MEDIUM TO LONG-TERM FUTURE SCENARIOS FOR NEUTRON-BASED SCIENCE IN EUROPE

Working Group on Neutron Facilities

European Strategy Forum on Research Infrastructures

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Mandate and Composition of the ESFRI WG on Neutron Facilities

The Working Group on Neutron Facilities was established by the European Strategy Forum on Research Infrastructures (ESFRI) at its meeting on July 3, 2002.

Its mandate is to carry out a comparative study of different scenarios for the development of facilities for neutron based science in Europe. The study will focus on scenarios that (1) include the building of the ESS (either now or in a timely manner) and (2) scenarios which has major upgrades of ILL and ISIS as key elements and ESS as a subsequent option.

More specifically, the Working Group's task is to address the following questions by comparing different scenarios:

1. Output aspects:
   - type of research questions that can or cannot be addressed
   - European Research Areas perspectives and the influence on technology and the competitive position the European R&D base
   - socio-economic impact including benefits for the local economy around the proposed facilities/investments
2. Life time aspects
3. Input aspects:
   - construction costs
   - operating costs
   - auxiliary investments

The WG has been asked to report before the end of 2002. An Interim Report has already been submitted at the 3rd ESFRI meeting on October 14, 2002.

The composition of the ESFRI Working Group on Neutrons is as follows:

F. Barocchi	ENSA Chairman – Università di Firenze, Italy
J.K. Kjems	Chairman – Risø National Laboratory, Denmark
F. Mezei	Hahn-Meitner-Institut Berlin, Germany
W. Reiter	Naturwissenschaften, Bundesministerium für Bildung, Wissenschaft und Kultur, Austria
A. Taylor	ISIS Facility, CCLRC Rutherford Appleton Laboratory, UK
P. Tindemans	European Spallation Source
G.E. Törnqvist	Lund University, Sweden
C. Vettier	Institute Laue-Langevin Grenoble, France
M. Malacarne	European Commission
E. Righi	Scientific Secretary – European Commission

The WG has consulted members of EURAB with industrial background on the industrial scope of the scenarios.

European Strategy Forum on Research Infrastructures
Working Group on Neutron Facilities

Medium to long-term future scenarios for neutron-based science in Europe

Executive Summary

The Working Group on Neutron Facilities was established by the European Strategy Forum on Research Infrastructures (ESFRI) at its meeting on July 3, 2002.

Its mandate is to carry out a comparative study of different scenarios for the development of facilities for neutron-based science in Europe. The study will focus on scenarios that (1) include the building of the ESS (either now or in a timely manner) and (2) scenarios which have major upgrades of ILL and ISIS as key elements, with ESS as a subsequent option.

At its first meeting the Working Group learned that the Millennium Program at ILL and the plans for a Second Target Station at ISIS are well under way and decided to include these developments as a baseline for the scenarios considered.

This report contains a strategic analysis of three medium to long-term future scenarios (10 – 20 years) for neutron-based science and technology in Europe. The analysis has focussed on the existing and proposed top-rank facilities. The three scenarios are compared on the basis of their scientific and technical merits, socio-economic impacts, costs and timeliness seen in a global perspective. The aim of the report is to provide road maps for the decision-making by European governments in the spirit of the European Research Area, ERA.

Scenario 1 aims at a neutron landscape with ESS fully implemented as the new world leading facility, supplemented by a baseline including fully developed ILL and ISIS and a selected network of regional and national sources**. *This scenario would provide world-leading capability in all areas of neutron science and could serve a growing community of researchers*.**

Scenario 2 aims at a situation where only the first long pulse phase of ESS is implemented and where the rest of the landscape is similar to scenario one. ***In this case, Europe would be world leading in some fields and have some leads in others. The total capacity for highest quality neutron beam research would be reduced compared with scenario 1.***

Scenario 3 is the least ambitious, with the initial implementation of a new 1 MW short pulse source. ***This corresponds to maintaining the over-all level of capability and capacity in a manner where Europe would remain competitive but not leading over a broad range of disciplines.***

The common trend for all three scenarios is that they focus on the most powerful sources and propose to make them into assets for the whole of the European neutron community in the ERA spirit. The need for a European strategy for neutron science infrastructure represents a challenge for decision making in Europe. There is a window of opportunity to go forward in a coherent manner with one of the proposed scenarios. At the very least this would maintain the momentum that Europe developed over the years, and in the most ambitious case will develop new opportunities for science and technology commensurate with both the standing of Europe in the world and the ambitions expressed by the European leaders in the Lisbon and Barcelona summits.

Elements for an ERA strategy for neutron science infrastructures

- It should be recognised from the outset that the neutron landscape is dynamically changing without any joint decisions at the ERA level. By 2020 it is estimated that only half of the

current capacity for neutron experiments will be available, as existing facilities reach the end of their life span.

- A vital element of an ERA neutron strategy is the willingness of the present owners to recycle the funds from existing facilities to the new ones in the scenarios described here.
- The ERA strategy should follow the OECD recommendations with emphasis on the best performing facilities. The corollary is that efforts should be made to ensure that the least performing facilities are retired first.
- The analysis shows that the total recurrent operating costs for the existing (and newly retired) facilities in Europe are approximately 300 M€/year. Retaining the top four to five highest impact facilities would free only 100 to 120 M€ in recurrent spending. However, this would give an opportunity to cover the projected recurrent costs (including investments in instrumentation) in ***scenario 2*** and ***scenario 3***. The realisation of ***scenario 1*** would require additional recurrent costs in the range of 20 M€.

Transition to any of the proposed scenarios will require a capital injection in the range 600 to 1500 M€. Such an investment would sustain the field for the next 25 to 40 years. Using a payback period of 40 years and 2.5% government borrowing rates, it would result in an additional annual spending of 75 M€ for the full ESS, 50 M€ for the Long Pulse Target Station (LPTS) first in a staged approach towards ESS, 42 M€ for AUSTRON and 31 M€ for ISIS upgrade.

The neutron science community is well organised on both national and European levels and through the support from the EU Framework Programmes the community is prepared to take advantage of the opportunities that a common strategy and investment plan would bring in the spirit of the European Research Area. Benefits from the ERA approach would be to:

- provide a viable avenue for decision making, taking into account the possible couplings to other science infrastructure decisions;
- make possible the realisation of the most ambitious scenarios, ***scenario 1*** or ***scenario 2***;
- maximise the scientific return per unit cost. This is the only affordable way for Europe to maintain a strategic world lead in the broad disciplines and technologies underpinned by neutron science;
- provide unique and equal opportunities for European scientists, in particular for young scientists and scientists from the new EU member countries;
- Make a visible and credible major step towards the realisation of the Lisbon and Barcelona ambitions.

As an immediate step, the current incoherent landscape should be recast with a greater degree of joint responsibility for the development and utilisation of the best facilities. Such a step should include a decision on the scenario for the top tier with a realistic perspective on when to start actual construction.

1. Landscape of neutron science and facilities

Research using neutron beams underpins a broad range of science and technology in Europe. The relationship between neutron science, emerging technologies and benefits to society is multi-faceted. On the other hand the coupling between neutron science and industrial products is rarely direct and the socio-economic benefits rest on the scientific advancements achieved over a broad front of disciplines and projects. To give an example, in many areas of materials science like the study of superconductors the use of neutrons has been "mainstreamed" and the facilities have become an indispensable tool for scientific investigation. It is in the direct interaction between industry and materials research groups on problem-oriented projects that the knowledge gain from neutron science is transferred to society at large.

The scientific value of neutron scattering research can be also gauged by the statement of the Hälg Prize Committee, which includes two Nobel laureates: "For the last half-century neutrons have played a crucially important role in developing and refining our understanding of many key scientifically important and technologically significant aspects of condensed matter across the disciplines of physics, chemistry, materials, and the life, earth and engineering sciences. These disciplines and their associated fields of scientific and technological endeavor will undoubtedly remain "topical" well beyond the end of the next decade. Correspondingly there is no doubt that neutron research will continue to make a major, and indeed growing, contribution to each of these fields. Moreover, neutron scattering is a uniquely powerful and ubiquitous tool that continues to rise to the most exacting challenges set by condensed matter research and development. Neutron scattering techniques are well suited to characterization of materials in high growth research fields such as nanoscience, biology and polymer science, and demand for these techniques continues to increase."

Presently, Europe has the global lead in neutron science, based on a growing community of some 5000 researchers from academia and industry. The community is served by two world-leading high flux facilities, the ILL-reactor in Grenoble (F) and the ISIS spallation source at the Rutherford Laboratory (UK), together with a network of medium and low flux national facilities (see Table 5.3). The European user community is well organised both nationally and on the European level. The Framework Programs of the EU have supported the international use of existing facilities and their networking, and hence created the basis for further development of the field with a common European strategy.

Production of high-intensity neutron beams for research requires large reactor- or accelerator-based neutron sources and advanced neutron scattering instruments for their exploitation. Neutron facilities are costly, with long lead times in both planning and construction. The optimal exploitation requires continued development of instruments and supporting facilities as well as broad trans-disciplinary and trans-national access based on scientific merit.

The only conceivable way to establish a new world-class neutron science facility in Europe is through international collaboration on a European scale. There is a global consensus that such a facility should be an accelerator-based spallation source, and the scientific community as well as the institutions engaged in neutron science have over the last decade prepared detailed proposals, which are ready for political considerations.

Europe cannot maintain its lead in neutron science without enacting a new common strategy for the field. The USA are currently building the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory in Tennessee (its completion is foreseen in 2006). Japan is building a source of similar performance in Tokai (J-PARC), which should be ready in 2007. Europe however has pointed the way to the MW spallation range, since the SNS is built essentially based on the initial design of the European Spallation Source, ESS.

The OECD Mega Science Forum has developed a global strategy for the provision of neutrons, which was endorsed by the OECD Ministers of Science and Technology Policy in 1999. Its main recommendation is that there should be a next generation MW spallation facility in each of the USA (North America), Japan (Asia-Pacific), and Europe. Such is the demand for neutrons. The strategy also asked for maximised utilisation of the two best present sources, ILL and ISIS, in order to provide opportunities for cutting-edge science and maintain capacity in the near to medium term. The European Neutron Scattering Association, ENSA, has also recently presented their road map on how to proceed with investments in new facilities.

Numerous analyses have shown that, unless new actions are taken, there will be a declining capability of neutron facilities in Europe. Although the life span of some of the facilities can be extended, they will eventually be shut down as their scientific competitiveness diminishes and/or as a result of cost/benefit considerations by the operators/owners.

In this Report three scenarios for the future development of the neutron science landscape in Europe are considered:

Scenario 1 aims at a neutron landscape with ESS fully implemented as the new world leading facility, supplemented by a baseline including fully developed ILL and ISIS and a selected network of regional and national sources**.**

Scenario 2 aims at a situation where only the first long pulse phase of ESS is implemented and where the rest of the landscape is similar to scenario one.

Scenario 3 is the least ambitious, with implementation of a new 1 MW short pulse source in addition to a selected range of regional and national facilities.

The base line for all three scenarios considered in this Report is the assumption that ISIS will be upgraded to ISIS-2 by adding a second target station, and that ILL will be enhanced through the proposed Millennium Program, in line with the current planning by its owners and associates.

ISIS-2 has been assumed as funded, with the second target starting operation in 2006 and its instrumentation suite being completed by 2012.

ILL will bring to fruition the entirety of or a fraction of the ILL Road Map. The resulting programme, the content of which is called the Millennium Programme, rests with funding decisions to be made by the ILL Associates.

1.1 Outline of the Report

In section 2 of this Report the different scenarios have been compared according to their level of scientific ambition and potential impact on European science and technology. The need to maintain a strongly competitive base of high quality auxiliary investments has also been included.

Neutron scattering has been established as an indispensable method with applications across a range of scientific fields. The scientific, technological and socio economic impacts are typically indirect and associated with transfer of background knowledge that helps to provide answers in subsequent applied projects.

The short-term, local/regional effects and long-term, global effects on the socio-economics of the potentially affected regions are further explored in section 3 for the three scenarios.

The different strategic options have been characterised by their level of scientific ambition and potential impact on European science and technology. They lead to different neutron landscapes in the years beyond 2015 – 2020, outlined by the timelines in section 4.

The common trend for all three scenarios is that they focus on the most powerful sources and propose to make them into assets for the whole of the European neutron community in the ERA spirit. The transition to any of these scenarios will require significant new investments in a new common facility. Total running costs, however, would not rise dramatically. In section 5 on costing it is shown that the European total rate of expenditure (running costs) for neutron facilities would increase by some 15% for scenario 1, remain about constant for scenario 2 and decrease in scenario 3 if compared to the present situation in Europe, provided funds were recycled to the the facilities from the older closed down facilities

For all the above sections annexes have been included, where further details can be found.

Lastly, the findings of this Report have been summarised in section 6, where a possible timeline for a decision-making process, which should enable Europe to maintain its worldwide leadership in neutron-base science, is also indicated.

2. Scientific Scope, Output and Instrumentation

2.1. General remarks

Before discussing the issues related to the three proposed scenarios, two essential points need to be clarified.

Firstly, the scenarios under examination have realisation times of the order of 10 years: during this period major scientific and technical developments can become available. The discussion of the scientific scope of the various options may therefore be based only on present knowledge and on what could be done if the proposed neutron sources were available today. Secondly, when experimental scientists have the possibility of using either improved (even a factor 2 of improvement can sometimes be extremely important) or new instrumentation, progress in scientific knowledge is achieved, which in turn is translated into applications useful for society.

Therefore, once scientists have proven their scientific case, investment in a new and unique large-scale scientific facility is based mostly on economical and political considerations. The most developed science case for neutron science is that delivered at the European Source of Science meeting in Bonn, May 2002. The working group used that as basis for our analysis.

2.2 Methodology

In order to compare the scientific performance of the three scenarios, the Working Group has drawn upon a special workshop of scientists and instrument specialists from all over Europe called by the Science Advisory Committee of ESS in November 2002. Performance of a neutron facility depends on the increase in useful neutron intensity for the source (the so-called source gain) and gains obtained by building better and novel instruments. Instrument gains have not been considered when comparing scenarios since they can be achieved on any source, but of course the overall advance of neutron science will also in the future very much depend on the continuing and exciting improvements in instrument performance. The source performance gains of the set of priority instruments selected for ESS have been analysed for each of the three options. By linking instruments to the fields of science for which they are best suited, these performance gains have then been related to the flagship areas[1] that where identified in the various scientific fields where neutron spallation sources of the next generation are globally considered to be strategic tools with a very high impact.

[1] A flagship area has been defined as an area where a major increase in source intensity beyond a certain threshold (of the order of a factor of 10 to 100) is needed in order to achieve the targets or visions perceived.

To put the source gains for the three scenarios into perspective, the most ambitious one (a full ESS at 2×5MW) will increase the available neutron source intensity, at the various possible different instruments devoted to experiments, by a factor approximately between 10 and 100 compared to existing sources (ILL and ISIS are the most powerful), and a factor between 3 and 20 for sources actually under construction (1.4 and 1 MW spallation sources are presently under construction in USA and Japan, SNS and J-PARC, respectively). In comparison, the source gain of ILL with respect to the first dedicated research reactors is only 4. The enormous source gains now under consideration are indeed needed to arrive at breakthroughs in many important areas, such as energy conversion, where a gain of 30-40 is considered necessary, magneto-electronics, where gains of 70 are needed, and dynamic phenomena in complex materials like bio-molecules, where improvements of two orders of magnitude must be obtained.

In annex 3 detailed information can be found both on the gains in instrument performance on the basis of the source gains, and on the way this translates into the performance of the various scenarios in the different fields of science. Before presenting the results in a table, however, some consideration must be given to the definition of the parameter “competitiveness with respect to the USA (or Japan)”, used to express this comparison.

2.3 Global competitiveness

Neutron research underpins large domains of condensed matter science and technology, also in areas that are vital for many of today’s and tomorrow’s major industries. Being competitive or being in the lead has therefore not only to be gauged in scientific terms but also in terms of the impact on the overall economic performance. In fact, this was a major argument behind the OECD global strategy. The reason for having three new generation facilities is precisely that their use and their impact would affect such a wide range of disciplines and industries. They are strategic assets in the scientific landscape of the three continents or regions concerned, and will all be fully utilized by the many thousands of users. The point came out once more very clearly at the OECD Global Science Forum meeting on accelerator-based facilities. While there is increasing agreement that the next generation of very expensive facilities in particle physics or in nuclear physics will be ‘single copy’ global facilities, this does not apply to the neutron spallation sources. Moreover, discussions held at the OECD Global Science Workshops show that while SNS will be open for collaborative projects with Europe, it cannot be a substitute for any of the three scenarios.

It has already been stated that Europe has built up over the last decades the world leadership in neutron science. How should one value such a position? Science is about competition. It is clear that the Americans have not held up across the board in neutron science. European publications constitute a great majority of all neutron scattering publications. This does not translate directly into a loss of American competitiveness in industry, however, because the impact of this type of basic and long-term application-oriented science is worldwide. In fact, the economic arguments to support public basic science are strong, but the economic and social impacts of its results, are localized only to a small degree.

