ESF Studies on Large Research Facilities in Europe

The Scientific-strategic Case for a Next-generation European Spallation Neutron Source for Science and Research (ESS Project)

Interim Report
2000

This report is jointly published by:

– the European Science Foundation
– the European Neutron Scattering Association
– the R&D Council of the ESS Project

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Contents

	Page
ESF Preface	5
ENSA Preface	7
ESS R&D Council Preface	9
ESF Open Questions and Issues	11
Response by the European Neutron Scattering Association (ENSA)	13
Response by the ESS R&D Council	35

Study report *(edited by John Finney, 1997)*

Foreword	53
1. Introduction	55
Neutron science	55
The need for a next generation neutron source	56
Neutron sources	56
ESS source specification	57
Times scales for the ESS	58
2. The scientific potential of the ESS	59
New opportunities cretated by the ESS	59
The scientitic impact of ESS in specific areas	61
Polymers and soft matter	62
Disordered materials	67
Structural materials chemistry	72
Chemical reactivity and molecular motions	74
Biology and biotechnology	78
Earth and environmental sciences	82
Engineering	84
Condensed matter and materials physics	88

Fundamental neutron physics 94
Exploitation of other particle sources at ESS 96
Muon spectroscopy for condensed matter science 96
Muon particle physics 98
Neutrino studies 98
Radioactive nuclear beams 99
Irradiation for fusion materials research and development 100
Isotope production 100
Complementarity of the ESS with other techniques 101
Societal needs and the ESS 107

3. Neutron instrumentation at the ESS 110

A reference instrument suite for the ESS 110
Experimental infrastructure and support facilities 114
R&D for neutron scattering instrumentation and techniques 115

Contributions to the development of the scientific case

(edited by Uschi Steingenberger, 1997)

Prologue 119

Themes

Soft solids and neutrons 121
Liquids, amorphous materials, ionic conductors 145
Solid state chemistry 175
Vibrational spectroscopy 201
Biology, biotechnology and biomedical applications 215
Neutron scattering in the earth and environmental sciences 229
Engineering 241
Condensed matter physics 259
Particle and nuclear physics 267
Scientific case for a muon facility at the ESS 279

Other scientific opportunities with the ESS

NESS: Neutrinos at the European Spallation Source 303
Radioactive nuclear beams at the ESS 313
A comment on the use of the ESS as an irradiation facility 317
Neutron applications for ISIS/ESS – isotope production 321

ESF Preface

As the need for science to access larger, more sophisticated research facilities and the costs of establishing and operating them both increase, European collaboration becomes even more essential – for Europe's scientific community as well as for the involved research funding agencies. By making optimum use of the continent's research facilities, we will not only be able to use our existing resources more effectively but also enhance our decision-making on future research investments. In line with its mission to strengthen fundamental science in Europe, the European Science Foundation (ESF) is mandated to promote cooperation and produce advice on the use of existing facilities and in the planning and provision of new facilities. Increasingly, ESF acts as a a multi-disciplinary 'scientific clearing house' in Europe for investigating and evaluating scientific-strategic issues of large research facilities (LRFs). ESF is able to provide scientific advice and assessment, and serves as an independent European forum to discuss LRF issues, bringing together both users (the science communities) and operators/owners of LRFs. This engagement and action by ESF was endorsed at the recent 'Strasbourg Conference on Research Infrastructures, September 2000' organised by the European Commission under the French presidency in collaboration with the ESF.

Before agreeing to coordinate the trans-national use or to share the large financial costs of existing or projected facilities, it is imperative that the users' scientific case is investigated and proven. Ensuring that there is a critical mass of challenging science and research problems and, even more importantly, a critical mass of committed researchers in Europe who are capable of moving science and research forward, these must be the *sine qua non* for any facility of excellence.

Within this framework, the ESF Standing Committees, in particular PESC (physical and engineering sciences), have studied and coordinated a series of science case studies on various types of research facilities/ infrastructures including research neutron sources for fine matter analysis which have been and still are eminent subjects for evaluation. In the studies on research neutron sources ESF-PESC has had a very fruitful collaboration with the users-based expert committee ENSA (European Neutron Scattering Association) which I very much appreciate.

In this context I welcome the joint publication of the present report of the 'updated science case 2000' of the 'ESS project' for a next-generation European spallation neutron source. While the results and opinions given in this document do not necessarily reflect, at this stage, the views of the ESF or its Member Organisations, the report should serve to broaden the basis for assessment and support at the national, European, and international level for the project of a next-generation European neutron source. This report is to be considered as one more contribution to a European approach to research infrastructure.

Professor Enric Banda
ESF Secretary General

ESF-PESC Preface

During the last five years, the ESF Standing Committee for Physical and Engineering Sciences (PESC), in liaison with its sister committee LESC (Life and Environmental Sciences), initiated and coordinated a series of 'European Neutron Source Studies (ENS Studies)', in order to investigate the scientific case for neutron sources for future research in Europe in the natural sciences, life sciences, and technical sciences. These studies were undertaken in fruitful collaboration with the users-driven expert committee ENSA (the European Neutron Scattering Association).

In 1996, a comprehensive ESF-ENSA Exploratory Workshop (Autrans, January 1996, chaired by Professors Gerard Lander and Hubert Curien) was held on the "Scientific Prospects for Neutron Scattering with Present and Future Sources" which resulted in the widely acknowledged ESF "Autrans-Report".[1] ESF-PESC also worked in liaison with the OECD Megascience/ Global Science Forum, which pursues related and complementary studies at the global and inter-governmental level. A result of such cooperation was the joint ESF-OECD Report 1998 with a scientific-strategic European and global outlook for research neutron sources over the next twenty years (elaborated by Professors Dieter Richter and Tasso Springer).[2] The exploitation of research neutron sources for science and research in Europe was the subject of further ESF-ENSA surveys and studies.[3] In a direct context, the ESF undertook a review of the Austrian project for a medium-scale regional neutron source (AUSTRON).[4]

As regards the ESS project for a next-generation 'European neutron spallation source', the ESF agreed, in response to requests from the ESS Council and ENSA, to support the investigation of the scientific case of this project through a series of exploratory scientific meetings (chaired by Professor John Finney). The ESF supported studies resulted in a substantial report on the science case of the ESS project.[5] Based on these studies and investigations the ESF-PESC Intercommittee Working Group on 'Science Needs for Research Neutron Sources' (chaired by Professor Norbert Kroó) began to evaluate the development of the scientific case of the ESS project (in the context also of large research neutron source projects coming up in the USA and Japan). In this regard the ESF-PESC Working Group considered that ESF should thoroughly investigate the scientific relevance and timeliness of such a project and, consequently, identified a series of eight 'open questions' on the ESS project. Both the ENSA and the ESS Council, after extensive consideration, answered these crucial questions.

These developments lead to the present joint publication of the 'Interim Report 2000' on the updated science case of the ESS project, containing a reprint of the 1997 report[5], ESF-PESC's 'Open Questions' on the ESS project, and the answers produced by ENSA and the ESS Council.

Professor Juan M Rojo
Chairman, ESF Standing Committee PESC

Dr. Hans U Karow
Head, ESF-PESC Unit

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[1] *Scientific prospects for neutron scattering with present and future sources* (The Autrans Report), October 1996

[2] *A twenty years forward look at neutron scattering facilities in the OECD countries and Russia*, November 1998

[3] *Survey of the neutron scattering community and facilities in Europe*, October 1998

[4] *Assessment of the Austrian feasibility studies AUSTRON and EURO-CRYST*, October 1997

[5] *ESS a next generation neutron source for Europe*, Vol. II The scientific case, March 1997. (Out of print)

A European perspective of neutron scattering science and technology

Neutron scattering plays a crucial infrastructural role in underpinning much of condensed matter science and technology within the disciplines of physics, materials science, chemistry, the life sciences, the earth sciences and engineering[i,x,xi*].

Consequently there is little doubt that Europe can legitimately claim a significant strategic advantage in these fields of research, not only because Europe boasts the world's premier neutron scattering sources but also because Europe hosts the largest, most experienced and broadest-based community of neutron beam users[iv*]. Indeed almost 5000 neutron scatterers, over two thirds of the world's total number, reside in Europe and exploit European neutron facilities.

It is therefore tempting to conclude that European neutron scattering science is currently enjoying a "golden age". From a short-term perspective such a view is well justified: the European neutron scattering community can be proud of its achievements, and confident in its world lead. However, a medium- to long-term perspective reveals that this lead is not unassailable.

On the one hand, Europe in particular faces the impending reality of the much discussed "neutron drought". The drought, originally forecast by the late Tormod Riste in a 1994 Analytical Report commissioned by the OECD Megascience Forum[ix*], is a consequence of the continuing expansion of a multidisciplinary neutron scattering community and the imminent closure of many ageing research reactors.

On the other hand, a very serious challenge to European scientific and technical supremacy in the field of neutron scattering has been mounted by the USA[viii*] and Japan, both of whom are well advanced with their own plans to alleviate their local "neutron droughts" through major financial, scientific and technological investments in third generation advanced neutron sources.

Despite a continuing programme of optimisation, development and increasing exploitation of existing second generation European neutron beam facilities, it is universally recognised that the longer term future of European neutron scattering, and the preservation of Europe's lead on the world stage, can be secured only through the provision of the world's most powerful third generation neutron source - *The European Spallation Source*.

Securing the future of neutron science and technology in Europe through the European Spallation Source Project

Over the last decade, the Scientific Case for the European Spallation Source (ESS) Project has been developed and refined with the widest support and collaboration of the multidisciplinary European neutron scattering community[ii*].

The Scientific Case for the ESS, with an accompanying detailed Technical Feasibility Study, was compiled and published in May 1997. The resulting

* See references p.30

documents were widely circulated amongst the condensed matter science community. They were also presented to national and international funding agencies and committees, as well as research advisory bodies including the European Science Foundation.

Despite strong and vociferous support from the scientific community, and despite the support and close collaboration of the ESF in the preparation and evaluation of the Scientific Case, there has been relatively little progress in moving the ESS project forward.

In the meantime the global neutron scattering scene has undergone considerable changes (such as the funding of the Spallation Neutron Source Project in the United States and the imminent approval of the Japanese Joint Monbusho-JAERI project) which have brought a new and particular urgency to the resolution and conclusion of the ESS debate.

The ENSA response to the ESF Open Questions on ESS

As one component of the ESS debate the ESF/PESC Inter-Committee Working Group has identified a series of "*Open Questions*" regarding the Scientific Case for the ESS. The European Neutron Scattering Association (ENSA) as the representative body of almost 5000 neutron scattering scientists from eighteen European nations has welcomed the opportunity to address these specific questions.
The answers provided by the ENSA Committee are presented in this document (*see p. 13*).

Professor Bob Cywinski
Chairman of ENSA
University of Leeds, UK

ESS R&D Council Preface

There is no doubt that Europe led and still leads the world in research with neutrons. That is in no small measure due to the fact that the present two best facilities are located in Europe: the ILL in Grenoble, and the ISIS facility at RAL near Oxford. They and the many smaller facilities, as well as the sophisticated wide range of instruments developed for them, are the basis for the 4000 users in Europe and at the same time for advanced technical capabilities which are of a much wider importance.

Europe moreover was very timely in recognising that we should start thinking about the next generations of neutron sources: the origins of the ESS project go back to the early nineties. In the meantime the urgency has been demonstrated convincingly. In a report made for the OECD Megascience Forum, in conjunction with the ESF, the shortfall of available neutrons that will build-up from now to 2015 turns out to be dramatic if we do not embark globally on new facilities. As a consequence a three-pronged strategy was developed: build new instruments and also otherwise refurbish some of the smaller and older facilities, extend the degree of utilisation of the current top facilities by new instruments by extending operating time and so on, and then thirdly by constructing in each of the three regions of the world (Europe, AsiaPacific and North America) a third generation source of the spallation type.

