26th June, 1961 NI/61/16

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

GOVERNING BOARD

A 4 GeV Electron Synchrotron - Revised Paper

(Covering note by the Secretary)

The enclosed paper prepared for submission to the Minister for Science and the Treasury incorporates the amendments to paper NI/61/2 which were agreed at the Board meeting on May 24th.

Rutherford High Energy Laboratory,
Harwell.

26th June, 1961 NI/61/16

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

Proposal for a 4 GeV Electron Synchrotron

SUMMARY

The National Institute for Research in Nuclear Science recommend the construction of a 4 GeV electron synchrotron in a new laboratory in the north under their management, at an estimated capital construction cost of £3½ million and an annual cost rising to £1¼ million. High priority is attached to this proposal in the Institute's programme of development.

The question of siting is under careful consideration and a recommendation will be made shortly.

1. Introduction

In paper NI/60/7 "Research in the Field of High Energy Physics" which was submitted to the Minister for Science on September 8 1960, the National Institute for Research in Nuclear Science made recommendations for future development. One of these recommendations was for a design study for an electron accelerator with an energy not exceeding 4 GeV which it was hoped to construct in a new Institute laboratory. At that time the comparative merits of two possible forms of the accelerator, namely a linear accelerator and a synchrotron, were being examined by a working party set up by the Institute's Physics Committee. The working party approached their task by considering in detail the field of experiments open to each form of accelerator. Their work resulted in a unanimous decision in favour of the synchrotron.

2. Priority

The extent and fundamental interest of the field of experimental work shown to be open to the 4GeV electron synchrotron, and its fitness to actual university requirements, have led the Institute to re-assess the order of priority of the projects in their recommendations to the Minister for Science already referred to, and to raise the electron synchrotron to high priority second only to making full use of existing machines. The recommendations in their revised order are:-

(a) Full use of existing accelerators in the U.K. and at C.E.R.N.

(b) Design, followed by construction, of a 4 GeV electron synchrotron at a new Institute site in the North.

(c) Research into new methods of accelerating particles and into particle detection systems should be extended, as well as research on storage rings.

(d) The Rutherford Laboratory proton linear accelerator should be extended, by stages, to produce pi meson beams with energies up to a few hundred MeV.

(e) Possible methods of producing intense beams of strange particles should be studied with a view to submitting a detailed proposal for a high intensity proton accelerator.

In paper NI/60/7, recommendation (e) above was given fourth place, and included the recommendation that the construction of a high intensity proton accelerator should be begun in about 1965. The Institute recognise that approval of the 4 GeV electron accelerator would make it very unlikely that a very large proton accelerator could be started as early as 1965.

3. The field of physics open to the accelerator

The accelerator would be used in experiments on electron scattering by nucleons and on the production of strange particles in the threshold and resonance regions by electrons and by photons. This is a wide and important field of fundamental research which can only be entered by a high energy electron accelerator. The energy of 4 GeV is sufficiently above the appropriate thresholds to cover the whole range of photo-kaon physics and to investigate the kaon-hyperon interaction and is adequate for the important field of electron-nucleon scattering. It is just sufficient to make anti-nucleons, but no attempt is made to compete in this field or in that of hyperon pair production. A machine to cover this higher energy range would cost twice as much; it is considered that a 4 GeV machine would give better value for both money and manpower and is in accord with British resources.

Experiments in this field will not be possible at the Rutherford Laboratory or at C.E.R.N. On the other hand, Nimrod and the C.E.R.N. proton synchrotron are much more powerful sources of secondary beams and are also available for studies of those processes specifically involving proton bombardment. The programme of work on the proposed new machine would therefore be complementary to that possible on the other machines available to British physicists.

Two larger electron machines are under construction, at Harvard-MIT (6 GeV) and Hamburg (7.5 GeV). It is believed that a third is planned in the Soviet Union. One is being discussed informally in Italy. These will be able to cover the same field and also the higher energy region already mentioned. A 4 GeV machine is planned at Cornell University. The field of electro - and photo - high energy physics is considered to be of sufficient breadth and fundamental importance to justify a machine in the United Kingdom, in addition to those in the U.S.A., Germany and the Soviet Union. In the complementary high energy proton field there are machines in the U.S.A. (5), C.E.R.N. (1), France (1 existing and another under discussion), U.S.S.R. (3) and U.K.(1).

