Submitted to the 13th meeting of the Megascience Forum

OECD MEGASCIENCE FORUM

Report of the

NEUTRON SOURCES WORKING GROUP

The Neutron Sources Working Group of the OECD's Megascience Forum has proposed a three-tier global strategy for the evolution of neutron facilities for neutron-scattering research. It notes that neutron scattering plays, and will continue to play, a crucial role in an extraordinarily diverse range of basic, strategic and applied research; that there is to be a dramatic, and inevitable, decline in the number of facilities worldwide, which requires urgent government attention; and that considerable benefits can be gained through international co-operation in the provision and utilisation of neutron sources.

Accordingly, the Working Group has proposed the following strategy as a basis for its conclusions and recommendations:

- to maintain, as far as appropriate, existing national sources, noting their importance for maintaining local neutron-scattering infrastructure;
- to maximise the utilisation of current front-rank facilities, noting their potential for refurbishment and up-grading which can lead to substantial increases in performance and efficiency;
- to prepare for provision of next-generation regional sources, noting the long lead times involved and the necessity to ensure that governments are appropriately informed of future proposals.

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Introduction

1. The **Neutron Sources Working Group** was established by the Megascience Forum in January 1996 to consider the future evolution of facilities for neutron scattering research. It has the following aims:

   - to estimate the future level of neutron undersupply, giving consideration both to likely demand, and supply, over a 20-year timescale;

   - to establish what is required to meet the anticipated demands in terms of new and refurbished facilities and instrumentation;

   - to identify technical problems associated with the development or up-grading of new or existing neutron sources and to recommend, where appropriate, co-operative R&D activity to solve these problems.

2. The Working Group consists of some 35 national delegates, comprising both government officials and government-designated scientists, from the following countries:

Australia	Germany	Portugal
Austria	Hungary	Russia
Belgium	Italy	Sweden
Canada	Japan	Switzerland
Denmark	Korea	United Kingdom
France	Netherlands	United States

3. The Working Group has met on four occasions, in Lisbon (May 1996), Interlaken (October 1996), Toronto (August 1997) and Tokyo (April 1998). The Group established individual panels to investigate specific areas of its remit, concerned with (a) the refurbishment and up-grading of existing facilities, (b) international co-operation in the development of neutron instrumentation, and (c) opportunities for international co-operation in the development of new neutron sources. Consultants have been commissioned to conduct a survey of future prospects for neutron scattering facilities (see paragraph 13 below).

4. This report is concerned with facilities for **neutron scattering research,** and is largely concerned with dedicated high-flux reactor and accelerator-driven (spallation) sources. We recognise that this omits many areas for which neutron sources are of fundamental importance, including radiation damage studies, reactor experiments, neutron nuclear physics, isotope production, activation analysis and others. This omission should not be taken as a judgement on the merits of these fields, but as a response to the mandate of the Megascience Forum itself. In these fields, multipurpose reactors with large irradiation volumes and high neutron flux will continue to play a strong role for the foreseeable future.

Background

5. **Neutron scattering** is a widely-applied tool in condensed matter research, and many reports[(1) - (9)] have detailed the applications of the technique, along with the future opportunities offered with more powerful sources. The introduction to the European Spallation Source report[(4)] summarises the situation as follows:

"Much of what underpins our present-day quality of life depends upon our understanding, and consequent control, of the behaviour of materials. Ultimately, this behaviour is dictated by their structure and dynamics at the atomic and mesoscopic level and our knowledge of these comes from a wide range of sophisticated scientific techniques…. The neutron is, in many ways, the ideal probe for the investigation of condensed matter, having significant advantages over other forms of radiation in the study of microscopic structures and dynamics.

Neutron scattering has consequently made outstanding contributions to our detailed understanding at a microscopic level of technically important material such as plastics, proteins, polymers, fibres, liquid crystals, ceramics, hard magnets, and superconductors as well as to our understanding of fundamental phenomena such as phase transitions, quantum fluids and spontaneous ordering. The 1994 Nobel Prize in Physics to Brockhouse and Shull for their pioneering efforts in the 1950s was a public acknowledgement of the importance of neutron scattering to the scientific community."