The reason to highly value leadership in science has much more to do with the overall science policy perspective for Europe and its vital importance for the economic and social ambitions Europe has staked for its future based on knowledge. The Lisbon and Barcelona summit statements have already been invoked by many. The ambition to be the leading knowledge-based economy or society would seem to be rather hollow without the corresponding ambition to be leading in at least several areas of science and technology. It would therefore be a rather contrary signal to give up or not to reclaim world leadership in the area of neutron science: there are not many areas where Europe has a recognized leading role, after all. It would have a particularly negative effect on the next generations of scientists and even on those who consider, and are strongly encouraged to choose a career in science. To maintain a vibrant neutron science community in Europe a future perspective is needed that maintains competitiveness and provides exiting opportunities for young scientists.

For this reason the Working Group has cast the results of the scientific performance of the three scenarios in a way that brings out their impact on the competitive position of Europe vis-à-vis the USA, i.e. SNS (and implicitly Japan). In Table 2.1 three categories have been used, with the following meaning:

world leading	significantly better than SNS in all applications;
some lead	significantly better than SNS in at least some applications, and competitive in all other areas;
competitive	within a factor of two of the performance of SNS in all applications.

2.4 Conclusions

The assumption is here made that the next generation neutron source projects currently under construction in the USA and Japan will not be followed up within 2 decades by upgrades or new investments beyond the initial scope of the project goals (i.e. a 1.4 MW single target station at SNS, and a 1 MW single target station at J-PARC). With this in mind, the following conclusions can be drawn:

scenario 1 with ESS fully developed will give Europe unique scientific opportunities in various research fields and an overall leading position in all fields of science where neutrons are important;

scenario 2 with the 5MW long pulse target station alone as a first step of a staged approach towards ESS would give Europe a leading position in many areas of science, and some lead in all others;

scenario 3a with the 1 MW 10 Hz short pulse option would provide some lead in fundamental physics and soft condensed matter, and be competitive in all other areas;

scenario 3b with the 1 MW 50 Hz short pulse option would be competitive in all areas.

It has to be remembered, however, that in both cases of SNS and J-PARC potentials of a staged upgrade to 2-4 MW power have been identified from the outset. According the latest information this upgrade could start as early as 2012-14. A second target station for SNS has also been envisaged. The full capabilities in any of the European scenarios considered here will not be achieved before 2018 – 2020, and further upgrades cannot be envisaged before this time. In view of these timelines an eventual early upgrade of SNS would strongly reduce the competitiveness of the European scenarios compared to the conclusions of the present Report.

2.5 Enhancing the science impact by auxiliary investments.

The scientific impact of neutron scattering facilities in any of the scenarios considered will by conditioned and largely enhanced by investment in auxiliary equipment of sample environment, sample preparation and characterisation, selective deuteration of biological samples and in-situ experimentation. The size of this effort per facility has little dependence on the power of the facility, while the highest neutron scattering capability offers the highest return on this investment.

Table 2.1.
Summary table of scientific performance for the three scenarios. The competitiveness indicators are measured against SNS at its current design level of 1.4 MW.

Important Contribution to European Priority Research Mission	***Flagship Field of Research***	***Scena-rio 1: ESS***	***Scen-ario 2 5 MW Long Pulse***	***Scenaœ rio 3 a 1 MW Short Pulse 10 Hz***	***Scena-rio 3 b 1 MW Short Pulse 50 Hz***
Functional Materials, Microsystems and Information Technology, Nanotechnology.	← Solid State → Physics	WL	SL	C	C
Microsystems and Information Technology, Functional Material, Nanotechnologies, Traffic and Transport, Sustainable Development.	← Material → Science & Engineering	WL	SL	C	C
Functional Material, Nanotechnologies, Traffic and Transport, Sustainable Development	←Liquids &→ Glasses	WL	SL	C	C
Functional Material, Nanotechnologies, Traffic and Transport, Sustainable Development	← Soft → Condensed Matter	WL	WL	SL	C
Functional Material, Health, Sustainable Development	← Chemical → Structure Kinetics & Dynamics	WL	SL	C	C
Health and Biotechnology	← Biology & → Biotechnology	WL	WL	C	C
Traffic and Transport, Cultural Heritage, Sustainable Development	← Mineral→ Science, Earth Science, Environment and Cultural Heritage	WL	SL	C	C
Cosmology, Origin of the Universe, Education, public understanding	←Fundamental→ Physics	WL	WL	SL	C

WL = World Lead
SL = Some Lead
C = Competitive

3. Socio-Economic Effects

Universities and research Institutes are an important driving force underlying technological and industrial development. There is a fundamental relationship between research and higher education on the one hand and the international competitiveness of the economy on the other, though the essence of a knowledge-based economy is exploitation rather than simply adding to the knowledge base. Like all major research fields with a medium- and long-term application potential, neutron science contributes to innovation through interactive learning involving an innovation system or innovation clusters with many different players. The term system or clusters refers to a network that binds together institutions or players that have mutual contacts and trust. This applies for instance to researchers, decision-makers within public administration and employees in various types of firms. The formation of clusters does not need to imply that all the activities concerned are bound together by a close physical proximity. Shared interests, shared information, mobility links, supplier relations can all contribute to establish a coherent, functioning system even if some partners are wide apart. Viewed in this perspective, a large neutron-based research centre assumes a strategic importance in the future knowledge-based economy, given its size and its very broad range of activities, from fundamental science to a wide spectrum of applied fields of research.

The OECD Mega Science Forum in 1999 put forward a global strategy for neutron facilities. It recommended that each of the industrialised continental regions should develop its network of sources topped by a multi-MW spallation source in each of the regions. The USA and Japan have acted in accordance with this strategy and are currently building such sources (SNS and J-PARC respectively). In the USA a further step has been taken. The Office of Science and Technology Policy (OSTP) has released a study, which recommends a major up-grade of the instrumentation at the other neutron sources HFIR, NIST and LANSCE to “best in class” on an international scale. Only in this manner can the expected demand be met.

Figure 3.1 provides a simple illustration of how a neutron source may form the centre of a complex of activities. Around the central core, there is a ring of scientific spheres that are dependent on the activities that are conducted at the neutron source. Outside the ring of scientific spheres, there are several examples of technical applications and industries that can benefit from the scientific advances. Research and development are increasingly conducted within international networks that extend beyond national boundaries. Neutron science fits well into such networks of universities, research institutions and industries that are bound together in cross-border relations. Hence, the establishment of a new research centre should not be seen in a local or regional context only.

Investments in neutron science and its large experimental facilities will lead to different types of impacts, as discussed more in detail in annex 5 of this report:

1: *direct*, localised and short-term impacts, related to the economic activity generated by building, operating and using a large facility;

2: *indirect*, network-type medium- and long-term impacts, related to the potential for attracting other research institutions and high tech industries to the region that hosts a new large facility and strengthening its knowledge fabric;

3: *global*, diffused, public domain and long-term impacts, related to the science and technology that stems from the use of the facility.

The *direct impacts* occur both during the time of construction and later on. The demands on both material and intellectual resources will depend on which of the three alternatives are discussed. For the most advanced project, ESS, the need for land is estimated to be 1.0 – 1.2 sq. kilometres while the investment expenditure is expected to be of the order of 1.5 billion €, translating into 3500 years of cumulative man-power needed during construction. The personnel requirements are expected to be of the order of 600 persons on a permanent round the clock basis. It is anticipated that as many as 4000 to 5000 scientists will make use of the facility every year. As pointed out in annex 5, these direct localised effects have their greatest impact on places that have a limited labour market and a restricted range of services. Large, diversified regions with dense supplier and customer networks will be least affected since there is usually a degree of more or less latent over-capacity among building firms, sub-contractors, retail trade outlets and service companies. According to traditional studies, a multiplier of 2-3 could be expected in larger regions, i.e. 1000 new employment opportunities could raise the working population in the area by 2000-3000 persons. In smaller places with limited labour markets, the employment multiplier could be as large as 5-6. Hence the direct socio economic impacts of the different scenarios will scale with the size of the investments and the recurrent costs.

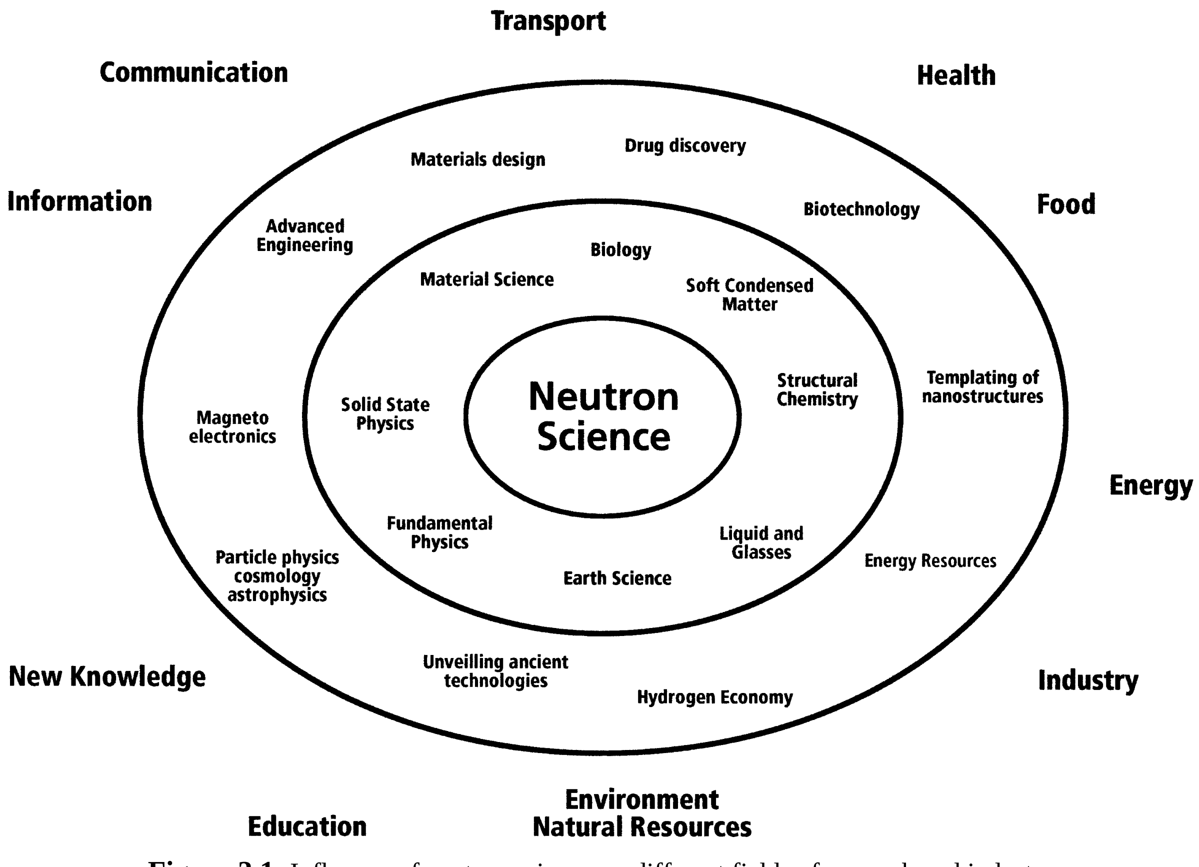

Figure 3.1. Influence of neutron science on different fields of research and industry.

The *indirect impacts* from investments in neutron science and facilities will occur most quickly in agglomerated environments where institutional frameworks and social webs are already tight and well functioning. The indirect impact can be expected to grow over time. The Grenoble region is an example of a successful agglomeration of this kind, where the original investment in the world-leading neutron source, the Institut Laue-Langevin (ILL), has attracted subsequent investments in complementing institutions like the European Molecular Biology Laboratory (EMBL) out-station and the European Synchrotron Radiation Facility (ESRF). This in turn has fuelled substantial growth of the universities and high-tech industries in the region. Hence, this is an example of a *growth pole* that could be the result of a new investment in a front-rank neutron facility. The analysis reported in annex 5 shows that especially cross-border regions may have a latent potential that could be released through realisation of one of the scenarios discussed here. The size of the indirect impacts will to a first approximation scale with the overall size of the effort related to the new facility, but it is important to note that there is no automatic route to success. The outcome will depend on the manner in which the interactions evolve between the new facility and local government, research institutions and industry in the region. A combination of factors that appear to be successful in one region would not necessarily produce the same effects in another one.

In an overall perspective the *global impacts* are of most importance to discuss and assess. The future of the advanced economies no longer depends to the same extent as in former days on natural resources and human diligence. Scientific excellence and communication of knowledge, together with the capacity to innovate, have become vital factors in promoting economic and social change. Neutron science is an important source of new knowledge that can feed long-term industrial innovation. Neutron-based science, such as material science, solid state physics, energy and biotechnology, has a long-term impact on industry mainly by understanding phenomena and translating this understanding in technology. It remains a critical target to carefully prioritise such research areas and to increase the points of contact between neutron science and industry. Examples of useful links between neutron-based science and technologies can be found in "ESS- The Science Case" (see References). The realisation of any of the three scenarios will increase the contributions of neutron science to the priority themes of the EU's 6th Framework Programme and the national science and technology policy agendas: microsystems and information technologies; functional materials; health and biotechnology; nanotechnologies; artefacts and materials in cultural heritage; traffic and transport; sustainable development, clean technologies and environmental systems; questions about the origin of the universe.

In scenarios 1 and 2 the odds will be higher than in scenario 3 for new breakthroughs in science, such as high-temperature superconductivity and "colossal' magnetoresistance, in-situ, real-time investigations on full-scale components and 3D images of engineering parts under working conditions, the dynamics and functions of proteins and biological complexes and protein folding. Breakthroughs will also be likely in multi-billion Euro applications of great industrial and intellectual interest, such as magnetic recording and spintronics, tertiary oil recovery, chemical and pharmaceutical applications, future superconducting electrical systems or materials for energy storage and conversion. These problems can be only marginally addressed with existing sources.

Table 3.1. Summary of the socio-economic impact for the three scenarios.

scenario	direct impact	indirect impact	global impact
1: ESS fully implemented	large regional impact	major growth pole potential	major breakthroughs and technological gains
2: 5 MW Long pulse	large regional impact	growth pole potential	breakthroughs and technological gains
3 a or b: 1 MW short pulse	medium regional impact	some growth pole potential	some breakthroughs and technological gains
ILL millennium program	limited regional impact	synergies already established	incremental technological gains
ISIS second target	limited regional impact	synergies already established	incremental technological gains

4. Timelines

The three scenarios considered in this Report will offer enhanced capabilities to the European scientific community according to different time scales. How do these projects compare with the current situation in Europe? How will their relative scientific potentials evolve with time over the next twenty years? This section summarises the relevant parameters and the results of such comparisons.

The development of the three options for the third-tier European scenario should not be considered as an isolated project, but rather it should be put into perspective with the situation in the rest of the world as well as with the underlying network of neutron facilities in Europe.

In the following, the performance over time of the most powerful facility in the different scenarios will be compared with the Spallation Neutron Source (SNS) project in the USA, with its present specification of 1.4 MW, which went officially under way in December 1999, and a baseline plan for neutron scattering in Europe which comprises the ILL Millennium Programme and the ISIS-2 project.

The quantity taken into account here when comparing time profiles is the scientific output. The potential scientific output of neutron scattering installations is related to the number of neutron instruments that are made available by these facilities to the scientific community. However, not all instrument-days can be directly compared. Setting aside experimentalists' inventiveness and skills, instrument quality and source performance are the main parameters that confer value to beam time, as discussed in section 4.2.

In the first part of this section the various options are compared on the basis of gain factors. Then, the timeline for the European baseline option is presented together with the planned time schedule for SNS. Finally, timelines for the three options for front rank facility in the different scenarios are presented on a relative time scale.

4.1. Gain factors

Estimates for the relative values of the different options are given in the table below. The reference point has been taken to be ILL as it was in the year 2000. In order to make meaningful comparisons, several factors must be taken into account: the power and brilliance of the neutron source, the amount of beam-time delivered to users, the number of instruments, and the gains obtained on instruments due to new concepts and technological developments which will have taken place after the year 2000. All these factors are listed in the table below.

Source gains and instrument gains have been established by the ESS project team for the full ESS option, the ESS 5 MW Long Pulse Target Station, LPTS, alone and for SNS. The ILL Millennium Programme comprises a full refurbishment of the instruments and the ageing infrastructure. A comparison with the current state of the ILL infrastructure shows a factor of 2 in the instrument gain for the refurbished facility. Values for ISIS, ISIS-2 and the 1 MW Short Pulse Target Station (SPTS) scale from the value for optimised 5MW SPTS of ESS. For the latter case it is further assumed that the instrument suites will be ideally optimised to the short pulse structure of the sources. The number of instruments and the number of neutron-days to users have been taken from reports published by the facilities. More details can be found in the annex 6 to this Report.

A strong word of caution is in place concerning the use of one number to describe the over-all performance of the top rank facility in a given scenario. The number takes into account both quality and quantity in a simplified way, with emphasis on quantity. As shown in the previous chapter the intrinsic source strength is a better indicator for the capability of a facility to break new ground. Hence, even if an existing facility like ILL can be upgraded to a higher gain factor by the metric used in this chapter, it will not substantially increase the probability for new breakthroughs. A global quantitative comparison cannot probably reflect the high potential scientific impact of qualitatively new capabilities at the next generation sources in the particularly favourable cases.