The ESS technical study report and the science case from 1997 formed a very solid base for beginning to prepare decisions, actually solid enough to assist the Americans in moving ahead very quickly to groundbreaking in December 1999 for the SNS Project.

In Europe times were less propitious to obtain transnational agreements on large facilities.

But recent decisions and proposals might point to a better climate.

The interaction between the European Science Foundation on the one hand, and on the other hand ESS and the European neutron users in ENSA (the European Neutron Scattering Association) leading to the present clarification of the science case – which incidentally is one instance of the closer links between ESF and ESS – marks the first of three major steps set by the ESS Council to accelerate developments.

In order to best serve the users we have increased the stakes. ESS should aim to be by far the best facility for all sorts of neutron instruments, which means that we must not only try to build into the design some very promising recent technological options for the accelerator and the target, but also show once more that Europe has a tradition to uphold in applying innovative instrument strategies. To ensure that this will be elaborated in close interaction with the users we have created a Science Advisory Council, chaired by Professor Dieter Richter. Since ESS will be a science driven project, we aim for continuous inputs from established and not-yet-so-established users in finalising the design of the ESS.

It was decided to initiate, together with the Commissariat à l'Energie Atomique in France, a feasibility study into a high power proton accelerator as a driver for many applications simultaneously: research with neutrons, nuclear research with radioactive beams, a neutrino and muon factory, transmutation of radio-active waste and other accelerator driven systems, and irradiation damage. We have invited all the relevant communities in Europe to co-operate so as to make this really a pan-European effort which should tell us if such a multipurpose option is technically and organisationally feasible and more cost-effective than stand-alone options. Dr. Jean-Louis Laclare from CEA is now setting up the team. We expect the results to be available two years from now.

We have strengthened the ESS organisation, appointed Professor Kurt Clausen as project director, and we have redefined the schedule for ESS; it has now three milestones.

Until 1 June 2001 we will carry out all research and other work to fix the reference parameters for the neutrons it is going to produce. In particular the technical study needs to be updated, and some exciting new technical possibilities that would improve considerably the ESS performance will be investigated.

The date of 1 June 2002 will then mark the completion of the multipurpose study after which a decision will be taken to go that way, or if this turns out not to be feasible or practical, to go back to the stand-alone version.

By 1 June 2003 the ESS Council will provide the governments and the funding agencies with a final proposal that is sufficiently detailed to start the process of decision making. That proposal will of course include the considerations on the so-called neutron road map where several scenarios for the existing facilities in Europe will be developed.

The ESS website and a regular news bulletin will keep readers up-to-date.

Peter Tindemans
Chairman ESS R&D Council

Joergen Kjems
Past Chairman ESS R&D Council

Assessment of the Scientific-strategic Case for a

European Spallation Neutron Source

(ESS Project)

Open Questions

Under the *'European Neutron Source Studies ('ENS Studies')'* coordinated by the PESC Inter-Committee Working Group of the ESF-PESC Standing Committee, the pending task is to review and assess, from today's best knowledge and understanding, the scientific-strategic case for a next-generation European neutron facility for science and research (ESS project). Solving this task should complete the current phase of the 'ENS Studies' of ESF/PESC.

For this review and assessment, a substantial reference basis has been achieved in the last three years through ESF/PESC-supported action, comprising:

(i) the ESF Report of the ESF-ENSA Exploratory Workshop on '*Impact and prospects of neutron methods and neutron sources for European science and research*', Autrans, January 1996;
(ii) the 1997 ESS Report/Volume II with the proceedings of the ESF-supported panels on the scientific case of the 'European Neutron Spallation Source (ESS project)', Firenze, May 1996;
(iii) the 1997 ESF Assessment Report on the AUSTRON facility project, and in response the 1998 revision of the AUSTRON project by the Austrian parties;
(iv) the 1998 ESF-ENSA Technical Report *'Survey of existing neutron facilities and users communities'*;
(v) the 1998 ESF-OECD Technical Report with a European and global forward look on future neutron facilities for science and research;
(vi) in a wider context: the 1998 ESF Review on European needs for synchrotron facilities and beam-lines for bio-medical research.

Beyond the above references also other sources need to be taken into consideration, such as

(vii) the 1998 Report of the OECD Megascience Forum WG on neutron facilities;
(viii) the 1998 Report on the US spallation neutron source project (SNS).

For its review and assessment, the ESF-PESC Inter-committee Working Group identified a series of open *'Questions and Issues'* answers to which are essential for determining the validity of the ESS case.

Questions and Issues

Question 1:

Considering reference (ii) as the current main document for the ESS science case: **Which are – in general - the most important new facts and arguments for the ESS case arising from the recently elaborated reference basis (iii)-(viii), including new developments such as the up-coming/projected facilities, FRM2 and AUSTRON ?**

Question 2:

"To maintain Europe's lead" is one strong & general statement used for arguing the ESS case. But: **What does 'maintaining Europe's lead' mean concretely ?**

Was the European lead of the past mainly a lead in neutron facilities of excellence, or did this lead in facilities establish a European lead in structural and dynamic matter & materials research ? Can this be exemplified ?

What would have been the draw-backs for European research if these leading facilities would not have been in operation in Europe ?

On the other hand: What in fact have been the draw-backs for science and research in the US or Japan through the non-availability of neutron facilities of excellence in their regions ?

Question 3:

"Averting a neutron drought in Europe in the next decades" is another strong & general argument for the up-grading of existing neutron facilities, and for the construction of new and advanced neutron sources, culminating in the ESS project.

3.1 What is the projected positioning and role of the ESS as the largest neutron source in the European network ?

3.2 What will be the unique positioning and role of the ESS for European (and global) science and research as the highest-brilliance pulsed source ?

These questions are needing conclusive answers based on

- today's scenarios/schedules/strategies for optimised operation/up-grading of existing neutron sources in Europe, including the evolution of advanced instrumentation;
- today's up-coming new neutron sources or facility projects (SINQ, ISIS2, FRM2, AUSTRON, ESS), including their concepts for instrumentation/data acquisition.

Finally, answers are needed in the (semi-)quantitative format of ref. (v), resulting in up-dated input on ESS in Tab. 4, Tab. 6 and Fig. 3. For comparison, ESF-PESC is inviting also the AUSTRON project team for their answers, resulting in up-dated input in Tab. 4, 6, and Fig. 3 on the AUSTRON project. (Respective answers for FRM2 and ISIS2 would also be relevant.)

Question 4:

"ESS will serve outstanding 'small science' R&TD in many fields of physical, life, and technical sciences" is another strong and general argument widely used.

But: what is the supporting evidence for that?

- extrapolated from the current use by the respective research communities of neutron sources and photon sources for structural and dynamic research ? and
- based on the concrete answers to question 3.2 ?

Question 5:

If the answers to question 4. do not project a substantial role of the ESS for life sciences R&TD: **Can ESS's 1 billion Euro-case be credibly argued and defended with the use of ESS solely for physical and technical sciences research ?**
Answers and rationales should take into account the competitive environment in which life science communities (and others) strongly demand the upgrading or construction of complementary photon facilities of excellence (advanced synchrotron radiation sources, X-ray free-electron lasers).

Question 6:

In terms of "value for money": **What are the approximate costs**, based in a comparable manner on facility operation costs/investment costs, of **"typical experiments"** at advanced neutron sources in Europe and envisaged at the ESS, **in comparison to the costs of "complementary experiments"** at existing and projected photon sources ?

ESF-PESC Inter-committee Working Group on 'European Science Needs for Neutron Sources'
N Kroó (chair), P Day, JL Joron, HU Karow (secretary), J Mlynek, FW Sluijter

March 1999

The scientific case for the European Spallation Source

– a response to the ESF Open Questions
by the European Neutron Scattering Association (ENSA)

ESF Question 1

Considering reference (ii) as the current main document for the ESS Science case: Which are – in general – the most important new facts and arguments for the ESS case arising from the recently elaborated reference basis (iii)-(viii), including new developments such as the upcoming/projected facilities, FRM-II and Austron?

ENSA's answer to Question 1

Since the publication of the Scientific Case for the ESS[ii] the USA has seized the initiative in condensed matter science from Europe by commencing construction of a third generation advanced Spallation Neutron Source[viii]. The Japanese are close to finalising the funding framework for a similar advanced neutron source project. Both sources will be operational many years ahead of the ESS, even if funding for ESS was made available immediately. Consequently there is no longer any doubt that we shall see the centre of gravity for cutting edge condensed matter science shift from Europe during the next decade. However, with the ESS project underway, as the hub of a European network of optimised national and regional neutron sources (of which FRM-II and Austron will be integral components), Europe will be in a position to reclaim its scientific lead. Indeed, the concept of a European network of neutron facilities is timely. Firstly it is ideally suited to fulfil the ideological, scientific and technical goals of the recently proposed European Research Area Initiative. Secondly the ESS development and design may well impact major science projects in other fields (such as accelerator driven transmutation of radioactive waste). Finally, a recent ENSA survey[iv] of the multidisciplinary European neutron scattering community has provided the very strongest scientific support for the ESS, together with an early indication of the major scientific opportunities presented by such a world leading source.

There are several new scientific, technological and political developments that impact directly the Case for Support for the European Spallation Source. These are:

(a) Commencement of the construction of the Spallation Neutron Source (SNS) in the United States[viii]

The discussion of the scientific, technological, economic and political case for an advanced next generation spallation neutron source in the United states has been concluded and $1.3b has been committed to the SNS project. The design and construction of the SNS has already commenced. There is therefore no longer any doubt that, in the absence of a European commitment to the ESS, the world lead in the strategic use of neutron scattering in condensed matter science and technology will return to the United States within approximately 6 to 8 years and reside there for the foreseeable future.

When SNS is complete and operating at 2 MW, it will offer unprecedented performance for neutron-scattering research, with more than an order of magnitude higher flux than any existing facility in several areas of applications. Moreover, at the new facility there will be the opportunity, the motivation and the resources to develop and construct a world-class suite of instruments that makes optimal use of the SNS beams and that is suited to the needs of users across a broad range of disciplines including chemistry, condensed matter physics, materials science and engineering, and biology.

> "*…ORNL will be the site for the most advanced accelerator based Spallation Neutron Source in the world. This new facility will help us reclaim America's position as the world leader in the technology we invented…..*"
>
> Vice President Al Gore, *21 January 1998 (Office of the Vice President)*

(b) The Japanese Joint Hadron Facility/Neutron Science Project

While the US is moving ahead with construction of the SNS Japan is also taking steps to substantially enhance its competitiveness in the strategic use of neutrons in condensed matter science and technology and alleviate its own neutron drought. Two major projects, the Japanese Hadron Facility (JHF) and the Neutron Science Project (NPS) have been united and are being promoted jointly by KEK and JAERI. Currently, a budget request for the entire plan is being prepared at both KEK and JAERI who are conducting intense negotiations regarding the funding of the joint project with the Government. Very positive signals have been received from both the Monbusho and STA agencies.

Hopes are for construction to start in the Japanese Financial Year 2000 (JFY00), but even if full funding is not approved until JFY01 it is believed start-up funding will be forthcoming in JFY00, in which case, the first neutrons will be available in JFY05 or 06.

While the JHF/NSP will operate at half the power of SNS, the facility will still surpass existing European facilities in many fields of application. It should also be noted that those advanced neutron instrumentation concepts, most of which have been developed at European facilities, can easily be implemented on new well funded sources such as SNS and JHF/NSP, thereby increasing considerably the effectiveness of these sources.