6. The utility of neutron beams arises from the **physical properties of the neutron** itself, ranging from the ability sensitively to observe atomic or molecular magnetism, to the ability to observe the details of atomic and molecular motions in both space and time, to the ability to use atomic isotopic substitution to label particular regions of complex structures. Indeed the importance of neutron scattering as a research technique is emphasised by the breadth and depth of its application to problems in virtually all areas important to a technologically advanced society. But for many advanced applications, the utility of neutron scattering is limited by the intensity available at existing sources.

7. At the present time a world-wide **scientific community** of the order of 6000 scientists uses neutron scattering for research across a wide spectrum of scientific disciplines. This multidisciplinary character of neutron scattering research was recently documented in a survey[(6)] by the European Neutron Scattering Association which revealed the distribution of neutron users in Europe to be physics 46%, chemistry 27%, materials science 19%, biology 4%, engineering 3% and earth sciences 1%, with a tendency to broaden even further. Another aspect of the neutron scattering community is their prevailing youth. More than half are PhD students and postdoctorals, who in addition to carrying out frontline research are being educated in the international environment of the large neutron establishments thereby preparing them for the challenges of professional activity in an increasingly global scientific and industrial world.

8. A study[(3)] published by the European Science Foundation and the European Neutron Scattering Association in 1996 (usually referred to as the *Autrans Report*) provided a forward look at the likely development of the demand for neutron scattering. It convincingly demonstrated that research using neutrons can be expected to continue to grow both in traditional fields like solid state physics, materials science and physical chemistry, and also in new and rapidly developing areas for neutron research like biology, engineering and earth sciences. This will involve an increase in the

complexity and sophistication of the scientific work rather than a mere growth in the number of experiments. Entirely new and exciting results can be expected from development of novel measurement techniques and data analysis methods.

9. The Autrans Report concluded that non-neutron tools for matter investigation, such as synchrotron radiation, cannot substitute the future use of neutron beams.[10] Even in the long term, both neutron scattering and synchrotron radiation research will continue to be indispensable, because the two techniques cannot replace each other (nor be replaced by third methods); indeed they complement and extend each other's range and opportunities.

10. The importance of the results obtained using neutron scattering techniques lies not only in their significant - often crucial - contribution to the corpus of scientific knowledge, but equally to their impact on a remarkably wide diversity of technological and industrially important areas. Present and future examples that can be cited include biotechnology, drug design, pharmacology, materials processing, environmental technologies, catalysis, energy storage, new materials, energy transmission, transport, data storage, quantum devices, all covering crucially important aspects of modern civilisation.

11. There are currently about 25 major sources in the world which produce neutron beams for condensed matter research. Though the leading installations are in the large - "megascience" - category, neutron scattering experiments at these centres are typically carried out by small research teams based at universities, research institutes and industrial laboratories, and constitute the kind of research that is generally considered to be "small science". The majority of users require recurrent short-term access to the facilities, often for no more than a few days at a time. The research carried out at these sources contributes to the scientific and technological infrastructure in the regions, and indeed it is this endeavour, rather than the sources themselves, which underpins the industrial competitiveness in the region.

How can the demand for neutrons be met?

12. Most of today's neutron sources are based on **nuclear reactors**; additionally there are a number of **accelerator-based sources** which produce neutrons by the nuclear **spallation** process. Most of the reactor sources were built in the 1950s and 1960s, and will come to the end of their useful lives in the next ten years or so; in fact some time between the years 2010 and 2020 the presently-installed capacity of neutron sources for beam research will decrease to a level below one third of that today.

13. To provide an estimate of the extent of the "neutron gap" - the increasing divergence between neutron demand and neutron supply - the Megascience Forum has commissioned a detailed study by D Richter and T Springer *"A Twenty Years Forward Look at Neutron Scattering Facilities in the OECD Countries and Russia"*.[7] Their report quantifies the decline in existing sources indicated above, and provides a global overview of the planned sources and their impact.

14. Given the long lead time from the conceptual design to the commissioning of a new source - at least 10 years - political decisions on new facilities are necessary in the next few years, and certainly before 2005. Otherwise, vital areas of science and technology

will be deprived of an important and unique research tool. The Working Group has considered three scenarios to face the future demand:

a) No further investment in major new facilities. The inevitable result of such inaction would be the decrease in the number of sources to less than a third of the present worldwide inventory, in the face of increasing demands for higher intensity and higher quality neutron facilities. Refurbishments and upgrades of the best existing facilities could alleviate the situation in the short to medium term, but would not prevent an eventual widening gap between supply and demand. The Working Group believes this is an unacceptable option.

