IN CONFIDENCE

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SCIENCE RESEARCH COUNCIL

RESEARCH REACTOR COMMITTEE

Report of Panel on Neutron Beam Facilities for Universities

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MEMBERSHIP OF THE PANEL

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1. TERMS OF REFERENCE

At their meeting on 3rd May, 1965, the Research Reactor Committee of the N.I.R.N.S. set up a Panel under the Chairmanship of Professor E. W. J. Mitchell to examine the current and future University requirements, including those in the three University Reactor Centres, for neutron beam facilities and to report to the Research Reactor Committee on the requirements and how they could best be met. The Panel have met on three occasions and the following report is based on the evidence presented and conclusions reached at these meetings.

2. THE PRESENT POSITION

In the past few years there has been a considerable increase in the use of neutron beam facilities by University scientists. This has occurred as the knowledge of the potentialities of the technique in both physics and chemistry has become more widespread. For most of this research work the neutron beams available at University Reactor Centres are not suitable because their neutron fluxes are about two orders of magnitude too small. Access to A.E.A. reactors and associated experimental facilities have therefore been essential. There have been three ways by means of which University scientists have been able to use A.E.A. facilities;

(a) By agreements through N.I.R.N.S. (now taken over by S.R.C.). These agreements include full time block allocation of reactor facilities on HERALD at Aldermaston and occasional access to irradiation facilities at Harwell.

(b) By extra-mural contract with A.E.R.E.

(c) By 'ad hoc' arrangement between individual A.E.A. staff and University staff.

Quite a significant proportion of the University access to A.E.A. facilities has been via routes (b) and (c). It is understood however that the A.E.A. may now have to be more selective with extra mural contracts than was necessary in the past. Accordingly, all the present extra mural contracts for basic research employing neutron beams may not be renewed when they expire. In addition the number of University research workers requesting access to neutron beams is increasing and ad hoc arrangements cannot be regarded as satisfactory. Consequently we feel that it is part of our task to produce an overall scheme in which scientists requiring neutron beams for their work can easily determine what facilities are available, what they have to do to make use of them, what the arrangements are for extended use and who pays for the various expenditures involved - reactor charge, "standard" neutron beam equipment, "special" neutron beam equipment, travel and subsistence when away from home University. The latter is financially the most insignificant, yet it is the cause of much frustration and will be discussed later.

The principal University users of neutron beams over the last few years are:

			Category (see above)
Professor G. E. Bacon	-	Sheffield	b
Professor W. Cochran	-	Edinburgh	c*
Professor E. W. J. Mitchell	-	Reading	a
Dr. G. L. Squires	-	Cambridge	b
Professor J. Walker	-	Birmingham	a
Dr. J. W. White	-	Oxford	b

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*Professor Cochran has also used the facilities at Chalk River, Canada.

This has involved a total of about 15 - 20 users, including research students, at any given time. However, an increasing number of people have been making use of facilities for short periods, e.g. Professor Hodgkin, Professor Anderson and Dr. Fender, all of Oxford; and Professor Mason of Sheffield - a total of about ten users, again including research students. Thus the total number of University based users of neutron beams has been 25 - 30 people including research students.

In order to obtain detailed information we have circulated all the University scientists who, as a result of our collective experience, we thought would have an interest in neutron work. In compiling our list we used the results of the more general surveys conducted by the N.I.R.N.S. We circulated 38 University neutron beam users or potential users and have received replies from 30. We apologise to anyone who has inadvertently been overlooked, but nevertheless feel that our survey is reasonably complete and certainly complete enough for the purpose of considering our appointed task. The difficulty with which users have been faced in answering our letter is to predict what the extent of their use of neutron beams will be over the next three or four years. These predictions have been made on the assumption that reasonable access to facilities is available. The information which is important for the Panel is the estimate of numbers of research workers involved, the nature of the work and the facility required, and the estimated access time required.

3. THE REQUIREMENTS FOR NEUTRON BEAMS FOR THE UNIVERSITIES OVER THE NEXT FEW YEARS

3.1 Categories

It is convenient to divide the users into three categories:

(a) those long term users who are using neutron techniques in areas in which the power of the technique has been more or less established.

(b) cases in which a significant increase in the number of users is dependent on the outcome of current or proposed experiments or the development of new techniques.

(c) users who wish to have access to neutrons to solve specific problems in crystallography, dynamics or defects as the need arises in their own research, which will not primarily be concerned with neutron beams.

3.2 Tabular summaries

We have summarised the information about users in these categories in the following tables.

