THE OPERATIONAL EXPERIENCE WITH NIMROD

D.A. Gray
Rutherford High Energy Laboratory, England

The recent experience with Nimrod operating at 1.5×10^{12} protons/pulse is discussed. The novel techniques for measuring radiation dose in the accelerator vacuum vessel are described with estimates of the radiation damage to components of the machine. A major re-shuffle of the main experimental area with two extracted beams is in progress and is described. Details are given of a new experimental hall for which full approval has been given.

Operation

Following the repair of the magnet power supply alternators[1], Nimrod became fully operational again in February 1966. Since that date, scheduling has been on the basis of a 3-week cycle, 404 hours for high energy physics, 88 hours for machine development and 12 hours for routine maintenance. Of the 5560 hours scheduled for high energy physics, beam was available for 4590 hours, an efficiency of 82.5%. During this time the extracted proton beam, feeding two secondary beams from the same target, produced 1940 hours of good beam time. The causes of lost beam time are given in Table 1.

Planned shutdowns since February were for three weeks in May-June for inspection work on the alternators and for installation of a new extractor magnet. A week's shutdown in October was required for the installation of a new beam line. A six-week shut-down started in mid-January 1967 for major installation work (see 'Experimental Area Layout').

The average circulating beam intensity varied from 1 to 1.5×10^{12} protons/pulse at a repetition rate of 22 per minute. To achieve this intensity the 15 MeV linac injector runs at 18-20 mA with a 350 μs long pulse. The r.f. ion source, which has been unchanged for two years, provides 42 mA from the 600 keV pre-injector.

Acceleration to 7 GeV, at the intensity quoted, is achieved using pole face winding correction on the magnet n-value during the first 75 ms of acceleration only, with a phase lock, and a radial lock for the first 40 ms. After this time, the resistive wall instability, discussed in another paper[2], requires the beam to be steered off the central radius of the machine to prevent beam blow-up.

In the last year, 11 physics experiments were completed. A total of 3.5 million bubble chamber pictures were obtained from the 82 cm Saclay hydrogen chamber or the 1.6 m heavy liquid chamber. The British National 1.5 m hydrogen chamber will be ready for operation in March after its return from CERN and the 80 cm helium chamber has recently taken its first pictures.

Development

A major part of the development time during the last year was given to development of the extraction system[3]. This is a modified Piccioni system with a radially focusing quadrupole at approximately quarter of a betatron wavelength from the energy loss target followed by a kicker magnet at half a wavelength. Studies of this system using computer programmes LIMP and NIMDYN and a magnetic field model, derived from the magnetic survey of the main magnet, the quadrupole and the kicker magnet, were made in parallel with a series of experimental investigations. The variables investigated included change of main magnet field shape using the pole face windings, the shape of the kicker field and the relative radial positions of the components in the machine. The extraction efficiency achieved for long spill targetting under operating conditions was 20% with the circulating intensity at 1.3×10^{12} protons/pulse. Experiment and theory are now in agreement. Half the beam from the energy loss target was hitting the septum of the quadrupole and half of this 50% was lost for matching reasons at the exit from the machine. A quadrupole with a thinner septum and off-set field centre is being built to improve both these losses. The emittance of the beam at the external target was π x 15 mm.mrad vertically and horizontally. A focused overall spot size of 3 mm vertically and 5 mm horizontally was obtained.

A system for resonant extraction using $Q_R = 2/3$ is being developed. As well as theoretical studies, experimental work has shown that Nimrod may be tuned to $Q_R = 2/3$ using the pole face windings at full energy. The resonance has been excited by further pole face windings to give the pertubation $B = B_o(R_o - R)^2 \cos 2\theta$. The beam has been seen to jump a soft septum in the machine on to a scintillator. A septum magnet has been designed and made and is undergoing preliminary tests. It is intended to install this in the machine at about the middle of the year.