4. University needs and resources in relation to this proposal

Three universities have strong schools of high energy physics based on their own machines:

Liverpool (400 MeV protons)
Birmingham (1 GeV protons)
Glasgow (400 MeV electrons)

Others are closely interested in this field but have no machine. Oxford University will devote a large part of its considerable resources to high energy physics but has no big machine and will use the Rutherford Laboratory. Similarly, substantial teams aimed at Nimrod are supported by University College and Imperial College, London, and smaller ones by Cambridge University; King's College, Queen Mary College, and Westfield College, London; and Southampton University. It is expected that the more distant universities such as Birmingham and those in the north will also make use of Nimrod. There are strong grounds for believing that Nimrod will be overloaded, to the extent that deserving users with good programmes will have to be turned away. The practical difficulties of working at a place remote from the university will tend in these circumstances to limit the large scale use of Nimrod by particular schools to those within easy commuting distance, i.e. those in the south. In passing it may be mentioned that the Physics Committee have urged the Institute to consider means of increasing the mobility of research workers, such as the use of aircraft and the provision of furnished flats for visitors.

An indication of the likelihood of saturation of Nimrod is provided by the present situation on the P.L.A. This machine has already been saturated by teams from the following laboratories:

- Birmingham University
- Oxford University
- University College, London
- Queen Mary College, London (not yet started to use the machine).
- King's College, London
- A.E.R.E.
- N.I.R.N.S.

and by smaller teams, including some individual investigators, from:

- Exeter University
- Glasgow University - becoming a larger group from Westfield College, London (Dr. Bellamy).
- A.W.R.E.

Manchester University also plan to use the P.L.A. but have not yet started. All these groups plan to use Nimrod with the addition of Imperial College, Liverpool and Southampton. Several others who work at present mainly in the cosmic ray field are becoming interested in putting some of their effort into research with machines (e.g. Durham and Leeds).

Moreover, we have to consider the effect of expansion. It is assumed, and considered vital for the maintenance of proper standards, that the planned university expansion will maintain approximately the present staff-student ratio. In one of the northern universities active in low and high energy nuclear physics, for example, this would require an increase of professorial and lecturing staff in the physics department of 11 by 1962/3 and 34 by 1966/7. Additional posts (4 by 1962/3 and 6 by 1966/7) are estimated to be required to cover extended absence on leave from teaching duties for work at C.E.R.N. and the Rutherford Laboratory. When the needs of existing programmes and a planned diversion into a "non-nuclear" field of physics are taken into account, 16 staff members and a somewhat larger number of fellows and research students will need new research facilities in this particular department by 1966/7. In view of the interests and standing of the particular university in the field, and the importance of the field, the only proper solution would be to provide facilities in high energy physics.

It is estimated that the proposed electron accelerator would support the equivalent of about 40 university staff and research students full time (compared with about 60-80 on Nimrod). Since one university alone expects to need new facilities for nearly this number by 1966/7 it is certain that the machine would fulfil a genuine need in the universities and that it would be fully used, and that full use would still be assured even with a substantial shortfall in the desired expansion of staff numbers. No account is taken of the possible obsolescence of existing university machines. This is not expected to be a factor for some time to come, but will, of course, increase the load on newer facilities when it occurs.

5. Design and cost

5.1 Accelerator

A theoretical design study has been made of an alternating gradient synchrotron with a maximum energy of 4 GeV. Full use has been made of theoretical and experimental data from similar projects at Cambridge, Mass., and Hamburg.

The parameters so obtained are presented in table 1. The machine radius is roughly half that of the Hamburg machine, approximately equal to that of Nimrod and a quarter that of the C.E.R.N. proton synchrotron. The magnet cross section needs to be almost identical with that of the Hamburg machine. The magnet weight is a half that of the Hamburg machine, and only one tenth that of the C.E.R.N. P.S. and one twentieth that of Nimrod. The injector is a 40 MeV electron linear accelerator operating at the usual R.F. frequency of 3,000 Mc/s. The radio-frequency accelerating system is a number of cavity resonators spaced around the accelerator and fed with power from a 500 Mc/s klystron.

