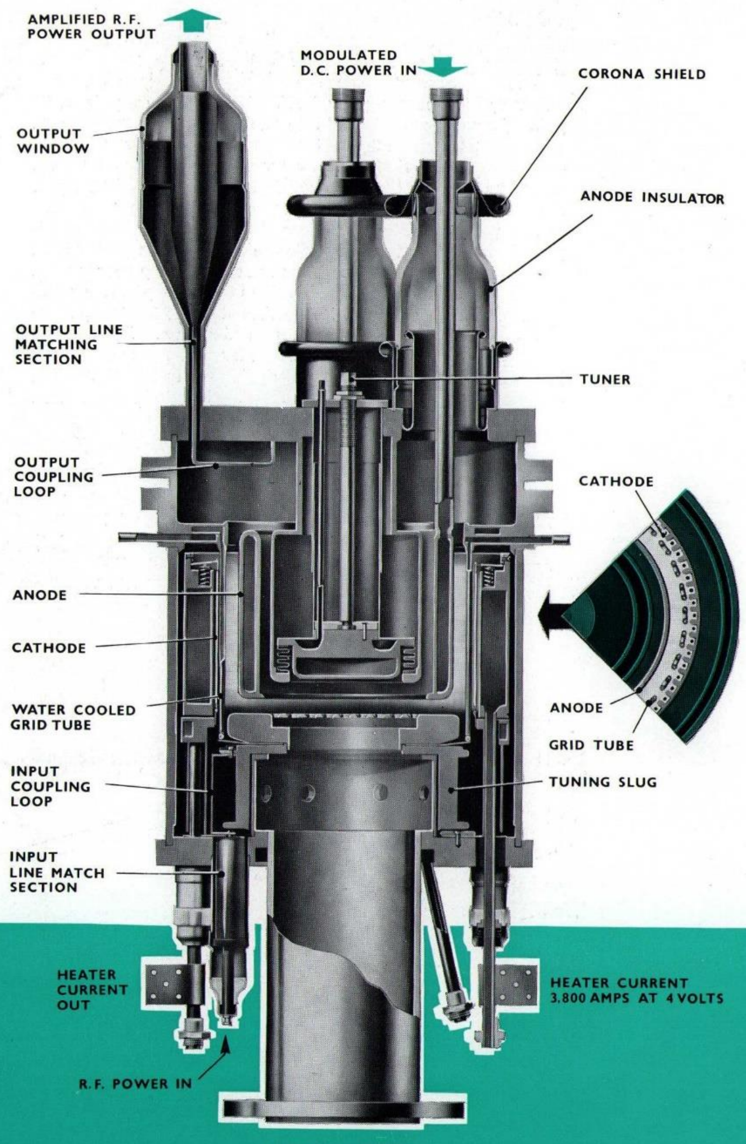
1. BUNCHER
2. PHASE SHIFTER
3. TANK 1
4. VACUUM WINDOW
5. REFLECTOMETER
6. PHASE REFERENCE POINT
7. VALVE TUNING STUB
8. TRANSFORMER SECTION
9. GROUNDED GRID TRIODE VALVE
10. TANK 2
11. PULSED STAGES LOW POWER DRIVE
12. BR 1106
13. MATCHING STUB
14. DRIVE MODULATOR
15. 2·5 MC/S CRYSTAL OSCILLATOR (IN OVEN)
16. HIGH POWER DRIVE
17. TANK 2 PARALLELING SYSTEM
18. FOUR FREQUENCY TRIPLING STAGES TO 202·5 MC/S
19. DRIVE POWER SPLITTING SYSTEM FOR TANK 3 G.G.T. VALVES
20. CV 2666 STAGE
21. SUPPORT STUB
22. TANK 3 PARALLELING SYSTEM
23. TANK 3
24. ACT 27 STAGE
25. FLEXIBLE SECTION
26. DRIVE POWER SPLITTING SYSTEM FOR TANK 2 G.G.T. VALVES
27. TANK 2 100 kW MODULATOR
28. LOADS
29. VARIABLE ATTENUATOR
30. POWER DIVIDING BRIDGE: RATIO 1·6/1
31. BRIDGE: RATIO 1/1
32. ACT 25 STAGE
33. 1½" CO-AXIAL LINE (50 OHM)
34. 3" CO-AXIAL LINE (50 OHM)
35. 4½" CO-AXIAL LINE (50 OHM)
36. 6" CO-AXIAL LINE (50 OHM)
37. CABLE
38. PHASE COMPARISON BRIDGE
39. TAPERED SECTION OF CO-AXIAL LINE
40. VARIABLE COUPLING PICK UP POINT



