

Farewell to Nimrod

with details of experiment and phenomenology.

With hadronic and electro-weak gauge theories in such good shape, it was natural for Weinberg to turn to unification schemes bringing together the different aspects of particle behaviour. One possible consequence is the existence of a new realm of 'hyperweak' interactions with only a minute fraction of the strength of conventional weak interactions. These forces would convert quarks to leptons and make the proton unstable.

This topic was taken up by Abdus Salam, who pointed out the range of group structures now on the market to describe unified colour and electro-weak effects. Depending on the nature of this grand symmetry, new phenomena are conceivable from new particle accelerators in the not too distant future. On the other hand, the underlying unification scheme might be such that the energies required to see its effects will be unattainable. Another approach is via the lifetime of the proton and, from his lofty theoretical seat, Salam urged experimentalists to search for signs of proton decay.

While the conference had no major breakthroughs to report, it showed steady progress over a broad front in our understanding of particles. If this progress continues when new results come in from the next generation of machines, we could at last begin to glimpse the unified picture of Nature of which Kepler and Einstein could only dream.

On Tuesday 6 June, the Rutherford Laboratory's proton synchrotron 'Nimrod' was switched off for the last time, bringing to a close an era of home-based facilities for high energy physics research in the United Kingdom. The increasing cost of particle physics research, coupled with widespread financial pressures over the past few years, has forced the UK to close its national facilities in favour of maintaining a full commitment to the research programmes at CERN and at PETRA. As a result, Daresbury's electron synchrotron, Nina, was closed on 1 April 1977 (see April 1977 issue, p. 101), and now Nimrod has been shut down.

The construction of a 7 GeV proton synchrotron was approved by the UK government early in 1957. The Rutherford High Energy Laboratory (as it was then called) was set up as the first research establishment of the UK National Institute for Research in Nuclear Science, to be responsible for the construction and operation of facilities and equipment for universities and institutions carrying out research in the nuclear field. Dr. T.G. Pickavance was appointed as the Laboratory's first Director. The Laboratory became a part of the UK Science Research Council in April 1965.

With the approval of Nimrod, the UK university scientists were provided with a powerful proton accelerator having the second highest energy in Europe (or fifth in the world) and amongst the leaders in beam intensity (aiming for 10^{12} protons per pulse and 22 pulses per minute). The variety of particle beams available from Nimrod offered a broad range of possibilities for research into the properties of known particles and to search for new phenomena. Appropriately, the accelerator was named 'Nimrod' - 'the mighty hunter' according to the Book of Genesis.

The construction of Nimrod was

completed in 1963 and on the 27 August protons were accelerated to the design energy of 7 GeV. The research programme officially started in February 1964 and by September 1964 the design intensity of 10^{12} protons per pulse was reached. This figure has since been exceeded by a factor of four.*

Nimrod was officially inaugurated on the 24 April 1964 by the Rt. Hon. Quintin Hogg, then the UK Secretary of State for Education and Science, who described the project as '...essentially an act of faith in the value to a nation of knowledge acquired for its own sake, of brains engaged in free speculation about the ultimate nature of the Universe and the structure of matter'.

The machine has been successfully operated throughout fifteen years of high energy research providing about 60000 hours of beam time (or 2×10^{20} accelerated protons). About 20 universities have made use of the research facility and completed about 80 major experiments. There has been a great variety in the research programme which has been supported by the skilful development of new detection techniques and the provision of large-scale and complex sets of apparatus. Extensive computing facilities have been provided for the analysis of the experimental results.

The outstanding feature of the Nimrod experimental programme has been the systematic high-accuracy study of the resonance region below 2.5 GeV. The pion-proton elastic channel has been studied with all combinations of pion charge, with and without polarized targets, including the very difficult measurements of the charge exchange polarization. The statistical accuracy and momentum coverage has overwhelmed earlier data.

In addition, the first systematic measurements of the inelastic final states lambda-kaon and sigma-kaon using electronic techniques have been carried out, including a measurement

Sir John Cockcroft breaks new ground for the Rutherford Laboratory in 1957.

The Laboratory's first Director, Gerry Pickavance, and the Secretary of State for Education and Science, Quintin Hogg, at the inauguration of Nimrod in 1964.

(Photos Rutherford)

of the spin rotation parameters in the lambda-kaon reaction using a longitudinally polarized target. In recent years some of the attention has shifted to the kaon-nucleon system with high accuracy measurements of the kaon-proton elastic differential cross-section and polarization, and measurements of the polarization in the reactions $K^+n \rightarrow K^+n$ and $K^+n \rightarrow K^0p$ using a polarized deuteron target.

The analysis of all these data has produced the well-known superabundance of resonance states which prompted theoreticians to search for underlying symmetries and structure to explain the seeming chaos, producing first of all SU(3) and then SU(6) as classification schemes, and introducing quarks as the fundamental constituents of matter.