TABLE I : MAJOR USERS

User	Department/ University	Topic	Instruments	No. of Workers	Estimated Acce[illegible] (%)
Prof. G. Bacon	Physics, Sheffield	Non-magnetic and magnetic crystallography, molecular structure of thermal motion. Liquids and glass	Single crystal diffractometer Time of flight Powder diffractometer	5*	50 50 100
Prof. B. Bleaney	Physics, Oxford	Magnetic properties of rare earths, Inelastic scattering	Single crystal diffractometer Time of flight	2*	20 20
Prof. W. Cochran	Physics, Edinburgh	Crystallography of transitions, Inelastic	Single crystal diffractometer 3 axis spectrometer	4	20 40
Dr. J. E. Enderby	Physics, Sheffield	Structure of liquid metals and alloys	Powder diffractometer	4	50
Dr. B. E. F. Fender	Chemistry, Oxford	Defects; Electron distribution	Long wavelength, Time of flight	3	20 20
Dr. J. W. Jeffrey	Crystallography, Birkbeck	Crystallography	Single crystal diffractometer	3	50
Dr. D. W. Jones	Chemistry, Bradford	Crystallography	Single drystal diffractometer	2	50
Prof. R. Mason	Chemistry, Sheffield	Molecular structure, Magnetic structures	Single crystal diffractometer Powder diffractometer	4	125
Prof. E.W.J. Mitchell	Physics, Reading	Defects (Total and diff)	Long wavelength, with time of flight	5	100** 50
Mr. D. A. Read	Physics, Leeds	Magnetic crystallography and diffuse scattering	Powder diffractometer	2	40
Dr. G. L. Squires	Physics, Cambridge	Lattice vibrations in metals	Time of flight, 3 axis spectometer	4	40 (including some time 40 on hot source)
Dr. W. Taylor	Physics, Cambridge	Magnetic crystallography, Spin distributions	Powder diffractometer single crystal diffractometer	6	50 50
Prof. J. Walker	Physics, Birmingham	Inelastic Radiography	Time of flight Hot source	6	80 20
Dr. J. W. White	Chemistry, Oxford	Defects; Dynamics of liquids	Long wavelength, Time of flight	4	25 25
Dr. T. Smith	Physics, Aberdeen	Lattice vibrations	3 axis spectrometer	3	40
			Total ...	57	

*Bacon and Bleaney both envisage further expansion of staff in four years' time.

**Long wavelength experiments tend to take longer : Herald experiments take longer

TABLE II

The following proposals are tentative dependent on the outcome of current work or development of new techniques:

Dr. E. W. Arndt	M.R.C. Unit., Cambridge	Experiments on large molecules dependent on availability of HFBR flux and co-ordinate detectors
Professor D. Hodgkin	Chemistry, Oxford	Some pilot experiments on large bio-molecules in progress at Harwell. Future demand depends on outcome.
Professor K. F. Smith	Physics, Sussex	Proposed experiment to measure dipole moment of neutron using long wave length neutrons. Feasibility experiment under discussion.

The final category of occasional users is difficult to estimate closely but is certainly large. Six groups who replied to the questionnaire indicated they may wish to use neutrons in this way to supplement X-ray methods, but clearly all crystallography groups should be included as potential users. Likewise, those studying dynamical properties of condensed matter.

It will be seen from Table I that 55 - 60 research workers will require facilities by 1969 compared with the 25 - 30 currently using beam facilities. In addition facilities are required for the considerable number of casual users (category (c)) from the groups mentioned above.

3.3 Conclusions about facilities

The facilities required by the category of major users are, from Table 1:

		Estimated Number of Users
Single crystal diffractometer	3.4 instruments on beams	15
Powder diffractometer	2.6 " " "	12
Inelastic (3 axis spectrometer (time of flight	3.5 " " "	20
Long wave length apparatus	2.5 " " "	10
		57

In this list "diffractometer" means a fully automated programmed instrument.

In addition to the major users the casual users of category (c) might require particularly diffractometers, but also triple axis spectrometers and time of flight apparatus. Thus if we were planning a reactor to cope with University work in three years' time we should provide:

4 Single crystal diffractometers

3 Powder diffractometers

4 Inelastic scattering instruments

3 Long wave length instruments

This set of facilities would require 13 beams and perhaps 9 beam holes.

3.4 Order of magnitude of costs

The costs for this type of work break down readily into five cagegories:

1. The reactor hire charges - or if owned, the reactor running costs.
2. The provision and operation of standard neutron beam associated facilities (excluding computers, but including cold sources, hot sources, standard electronics, diffractometers, etc.....)
3. Salaries and overheads of experimental staff and technicians required to assist visitors in carrying out experiments.
4. Facilities specifically related to a particular experiment. (Specially constructed automatic sample holders when a standard pattern cannot be used; specimen preparation etc...)
5. Travel and subsistence of University visitors attending reactor in connection with experiments.

We discuss (4) and (5) later when we discuss organisation; they are not expected to constitute large amounts. The cost in (1) depends, of course, on what is agreed about reactor charges and we also refer to this later. But at current rates (~ £30 k - £50 k per hole per year) the list of facilities given at the end of Section 3.3 would probably cost about £300,000 per annum. Regarding the second item, we can say that an average capital cost of standard facilities will be about £50,000 per beam instrument. Thus the real cost of providing these facilities will be near to £750,000.