(c) The Neutron Science Park Scenario

The JHF/NSP concept is that of a multipurpose high power accelerator-based neutron facility that extends even beyond the broad remit of a multi-disciplinary condensed matter science facility involving nuclear physics, muon physics and transmutation and waste recycling.

It has been suggested in some quarters that the ESS project itself might not only fit into such a Neutron Science Park scenario but might also constitute an important first stage of the development of a multipurpose facility in which transmutation of radioactive waste and the development of accelerator driven energy amplification are realisable goals. Such a possibility is the subject of discussions between the ESS R&D Council and the CEA in France. It is yet too early to ascertain whether such a joint project in Europe is either feasible or even desirable. ENSA eagerly awaits the outcome of these discussions.

(d) Progress towards the European Research Area

In January 2000 the European Commission adopted a document paving the way towards a

> *"…Europe's investments in research are also failing to keep pace with our competitors in Asia and America….."*
>
> EC Research Commissioner Busquin *on the* Towards a European Research Area *initiative (January 2000)*

European Research Area, ie the creation of a frontier-free area for research where scientific resources are used to create jobs and increase Europe's competitiveness. Special attention is to be given to the networking of centres of excellence and developing a European approach to large research infrastructures.

The neutron facilities are large research infrastructures that have been operating precisely within the spirit and the philosophy of the European Research Area context for the last quarter of a century: Condensed matter scientists across Europe have had highly competitive but relatively unhindered access to the best neutron beam facilities in the world in order to underpin their respective strategic research programmes. Neutron scattering science has therefore developed into a truly multidisciplinary research activity and the large scale neutron facilities are Centres of Excellence, as defined by the Research Area Initiative, within which concepts, ideas and techniques develop and flow freely between physicists, chemists biologists and engineers and between academic research and industry.

It is envisaged that the ESS will be no less than a world leading Centre of Excellence in condensed matter science in which such liberal research philosophies will be nurtured. However, it is clear that Europe's investment in neutron scattering research is falling short of our principal competitors in America, and potentially Asia, with the inevitable consequence that Europe's competitiveness in condensed matter science and technology will be severely compromised.

It is therefore timely that the ESS is sited securely and centrally on the European Research Area landscape and placed firmly on the EC agenda.

> *" The European neutron scattering community is well aware of the scientific and technological opportunities afforded by the next generation neutron source. It is already planning novel and exciting experiments that will best utilise the characteristics of such a source ".*
>
> Conclusion 8 from the ENSA survey of the Neutron Scattering Community and Facilities in Europe
> *(Published by ESF, August 1998)*

(e) The views of the user community

It is crucial to emphasise most strongly that ENSA is not a lobby group for large-scale physics facilities. It is a broad based association that represents physicists, chemists, and materials scientists, biologists, earth scientists and engineers in almost equal number. Indeed ENSA speaks principally for almost 5000 European condensed matter scientists many of whom use neutrons as only one component of a wider research programme.

It is therefore important to note that the ENSA Survey of the Neutron Scattering Community and Facilities in Europe[iv] indicates extremely strong grass roots scientific support for the ESS. This survey was published jointly by ENSA and ESF in August 1998, ie after the Case for Support for the ESS had been published, and its findings can therefore be presented as new facts and arguments for the ESS case.

Not only does the ENSA survey confirm that scientific community believes there to be a desperate shortage of neutrons within Europe, that can only be alleviated by the ESS, but also that progress in condensed matter science is dependent upon the provision of the ESS, with experiments in real time kinetic studies, measurements on very small samples and detailed maps of material properties in complex parameter space being highlighted as research opportunities on a next generation source.

FRMII and AUSTRON in the context of ESS

FRMII and the AUSTRON[iii] project are, respectively national and national/ regional sources. The ENSA survey[iv] and the Richter-Springer Twenty Years Forward Look at Neutron Scattering Facilities in the OECD Countries and Russia[v] (also published by ESF in 1999) both emphasise the key role of such "local" neutron facilities, partly as a means of addressing and alleviating the problem of the impending neutron drought.

On the one hand FRMII, as a 20MW reactor, will be competitive in a some areas of science with the 58MW research reactor at ILL (although possibly not with a suitably refurbished ILL) whilst AUSTRON, as a fully instrumented pulsed neutron source will be able to compete with an ever developing ISIS and in some areas of science with the American SNS.

ENSA believes that the Case for Support for ESS is if anything strengthened by projects such as FRMII and AUSTRON: such projects will have optimised characteristics that, in specific areas of science, will certainly be internationally competitive. They will also provide a route through which those neutron experiments that are best suited for, or in most need of, the advanced features of ESS instrumentation can be tested and vetted, leading to optimal utilisation of ESS. Moreover they will provide an invaluable service as regional training grounds for young scientists who will then be best able to exploit fully the advanced features of the ESS.

ESF Question 2

"To maintain Europe's lead" is one strong and general statement used for arguing the ESS case. But: what does "maintaining Europe's lead" mean concretely?

Q2.1 Was the European lead of the past mainly a lead in neutron facilities of excellence, or did this lead in facilities establish a European lead in structural and dynamic matter and materials research? Can this be exemplified?

Q2.2 What would have been the draw-backs for European research if these leading facilities would not have been in operation in Europe?

Q2.3 On the other hand: what in fact have been the draw-backs for science and research in the US and Japan through the non-availability of neutron facilities of excellence in their regions?

ENSA's answer to Question 2

The very real European lead in neutron scattering science and technology, is openly acknowledged by US scientists and politicians alike. It has evolved via a symbiosis between Europe's world-leading neutron sources and an experienced and energetic multidisciplinary neutron scattering community, facilitated through advanced concepts of access to, and support for, a wide network of neutron facilities. Consequently advanced neutron instrumentation has been developed within Europe which in turn has contributed directly to Europe's strategic lead in many aspects of condensed matter science. Without this lead Europe today would not be the centre of gravity for cutting edge research in fields such as structural and dynamic polymeric science, pure and applied magnetism, wet colloidal science, novel materials and many other areas of scientific and technological importance. Over the last thirty years the US and Japan have correspondingly and progressively fallen behind, not just in neutron scattering, but also in these strategic areas of condensed matter science. Moreover, the lack of major facilities of excellence in these regions has severely hampered the growth of a large and broad-based expert user community comparable to that found in Europe.

2.1 The evolution and nature of the European lead

Neutron scattering began both in Europe and the United States as a parasitic activity at nuclear reactors designed for other purposes. Throughout the 1950s and 1960s only a few scientists, generally based at the facilities, were involved in neutron beam research. Indeed the award of the 1994 Nobel Prize in Physics to Shull and Brockhouse, for "showing where atoms are and what atoms do" respectively, was in recognition of the pioneering work of their research groups in this period and correspondingly reflected the lead held by the US in the same period.

Despite excellent and expanding neutron beam research programmes in Europe the US maintained this lead until the late 1960s when an entirely new philosophy developed in Europe. The isolation of the reactor based research groups and their selected colleagues from academia broke down and facilities across Europe began to open their doors to outside scientists. This open door policy led to a marked expansion, not only in the number of European scientists using neutron beam methods, but also in the range of applications to which neutrons were put.

The increasing demand for neutrons by a large, vigorous, imaginative and multidisciplinary condensed matter community in turn led to investment not only in new advanced neutron instrumentation but also new advanced neutron sources such as ILL and ISIS, which were considerably more intense, but also more sophisticated than their American counterparts.

In addition, a parallel philosophical and logistical development, that of the expert "local contact", opened the door yet wider to scientists of all disciplines, who, although not necessarily versed in neutron scattering techniques, could tackle important condensed matter problems of remarkable complexity thanks to the support of the local contact. Moreover, experimental proposals to the facilities could be made by experts and non-experts alike: It was upon the strength and importance of the *underlying scientific case* that experiments were awarded beam time.

By the mid 1970's Europe had thereby wrested the lead in neutron scattering science from the US, a lead which it has continued to strengthen right up to the present day.

Not only has Europe developed the most powerful and best optimised facilities (*ILL and ISIS*) and most advanced neutron instrumentation and techniques (*neutron spin echo, spherical neutron polarimetry, small angle scattering, highest resolution and highest intensity powder diffractometry, kinetic diffraction, single crystal chopper spectrometry, high resolution backscattering spectrometry, reflectometery, multidetectors, supermirrors, neutron guides, choppers and monochromators etc*) it has also developed the largest, most experienced and broadest-based community of condensed matter scientists.

These scientists, from both academia and industry, consider neutrons as a vital tool in their investigations of structures and dynamics in scientifically interesting and technologically important materials. Indeed neutrons provide them with a clear strategic advantage on the world stage. Correspondingly European scientists have made the greatest progress in our understanding of the microscopic properties of *polymers, proteins, plastics, zeolites, alloys, glasses, ionic conductors, liquid crystals, ceramics, surfactants, pharmaceuticals, quantum fluids, magnets, superconductors and even internal strain fields in key engineering components*, directly, and often solely, from the results of neutron scattering studies[i,x,xi].

The information provided by such neutron studies has been, and will continue to be, crucial to the development and optimisation of many of the structural and functional materials upon which our present and future technologies depend.

It is certainly unusual for a leading a American politician to openly admit that his own country falls short of a world lead in any field of endeavour. Vice President and Presidential nominee Al Gore has made precisely such an admission with respect to the European lead in neutron scattering science with the accompanying statement that it would be "irresponsible not to reclaim the world lead in this critical field".
So, the phrase "European lead" can be understood in terms of Europe's leading neutron sources, leading neutron instrumentation, leading neutron scattering community and concepts of access and support. Each of these translates directly into a strategic lead in condensed matter science, a lead that has played a key role in three European Nobel Prizes (for high temperature superconductivity, for polymer dynamics and for buckminsterfullerene) in the last decade alone.

> *" Although Oak Ridge National Laboratory was the site of the world's first experiments in neutron scattering, the world's leading neutron source is no longer in the United States; it is now in Europe. A new Spallation Neutron Source will change that. Given the medical, scientific, economic and environmental benefits available through neutron science it would be irresponsible not to reclaim world leadership in this critical field ."*
>
> Vice President Al Gore *announcing the first construction stage of SNS, January 21 1998 (Office of the Vice President)*

European advances in neutron instrumentation have in many cases been adopted by neutron facilities in the US. But it is the SNS, itself based in large part upon innovations introduced through technical consideration of the ESS, that will erode the European lead.

The increased intensity of the SNS coupled with the investment in advanced instrumentation will lead to science and technology of increasing complexity being performed not in Europe by European condensed matter scientists, but in the US by a neutron community that will soon benefit from the open door policy that is a direct emulation of that pioneered at European facilities.

2.2 The draw-backs for European research had there not been leading facilities operating in Europe.

The present strength of European neutron scattering is associated directly with the innovative condensed matter science it supports, and this science is itself the product of an energetic and experienced multidisciplinary scientific user base which has access to the best facilities and instrumentation in the world.

The symbiosis between the facilities and the user community is so complete that it is extremely unlikely that European neutron instrumentation would have developed to its current status without the community, and conversely the community would not have developed to its current strength and diversity without enlightened investment in the facilities.

Most importantly, however, Europe would not play such a pivotal role in structural science, structural and dynamic polymeric science, “wet” colloidal science, pure and applied magnetism, superconductivity, nanostructured and mesostructured materials, materials processing, dynamic (relaxational, diffusional and excitational) phenomena, and non-destructive strain field analysis in engineering materials had it not been for the neutron facilities and the associated user community[x,xi]. Correspondingly, the transfer of technology, ideas and skilled human resources from academia to industry and manufacturing in many aspects of condensed matter science would not have been possible.

2.3 The draw-backs for science and research in the US and Japan through the non-availability of neutron facilities of excellence in their regions

The growth of a large multidisciplinary user base, and the resultant strategic advantages, in condensed matter studies outside Europe has been severely stunted by the corresponding non-availability of leading neutron sources and instrumentation.