The last row of Table 4.1 compares the expected gain factors after full completion of all the various options compared to ILL in the year 2000. To illustrate the possible gains that can be achieved one notes that the full ESS would be equivalent to 85 ILLs or equivalent to reactor source of 5000 MW!

Table 4.1.

Gain factors for the different options. The ILL's instrument-gain includes a factor 1.4 due to the refurbishment of infrastructure. ESS and ISIS-2 projects combine two options each.

SOURCE	**ESS**		**LPTS 5MW**	**SPTS 1MW 50Hz**	**SPTS 1MW 10Hz**	**SNS 1.4 MW**	**ISIS-2**		**ILL after 2012**
	LPTS 5MW	**SPTS 5MW**					**2nd target**	**ISIS**	
source gain	**10**	**20**	**12**	**5**	**5**	**5**	**1**	**1**	**1**
instrument gain	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**5**	**7**
total gain	**50**	**100**	**60**	**25**	**25**	**25**	**5**	**5**	**7**
number of instruments	**20**	**20**	**20**	**20**	**20**	**24**	**20**	**20**	**38**
operating days	**230**	**230**	**230**	**200**	**200**	**200**	**225**	**225**	**225**
reliability	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**1**
fraction to users	**0.8**	**0.8**	**0.8**	**0.8**	**0.8**	**0.8**	**0.8**	**0.8**	**0.8**
neutron-days to users	**166**	**166**	**166**	**144**	**144**	**144**	**162**	**162**	**180**
final gain	**85**		**34**	**12**	**12**	**15**	**6**		**8**

4.2. The baseline: ILL Millennium and ISIS-2 versus SNS

The ILL Millennium Programme and ISIS-2, which constitute improvements in the second tier of a hierarchy of European neutron scattering facilities, are compared to the SNS project in the USA. It is assumed that ILL will bring to fruition the entirety or a fraction of the ILL Road Map, which has defined the ILL strategy for the next decade. The resulting programme, the contents of which is called the Millennium Programme, rests with funding decisions to be made by the ILL Associates. The ILL Millennium Programme was launched in 2000. A careful mix of instrument upgrades and infrastructure renewal will lead to a gain factor of 8 over the present situation by the years 2010-2012. This includes in particular the increase in the number of operating instruments up to almost 40. Furthermore, potential gain sources could be envisaged by upgrading the two cold sources that ILL currently operates.

Similarly, ISIS-2, the second target project for ISIS, is assumed to be well underway. The second target is expected to start operation in 2006 with a full suite of instruments by 2012. A suite of roughly 20 instruments will be constructed at a pace of 3-4 per year, paralleled with the progressive upgrade of the 20 instruments located at the present ISIS facility. The number of instrument-days available would be similar to ILL's figure.

Figure 4.1 represents the comparison between the baseline option, ISIS-2 plus the ILL Millennium Programme, and the already funded project SNS in the USA.

By the year 2010/2012, the SNS at 1.4 MW will match ILL in terms of overall scientific output. However, some instruments will allow SNS to outperform European facilities as soon as SNS approaches the MW level. It is also likely the SNS power can be raised to 2 MW in the same timeframe. Furthermore, the USA will continue to operate two powerful research reactors: HFIR at Oak Ridge and NIST near Washington. A comparison of scientific output (number of publications) indicates today that ILL is over-performing NIST by a factor of 2. However it can be expected that the NIST and the HFIR will follow more or less ILL's evolution in terms of gain in efficiency. It is therefore clear that, in the absence of a quick decision, the performance of the front-rank neutron scattering facilities in the USA will be augmented faster than the European ones, and they will have the potential to overshadow the European scientific output of ILL and ISIS-2 in the next decade. The most recent plans (of December 2002) for the SNS ramp-up may result in a faster growth in performance than indicated in Fig. 4.1.

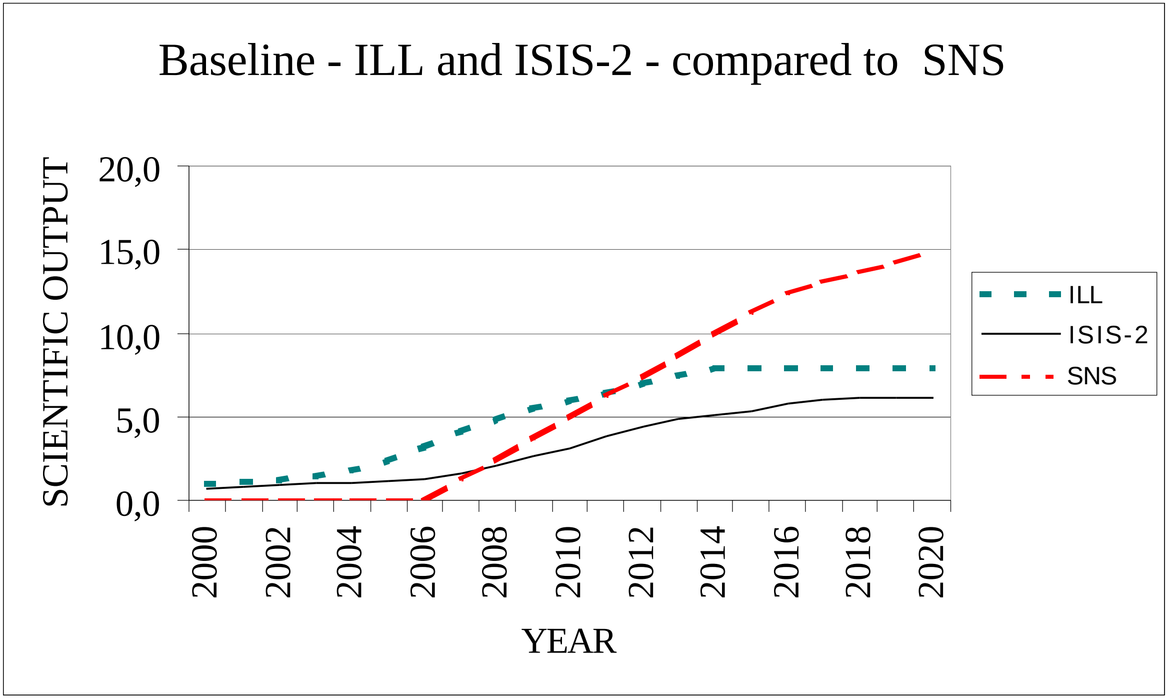

Figure 4.1. Timeline for the underlying baseline in the European landscape for neutron scattering (ILL Millennium and ISIS-2) compared to SNS at 1.4 MW.

4.3. The European options

The three options for the front rank facility in the scenarios are compared in figure 4.2. The full ESS, with 40 instruments in operation on the two target stations 20 years after the decision for construction is made, will provide scientific output equivalent to 85 times that of ILL in 2000. The 5 MW LPTS project, with 20 instruments, will lead to a potential gain of 34, 15 years after the decision to build it is made. A short pulse target station at 1 MW with 20 instruments would lead to a long-term gain in scientific output of the order of 12 but with an earlier start.

In terms of scientific output, the full ESS project is obviously the most powerful one. Looking at the time profiles above, it appears that, if the decision to build ESS were made in 2004, either the full ESS or the LPTS would reach the SNS level around 2012 and will be world-leading after 2015. A 1 MW source will certainly be competitive with SNS at 1.4 MW, but will not outclass it.

In the USA there are indications that as the SNS project with its current specification of 1.4 MW reaches maturity, potential future upgrades to 2-4 MW and the addition of a second target station may be possible.

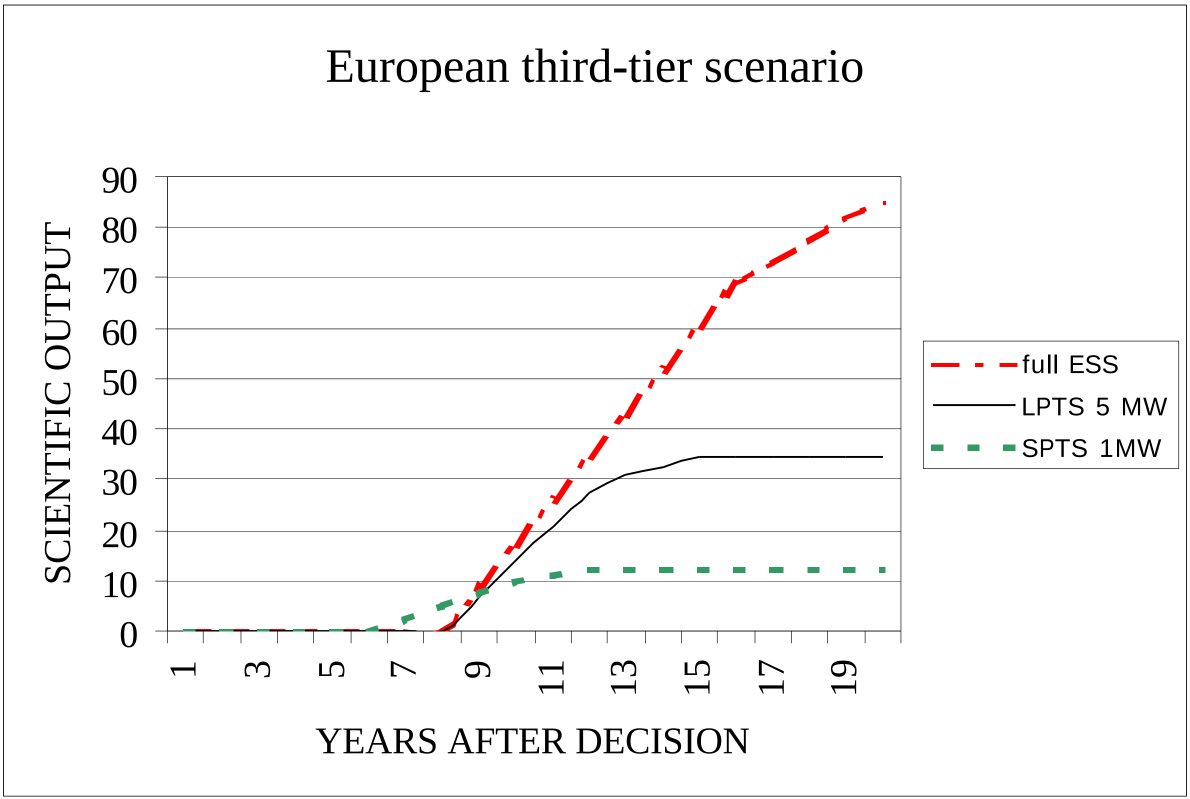

Figure 4.2. Timelines for the front rank facilities in the three European scenarios for neutron scattering.

If Europe intends to maintain its leadership in neutron scattering, it is necessary to build a new front rank facility in one of the scenarios considered here. The time scale for such a decision is discussed section 6 of this Report. In any event, it would be highly desirable that the neutron scattering community in Europe co-ordinate the optimisation of instrument suites at the major facilities according to the adopted scenario once this scenario has been defined approved and funded. As part of this strategy, all the European facilities should focus on the best instrumentation optimised to their source characteristics.

5. Costing

In this section construction costs and structural annual operating costs for the scenarios are given. These costs can be easily converted into total annual costs over a typical lifetime of 40 years.

Separately similar figures are given for the ILL Millennium Programme and the ISIS Second Target Station that are part of all the scenarios considered in this Report. An estimate has also been made of the current total European annual expenditure on neutron facilities. The difference between current and projected expenditure including one of the new scenarios should be evaluated in the light of the Barcelona perspective of 3% GNP goal for R&D funding by 2010.

5.1. Assumptions

In comparing both construction and operating costs several assumptions had to be made, as described in more detail in annex 7. Most figures are available for the ESS options, less for others, although the estimates have been considered sufficiently good for the present purposes. The choice of a site will, of course, determine not only the exact engineering and costing details of the conventional facilities, but also the costs of labour and the possibility of getting contributions in kind. Any such site-dependent cost differences might be a factor in a final decision to go ahead with a given project. In order to make a meaningful comparison these differences are not taken into account here. Target stations have been assumed to be equipped with same number of instruments of the same costs as those for ESS. All cost estimates are in Euros of the year 2000.

5.2. Technical maturity and risk

In assessing options it must be realised that they differ considerably in the degree to which a detailed technical design is available.

For ESS there is the detailed proposal for the science programme, the technical design and the costing, presented in Bonn. Under the Memorandum of Understanding the ESS partners have signed up to, this is now being detailed in a baseline engineering design, which will be ready by the end of 2003.

The 1 MW upgrade of ISIS is based on well documented, established and operational technology at ISIS.

The proposal putting forward a 1 MW version of AUSTRON shows an obvious way to reach 1 MW, but also states that further options for the accelerator-ring complex still have to be analysed in more detail. A detailed cost estimate is also not possible without further thorough studies.

The estimates incorporated here should therefore be read in this perspective, and substantiated after a technical risk assessment of a documented technical proposal. A similar caution is appropriate, of course, when it comes to the time schedule.

The 5MW SPTS represents a significant enhancement on what has been realised to date and correspondingly carries a certain risk, particularly in the area of target technology. However recent progress in international R&D effort, together with SNS and J-PARC, to demonstrate the viability of the envisaged solutions is quite encouraging. The 5MW LPTS is a qualitatively new type of source and will require the development of new instrument concepts Potentially this carries risks, but also gives greater headroom for development. Risks associated with the accelerator and target for this option are less than those for a 5 MW SPTS. Of the 1 MW SPTS options, the 50Hz version has medium risk, similar to that of the US and Japanese projects. The 10 Hz 1MW source would deliver the same energy per pulse as the ESS SPTS and so has comparable risk. Both the ILL Millennium programme and ISIS-2 are low risk projects.

It is also to be noticed that in general accelerator-based facilities can be further upgraded in the long run, and all the options considered here are no exception. This possibility is illustrated by the 1 MW AUSTRON design, which is an “extension” of the detailed 0.5 MW design, by the identification of a 5 MW upgrade of the 1 MW ISIS (which would then become equivalent to the 5 MW SP ESS option), or of a 10 MW LP ESS first stage. In view of the timeline of realisation, commissioning and gaining full experience with operational properties at the originally designed power, such an upgrade cannot be expected to be realised within the 20 years time frame covered by this analysis and are therefore not considered here.

5.3. ILL Millennium Programme/Road Map costs and ISIS Second Target Station

Capital and/or investment costs of ILL and ISIS that are part of the current budgets have not been singled out, but they are included in the annual operating costs mentioned later. Since the baseline scenario assumes implementation of both the Millennium Programme/Road Map of ILL and the Second Target Station of ISIS (both of which amount to the implementation of the 2nd tier recommendations of the OCED Mega Science Forum strategy for neutrons), the additional construction and operating costs of these two elements need to be mentioned. For the Millennium Programme/Road Map of ILL the additional construction and annual operating costs are 85 M€ cumulatively and 3 M€, respectively. For the Second Target Station of ISIS, using the same assumptions as for ESS, capital costs are 150 M€ and the incremental annual operating costs 26 M€. The figures for ILL assume 30 public instruments and 11 CRGs[1], the costs of the latter not being included. There is a potential to go to 40 public instruments, but this is not yet incorporated in any scenario.

5.4. Cost comparison of different spallation neutron source proposals

Table 5.1. Cost comparisons of spallation neutron source proposals.

Spallation neutron source Sub systems		**ESS 5 MW SP+ 5 MW LP**	**ESS Staged**		**AUSTRON 1 MW***	**ISIS 1 MW**
			5 MW LP	**5MWLP +SP**		
Instruments & Scientific Utilization		115	60	115	60	60
Target Systems		180	90	180	90	90
Accelerator Systems	Linac	370	330	410	267	
	Achromat & Rings	85	0	85		390
	Beam transfer to targets	20	10	20		
Conventional facilities		465	305	520	260	
Controls & networks		55	30	55	25	
Management & admin. Support		60	35	60	24	
Total estimated costs		1350	860	1445	726	540
Contingency (15%)		202	131	217	109	81
Total construction costs(including manpower)		**1552**	**991**	**1662**	**835**	**621**

*Extrapolated from the 0.5 MW AUSTRON costing using ESS methodology. This does not take into account local labour rate differences.

[1] A CRG instrument is paid and operated by a so-called Collaborative Research Group.

Construction time, including preparation and commissioning of the facility, is 8 years for the ESS options and for AUSTRON (with two more years for detailed design), and 7 years for ISIS upgrade. The most efficient budget profile is similar for all options, ramping up quickly in four years, and then decreasing to annual operating costs.

5.5. Operating costs

While the estimates for the running costs are not equally detailed, it is generally reasonable to make the empirical assumption that the total running costs are of slightly less than 10% of the total investment costs for a new facility.

Secondly, it is important to realise that the ESS estimates include the costs for completing the full set of 40 instruments, and later on to continuously replace them. Underestimating or even ignoring these costs, for example by assuming that they will largely be borne from national sources, amounts to hiding from reality in the European situation. The same approach is used for the other options.

For comparison's sake the operating costs of the present two top facilities, ILL and ISIS, are also given.

Table 5.2. Summary of the operating costs.

