NOTES ON THE 50 MEV P.L.A.

(MACHINE ONLY, NOT EXPERIMENTAL AREAS)

Each of the notes is numbered; the cross references between these numbers and the numbers on the diagram are given below:

NOTE NUMBER	DIAGRAM NUMBER
1	11
2	12
3	13
4	14
5	15
6	17
7	22
8	21*
9	25
10	21*
11	45
12	21*

* Each of the modulators is on the opposite side of the gangway to the tank (accelerator) with which it is associated.

COCKCROFT WALTON MULTIPLIER (1)

THIS APPARATUS PROVIDES THE HIGH-VOLTAGE SUPPLY (500,000 VOLTS) FOR THE INITIAL ACCELERATION OF THE PROTONS AT THE D.C. GUN.

An AC voltage of about 50,000 volts at 500 cycles/sec is fed to this apparatus which rectifies and multiplies it to a level of 500 KV. Under running conditions the output current is about 3.5 milliamps.

In effect, the apparatus consists of a number of condensers which by means of rectifiers, are charged in parallel and discharged in series.

CONDENSER STACK (2)

THIS APPARATUS SMOOTHS THE OUTPUT VOLTAGE FROM THE COCKCROFT WALTON MULTIPLIER AND ACTS AS A RESERVOIR.

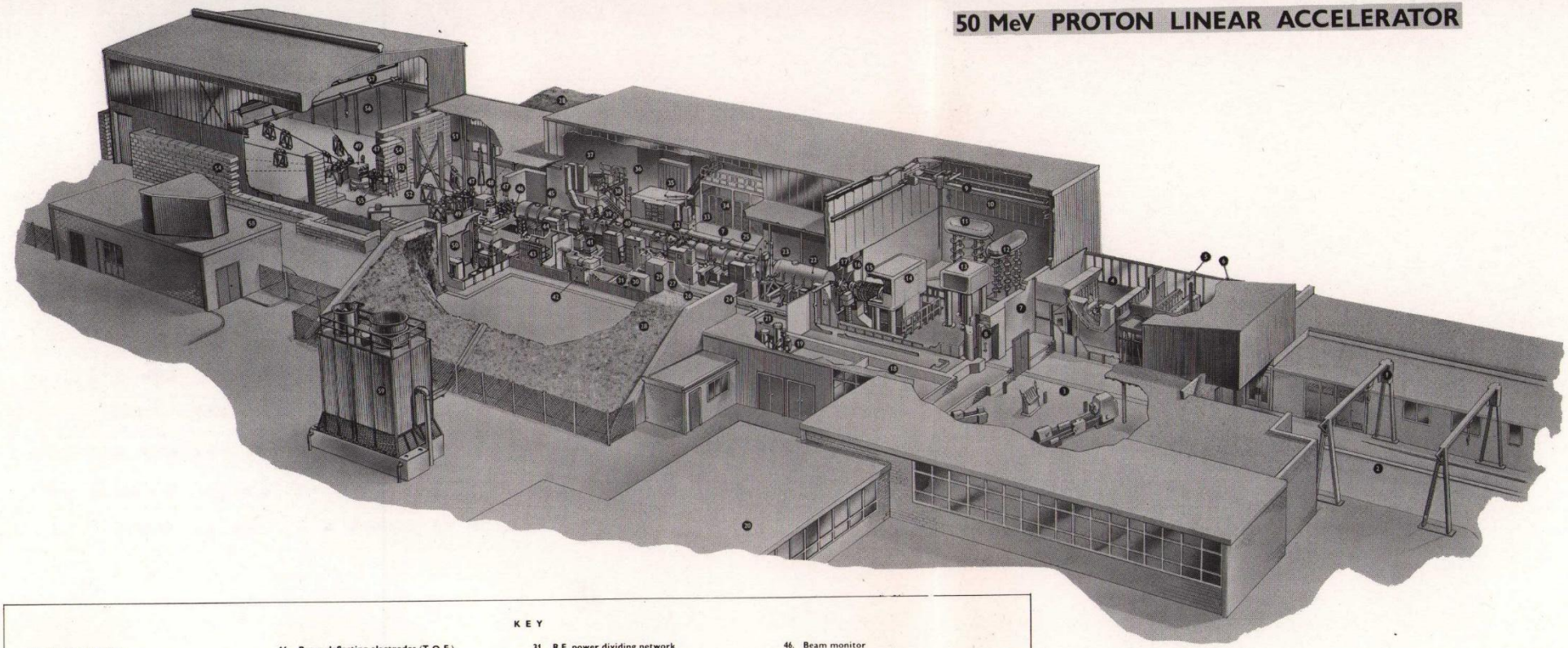
Superimposed on the steady current drawn from this circuit by the various shunt resistance paths is a pulsating current of three to four times the average current. This is due to the pulsating proton beam. The size of capacitor is chosen to reduce the voltage variation during the current pulse, to a reasonable level.