Approximately two thirds of the world’s neutron scatterers reside within Europe and use European facilities. This distribution is clearly evident in attendance at the major European Conferences on Neutron Scattering[x,xi] (organised by ENSA) and International Conferences on Neutron Scattering. The first two conferences in the ECNS series each attracted almost double the attendance of any of the previous International Conferences on Neutron Scattering held in the US and Japan. Although several of the world’s leading experts in neutron scattering science hail from the US and Japan it is not at all unusual to find these experts competing fiercely for beam time at European facilities, frequently in collaboration with members of the European user community.

Investment in neutron scattering science in both the US and Japan has been largely stimulated by the wide-ranging significance of the technique in condensed matter science and technology, as demonstrated by the European facilities and scientists, rather than by the demands of a large multidisciplinary user base.

Moreover there is a recognised danger that optimal utilisation of SNS and Japanese joint projects may well suffer in the short term from the lack of national experience in neutron scattering in general and neutron instrumentation in particular. It will almost certainly prove necessary in the first instance to “borrow” appropriate expertise from Europe.

ESF Question 3

“Averting a neutron drought in Europe” in the next decade is another strong and general argument for the upgrading of existing neutron facilities and for the construction of new and advanced neutron sources, culminating in the ESS project.

Q3.1 What is the projected positioning and role of the ESS as the largest neutron source in the European network?

Q3.2 What will be the unique positioning and role of the ESS for Europe (and global) science and research as the highest brilliance pulsed source?

These questions are needing conclusive answers based on:

- **today's scenarios/schedules/ strategies for optimised operation/up-grading of existing neutron sources in Europe, including evolution of advanced instrumentation;**
- **today's up and coming new neutron sources or facility projects (SINQ, ISIS2,FRMII, AUSTRON, ESS) including their concepts for instrumentation/data acquisition.**

ENSA's answer to Question 3

The ESS is proposed as the flagship neutron facility at the hub of a network of optimised regional neutron sources. It is through this network, which incorporates the new regional projects such as SINQ, ISIS2, FRMII and Austron alongside some of the existing neutron facilities, that Europe will avert its local neutron drought. In this context the ESS is a crucial prerequisite for Europe to meet the growing demand for neutrons. However, it should be noted that over the past fifty years cutting edge science has invariably emerged from the leading neutron sources. The unique positioning and role of the ESS both within Europe and globally is therefore a consequence not simply of the quantity of neutrons it produces but the quality of the source itself and the quality of the new and innovative science that it facilitates.

Furthermore, the network of regional sources is crucial to establishing and maintaining this quality, for it is at the regional sources that highly trained expert users and providers of neutron beams work together to continue developing the advanced neutron instrumentation and techniques that will form the basis of the ESS instrument suite.

3.1 The projected positioning and role of the ESS as the largest neutron source in the European network

The ENSA Survey of the European Neutron Scattering Community and Facilities[iv] clearly shows that the European user base today enjoys excellent infrastructural support based upon an extensive network of well instrumented national neutron sources and two major and complementary sources, ISIS and ILL, each an approximately an order of magnitude more intense than any other sources of their kind in the world.

However, this community is particularly vulnerable to the impending reality of the much discussed "neutron drought", forecast by the late Tormod Riste in a 1994 Analytical Report commissioned by the OECD Megascience Forum[ix]. The drought is a direct consequence of the continuing rapid expansion of a multidisciplinary neutron scattering community and the imminent closure of many ageing research reactors. Within 15 years, many of the existing national sources will have closed, and the infrastructural network will have diminished considerably. SINQ, and FRMII are likely to function as regional sources, as will Orphée (if CEA and CNRS can agree a long term funding mechanism), AUSTRON (if its is built) and PIK (if it is completed).

Of the current flagship facilities, the ILL reactor will be approaching the age at which a decision to replace it for a second time might be necessary, and an enhanced ISIS with a second target station (ISIS2) should be operational.

If the ESS project is approved for funding within the next year, it should reach design specifications within approximately 10 years, somewhat behind the SNS and possibly the JHF.

ESS will then be the world-leading flagship facility at the hub of a network of relatively new and considerably refurbished regional facilities. Such a scenario would adequately avert the neutron drought within Europe, effectively increasing the current figure of merit (developed for neutron facilities in the Richter-Springer OECD/ESF report[v]) of the European network by 80%, whilst also providing Europe with a world leading source which will pave the way for entirely new scientific opportunities.

Without a rapid decision to fund the ESS project the associated scientific and technical opportunities will not be realised, and the total figure of merit will be reduced by at least 30%. If, in addition, funding mechanisms are not established for AUSTRON, PIK, and Orphée the network of European neutron facilities will fall far short of satisfying the demand created by the increasing user base, the neutron drought will take hold.

3.2 The unique positioning and role of the ESS for Europe (and global) science and research as the highest brilliance pulsed source

Advanced neutron instrumentation, much of which has been developed at European sources, and based upon, for example, *neutron polarisation analysis; ultra-high energy resolution; ultra high energy transfers; ultra-high spatial resolution; finely collimated beams for tomographic studies; special environments at the extremes of temperature, pressure; and magnetic fields; and high intensity beams with high count rate multidetector technology for real time kinetic studies and for investigation of small samples*, is at the cutting edge of current neutron science.

On the one hand such instrumentation tantalisingly offers enormous potential for the exploration of new materials and key phenomena that are beyond the limits of present capabilities. On the other hand driving instrumentation to these limits also places over-stringent demands on currently available neutron beam flux.

Exciting developments in condensed matter science and technology have both prompted and followed the development of neutron instrumentation, which in turn has relied upon opportunities offered by increased intensity either of the neutron source itself, or by significant developments in the technology of beam line components such as guides, focussing monochromators, choppers, polarisers and detectors.

Correspondingly, innovative yet barely practical instrumentation developed at modest neutron sources can be successfully translated to intense neutron sources with an accompanying explosion of new and exciting science technology, as indeed was witnessed at ILL in the early 1970's and at ISIS in the 1980's.

Similarly the demands of the ensuing science can precipitate instrument development and re-evaluation of existing techniques. So, for example, recent science-driven instrument and technique innovation at ISIS, as part of the Millennium programme at ILL, and also at some medium flux sources, brings increases of between 2 and 10 in the efficiency of several existing instruments. Such developments, which are jointly driven by new ambitious scientific goals and advancing technology, will ultimately translate to the ESS, further enhancing the tremendous strategic gains already offered by this project. It is important to emphasise that the corresponding increases in useful neutron flux will pave the way not simply to more of the same science, but to entirely new and innovative science.

History has shown that cutting edge neutron science, by definition and out of necessity, is carried out at the most advanced neutron facilities. In this context it is important to note that although the ESS will provide uniquely intense neutron beams it is not only the *quantity of neutrons* per se but the *quality of the source itself and the science that it facilitates* that will secure a world leading role for the ESS.

In this respect it is illustrative to draw a direct analogy between the ESS and the flagship astronomical observatory, the orbiting Hubble Telescope:

It is the Hubble telescope, as part of a network of less powerful ground-based observatories, that is changing our perception of the "outer universe", enabling us to see deeper and with greater clarity than ever before, elucidating phenomena that were previously at the limits of detection and revealing new phenomena beyond those limits.

There is no doubt that a fully optimised ESS will similarly facilitate neutron scattering studies that will change our perception of the "inner universe", revealing new scientific phenomena and technological functionality through the deeper characterisation of the structural and dynamical properties of matter across all of the scientific the disciplines.

This will be the unique positioning and role of the ESS.

ESF Question 4

"The ESS will serve outstanding 'small science' R&TD in many fields of physical, life and technical sciences" is another strong and general argument widely used. But: What is the supporting evidence for that? – extrapolated from the current use by the respective communities of neutron sources and photon sources for structural and dynamic research and – based upon the concrete answers to 3.2?

ENSA's answer to Question 4

Clear evidence for the ubiquitous use of neutron scattering in "small" condensed matter science is provided directly by the ENSA survey of the European community. The same survey emphasises the community's strongest support for the ESS, not only *to alleviate the "neutron drought" but also to push forward neutron studies of condensed matter science well beyond the limitations of current instrumentation. Moreover, even since the publication of the ENSA survey, there has been a considerable growth in the use of neutron scattering by, for example, the engineering sciences, but also particularly in the study of soft and organic matter, (including biological and biotechnical materials) principally by physicists, material scientists and chemists. Such soft matter studies account for between 25% and 30% of all beam time requests. It is confidently predicted that with continuing advances in neutron technology and with the additional flux provided by the ESS there will be a marked increase in the number of life scientists exploiting neutron scattering to study biological and biotechnical materials. Indeed the life scientists themselves acknowledge that neutron scattering affords some important advantages over synchrotron radiation but that the use of neutrons in biology has been severely restricted by lack of available beam time.*

The ENSA Survey of the European Neutron Scattering Community[iv] provides conclusive evidence that condensed matter scientists of all disciplines use neutron scattering as a vital part of their research programme. The statistical breakdown of the user community amongst the principal disciplines at the time of the Survey was

Physics	46%
Chemistry	27%
Materials science	19%
Life sciences	4%
Engineering	3%
Earth science	1%

Condensed matter science, by its very nature, is "small science". However, the ENSA survey further shows that condensed matter scientists readily turn to large scale neutron facilities, when the particular properties of the neutron (its deep penetration, its sensitivity to neighbouring elements, light elements and isotopic substitution, its magnetic moment and most importantly its unique kinematics that allow simultaneous determination of structural and dynamic properties of a sample) are vital for the solution of a particular problem.

Since publication of the ENSA report there has been a notable expansion of neutron applications in the engineering sciences (particularly in-situ tomographic studies, strain scanning etc in support of the aerospace industry) principally as a consequence of substantial investment in dedicated instrumentation at ISIS, ILL and elsewhere. This area is seen as one of considerable growth and of increasing industrial importance.

Similarly the advent of even higher resolution and higher count-rate diffractometers facilitating the structural characterisation of complex multiphase minerals, soils and clays is expected to lead to a growth in the use of neutrons by the earth scientists, via a transfer of neutron technology from physics, chemistry and materials science.

" ...neutron scattering emerges as a widely applicable technique which underpins a broad and vibrant condensed matter base incorporating not only physicists

but also chemistry, materials science, life sciences, earth sciences and engineering. Moreover, the majority of European neutron scatterers use the technique as only one component of a much wider research programme."

Summary of the ENSA survey of the Neutron Scattering Community

(Published by ESF, August 1998)

However, by far the greatest area of growth in neutron scattering over the last decade has been in applications to the study of soft condensed matter (including biological and biotechnical materials). Such applications now account for between 25% and 30% of all beam time requests, principally from the areas of physics, chemistry and materials science.

A correspondingly marked increase in the direct application of neutrons in biology by the life scientists themselves is confidently predicted. This will result in part from the enormous current investment in the life sciences associated with development of technological functionality of organic, biological, biomimetic and biocompatible materials.

Such materials will demand the same rigorous structural and dynamic characterisations that are required for the technological development of inorganic materials today.

In this context it should be noted that neutrons offer considerable advantages over X-rays in the study of such biological systems. For example, the unique ability of neutrons to "see" protons and hence water in samples of biological origin[vi] provides the opportunity for crystallographic studies of biological structures through which functionality/structure relationships can be studied in solution, in dilution and in-vivo. Moreover, although there is great demand from the life science community for new and brighter X-ray sources, this community will not benefit proportionally from the enhanced intensities anticipated for the fourth generation synchrotron sources. The intense radiation from such sources will instantly destroy samples of biological origin. Neutrons, on the other hand, interact only weakly with matter, and no damage to delicate samples will result from intensity increases of even three orders of magnitude over those available at present.