Targetting methods have included one or two 0.5 ms bursts for bubble chambers with a magnet flat top of 500 ms. The 'noise-spill' technique[4] has been developed to give effective spill times, neglecting the r.f. structure, of up to 400 ms. This is achieved by servoing the rate of loss of beam from trapping to be constant. For some experiments the r.f. structure using this technique is too great and the accelerating r.f. volts are reduced during flat-top by a factor of about 10. The effective spill time, including r.f. structure, is then 300 ms. Sharing between targets on flat-top is achieved by adjusting their relative radii.

Studies of injection have continued. The saturation effect of trapped beam intensity with injected beam current has been shown to be due to both a space charge effect and an increase of injected beam emittance with increasing injector beam current. Measurements of average n-values during the injection process have proved to show a slightly higher n-value than that measured in the magnetic survey. There is still an unexplained loss of beam of about 30% during the first 25 ms of acceleration.

Radiation Dosimetry in the Synchrotron

The Nimrod vacuum vessels are made from epoxy resin impregnated glass cloth laminate. Discussion of the degradation of these vessels[5] gives a total allowable radiation dose of 3.3×10^7 rad at which the flexural strength of the inner vacuum vessel is estimated to be the limit for reasonable operation.

A study of integrating dosimeters[6] has led to the development of a system based on the measurement of the quantities of hydrogen evolved during the radiation degradation of polyethylene. The dosimeters consist of a metal cylinder filled with polyethylene and fitted with a bourden tube pressure gauge. Care is taken to ensure that all air is replaced by an atmosphere of hydrogen in order to avoid interference from oxydative side reactions. A residual positive pressure of about 2 p.s.i. is left after purging to remove inaccuracies which occur in the gauge at the extremes of its range. The total free volume of the enclosure is measured and related to the weight of polyethylene used. Typical pressure increases are 0.5 p.s.i. per megarad for 16 gm of polyethylene.

The device provides an easily operated dosimeter, there being no requirement to open up the vessel as there was with the rubber dosimeters used previously[5]. At present 125 dosimeters are installed in Nimrod covering some octants with a radial spacing of 10 cm and irregular azimuthal spacing of about 3 m. The rubber dosimeters will gradually be replaced. The hydrogen dosimeters are read at three-weekly intervals and have shown doses of approximately 1 megarad per week. The radial distribution shows a maximum at about 10 cm from the back wall of the vessel. At this radial position, the total integrated dose up to October 1966 received by the vacuum vessel and obtained by adding the rubber and hydrogen dosimeter results is shown in Figure 1. Table 2 shows the dose received since October 1966 in the positions where hydrogen dosimeters are installed. (The fact that these results are available whilst those from the rubber dosimeters are not, is a true indication of the advantage of the hydrogen pressure dosimeters).

The maximum total dose recorded to date is 11.2×10^7 rads. Comparison with the 'permitted' dose shows that the Nimrod vessels are good for many years with present operating conditions.

Radiation levels

The residual activities in some parts of the synchrotron have been very high, notably in targets and in the extraction magnets. This has led to the requirement for more facilities for working on active components and a new active workshop and store has been built. This leads directly off the 'North Tunnel' to the synchrotron.

Measurements of the radiation level at a point 9 ft from the outside edge of the synchrotron magnet have been made since Nimrod first worked. The levels are shown in Table 3 at 1 hr after shutdown and 2 weeks later during the latest shutdown. There has been no significant increase in this residual level in the past two years of operation.

The radiation levels in the experimental area with 2×10^{11} protons/pulse extracted were roughly 5 mR/hr at floor level 40 ft from the external target. On the roof of the blockhouse where the shielding is thinner the level in some places reached 1 R/hr. The number of slow neutrons produced in a beam line about 75 ft from the target was such that the experiment could not run with the external beam operating.

Nobody working in the Nimrod area has received a dose as large as 1.5 R during the last year.

Experimental Area Layout

Since February, as their experiments were completed, 2 counter beams in the main hall and the beam for the heavy liquid chamber were dismantled. Two other counter experiments were installed. Also in Hall 1, a branch off the beam for the Saclay bubble chamber was made for the helium bubble chamber. A start was made on a beam for Hall 2 with the installation of the π5 beam (see Figure 2). The P1 extracted proton beam with its two secondary beams was dismantled.