HIGH-VOLTAGE PLATFORM (3)

THIS APPARATUS HOUSES THE MANY AUXILIARY POWER SUPPLIES REQUIRED TO FEED THE ION (PROTON) SOURCE AND THE D.C. GUN.

The power for these supplies is generated by a 2,000 cycles/sec generator which is mounted on the platform and is belt-driven up one of the legs. This belt has to withstand 500 KV along its length.

50 MeV PROTON LINEAR ACCELERATOR



KEY

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. Polarised 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 focussing 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

ION SOURCE (4)

THIS APPARATUS PROVIDES THE PROTONS WHICH ARE TO BE ACCELERATED.

Low pressure hydrogen gas is fed into an open-ended bottle which is enveloped by a coil that generates radio waves. The field set up in the bottle by these waves agitates the gas molecules causing some of the electrons to become dislodged from the hydrogen atoms leaving protons behind. These protons are extracted from the open end of the bottle by an electrode which is pulsed negatively for 200 microseconds 50 times a second. By virtue of their opposite polarity, protons are attracted towards this electrode during the 200 microsecond period and are fed into the D.C. gun ready for acceleration.

A second, very special, ion source, known as the P.P.I.S. (Polarized Proton, Ion Source), is also provided. Protons may be regarded as tiny balls which rotate on their axes. Normally these axes point randomly in all directions. If the axes can be made to point in one direction, the protons are said to be polarized the percentage polarization depending on the proportion of protons with axes pointing in one direction. This facility together with a means of controlling the direction of polarization is provided by the P.P.I.S. It enables experiments of a greater resolving power to be conducted.

D.C. GUN (5)

THE PROTONS EXTRACTED FROM THE ION SOURCE ARE ACCELERATED ALONG THE GUN TO AN ENERGY OF 500,000 ELECTRON VOLTS.

The end of the gun furthest from the wall is connected to the positive side of the 500 KV supply. The other end is at zero volts (earthy). However "looked at" from the ion source, the earthy end of the gun appears to be 500 KV negative. This is the voltage seen by the protons and, since they are positively charged, they are attracted towards it. When the protons reach the end of the gun they are travelling at a 1/30 the speed of light and are said to have an energy of 0.5 MeV (Half a million electron volts).

BUNCHER (6)

THE BUNCHER ADJUSTS THE TIME OF ARRIVAL OF THE PROTONS AT TANK I IN A MANNER SUCH THAT THEY ARRIVE AT THE TIMES MOST FAVOURABLE FOR ACCELERATION.

The protons leaving the D.C. gun occur in pulses of 200 microseconds (μs) at a frequency of 50 pulses per second. They are evenly distributed over the 200 μs period but since the accelerator (Tank I) will only accelerate for about one in every five nS (thousandths of a μs) during the 200 μs pulse, most of the protons are wasted. The object of the buncher is to concentrate as many as possible of the protons into 1 nS bunches timed to arrive at the accelerator when conditions are most favourable for acceleration. This is achieved by generating a radio frequency voltage (of the same frequency as used for the main tanks) inside the buncher. The effect of the radio frequency voltage is to alternately accelerate and de-accelerate the protons as they pass through and so cause them to bunch.

The number of protons accelerated down the tank is increased by a factor of 3 : 1 in this manner.