4. EXISTING SOURCES

As we show in a separate section, there are almost no facilities available at the University Reactor Centres for the research which the users in the present survey wish to undertake. The fluxes of these reactors are too low. The only existing U.K. facilities are therefore the beam holes on PLUTO, DIDO and HERALD where thermal beam fluxes range from $6 \times 10^{13} - 2 \times 10^{13}$ n/cm^2 sec. We use the term "Medium flux source" to describe these reactors in comparison with "The high flux source" of the H.F.B.R. They may be compared with the University reactors ($10^{11} - 10^{12}$ n/cm^2 sec) and the proposed H.F.B.R., $1 - 2 \times 10^{15}$ n/cm^2 sec. Comparable facilities to PLUTO/DIDO could probably be mounted on the Dounreay M.T.R. although no beam experiments are carried out there at the moment. The instruments on PLUTO, DIDO and HERALD are shown in Appendix II. With the exception of the crystal spectrometer beam on HERALD, and to a lesser extent the A.E.R.E. fast chopper hole, the facilities described are in continuous use for solid and liquid state research by A.E.A. and University scientists. The relevant European reactors are listed in Appendix I and there is at the moment an examination being made by the S.R.C. of whether a particular inelastic experiment can be done at Petten. Valuable as this may be to help out in difficult cases

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it should not be necessary for University scientists to look overseas for facilities which should exist in the U.K., even though at present these facilities can be provided free of reactor charges. It is unlikely this would continue if a large number of users became involved. If a European centre were set up with a Users Allocation Committee and some guarantee of facilities it would be a different matter. Such an arrangement has not been contemplated and we would only recommend S.R.C. finance for the use of overseas facilities where efforts to secure them by the individual user in the U.K. have been tried without success.

5. PROVISION OF FACILITIES 1966-1970

5.1 Perspectives

We wish first to state clearly that we think the S.R.C. has a responsibility to University scientists to ensure that they have access to advanced research facilities. We are fully aware of the other major claims which conflict with reactor facilities - nuclear physics, computers, space physics and the whole special grant procedure. The areas of physics and long range technology have been discussed in detail in former reports (N.I.R.N.S., NIR/N.71: "A High Flux Beam Reactor for Solid State Research", November 1963; A.E.A., "Report of the Study Group on High-Intensity Sources of Thermal Neutrons", May 1965). The Research Reactor Committee and the A.E.A./Universities Study Group have emphasised the necessity of providing higher flux neutron beams and in particular a H.F.B.R. by 1970. There are three high flux beam reactors being built in the U.S.A. and possibly one in Europe shared between France and Germany. If the U.K. is not to lag behind in this scientific and technologically important area of science there must be a H.F.B.R. in the U.K. by 1970. The present panel has to deal with the question of how, in the meantime, can the S.R.C. fulfil its responsibility to University scientists and provide adequate facilities for neutron beam research. There was certainly a time when it would have been desirable to build a DIDO/PLUTO reactor for University users. Although this would relieve the current pressure from University users we feel that in the shadow of the H.F.B.R. proposal an investment in an M.F.B.R. would be inappropriate. All investment of that magnitude in the neutron field should be toward the provision of a H.F.B.R. in a National Centre. The first obvious fact is that all existing facilities are the property of the A.E.A. Consequently to satisfy the University users the S.R.C. must negotiate with the A.E.A. for the extension of guaranteed facilities on the A.E.A. medium flux reactors. There is a considerable amount of goodwill in the A.E.A. towards University users and a desire by A.E.A. scientists to regularise the procedure whereby University scientists can use a range of reactor facilities. For their part, University scientists see the A.E.A. facilities as the only ones of any use to them, but clearly need some kind of guarantee that they would be available on a continuing basis.

5.2 Joint use of A.E.A. facilities

The A.E.A. facilities are at A.W.R.E. Aldermaston,

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and A.E.R.E., Harwell. The S.R.C. have already been renting on a full-time basis, part of HERALD for approximately £100,000 per annum and have supported the construction of instruments which are now in full time use in the two holes, CIG and G2C, and on a third hole G1C when the cold source is in operation. An additional hole on HERALD could possibly be rented for an extra charge of £20,000 per annum. By increasing the instrumentation on the two cold source holes C1G/G1C their usefulness and availability to some of the major users of Table I will be improved. This requires more detailed consideration than has yet been done but it might comprise:

C1G/G1C Further development to make:

(i) large coverage of scattering angle for 4Å time of flight spectrometer

(ii) gated angular coverage for defect differential cross-section 6-15A

£30,000

By providing suitable diffractometers on the additional hole which it is proposed should be rented full-time on HERALD, the needs of at least one major crystallography research group and some service users would be met. Suitable instrumentation might comprise:

Two diffractometers - £50,000

It is also conceivable that part-time use of two further holes together with associated instrumentation might be rented on HERALD; which would accommodate some of the University users. For example, hole D1 is equipped with a crystal spectrometer with goniometer sample table which would be suitable for powder diffractometry, and hole F1 is equipped with a neutron chopper and time-of-flight instrumentation for neutron crystallography. The optimum choice of instrumentation which should be mounted on HERALD requires careful examination in relation to the total University need and the facilities available on a part time basis on Harwell reactors. It is proposed that recommendations on the details of the optimum equipment and costs should be brought forward to the Research Reactor Committee by the HERALD Sub-Committee which is already in existence. Its membership would be extended to take into account the wider usage of HERALD facilities.

Even with these instruments, however, it will not be possible to meet the University users' needs set out earlier. It will be necessary for the S.R.C. to negotiate with the A.E.A. for guaranteed access to instruments at Harwell. There are a number of neutron beam instruments on DIDO and PLUTO and these are mounting the A.E.R.E. programme. If the S.R.C. is going to pay for time on these instruments - which are clearly going to be used part by A.E.A. and part by Universities - there would need to be a joint A.E.A./University Users Panel. It would be improper for S.R.C. money to be used but for the A.E.A. to decide which of the Universities it would allow to use the instruments.