During the six-week shutdown which has just been completed, a major re-organisation of the beam lines in Hall 1 has started. The main shield wall between the machine and the hall has been rebuilt to allow the installation of a versatile separated beam for the 1.5 m British National Hydrogen Bubble Chamber. This beam, which will be commissioned at the end of March, will provide kaons between 2 and 4 GeV/c and protons and pions governed by the Nimrod primary proton momentum.

A second extracted beam line will provide a beam for the 1.6 m heavy liquid chamber and 4 counter beams from the same external target. These beams will give an available range of kaon momentum ranging from 0.4 to 3.0 GeV/c. It is expected that all of these beams will be ready for use at the end of 1967.

To make full use of the beam lines, switching between the two extracted beams during the same machine burst will be made possible by means of changing the excitation of the extractor kicker magnet. The equipment for this is well under way.

New Experimental Hall

Last December full approval to proceed was given for the building of a new experimental hall for Nimrod (see Figure 3). This will be a single span building 150 ft wide by 300 ft long. There will be a 30 ton crane covering the main area with a smaller span 30 ton crane over the 'beam switching area'. The crane hook height in the main area will be 35 ft. The structure of the building has been designed to take a further 30 ton crane in the main area. Other features include two longitudinal service tunnels 10 ft x 10 ft with smaller ducts running across the hall. Plant such as beam handling component power supplies will be installed on an internal gallery running round the hall. The scheme for the hall includes the provision of 10 MVA of a.c. power and cooling capacity with the possibility of extension later.

In the switching area there will be, initially, a continuation constructed from blocks, of an existing tunnel from the machine room. An extracted proton beam derived from a Piccioni system with target in octant 5, quadrupole in straight 2 and kicker in straight 4 is planned to feed the new hall via this tunnel. Of course, if resonant extraction trials prove successful, this system would replace the Piccioni system. It is not envisaged that there will be internally derived secondary beams into this hall.

Excavation of the site has just started and the hall will be complete by the end of 1968.

References

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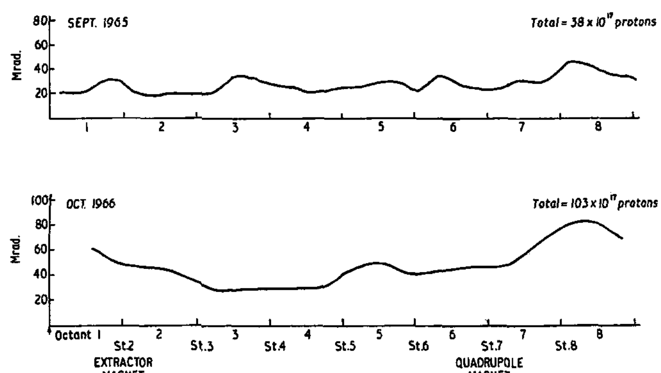

Fig. 1. Total integrated dose received by the Nimrod inner vacuum vessel up to October 1966.

Table 1. Main causes of lost beam time

System	Beam time lost as percentage of total scheduled time
Extraction	3.3 (relative to scheduled extracted beam time)
Injector	3.1
Synchrotron radio frequency	2.3
Synchrotron magnet and auxiliaries	1.6
Synchrotron magnet power supply	1.2 (since 31 August)
Target mechanisms	1.2
Vacuum	1.1

Table 2. Radiation dose received by the inner vessel since October 1966 at 10 cm from the back wall.

Octant	Average dose over octant. 10^6 rads.
1	35.5
2	14.5
5	40
7	33.5
8	36

The number of protons accelerated was 24×10^{17}.

