SECTION 1

INTRODUCTION

The preliminary considerations, which lead in 1957 to the decision to build a 7 GeV proton synchrotron in England, took place during the previous two years. The original intention was to produce a proton intensity of at least 10^{11} protons per second at an energy of 6.5 GeV and thus to provide a strong source of all the elementary particles known at that time.

The CERN and Brookhaven machines were then under construction. They embodied a number of new and difficult problems, and estimates of their intensity varied from a few times 10^8 to a few times 10^9 protons per second. On the other hand, the Bevatron was already producing about 10^{10} protons per pulse (once every 6 seconds) and was clearly capable of considerable development along known lines. The large aperture of the weak focusing magnet is costly in steel and power but multi-turn injection allows a strong circulating beam to be set up before acceleration begins. The only sure way to get 10^{11} protons per second, in 1957, was with weak focusing.

A weak focusing machine was therefore chosen and an alternative proposal for a 12 GeV alternating gradient synchrotron was rejected in discussion with future users. Initially, it was intended to increase the strength of vertical focusing significantly by the use of spiral ridges, to give a Q_V of 3 while retaining the main properties of weak focusing machines, but this proposal was abandoned when severe dynamical problems were found to be associated with the presence of the straight sections which are essential. In the subsequent detailed design the energy was raised to 7 GeV and the intensity to about 5×10^{11} protons per second. The main Nimrod parameters are given in Table 1(I).

The magnet was designed with saturable polepieces so as to give a good field region matched to the required radial aperture which shrinks during acceleration, thus yielding considerable economy in magnet weight and power. A double walled vacuum vessel was also chosen with the same economy in mind. An outer vessel is pumped to rough vacuum and contains the magnet poles, which also provide its support. An inner vessel sits in the gap between the poles and is pumped to the necessary degree of fine vacuum. Thus neither vessel has to withstand atmospheric pressure without support and the walls of both can be thin and the maximum possible vertical aperture is thus available for the beam itself.

The magnet ring is divided into eight equal magnet segments or "octants", separated by straight sections which are required for beam injection and extraction systems, the r.f. accelerating cavity and beam control systems.

An injection energy of 15 MeV was chosen as one which could be achieved at reasonable cost while at the same time avoiding serious problems from gas scattering or from too low an initial magnetic field in the synchrotron magnet.

In order to obtain the maximum useful injection interval, the magnet power supply includes a facility for controlling the initial rate of rise of field independently of that during the main acceleration period. Injection intervals up to 1.5 ms are provided, the optimum time being found experimentally.

The synchrotron r.f. system operates with a harmonic order of 4. Although this demands a wide bandwidth in the system, the amplitude of the radial synchrotron oscillations is thereby reduced to half the value produced by operation on the fundamental. Signals from beam induction electrodes are available to give servo control on both the frequency and phase of the accelerating voltage, in addition to the programme control by the main magnet field plus curve correctors.

Besides the use of internal targets, a Piccioni type system will be used for extracting the circulating beam. A second extraction system may be added during subsequent development. Both slow and fast beam spills will be available.

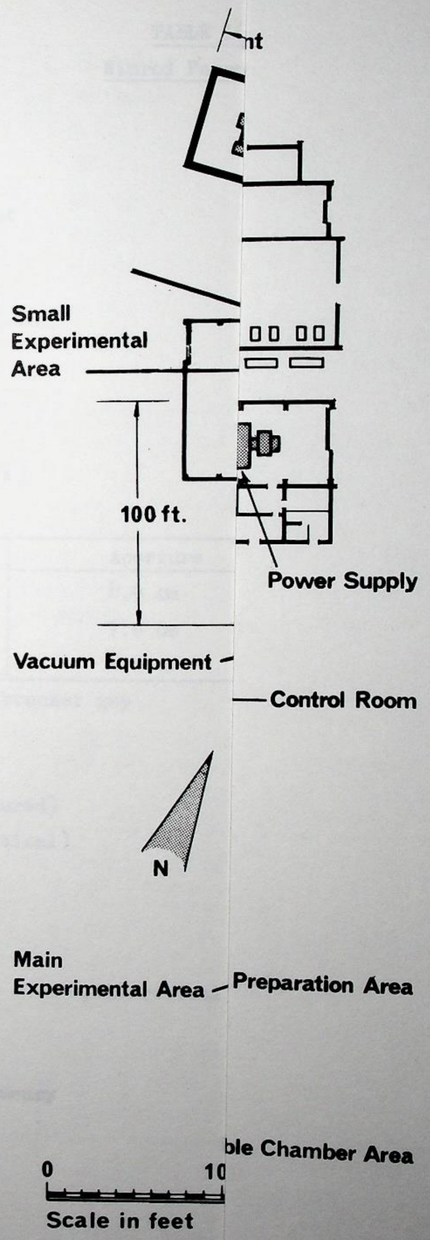
The magnet ring is housed in a large, circular, reinforced concrete building 200 ft in diameter. It is built partly below ground level and covered by 20 ft of earth mounding to serve as an additional radiation shield. The injector section has a separate hall, also covered by earth mounding, which projects almost tangentially from the main building. The magnet is positioned on a large concrete monolith which takes the form of a partly hollow disc, reinforced by radial and circular internal walls to form sixteen cavities which are used to contain auxiliary equipment. An annular trench surrounds the magnet and provides accommodation for the vacuum pumps and for general services. Numerous underground ducts and tunnels are also provided for interconnection of services, power supplies and control systems.