We are not in a position to say to what facilities the A.E.R.E. would be prepared to admit University users on some form of guaranteed basis administered by a Users Panel. We can see from those listed in Appendix II that some and possibly many of the following might be included in a possible set:

/DIDO

DIDO	4H1	2 Diffractometers
	4H2	Powder diffractometer
	4H5	Cold neutrons: time of flight
	6H	Available as time of flight
	10H	Triple axis and hot source.
PLUTO	7H1R	Time of flight
	7H1L	2 Polarized neutron diffractometers
	7H2R	Fully automatic triple axis
	7H3R	Powder diffractometer but also GLOPPER
	7H3L	Time of flight: Diffuse and small

It would greatly help to satisfy University users if they could be accommodated for periods on some or all of these facilities with some guarantee that further periods would be available. The cost and number must be negotiated. If the A.E.A., under the wider mandate of the Technology Bill, has an educational role them more favourable rates per instrument should be obtained than have been suggested in the past. The upkeep of the instruments would be the responsibility of the A.E.R.E.

If there is no educational mandate then 50% use of ten instruments would be expected to cost about £150,000 per annum. It is essential from the Universities' viewpoint that this should buy time on a complete range of instruments.

Powder diffractometer	(2)
Single crystal diffractometer	(4)
Inelastic - time of flight) Inelastic - triple axis)	(4)

This range of 50% guaranteed facilities on DIDO/PLUTO and 100% on HERALD would go a long way to meeting University users' needs over the 1966-70 period. Two current major users have A.E.R.E. contrzcts which expire in September 1966 (two more contracts expire in late 1967); also during 1966 the second triple axis spectrometer is expected to come into operation*. Thus the financial breakdown year by year might be

		1966	1967	1968	1969	1970
A.W.R.E.	Block rent	£100k	£140k	£140k	£140k	£140k
	Equipment	£60	£20	£1	£1	£1
	S.R.C. staff*	£5	£5	£5	£5	£5
A.E.R.E.	Block rent	£30	£100	£150	£150	£150
		£195k	£265k	£296k	£296k	£296k

These figures are quoted to indicate the sort of build up involved. It is clear that we are not committing anyone to them at this stage. During 1966 it would be desirable to get an A.E.A./University users panel working over all facilities so that by 1967, when a reasonably complete range of A.E.R.E. facilities might be guaranteed, allotment of time to all University users would be through the Users' Panel. The panel would assess priorities of applications which would be influenced by scientific priority, A.E.A. programme priority and University research student priority. The panel

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* At University rates; the sum would be greater if AEA staff overheads are included

would have to meet about six times per year and it would have to authorize some of its members to make alterations in the programme in the light of reactor circumstances. If the A.E.A. wished to allot some of its own reserved time on instruments to University users with whom it had contracts for special purposes it would clearly be able to do so. This would not, however, be expected to interfere with the University (S.R.C.) allotments throughtthe joint Users' panel. The facilities available to the panel would constitute an effective M.F.B.R. and the operation of the panel would afford valuable experience for running a H.F.B.R. users' panel in a National Centre.

The present scheme will go a long way to satisfying users' predictions in our survey. Compared with our estimate of requirements in Section 3.3 the scheme will provide:

Powder diffractometer	(=100%)	2 instruments
Single crystal diffractometer	(=100%)	3 instruments
Inelastic: Time of flight Triple axis	(=100%)	3 instruments
Long wavelength	(=100%)	2 instruments

It is hoped that the difference can be made up by increased collaboration between University users themselves. In any case the ordering of the arrangements for the use of the beam facilities by University scientists will lead to a higher usage per hole and a keen sense by all users of the value of the time "at the reactor face". We also feel that the consideration of experiments from all users by The Users' panel will be good for everybody's scientific efficiency and for the optimum use of time. We should expect membership of the Users' panel to be changed at the time of a three year review of the trial scheme and also that the review would indicate how the membership of the Panel should vary in a regulated way if the panel became a permanent feature. The Users' Panel would be responsible to the Research Reactor Committee but it would also send reports of its work to the Directors of the establishments involved.

6. SPECIAL GRANTS AND TRAVEL

6.1 Special grants for any special facility associated with reactor experiemnts, including neutron beam work, should be considered by the Research Reactor Committee. If the Research Reactor Committee were satisfied that the special facility existed elsewhere underused they should consider whether that facility could not be used without undue inconvenience to the applicant. As far as beam experiments are concerned, the Research Reactor Committee should be in a position to recommend grants and all applications for special equipment for use at reactor facilities should be referred by the University Science and Technology Division to the Research Reactor Committee.

6.2 Travel is often the most frustrating and the least expensive item of the cost of neutron users' experiments. In general there are no problems for University staff who can claim from the S.R.C. However, it is essential that the research students involved can

/attend

the reactor for suitable periods and not be out of pocket. Unless the periods are very long a research student must in addition to his temporary accommodation keep up his place of living at his home University. For travelling to a national facility such as a reactor or a nuclear machine, the simplest procedure would be for the appropriate S.R.C. Committee (in this case the Research Reactor Committee) to be able to grant travel and subsistence to neutron beam users, research student or staff. For someone engaged on an experiment a 2-week visit is probably the minimum but staff when supervising may make much shorter visits.