	ESS 5 MW SP + 5 MW LP	**ESS 5 MW LP**	**AUSTRON 1 MW**	**ISIS**	**ISIS +TgT II**	**ISIS 1MW +TgT II**	**ILL now**	**ILL +Mill**
AC power	107 MW	36 MW	24 MW	10 MW	13 MW	25 MW		
Energy costs	28	9.5	6.5	2	2.5	5	7	7
Other consumables	23	15	18	16	21	27	10	10
Maintenance, spares	22	14	16.5				5	6
personnel	44	28	24	18	24	28	30	31
instruments	25	12.5	12.5	10	25	25	8	25
Total	**142**	**79**	**77.5**	**46**	**72.5**	**85**	**60**	**79**

The scientific impact of neutron scattering facilities in any of the scenarios considered will be conditioned and largely enhanced by investment in auxiliary equipment of sample environment, sample preparation and characterisation, selective deuteration of biological samples and in-situ experimentation. The initial investment, staff and annual budget needed (without highest magnetic fields and operational costs directly related to experiments on the neutron scattering instruments) amounts to 25-30 M€, 25-30 full time collaborators and about 2.5 M€, respectively, for a new facility. Since most of the required equipment is new and little of what exists today will be adequate in a few years time, essential savings at an upgraded facility will mainly come from the partial availability of laboratory space only. Achieving state of the art high magnetic fields (either pulsed or steady-state) in neutron work will require an additional investment of 10-80 M€, staff of 10 full-time collaborators and an annual budget of 2-7 M€.

5.6. Estimated total European annual expenditure on (major) neutron sources.

The scenarios represent different ways of realising Europe's provision of neutrons in the top tier as defined by the OECD global 3-tier strategy for neutrons. However a direct comparison of annual running costs or of total annual costs over lifetime (including investment) based on Tables 5.1 and 5.2 hides several important aspects. Firstly, the number of additional instruments made available is different: 40 for the full ESS, 20 for both the LP first ESS option and the AUSTRON option, 0 for the ISIS 1 MW upgrade and 20 for ISIS-2. Secondly, while the ESS and the AUSTRON options concern a European facility from the outset, ISIS upgrade involves transforming a national facility into a European one, which unavoidably will imply redistribution of the operating costs of the current ISIS facility among other partners. More generally, it is clear that the set of facilities in Europe in 2015 will anyhow be different from present day for two reasons. The first one is ageing, while the second one is that scientific output can be substantially increased by trading existing sources for new ones in the top tier class discussed in this Report. Therefore, operational costs of the current facilities need also to be taken into account.

There are several reasons why it is not easy to draw firm conclusions from such a comparison. Firstly, only in a few cases more or less clear phasing out strategies exist. Another is that it is generally not known from which budgets decommissioning costs will have to be paid. Thirdly, the assumption that national funds thus freed would be freed would become available for a European overall solution is rather optimistic, though perfectly in the spirit of a European Research Area. In that same spirit it would be quite appropriate that all countries whose scientists benefit from a network of international facilities contribute to financing the running costs.

Considering these cost comparisons leads naturally to thinking about the overall evolution of the existing network of national facilities (plus the ILL) in a European scenario over the next 10 to 20 years. In areas such as particle physics or astronomy such a switch from a largely national or even regional and local outlook to a European one had to take place earlier. But it might well be the only rational way to come to grips with the difficulty of deciding which facilities to close down, and when. Assuming that, for instance, 15 years from now quite a few of the existing facilities will (have to) be closed, the question is then not so much which facility or facilities a new top tier facility will be obsolete, but rather which remaining set will be the best option for European science, as well as affordable and viable. Redistribution of the financial burden over countries will be very complex, but it is the very essence of a European Research Area to tackle these types of questions, including the role European level funds might play.

Table 5.3. Comparison of annual budget estimates for main existing European neutron facilities.

Facility	*Number of instruments*	*Annual budget in M€*
BBR Budapest	11	2
DR3 Risø (stopped in 2000)	7	12-15
R2 Studsvik	6	2-4 [1)]
FRG-1 Geesthacht	8	20-25
FRJ-2 Jülich	16	25-27
IRI TU Delft	4	3
ILL Grenoble	30	60
BERII Berlin	20	27
Orphée Saclay	25	21
IBR2 Dubna	12	4
ISIS Oxfordshire	20	47
SINQ Villigen	19	25
FRMII München	17	25-30?

1) Operation of the reactor comes from another budget

Table 5.3 summarises for the main neutron facilities the number of instruments and the running costs. The full costs include the running of the facility, salaries of the in-house staff (administrative, technical and scientific), and available budgets for refurbishment and replacement (in the case of SINQ it also includes the costs of write-off). In some cases estimates had to be made. A basic assumption is for example that considerably different power levels do not translate in equally large differences in running costs if a reactor is operated in a three-shift mode, and if the large share of fuel costs is considered.

Taking also into account a number of smaller facilities, a rough overall figure of close to 300 M€/year is obtained for the cost of the neutron facilities in Europe. (For comparison: CERN's budget alone is some 600 M€/year, which however also includes a fairly large amount for investments).

From the perspective of the science output, it is clear that a very large part of it comes predominantly from a few of the sources. This does not mean that others do not play a useful role, for instance in training. A truly European perspective, however, assumes that the overall European science output should come first. This may imply that the running costs of the remaining facilities would in the long run decrease from the present budget of 280 M€ by, for instance, 100 M€. As a consequence, the total European neutron running costs for the full ESS scenario would be 320 M€, which is of the order of 15% more than at present. Similarly, the LP ESS first stage would result in total running costs comparable to today's costs, and the 1 MW options in somewhat lower total running costs.

Apart from the assumption that the national freed funds remain available, and moreover flexibly throughout Europe, there is the problem of the investment costs to consider. There are different ways in which governments approach such investments. One way would be to consider them as one-off costs, as this Working Group has considered them so far. This approach would best apply if part of these costs were to be met from investment budgets that do not have only scientific purposes. The other way is to transform them into effective running costs. Using a payback period of 40 years and 2.5% government borrowing rates, they would result in an additional annual spending of 75 M€ for the full ESS, 50 M€ for the LPTS first in a staged approach towards ESS, 42 M€ for AUSTRON and 31 M€ for ISIS upgrade.

6. Summary

Neutron science in Europe is at a crossroads both politically and technically. Strategic choices must be made in the near future. This report shows that there are significant advantages to chart the way forward using the strength of the ERA concept. It is not an option to develop a neutron strategy for Europe only as a sum of decisions taken at the national levels.

Three scenarios have been presented, representing different levels of ambition, to make progress in a cost effective manner. Based on these scenarios, the neutron landscape in Europe can be developed in an integrated way. The guiding vision is to concentrate the efforts on the most scientifically productive facilities. In this way it is possible to arrive at a situation where fewer, higher performing facilities will deliver a significantly enhanced return on the current European annual expenditure of approximately 300 M€. The vision is to develop neutron scattering as an element of ERA. This will require open access for all European scientists to these key facilities and a coherent policy for the utilisation and development of the individual facilities.

The European situation must be seen in a global context. North America is increasingly adopting a national approach to its stewardship of large facilities. Not only is the USA investing $ 1.4 billion in SNS, but it is developing plans for upgrading the second tier facilities in a coherent manner with a goal that the majority of the instrumentation at these facilities should approach the “best in class” standard. This has sparked a revival of interest from university faculties, as witnessed by joint appointments with key universities. At the same time funds for nanoscience initiatives at $ 60 – 100 million each have been allocated to three of the neutron centres out of a total of five nanoscience initiatives.

These developments in the USA represent, together with similar ones in Japan, a strategic challenge for Europe. Short-term consequences are that young scientists will seek career opportunities in the USA and technical expertise, developed over the years in Europe, will be lost. The long-term consequence is the reduced ability to take advantage of the opportunities both scientifically and technically that can be provided by front rank neutron facilities with a vibrant user community.

Table 6.1.

Summary of the three scenarios, the ILL Millennium Programme and the ISIS-2 second target station.

Scenario *total gain*	Scientific impact	Socio economic impact Direct	Indirect	cost, M€ Cap.	recur.	Time to realise
ESS fully implemented *total gain: 85*	World leading in all areas; major breakthroughs and technological gains	large regional	Major growth pole potential	1552	143	8 years
ESS long pulse only *total gain: 34*	World leading in some areas and some leads in all others with breakthroughs and technological gains	large regional	Growth pole potential	991	79	7-8 years
1 MW AUSTRON type *total gain: 12*	competitive in all areas with some leads in few and breakthroughs and technological gains	medium regional	Some growth pole potential	835	77	8 years
1 MW ISIS upgrade *total gain: 12*	competitive in all areas with some breakthroughs and technological gains	medium regional	Some growth pole potential	621	85	5-7 years
ILL+millenium program *total gain: 8*	incremental technological gains	limited regional	already established	85	79	8 years
ISIS +second target *total gain: 6*	incremental technological gains	limited regional	already established	150	73	5 years

Because of the long lead times, and because of the rapid on-going development of neutron science and facilities outside Europe, it is urgent to develop a European strategy and corresponding road maps for neutron science infrastructure following one of the scenarios discussed here. The timelines in chapter 4 show that a new top-rank facility should be operational in the 2010- 2015 window in order to maintain a credible perspective for the user community and in order not to be left behind by the developments elsewhere, in particular in USA.

The need for a European strategy for neutron science infrastructure represents a challenge for decision making in Europe. There is a window of opportunity to go forward in a coherent manner with one of the proposed scenarios. At a minimum this can maintain the momentum Europe developed over the years, and in the most ambitious case it will develop new opportunities for science and technology commensurate with the standing of Europe in the world. The increased cost of the most ambitious scenario is well within the expansion rate needed for the European science budgets to reach an average 3% of the European GNPs.

6.1 Elements to an ERA strategy for neutron science infrastructure

- It should be recognised from the outset that the neutron landscape is dynamically changing without any joint decisions at the ERA level. By 2020 it is estimated that only half of the current capacity for neutron experiments will be available, as existing facilities reach the end of their life span.
- A vital element of an ERA neutron strategy is the willingness of the present owners to recycle the funds from existing facilities to the new ones in the scenarios described here.
- The ERA strategy should follow the OECD recommendations, with emphasis on the best performing facilities. The corollary is that efforts should be made to ensure that the least performing facilities are retired first.
- The analysis shows that the total recurrent operating costs for the existing (and newly retired) facilities in Europe are approximately 300 M€/year. Retaining the top four to five highest impact facilities would free only 100 to 120 M€ in recurrent spending. This would be sufficient to cover the projected recurrent costs (including investments in instrumentation) in ***scenario 2*** and ***scenario 3***. The realisation of ***scenario 1*** would require additional recurrent costs in the range of 20 M€.

Transition to any of the proposed scenarios will require a capital injection in the range 600 to 1500 M€. Such an investment would sustain the field for the next 25 to 40 years. Using a payback period of 40 years and 2.5% government borrowing rates, they would result in an additional annual spending of 75 M€ for the full ESS, 50 M€ for the LPTS first in a staged approach towards ESS, 42 M€ for AUSTRON and 31 M€ for ISIS upgrade.

The neutron science community is well organised on both national and European level and through the support from the EU framework programmes the community is tuned to take advantage of the opportunities that a common strategy and investment plan would bring in the spirit of a European Research Area. It is now up to the political decision makers and funding authorities the make the transition to the ERA mode of operation. Benefits from the ERA approach are that would be to:

- provide a viable avenue for decision making, taking into account the possible couplings to other science infrastructure decisions;
- make possible the realisation of the most ambitious scenarios, ***scenario 1*** or ***scenario 2;***

- maximise the scientific return per unit cost. This is the only affordable way for Europe to maintain a strategic world lead in the broad disciplines and technologies underpinned by neutron science;
- provide unique and equal opportunities for European scientists, in particular for young scientists and scientists from the new EU member countries;
- make a visible and credible major step towards the realisation of the Lisbon and Barcelona ambitions.

As an immediate step the current incoherent landscape should be recast with a greater degree of joint responsibility for the development and utilisation of the best facilities. Such a step should include a decision on the scenario for the top tier with a realistic perspective on when to start actual construction.

References

1. Proc. ESS European Conference, Bonn, Germany, 16-17 May 2002.
2. ***Report of the Workshop on Large Facilities for Studying the Structure and Dynamics of Matter,*** OECD 2002**.**
3. ***Scientific trends in condensed matter research and instrumentation opportunities at ESS*** ("Engelberg report"), ESS – SAC/ENSA, 2001.
4. ***The scientific-strategic case for a next-generation European spallation neutron source for science and research***, European Science Foundation, 2001.
5. ***Fine analysis of matter: report of Working Group,*** http://www.icmm.csic.es/fam-eg/finalreport_fam-eg.pdf, 2001.
6. ***Neutrons and Life: A review of biological research at the ILL*** Institut Laue Langevin, Grenoble, 2000.
7. ***Report of the Basic Energy Sciences Advisory Committee Subpanel on neutron scattering*** ("Blume Report"), U.S. Department of Energy, 2000.
8. ***Cooperative stewardship: managing the nation's multidisciplinary user facilities for research with synchrotron radiation, neutrons, and high magnetic fields***, U.S. National Research Council, 1999.
9. ***Condensed-matter and materials physics***, U.S. National Research Council, 1999
10. ***Scientific research facilities: a national resource***, U.S. Department of Energy, 1999.
11. ***Reflections on the Role of Research Infrastructures in the European Research Area.*** Highlights from the Research Infrastructures Conference, held in Strasbourg 18-20 September, 2000.
12. ***Large-scale facilities 1998***, European Commission, 1998.
13. ***Report of the Neutron Sources Working Group***, OECD, 1998.
14. ***Survey of the neutron scattering community and facilities in Europe***, European Science Foundation and European Neutron Scattering Association, 1998.
15. ***Final Report High Flux Isotope reactor upgrade and user program*** ("Crow Report"), U.S. Department of Energy, 1998.
16. ***A twenty years forward look at neutron scattering facilities in the OECD***

countries and Russia (D Richter and T Springer), European Science Foundation and OECD, 1998.

17. ***Scientific prospects for neutron scattering with present and future sources*** (The “Autrans Report”), European Science Foundation and European Neutron Scattering Association, 1996.

18. ***Neutron beams and synchrotron radiation sources***, OECD, 1994.

Technical Annexes

to the Report

Annex 1 - Synthesis of Science Expert Group Results

1.Methodology

The Science Advisory Committee of ESS has called a special workshop of scientists and instrument specialists from all over Europe to assess the scientific performances of the three options. The following approach has been used.

<u>Step 1</u>

The basis has been an analysis of the source performance gains of the set of priority instruments selected for ESS at each of the three options. The detailed outcomes can be found in annex 4.

> *To put matters in perspective: ESS will increase the available neutron source intensity, at the various possible different instruments devoted to experiments, by a factor approximately between 10 and 100 compared to existing sources (ILL and ISIS are the most powerful), and a factor between 2 and 5 for sources actually under construction (2 and 1 MW spallation sources are presently under construction in USA and Japan respectively). The increase in intensity is extremely important because at present neutron research is limited in its applications by two different factors, which may be relevant independently for different experiment, i.e. the power of the source and the available time duration for each experiment, which in turn is related to various factors as the power of the source itself, the stability of the overall instrumentation, the lifetime and dynamic evolutions of investigated samples and the necessity of performing several experiments per month at each instrument in order to satisfy the very high scientific level international demand (it is well known that the instrument at the highest power neutron sources have an average over subscription for experimental time request of the order of 2).*

Comparison has been made both to the full ESS to find out what one looses with the other options, and to SNS to determine where Europe would still be leading or competitive.

Instrument gains have not been considered since they can be achieved on any source, but of course the overall advance of neutron science will also in the future very much depend on the continuing and exciting improvements in instrument performances. Examples are the use of multiplex ideas in chopper based instrument spectroscopy and the phase space transformation to achieve highly monochromatic beams starting from an ultracold neutron source. To summarize: power isn't everything…. but it is most things.

The outcome of the analysis of instrument performance is as follows:

<u>ESS</u>

- The performance of all instruments would be world-leading;
- the two target stations would be complimentary;
- optimisation of instruments to provide unparalleled capabilities to serve a broad scientific programme of research in numerous fields not possible today.

<u>Long Pulse Target Station (LPTS)</u>

- Qualitatively new type of source;
- new instrument designs (Potentially greater risks, but more development head-room);
- a stand-alone source can deliver a balanced scientific programme of research in various fields not possible today;
- most instruments would be world leading, all would be world-class.

<u>1 MW 50 Hz Short Pulse Target Station (SPTS)</u>

- The performance of all instruments would fall below SNS.

<u>1 MW 10Hz Short Pulse Target Station (SPTS)</u>

- The performance of most instruments would fall below SNS;
- a few would provide comparable performance.

<u>Step 2</u>

This instrument performance gains have been related to the flagship area that where identified in the various scientific areas where neutron spallation sources of the next generation are globally considered to be strategic tools with a very high impact.

A flagship area has been defined as an area where a major of source intensity beyond a certain threshold (of the order of a factor of 10 to 100) is needed to achieve the targets or visions perceived. Examples of such thresholds are in the area of energy conversion where gain of 30-40 was considered necessary, magneto-electronics where gains of 70 would be needed and dynamic phenomena in complex materials where two orders of magnitude must be gained.