A feature of the Nimrod buildings is a massive concrete shielding bridge, between the magnet room and the main experimental area, which is 60 ft in arc length and 28 ft wide. A small central pillar (1 ft wide, 8 ft long and $2\frac{1}{2}$ ft high) carries 7,500 tons and is the only bridge support which interferes with the positioning of beam lines into the experimental area.

Separate buildings house the magnet power supply (a twin motor/alternator/flywheel set and convertor equipment), ventilation plant and water softening and cooling plant (including a block of four large evaporation coolers). A further building contains the main control room, crew rooms and offices for staff associated with the operation of the machine.

A simplified layout of some of the buildings is shown in Fig. 1(i) and a cut-away view of the complete installation is shown in the frontispiece. More detailed figures showing individual parts of the machine are contained in the appropriate sections of this report.

A list of general articles on Nimrod is presented at the end of the report.



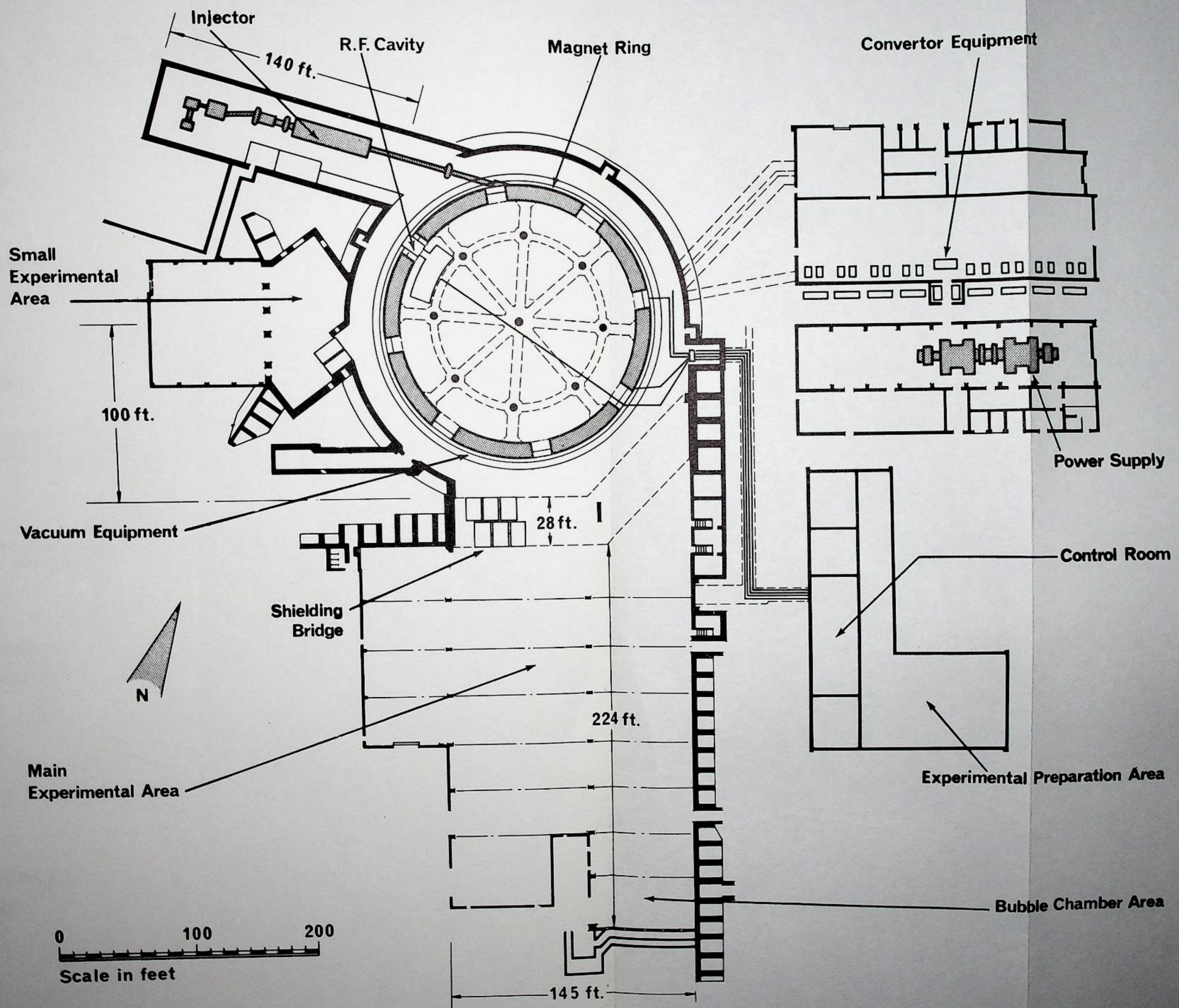


Fig. 1(i) A simplified plan showing the layout of the NIMROD installation.

TABLE 1(I)

Nimrod Parameters

INJECTOR

Ion Source

Extraction potential	5-25 kV
Extracted beam current	25-100 mA
Pulse length	50μ s - 1.5 ms variable 0.3μ s and 5μ s fixed
Pulse repetition frequency	2/s maximum

Pre-Injector

Focusing	Electrostatic
Energy	600 keV
Beam emittance (Area/π)	Up to 5×10^{-3} cm rad

Low Energy Drift Space

Focusing	Aperture	Maximum gradient
First triplet	8.9 cm	170 gauss/cm
Second triplet	7.6 cm	240 gauss/cm
Third triplet	6.4 cm	480 gauss/cm

Peak r.f. voltage on buncher gap	23 kV maximum
Buncher Q	1500 with external resistive loading
Buncher drift length	1.4 m
Bunching factor (measured)	2.2
Plateau width (theoretical)	6 keV

Linac

Frequency	115 Mc/s
Beam current	10 mA with buncher