" Neutron diffraction plays a small but important part in structural biology, notably because of its ability to detect hydrogen and distinguish between its isotopes H and D."

ESF Study Report: Review of the needs for European synchrotron and related beam-lines for biological and biomedical research

(Published by ESF, November 1998)

" The neutron approach is unique in providing simultaneously the energy transfers involved and the amplitude of the motions. Neutron studies in general provide information that cannot be obtained by other methods and are strongly complementary to X-ray, electron microscopy and NMR. The use of neutrons in biology,

however has been severely restricted by the lack of beam time due to the shut-down of reactors and the strong demand on the few existing instruments that have the necessary instrumentation."

ESF Study Report: Review of the needs for European synchrotron and related beam-lines for biological and biomedical research, 1998

Recent developments in neutron diffraction instrumentation (notably LADI at ILL, which uses image plate technology developed in direct collaboration with biologists), has shown the remarkable potential for rapid data collection from small single crystal samples of biological origin. When scaled by the increase in intensity afforded by the ESS, such techniques become both competitive and routine.

Similar increases in intensity will also facilitate studies of the *dynamics* of biological structures associated directly with biological functionality (eg in proteins, membranes and enzymes) opening the door to direct interrogation of life processes using high intensity adaptations of the neutron techniques (eg spin echo) used currently to probe polymeric dynamics.

It should be noted that only a decade ago there was less demand for synchrotron beam time by the life sciences than there is for neutron beam time today. However, advances in synchrotron technology have been accompanied by a growth to the present demand by the life sciences to 25-30% of synchrotron beam time. Within the next decade, and assuming the current progress in advanced neutron beam instrumentation for the life sciences coupled with the rapid launch of the ESS project, it is thus highly probable that a similar growth in the demand for neutron beam time by the life sciences will ensue.

ESF Question **5**

If the answers to question 4 do not project a substantial role of the ESS for life sciences R&TD: Can ESS's 1 billion Euro-case be credibly argued and defended with the ESS solely for the physical &technical sciences research. Answers and rationales should take into account the competitive environment in which life science communities (and others) strongly demand the upgrading or construction of complementary photon facilities of excellence (advanced synchrotron radiation source, X-ray free-electron lasers).

ENSA's answer to Question 5

The physical and technical sciences are fundamental to our technological society, and will probably remain so for many centuries, despite the tremendous progress that is being made in the life sciences. Whilst a substantial role for the ESS in the life sciences is confidently predicted, the rapidly increasing demands placed by society on physical and technical science research are sufficient justification for the ESS.

As emphasised in the answer to Question 4 above ENSA is able to project a substantial role for the ESS in the field of the life sciences. Even if this were not the case, our answer to Question 4 would be a resounding "YES"!

Condensed matter science provides the scientific basis for our high technology society. The continually increasing demands placed by society on material functionality in all fields from civil engineering, through mechanical engineering, electrical and electronic engineering, information technology to chemical engineering will ensure a central strategic role for neutron scattering.

It should also be emphasised most strongly that condensed matter science in general and neutron scattering in particular has presented significant intellectual challenges for theoretical physics and chemistry. The development of many body theories of superconductivity, superfluidity, quantum phenomena, magnetism, the microscopic understanding of phase transitions, the nature of the glass transition and relaxational dynamics in strongly interacting systems such as polymers and spin glasses are in many cases a direct consequence of neutron scattering studies[i].

The theoretical methods stimulated by these studies, have found applications in fields as diverse as particle physics, nuclear physics and biology, and the impact of the knowledge gained and the methods used to obtain it continue to have a far reaching impact in many other areas of science and technology. This substantial intellectual core provided by condensed matter science studies at neutron sources is itself sufficient justification for an ESS devoted solely to physical and technical science research.

While it is true that the life science communities are at present vociferously demanding new and brighter synchrotron sources, it must be recognised that in an historical context, the life sciences have generally adopted advances in instrumentation technology retrospectively: x-ray scattering, electron microscopy, NMR, ESR, optical spectroscopy and synchrotron techniques, were developed neither by nor for the life sciences, but were enthusiastically adopted by life scientists once the respective techniques had reached a stage of suitable sensitivity.

Neutron scattering is currently on the threshold of such sensitivity.

The ESS will push neutron scattering science well beyond that threshold.

ESF Question 6

In terms of "value for money": What are the approximate costs, based in a comparable manner on facility operation cost/ investment costs of "typical experiments" at advanced neutron sources in Europe and envisaged at the ESS in comparison to the costs of "complementary experiments" at existing and projected photon sources.

ENSA's answer to Question 6

The cost factor for neutron research averaged over the European facilities is approximately 1MEuro per 30 scientific publications. A similar *figure is anticipated for the ESS. In comparison the OECD have reported an average over the G7 countries of only 6 scientific papers per 1MEuro spent on civil research, indicating that neutron scattering, and comparably priced synchrotron research, are significantly more cost effective than most other research techniques. Moreover, inspection of the most prestigious scientific journals suggests neutron publications, in physics at least, have a well-above average impact factor.*

There is a general and widely held misconception that neutron scattering is an intrinsically expensive technique. While it is true that the construction and operation of an international neutron facility requires substantial funds, these funds are not excessive when considered against scientific output.

A reasonable estimate of neutron beam costs, obtained by averaging over the European facilities, is 8kEuro per day of beam time per instrument. Typically 3 to 4 days of neutron beam time will produce at least one scientific paper, which can therefore be costed at approximately 30kEuro.

However a recent OECD report containing the proceedings of an OECD workshop on the Evaluation of Basic Research (Paris, 1997)[xii] of the scientific output of government funded civil research in the G7 countries, expressed in terms of research papers per 1MEuro of government spending, places the UK ahead of the field with an index of 11, Germany and France with 3.5 and Italy with 2.5.

Correspondingly, the index for neutron scattering publications, ignoring the salary costs of the experimentalist, is approximately 30. Relatively, the cost-effectiveness of neutron scattering research is substantially greater than the index of 6 obtained by averaging over the G7 countries for all civil research programmes.

Closely similar figures are obtained for photon experiments at synchrotron sources and it is anticipated that similar cost effectiveness will be achieved by the ESS and projected photon sources.

Although "cost effectiveness" is an important criterion for establishing the merit of a research project it is certainly not the only criterion. In the particular case of large scale infrastructural facilities, the strategic role of the facility must also be evaluated. This is a notoriously difficult criterion to quantify.

However, in the case of neutron beam and synchrotron light sources it cannot be emphasised sufficiently strongly that each facility provides a strategic underpinning of science and technology across a wide range of disciplines, often in fields which are of direct technological relevance, and for which beneficiaries can be readily identified. This is to be contrasted with large scale nuclear and particle physics facilities which serve an intellectually significant but much smaller and narrower community which is well removed from the demands of wealth creation and quality of life issues.

Finally, as a concrete illustration both of the cost effectiveness of neutron scattering and its intellectual impact, it is worth noting that over the last ten years an amazing 7% of all articles in arguably the most prestigious and wide-ranging physics journal, Physical Review Letters, stem from neutron science. Within the discipline of physics it is therefore clear that the relatively small international community of some 4000 *physicists* world wide that actively employ neutron scattering techniques have made a vastly disproportionate contribution to scientific progress at the highest possible level.

Other disciplines lack the extremely focussed high profile publishing route offered by Physical Review Letters, but it is likely that a detailed survey of neutron scattering publications across these disciplines would reveal a similar disproportionate contribution by neutron scatterers.

Bibliography

The ESF questions incorporated references to the following reports, publications and policy statements:

i. Autrans Report *Impact and Prospects of Neutron Methods and Neutron Sources for European Science and Research* ESF Publication, 1996

ii. *ESS Volume II*, 1997

iii. *ESF Assessment Report of the Austron Project and the Revison of the Austron Case*, 1997

iv. ENSA-ESF Technical Report *Survey of the Neutron Scattering Community and Facilities in Europe*, 1998

v. ESF-OECD Technical Report *A twenty years forward look at neutron scattering facilities in OECD countries and Russia* (Richter-Springer), 1998

vi. ESF Study Report *Review of the needs for European synchrotron and related beam-lines for biological and biomedical research*, 1998

vii. *OECD Megascience Forum working group on neutron facilities*, 1998

viii. Report on the *US SNS Project*, 1998

In addition the ENSA answers to the ESF questions and the associated appendices have made use of the following publications:

ix. T. Riste, *Neutron Beam Sources in OECD Countries*, Neutron News, (1995), 6, 3

x. *Proceedings of the First European Conference on Neutron Scattering, ECNS'96*, Physica B Condensed Matter (1997); volumes 234-236.

xi. *Proceedings of the Second European Conference on Neutron Scattering, ECNS'99*, Physica B Condensed Matter (2000) volumes 276-278

xii. OECD *The evaluation of scientific research –selected experiences (OCDE/GD 97-194), 1997*

Introduction

Delegates from the neutron scattering communities and societies of several European nations first met in Grenoble in September 1994 to propose the foundation of a European Neutron Scattering Association, ENSA. From the start it was clear that ENSA had a vital role to play in providing a platform for discussion and a focus for action in neutron scattering science and technology in Europe and, at the inaugural ENSA meeting in December 1994 in Madrid, the delegates identified several specific aims which are now enshrined in the ENSA Articles of Association. Specifically ENSA seeks to:

- identify the needs of the neutron scattering community in Europe;
- optimise the use of present European neutron sources;
- support long-term planning of future European neutron sources;
- assist with the co-ordination of the development and construction of instruments for neutron scattering;
- stimulate and promote neutron scattering activities and training in Europe, and in particular to support the opportunities for young scientists;
- promote channels of communications with industry;
- disseminate to the wider community information which demonstrates the powerful capabilities of neutron scattering techniques and other neutron methods;
- assist, if appropriate, national affiliated bodies in the pursuit of their own goals.

ENSA today

Each of these aims is actively pursued with dedication and vigour by ENSA, which has now grown into a thriving affiliation of seventeen national neutron scattering societies and organisations that directly represent neutron beam users. Delegates from Austria, Belgium, the Czech Republic and Slovakia, Denmark, France, Germany, Greece, Hungary, Italy, the Netherlands, Norway, Poland, Portugal, Russia, Spain, Sweden, Switzerland and the United Kingdom, meet together twice yearly. Recently Romania has also sought membership of ENSA. Representatives of the major European neutron facilities and projects, the Neutron Round Table and the European Science Foundation all attend ENSA meetings with the status of observers and, correspondingly, the Chairman of ENSA has a seat at the Neutron Round Table and on the European Spallation Source (ESS) Research and Development Council.

ENSA activities

Over the last five years ENSA has succeeded in establishing an entirely unique forum in which neutron beam users and providers can meet together to co-ordinate research and development programmes and optimise and promote neutron beam utilisation at facilities across Europe. Indeed, ENSA initiatives in the development of neutron instrumentation and the creation of a neutron software database, are ongoing activities, carried out in collaboration with the neutron sources and the Round Table, and are well documented on the ENSA web pages (*http://www1.psi.ch/www_ensa_hn/welcome_ensa.html*)

Throughout its existence ENSA has also worked in close collaboration with the European Science Foundation. As part of this collaboration ENSA organised the "ESF Workshop on Scientific Prospects of Neutron Scattering with Today's and Future Neutron Sources", held at Autrans, near Grenoble, in January 1996[i] and more recently conducted a comprehensive

"Survey of the Neutron Scattering Community and Facilities in Europe"[iv]. Both activities have resulted in extremely informative and widely quoted ESF publications which not only place European neutron scattering in perspective but also provide a framework upon which future strategic decisions can be based. Both reports can be downloaded in full directly from either the ESF or ENSA websites.