TANK I ACCELERATOR (7)

THIS IS THE FIRST OF THE THREE TANKS IN WHICH THE PROTONS ARE ACCELERATED. PROTONS ENTER TANK I WITH AN ENERGY OF 500,000 ELECTRON VOLTS (0.5 MEV) AT 1/30 THE SPEED OF LIGHT AND LEAVE IT WITH AN ENERGY OF 10,000,000 ELECTRON VOLTS (10 MEV) at 1/7 THE SPEED OF LIGHT.

THE R.F. INPUT POWER INTO TANK I DURING THE PERIOD OF ACCELERATION (400 u SECONDS 50 TIMES A SECOND) IS ABOUT 600,000 WATTS.

The steel outer vessel of the tank is evacuated to about $\frac{1}{100,000,000}$ of atmospheric pressure. Inside the steel outer vessel is a copper cylinder, known as the cavity or resonator, which is 42 inches in diameter and runs the length of the tank. R.F. power at a frequency of 202.5 Mcs is fed into the cylinder and generates an oscillating voltage of 10,000,000 volts between opposite ends. Once cycle lasts for 5 nS ($\frac{5}{1000,000,000}$) For half-a-cycle the output end of the cylinder is negative with respect to the input end. During the next half-cycle the polarity of the voltage reverses.

When the output end of the cylinder is negative with respect to the input end, protons, which are positively charged, are attracted towards it. However, before the protons have had time to go very far the polarity of the voltage reverses and would attract the protons back to the starting point if it were not for the drift tubes - these are small copper cylinders spaced along the centre line of the main cylinder. The spacing between the tubes is arranged so that protons enter them when the polarity of the voltage is the wrong way round for acceleration and are shielded from its effect, and emerge when the voltage has reversed and is once more favourable for acceleration.

Specification:-

TANK 1

ALVAREZ TYPE RESONATOR (copper)	
LENGTH	18 ft.
DIAMETER	3½ ft.
DRIFT TUBES	41 + 2 Halves
FOCUSSING	Grids
POWER	Approx. 600 KW peak
FREQUENCY	202.5 Mc/sec.
PULSE LENGTH	400 u sec.
PRF	50 pps
Q VALUE	85000
DRIFT TUBE APERTURE	1.8 cm
ENERGY INPUT	Approx. 500 KeV
ENERGY OUTPUT	" 10 MeV
VACUUM VESSEL VOLUME	8000 litres
OIL DIFFUSION PUMPS	2 x 20" Metrovac
PUMPING SPEED	Approx. 2000 litres/sec
REFRIGERATED BAFFLES TEMP.	- 20°C

TANK I MODULATOR (8)

THIS APPARATUS PROVIDES A PULSED H.T. VOLTAGE TO THE ANODE OF THE AMPLIFYING VALVE WHICH IN TURN PROVIDES THE R.F. POWER FOR FEEDING INTO TANK I ACCELERATOR.

R.F. power is fed into the tank for a period of 400 microseconds at a frequency of 50 times a second. During this period the modulator delivers a high D.C. voltage, 25,000 to 30,000 volts at a current of 50-60 amps, to the anode of the above mentioned valve. This power is drawn from the modulator for only 2% of the total time (400 microseconds every 1/50 of a second). For the rest of the time no output is required. A special circuit (switched delay line) is used in the modulator which enables electric energy to be stored for 98% of the cycle and discharged into the amplifier valve in a fixed period of time (400 microseconds) at a constant voltage during the remaining part of the cycle. In this way the power supplies are only called upon to deliver the average power.

TANK II ACCELERATOR (9)

THIS IS THE SECOND OF THE THREE TANKS IN WHICH PROTONS ARE ACCELERATED. PROTONS ENTER TANK II WITH AN ENERGY OF 10,000,000 ELECTRON VOLTS (10 MEV) AND LEAVE IT WITH AN ENERGY OF 30,000,000 ELECTRON VOLTS (30 MEV).

PROTONS ENTER TANK II WITH A VELOCITY OF 1/7 THE SPEED OF LIGHT AND LEAVE IT WITH A VELOCITY OF $\frac{1}{4}$ THE SPEED OF LIGHT.

