Dr Stafford

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NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

GOVERNING BOARD

A 4 GeV Electron Synchrotron - Report by The Physics Committee

(Covering note by the Secretary)

The enclosed report NI/PC/61/2 to which NI/PC/60/5 is appended, is submitted to the Board by the Physics Committee. Many Members will have seen the draft as submitted to the Physics Committee for any comments and amendments. In fact there were no amendments, and the paper as now submitted to the Board is identical with the draft.

Rutherford High Energy Laboratory,
Harwell.

9th February, 1961.

NI/PC/61/2

NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

A 4 GeV Electron Synchrotron

A proposal from the Physics Committee

SUMMARY

The Physics Committee recommend that the Institute should construct a 4 GeV electron synchrotron in a new laboratory under their management, at an estimated capital construction cost of £2 million and an annual cost rising to £650,000. Arguments are presented to show that the machine would provide facilities for research in an exciting and fundamental field, would be fully used, and would fulfil an essential need in sustaining university research.

The Committee recommend that this project should have high priority in the Institute's programme, and that its siting should be given urgent consideration.

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NATIONAL INSTITUTE FOR RESEARCH IN NUCLEAR SCIENCE

GOVERNING BOARD

A 4 GeV Electron Synchrotron

A proposal from the Physics Committee

1. Introduction

In NI(60)7, "Research in the Field of High Energy Physics", the Governing Board stated their policy for future development. Included in the list of projects was a design study of an electron accelerator, with an energy not exceeding 4 GeV, which it was hoped to construct in a new Institute laboratory. At that time a working party set up by the Physics Committee was examining the comparative merits of the two possible accelerators, a linear accelerator and a synchrotron. The working party have reported to the Physics Committee their unanimous support for a 4 GeV electron synchrotron. The detailed report of the working party, attached as an Appendix, has been discussed and accepted by the Physics Committee.

2. 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 the 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 those 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).

3. 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.

4. Design and cost

4.1 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, a third 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 20 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		19 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 (approx.)		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 (approx.)		1.1 Megajoules
Injection energy		20 MeV
Magnetic field at injection		42 gauss
Repetition rate		50 cycles per second (resonated magnet)

Table 2 - Machine Cost Estimates

Magnet	345,000
Power Supply	250,000
Cooling	10,000
Correction Magnets	15,000
Injector	125,000
Injection System	15,000
R.F. system	130,000
Vacuum System	40,000
Regulation and Controls	30,000
Miscellaneous and Spares	40,000
	1,000,000

4.2 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 thenbe 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.

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 magnet room in a removable form. This is technically and financially feasible for this smaller scale project.

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

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 3 - Site and Building Cost Estimates

Ground investigation	10,000
Opening up site	100,000
Laboratory and office block	250,000
Magnet building	200,000
Generator House	40,000
Experimental Hall (including cranes and shielding)	250,000
Ancillary building	50,000
Mechanical and electrical equipment, furniture etc.	100,000
	1,000,000

4.3 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. The capital costs of new research equipment, spares, etc. are estimated to level off at £250,000 per annum.

4.4 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 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 latter half of the machine construction, and is estimated to level off at £400,000 per annum.

4.5 Summary of annual costs

The total capital cost of the accelerator and buildings, estimated at £2,000,000, the recurrent expenses for design and subsequent operation, and the capital cost of research equipment and development are estimated to spread over the years as shown in Table 4.

Table 4

Estimated costs by years, in £1,000's

Year	1961/2	1962/3	1963/4	1964/5	1965/6	1966/7 and subs.
Recurrent expenses	100	200	400	400	400	400
Capital expenses						
Minor capital items needed for design and development	10	50	50	50	50	50
Machine construction						
Buildings	50	200	450	250	50	0
Plant	25	100	300	400	175	0
Modifications and improvements						
Buildings	-	-	-	-	-	20
Plant	-	-	-	-	-	30
Nuclear Research equipment	-	-	50	200	200	150
Hostel and flats for visitors	-	-	25	50	25	-
Total capital	85	350	875	950	500	250
Grand Total (Recurrent and capital)	185	550	1,275	1,350	900	650

5. 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
15	30	50	55	55

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 P.L.A. 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 40 permanent professional staff for the new laboratory, divided about equally between applied physicists and engineers, and a further year in which to recruit 10 more to bring the laboratory up to full strength.

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 at most a quarter of that of the Rutherford Laboratory.

6. <u>Time scale</u>

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

7. <u>Siting</u>

A decision on the siting of the new laboratory will be very urgent if the Board decide to adopt the proposal. Not only would the Minister for Science and the Treasury need to know where it was proposed to establish the laboratory, but detailed building design could not start until a fairly detailed survey and soil mechanics study had enabled a choice to be made from available sites in the chosen area of the country. 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. The Physics Committee have not so far attempted to recommend a particular part of the country.

8. <u>Effect on the main programme</u>

The Physics Committee recommend that the order of priority given in NI(60)7 should be changed and that the first four recommendations should be:

(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.

The remaining recommendations previously made by the Physics Committee, which was put fourth by the Board, was that

"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, the construction of which would be begun in about 1965."

The Physics Committee recommend that this should now be put fifth, recognising 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.

9. Recommendations

The Physics Committee recommend:

(i) That the Institute should design and construct a 4 GeV electron synchrotron in a new laboratory under their management, at an estimated capital cost of £2,000,000 and an ultimate annual cost of £650,000.

(ii) That the Institute should give urgent consideration to siting this new laboratory.

(iii) That this accelerator should be raised to high priority in the Institute's programme, second only to making full use of existing machines.

T. G. P.
L. B. M.