The ENSA survey of the neutron community has, in particular, provided a remarkable and self-consistent insight into the nature and extent of neutron science within Europe. The survey dispels once and for all the widely held myth that neutron scattering is a specialist technique employed principally by physicists. Instead it emerges as a widely applicable tool exploited by a broad and vibrant condensed matter community Moreover, whilst the survey highlights the vital role of the pre-eminent high flux neutron sources, ILL and ISIS it also provides a clear indication that the future health of neutron scattering science within Europe is intimately linked to the development and construction of a major third generation high flux facility, such as the ESS, and that such a project must be considered as a matter of great urgency.

Perhaps the best-known ENSA activity has been the inauguration and organisation of the innovative European Conferences on Neutron Scattering[x,xi]. The first ECNS conference, held in Interlaken in 1996 in co-operation with the Paul Scherrer Institute (Villigen), proved to be the largest neutron scattering conference ever held with almost 700 delegates from 40 countries presenting over 650 published papers[x]. The second conference in the series (ECNS'99) held in Budapest in co-operation with the Budapest Neutron Centre, was equally successful[xi]. There is every reason to believe that ECNS'03 in Montpelier will continue the tradition.

ENSA and young scientists

ENSA has an extremely strong commitment to nurturing and promoting the younger members of the European neutron scattering community. Consequently an emerging hallmark of the ECNS conference series is the high profile afforded to young scientists. Both ECNS'96 and ECNS'99 were preceded by a Training Course, in each case attended by well over a hundred young scientists, many of whom received generous bursaries. At each meeting ten ENSA Young Scientist Awards were presented for outstanding scientific contributions. Also, as part of a new initiative to secure the active involvement of young scientists in the future development of neutron scattering science, techniques and facilities within Europe, ENSA convened, prior to ECNS'99, four Young Scientist Panels. The Panels, with a combined membership of 31 young experts from 14 European countries elected from over a hundred nominations, have considered issues as wide-ranging as neutron sources, instrumentation, sample environment and data analysis software, all viewed from a largely new perspective[xi]. It is hoped and intended that the Young Scientists Panels will continue to operate in conjunction with ENSA well beyond ECNS'99.

The Walter Hälg Prize

It is also important that the community should celebrate and publicise the tremendous achievements of the more experienced neutron scientists. In this context ENSA has established the extremely prestigious Walter Hälg Prize for European Neutron Scattering, with the help from a generous donation by Professor Hälg, the founder of neutron scattering in Switzerland. The prize of 10,000 CHF is awarded biannually to a European scientist for "outstanding, coherent work in neutron scattering with long-term impact on scientific and/or technical neutron scattering applications". A particular highlight of ECNS'99 in Budapest was the ceremony and plenary associated with the presentation of the first ENSA Hälg Prize[xi]. Ferenc Mezei (*HMI Berlin*) was the very worthy recipient of this prestigious award and it was quite fitting that he should receive it in the very city where he began his pioneering work on the neutron spin echo technique. The second ENSA Hälg Prize is to be awarded at ICNS'2001 in Munich.

ENSA and the future of European neutron scattering

It is clear that the work of ENSA has only just begun. From the perspective of ENSA the future of European neutron scattering science and research infrastructure is both exciting and challenging. The excitement stems from the wonderful opportunities that are provided by the continuing optimisation of existing neutron sources alongside the developing scientific and technical case for the European Spallation Source which promises a strategic facility that will keep Europe ahead of the field for at least the next half century. The challenge is to secure appropriate funding mechanisms to maintain our major facilities at the cutting edge of neutron science and to allow the ESS project to move rapidly ahead to realisation.

The scientific case for the European Spallation Source

– a response to the ESF Open Questions by the ESS R&D Council

The Scientific Case for the European Spallation Source (ESS) Project was developed by a wide cross-section of the condensed matter community in Europe, from universities, industry and national and international research facilities[1] . For practical reasons, ten scientific themes were selected, and the scientific case for each one explored by a team of leading scientists under the guidance of a Theme Co-ordinator. Similar teams were set up to examine the instrumentation that would be necessary to deliver the scientific programme. In May 1997 the result, the Scientific Case, together with the Technical Feasibility Study was presented to the scientific community, and to international and national funding committees, including the ESF.

[1] A list of the contributors to the Scientific Case is given in the Appendix (p.49)

From the start of the project, the ESF has supported the development of the ESS Scientific Case. The ESF/PESC Inter-Committee Working Group is now considering this report. The Committee has identified a series of "Open Questions' and has asked the ESS Council for clarification. The Council's response is given below.

ESF Question 1

Considering reference (ii) as the current main document for the ESS science case:
Which are – in general – the most important new facts and arguments for the ESS case arising from the recently elaborated reference basis (iii) – (viii), including new developments such as the upcoming/projected facilities, FRM2 and AUSTRON?

ESS R&D Council's answer to Question 1

The most important new fact is that in the US the discussion on a need for a next generation, spallation based neutron source has been concluded. The decision has been made to construct a 2 MW spallation neutron source, the SNS Project. The sum of $1.34 billion has been committed to the project and the design and construction has started. Likewise, in Japan the government has identified the need for a next generation pulsed neutron source and sees it as the top priority project for the new agency, resulting from the merger between STA and Monbusho.

In Europe and elsewhere there is a growing interest in the development of very high power accelerators to address important issues like the transmutation of radioactive waste and the possibility of accelerator driven energy amplification. The ESS project fits ideally into such an R&D programme. The construction of the ESS could be regarded as a major first step towards the realisation of these very high power accelerators. European and international collaboration on aspects of the R&D programme are already established.

The relevance and importance of neutron scattering techniques has not changed. All the arguments are clearly and extensively laid out in the reports listed in the reference list (*reference (i)* and *(ii)*). The ESS is still the most ambitious project and will lead to the world's most intense neutron source by a significant factor. With a neutron source of such a calibre, completely new scientific areas will be opened up. Examples of scientific advances include:

- Measurements under flow of polymer melts, with selective labelling of parts of molecules – a key technique in the developing science of structure / rheology relationships for polymer processing;
- Investigation of the size distribution mechanism in microemulsions;
- Unravelling the surface behaviour of complex molecules such as polyelectrolytes, biomolecules, liquid crystal polymers and molecules with specific functions such as chromophores;
- Determination of subtle effects in the structural correlations in solutions of polar, charged and apolar molecules that are of fundamental importance in much of chemistry, biology and biotechnology;
- Rapid, real time structural measurements to follow in real time the kinetics of phase transitions, chemical reactions and relaxation time phenomena; this includes the potential of kinetic studies of the adsorption of proteins – an issue at the heart of food colloidal stability;
- Extension of catalysis studies to important non-hydrogenous systems;
- Spectroscopy of the chemical reactions in buried interfaces, such as glue attached to its binding surface and curing, for example carbon-fibre / resin composite surfaces;
- Structural measurements of complex earth-forming minerals over the pressure-temperature regime that is of geological relevance;
- Exploring the effect of temperature and pressure on the stability of hydrous minerals;
- In engineering science measuring stresses, observing microstructures and monitoring behaviour during process or in-service in a dedicated Engineering Research, Development and Test Centre for Europe's engineers and material developers;
- Studies of the dynamics of the flux lattice in superconductors;
- Extending sample environments to new extremes: pulsed magnetic fields, pressures in excess of 300 kbars and ultra-low temperatures, and combinations of these conditions.

The new Munich reactor, FRM2 – a 20 MW reactor – and AUSTRON are national projects which will help to prevent a neutron drought in Europe, but do not offer the same scientific opportunities as the ESS. FRM2 will provide a future steady state source, with experimental capabilities in some areas as good as the ILL reactor in Grenoble. But it will not benefit from the pulse structure and time resolution of a high-power pulsed neutron source and hence the scope for new scientific opportunities is limited. Research at the ESS will benefit from a complementary network of regional sources, which provide the test ground for new experiments and techniques and training opportunities for young researchers in addition to serving national measurement needs.

ESF Question **2**

"To maintain Europe's lead" is one strong and general statement used for arguing the ESS case. But: What does 'maintaining Europe's lead mean concretely?

Was the European lead of the past mainly a lead in neutron facilities of excellence, or did this lead in facilities establish a European lead in structural and dynamic matter & materials research? Can this be exemplified?

ESS R&D Council's answer to Question 2

Europe's lead in neutron scattering which manifested itself in the 1980's is based on the availability of large scale facilities like the world's best steady state source, the ILL in Grenoble, and the world's best pulsed source, the ISIS Facility in the UK, combined with the spirit to develop neutron instrumentation and techniques in an unparalleled and creative way. This technical advantage led to Europe's leadership in scientific applications.

These large neutron science centres, together with a network of national medium flux neutron sources have a long tradition as user facilities providing access for the wider academic and industry based research community. Leading European high tech companies such as Rolls Royce, Mercedes, Unilever and ICI have benefited from the power of neutrons to understand material properties on a microscopic level, resulting in product improvement and increased global competitiveness.

This has led to a powerful, extensive and experienced user base of over 5000 European researchers (and still growing) using neutrons either as their main scientific tool or as an invaluable complementary tool to other methods.

The United States pioneered the development and use of early neutron sources. Also the basic instruments for diffraction as well as inelastic neutron scattering – the triple axis spectrometer – were invented there. The first important step which was taken in Europe was to develop cold sources providing long wavelength neutrons for higher resolution studies. In this context a large number of specialised instruments was invented. Examples include small angle neutron scattering (Jülich), backscattering (München), neutron spin echo (Budapest, ILL), time-of-flight spectroscopy (several centres in Europe) etc.

This has enabled new research into a wide range of science topics. In particular, this made neutron scattering techniques accessible for the first time to polymers and soft condensed matter in general, including biology and associated research topics.

Other important examples of instrument and technique development include:

- Neutron spin echo spectrometers incl. the zero field neutron spin echo method;
- Double crystal high resolution small angle scattering instruments;
- Development of high resolution (meV) spectroscopy;
- Development of isotope substitution methods;
- Development of ultra-low temperature sample environment for the

determination of nuclear spin ordering;

- Development of chopper spectrometers for single crystal spectroscopy;
- Three dimensional tomography;
- Multilayer neutron polarisers / analysers;
- Cryopad – three dimensional polarisation analysis;
- High transmission velocity selectors.

All this has led to a high profile neutron scattering programme in Europe in a wide range of scientific disciplines. Some specific highlights are given below:

- Determination of the polymer conformation in the melt and the amorphous state;
- Analogy between polymer structure and critical phenomena;
- First observations of topological interactions on a molecular level in polymer melts;
- Determination of individual pair distribution functions in complex liquids;
- Determination of the structural phase transitions in the buckminster fullerenes;
- Determination of the structure of high-T_c superconductors;
- Determination of the magnetic excitations in magnetic giant magneto resistance materials – bulk and multilayers;
- First measurements of the high energy spin dynamics in transition metal ferro – and antiferromagnets;
- Unequivocal determination of magnetic structures, including the moment direction even for complex systems;
- Determination of nuclear ordering at very low temperatures;
- Nuclear spin polarization of ribosome targets for the analysis of the location and function of individual proteins in the ribosome by means of polarised small angle neutron scattering;
- Determination of structures of planetary gases under high pressure;
- Determination of structure/ property relations in nanostructure materials;
- Identification of the nature of protonic entities in protonic conducting solids;
- Determination of structure and dynamics in disordered systems, i.e. glasses, liquids, polymers and biomaterials; this includes the determination of the structure of binary/tertiary supramolecular complexes and the aggregation state of integral membrane proteins.

