ICANS-XI International Collaboration on Advanced Neutron Sources
KEK, Tsukuba, October 22-26, 1990

SOME Thoughts on the Future of Neutron Scattering

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ABSTRACT
Attendees of ICANS meetings believe that neutron scattering has a bright future, but critics of neutron scattering argue that its practitioners are an aging group, that they use a few, very expensive neutron sources and that the interesting science may be done by other techniques. The ICANS committee asked me to comment on the future of neutron scattering in the light of this contrast.

Some comments will be made on the age distribution, on the proper distribution of sources, on the convenient availability of neutron instruments and methods, on the expansion into new areas of science, on applications to industry and on the probable impact of synchrotron sources. It is hoped that these comments will lead to an outward looking discussion on the future.

I. INTRODUCTION

Modern radiation scattering methods began in 1912 when von Laue[1] suggested that crystals would serve as natural diffraction gratings for X-rays and interpreted experimental results in this way. Subsequently the Braggs[2] improved the techniques and showed how powerful the ideas of von Laue were. From 1912 to 1942 only photons were available with sufficient intensity for good experimental work, but after Fermis' group developed the nuclear reactor a second technique became available. The first crystal spectrometer for neutrons was built by Zinn[3] in 1944 for the CP-3 reactor at A.N.L. Due to the background available from 30 years of X-ray diffraction, the development of this new technique was fairly rapid.

Enrico Fermi may be called the 'father of neutron scattering' because he (a) discovered thermal neutrons (b) built the first nuclear reactors which provided an adequate source (c) performed many of the underlying experiments upon which neutron diffraction and inelastic scattering are founded. Unlike neutron diffraction, the new subject of neutron inelastic scattering required a developmental period, but by 1957 when the first international conference took place in Stockholm it had become an established technique also. The age of the personnel then engaged in this work may be judged from the ages of the attendees at the neutron scattering conferences of this period (e.g. the I.A.E.A. meeting on inelastic scattering in 1960). A comparison with conferences held recently (e.g. the Cold Neutron Source meeting at Los Alamos 1990) shows that the average age of scientists engaged in neutron scattering has increased during the past 30 years. In fact many of those attending the ICANS-XI meeting are older than Fermi was when he made the basic experiments listed above.

It is useful to consider the trends in steady state neutron sources since the time of CP3. A plot of maximum thermal flux against year of completion is shown as figure 1. It can be seen that fluxes grew rapidly by three orders of magnitude, and that after this growth a longer time scale was required for further advances. At first the nuclear centres controlled the sources and users were centre employees. In later years the users came from many organizations (e.g. nuclear centres, Universities, Government and Industrial Laboratories, etc.), and for a number of sources the users assumed control (e.g. the I.L.L.). This trend in wider usage and user control was both natural and healthy, and is likely to be continued. However we see that in parallel with the aging of the personnel, there is an aging (and perhaps a flux limit) for the steady state sources. Pulsed neutron sources have been used since the beginning of this subject, but were not fully competitive with the steady state sources until recently. They have shown a rapid period of development in the 80's, but may also reach a plateau during the 90's. Neutron scattering communities (e.g. Europe, U.S.A., Japan, etc.) are now considering plans for future steady state and pulsed sources at the highest levels, but the time scales and costs are both quite large.

Against this background of trends in personnel and sources it may be useful to consider the future prospects for neutron scattering. Some of the topics which our field should discuss include, the proper distribution of neutron sources, access and availability to all scientists, the introduction of new areas of science, the expansion of industrial uses, and the impact of the new synchrotron sources. An initial attempt to discuss these matters follows.