Examples of Cost:

	Return Fare	At £2.10.0. per day 12 days	Total for 12 days	Annual Total for 6 visits per year
Edinburgh-Harwell	£17. 0. 0(air)	£30	£47	£282
Sheffield-Harwell	£ 4. 0. 0(rail)	£30	£34	£204
Bristol -Harwell	£2. 0. 0(rail)	£30	£32	£192

Taking Sheffield as a mean, a total of 50 staff and student users at these rates would represent an annual expenditure of £10,200. This the S.R.C. should award through the Research Reactor Committee to encourage University Users to make best use of A.E.A. facilities.

7. THE ROLE OF THE UNIVERSITY REACTOR CENTRES

Neutron beam physics in general requires the highest available flux and 24 hour operation. The fluxes of the University low power reactors (10^{11} - 10^{12} n/cm^{2}sec) are only adequate for preliminary beam studies, or for the development of new beam techniques. Some of the users from the areas of the University Reactor Centres replied to our letter of enquiry that, as far as neutron beam work is concerned, the fluxes are inadequate We have found no major user who expresses the contrary opinion. On the other hand we feel strongly that the University Reactor Centres should be encouraged to build up their work in fields in which their low flux is not a handicap, notably:

Reactor physics studies
Radiation damage work
Isotope work - particularly short lived
Development of new techniques
Biological and health work
Various aspects of teaching

The latter is not the prime concern of the S.R.C., while the research topics the S.R.C. would consider are individual projects requiring special funds which would be dealt with by their normal special grant procedure. The S.R.C., however, would look at the overall programme in the country. For example, if it made a grant for a liquid helium irradiation facility in one reactor, it would not make another grant for such a facility until it was confident that the former one was adequately used and would direct new requests (and pay travel and subsistence) to the underused facility.

Applications for special S.R.C. grants for equipment for beam work from the University Centres should not be allowed to consume appreciable sums of money since we are agreed that the reactors do not provide adequate fluxes for most work in the beam field. We would encourage neutron beam users in the Centres by:

(i) recommending acceptance for relatively simple crystal spectrometers for preliminary studies.

(ii) similarly for very preliminary studies in the inelastic field.

(iii) for the development of new techniques (e.g. neutron tubes).

In general we feel that it is squandering our too limited resources to invest considerably in beam work at the University Reactor Centres. Beam users, therefore, should be encouraged by the S.R.C. to use the higher flux reactors of the A.E.A. (PLUTO, DIDO, HERALD - and possibly the Dounreay M.T.R.).

8. RECOMMENDATIONS TO THE RESEARCH REACTOR COMMITTEE

We recommend that:

A. The S.R.C. should negotiate with A.E.A. to provide:

(i) On the HERALD reactor at Aldermaston, guaranteed full time access to one beam hole, and part-time access to two neutron beam facilities, in addition to the full time access to three beam holes covered by the present contract.

(ii) On Harwell reactors a guaranteed 50% access to ten neutron beam facilities.

When all holes are available the total block grant to A.E.A. for rental of reactor facilities would be about £300,000 p.a. on current rates.

B. The four beam holes allocated to S.R.C. on HERALD should be adequately instrumented to meet University requirements in the most efficient way. A detailed estimate of the necessary instrumentation and its cost should therefore be made. Preliminary estimates suggest that this might cost approximately:

£50,000 for diffractometers to cover major and some "service" users;

£30,000 for improved and extended instrumentation on the defect scattering and inelastic scattering holes.

C. For each neutron beam facility covered by S.R.C./A.E.A. agreement, there should be a scientist responsible for its operation - he may be A.E.A., University, or S.R.C., but he should be someone whose research interests involve a substantial use of the facility. To ensure an efficient and

/up-to-date

up-to-date crystallographic service at Aldermaston one scientist with suitable research interests should be appointed by S.R.C. To ensure full and safe utilization of the equipment a few suitably qualified A/Sc. or A.E.O. staff should be available who will be capable of assuming full-time control of the apparatus. It is estimated that 2-3 will be required at Aldermaston. Some staff at Harwell are required to help the University programme.

D. The allocation of time on the various facilities should be made by a joint A.E.A./Universities Users Panel who would be responsible to the Research Reactor Committee and who would be expected also to report to the Directors of the Establishments involved.

E. The Research Reactor Committee should, from its funds, provide for the improvements which will be needed from time to time in the general instrumentation of the equipment used primarily by University scientists. Proposals concerning these improvements should be brought forward to the Research Reactor Committee by the A.E.A./University Users Panel. Apart from these general items, individual users may need special items in order to perform a particular experiment. The latter items (special samples; special sample holders; travel) should be covered by a normal special grant application to the appropriate Physics, Chemistry etc. Committee.

F. The University Reactor Centres should be encouraged in the fields where their facilities are most suited, but applications to the S.R.C. for equipment for beam work at the Centres should not be allowed to consume appreciable sums of money since these reactors do not provide adequate fluxes for most work in the beam field.