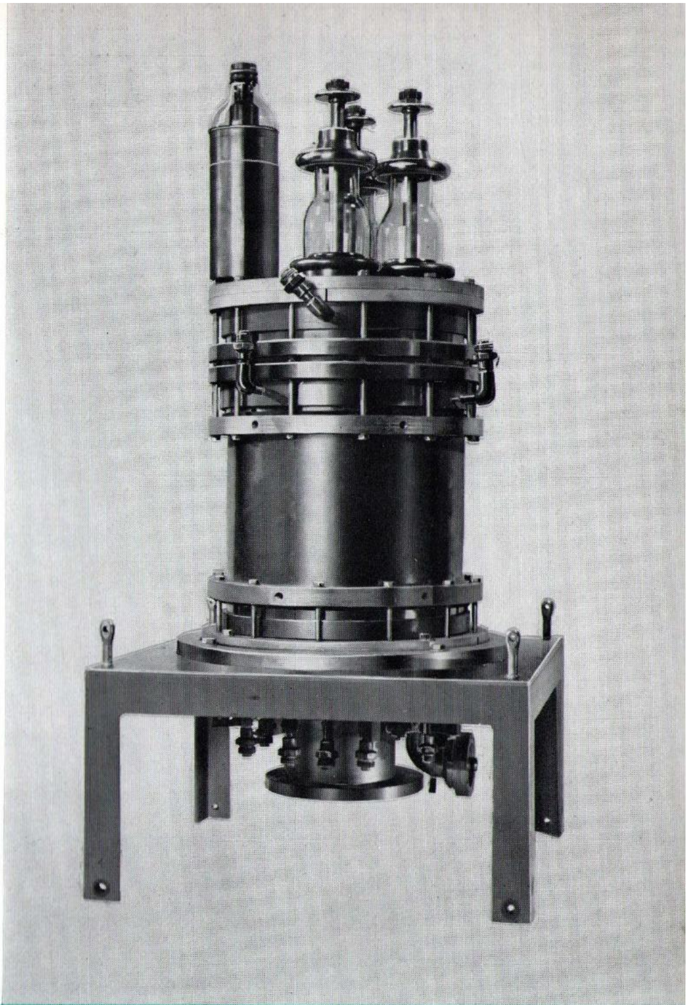
◀ SCHEMATIC DIAGRAM OF R.F. SYSTEM

LAYOUT OF R.F. COAXIAL LINES

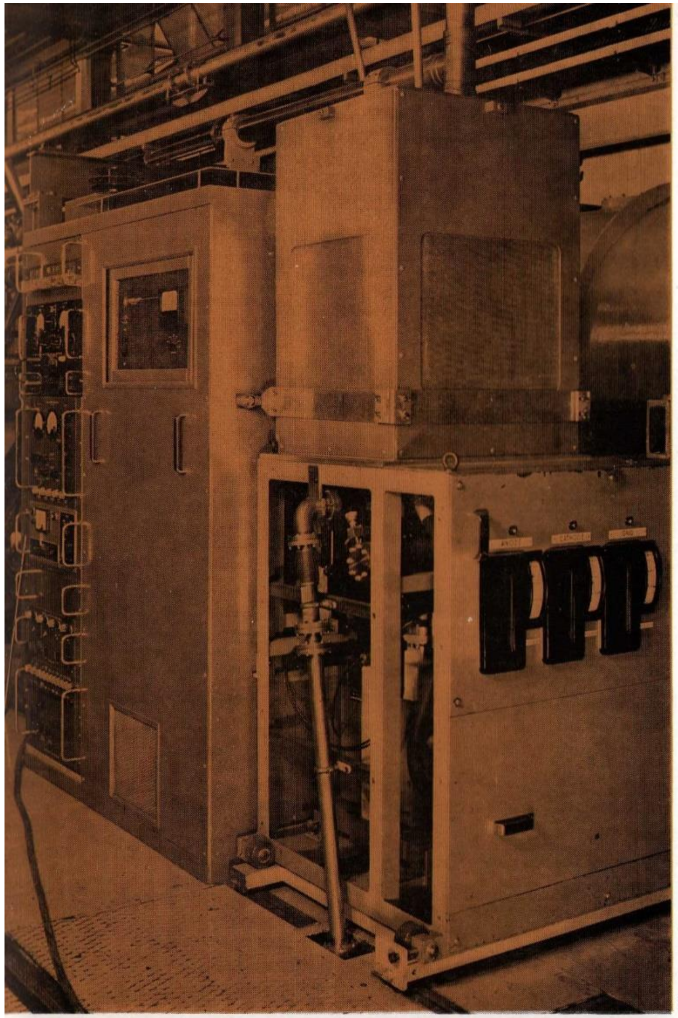




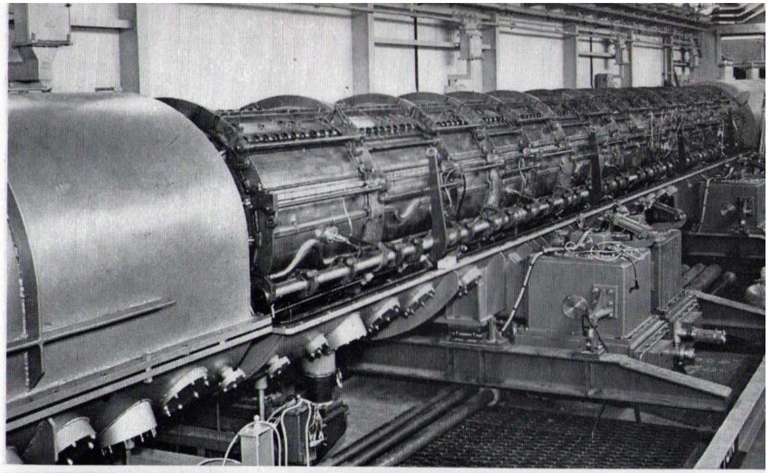
Grounded Grid Triode Valve



When the P.L.A. was designed, no valves were available commercially to work at a frequency of 200 Mc/s and give up to 1 MW (peak) pulsed r.f. power with a 2% duty cycle. Consequently, the demountable grounded grid triode valve shown above was specially developed for