II. NEUTRON SOURCES

The high flux reactor at the Institut Laue Langevin[4] (I.L.L.) was operated from the outset as a source which was easily accessible to a wide spectrum of users. It was also one where the scientists at the many smaller sources spread throughout Europe could interact with the I.L.L. scientists and contribute to the neutron scattering facilities. In these two respects the I.L.L. differed from the major facilities in N. America, and at the latter there was some discussion on whether the new system could operate successfully? In the U.S.A. local sources were being closed in favour of 'strengthening' central sources. However experience soon showed that the I.L.L. interactive approach led to the introduction of new ideas and methods, and to the expansion of neutron scattering both in numbers of participants and in its impact on new areas of science. It is likely that the interactions between the I.L.L. and the many local sources in Europe (shown schematically in figure 2) were an important contribution to its success. The interaction worked in both directions, the local scientists developed their ideas with their own resources and with help and encouragement from the I.L.L., and then many of these ideas became part of the landscape at the I.L.L. to the benefit of the whole of Europe. The leadership of the neutron scattering field left N. America for Europe probably as a consequence of the support of and interactions with local sources in Europe compared to the run-down of local sources in N. America. The recipe for success in the 70's and 80's was probably the combination of centralization with diversity practised at the I.L.L (figure 2).

The author believes that super-sources discussed at ICANS and elsewhere are not sufficient by themselves for the success of neutron scattering. In addition two other aspects must be emphasized:-

- the interactions with local sources
- the type and quality of access and the infrastructure at the source.

We may ask the questions: will a large central source fail if there are no local sources interacting with it?, and will a large central source fail if it fails to interact with a sufficiently broad spectrum of scientists and to attract new areas of science? For the general health and development of neutron scattering three levels of neutron source are needed:-

- the teaching laboratory source
- the local source
- the high flux central source.

In the past ICANS has concentrated on the latter category, but the author believes that ICANS should widen its scope and discuss advances in the other two categories. Of great importance today is the development of ideas for local sources which will lead to cheap, safe, easily operated sources which have sufficient flux for this purpose.

By combining the views expressed in this section with those given in the Introduction, it is possible to present three observations to the neutron community:-

a) the neutron community is aging while it is still increasing in number;
b) neutron sources are aging and are decreasing in number;
c) local neutron sources are few and are decreasing, but they are essential for the success of the super-sources and of this field generally.

The neutron scattering community should discuss these observations and consider strategies to offset their adverse aspects.

III. INDUSTRIAL AND LOCAL SOURCES

New areas of science to which neutron scattering techniques may be applied successfully are difficult to predict far in advance of their appearance. However they may be encouraged to appear if, at the neutron source laboratory, there is:-

- an interaction with a broad spectrum of scientists and a 'flow-through' system for some personnel;
- a belief that neutron scattering is applicable to all areas of science and that some neutron experiments can be done by novices;
- a good level of access for all scientists (including novices) in the broadest sense.

The implementation of these points will encourage both basic and applied science: in this regard some observations on the industrial application of neutron scattering may be worthwhile. Even with the above favourable environment, each industrial use of neutron scattering is likely to require an initiation period. But once that period is over it should be possible to borrow money (from the usual lending institutions) for construction of specialized industrial application instruments, and repay the loan through industrial user charges. Such industrial programs would be evidence that neutron scattering is a growing and maturing technology. Probably neutron radiography, and strain and texture work using neutron diffraction are examples where this market oriented strategy could be applied.

It is possible that neutron scattering techniques could be included in mass production processes in appropriate cases: for example where preset orientational limits or preset strains are required. Production line samples might be sent to a central source or a portable neutron source might be used on site. In addition there are various "in the field" neutron scattering measurements for which portable sources are necessary. Many people are familiar with the bore-hole survey, airport luggage scanner, activation analysis or radiography applications. However if cheaper, simpler and more powerful portable sources were available the range of applications would increase. In this event the distinction between an 'industrial source' and a 'local source' might disappear.

In the context of this paper, a 'local source' is one large enough to do useful experiments and to serve a geographical region. They could be cheap, small accelerator based sources which can be operated with no more difficulty (or danger) than a motor-car. To achieve this target requires more inventive designs made with these requirements in mind.

The author believes that accelerator designers should work on this problem as much as they have worked on the design of super-sources, and that the discussion of local sources are properly a part of ICANS and should be included in these meetings. To keep the cost of such sources down to an acceptable level will require the production and sale of many units. Consequently if similar designs can be used for local sources, industrial sources and teaching sources that would be an advantage to both user and manufacturer.