The quark model rests on two pillars: the first is the deep inelastic scattering of electrons, muons and neutrinos which shows that pointlike objects exist within nucleons and the second is the resonance spectrum, in particular that of the baryons, where an incredibly rich spectrum of states and their decay rates can be semi-quantitatively explained in terms of a very simple model of three quarks connected by harmonic oscillator forces.

The crowning glory of the quark model is, of course, the discovery of the psi and charmed particles, but it should not be forgotten that, without the earlier detailed work, to which Nimrod made a very significant contribution, and which first produced the quark model, there would have been no theoretical framework for these subsequent discoveries.

Nimrod has also been active in many other areas. Several experiments to check violations of fundamental symmetries have been performed, including one of the early investigations on the CP-violating decays of the long-lived kaon, a test of the $\Delta S = \Delta Q$ rule, and two experiments testing the

charge symmetry invariance of the electromagnetic decays of the eta meson. An experiment which only recently completed taking data is testing the speculation that the CP symmetry broken in $K_L^0 \rightarrow \pi^+\pi^-$ decays could be restored in a sufficiently high magnetic field. Pulsed fields of 30 T were obtained and it should soon be known whether or not the decay rate into two pions is reduced.

Hadronic experiments other than those directly concerned with resonance formation have tended to share the same features of high resolution and high statistical accuracy. A good example is the refined missing-mass technique used to measure directly the width of the omega (780), the eta prime (960) and the cusp in pion-proton elastic scattering near the eta threshold by making measurements at 1 MeV/c incident momentum steps near the thresholds for these resonances.

In the bubble chamber field Nimrod has also been very active. As well as heavy liquid and helium bubble chambers, two hydrogen chambers have taken over 11 million pictures, mostly on low energy formation or meson production studies. Two major innovative projects have been undertaken. The Rutherford Laboratory collaborated with CERN and DESY to produce the first operational track sensitive target in which the beam interacts in a volume of liquid hydrogen surrounded by a denser mixture of liquid neon and hydrogen. This technique combines the simplicity of interactions in the pure hydrogen chamber with the high gamma ray and electron detection efficiency of the heavy liquid chamber.

The second innovation was the construction of a rapid-cycling bubble chamber as the target for a specially-designed electronic detector system. Problems in the operation of the chamber and the early closure of



Nimrod did not permit the chamber to be used for physics experiments but the experience gained is currently being used in the design and construction, in collaboration with CERN, of a rapid-cycling chamber for the European Hybrid Spectrometer at the CERN SPS.

Nuclear physics experiments at Nimrod have included measurements of pion reaction and total cross-sections for a range of nuclei. This work gave some of the first definitive evidence that in heavy nuclei the neutrons and protons have very similar distributions and that there is no 'neutron halo' as had originally been thought. Since then there has been an extensive programme of experiments to study X-rays from exotic atoms formed when pions and kaons stop in a variety of targets. Work completed includes a series of measurements on kaonic and pionic atoms, the first measurements of X-ray shifts and

widths in sigma atoms and studies of recoil spectroscopy through measurements of gamma-ray spectra. An experiment to measure the K^-p scattering length by studying X-rays from kaonic hydrogen has just finished.

Tests have also been performed on Nimrod to investigate the potential of using negative pion beams for radiotherapy. Effects studied have included the irradiation of bean roots and several sensitive organs of mice, the ability of cancer cells to form clones and the aberration of chromosomes in human white blood cells. Various types of detectors have been used in the study of the properties of pion beams for irradiation.

There has been intense activity at Nimrod over the past year in an effort to complete as much as possible of the approved programme before the shutdown. Several groups have been committed to long-term programmes, using equipment that had been built up

over years or more, and some of these may now transfer their research to CERN. One large detector system, the Rutherford Multiparticle Spectrometer, is being shipped to the CERN 28 GeV Proton Synchrotron to continue its research programme.

Nimrod has had a highly productive fifteen years of research yielding a wealth of high precision data. Perhaps its most notable contribution has come from the many experiments which have contributed to our present understanding of the pion-nucleon interaction. Scientific knowledge can advance in two ways: the surprise result (such as the J/ψ) which suddenly opens up new ideas and possibilities, or the steady accumulation of detailed data over a broad front until eventually an underlying simplicity is revealed, as in the construction of the periodic table of the elements or the classification of the resonance spectrum in the quark model. It is through such a diligent compilation of precision results that Nimrod has accomplished its major contribution to high energy physics.



An aerial view of the Nimrod 7 GeV proton synchrotron complex at the Rutherford Laboratory showing the Injector Hall to the left and Experimental halls in the foreground and top right.

(Photo Rutherford)