this application. The design is unconventional, with a central anode and an external cylindrical cathode formed by sixty-four directly heated, carburized thoriated tungsten rods. The high operating frequency necessitates using input and output circuits in the form of 'built-in' folded coaxial resonant lines. The valve is evacuated continuously by a getter-ion pump and is water cooled.



1



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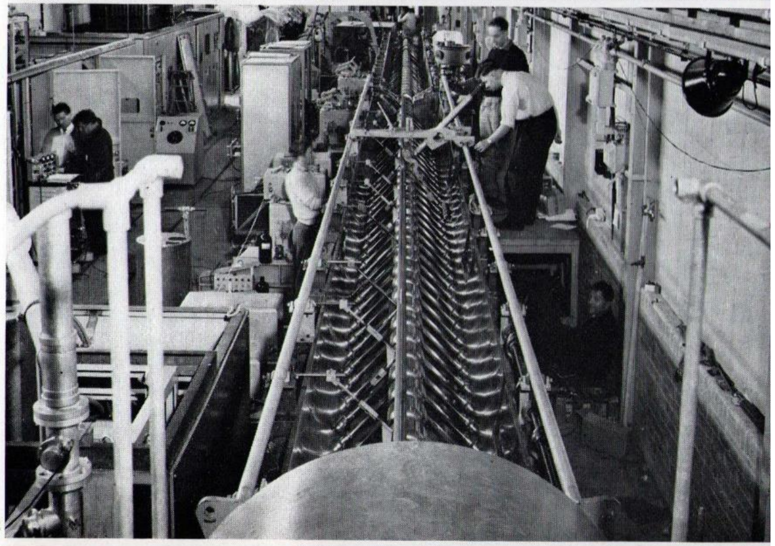