IV. TEACHING LABORATORY SOURCES

During the whole period that X-rays have been used to study the structure of materials, there have been X-ray sources available for teaching purposes in University laboratories. As a result these techniques are taught well and widely and several generations of scientists have used them in many applications. The same is not true of neutron sources, and as a result neutron techniques do not appear in most laboratory courses. In turn this means that these techniques are neither used widely, nor properly understood by many scientists. The availability of X-ray sources compared to the lack of neutron sources is related to the energy required to produce one particle, which is very much greater for a neutron than for an X-ray photon. It is therefore unlikely that copious neutron sources can be produced sufficiently cheaply to be purchased for teaching laboratories.

At the present time radioactive sources are the most suitable for teaching laboratories, since they are inexpensive, require negligible maintenance and have a relatively constant output. The greatest flux is obtained for the spontaneous fission source (^{252}Cf), with a heavy water moderator. However it has the disadvantage that the source needs renewal in about 5 years (due to the half-life) and the heavy water container may need maintenance. The Am/Be source using a paraffin wax moderator will give about an order of magnitude fewer thermal neutrons, but has a half-life of several hundred years and requires negligible maintenance. The reaction is:-

$$\alpha + {}^{9}Be \rightarrow {}^{12}C + n(\sim 5MeV)$$

The neutron energy is greater than for fission, and hence extra fast neutron shielding is required. A 2-Curie source (4 x 10^6 fast neutrons/sec) is used in the laboratory neutron diffractometer (figure 3) employed for teaching purposes at the University of Guelph. Bragg reflection intensities from a graphite crystal (5 cm high and 8 cm long) are about 100/min. Table 1 shows some of the matters which may be included in a normal laboratory course using this arrangement.

Table 1

Some topics which may be studied with the laboratory spectrometer of figure 3

Basic Properties of Neutrons
Neutron Detection
Design of a neutron diffractometer
Transmission in $(CH_2)_n$ and Pb compared to X-rays
Bragg reflections from single crystals
The Spectrum of thermal neutrons
The measurement of Plancks constant
etc.

In order to improve the presentation of such topics and to include further topics, some improvement in the source is required. Possibly a cheap commercially available packaged (^{252}Cf in D_2O) source would be acceptable. Beyond this, if the local source development program (see section III) takes place, new sources at the lower end of that program may be suitable. In any event it is important for the future of neutron scattering, that the neutron community encourage the expansion of teaching laboratory work.

V. THE IMPACT OF PHOTON SOURCES

High flux photon sources are coming into general use for condensed matter science. Shirane[5] has given a good account of the properties of these sources and their use in solid state physics. It is worth listing some of the properties of these sources; in a way which compares them to neutron sources:-

- the flux is much higher than for neutron sources
- narrow, highly collimated beams are available (and may be polarized)
- electron distributions (rather than nuclear distributions) are observed
- some isotopic effects occur and are interesting (e.g. there is a quantum effect in the structure of disordered systems which can be observed by the H/D substitution method)
- some inelastic scattering effects can be seen
- some magnetic scattering effects can be seen.

When users of synchrotron radiation sources look at neutron scattering one may expect them to say that neutron scattering has, a very few expensive sources, very weak neutron beams, very large samples (beam areas), poor statistics, poor collimation, long counting times, etc. Neutron scattering has many unique features (familiar to all neutron scattering professionals) which make experiments with all these disadvantages worthwhile, and in many ways the complimentary character of neutron and photon experiments may be exploited by able experimentalists[5]. These and similar points need to be included and explored in many teaching environments.

The growing use of synchrotron sources is likely to cause many condensed matter scientists to become familiar with radiation scattering methods and their advantages. This could offer the neutron community a fertile source of new neutron users. The scientist who shops around for the best radiation source and spectrometers for his/her scientific program, and who may use several different sources, could become the norm. The proper and advantageous ways to use all sources need to be widely disseminated in this environment. Then all kinds of users need reasonable access and convenient availability to neutron sources and spectrometers which exploit the intrinsic advantages of neutrons. In other words the neutron community needs to react in appropriate ways to a new and competitive environment.