To identify the relative position of the three options in the various field of science and flagship areas, also with respect to SNS, three categories are used: ‘world leading’ meaning more than a factor of 2 better than SNS, ‘competitive’ meaning a factor of the order of 1 relative to SNS and ‘loss of world lead’ in the other cases.

2. Conclusions for areas of science

In the following we give a short summary of the findings in the various areas of science. The report of the various expert groups is included as annex 4.

Solid State Physics

Solid state physics encompasses fundamental research that has underpinned much of the technological progress in the last 50 years. Recent trends include the emphasis on complexity, including organic materials and reduced dimensionality down to the scale of quantum dots. Scientific challenges beyond current thresholds, so called flagship areas in solid state physics are e.g. the understanding of strongly correlated electron systems and molecular magnets, the access to the dynamics of superlattices, thin films, wires and dots and to quantum phase transitions in general.

As alluded to in the appendix the different source options satisfy the requirements in the following way:

<u>5 MW stand-alone LPTS:</u>
A stand-alone LPTS would offer, averaged across all the flagship areas, 50% of the performance anticipated from the Bonn reference ESS. In the areas of “films and superlattices” and “spin glass dynamics” the facility would be world leading. In all other areas it would be competitive with SNS.

<u>1 MW SPTS at 50 Hz:</u>
A stand-alone 1 MW SPTS 50 Hz station would offer, averaged across all the flagship areas, 20% of the performance anticipated from the Bonn reference ESS. This distribution is almost uniform across all areas. The option falls a factor of two behind the SNS.

<u>1 MW SPTS at 10 Hz:</u>

A stand-alone 1 MW SPTS 10 Hz station would offer, averaged across all the flagship areas, less than 30% of the performance anticipated from the Bonn reference ESS. This distribution is once again almost uniform across all flagship areas. The option falls behind the SNS.

While the 5 MW LPTS provides a leading position in some areas of solid state physics the other two options fall behind the SNS.

Material Science and Engineering

Materials Science and engineering provide the keys to future technologies, economic wealth and sustainable growth. Flagship areas in Material Science are e.g. a molecular approach to lubrication phenomena, a quantitative evaluation of stress strain concepts in engineering, which is crucial for the assessment of residual stresses in manufacturing processes or in fatigue cycling, in situ observation of energy conversion processes and realistic studies of materials in magnetoelectronics. Material science studies with neutrons will unravel crucial information on functional materials such as magnetoresistive materials and high temperature superconductors, photoresponsive materials for holographic data storage and magnetic elastomers.

5 MW stand-alone LPTS:

A stand-alone LPTS will offer a European lead in microelectronics and tomographic applications. With a few exceptions in all other areas a competitive position would be achieved.

1 MW SPTS at 50 Hz and 10 Hz:

In no area these options would provide European lead, in contrast in nearly all fields Europe would significantly fall behind the SNS.

Liquids and Glasses

Neutron scattering is a key experimental technique in the study of the atomic structure and dynamics of liquids and glasses. The intensity gains provided by ESS together with the ever-increasing power of computer simulations will enable a visualization of " where the atoms are and what the atoms do". Extensive studies of structural effects in solutions will provide a coherent picture of solvent structures around molecules. Flagship areas are e.g. the determination of the solvent structure around biological macromolecules, crystallisation, nucleation, order-disorder transitions, kinetics, ageing, processing of e.g. nanocrystalline materials, element specific atomic dynamics of disordered matter (using isotopic substitution) and high information bandwidth atom specific dynamics combined with modelling and simulation studies (making movies).

5 MW stand-alone LPTS:

A 5 MW long pulse target station would achieve everything that the ESS Bonn design does in terms of dynamical studies and here it would provide a clear world lead.

In terms of structure the 5 MW long pulse option provides a small improvement over current capability but is not competitive with SNS.

1 MW SPTS at 50 Hz and 10 Hz:

A 1 MW short pulse target station would be internationally competitive in all areas, but not world leading in any.

Soft Condensed Matter.

Future trends in soft condensed matter will concentrate mainly in four different areas: i) kinetic and non-equilibrium studies will address e.g. the kinetics of biomineralization, of self-assembly and structure formation and possibly also protein folding. ii) Important breakthroughs are expected in the vast field of complex materials where the knowledge base to fine tune the structures achievable by self assembly will be created which could lead to e.g. nanostructured magnetic devices, self healing smart materials, photonic crystals, drug delivery systems and tailored catalysts supports. An understanding of the behaviour of complex fluids in porous media will be a prerequisite for tertiary oil recovery. (iii) In soft matter, dynamic phenomena to an even large extend than in hard matter determine the mechanical and rheological properties. It will be crucial to explore the unknown territory of collective dynamics in disordered complex materials, and the glassy state, and to address the dynamics of surfaces. (iv) The component behaviour in multicomponent formulations like e.g. oil additives, detergents, food additives and cosmetics needs to be addressed and phenomena like surface phase transitions, membrane protein interactions (biosensors) and the actions of compatibilisers need to be scrutinized.

5 MW stand-alone LPTS:
The full ESS as well as the LPTS would provide a leading European position in all areas of soft matter science with neutrons.

1 MW SPTS at 50 Hz and 10 Hz:
With the SPTS options the opportunities for breakthroughs in soft matter science relating to SANS, reflectometry and NSE will be lost, while in the field of short time dynamics major advances would still be possible. In none of the areas of the soft matter science a European lead would materialize.

Chemical Structure, Kinetics and Dynamics

Our understanding of materials is based upon a detailed knowledge of their structures and dynamics at the atomic and molecular level. With current neutron instrumentation, the instrument and not the sample generally determine the timescales of experiments; similarly, sample size is often dictated by flux limitations and not real life conditions. Flagship experiments cover a broad range of science and comprise the generic areas of materials processing and synthesis, in-situ measurements of lifetime performance and materials optimisation such as the kinetics of chemical reactions, in situ observation of catalytic processes, the electrochemistry in fuel cells or hydrogen bonding and proton dynamics in supramolecular chemistry to smart materials that respond to their environment.

5 MW stand-alone LPTS:
With LPTS alone, Europe will lead in the following flagship areas: electrochemistry at surfaces, in situ observation of polymer synthesis and diffusion processes in porous materials and will be competitive in all other areas.

1 MW SPTS at 50 Hz and 10 Hz:
With 1MW SPTS, leadership will be lost in all areas compared to full ESS. However, the facility will be still competitive (within a factor of 2) compared to the other worldwide neutron sources.

Biology and Biotechnology

Structure function and dynamics of biological macromolecules operate across a wide range of time and length scales that are well matched to the fundamental characteristics of neutron scattering. Current source limitations have restricted studies to simple and/or model systems. *ESS will make it possible to study real complex, interacting macromolecular systems such as:* self-organisation processes and functional aspects of *native* membranes with implications for biosensors and biochips, the interaction of proteins *in vivo* within their cellular environment, the mechanisms of drug binding and drug delivery and the understanding food processing at the molecular level.

5 MW stand-alone LPTS:
With the LPTS option alone Europe would keep the world lead in the majority of the flagship areas.

1 MW SPTS at 50 Hz and 10 Hz:
In virtually all cases, instrument performance is seriously reduced on both the 10hz and 50Hz 1MW source options with loss factors of between 5 and 20 compared with a full ESS. Such order of magnitude losses will leave Europe uncompetitive across all classes of experiment and, critically, would render priority and flagship areas of science unfeasible.

Mineral Sciences, Earth Sciences, Environment and Cultural Heritage

In geophysical science the prevention of hazards post by volcanic eruptions and earthquakes is a major scientific driver. Therefore, the understanding of the behaviour of matter under the conditions of the earth mantle is of prime importance. A number of flagship areas in this field are related to this challenge. Another field of importance is the investigation of continental shelf methane clathrates, which could serve as a basis for future energy supply. A third area investigates the history of the genesis of the earth. Finally, aspects of cultural heritage like the fingerprinting of archaeological materials and their non-destructive analysis come into play.

5 MW stand-alone LPTS:
It is evident that only the full ESS will achieve the flagship goals and provide the European lead in these areas of science. The LPTS retains some lead in the field of methane clathrate research and the tomographic investigation of fluids and melts under earth mantle conditions as well as the tomography of archaeological materials.

1 MW SPTS at 50 Hz and 10 Hz:
The 1 MW SPTS offers little or no advantage over other planned sources.

Fundamental Neutron Physics

Neutrons are a powerful tool for particle and nuclear physics and they are ideal probes for quantum investigations and gravitational physics. The related experiments depend on the availability of high densities and fluxes for cold and ultracold neutrons. The European Spallation Source is, therefore, of intense interest for fundamental studies in these fields. Contrary to the usual particle physics experiments, which take place at the highest possible energies of particles, these experiments with neutrons have energies, which are even much lower than those of ordinary gas molecules. Rather recently, new proposals for ultracold neutron sources using advanced moderation and pumping processes make density gains in the order of 10^3 – 10^4 feasible. ESS will open the door for completely new investigations into basic laws of physics. Issues are the physics beyond the standard model of particle physics, the origin of the matter antimatter asymmetry which occurred at early stages of cosmology and quantum gravity effects which could reveal deviation from the Newtonian potential due to large extra-dimensions in modern string theories.

In order to achieve the required high density of ultracold neutrons, a dedicated UCN target station is requested. In addition a high intense beam line for cold neutrons at the cold moderator is needed. Compared to such a potential UCN station at SNS the LPTS would gain a factor of 9, the 10 Hz 1 MW station would fall behind. Similarly for the cold neutron beam line the LPTS would be preferred.

Annex 2 - Auxiliary investments and special equipment

Standard sample environment, thermodynamic parameters

Access to a broad range of thermodynamic parameters during neutron scattering experiments is important both as a handle to help understanding matter by exploring its response under various conditions and to investigate behaviour under conditions of practical relevance. Examples are extreme low temperatures for the study of quantum phase transitions or extremely high temperatures and pressures for the study of matter under geological conditions. While the development of basic technologies to achieve high and low temperatures, high pressures and magnetic fields are not primarily done at neutron facilities, adapting these techniques to neutron scattering environment, maintaining the equipment and operational support during user experiments requires strong sample environment departments on the site in all scenarios. This includes the strengthening of these services both at ILL and ISIS compared to current levels, and actually the size of the effort should be the same in all scenarios. Development work will be needed towards more extensive combination of temperature, pressure and magnetic field capabilities and chemical environment control, such as controlled atmosphere. For a 20 – 22 instrument (one target station) facility the standard sample environment equipment will require an original investment of about 10 M€ (including laboratory space), a yearly capital equipment budget of 1.2 M€ and a staff of 10 (4 scientists and 6 technicians). Some economy of scale applies to a 40 – 50 beam line facility: 15 M€ initial equipment, 2.2 M€ yearly capital equipment budget and a staff of 16 (6 scientists and 10 technicians).

High magnetic fields

Under “standard sample environment” above super-conducting magnets can be envisaged for up to 17 Tesla today, and eventually 20 – 22 Tesla in 10 years time, unless an unsuspected breakthrough happens. Neutron scattering is a privileged probe of magnetism, and therefore the high field environment is of particular significance, for example for the study of vortex states in high T_c superconductors. Higher fields can either be achieved for neutron work in pulses of a few ms duration (which only allows to use the neutron source with some 2 orders of magnitude reduced efficiency) or by resistive DC magnets. Both approaches require substantial additional investment, a pulsed field capability up to 40 Tesla could amount to 10 – 15 M€ capital investment, and a similar DC field capability to 70 – 80 M€. Operating staff in both cases will require 10 FTE, with annual recurring costs, respectively, 2 and 7 M€.

User support laboratories

While the samples will be prepared and extensively characterized by the users before their arrival, more and more on site sample conditioning, storage and control capabilities are required. Samples often have a limited lifetime in the state to be studied, in particular biological ones, and cannot be completely prepared in advance. Phase transformations and hysteretic behaviour during the experiments makes a basic set of on site sample characterisation capabilities indispensable. An initial investment of about 4 M€ and a qualified support staff of 3 people will be required.

Deuteration and isotopic labelling

A key advantage of neutron scattering in the study of biological matter is its sensitivity to hydrogen atoms and the capability to selectively label these atoms by replacing them with deuterium. This type of sample preparation and conditioning is specific for neutron research and should be an integral part of experimental design. A deuteration facility needs to be part of any scenario, which will require 3 M€ initial investment, a staff of 5 people (including 2 scientists) and recurring costs of 0.5 M€ per year. Such a facility could serve several neutron scattering facilities across Europe, it could be eventually part of a larger biological laboratory and in these cases some economy of scale can be achieved. Nevertheless, to insure the best return on the substantial investment in the unique samples here produced, they will be primarily destined for utilization at the most powerful neutron facility (or facilities).

Nanoscience and in situ experimentation

In the investigation of nanoscale phenomena the fabrication of the samples contains much of the novelty and challenge. Neutron scattering will play an important role in this field, which will in particular include neutron investigation of processes and procedures in nanofabrication. To take best advantage of synergies, all three new nanoscience centres now being set up in the US are situated near major facilities, one of them being built (with 60 M$ funding) on the premises of the Spallation Neutron Source at Oak Ridge. Although much of the scope of such a laboratory can be accomplished without the immediate vicinity of a neutron facility (most samples expected to be transportable) in situ neutron scattering investigation of sample growth and function will open up new opportunities, as it already has been demonstrated in thin film research. In situ neutron work, including not only nanoscience but also the monitoring of functioning of whole systems (e.g. lubrication), will require auxiliary equipment in rapidly growing proportions, the initial effort can be estimated to be comparable to that for "standard sample environment", i.e. 10 M€ investment and a staff of 10 people with an operating budget of 1.5 M€.

Summary

The scientific impact of neutron scattering facilities in any of scenarios will by conditioned and largely enhanced by investment in auxiliary equipment of sample environment, sample preparation and characterisation, selective deuteration of biological samples and in situ experimentation. The size of this effort per facility depends little of the power of the facility and highest neutron scattering capability offers highest return on this investment. The initial investment, staff and annual budget needed (without highest magnetic fields and operational costs directly related to experiments on the neutron scattering instruments) amounts to 25 – 30 M€, 25 – 30 full time collaborators and about 2.5 M€, respectively, for a new facility. Since most of the required equipment is new and little of what exists today will be adequate in a few years time, essential savings at an upgraded facility will mainly come from the partial availability of laboratory space only. Approaching state of the art high magnetic fields in neutron work in pulses or as much more efficient stationary fields will require additional 10 – 80 M€ investment, staff of 10 and 2 – 7 M€ annual budget.

Annex 3
Comparison of Instrument Performances at the Different Sources

ESFRI – Scenarios

The scenarios to be considered by the ESFRI Working Group are the following:

1. build ESS as proposed with both the 5MW long pulse target station (LPTS) and 5MW short pulse target station (SPTS);
2. phase the ESS construction by building first the long pulse target station (5MW), with the option of adding the short pulse target station at a later stage;
3. build an up to 1MW short pulse target station either as an upgrade of ISIS or as a new facility of the AUSTRON type elsewhere in Europe.

Technical remarks on scenario 2:

1) In the initial absence of a SPTS on the same site the linac will accelerate H^+ ions, which can be done as well as using H^- ions required for injection into ring accelerators. The reason for this is that H^+ ion sources are much easier to build and therefore are the preferred ion sources to realise a 5MW LPTS compared to H^- sources.
2) The relative low peak flux of the LPTS in the hot neutron domain (0.4 – 0.9Å) can be enhanced by replacing one of the moderators by an ILL or LLB type hot source of graphite at about 2000K temperature. This is a new idea for a spallation source, and the first neutronics calculations for evaluating its performance are in progress. At present it was assumed, that it works with a rather similar efficiency compared to the thermal coupled moderator as the hot sources do at reactors (the coupled moderators being rather reactor like). The hot moderator would also remedy a weak point of current or currently planned pulsed spallation source performance in comparison to reactors operating a hot source: the low time average hot neutron flux so valuable for single crystal work, e.g. with polarized neutrons.

Neither of changes 1) and 2) compared to the ESS reference design is an essential modification of the basic ESS hardware and has no influence on the upgradeability of the facility to full ESS specifications.

Technical basis of the performance comparison

Basis for the comparison of the instrument performance at the different sources defined in the above scenarios is the neutron – wavelength dependent moderator performance as illustrated in Fig. 1 for different moderators at a 5MW, 50Hz SPTS and a 5MW, $16^2/_3$Hz LPTS. More detailed information on the procedure to arrive at numbers for the expected performance of generic instruments on various sources, i.e. gain factors for the instrument performance compared to existing instruments at the best neutron sources of today (ILL and ISIS) can be found in ESS Vol. IV “Instruments and User Support”.