b) A second option might be to build a single, extremely high-power, source to serve worldwide needs at the highest possible intensities, while letting existing sources decline as in option (a). Given the diverse character of the user community and the effects of cross-disciplinary interactions, the societal and industrial impact of the scientific activities at the "super source" would be significantly higher in the host region than in other parts of the world. It could also lead to a situation where the use would be essentially limited to a small elite coterie of scientists. The Working Group does not support this option.

c) A third and preferred option is to adopt a strategy based on a regional provision of sources, where in each significant world region - Europe, North America, the Asia / Pacific area - there would be at least one major next-generation source. Such a strategy would provide access to quality facilities for the vast majority of scientists requiring neutrons for their research. It would support numerous research teams working in a variety of fields and providing a critical research infrastructure throughout the different regions of the world. We note that this strategy is consistent with present plans and proposals to provide new (accelerator-based) sources in Europe, the United States, and Japan, and is the way synchrotron radiation sources are distributed worldwide.

Next-generation sources

15. The next generation of neutron sources will create significant new scientific opportunities - it is not simply a case of compensating for sources that have shut down. Most of the projects under contemplation have incorporated special features that will enhance their performance and potential when compared with present day sources. This means that plans for projects often venture into undeveloped areas of technology which require R&D for proof of concepts, design, testing and validation, as well as prototyping.

The most important class of next-generation sources consists of the accelerator-based spallation facilities, whose increased power will lead to improvements in the quantity and quality of research, and enable expansion into new scientific areas. At present a number of specific projects are in the planning stage: in Europe the European Spallation Source, ESS, and an Austrian proposal, AUSTRON; in North America the Spallation Neutron Source, SNS; and in Japan the Japan Hadron Facility, JHF, and the Neutron Science Research Program, NSRP. However the earliest realistic date that any of these facilities could be operational would be after 2005, with the most significant scientific and technological impacts following a decade or more later. It is because of this long lead-time that plans to fill the intervening gap are crucial to satisfy the scientific need.

How to fill the gap

16. There is certain to be a critical period in the early years of the next century when a majority of today's existing sources have shut down, and before the next generation of new sources are fully in operation. The Working Group has given attention to the problem of filling this "neutron gap". It is believed that the situation can be alleviated by the completion of new facilities that are already under construction, and those that have already been approved, by the up-grading of existing front-rank sources, and by improvements in neutron scattering instrumentation. This strategy will reduce the impact of the neutron gap and at the same time provide the network of well-equipped intermediate sized sources needed to serve national communities as home base for the large class of experiments which do not need the highest flux, and for the development of new techniques.

17. In Europe, the Swiss Spallation Source, SINQ, started operation in 1996, and a new German reactor, FRM-II is under construction with a planned start date in 2001. In addition there are plans to increase the power of the UK's ISIS facility, which could be further augmented with the addition of a second target station. At the ILL and Orphée-LLB reactors, current instrument upgrades promise considerable gains in intensity and efficiency, and there is scope for the installation of new instruments, which will increase the user capacity. In North America there are approved projects under way to enhance substantially the capability of the LANSCE accelerator-based facility, and the HFIR and NIST reactors. There are plans to upgrade the HFBR reactor, and to construct a new research reactor, the IRF, in Canada. In Australia the HIFAR reactor is to be replaced by a research reactor of increased capacity by 2005. In Russia a new small spallation source IN-06 at the Moscow Meson Factory will start in 1998. There are plans to enhance the capability of the IBR-2 pulsed reactor and to complete a new research reactor PIK at St Petersburg. All these projects, coupled with continuing improvements in instrumentation, will provide a network of sources which is part of the scientific and technological infrastructure of the different OECD countries. They will allow a continuous exploitation of neutrons through the critical time of the neutron gap and serve as an integral part of the world's neutron infrastructure once the new next-generation sources are operational.

Scope for international co-operation

18. The necessary R&D to achieve the above aims is costly and often requires access to unique facilities. Sharing of tasks and costs and avoidance of duplication are clear benefits from co-operation. The Working Group is convinced of the value of international co-operation in the provision of new sources, in the up-grading of existing facilities, and in the development of new instrumentation. To this end, formal co-operation networks might be established for each topical area, each being open to participation by institutions that are active in the respective fields.