3

Typical Operating Conditions

Frequency	202·5 Mc/s
Pulse length	400 μs
Pulse repetition frequency	50 p/s
Heater power	15 kW
Anode volts (pulsed)	30 kV
Anode current (pulsed)	66 A
R.F. drive power (pulsed)	80 kW
R.F. output power (pulsed)	800 kW
Anode impedance	458 ohm
Gain	10
Efficiency	40%
Running pressure (at 800 kW output)	less than 10^{-6} torr

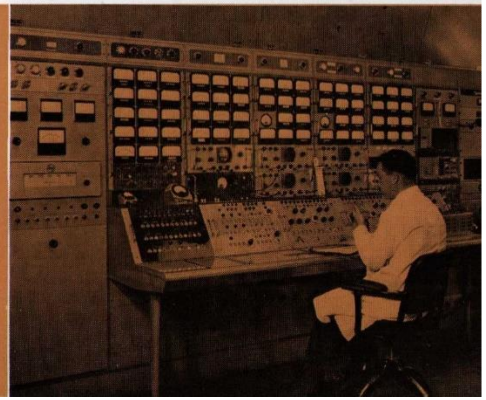
1 A typical G.G.T. valve installation near tank 2; the replaceable trolley containing the valve can be seen in the foreground with the control cubicle beyond.

2 Tank 2 resonator *in situ* with the vacuum envelope lid removed.

3 The optical alignment of tank 2 drift tubes using an axial telescope and a travelling microscope.

4 A general view of the control room with the main control desk.

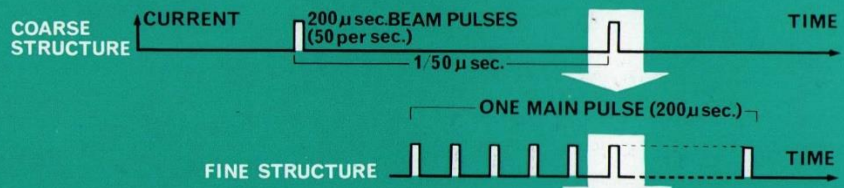
4



Output Beam

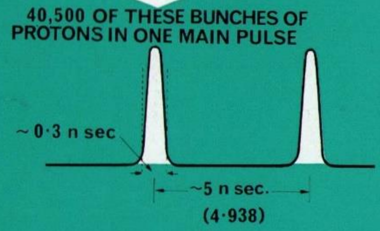
Coarse time structure

The P.L.A. operates in pulses:
The beam pulse length is variable up to a maximum of 200 μs.
The maximum pulse repetition rate of 50 per second can be divided by 2, 4, 8 or 16.
The maximum duty cycle is therefore 1%.



Fine time structure

As a result of the accelerating action in the machine and injection acceptance over a limited portion of each r.f. cycle, the output beam is bunched—one bunch for each r.f. cycle.



With 1, e.g., μA mean beam current from the P.L.A. (at 50 pulses/second):—
The peak beam current averaged during the 200 μs pulse (1% duty cycle) .. = 100 μA
The number of protons/second .. = 6×10^{12}
The number of protons/pulse .. = $1{\cdot}2\times10^{11}$
The number of protons/bunch .. = 3×10^{6}

(NOTE. Since there is an energy spread in the output beam the bunch width may change by the time the beam has travelled down the beam pipe to an experiment. The time width of the bunches may be reduced when the beam deflector for time of flight (T.O.F.) measurements is in use but only single pre-selected bunches, separated in time by an integral number of r.f. cycles, will then be produced.)