Acceptance (area/π) (+- +- , theoretical)	3.0×10^{-2} cm rad at 600 keV
Synchronous phase	30°
R.F. pulse length	2.5 ms
Pulse repetition frequency	2/s maximum
Quadrupole gradients:	
First drift-tubes	3,700 gauss/cm
Last drift-tube	640 gauss/cm
Tank length	13.45 m
Tank diameter (effective)	1.69 m
No. of drift tubes	$48 + 2 \times \frac{1}{2}$
Drift-tube diameter	28.2 cm

Input aperture	2.1 cm
Output aperture	5.0 cm
Output energy	14.9 MeV
Resonator Q (measured)	80,000
R.F. power at Q = 80,000 (theoretical)	800 kW
Peak r.f. voltage on input gap	140 kV
Peak r.f. voltage on output gap	680 kV
*Energy spread (total)	300 keV
Operating temperature	20°C

High Energy Drift Space

Focusing	Aperture	Maximum gradient
First triplet	7.6 cm	730 gauss/cm
Second triplet Third triplet Fourth triplet	8.9 cm	430 gauss/cm

Peak r.f. voltage on de-buncher gap	240 kV
De-buncher Q (measured)	20,000
De-buncher drift length	10.7 m

Achromatic Inflector System

Achromatic mode	Single crossover
Total deflection	+ 25°
Number of elements	5

Element	Type	Angle	Radius of Central Orbit	Corresponding Field	Apertures	
					Radial	Vertical
E_1	'C' magnet	-25°	0.7 m	8 kg	6 cm	9 cm
E_2	'C' magnet	+50°	0.7 m	8 kg	6 cm	9 cm
E_3	'C' magnet	-36.5°	0.7 m	8 kg	6 cm	9 cm
E_4	Shielded 'C' magnet	+26°	1.124 m	5 kg	5 cm	8 cm
E_5	Electrostatic	+10.5°	6.0 m	50 kV/cm	3 cm	8 cm

VACUUM SYSTEM

Location	Number of Pumps	Size/ Speed	Type	Working Pressure Range
D.C. gun	2	9 in	Mercury	3×10^{-6} torr
Buncher	1	9 in	Mercury	1×10^{-6} torr
Linac	Up to 4	24 in	Mercury	$1\text{-}2 \times 10^{-6}$ torr
Beam chopper	1		Ion pump	
High energy drift space	2	6 in	Mercury	$1\text{-}5 \times 10^{-6}$ torr
De-buncher	1	9 in	Mercury	$1\text{-}5 \times 10^{-6}$ torr
Achromatic inflector	2		Ion pump	

R.F. SYSTEM

(The following data assumes an initial $\dot{B}$ of 3 kilogauss/s rising in 10 ms to a steady value of 20 kilogauss/s.)