VI. CONCLUSIONS

The object of this paper is to initiate a discussion on future directions in neutron scattering. Some of the points covered above may be regarded as 'obvious' or 'over-simplified' etc., but nevertheless need to be included in a paper of this kind. While there are many items which may be selected for further discussion from those touched on in this paper (and in other similar papers), it is important to select a few items as the most important in todays environment. In the authors view the top items are:-

(A) Local sources are in urgent need of study - while super-sources are important and worth support it may be more important to the field to study local sources

(B) Interactions with a progressively wider user base need study: new methods of developing these interactions are needed,
   - with synchrotron users
   - with general scientists (mainly non-experts)
   - with industrial people (mainly non-experts).

These topics are not new and have been studied before - the question for today is "Can the ICANS conference do better?"

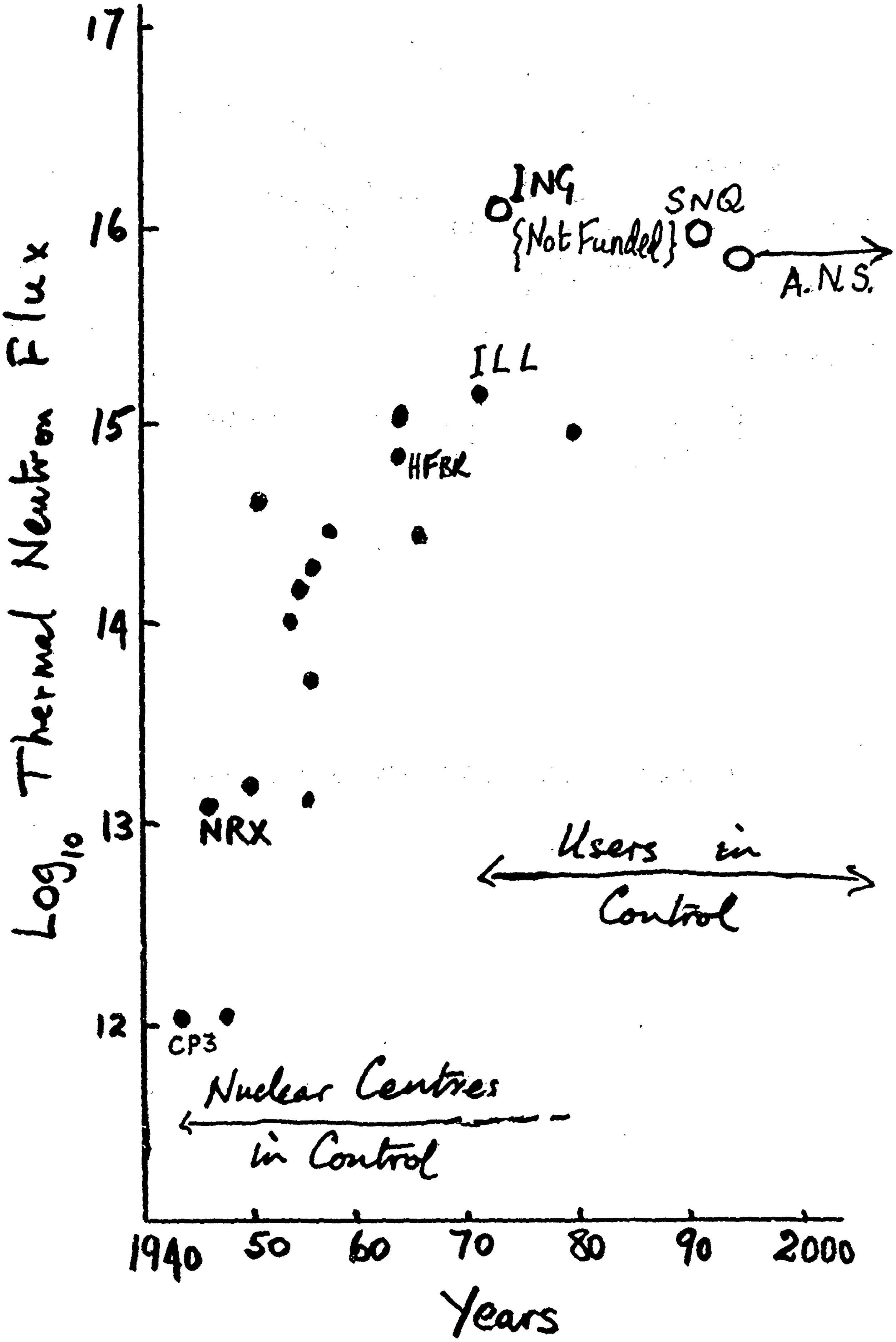
References

1. von Laue M., Münchener Sitzungsberichte p. 363 (1912), and Ann. der. Phys. <u>41</u>, 989, (1913).
2. Bragg W.H. and Bragg W.L. Proc., Roy. Soc. London <u>88</u>, 428 and 89, 246, (1913).
3. Zinn W.H., Phys. Rev. <u>71</u>, 752, (1947).
4. Maier-Leibnitz H., p. 135 in "Fifty Years of Neutron Diffraction" ed. G.E. Bacon (Hilger, Bristol, 1986).
5. Shirane G., previous paper.

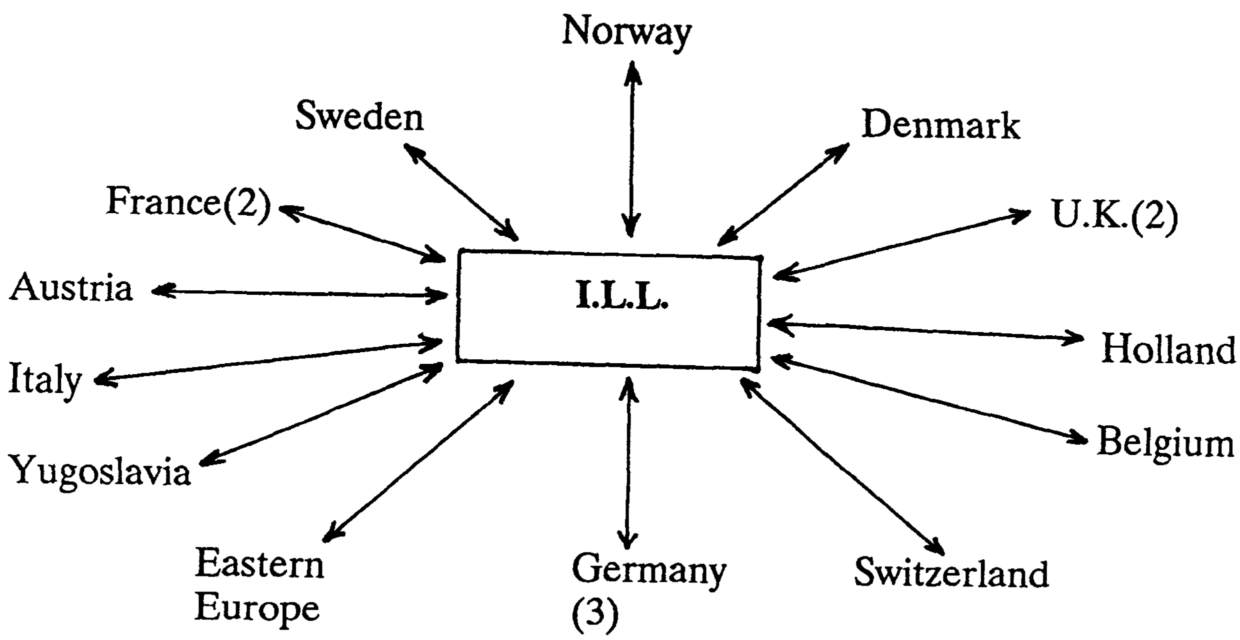
Figure Legends

1. A plot of maximum thermal flux against year of completion for steady state sources from CP3 to the present.
2. A schematic diagram showing the two-way interaction between pre-existing local sources throughout Europe and the new high flux source at the I.L.L.
3. Cross-section of the teaching laboratory neutron diffractometer at the University of Guelph.

FIG. I.