Energy

Alternatives of 9·95, 29·9 or 44·9 MeV are available.
Stability: Better than $\pm\frac{1}{2}$%
Spectrum: Dependent on machine adjustment
Under good performance conditions the following half height spectrum widths can be obtained:—

30 keV at the nominal 10 MeV output energy
100 keV at the nominal 30 MeV output energy
150 keV at the nominal 50 MeV output energy

Current

With the normal (unpolarized) ion source the P.L.A. output current is continuously variable up to a maximum near 3 μA mean.

With the polarized proton source intensities in excess of 10^{8} protons per seeond are at present available (with 40% polarization).

(NOTE. Future improvements to tank 1 of the machine should increase all beam intensities by a factor of 10, while development of the polarized proton source should raise its output by another factor of 5 to 10, with double the present polarization.)

Emittance

The emittance has not been measured accurately but is of the order of 50 mm mrad.

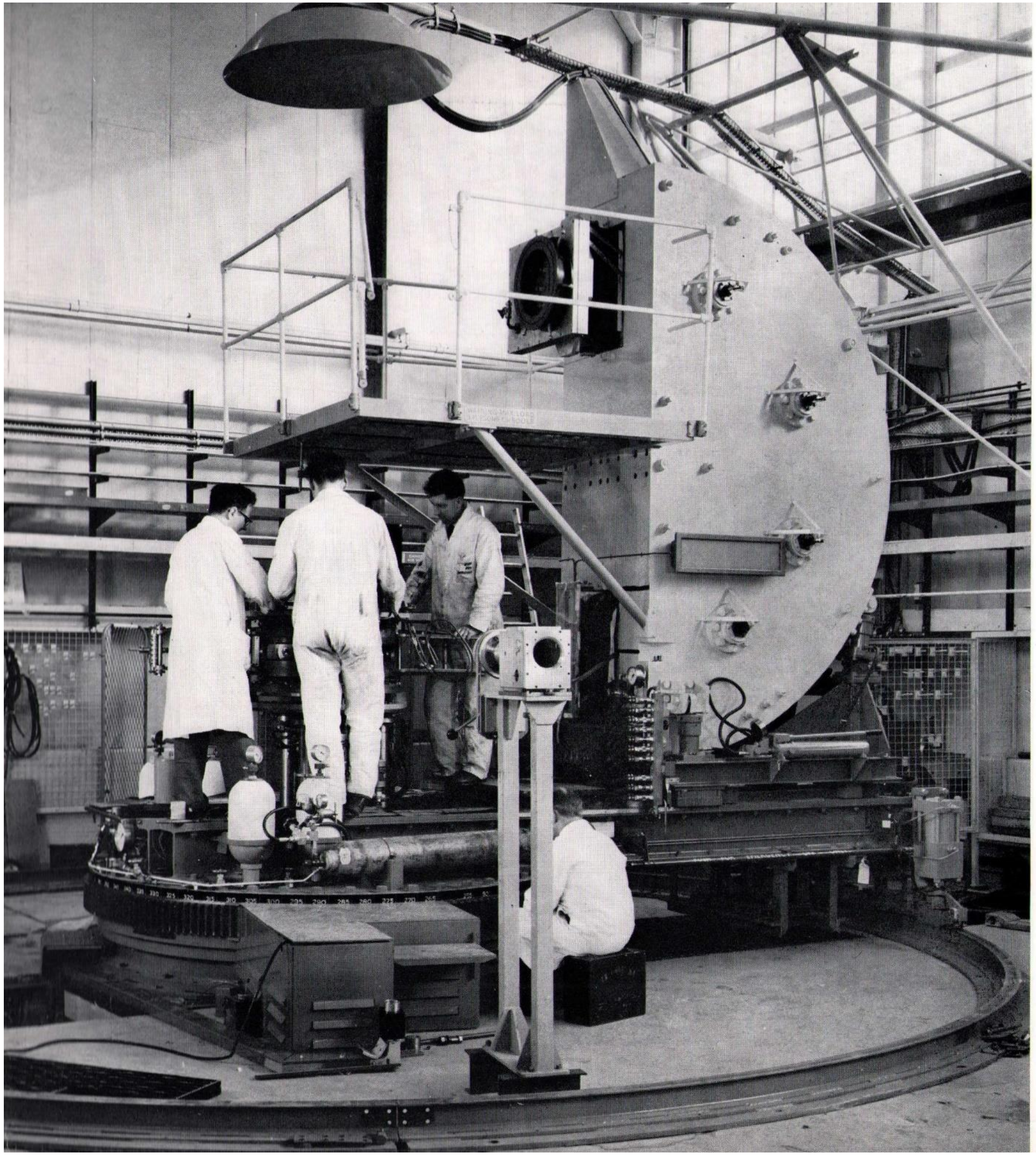
ERRATA. OUTPUT BEAM (Left)
COARSE STRUCTURE figure. Delete μ in: "1/50μ sec."
Fine time structure. Para. 2, line 1, should read: "With, e.g., 1 μA mean . . ."
Energy. Line 1. "44.9 MeV" should read: "49.4 MeV".
Current. Line 3. "seeond" should read: "second".