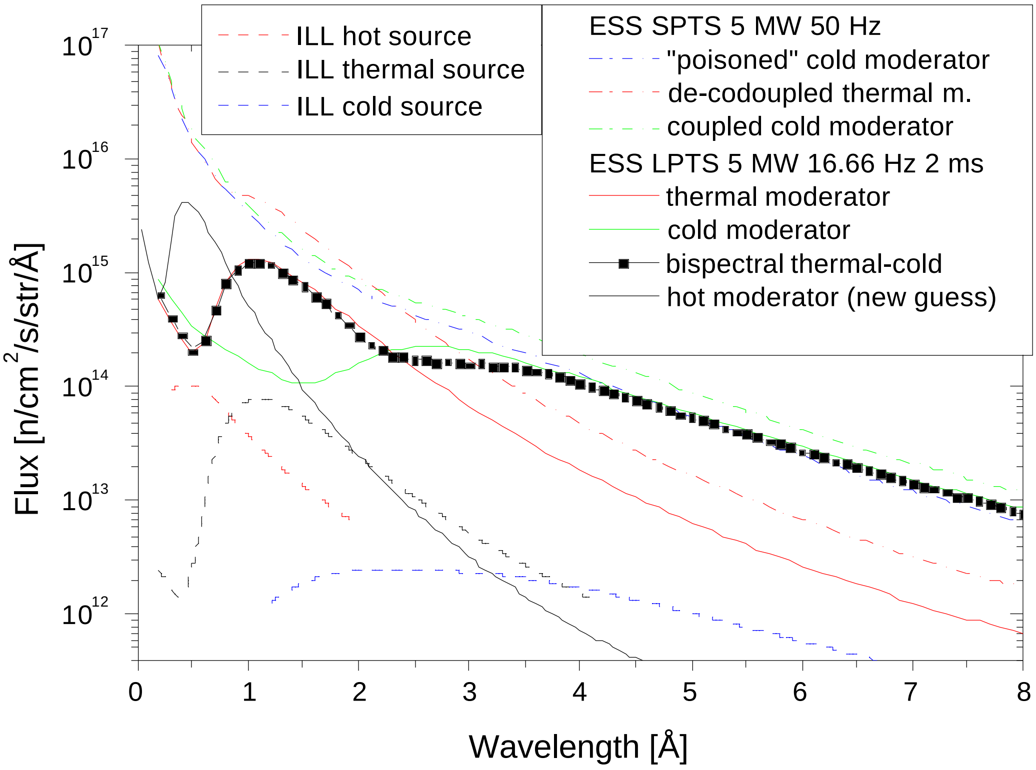

Figure A3.1: Comparison of moderator performances at the ESS SPTS and LPTS.

Comparing neutron performances between a LPTS and a SPTS – as requested by the above scenarios - for the same set of applications is not quite straightforward. Basically one can distinguish two cases:

1) Applications which were found to be better served by a $16^2/_3$Hz 5MW, 2ms LPTS than by a 50Hz SPTS of equal power: In these cases (e.g. SANS, reflectometry, certain types of spectroscopy…) the relative figure of merit scales somewhere between the time average flux and the time integrated neutron flux per pulse.
2) In the other applications (which essentially concern higher wavelength resolutions and thermal and epithermal neutrons) the peak flux has been found to be a reasonable figure of merit. This is based on the fact, that novel multiplexing chopper techniques will allow us to cut the long pulses to lengths required for the resolutions offered by the various equivalent short pulse instruments. Above 0.9Å wavelengths multiplexing disc chopper systems can do the job (with curved guides or conventional T_o choppers used to filter out fast neutrons) and below this wavelength Fermi choppers provide adequate performance (with no need for multiplexing for a < 1Å wavelength band and also eventually combined with T_o choppers)

In view of the expected peak fluxes for the above scenarios, the 5MW LPTS outperforms the 1MW SPTS by a factor ranging from 2 – 9 for the whole wavelength range > 0.4Å (without the hot source for wavelengths > 0.9Å only). At wavelengths < 0.4Å the 1MW SPTS is gradually more and more efficient than the 5MW LPTS by a factor which reaches some 25 : 1 below 0.2Å in applications that require the best available wavelength resolution.

However, the peak flux as guide does not apply to instruments in an LPTS - SPTS comparison without limits. The physical reason for this is the exact mapping of resolution and wavelength band by making the lower rep rate LPTS instruments longer in proportion to the rep rate ratio. The same resolution then requires correspondingly longer and more intense pulses, which can be carved out from the flat LPTS pulses. This matching for TOF inelastic scattering already implies the use of repetition rate multiplication, i.e. both the pulses have to be made longer and rep rate needs to be multiplied. (This is because mathematically true mapping would also require making the secondary spectrometer proportionally larger, which is just not practically possible). This mapping is not possible with a lower repetition rate short pulse source. A comparable approach would be on the lower rep rate SPTS source to replace the moderators with more coupled (longer pulse, higher intensity) ones. The actual potentials for this are, however, limited. For epithermal (< 0.7Å) neutrons the standard Gd poison is not effective, so all moderators are about the same. As ambient moderator the de-coupled (not-poisoned) H_2O moderator is the reasonable choice for 50Hz (see ESS). The coupled H_20 moderator offers more flux, however with much of it in a very long tail, and therefore it is not a good choice even for a 10Hz machine. For cold neutrons the coupled moderator is the workhorse already at 50Hz. The only real potential gain for the 10Hz here is to use a thick de-coupled H_2 in the slowing down range between 0.7 and 2.5Å, which offers a 2 fold gain in diffraction work.

Repetition Rate Multiplication helps to increase the efficiency of low rep rate sources, within certain limits though. For hot and thermal neutrons it would ideally be needed at 50Hz too, but since the ideal instrument lengths are rather short in order to achieve best intensity (typically 13 – 20m), the wavelength band of the multiplied pulses is already too large (= 4Å) even at 50Hz to be fully useful. In this range one can think of a useful multiplication to max 5 times, independently of whether the SPTS source runs at 10 or 50Hz. A little more can be achieved with an LPTS, if one makes the instrument very long, taking advantage of the very much expandable pulse length to maintain resolution. In the cold neutron range rep rate multiplication will, on the other hand, really help the 10Hz SP facility compared to the 50Hz one, but again not without limits. Making the instrument longer will result in reduced intensity due to inherently enhanced incoming wavelength resolution and thus this is not an acceptable choice. Staying with the lengths reasonably chosen for the coupled H_2 moderator (40m at ESS SPTS, 63m at Los Alamos), the multiplied wavelength band will be larger than 6Å, which again cannot be considered simultaneously useful in most cases.

Resulting Source Gain Factors

To compare the instrument performance at the various options of the scenarios defined above, in the following tables only source gain factors are used. This is because additional gain factors due to the improvement of instruments (“instrument gain factors”) can be realized at any source and do therefore not depend on the scenario. Additionally, working with source gain factors facilitates a incessant comparison with the source gain from the Chalk River neutron source in the fifties to the ILL, which was only a factor of 4.

The instruments are subdivided into two groups: The “priority instruments” were chosen in the coarse of ESS – SAC expert meetings which were attended by scientists from all over Europe and beyond (for details see ESS Vol. II). In these meetings instrument capabilities and scientific and technological needs were mapped to each other. The basis for the instrument prioritisation was a list of about 30 generic instruments. Instruments which didn’t fall in the priority class are in the group "other instruments".

Tables A3.1 (priority instruments) and A3.2 (other instruments) list the instrument source gains of the ESS priority instruments and others with respect to the best existing instruments at either ILL or ISIS.

Tables A3.3 (priority instruments) and A3.4 (other instruments) benchmark with respect to the full ESS. From this table the losses in instrument performance for the scenarios 2 or 3 are evident.

Finally, in tables A3.5 (priority instruments) and A3.6 (other instruments) the instruments are benchmarked against SNS 1.4 MW (J-PARC would look very similar). This table shows where Europe would stand with the different options and furthermore, how the present European sources will look like in the world arena.

Table A3.1: Source gain of high priority instruments at different source options benchmarked against today's best instruments *

			FULL ESS					
Instrument	**50Hz 1MW**	**10Hz 1MW**	**ESS SPTS**	**ESS LPTS**	**LPTS $16^{2}/_{3}$Hz 5MW**	**SNS 1.4MW**	**Benchmark**	**Instrument gain**
thermal chopper	$6^{2}/_{3}$	$6^{2}/_{3}$	30	10	10	9	ISIS (HET)	8
cold chopper	13.12	$26^{1}/_{4}$	60	30	30	19	IN5 (ILL)	$26^{2}/_{3}$
variable cold chopper (high resolution)	13.12	$26^{1}/_{4}$	40	30	30	19	IN5 (ILL)	40
variable cold chopper (high intensity)	1.5	3.1	7	22	22	2	IN5 (ILL)	40
backscattering 0.8 μeV	5.5	5.5	25	6	6	8	IN16 (ILL)	2
high resolution NSE	1.1	3	5	20	20	1.2	IN11 (ILL)	10
wide angle NSE	1	2	4	9	9	1.1	SPAN (ILL)	$33^{1}/_{3}$
chemical single X	4.4	6	20	10	10	6.5	SXD (ISIS)	1
high resolution protein	4.4	8	20	10	10	6.5	LADI (ILL)	1
low resolution protein	0.85	0.85	4	4	4	1.4	DB21 (ILL)	1
high resolution powder	11	22	50	15-50	15–50	13	HRPD (ILL)	2 - 4
magnetic powder	13	13	60	35 – 50	35– 50	18	OSIRIS (ISIS)	1
high intensity reflectom.	2	4	10	22	22	5	ADAM (ILL)	2
liquid diffractometer	4.5	4.5	20	1 – 10	1 – 10	6.5	SANDALS (ISIS)	1
high intensity SANS	1	2.5	4-5	15	15	1.4	D22 (ILL)	1
engineering diffractom.	$6^{2}/_{3}$	10	30	10 – 25	10 – 25	12	ENGIN-X (ISIS)	3
fm-SANS	1	2.5	5	15	15	1.4	ILL	
Bragg edge TOF tomogr.	35	35	200	40	40	50		--
single pulse diffraction	$6^{2}/_{3}$	30	30	15 - 30	15 - 30	9	GEM (ISIS)	15

Table A3.2: Source gain of other instruments compared to best instruments of today *

			FULL ESS					
Instrument	**50Hz 1MW**	**10Hz 1MW**	**SPTS**	**LPTS**	**LPTS 5MW $16^2/_3$Hz**	**SNS 1.4MW**	**Benchmark**	**Instrument gain**
high energy chopper	6.6	6.6	30	10	10	9	MAPS (ISIS)	1
backscattering 1.5 μeV	22	22	100	22	22	30	IN16 (ILL)	3
backscattering 17μeV	33	33	150	150	150	45	IRIS (ISIS)	4
const .Q spectrometer	22	22	100	44	44	31	PRISMA (ISIS)	5
molecular vibration spectrometer	11	11	50	2– 45	2 – 45	15--3.5	TOSCA (ISIS)	2
eV-resonance-spectrom.	6.6	6.6	30	0.5	0.5	9	eVS (ISIS)	10
triple axis	0.05 – 0.4	0.05 – 0.4	0.25 – 0.2	0.25 – 3	0.25 – 3	0.07 – 0.6	RITA (ILL)	2 – 4
high resolution single X	4.4	6	20	4– 10	4 – 10	6.5	D9 (ILL)	1
single peak cryopad	0.06 – 0.6	0.06 – 0.6	0.3 – 3	3 – 10	3 – 10	0.09 – 0.9	D10 (ILL)	1
high Q powder	13	13	60	40	40	19	POLARIS (ISIS)	3
high resolution reflectom.	27	50	120	90	90	32	SURF (ISIS)	2
high λ resolution SANS	35	70	150	150	150	50	ISIS	1
ultra cold neutron factory								
source gain	13	67	67	200	200	15	PSI	48
total gain	640	3200	3200	9600	9600	750	ILL	

* The last column indicates instrument gains, which on the top of the source gain appear to be possible. The final performance figure is the product of source and instrument gain.

Table A3.3: Source gain benchmarked against full ESS (high priority instruments)

Instrument	**50Hz 1MW**	**10Hz 1MW**	**LPTS 5MW $16^{2}/_{3}$Hz**	**SNS 1.4 MW**	**ISIS/ILL**
thermal chopper	0.22	0.22	0.33	0.31	0.03
cold chopper	0.22	0.44	0.5	0.31	0.02
variable cold chopper (high resolution)	0.22	0.44	0.63	0.31	0.025
variable cold chopper (high intensity)	0.07	0.14	1	0.10	0.05
backscattering 0.8 μeV	0.22	0.22	0.24	0.31	0.04
high resolution NSE	0.06	0.15	1	0.065	0.05
wide angle NSE	0.11	0.22	1	0.12	0.11
chemical single X	0.22	0.3	0.5	0.32	0.05
high resolution protein	0.22	0.4	0.5	0.32	0.05
low resolution protein	0.21	0.21	1	0.35	0.25
high resolution powder	0.22	0.44	0.3 – 1	0.25	0.02
magnetic powder	0.22	0.22	0.6 – 0.86	0.29	0.02
high intensity reflectom.	0.09	0.18	1	0.24	0.05
liquid diffractometer	0.22	0.22	0.05 – 0.5	0.32	0.05
high intensity SANS	0.07	0.17	1	0.09	0.07
engineering diffractom.	0.22	0.33	0.33 – 0.83	0.39	0.03
fm-SANS	0.07	0.17	1	0.09	0.07
TOF tomography	0.18	0.18	0.2	0.25	--
single pulse diffraction	0.22	1	0.5 – 1	0.31	0.03

Table A3.4: Source gain benchmarked against full ESS (other instruments)

Instrument	**50Hz 1MW**	**10Hz 1MW**	**LPTS 5MW $16^2/_3$Hz**	**SNS 1.4 MW**	**ISIS/ILL**
high energy chopper	0.22	0.22	0.33	0.30	0.03
backscattering 1.5 μeV	0.22	0.22	0.22	0.30	0.01
backscattering 17μeV	0.22	0.22	1	0.30	0.007
const .Q spectrometer	0.22	0.22	0.44	0.30	0.01
molecular vibration spectrometer	0.22	0.22	0.04 – 0.6	0.32	0.02
eV-resonance-spectrom.	0.22	0.22	0.02	0.30	0.03
triple axis	0.22	0.22	1	0.28	0.3 – 4
high resolution single X	0.22	0.3	0.2 – 0.5	0.32	0.05
single peak cryopad	0.02 – 0.06	0.02 – 0.06	1	0.03 – 0.09	0.1 – 0.33
high Q powder	0.22	0.22	0.66	0.30	0.02
high resolution reflectom.	0.22	0.44	0.73	0.27	0.008
high λ resolution SANS	0.22	0.44	1	0.33	0.007

Table A3.5: Source gain benchmarked against SNS 1.4 MW (high priority instruments)

Instrument	50Hz 1MW	10Hz 1MW	Full ESS	LPTS 5MW	ISIS/ILL
thermal chopper	0.7	0.7	3.2	1	0.11
cold chopper	0.7	1.4	3.2	1.6	0.055
variable cold chopper (high resolution)	0.7	1.4	2.2	1.6	0.055
variable cold chopper (high intensity)	0.7	1.4	10	10	0.45
backscattering 0.8 μeV	0.7	0.7	3.2	0.7	0.13
high resolution NSE	0.8	2.4	15.5	15.5	0.85
wide angle NSE	1	1.8	8.5	8.5	1
chemical single X	0.7	1	3.1	1.6	0.15
high resolution protein	0.7	1.3	3.1	1.6	0.15
low resolution protein	0.55	0.55	2.8	2.8	0.7
high resolution powder	0.8	1.7	3.9	1.2 – 4	0.085
magnetic powder	0.7	0.7	3.4	2 – 2.8	0.055
high intensity reflectom.	0.4	0.7	4.2	4.2	0.18
liquid diffractometer	0.7	0.7	3.1	0.15 – 1.5	0.15
high intensity SANS	0.7	1.8	10.5	10.5	0.7
engineering diffractom.	0.55	0.9	2.5	0.8 – 2.1	0.085
fm-SANS	0.7	1.8	10.5	10.5	0.7
TOF tomography	0.7	0.7	4	0.9	--
single pulse diffraction	0.7	3.2	3.2	1.6 – 3.2	0.11

Table A3.6: Source gain benchmarked against SNS 1.4 MW (other instruments)

Instrument	**50Hz 1MW**	**10Hz 1MW**	**Full ESS**	**LPTS 5MW $16^{2}/_{3}$Hz**	**ISIS/ILL**
high energy chopper	0.7	0.7	3.2	1.1	0.11
backscattering 1.5 μeV	0.7	0.7	3.2	0.7	0.028
backscattering 17μeV	0.7	0.7	3.2	3.2	0.028
const .Q spectrometer	0.7	0.7	3.2	1.4	0.028
molecular vibration spectrometer	0.7	0.7	3.2	0.13 – 2.8	0.055
eV-resonance-spectrom.	0.7	0.7	3.2	0.055	0.11
triple axis	0.7	0.7	3.5	3.5	1.7 – 14
high resolution single X	0.7	0.95	3.2	0.55 – 1.5	0.15
single peak cryopad	0.7	0.7	~14	~ 14	1.1 – 11
high Q powder	0.7	0.7	3.2	2.1	0.028
high resolution reflectom.	0.7	1.5	3.8	2.8	0.028
high λ resolution SANS	0.7	1.4	3.2	2.9	0.014

Annex 4 - Expert Group Reports

Solid State Physics

A. Furrer, C. Vettier, R. Cywinski

Material Science and Engineering

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Chemical Structure, Kinetics and Dynamics

W.I.F. David, H. Jobic, M. Latroche

Soft Matter

J. Colmenero, D. Richter, A. Arbe

Liquids and Glasses

F. Barocchi, R. McGreevy, F. Mezei

Biology and Biotechnology

G. Fragneto, D. Myles, P. Timmins

Mineral Sciences, Earth Sciences, Environment and Cultural Heritage

R. Rinaldi, B. Winkler, S. Redfern

Fundamental Neutron Physics

H. Rauch, H. Abele

List of Participants

Solid State Physics

1. Frontier research in terms of flagships

Solid-state physics encompasses fundamental research that has underpinned much of the technological progress in the last 50 years. Recent trends include the emphasis on complexity including organic materials and reduced dimensionality down to the scale of quantum dots. One basic interest in solid-state physics is to establish the ground state of relevant systems. This may be done by exploring possible excitations out of the ground state. Neutrons are a versatile and often unique probe with which to accomplish this goal.