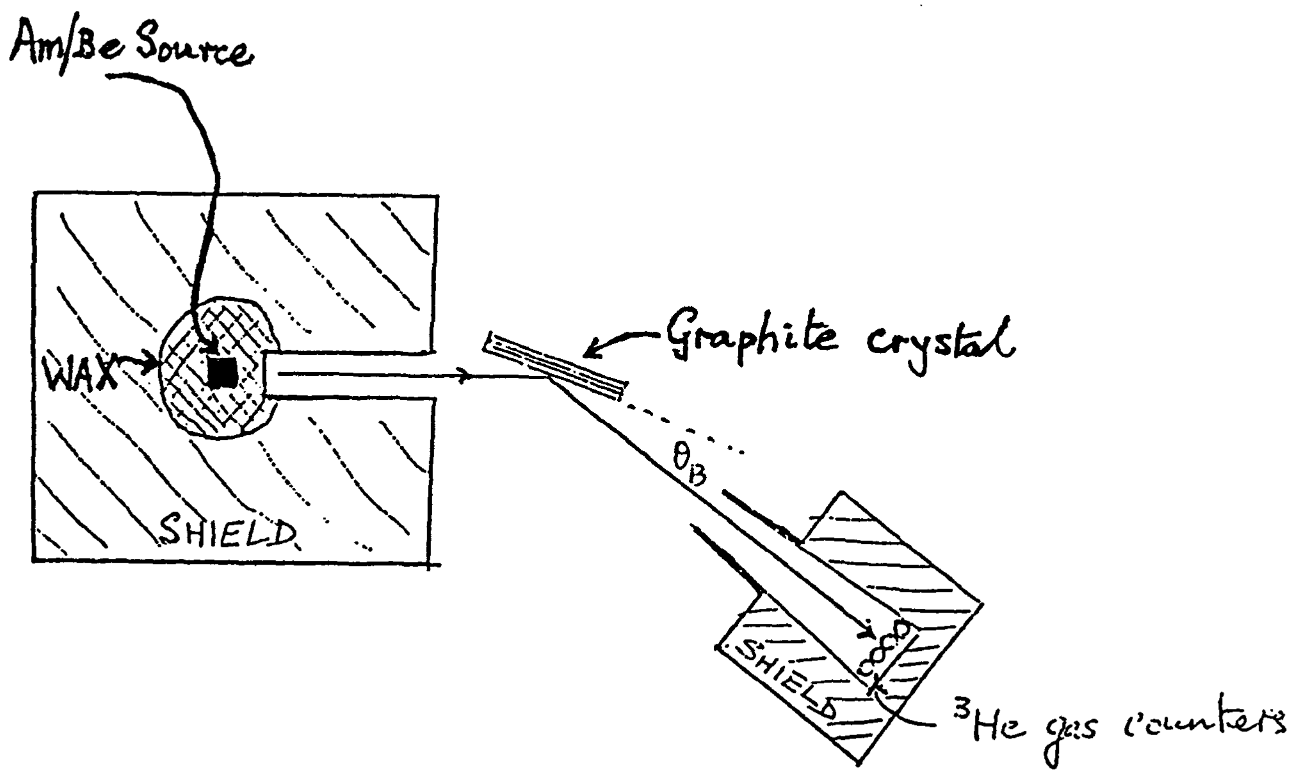
Log10 Thermal Neutron Flux
17
16
15
14
13
12
ING {Not Funded}
SNQ
A.N.S.
ILL
HFBR
NRX
CP3
Users in Control
Nuclear Centres in Control
1940
50
60
70
80
90
2000
Years



<u>Centralization plus Diversity was a success in the 70's</u>

FIG. 2.

FIG. 3.



Am/Be Source
WAX
SHIELD
Graphite crystal
θ_B
SHIELD
^{3}He gas counters

C(J.L.Finney): One other positive effect of increased use of synchrotron photon sources is that it gets scientists used to working in central facility made. This in itself is encouraging wider use of the UK neutron community at least, which is growing at the rate of 10% a year.

Q(I.M.Thorson): For condensed matter science one should include muon facilities which can be associated with most pulsed-neutron facilities at modest incremental cost.

A(P.A.Egelstaff): Yes.

Q(J.B.Hayter): The average student today has more computer power at home than was available to the designers of the last U.S. reactor. Can we not exploit this as a teaching tool, e.g. by distributing programs to teachers?

A(P.A.Egelstaff): Yes, I think this is a good idea only waiting to be executed. Some people have told me that the best way to do it is to get senior high school students to do it. In this case ORNL would hire local high school students in the summer, train them in the elements of radiation scattering and let them write software for the local high schools computers.