Use in Research

The Nuclear Physics experiments can be divided into two broad classes. The first: scattering experiments in which a suitable target is bombarded by a beam of polarized or unpolarized protons. By measuring the numbers of particles scattered through various angles, information can be obtained about the force between the proton and the target nucleus. For example, by bombarding a liquid hydrogen target, data about the force between two protons can be obtained. The nature of this force is so complex that many different, high-precision, experiments are required. In one experiment the absolute scattering cross-section was measured with an error less than 1%. With an incident beam of polarized protons the asymmetries in the scattering were measured to elucidate the way in which the force depends on the spin of the proton. The accuracy was greatly improved due to the availability of the P.L.A. polarized proton source. Other experiments determine the 'rotation parameters' which describe how the spin direction is changed by scattering. The same measurements are also made with more complicated targets than the protons of liquid hydrogen, usually separated isotopes.

The second class of experiments is concerned with nuclear reactions. 50 MeV protons overcome the electrostatic repulsion from the charge of even the heaviest of nuclei and nuclear reactions can take place ranging in complexity from emission of a single neutron to almost complete disintegration. To understand what happens in such reactions, it is at present necessary to confine attention to the simpler cases and have instruments which identify the different emitted radiations (γ rays, neutrons, the hydrogen and helium isotopes) and measure their energies. Detectors currently in use include sodium iodide and plastic scintillation counters, solid state counters, sonic spark chambers, and a high-resolution double-focusing magnetic spectrometer. The customary pulse height analysis and coincidence techniques are much used. Time of flight methods, which take advantage of the very short duration of proton bursts, have been developed for measurement of neutron energy and for particle identification. In cases where more than one product from a single nuclear reaction is studied, data-handling equipments capable of analysis into several thousand channels are used. Nuclear chemistry has been useful too.

Details of all the experiments currently proceeding on the P.L.A., together with lists of reports and publications, can be found in the Annual Progress Reports of the P.L.A. group.



Users

Over fifty experimental nuclear physicists and chemists, grouped into nearly a score of separate teams, have already carried out experiments employing the P.L.A.; the majority are from universities, but included are two resident R.H.E.L. teams and one from A.E.R.E. Overseas visitors have come from Canada, the U.S.A. and Poland to use the P.L.A. Many of the experiments are carried out as joint projects between the visiting and resident groups.

The following institutions have been the major users during the first 4 years of operation:—

A.E.R.E. (Nuclear Physics Division)
Birmingham University (Physics Dept.)
Kings College, London (Physics Dept.)
Oxford University (Nuclear Physics and Chemistry Depts.)
Queen Mary College, London (Physics Dept.)
The Queen's University, Belfast (Physics Dept.)
R.H.E.L.
University College, London (Physics Dept.)
Westfield College, London (Physics Dept.)

The double-focusing magnetic spectrometer during installation in the experimental area. The magnet will be used to measure the energies of charged particles emitted in nuclear reactions.

Rutherford
High Energy
Laboratory

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

Chilton
Berkshire
England

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