Table A4.1 summarises some of the research areas that are expected to be of major interest in 10 years time.

Table A4.1: frontier Research Areas in Solid State Physics.

Dimensionality	**Complexity**	**Structures and lattice effects**	**Non-equilibrium and time-dependent phenomena**	**New Materials**
Quantum dot arrays Transport and magnetic properties in 1-d systems Domains walls, domains correlations, grain boundaries Surfaces and thin films	Interplay of spin, orbital and charge degree of freedom Coupled excitations Strongly interacting electron systems Flux line lattices Phase transitions, quantum critical points	Frustration Disorder, interfacial roughness Proximity effects Lattice modes Confinement	Fast response to external probes and fields Magnetic fluctuations and relaxations Tunnelling	**Molecular magnets** **Interfaces/hybrid structures** **Self-organising molecular systems** **Novel magnets and superconductors** Organic materials

Out of these a number of flagship areas, which denote scientific challenges beyond current thresholds were selected (Volume II, ESS Science Case).

- Strongly correlated electron systems
- Molecular magnets
- Dynamics of superlattices, thin films, wires and dots
- Spin density waves in organic materials
- Revealing exotic interactions
- Coupled excitations
- Physics of defects at the dilute limit
- Spin glass dynamics
- Quantum phase transitions

2. Preferred instrumentation and threshold requirements

The appropriate instrument suite was then chosen to meet best the given demands. These instruments are: high energy chopper spectrometer, cold chopper spectrometer, thermal copper spectrometer, high resolution back-scattering spectrometer, medium resolution back-scattering spectrometer, high resolution spin-echo spectrometer, chemical single crystal diffractometer, high resolution powder diffractometer, magnetic powder diffractometer, high intensity reflectometer and diffuse scattering diffractometer.

Each of the instruments was weighted according to their relative importance to the respective flagship areas.

A further scaling factor was introduced to account for the power ratings of the three principal ESFRI scenarios together with a comparison of the SNS 1.4 MW (see Tables A4.2-4).

3. Maintaining a European lead

5MW stand-alone LPTS:
A stand-alone LPTS would offer, averaged across all the flagship areas, 50% of the performance anticipated from the Bonn reference ESS. Only in the areas of "films and superlattices" and "spin glass dynamics" the facility would be world leading. In all other areas it would be merely competitive with SNS.

1MW SPTS at 50HZ:
A stand-alone 1MW SPTS 50Hz station would offer, averaged across all the flagship areas, 20% of the performance anticipated from the Bonn reference ESS. This distribution is almost uniform across all areas. The option falls a factor of two behind the SNS.

1MW SPTS at 10HZ:
A stand-alone 1MW SPTS 10Hz station would offer, averaged across all the flagship areas, less than 30% of the performance anticipated from the Bonn reference ESS. This distribution is once again almost uniform across all flagship areas.

While the 5MW LPTS provides leading position in some areas of solid-state physics the other two options fall behind the SNS.

Instrument score tables for solid state physics at the ESFRI scenarios

Table A4.2. Stand-alone LPTS (5MW $16^2/_3$ Hz)

	rating: LPTS / Bonn best target stn	Strong correlations	Molecular magnets	films and superlattices	Spin density waves	Exotic interactions	Coupled excitations	Defects at dilute limit	Quantum phase transitions	Spin glass dynamics
High Energy Chopper	0,3	2	0	0	0	2	2	0	0	0
Thermal Chopper	0,3	3	1	1	2	3	3	2	1	0
Cold chopper	0,5	3	3	2	2	1	2	2	3	0
High res BS	0,2	0	1	0	0	0	0	1	1	1
Med Res BS	1,0	0	1	0	0	0	0	0	1	1
High res NSE	1,0	0	0	0	0	0	0	0	0	3
Chem SXD	0,5	1	1	0	3	0	0	0	2	0
HRPD	0,5	1	1	0	1	0	0	0	0	0
Mag Pow	0,7	1	1	0	1	0	0	0	0	0
Hig I ref	1,0	0	0	3	0	0	0	0	0	0
Diffuse	1,0	0	0	0	0	0	0	1	0	1
Score		11	9	6	9	6	7	6	8	6
Score * scaling		4,87	4,77	4,33	4,37	2,17	2,67	2,91	4,07	5,24
Score * scaling/score		**0,44**	**0,53**	**0,72**	**0,49**	**0,36**	**0,38**	**0,48**	**0,51**	**0,87**

Average normalised score: 0.53

Table A4.3. Stand-alone SPTS (1MW 50Hz)

	rating: LPTS / Bonn best target stn	Strong correlations	Molecular magnets	films and superlattices	Spin density waves	Exotic interactions	Coupled excitations	Defects at dilute limit	Quantum phase transitions	Spin glass dynamics
High Energy Chopper	0,2	2	0	0	0	2	2	0	0	0
Thermal Chopper	0,2	3	1	1	2	3	3	2	1	0
Cold chopper	0,2	3	3	2	2	1	2	2	3	0
High res BS	0,2	0	1	0	0	0	0	1	1	1
Med Res BS	0,2	0	1	0	0	0	0	0	1	1
High res NSE	0,1	0	0	0	0	0	0	0	0	3
Chem SXD	0,2	1	1	0	3	0	0	0	2	0
HRPD	0,2	1	1	0	1	0	0	0	0	0
Mag Pow	0,2	1	1	0	1	0	0	0	0	0
Hig I ref	0,1	0	0	3	0	0	0	0	0	0
Diffuse	0,1	0	0	0	0	0	0	1	0	1
Score		11	9	6	9	6	7	6	8	6
Score * scaling		2,42	1,98	0,97	1,98	1,32	1,54	1,20	1,76	0,71
Score * scaling/score		**0,22**	**0,22**	**0,16**	**0,22**	**0,22**	**0,22**	**0,20**	**0,22**	**0,12**

Average normalised score: 0.20
(Average normalised score for 1.4 MW SNS: 0.28)

Table A4.4. Stand-alone SPTS (1MW 10Hz)

	rating: LPTS / Bomn best target stn	Strong correlations	Molecular magnets	films and superlattices	Spin density waves	Exotic interactions	Coupled excitations	Defects at dilute limit	Quantum phase transitions	Spin glass dynamics
High Energy Chopper	0,2	2	0	0	0	2	2	0	0	0
Thermal Chopper	0,2	3	1	1	2	3	3	2	1	0
Cold chopper	0,4	3	3	2	2	1	2	2	3	0
High res BS	0,2	0	1	0	0	0	0	1	1	1
Med Res BS	0,2	0	1	0	0	0	0	0	1	1
High res NSE	0,2	0	0	0	0	0	0	0	0	3
Chem SXD	0,3	1	1	0	3	0	0	0	2	0
HRPD	0,2	1	1	0	1	0	0	0	0	0
Mag Pow	0,2	1	1	0	1	0	0	0	0	0
Hig I ref	0,2	0	0	3	0	0	0	0	0	0
Diffuse	0,2	0	0	0	0	0	0	1	0	1
Score		11	9	6	9	6	7	6	8	6
Score * scaling		3,10	2,65	1,64	2,60	1,54	1,98	1,70	2,57	1,28
Score * scaling/score		**0,28**	**0,29**	**0,27**	**0,29**	**0,26**	**0,28**	**0,28**	**0,32**	**0,21**

Average normalized score: 0.28

Materials Science and Engineering

1. Frontier research areas in terms of flagship experiments

Materials science and engineering provide the keys to future technologies, economic wealth and sustainable growth. They are also the keys to mastering many of the challenges for the next generation, such as the development of new energy sources and the reduction of pollution. Because of these many different aspects, materials scientists and engineers use a large number of experimental techniques. Neutron scattering has always been an important tool for the provision of structural information on the atomic scale and for the understanding of dynamical properties of solids and liquids. Because of its sustained success in providing unique answers to materials science problems, neutron scattering has become increasingly popular among materials scientists and likewise engineers. Today the advance of numerous materials science topics relies heavily on the availability of strong neutron sources. Presently the data acquisition is often too slow for in-situ and real-time studies of dynamic changes and process monitoring. Modern technologies demand information from smaller sampling regions, sometimes buried in larger component volumes or environmental chambers, samples in complex environments, samples in real time evolution and from samples in extreme fields.

In the ESS Science Case document the opportunities for progress beyond current thresholds have been exemplified in terms of 6 flagship areas. The corresponding experiments are expected to have a high impact factor on their respective field. Those areas are:

- structure and dynamics of lubricants as concerns their thickness for relevant technical applications;
- mechanism of deformation and damage in realistic fatigue cycles;
- energy and conversion devices as concerns time resolution;
- spin structures and hysteretic behaviour of magneto-electronics devices covering a large parameter space of temperature and magnetic fields;
- process monitoring and optimisation of large running engine parts with respect to time dependence;
- monitoring the diffusivity of protons in thin films with switchable properties with respect to sample volume.

2. Preferred instruments and thresholds requirements

In following we give estimated instrument gain threshold factors required for the different flagship areas compared to the best instruments of today (ILL or ISIS).

a. Lubrication.
Factor of 30 is required for reducing the film thickness from 300 μm (10% scatterer) to 10 μm, i.e. for technical realistic conditions.

b. Deformation and damage.
Assuming a cycling machine at a frequency of 3000 – 6000 rpm (50 to 100Hz), and requiring Bragg-peaks to be recorded on the same time scale, a gain factor of 30 to 50 is needed as compared to the best existing instrument.

c. Energy conversion.
Charging of a battery takes place on a time scale of a few hours. In order to monitor the ion diffusion and structural changes during charging, a time slicing of 1 to 2 minutes is necessary. For this a gain factor of 30-40 is required.

d. Magneto-electronics.
Taking a reciprocal space map for all four cross sections requires 12 hours at the best performing reflectometer. To cover a reasonable temperature and magnetic field parameter space, the recording time of a map should be reduced to 10 minutes. This implies a gain factor for the threshold experiment of at least a factor of 70.

e. Tomography.
Significant gains in time resolved normal and structurally sensitive Bragg edge tomography are necessary in order to observe structural changes within a running engine. Requiring exposure times of ~ 1ms gain factors for the thresholds experiments are about 30.

f. Monitoring protons.
The goal is to measure hydrogen diffusivity in thin films of about 1 μm thick. An example may be hydrogen switchable mirror films of Yttrium. Stacking 5 films on top of each other, an effective material thickness of 5 μm could be reached, which is a factor of 20 less than present day abilities (0.1 mm thick hydrogen containing samples of the density equivalent to water). This requires at least a gain factor of 20 as compared to IN 6. Table A4.5 lists source gain factors, which may be realised with the different source options in the respective flagship areas.

Table A4.5.

Source gain factors* provided by the different source options. Third column: gain factor required to perform the specified experiment under reasonable sample and time conditions; forth column: gain factors expected for a fully operational ESS with two target stations; fifth column: gain factors expected if only a long pulse 5MW, $16^2/_3$Hz target station of the ESS would be available; sixth column: gain factors expected if only a short pulse 1MW, 50Hz target station of the ESS would be available; seventh column: gain factors expected for SNS 1.4 MW.

Flagship	Instrument required	Gain factor threshold	Full ESS	LPTS	SPTS	SNS
Lubrication	Back scat. 1.5 μeV	30	100	22	22	30
Def. and Damage	Eng. Diffracto-meter	20-30	30	17.5	7	12
Energy Conv.	High resolut. Powder	30-40	50	33	11	12
Magneto electronics	High res. Reflecto-meter	70	120	90	27	31.5
Process monitoring	Normal Tomography	30	40	16	7	10
Process monitoring	Bragg-edge Tomography	30	200	40	35	50
Monitoring protons	Cold chopper	20	60	30	13	18

*Source gain factors would be further improved by the instrument gain factors of tables A3.1 and A3.2 in Annex 3.

3. Maintaining the European lead

5 MW stand-alone LPTS:
A stand-alone LPTS will offer a European lead only in microelectronics and tomographic applications. With a few exceptions in all other areas a competitive position would be achieved.

1 MW SPTS at 50 Hz and 10 Hz:
In no area these options would provide European lead, in contrast in nearly all fields Europe would significantly fall behind the SNS

Chemical Structure, Kinetics and Dynamics

1. Outline of frontier research in terms of flagships

Our understanding of materials is based upon a detailed knowledge of their structures and dynamics at the atomic and molecular level. Neutron scattering is an invaluable tool in realising this goal. Single crystal and powder diffraction, small angle neutron scattering and reflectometry, inelastic and quasi-elastic spectroscopy and neutron spin echo measurements all contribute to our understanding of chemical structure, kinetics and dynamics. However, with current neutron instrumentation, the timescales of experiments are generally determined by the instrument and not the sample; similarly, sample size is often dictated by flux limitations and not real life conditions. Flagship experiments cover a broad range of science and comprise the generic areas of materials processing and synthesis, in-situ measurements of lifetime performance and materials optimisation. In the ESS Science Case document the following flagship areas were selected:

- Kinetics of chemical reactions
- In-situ observation of catalytic processes
- Energy storage and conversion materials
- Electrochemistry at surfaces, e.g. in fuel cells
- Hydrogen bonding and proton dynamics in supramolecular chemistry
- Diffusion in porous materials
- Quantum dynamical processes

Scientific issues range from fuel cells, batteries and hydrogen storage to smart materials that respond to their environment. New advanced materials may be studied in bulk (e.g. for chemical processing) or as thin films to build new devices. All these developments require an extension of the analytical tools to study chemistry and chemicals in small quantities, in complex mixtures and under the conditions of imposed external environments such as stress, temperature and pressure.

2. Preferred instruments and thresholds requirements

Research into chemical structure, kinetics and dynamics requires a broad suite of instruments covering elastic, inelastic and quasi-elastic scattering and reflectometry: high resolution powder diffractometer, high energy chopper, molecular vibration spectrometer, chemical single crystal diffractometer, high resolution NSE, cold and thermal choppers, backscattering spectrometers, high intensity reflectometer, high intensity SANS, high Q powder diffractometer, single pulse diffractometer, magnetic powder diffractometer.

Threshold requirements will be diffraction within the pulse leading to timescales of tens of microseconds, medium resolution diffraction of milligram-sized samples, high-resolution diffraction in seconds, inelastic scattering in minutes, parametric single crystal diffraction and molecular vibrations at low momentum transfers.

3. Maintaining a European lead in scientific flagship areas

Only the full ESS will allow to realise all flagship experiments through the exploitation of a wide range of instruments optimised across both short-pulse and long-pulse target stations.

5MW stand-alone LPTS

With LPTS alone, Europe will lead in the following flagship areas: electrochemistry at surfaces (high intensity reflectometer), polymer synthesis (high intensity SANS) and diffusion in porous materials (cold chopper, high resolution NSE) and will competitive in all other areas.

1MW SPTS at 50Hz and 10Hz

With 1MW SPTS, leadership will be lost in all areas compared to full ESS. However, the facility will be still competitive (within a factor of 2) compared to the other worldwide neutron sources.

Soft Matter

1. Outline of frontier research in terms of flagships

Neutron scattering techniques play a unique role in the study of both the structural and dynamical properties of the wide range of substances categorised as “soft matter”. Among the advantages presented by these techniques, two are of crucial relevance in the soft matter field: the suitability of the length and time scales accessed by neutrons, and the capability to manipulate the contrast by specific deuteration of any constituent of the system. *Neutron scattering is the only tool* for unravelling the molecular morphology and motions in soft matter systems at the different relevant length scales. On the other hand, the understanding of structural properties and dynamics at a molecular level is the key for advancing this field.

Future trends in soft condensed matter will concentrate mainly in four different areas:

i) Kinetic and non-equilibrium studies will address e.g. the kinetics of biomineralization, of self-assembly and structure formation and possibly also protein folding.

ii) Important breakthroughs are expected in the vast field of complex materials where the knowledge base to fine tune the structures achievable by self assembly will be created. This could lead to e.g. nanostructured magnetic devices, self-healing smart materials, photonic crystals, drug delivery systems and tailored catalysts supports. An understanding of the behaviour of complex fluids in porous media will be a prerequisite for tertiary oil recovery.

(iii) In soft matter, dynamic phenomena to an even larger extend than in hard matter determine the mechanical and rheological properties. It will be crucial to explore the unknown territory of collective dynamics in disordered complex materials, to understand the molecular basis of rheology, to solve the mysteries of the glass transition and the glassy state, and to address the dynamics of surfaces.

(iv) The behaviour of complex materials is often governed by key components which are only present in very small volume fractions. The component behaviour in multicomponent formulations like e.g. oil additives, detergents, food additives and cosmetics needs to be addressed and phenomena like surface phase transitions, membrane protein interactions (biosensors) and the actions of compatibilisers need to be scrutinized.