Table 3. Radiation levels at 9 ft from magnet during shutdown mR/hr

	01	S1	02	S2	03	S3	04	S4
1 hour	2.0	2.2	1.5	2.5	2.0	2.0	2.0	10.5
2 weeks	0.9	0.8	0.5	2.0	0.7	0.7	0.6	0.4
	05	S5	06	S6	07	S7	08	S8
1 hour	2.5	10.0	4.0	3.5	5.0	30.0	5.0	3.0
2 weeks	0.5	3.0	1.9	1.0	1.7	9.0	1.0	1.2

O = Octant
S = straight

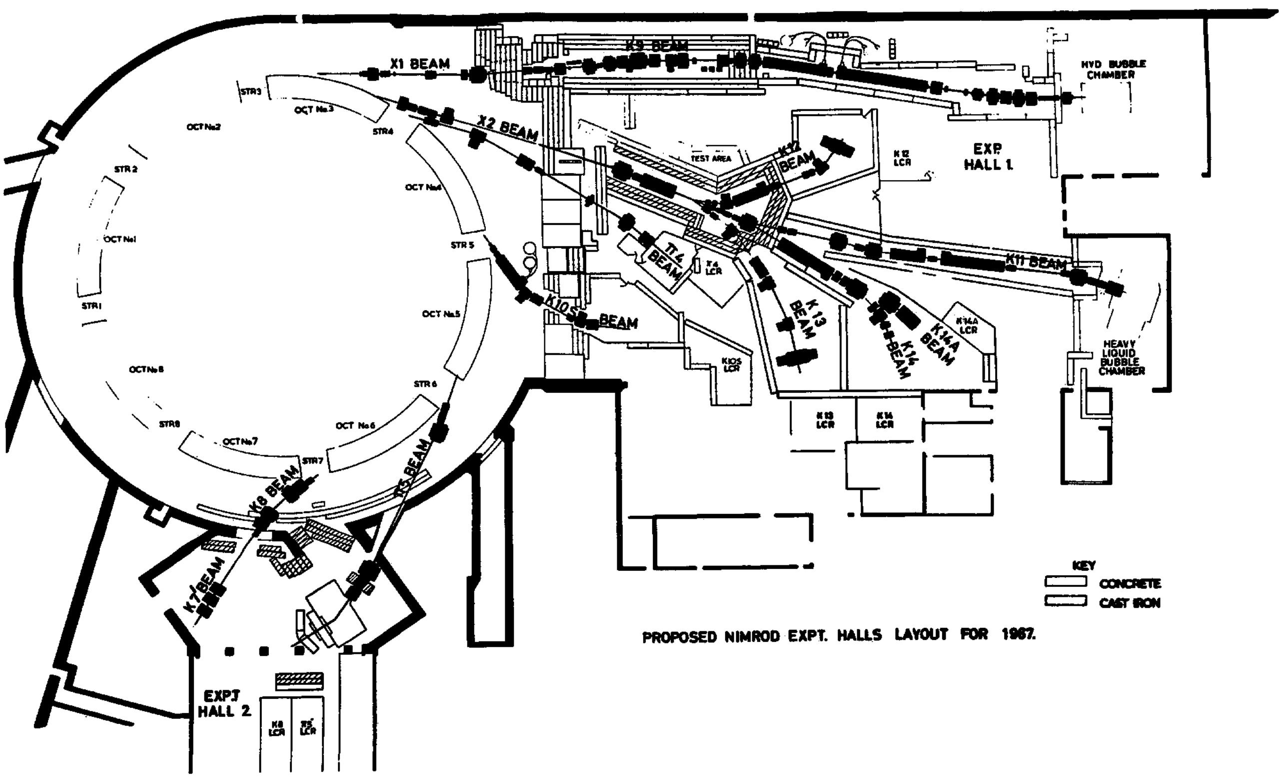

Fig. 2. The beam layout in the Nimrod experimental halls in 1967. X1 is an extracted beam feeding a target in for K9. X2 is a second extracted beam. K12 and K13 are beams at 15° production from the target. K11, K14 and K14A are zero angle production beams. π4, K10S, π5 and K8 with K7' are internally derived beams.