Estimates of cost have been obtained by scaling from the Cambridge and Hamburg information. National Institute and C.E.R.N. experience has also been taken into account. This method is superior to detailed engineering estimates at the approval stage of the project, since, although such estimating may be accurate, the schedule of parts is by no means adequate until detailed engineering design has been completed. Corroboration has been obtained by comparison with very recent estimates by Cornell University for substantially the same machine.

Further theoretical studies are now being directed towards refinement of the parameters. This is essential in the limited context of the accelerator itself, but at the same time great emphasis is being placed on its detailed application to nuclear physics experiments. Some improvement can undoubtedly be made as a result of advancement of the art and experience on other electron synchrotrons. Any resultant changes will be of a detailed nature and the size and cost of the project will not be affected.

TABLE 1 - Machine Parameters

Mean radius of particle orbit		25 metres
Radius of curvature of magnet sections		16 - 18 metres
Number of magnet periods		16
Number of magnet sections		32
Total number of straight sections		32
Average length of straight sections		1.8 metres
Field index (approximately)		35
Q value		4.25
Magnet aperture (average)	Height	6.5 cm
	Width	11.5 cm
Magnet weight	Steel	280 tons
	Copper	40 tons
Maximum magnetic field		8.5 kilogauss
Maximum stored energy (approximately)		1.1 Megajoules
Injection energy		40 MeV
Magnetic field at injection		84 gauss
Repetition rate		50 cycles per second (resonated magnet)

TABLE II - Machine Cost Estimates

	£
Magnet	400,000
Power supply	400,000
Injector	250,000
R. F. System	130,000
Vacuum system	80,000
Regulation and controls	100,000
	£ 1,360,000

5.2 Site and Buildings

It is essential that a site be chosen with good stability for the foundations of the accelerator. Preliminary ground investigation is required in choosing the site, which must be large enough to ensure satisfactory radiation protection of the surrounding population. After choosing the site, more detailed ground investigation is required to settle the position of the magnet building. The disposition of other buildings can then be finalised and the site opened up with excavations, roads and services.

The buildings required are as follows:-

1) Laboratory and office block - including workshops, control rooms and counting rooms, library etc.,

2) Magnet building - this is a ring building with special foundations to house the accelerator proper.

3) Generator house - for the magnet power supply and other auxiliaries.

4) Experimental hall and shielding.
Although experiments will be carried out on internal and external beams and great attention needs to be paid to the layout of the experimental hall, the facilities required are simpler than with proton synchrotrons which also require long flight paths for the production of clean beams of secondary particles. Flexibility and provision for extension can be

introduced by having a substantial amount of the outer wall of the nagnet room in a removable form. This is technically and financially feasible for this smaller scale project.

5) Ancillary buildings for stores, equipment assembly, etc.

6) Canteen

Table 3 gives estimates of building costs. The figures are based on known costs of this kind of construction work, taking note of experience at Harwell and other laboratories.

TABLE III

Site and Building Cost Estimates

	£
Ground investigation	10,000
Opening up site (token figure - dependent on site)	100,000
Laboratory and office block, including library and colloquium rooms	280,000
Magnet building	350,000
Generator House	50,000
Experimental halls (including cranes and shielding)	250,000
Ancillary buildings	80,000
Mechanical and electrical site services (including sub-stations)	200,000
Roads, Car park	50,000
Canteen	30,000
Total	£1,400,000

5.3 Research Equipment

Further capital grants will be required to cover research equipment associated with the use of the machine,

In the first instance there will be a general requirement for target mechanisms, bending and analysing magnets, quadrupole lenses, magnet power supplies, electronics equipment and cables. Because of the smaller scale of the project, the lower energy of the machine and the different nature of electron/photon physics as compared with protons, the cost of such equipment will be much less than is required for NIMROD. Since the machine cannot compete as a source of clean and intense beams of secondary particles for further experiments, the beam handling equipment will be on much smaller scale.

As specific new schemes for particular experiments emerge further grants will be required, but again the scale of cost will be much less than is involved in the full use of NIMROD. It is for example most unlikely that any new requirements will emerge for large and expensive bubble chambers. Computing facilities will be required, but will not be needed separately if a nearby university has a powerful computer and can make time on it available. Provision for a computer has therefore not been included. The capital costs of new research equipment, spares, etc. are estimated to level off at £330,000 per annum.