Orbital frequency: at injection (14.9 MeV)	355.6 kc/s
at design energy (7 GeV)	2.003 Mc/s
Harmonic number	4
Synchronous phase angle	30°
Energy gain per turn: at 3 kilogauss/s	837 eV
at 20 kilogauss/s	5.58 keV
R.F. frequency error for 1 cm shift of closed orbit at injection	450 c/s
Potential well depth: at injection, 3 kilogauss/s	51.5 keV
at 7 GeV, 20 kilogauss/s	1.55 MeV
Energy spread at 7 GeV (assuming W.K.B. approximation)	1.01 MeV
Phase oscillation frequency: at injection	2.004 kc/s
at 7 GeV	2.496 kc/s
Radial synchrotron amplitude at injection	8.11 cm
Maximum stable synchrotron amplitude at 7 GeV	0.92 cm
Damped synchrotron amplitude at 7 GeV (W.K.B. approximation)	0.64 cm
Radial betatron amplitude at 7 GeV	7.32 cm
Accelerating cavity Q: at injection	10
at 7 GeV	40
Mean cavity power during pulse	35 kw
Beam loading on cavity : at 10^{12} protons per pulse (7 GeV)	1.6 kw

Ferrite properties : at 1.4 Mc/s $\left.\begin{array}{l}\mu = 600\\ Q = 10\end{array}\right\}$ Peak r.f. flux = 60 gauss

biased to 8 Mc/s Q = 40

bias field = 12 AT/cm

Total ferrite wt. = 6 ton

Cavity impedance :

at 1.4 Mc/s	3000 Ω
at 4.5 Mc/s	2000 Ω
at 8.0 Mc/s	8000 Ω

MAGNET AND POWER SUPPLY

General

Magnet sector radius, R_o	18.781 m
Mean orbit radius, R_m	23.633 m
Proton kinetic energy: for B_o = 10 kilogauss	4.77 GeV
for B_o = 14 kilogauss	7.00 GeV
for B_o = 15.8 kilogauss	8.00 GeV
Total straight section length (design)	30.480 m
Number of straight sections	8 (4 long, 4 short)
Design length of long straights (each)	4.267 m
Design length of short straights (each)	3.353 m
Magnetic field index, n (design)	0.60
Magnetic length of octant at R_o (design)	14.751 m
Total number of magnet yoke blocks	336
Total number of polepieces	672
Number of pairs of polepieces per octant, type MkI	28 (at centre of octant)
Number of pairs of polepieces per octant, type MkII	12(6 each side of MkI's)
Number of pairs of polepieces per octant, type end	2

Yoke

Number of yoke blocks per octant	42
Angle between centre lines of extreme blocks	44.03°
Thickness of a yoke block (at R_o)	12.50 in (maximum)
Angle between centre lines of adjacent blocks	1.074°
Block-block spacing at R_o	13.859 in
Block-block spacing at front edges	14.253 in
Block-block spacing at back edges	12.202 in
Thickness of block at back edge	12.10 in (maximum)
Front edges of sectors lie on sector radius	19.355 m
Weight of yoke block	19.5 tons
Total number of laminations per block	47
Steel silicon content	80% minimum, 100% maximum
Vertical yoke gap	23.000 in

Polepieces

Total number of laminations	450 approximately
Thickness of laminations - thin type	0.020 in nominal
Thickness of laminations - thick type	0.030 in nominal
Ratio of thin to thick laminations	1 : 2
Silicon content of thin laminations	3.5%
Silicon content of thick laminations	1.0%
Sector radius of outside edge of magnetic profile of polepieces	63ft 7.9 in
Radial length of magnetic profile of poleieces	45.5 in
Vertical height of polepieces at R_o	5.875 in
Vertical gap between polepieces	10.09 in (minimum)

Magnet Coil

Number of coil turns	42
Peak current (design)	9150
Total copper cross-section	155 in^2
Length of mean turn on an octant	117 ft
Total weight of copper	250 ton
Coil resistance (at 50°C)	0.108 Ω
Magnet inductance (low currents)	1.1 H

Magnet performance under standard pulse conditions

Peak current	9150 A
Rise time	0.72 s
Duration of flat-top	0.115 s
Current decay time	0.80 s
Repetition rate	26/min
Mean voltage during rise	13.9 kV
Assumed voltage variation during rise	16.0 tc 11.8 kV
Mean voltage during decay	-11.7 kV
Assumed voltage variation during decay	-11.0 to -13.4 kV
R.M.S. current	4550 A
VI at top of current rise	108 MW
VI during flat-top	9.1 MW

Energy delivered to magnet during current rise:	
Stored energy	39 MJ
Copper loss	1.92 MJ
Eddy current loss	0.07 MJ
Energy delivered during flat-top	1.04 MJ
Energy required during current decay:	
Stored energy	39 MJ
Copper loss	2.03 MJ
Eddy current loss	0.08 MJ
Iron loss (hysteresis)	0.12 MJ
Nett energy loss/pulse	5.26 MJ
Overall average losses	2.22 MW