European neutron instrumentation experts are in great demand with neutron facilities in the US and Japan, serving in many high profile advisory roles and as consultants on neutron instrumentation. The Forschungs-zentrum Jülich has been constructing a Neutron Spin Echo instrument for the National Institute for Science and Technology (NIST) and currently, together with the Hahn-Meitner Institute is preparing to design and build a neutron spin echo for the new US spallation source. Argonne and Los Alamos National Laboratories are developing a copy of the high resolution spectrometer IRIS at ISIS.

Europe's lead is also based on the spin-off from its neutron centres of excellence. This includes:

- Training highly qualified personnel for industry and commerce, thus providing efficient and effective knowledge and technology transfer;
- Providing a source of expert advise to industry and commerce;
- Involving high tech industry in the development and commercialisation of state of the art instrumentation. Examples here include technology transfer for the production of scintillation neutron detectors and the production of supermirror and polarisation devices, and more recently the development of three-dimensionally curved supermirror optics;

Consequently, many layers of the European society benefit directly or indirectly from the research performed in the neutron centres.

What would have been the draw-backs for European research if these leading facilities would not have been in operation in Europe?

Without the European efforts our knowledge in many key disciplines in condensed matter research would be severely limited. Examples are wide ranging and include:

- Understanding of the dynamics in solids;
- Understanding the structure and spin dynamics in magnetic materials;
- Understanding of the structure and underlying microscopic mechanisms in high temperature superconductors;
- Understanding the role of hydrogen in biological materials;
- Understanding of colloid behaviour;
- Understanding of phase separation kinetics;
- Understanding the structure of the interfaces of magnetic multilayers;
- Understanding of the embrittlement of reactor pressure vessel steel;
- Understanding of the structure and morphology of polymers;
- Understanding of the motional mechanics which are behind the viscoelasticity of polymers.

It is not an overstatement, if one concludes that basically all important developments in the field of high resolution neutron scattering were coming from Europe and most discoveries in this field were done here. They gave European science an indisputable lead in fields where such experiments were of crucial importance.

On the other hand: what in fact have been the draw-backs for science and research in the US and Japan through the non-availability of neutron facilities of excellence in their regions?

The lack of world class facilities in the US and Japan has limited the expansion of the scientific programme on a national basis, in comparison to Europe and has slowed down the practical applications of neutron science for technology and industry. The lack of world class facilities in the US and Japan makes researchers fight for access to European neutron sources.

Although the US had an early lead with the first generation of neutron instruments as exemplified by the Nobel Prize to Brockhouse and Shull, they rapidly fell behind in areas such as high resolution spectroscopy, spin echo instruments (their only instrument was built by Jülich) and their development and understanding of small angle scattering. As a result, the development in the understanding of the dynamics of polymer molecules has been dominated by European groups. Furthermore, the application of small angle scattering techniques to prove fundamental concepts in polymer science was also first carried out by European groups[2]. There is general consensus that the US are far behind Europe in its ability to investigate colloidal systems; application of neutron reflectometry to wet systems by US researchers is negligible.

Both the US and Japanese neutron communities are facing severe problems in conceiving and building instrumentation for the planned spallation neutron sources because of the lack of national expertise.

ESF Question 3

> **"Averting a neutron drought in Europe" in the next decade is another strong & general argument for the up-grading of existing neutron facilities and for the construction of new and advanced neutron sources, culminating in the ESS project.**
>
> **Q3.1 What is the projected positioning and role of the ESS as the largest neutron source in the European network ?**

ESS R&D Council's answer to Question 3

The importance of the ESS within the European theatre can be assessed best on the basis of the ESF-OECD report (*ref. v*) focused on Europe. At present there exists a relative large number of medium flux reactors used for neutron beam research. In addition there are SINQ as a continuous and ISIS as well as IBR-II as pulsed neutron sources. At the centre of this network of European sources are ILL and ISIS which provide sources about one order of magnitude better than the others. In fifteen to twenty years from now the scene will have changed completely. Most of the presently active European sources will have closed down; we expect that the following *regional* sources are going to be present: ISIS with a second target station, SINQ, FRM-II, AUSTRON, if it is built, the ORPHÉE reactor in Saclay, and, if completed, the PIK reactor in St Petersburg. Amongst these sources ESS will stand out as the central European facility, again about at least one order of magnitude better than the rest. Thus, compared to the Europe of today, with the ILL and ISIS as flagships, the Europe in fifteen to twenty years from now will have the ESS in this role. In a semi-quantitative format this is shown in the diagrams I and II of the ESF-OECD report (*ref. v*).

Today in Europe 16 major neutron sources are in operation, serving about 180 neutron scattering instruments. Even if all projects would be realised, in fifteen to twenty years from now the number of sources will have been reduced to 9, roughly half of those today. At the same time, although the

[2] The absence of such facilities would have severely hindered the expansion of random phase approximation theory to polymer systems and the Nobel Prize awarded to de Gennes would certainly have been delayed and, arguably, may not ever have been awarded.

overall number of instruments will remain unchanged, the accumulated figure of merit (*ref. v*) will rise from ~ 500 to ~ 900, in other words nearly double. Hence focusing resources on front rank facilities will lead to qualitative improvements for research opportunities with neutrons. In this scenario, the ESS will play a central role contributing ~ 1/3 to the increased figure of merit.

Thus, the ESS will be the largest and most powerful neutron source in the European network. The source strength combined with the envisaged infrastructure – from the dedicated engineering research, development and test centre to advanced and complex sample environment equipment - will provide unique research capabilities for the European science community. It should be noted that the ESS project is driven by a consortium of research centres that operate the current neutron sources in Europe in close collaboration with the user community. This documents that these centres see the ESS either as a complement or as a replacement for their present source. The ESS will enable European researchers to carry out research at the cutting edge and maintain their leading position in many technological relevant areas, including polymer research, magnetic materials and engineering science. The European network of neutron source providers and users will clearly be strengthened by the advent of the ESS.

The role of medium sized national sources will first of all be to satisfy the national need for neutron experiments which do not necessarily need the highest flux. Furthermore they will enable explorative studies, provide training opportunities for students and test facilities for new concepts and techniques, whereas the high flux of the ESS will provide the opportunity to perform *unique* experiments.

Q3.2 What will be the unique positioning and role of the ESS for Europe (and global) science and research as the highest-brilliance pulsed source? These questions are needing conclusive answers based on:

- **today's scenarios/schedules/ strategies for optimised operation/up-grading of existing neutron sources in Europe, including the evolution of advanced instrumentation;**
- **today's up-coming new neutron sources or facility projects (SINQ, ISIS2, FRM2, AUSTRON, ESS), including their concepts for instrumentation / data acquisition.**

If Europe is successful in achieving the change from the present situation characterised mainly by reactor sources from the 1960's and early 1970's to next generation sources in fifteen to twenty years, Europe will have renewed its potential in this field and again be in a leading position, with the ESS as a world class facility, the centre of the network of regional sources. This would be a very powerful scenario for European research with neutrons.

It is this interplay of regional sources of high quality and central European high performance facilities, at present the ILL and ISIS, and in future the ESS, that makes European neutron scattering very competitive, innovative and scientifically rich. Technique developments and scientific ideas as well as promising young scientists have the opportunity to blossom at many places in different national environments and different scientific traditions. These scientists come together at the European centres, exchange their views and ideas, implement their methods and create an exciting and open atmosphere of scientific and human progress, an atmosphere which attracts the best talents around. In order to maintain this very creative network structure, a central high class facility, the ESS, is indispensable.

Neutron scattering has always been and will always be intensity limited. Hence the flux of a neutron source plays a prime role and a flux increase benefits basically all applications. If we compare a high flux neutron source providing ~ 10^{15} neutrons/cm^2/sec with a standard laser emitting 10^{21} monochromatic photons, we realise that intensity has a special meaning in neutron research. The vision of a European network of facilities with up to two orders of magnitude more powerful sources is therefore a fascinating and highly attractive scenario.

To exemplify: With the advent of the high flux reactor at the ILL a general increase in neutron flux by up to a factor of 10 was realised compared to a medium flux reactor. A large variety of new techniques which had already been tried out at the weaker sources very quickly became mature (e.g. back-scattering, neutron spin echo, time-of-flight techniques with cold neutrons, polarisation analysis) and new scientific applications were fostered. Examples include: dynamics of soft condensed matter and generally disordered systems, tunnelling and rotational dynamics in molecular crystals, biological mesoscopic structure analysis, magnetic excitations in complex and exotic systems etc. New fields comprised application in polymer science, material science, biology and chemical physics.

Effective flux increases by 2 orders of magnitude with the ESS (and for certain applications even more) could change the field in many directions. In general, the feasibility of experiments fills a continuum of degrees of difficulties from easy to impossible. A significant flux increase will shift the border sufficiently and therefore much of what is impossible or very impractical today will surface.

- Measurements to higher resolution in both space and time;
- Measurements of weaker signals;
- Measurements over shorter times - allowing real time studies and kinetic studies;
- Measurements on smaller systems – some samples are *inherently* small, such as a crack tip;
- Measurements in more extreme sample environments – pulsed magnetic fields, higher pressure (which limits sample volumes), ultra low temperatures (which can only be maintained over short periods).

With shorter measuring times neutron based biological structure determination could become important – providing routinely also the hydrogen positions. The exploration of complex structures in soft condensed matter science involving large series of contrast variation experiments could become feasible on a routine basis. Experiments on the processing procedure of materials and other kinetic studies would become significantly more powerful. Studies of matter under extreme conditions which are important e.g. in earth science and fundamental magnetism research would progress considerably.

Advances in instrumentation – from neutron optics to more sophisticated and extreme sample environment to intelligent data acquisition systems – will benefit instruments at existing, planned and future neutron sources. It is the *combination* of source strength and cutting edge instrumentation technology, which are at the heart of the unique capabilities of the ESS.

The ESS will not just enable more science to be done using neutron beams; it will enable *wholly new classes* of experiments to be addressed. For example, 'real time' experiments will become possible. Such experiments are just about possible for some systems with long relaxation rates on the state-of-the-art small angle scattering instrument D22 at the ILL and the SURF reflectometer at ISIS. Neutron sources will never match the brightness of synchrotron sources, however, the point is that neutrons will continue to explore scientific aspects which cannot be addressed by X-rays and hence provide vital and essential complementary information[3].

The case for the ESS, the largest and highest-brilliance pulsed neutron source in Europe is not simply a case for compensating the 'neutron gap' (*reference (vii) item 15*). The role of the ESS will be

- to create new scientific opportunities and enable expansion in new scientific areas (*reference (ii)*) for the European science community, far beyond the existing neutron community, and
- to maintain Europe's lead in the way specified in the answers to questions and issues under point 2.

This is the unique positioning and role of the European Spallation Source.

The other operational front-line facilities, ISIS and ILL, and the new planned sources, FMR2 and AUSTRON, will continue to play an important role in combination with the ESS:

- serving specialised scientific needs of the user community,
- pursuing instrument and component developments and exploring new designs for next generation instrumentation,
- training of young researchers and
- providing a home base for the ever growing neutron science community.

[3] For example, neutrons have been used to establish the kinetic parameters of interpolymer reactions. This is simply not observable by X-rays or any other technique where the species are chemically identical. Experiments with selectively deuterated samples are another example.

ESF Question 4

"ESS will serve outstanding 'small science' R&TD in many fields of physical, life and technical sciences" is another strong and general argument widely used. But: what is the supporting evidence for that?

- **extrapolated from the current use by the respective research communities of neutron sources and photon sources for structural and dynamic research ? and**
- **based on the concrete answers to question 3.2 ?**

ESS R&D Council's answer to Question 4

The European neutron user programme attracts a wide spectrum of users from both academia and industry. The European user base currently exceeds 5000 researchers with a steady growth of the community of ~200 to 300 per year. In recent years, particularly strong growth has been seen in the field of soft condensed matter (including biological and biotechnological applications), which now attracts some 25 – 30 % of the request for beam time. Emerging fields include earth sciences, engineering and high pressure studies.