THE PRINCIPLE OF OPERATION IS SIMILAR TO THAT OF TANK I.

Specification:

LENGTH	39 ft.
DIAMETER	3 ft.
NUMBER OF DRIFT TUBES	40 + 2 halves
FOCUSSING	Magnetic Quadrupoles alternating gradient
DRIFT TUBE APERTURE	3.5 cms
R.F. POWER	1.25 MW peak
FREQUENCY	202.5 mc/sec
PULSE LENGTH	400 u sec
PRF	50 PPS
Q VALUE	57000
INPUT ENERGY	Approx 10 MeV
OUTPUT ENERGY	Approx 30 MeV
VACUUM VESSEL VOLUME	15000 litres
OIL DIFFUSION PUMPS	4 x 20"
PUMPING SPEED	Approx 2000 litres/sec
BAFFLES TEMP	-20°C

TANK II MODULATOR (10)

THIS APPARATUS PROVIDES A PULSED HT VOLTAGE TO THE ANODES OF THE AMPLIFYING VALVES WHICH IN TURN PROVIDE THE R.F. POWER FOR FEEDING INTO TANK II. THE PRINCIPLE OF OPERATION IS SIMILAR TO THAT OF TANK I MODULATOR.

TANK III ACCELERATOR (11)

THIS IS THE THIRD AND LAST OF THE ACCELERATING TANKS IN WHICH PROTONS ARE ACCELERATED. PROTONS ENTER TANK III WITH AN ENERGY OF 30,000,000 ELECTRON VOLTS (30 MEV) AND LEAVE IT WITH AN ENERGY OF 50,000,000 ELECTRON VOLTS (50 MEV)

PROTONS ENTER TANK III WITH A VELOCITY OF $\frac{1}{4}$ THE SPEED OF LIGHT AND LEAVE IT WITH A VELOCITY OF $\frac{1}{3}$ THE SPEED OF LIGHT.

THE PRINCIPLE OF OPERATION IS SIMILAR TO THAT OF TANK I

Specification:

LENGTH	37 ft.
DIAMETER	32 inches
NO. OF DRIFT TUBES	26 + 2 halves
FOCUSSING	Magnetic quadrupole Alternating gradient
DRIFT TUBE APERTURE	3.5 cms
R.F. POWER	1.35 MW peak
FREQUENCY	202.5 Mc/sec
PULSE LENGTH	400 u sec
P.R.F.	50 pps
Q VALUE	47000
INPUT ENERGY	Approx 30 MeV
OUTPUT ENERGY	Approx 50 MeV
VACUUM VESSEL VOLUME	14000 litres
OIL DIFFUSION PUMPS	4 x 20"
PUMPING SPEED	2000 litres/sec
BAFFLE TEMPERATURE	-20°C
MAX OUTPUT CURRENT	
NORMAL SOURCE	12.5×10^{12} PROTONS/SEC MEAN
POLARISED SOURCE	4.2×10^{8} PROTNS/SEC MEAN

TANK III MODULATOR (12)

THIS APPARATUS PROVIDES A PULSED H.T. VOLTAGE TO THE ANODES OF THE AMPLIFYING VALVES WHICH IN TURN PROVIDE THE R.F. POWER FOR FEEDING INTO TANK III.

THE PRINCIPLE OF OPERATION IS SIMILAR TO THAT OF TANK I MODULATOR.

PROTON-PROTON SCATTERING MODEL

The red balls represent protons, and the lights their spin directions (corresponding to the north pole of the earth). The switch at the back (6 position) shows how different spin directions can be chosen at the polarised ion source.

You can follow how the protons travel through the accelerator and the beam bending magnet. After collisions with protons in the liquid hydrogen target the spin directions become confused (flashing lights!). The probability of the spin being 'up' after the proton proton collision is measured by finding the probability that the proton scatters left, rather than right, when it strikes a nucleus of helium, and correspondingly for other spin directions.

The degree to which the proton remembers its spin direction gives us deeper understanding of the forces between protons.

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