G. The Research Reactor Committee should explore with A.E.A. the need for the development of new techniques for the more efficient use of neutron beams. In this context we draw attention to the need for work on co-ordinate neutron detectors.

APPENDIX I

Neutron Beam Research Reactors in Europe (Peak flux 10^{13}).

Reactor	Site	Type	Power	Fuel	Fluxes			
					Average Thermal	Peak Thermal	Average Fast	Peak Fast
ASTRA	Seibersdorf Austria	Swimming Pool Tank Type Research Reactor	5 MW (convertible to 12 MW)	MTR-type fuel elements, 90% enriched U235	3.10^{13} n/cm^{2}sec.	7.5 10^{13} n/cm^{2}sec.	0.91 10^{14}n/cm^{2}sec	1.8 10^{14} n/cm^{2}sec
BR 2	Mol, Belgium	Tank type, fully enriched (90%) uranium light water moderated and cooled, Be reflected.	50 MW thermal	90% enriched, alloyed with 75-80% wt. Al, 244 g U235 per element, 6 concentric tubes, active length 762 mm.	4.6 10^{14} n/cm^{2}sec	6.2 10^{14} n/cm^{2}sec	1.0 10^{15} n/cm^{2}sec	2.4 10^{15} n/cm^{2}sec
DR 2	Risø, Denmark	Tank type, H_2O moderated.	5000 k^{W}	Highly enriched uranium (90%)	2.3 10^{13} n/cm^{2}sec	In the core 8 10^{13} n/cm^{2}sec In experimental facilities 10^{14} n/cm^{2}sec		5 10^{13} n/cm^{2}sec A 1^{27} (n,^{a}) 3.7 10^{13} n/cm^{2}sec S^{32} (n,p)
DR 3	Risø Denmark	Tank type PLUTO heavy water moderated and cooled	10,000 k^{W}	Highly enriched uranium (80%)	0.77 10^{14}n/cm^{2}sec	1.6 10^{14} n/cm^{2}sec	0.12 10^{14}n/cm^{2}sec	0.35 10^{14}n/cm^{2}sec
EL-3	Saclay, S. et O., France	Tank type enriched (1.35%) uranium, heavy water cooled and moderated, graphite and heavy water reflected.	15 MW thermal	Hollow rods Ø 2.14, Ø 2.9 x 32 cm, 1.35% enriched uranium alloyed with 1.5% Mo	5 10^{13} n/cm^{2}sec	1 10^{14} n/cm^{2}sec		4 10^{13} n/cm^{2}sec
MELUSINE	Grenoble, Isere, France	Pool type, enriched (20%) uranium, light water moderated and cooled.	1.2 MW thermal	MTR type, 20% enrichment, alloy 45% uranium, 52% Al, 3% Si.	0.6 10^{13}n/cm^{2}sec	1.7 10^{13}n/cm^{2}sec	2.0 10^{13} n/cm^{2}sec	5.0 10^{13} n/cm^{2}sec
SILOE	Grenoble	Tank type	10 MW			6 x 10^{13}n/cm^{2}sec		
TRITON	Fontenay-aux-Roses, France.	Pool type, enriched uranium, light water moderated and cooled.	2 MW thermal	MTR type, 20% enrichment, alloy 45% U, 52% Al, 3% Si.	1.2 10^{13}n/cm^{2}sec	4 10^{13} n/cm^{2}sec	2 10^{13} n/cm^{2}sec	5 10^{13} n/cm^{2}sec
FRJ 2 DIDO	Julich, Germany.	Heavy water moderated and cooled.	10 MW	U_{235}		1.6 10^{14}n/cm^{2}sec		0.35 10^{14}n/cm^{2}sec
MERLIN	Julich	Light water, pool type	5 MW	80% U_{235}		5 x 10^{13}n/cm^{2}sec		
FRM	Garching-Munchen Germany	Swimming pool	1 MW	Enriched uranium	0.2 10^{13}n/cm^{2}sec	1.5 10^{13} n/cm^{2}sec	0.4 10^{13}n/cm^{2}sec	2 10^{13} n/cm^{2}sec
FR II	Gemarkung Leopoldshafen Karlsruhe, Germany.	Tank type, D_2O-natural uranium.	12 MW	Natural uranium	1.5 10^{13}n/cm^{2}sec.	4 10^{13} n/cm^{2}sec	0.8 10^{13} n/cm^{2}sec	2 10^{13} n/cm^{2sec}
ISPRA 1	Ispra, Varese, Italy.	Tank enriched (20%) uranium, heavy water moderated and cooled heavy water and graphite reflected.	3 MW	a) MTR type, 20% enrichment b) MTR type, 90% enrichment Alloy U-Al	3 10^{13} n/cm^{2}sec	10^{14} n/cm^{2}sec		8 10^{13} n/cm^{2}sec
PETTIN REACTOR (HFR) NL-2	Petten, Netherlands	Tank type High Flux Reactor,	20 MW	MTR-type 90% enrichment.	1.5 10^{14}n/cm^{2}sec	2.5 10^{14}n/cm^{2}sec		7.8 10^{14}n/cm^{2}sec

Neutron Beam Research Reactors in Europe (cont'd).