A recent survey at the ISIS Facility demonstrated that the spectrum of requests for beam time per year covers a broad range: the largest request was for 96 days and the smallest for a single day, illustrating the diverse nature and needs of the user communities. For some people their neutron programme dominates their entire research effort, for others, neutrons are simply another tool which is used when needed to obtain a piece of unique information.

The ENSA survey of the European neutron scattering community provides a statistical analysis of the breakdown of the neutron programme into different disciplines:

Physics	46%
Chemistry, including soft condensed matter	27%
Materials science	19%
Life sciences	4%
Engineering	3%
Earth science	1%

The life science at neutron sources still form only a small component of the global neutron science programme. However, the life sciences are a constantly expanding scientific discipline and the use of neutrons will become increasingly important.

The substantial power of neutron scattering techniques for the investigation of the structure and dynamics of biological systems and related biomolecular-based materials arises primarily from the essentially isomorphous nature of the substitution of deuterium for selected hydrogen atoms in these systems, coupled with the extreme sensitivity of the neutron scattering cross-section to this isotopic substitution. Neutrons possess hence the unique ability to 'see' the protons, both in biological structures and in the water associated with biological materials.

As molecular and cell biology fuse into a single subject area, neutron scattering studies with a powerful source like the ESS will be able to determine how the smaller units, whose high-resolution structures are known, are assembled into the supramolecular assemblies that control cellular metabolism. Membrane systems will attract particular attention and are especially amenable to neutron scattering studies, owing to their very high contrast.

Although in the last ten years many important structural studies have been successfully completed in biological matter, it is clear that the new frontier in the post genome research period is in the understanding of the relationship between structure, dynamics and biological function. To this aim standard structural techniques (X-ray diffraction, NMR, etc.) on their own are not anymore sufficient tools and neutron scattering will make increasingly important contributions. There is a need of performing dynamical as well as structural studies in biological matter under more 'realistic' conditions, such as in solutions more diluted (less that 1% concentrations) than those which can be studied at the present (10% concentrations). Such measurements will be made possible by the high brightness of the ESS. It will also allow the study of kinetics in chemical reactions and dynamical phenomena in food science, for example explore aspects of the ageing in sugar. The dynamical studies on biological matter related to protons and water at the ESS will provide unique information, which cannot be obtained with any photon source.

ESF Question 5

If the answers to question 4. do not project a substantial role of the ESS for life sciences R&TD: Can ESS's 1 billion Euro-case be credibly argued and defended with the use of ESS solely for physical & techncial sciences research ?
Answers and rationales should take into account the competitive environment in which life science communities (and others) strongly demand the upgrading or construction of complementary photon facilities of excellence (advanced synchrotron radiation source, X-ray free-electron lasers).

ESS R&D Council's answer to Question 5

The physical and technical sciences are and will continue to be for a long time the basis of our scientific and technical civilisation. The understanding and subsequent control and design of materials will remain an outstanding and overall extremely important task upon which the creation of wealth in our societies will depend on to a non-negligible amount. Beyond that curiosity driven research in condensed matter science is one of the engines of progress. In order to contract the best talents into such endeavours, a vision for new scientific opportunities and new scientific challenges is needed.

Given the scope of science which is served by the ESS, ranging from condensed matter physics and polymer science to chemistry and material science, from earth science to engineering, to fundamental problems in particle and nuclear physics, an investment of 1000 MEuro over a 10 year period is not very large on a European scale.

Furthermore, the potential for neutron scattering to make a significant impact in the life sciences exists, given enough intensity. A similar situation existed between synchrotron radiation and the life sciences before the advent of 3rd generation synchrotrons. The biology community was actually not particularly strongly involved in the development of the scientific case for these sources; the involvement came only later when biologists realised what could be achieved scientifically with these new machines. For example, until the arrival of those sources, protein crystallography was considered a dormant field[4].

Based on current user statistics, between 1995 and 1998 4170 scientists from 21 countries performed experiments at the ILL. Amongst these were 110 users from the life science community; 47 of them also performed synchrotron experiments at the ESRF to complement their analysis. Like synchrotron radiation (and unlike accelerators for high energy physics!) neutron scattering will always remain a highly interdisciplinary research tool for physics, chemistry, materials science, biology and biotechnolgy, earth science and engineering. Cross-fertilisation of ideas and lateral thinking are a characteristic and vital ingredient of the research atmosphere in a neutron centre.

The overall contributions neutron scattering is making in general to progress in the physical, chemical and technical/engineering sciences, much of which underpins progress on a much wider scale, cannot be emphasised enough. On the basis of the evidence presented in the documents of the reference list, in particular *reference (i)* and *(ii)*, we are convinced the case for the ESS can be made on its contributions to the physical, chemical and technical sciences disciplines.

ESF Question 6

In terms of "value for money": What are the approximate costs, based in a comparable manner on facility operation cost/investments costs, of "typical experiments" at advanced neutron sources in Europe and envisaged at the ESS. In comparison to the costs of "complementary experiments" at existing and projected photon sources ?

ESS R&D Council's answer to Question 6

Neutron and synchrotron radiation sources are multidisciplinary user facilities; costs are dominated by support staff. Although apparently expensive facilities, they are efficient and the average cost per neutron science paper is certainly not more than that of other science paper. For example, the average cost for a paper at ISIS and the ILL is 60 kEuro, whereas the average cost in the universities for a science paper is 100 kEuro.

At neutron and synchrotron radiation facilities experiments are performed by small groups of users (typically 2 to 3 researchers), lasting from 1 to 7 days.

[4] Even the science case for 4th generation synchrotron radiation sources is also not particularly strong in biology, because the huge intensities expected from these machines are so high that they will destroy the sample.

The costs of typical experiments at neutron and photon sources are comparable. The ESS as an advanced neutron source will have similar operating costs to existing sources; the cost estimate from the feasibility study forecasts even an economy of scale for the ESS, as far as operating costs are concerned.

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Appendix 1

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- H. Heumann, Martinsried, Germany
- A. Hewat, ILL, France
- R. Hillman, Leicester, UK
- T. Holden, AECL, Canada
- A. J. Horsewill, Nottingham, UK
- W. S. Howells, ISIS, UK
- A. Hüller, Erlangen, Germany
- M. Hutchings, AEATech, UK
- W. Jauch, HMI Berlin, Germany
- U.A. Jayasooriya, East Anglia, UK
- H. Jobic, Lyon, France
- M. Johnson, ISIS, UK
- D. Juul Jensen, Risø, Denmark
- R. A. L. Jones, Cambridge, UK
- Kalvius, München, Germany
- Kaplan, Jerusalem, Israel
- Karlsson, Uppsala, Sweden
- Karlsson, Mech. Eng., Sweden
- J. Kearley, ILL, France
- Keller, Zürich, Switzerland
- J.Kleinfeller, Karlsruhe, Germany
- Krasnoperov, Moscow, Russia
- Krawitz, Missouri, USA
- de Kruif, NIZO, The Netherlands
- P. Lacorre, Le Mans, France
- G.H. Lander, Karlsruhe, Germany
- M. Latroche, Meudon, France
- R. Lechner, HMI Berlin, Germany
- P. Leconte, ILL, France
- S. Lee, St. Andrews, UK
- T. Leffers, Risø, Denmark
- O. Leichtweiss, Dortmund, Germany

- J. Litterst, Braunschweig, Germany
- A. Lodini, Reims, France
- M. Loewenhaupt, Dresden, Germany
- T. Lorentzen, Risø, Denmark
- B. Lüthi, Frankfurt, Germany
- R. Magli, Firenze, Italy
- J. Major, MPI Stuttgart, Germany
- D. Martin, Madrid, Spain
- R. Maschuw, Bonn, Bermany
- R. May, ILL, France
- R. McEwen, British Aerospace, UK
- S. McKenzie, Rolls Royce, UK
- T. C. B. McLeish, Bradford, UK
- P. C. H. Mitchell, Reading, UK
- E. Morenzoni, PSI (Villigen), Switzerland
- M. C. Morón, Zaragoza, Spain
- K. Mortensen, Risø, Denmark
- O. Moze, Parma, Italy
- H. Mutka, ILL, France
- R. J. Newport, Kent, UK
- Ch. Niedermayer, Konstanz, Germany
- G.J. Nieuwenhuys, Leiden, The Netherlands
- C.-H. De Novion, Saclay, France
- M. Ono, Kyoto, Japan
- H.-R. Ott, ETH Zürich, Switzerland
- R. H. Ottewill, Bristol, UK
- F. Palacio, Zaragoza, Spain
- D. McK. Paul, Warwick, UK
- T. G. Perring, ISIS, UK
- C. Petrillo, Perugia, Italy
- T. Pirling, Darmstadt, Germany
- L. Pintschovious, Karlsruhe, Germany
- M. Prager, Jülich, Germany
- H. Prask, NIST, USA
- K. Prassides, Sussex, UK
- F. Pratt, ISIS, UK
- H. Priesmeyer, Kiel, Germany
- R. Pynn, Los Alamos, USA
- A. Pyzalla-Schieck, HMI, Germany
- J. Rant, Lubljana, Slovenia
- H. Rauch, Wien, Austria
- G.H. Rees, ISIS, UK
- S. Refern, Cambridge, UK
- W. Reimers, HMI, Germany
- A. R. Rennie, Cambridge, UK
- R. de Renzi, Parma, Italy
- C.J. Rhodes, Liverpool, UK
- R. W. Richards, Durham, UK
- R. Richardson, Bristol, UK
- R. Rinaldi, Perugia, Italy
- B. H. Robinson, East Anglia, UK
- E. Roduner, Stuttgart, Germany
- D. K. Ross, Salford, UK
- F. Rustichelli, Ancona, Italy
- M. Satre, CEN-Grenoble, France
- W. Schäfer, Jülich, Germany
- K. Schreckenbach, München, Germany
- C.R. Schwab, CNRS/PHASE (Strasbourg), France
- D. Schwahn, Jülich, Germany
- V. Sechovsky, Prague, Czech Republic
- A. Serebrov, Gatchina, Russia
- L. Simons, PSI, Villigen, Switzerland
- L. G. Sjölin, Göteborg, Sweden
- C. Small, Rolls Royce, UK
- D. Smith, Bristol, UK
- A. K. Soper, ISIS, UK
- S. Spooner, ORNL, USA
- E. J. Staples, Unilever Research, UK
- U. Steigenberger, ISIS, UK
- G. Swallowe, Loughbrough, UK
- A.D. Taylor, ISIS, UK
- J. Teixera, Saclay, France
- R. K. Thomas, Oxford, UK
- P. Todescheni, EDF, France
- J. Tomkinson, ISIS, UK
- R. Triolo, Palermo, Italy
- H. Ullmaier, Jülich, Germany
- P. Verkerk, Delft, The Netherlands
- A. de Visser, Amsterdam, The Netherlands
- R. Wäppling, Uppsala, Sweden
- R. Wagner, GKSS, Germany
- G. Webster, London, UK
- P. Webster, Salford, UK
- A. Weidinger, HMI (Berlin), Germany
- J. D. Wicks, London, UK
- G. Wiesinger, Vienna, Austria
- C. Wilkinson, EMBL Grenoble, France
- W. G. Williams, ISIS, UK
- C. C. Wilson, ISIS, UK
- R. Wimpory, ILL, France
- B. Winkler, Kiel, Germany
- R. Winter, Dortmund, Germany
- A. Yaouanc, CEA (Grenoble), France
- T. Youtsos, JRC-Petten, The Netherlands
- J. Zaccai, IBS, Grenoble, France
- A. Zeilinger, Innsbruck, Austria
- B. Zeitnitz, Karlsruhe, Germany