5.4 Recurrent Expenses

The recurrent expenses of the laboratory covering all salaries, wages, expenses, equipment, services etc. will build up in parallel with the complement. After completion of the machine expenditure will continue at a similar rate to cover the

the operation and use of the machine and the general running of the laboratory.

The financial support of University work in connection with the use of the machine, both within the Universities and at the Laboratory, should also be covered by a recurrent budget. Expenditure will build up during the machine construction, and is estimated to level off at £800,000 per annum.

5.5 Total Cost

The estimated total capital construction cost is £3½million made up as follows:-

	£ 000
Buildings	£1,400
Plant	1,360
Contingency on the above	240
	3,000
External electron beams (to be provided later)	300
Hostel and flats for visitors	100
	3,400
	£say £3½ million)

The estimated annual cost after completion is £1¼ million, made up as follows:-

	£000	£000
Capital items - nuclear research equipment	200	
Modifications and improvements -		
to buildings	20	
to plant	30	
Minor capital items needed for design and development	80	
Total capital		330
Salaries, wages etc.	460	
Stores, materials and services	280	
Other current expenditure	60	
Total non-capital		800
Total annual expenditure		1,130
		(say £1¼ million)

TABLE 4

Estimated cost by years, in £1,000's

Year	61/2	62/3	63/4	64/5	65/6	66/7
Capital Construction						
Buildings	20	300	530	330	220	0
Plant	5	100	400	400	365	90
Contingency	-	-	-	-	-	240
External electron beams	-	-	-	-	-	150
Hostel and flats	-	-	25	50	25	0
Annual Cost						
Nuclear research equipment	-	-	50	200	200	200
Modification and improvements	-	-	-	-	-	50
Minor capital items	25	30	40	50	65	80
Non-capital	50	300	500	650	750	800
Total	100	730	1545	1680	1625	1610

6. Manpower

Table 5 estimates the numbers of professional staff required to construct and operate the machine.

TABLE 5

Scientific and Engineering Manpower - Professional Grades

(The appropriate grades at the Rutherford Laboratory are Scientific Officers, Experimental Officers, Engineers and Assistant Design Engineers.)

1961/2	1962/3	1963/4	1964/5	1965/6	1966/7
15	40	60	70	75	80

The critical period is the first year or so of the project when about 20 key professional staff are required to determine the scientific details of the accelerator and to set the pattern for all the features of the machine and the laboratory. About 6 of these could be provided from the Rutherford Laboratory without causing serious harm to the Nimrod and PLA programmes; they could be replaced at the Rutherford Laboratory by new recruits. In addition, in the early stages the work could be greatly helped by dividing the research and development required for the design between the Rutherford Laboratory and the universities most concerned; experienced staff could then share their time between existing tasks and the new project, before new staff and a new site could be made available. A total of about 20 people of professional status could be freed for the design work at the universities. Most of them would work mainly on a "sabbatical" basis, i.e. they would each give up their normal research for about a year. In this way the necessary knowledge and enthusiasm could certainly be provided and there would be about two years in which to recruit about 50 permanent professional staff for the new laboratory, dividing about equally between applied physicists and engineers.

The investment of nuclear research workers in machine building would consist of a proportion of the 20 university people working for an average of one year each. Since the presence of nuclear physicists in the design team is essential to ensure a design satisfactory to users, this seems to be reasonable.

The remainder of the staff would be technicians, administrative and clerical, craftsmen, etc. They would outnumber the professionals by perhaps 2 to 1. The overall scale envisaged for the new laboratory is about a quarter of that of the Rutherford Laboratory.

7. Time scale

It is estimated that the laboratory and the machine could be constructed in 4 to 5 years from the date of financial approval.

8. Siting

It is clear that the site should be well to the north of the Rutherford LAboratory in view of the geographical distribution of those universities which are actively interested in nuclear physics and are not near Harwell. A detailed study is in progress, and recommendations concerning a site will be made shortly.

Rutherford High Energy Laboratory,
26th June, 1961.