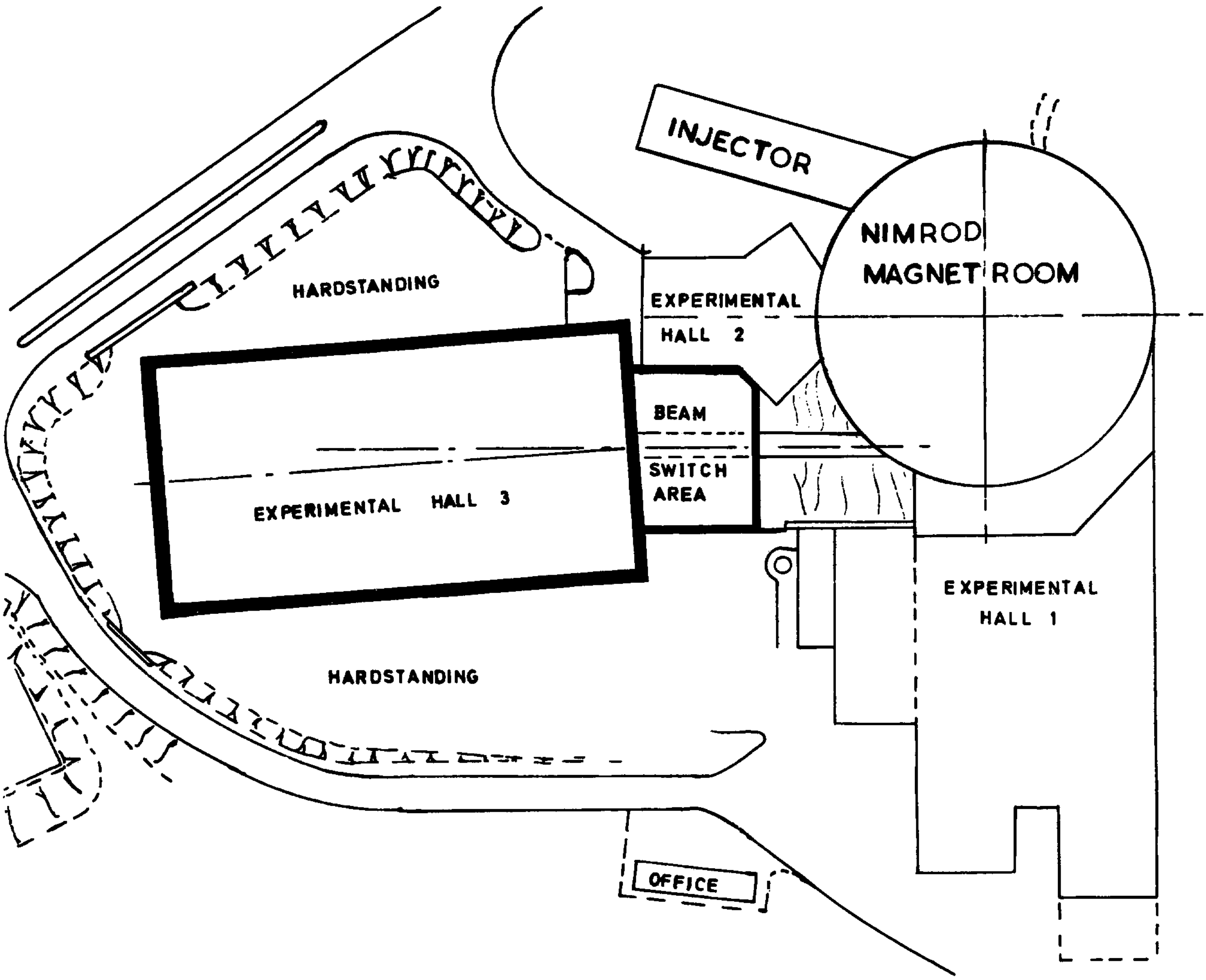

Fig. 3. Layout showing the new experimental hall for Nimrod.