Reactor	Site	Type	Power	Fuel	Fluxes			
					Average Thermal	Peak Thermal	Average Fast	Peak Fast
JEN 1	Moncloa, Spain	Swimming Pool	3,000 kW	Enriched uranium (20%)		3.5 10^{13}n/cm^{2}sec.		1 10^{14}n/cm^{2}sec
R 2	Studavik, Tystberga, Sweden	Tank type, light water moderated and cooled(MTR ORR).	30,000 kW	High enriched uranium (90%)	2 10^{14}n/cm^{2}sec	3.1 10^{14}n/cm^{2}sec	6.5 10^{14}n/cm^{2}sec	1.5 10^{15}n/cm^{2}sec
DIORIT	Eidg. Institut für Reaktorforschung, Würenlingen Aargau, Switzerland.	Heavy water moderated and cooled.	20,000 kW	Natural uranium, metallic rods	1.7 10^{13}n/cm^{2}sec.	3.5 10^{13}n/cm^{2}sec.	1.5 10^{13}n/cm^{2}sec	3 10^{13} n/cm^{2}sec
DIDO	Harwell, Berkshire. (Atomic Energy Research Establishment)	Tank type, heavy water moderated and cooled.	15,000 kW	Fully enriched uranium (93%)	0.7 10^{14}n/cm^{2}sec	1.9 10^{14}n/cm^{2}sec	Peak epithermal 0.12 10^{14} n/cm^2 sec	0.35 10^{14}n/cm^{2}sec
PLUTO	Harwell, Berkshire (Atomic Energy Research Establishment)	Tank type, heavy water moderated and cooled	15,000 kW	Fully enriched uranium (93%)	0.74 10^{14}n/cm^{2}sec	1.8 10^{14}n/cm^{2}sec	Peak epithermal 0.12 10^{14}n/cm^{2}sec	0.35 10^{14}n/cm^{2}sec
DMTR (Dounreay Materials Testing Reactor)	Dounreay, Scotland.	Tank type, heavy water moderated and cooled.	10,000 kW	Fully enriched uranium(93%)	0.74 10^{14}n/cm^{2}sec	1.2 10^{14}n/cm^{2}sec	Peak epithermal 0.12 10^{14} n/cm^2 sec	0.35 10^{14}n/cm^{2}sec
HERALD	Aldermaston, Berkshire. (Atomic Weapons Research Establishment)	Merlin type swimming pool	5,000 kW	Fully enriched uranium	Vertical 3.55 10^{13}n/cm^{2}sec Horizontal 3.1 10^{13}n/cm^{2}sec	Vertical 4.5 10^{13}n/cm^{2}sec Horizontal 5.2 10^{13} n/cm^{2}sec	Vertical 13.3 10^{13} n/cm^{2}sec Horizontal 11.2 10^{13}n/cm^{2}sec	Vertical 17.2 10^{13}n/cm^{2}sec Horizontal 17.2 10^{13} n/cm^{2}sec

Neutron Beam Equipment at Harwell

APPENDIX II

1. Diffractometers

(a) Single crystal diffractometers, crystal monochromator $\lambda \sim 1$Å. Crystal sizes between $\frac{1}{2}$ and 10^{-3} cm^3.

Reactor	Hole	Description	Number of Instruments
PLUTO	7H3R	Collimation 1° in vertical and horizontal planes, $2\theta = 50^\circ$	One
DIDO	4H1	Two diffractometers $\left.\begin{array}{l} 2\theta = 90^\circ \\ 2\theta = 75^\circ \end{array}\right)$ both have collimation of 1° in vertical and horizontal planes	Two
PLUTO	7H4R	One single crystal hand-operated instrument for three dimensional structure-factor work. Wavelength variable in steps 0.8-1.5Å. $2\theta = 50^\circ, 90^\circ, 130^\circ$.	One
		One fully automatic (Mk. 1) single crystal diffractometer. Variable wavelength 0.1-1.5Å. Two further fully automatic (Mk. 2) diffractometers installed in April 1965	Three
DIDO	6HGR8	High resolution beam (3') for Bragg scattering from large crystals.	One

(b) Powder diffractometers, crystal monochromator, λ 1Å. Large beams to use polycrystal specimens up to about 10 cc.

DIDO	4H2	Collimation 1° in vertical and 20 minutes in horizontal planes, $2\theta = 22^\circ$.	One
PLUTO	7H4L	To be installed in 1966. Crystal monochromated. Variable wavelength 0.8-1.5Å Variable collimation $1/4^\circ$ to $3/4^\circ$. Fully automatic, $2\theta = 20^\circ$ to 90°.	One
PLUTO	7H3R	Collimation 1° in vertical and 20 minutes in horizontal planes, $2\theta = 22^\circ$.	One
DIDO	6HGR3	Collimation 1° in vertical and 20 minutes in horizontal planes, $2\theta = 25^\circ$.	One

(c) Polarised neutron diffractometers, 1 variable wavelength, Co-Fe crystal polarisers, $\lambda \sim 1$Å. 99% polarisation. Radio frequency resonance neutron spin-reversal. Beam area 1 cm^2. Large specimens of single crystal required.