19. There will be a need to help the formation of such networks and to monitor their progress. It may also be appropriate from time to time to negotiate the incorporation of such networks into existing frameworks for international co-operation. In Europe, in particular, it will be useful to maintain a forum for consultation at governmental level to achieve a proper balance between national and regional priorities in decisions concerning neutron sources. The user communities represented by their regional

organisations should participate in this process. Both of these functions could be taken care of by the OECD Megascience Forum or a similar organ.

20. The proposed co-ordination of effort in the R&D stages would lead to considerable savings in both cost and time, and also offers the possibility of even greater gains in the construction phases. Adoption of standard solutions for all three regional sources would increase the market for global competitive bidding on a range of components, and co-ordinated purchases could enhance this effect. It has been estimated that this could reduce construction costs by at least 10% and R&D costs by as much as 40%. The Working Group has not looked in detail into this perspective, but it could serve as an inspiration for a future phase of the Group's activities.

21. Indicative costs for neutron facilities are as follows:

FACILITY	EXAMPLES	COST
Next-generation spallation sources	ESS, JHF,NSRP,SNS	$1 - 1.5 bn
New reactors, spallation sources	AUSTRON, FRM-II, HIFAR-II, IRF	$200 - 400M
Up-grades to existing sources	ISIS-II, LANSCE	$50 - 200M
Replacement instrument suites	ILL, NIST, etc	$10 - 50 M

23. Topics which require significant levels of R&D, and which could benefit from international collaborative activities, have already been identified in the following areas:
    - accelerator technology
    - spallation target technology
    - research reactor design
    - neutron scattering instrumentation

24. In this context, the Working Group has already initiated some preliminary studies, sponsoring two international collaborative activities. In September 1997 it supported a workshop on cold moderators for pulsed neutron sources, which has already led to the formation of an international task group. And it has supported the AGS Spallation Target Experiment at Brookhaven National Laboratory, which is providing fundamental data for the next generation of high-power spallation sources.

Summary: findings and recommendations

25. By the year 2020 more than two-thirds of the world's neutron sources for beam research will have been shut down. Given the long lead time from the conceptual design to the commissioning of a new source (at least 10 years), firm political action to avert the threatened shortage of neutrons is recommended. **Commitments on new facilities are necessary in the next few years, and certainly before the year 2005**. Otherwise, vital areas of science and technology will be deprived of a crucial and unique research tool.

26. The next generation of neutron sources will create significant new scientific and engineering opportunities as well as replace the capacity that will be lost by the shutdown of existing sources over the next twenty years. **The Neutron Sources Working Group recommends a scenario which aims at the construction of advanced neutron sources in each of the three regions Asia/Pacific rim, Europe and North America, to be operational within 20 years, and catering for regional needs in a wide range of scientific and technological applications.** This is consistent with the plans for next generation multi-megawatt spallation sources which are already at advanced stages of planning in Europe, Japan and the USA. The Working Group also recommends that the new advanced sources be supplemented by a network of new and/or upgraded existing sources as required to serve both regional and national science and technology needs. In each case, the justification for the operation of such sources should be on the basis of the excellent science and technology that is being supported, as well as other national goals as appropriate.

27. Steps should be taken to compensate for the potential "neutron gap" in the interim years early in the next century when a majority of today's sources have been shut down and before the new advanced sources are in operation. Although new facilities are currently entering service (SINQ), are under construction (FRM II), or are planned (HIFAR-II and IRF), **urgent attention must be given to refurbishing or up-grading front-line facilities such as ILL and ISIS in Europe, and HFBR, HFIR, LANSCE and NIST in the USA. Consideration should be given to achieving this aim on an international basis.** Coupled with continuing improvements in instrumentation, such projects would compensate in part for the projected decline in available neutron capabilities over the next two decades, and would be the foundation for the network of local sources needed to supplement the major new sources recommended above.

28. The development of the advanced sources as well as the up-grading of existing ones and the continued development of instrumentation requires R&D for proof of concepts, design, testing and validation as well as prototyping. **International collaboration and task-sharing is strongly recommended in order to achieve technical synergy and cost reductions.**

29. **Consideration should be given to the establishment of a global network - a follow-on body to the Neutron Sources Working Group, perhaps, but not necessarily, under the OECD umbrella - in order to achieve the aims of the Working Group.**

References

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5) *Proposal for Japan Hadron Facility*, JHF Project Office(May 1997)

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10) G Lander and H Curien, *Executive summary*, reference (3)