PLUTO	7H1L	Collimation 1° in vertical and horizontal planes $2\theta = 33^\circ$. Variable wavelength collimation $3/4^\circ$ in horizontal and 1° in vertical planes, $2\theta = 22^\circ$.	Two

2. Diffuse and Small Angle Scattering

PLUTO	7H3L	Mechanical chopper, pulses 250 μs, repetition 800/sec., filtered beam in range 4Å-10Å. 2" diameter beam, relaxed collimation $\pm 1^\circ$, low resolution counter, with crude time-of-flight analysis.	One
DIDO	6HGR2	Small angle scattering by spin waves. Complete Maxwell spectrum, collimated to six minutes, minimum usable angle 12'.	One
DIDO	6HGR10	White beam and large diffractometer for studies on spin waves. Beam area 1 1/4" x $\frac{1}{2}$", collimation 30' of arc; counter subtends -5° to $+55^\circ$.	One
DIDO	2 TAN	The helical selector (a wavelength-selection facility of high throughput) to be installed 1966.	One

3. Inelastic Scattering

DIDO	4H5	Cold neutron apparatus; liquid H_2 source; twin-rotor chopper.	One
DIDO	6H	Fast Chopper - 100 metre flight path, also available as twin-rotor chopper for 2 Å neutrons.	One
DIDO	10H	A three axis spectrometer used for automatic constant Q work (hot neutron source to be installed end 1965).	One
PLUTO	7H1R	Twin rotor chopper, time-of-flight analysis. λ from 1.2 upwards, beam area 2 cm x 1 cm; pulse length 28 sec., repitition time in the range 2000 μsec.- 667 sec. Flight path 2 metres; collimation variable $\pm 1/8^\circ$ to $\pm \frac{1}{2}^\circ$.	One
PLUTO	7H2R	Triple axis spectrometer at PLUTO to be installed mid-1966, will be fully automatic.	One

4. Apparatus at BEPO

(a) Crystal spectrometers are available.
(b) Some beam holes (central flux ~ 1012 n/cm^2 sec., area 4", length 20") can be made available.

Neutron Beam Equipment on HERALD

1. Slow Chopper Spectrometers

Hole	Description	Present Use	User
H2	Curved slit, elliptical rotor and flight path variable up to 5m. Pulses from 10 µsec minimum at 24,000 r.p.m. Sample size from 1 1/4 inch x 1 1/4 inch minimum over range 0.004 ev to 0.06 ev. Auto read-cut, 100 channels.	Total cross sections, water and graphite	AERE
C1G	Cold neutron inelastic scattering apparatus with curved slit, elliptical rotor, 1.6 metre flight path and 8 BF_3 counters at 20° - 90° to incident beam. Cooled Be filter and rotor produce 4Å neutrons, 20 µsec bursts, at 500 cps. Sample size 1 inch by 1 3/4 inch and energy resolution typically 24%. 1024 time analyser and paper taps; 4000 channel magnetic core store with "add-one" to be incorporated.	Terphenols, diphenol, benzene	Birmingham University
G1C/G2C	Disc chopper with five radial slits produces 240 µsec bursts at 2,000 r.p.m. over energy range less than 0.005 ev (4Å). Beam size variable up to 2" x 2". Flight path 2m or 5m. Resolution 10% at 10 Angstrom.	Neutron source spectrums	AWRE

2. Mechanical Monochromators

G2C/G1C	Two velocity selection for range 6 - 15Å; each containing seven phased discs with 80 radial slits, spinning up to 8,000 r.p.m. Transmission 30%. Collimation 20 mins. Resolution 4%. Sample size 1" x 1". Cooled Be filter; auto sample changer and decimal printers.	Crystal defects	Reading University
F1	For range 0.001 to 0.3 ev in low cadmium ratio beams; cylindrical "helical path" rotor with 370 radial slots spinning at 10,000 r.p.m. Transmittivity 30%, Collination 3 minutes. Resolution 15% at 0.025 ev; sample size 0.25 inch x 0.25 inch.	Fission mechanism	AWRE

3. Fast Neutron Chopper

E1	U238/ duranickol rotors; speeds 600 r.p.m. to 15,000 r.p.m. Burst width 130 usec. to 3 usec. Transmittivity 0.8%. Flight stations 10 metres and 25 metres + space available near to chopper. Resolution from 0.1 - 3.0 usec/metre. Energy range 0.005 ev to Kev. Beam areas greater than 150 cm^2.	None	-
	Identical specification but lowest range of operational speeds for coherent elastic scattering experiments by time-of-flight, Resolved count rate 300 hr^{-1} off A1, powder (111) Crystal planes at 4% wavelength resolution and 12 inch x 1 inch BF3 counter; Flight path 6.59 m, burst width 130 µsec. Modification planned to optimise for crystal structure work.	Structure analysis elastic and possibly inelastic	A.W.R.E./S.R.C. possibilities

D1	Twin axis, turret mounted. Collination 5 mins. to 50 mins. Sample size 1.5 inch x 3 inch. Range 0.015 ev to 2 ev. Resolution 0.5% $0_B = 30^\circ$, 20% for $0_B = 3^\circ$. With mechanical filter and sample cryostat, Room for polarising magnets and collimeter.	Radiography Magnetics - exploratory experiment	Birmingham University Leeds University