The future trends will require a wide variety of experiments, including investigations on dilute components, or on very small amounts of matter such as particular topological points or at interfaces. Sometimes these experiments involve polarisation analysis, short time measurements or in-situ studies. In all these cases, very high intensities of the neutron beam are required.

In the ESS Science Case considerations, these future trends were exemplified by flagship areas defining scientific tasks beyond current thresholds. They are listed in table 1 together with the required neutron instruments. Furthermore, under the column "thresholds" we list the current limitations inhibiting such experiments on a broad basis.

Table A4.6. Soft matter flagship areas defined in the ESS Science Case document including instrumentation requirements and current thresholds generally inhibiting such experiments.

Flagship area	Instruments required	Thresholds
Molecular rheology	NSE, SANS, reflectometry	High resolution, dilute key-components
Buried interfaces	Reflectometry	Size of the interface
Self assembly and structure formation	SANS, reflectometry	Time resolution in kinetics, multicomponent materials
Window to biology	SANS, reflectometry, NSE, TOF	Time resolution in kinetics and dynamics, small size
New materials by external constraints	SANS (fm)	Time resolution in kinetics, large scales
Soft-hard nanocomposites	SANS (fm), NSE	Time resolution in kinetics, component dynamics
Complex liquids in porous media	SANS, NSE	Identification of kinetics and dynamics of key-components
Molecular dynamics in non-crystalline matter	NSE, BS, TOF	Sufficiently high intensity

Most of these areas are directly correlated to technological applications with a strong impact in the fields of nanotechnology and functional materials.

2. Instrumentation and thresholds requirements

The most relevant neutron scattering techniques satisfying the future trends in soft matter are SANS, reflectometry and also NSE for dynamic properties. Table A4.7 includes a priority list for the instruments based on earlier SAC evaluations (ESS Science Case).

From Table A4.7 it is evident that for key soft matter instruments only the full ESS and the LPTS station provide more than an order of magnitude gains both compared to present sources as well as with respect to SNS. Concerning the investigation of short time dynamics including backscattering studies all source options will provide major advances compared to present capabilities.

Table A4.7.: source gain factors benchmarked against SNS 1.4 MW.

Source gain factors underlying the instrument performance of typical neutron scattering instruments for soft matter studies. In order to display the competitive arena after the start of the MW spallation sources in USA (SNS) and Japan (J-PARC), the performance is benchmarked against the SNS instrument capabilities. The instrument priorities were taken from the Science Case document using the prioritisation of the soft matter science and the nanotechnology groups.

Instrument	Priority	50Hz 1MW	10Hz 1MW	Full ESS	LPTS 5MW	ISIS/ILL
High Intensity SANS	100	0.7	1.85	10	10	0.7
High Intensity reflectometer	67	0.43	0.7	4.3	4.3	0.18
Focussing Low Q SANS	49	0.7	1.85	10	10	0.7
High Resolution NSE	33	0.85	3.6	15.8	15.8	0.8
Variable cold Chopper (HR)	25	0.7	1.4	2.1	1.85	0.06
Variable cold Chopper (HI)		0.7	1.4	10	10	0.46
Cold Chopper		0.7	1.4	3.3	1.6	0.06
Wide Angle NSE	16	1	1.85	8.6	8.6	1
Backscattering 1.5?eV (HR)	9	0.7	0.7	3.3	0.73	0.028

3. Maintaining a European lead

Full ESS or 5MW stand-alone LPTS

Across the board either the full ESS or the LPTS will establish a leading European position in the field of soft matter and in the associated fields of nanotechnologies and functional materials.

SPTS options

With the SPTS options the opportunities for breakthroughs in soft matter science relating to SANS, reflectometry and NSE will be lost, while in the field of short time dynamics major advances would still be possible. In none of the areas of the soft matter science a European lead would materialize.

Current capabilities

Comparing the capabilities of ILL with SNS and thus assessing the competitive situation of Europe on the basis of existing capabilities (last column of Table A4.7) we find that for SANS as well as for NSE a competitive situation would remain, though none of the addressed flagship areas could be accomplished. On the other hand, in the field of dynamic studies addressing for example the origin of mechanical properties, Europe would completely lose any competitive position. This is also true in the field of surface studies featured by reflectometry.

In summary, the full ESS as well as the LPTS would provide a leading European position in all areas of soft matter science with neutrons. None of the others will achieve this goal.

Liquids and Glasses

1. Frontier research in terms of flagships

Neutron scattering is a key experimental technique in the study of the atomic structure and dynamics of liquids and glasses. The intensity gains provided by ESS together with the ever-increasing power of computers will enable a visualization of "where the atoms are and what the atoms do". Neutrons at ESS will be used as the central part of studies using multiple complementary techniques, e.g. X-rays, light scattering and NMR, each providing information on specific aspects of the structure or dynamics of complex disordered materials. The data obtained will be simultaneously analysed with sophisticated modelling techniques or used as a stringent test of computer simulations. Such a coherent approach will not only enable a radical step forward in our understanding of the basic physical processes in disordered materials, but also in our ability to understand, control and eventually exploit the atomic scale structure and dynamics for the production of materials with optimised properties for technological and other applications. A future trend in experimental terms will be the need to measure over a wider Q range for structural studies, combining SANS and diffraction (e.g. for liquids in porous media), or a wider (Q,ω) range for dynamics using a series of measurements from spin-echo to high energy chopper (e.g. for studies of the glass transition).

In the ESS Science Case document the following flagship areas were identified

§ Influence of molecular entities on solvent structure in solution as a function of multiple parameters (concentration, T, P …)
§ Multicomponent magnetic metallic glasses, ion conductors with low concentrations of mobile ions, impurities and dopants in optical fibres.
§ Crystallisation, nucleation, order-disorder transitions, kinetics, ageing, processing of e.g. nanocrystalline materials
§ Element specific atomic dynamics of disordered matter (using isotopic substitution)
§ High information bandwith atom specific dynamics (isotopic substitution, wide Q,ω range, Brillouin scattering) combined with modelling/simulation studies (making movies)

2. Preferred instrumentation and threshold requirements

Structure: Liquids diffractometer, SANS, high intensity reflectometer.
The current limit in isotopic substitution diffraction experiments is set by instrument stability rather than achievable statistics. Gains in count rate can therefore be considered to produce an approximately linear gain in experimental capability, rather than square root. For phase diagram studies or kinetics the gain is also linear. The same arguments therefore apply to all structural flagship experiments. The ESS Bonn design offers a 20x gain relative to current capability. This means using isotope concentrations an order of magnitude lower, increasing the range of elements that can be substituted, significantly wider coverage of phase diagrams etc. For kinetic experiments the reduction in time resolution is again more than an order of magnitude.

For SANS and reflectometry the gain is in a factor of 20, meaning either one order of magnitude gain in phase diagram coverage or a factor of 4-5 in statistical accuracy, e.g. a reduction of 4-5 in elemental or isotope concentration.

Dynamics: All chopper and backscattering spectrometers and spin-echo spectrometers.
Here the increases in instrument capability for the ESS Bonn design range from 20 to 100. This means that isotope substitution in dynamical studies will becomes as routine as it is now in structural studies. Alternatively an order of magnitude increase in statistical accuracy means a considerable extension in the (Q,ω) rage that can be effectively covered, giving opportunity for inversion to real space or dynamical modelling (making movies of atomic dynamics). Again, effectively the same arguments apply to all dynamics flagship experiments.

3. Maintaining the European lead

The comparison of different source options from a scientific point of view can very conveniently be separated into structure and dynamics.

The ESS Bonn design will provide a clear world scientific lead and achieve the thresholds for flagship experiments in all areas.

5MW stand-alone LPTS:
In terms of dynamical studies a 5MW long pulse target station would achieve everything the ESS-Bonn design does and would provide a clear world lead. That also holds for all applications dealing with surface or large-scale structures. Investigation into atomic structures is only marginally improved and a competitive position versus SNS is not achieved.

1MW SPTS at 50Hz and 10Hz:
A 1MW short pulse target station would be internationally competitive in all areas, but not world leading in any.

Additional remark

For the single target station options the reduction in the number and range of instruments due to having only a single target station, with approximately 20 instruments, could be considered as effectively a significant reduction (at least a factor 2) in the information bandwidth achievable, since experiments at several instruments are necessary to cover e.g. the whole (Q, ω) range, and on average only half of the instruments are available to an individual user. Also the smaller range of instruments typically implies that the optimisation for some particular experiments is not as great, giving another reduction in effective experimental quality. In this sense one should multiply gain factors for the ESS Bonn design, relative to e.g. SNS, by more than a factor of 2. The advantages of the ESS Bonn design relative to either the 5MW LP or 1MW SP option are then even more obvious.

Biology and Biotechnology

1. Frontier research in terms of flagships

Structure function and dynamics of biological macromolecules operate across a wide range of time and length scales that are well matched to the fundamental characteristics of neutron scattering. The need to understand these systems at the atomic, molecular and cellular level now demands an integrated suite of cutting-edge instruments that will enable new opportunities to be exploited across the life sciences.

Current source limitations have restricted studies to simple and/or model systems. *ESS will make it possible to study real complex, interacting macromolecular systems.* In the future the need for more detailed information will be enforced as the studies will proceed from the investigation of single biomolecules to complex biomolecular machines (large chaperones, multi-subunit protease complexes, and eventually to proteins *in vivo*) where interactions in protein-lipid, protein-RNA/DNA, glyco-lipid complexes will have to be understood.

Some flagship areas of research will include:

- self-organisation processes and functional aspects of *native* membranes
- interaction of proteins *in vivo* within their cellular environment
- kinetic studies of macromolecular interactions
- mechanisms of drug binding and drug delivery
- design and characterisation of membrane based biosensors and biochips
- improving biocompatiblity in medicine
- understanding food processing at the molecular level

Deuterium labelling is a unique tool that enables neutron scattering to highlight specific components of complex systems. The realisation of all the above flagship activities will be critically dependant on the provision of specifically deuterium labelled macromolecules.

2. Preferred instruments and threshold requirements

Instruments are required that cover the broad time and length scales over which life functions. The instrument requirements relevant for biology are summarised in table 1.

Each of the flagship areas requires a number of the instruments of Table A4.8. Therefore, in order to remain world leaders throughout the flagship areas both the LPTS and SPTS will be required. Whilst with the LPTS option alone we would keep the world lead in a number of areas, in two key fields this would not be the case. In neutron protein crystallography and nano-second dynamics the two to four fold gain provided by SPTS will be essential to cross the critical threshold which will make the flagship experiments possible.

Table A4.8.
Source gain benchmarked against full ESS (SPTS + LPTS). The first seven instruments are ESS-priority instruments; the classifications in 'class' assess the LPTS station compared to SNS.

Instrument	**50Hz 1MW**	**10Hz 1MW**	**SNS**	**ESS LPTS Only**	**Class**
High resolution backscattering	0.22	0.22	0.3	**0.25**	Competitive
high resolution protein	0.22	0.4	0.3	**0.5**	World leading
variable cold chopper (high intensity)	0.07	0.14	0.1	**1.0**	World leading
variable cold chopper (high resolution)	0.22	0.44	0.3	**1.0**	World leading
high resolution NSE	0.06	0.23	0.06	**1.0**	World leading
high intensity reflectom.	0.09	0.18	0.24	**1.0**	World leading
high intensity SANS	0.07	0.17	0.09	**1.0**	World leading
backscattering 17μeV	0.22	0.22	0.3	**1.0**	World leading
molecular vibration spectrometer	0.22	0.22	0.3	**0.1**	Not competitive
high resolution reflectom.	0.22	0.44	0.25	**0.75**	World leading
high λ resolution SANS	0.22	0.44	0.33	**1**	World leading

3. Maintaining the European lead

Since biological systems are extremely complex and the consecutive challenges to neutron scattering involve always many facets, only the full ESS ensured Europe's world lead in all applications of neutron scattering to biology and biotechnology.

<u>5MW stand-alone LPTS:</u>
With the LPTS option alone Europe would keep the world lead in the large majority of the flagship areas.

<u>1MW SPTS at 50Hz and 10Hz:</u>
In virtually all cases, instrument performance is seriously reduced on both the 10hz and 50Hz 1MW source options with loss factors of between 5 and 20 compared with a full ESS. Such order of magnitude losses will leave Europe uncompetitive across all classes of experiment and, critically, would render priority and flagship areas of science unfeasible.

Mineral Sciences, Earth Sciences, Environment and Cultural Heritage

1. Outline of frontier research in terms of flagships

In geophysical science the prevention of hazards posed by volcanic eruptions and earthquakes is a major science driver. Therefore, the understanding of the behaviour of matter under the conditions of the earth mantle is of prime importance. A number of flagship areas in this field are related to this challenge. Another field of importance is the investigation of continental shelf methane clathrates, which could serve as a basis for future energy supply. A third area investigates the history of the genesis of the earth. Finally, aspects of cultural heritage like the fingerprinting of archaeological materials and their non-destructive analysis come into play.

In the ESS Science Case the following flagship areas were identified:

- Pressure induced spin dynamics and spin collapse of iron;
- Molecular dynamics of H_2O, OH and CO_2 under earth mantle conditions;
- In-situ diffraction and spectroscopy of methane clathrates;
- Time resolved neutron radiography and tomography of fluids and melts under earth mantle conditions;
- In-situ measurements of stress strain partitioning during rock deformation;
- Influence of stress and development of texture upon deforming geo-materials;
- Fingerprinting of archaeological materials and non-destructive analysis.

2. Preferred instruments and thresholds requirements

The “Flagship areas” all require multi-experiment approaches for their successful solution. The gains required to achieve these solutions are all met by the full ESS instrument suite, which would be world leading. The scientific challenges envisaged in this area require both structural and dynamic information. We have considered the effect of reducing the instrument suite by implementing only the 5MW LPTS component, or a 1MW SPTS. As is shown below, we find that the 5MW LPTS retains some lead in a few of the flagship areas, while the 1MW SPTS offers little or no advantage over other planned sources (Table A4.9).

Table A4.9.
Instrument performance at full ESS and lower options displayed for the different flagship areas.

Flagship Areas	Full ESS	5MW LPTS vs 1MWSPTS	5MW LPTS still leading?
1	OSIRIS(x60) / PRISMA(x500)	OSIRIS LPTS competitive	no
		PRISMA LPTS competitive	no
2	TOSCA (x100) / eVS (x300)	TOSCA LPTS competitive	no
		eVs 1MW SPTS competitive	no
3	HRPD (x150)	LPTS still leading	yes
		1MW SPTS competitive	no
4	Tomography (x100)	LPTS leading	yes
5	Engin-X (x100)	LPTS competitive	no
6	Engin-X (x100)	LPTS competitive	no
7	Tomography (x100)	LPTS leading	yes
	Engin-X (x100)	LPTS competitive	no

We have considered each flagship area in terms of the combined source and instrument gains required to achieve a leading position. For simplicity and brevity we have employed existing familiar acronyms for typical instruments in the discussion and table below, rather than generic names. Each of the flagship areas of research is clearly outlined in the Bonn Report under the same headings reported here.

Assessing the different flagship areas following Table A4.9 we arrive at the results:

1. Pressure induced spin dynamics and spin collapse of iron ions.
   Work in this area requires *OSIRIS* and *PRISMA* type instruments. These would offer a lead at the 5MW SPTS but would still be competitive on a 5MW LPTS. The prospect of a 1MW SPTS would not offer significant advantages.
2. Molecular dynamics of H_2O, OH and CO_2 under Earth mantle conditions.

This flagship area is dependent upon measurements on *TOSCA* and *eVS* type instruments. Results from such experiments would be leading for the 5MW SPTS but while a *TOSCA*-type instrument would still be competitive on a 5MW LPTS, the *eVS* would certainly not. The prospect of a 1MW SPTS would not offer significant advantages.

3. In-situ diffraction and spectroscopy of methane clathrates.
   For experiments in this area we envisage the need of an *HRPD* type instrument. This would offer a lead if implemented at a 5MW SPTS and also at a 5MW LPTS. With a 1MW SPTS competitive experiments could still be performed.

4. Time resolved neutron radiography and tomography of fluids and melts under Earth mantle conditions.
   For this kind of experiment instrument requirements call for the development of fast detectors with high spatial resolution. The accent is therefore on integrated intensity per pulse hence a 5MW LPTS would have the lead over a 5MW SPTS.

5. In-situ measurements of stress and strain partitioning during rock deformation.
   To tackle this flagship area we envisage the need of an *ENGIN-X* type instrument. This would provide a lead at 5MW SPTS and be competitive at a 5MW LPTS. With a 1MW SPTS competitiveness would be lost.

6. Influence of stress and development of texture upon deforming geo materials.
   The instrumental requirements are identical to those needed for the flagship area above (5), and once more will only be leading at a 5MW SPTS.

7. Fingerprinting of archaeological materials, non-destructive analysis.
   For the tomography aspects of this area the instrument requirements call for the development of fast detectors with high spatial resolution. The accent is therefore on integrated intensity per pulse hence a 5MW LPTS would offer the lead over a 5MW SPTS. For the diffraction aspects of this kind of experiments we envisage the need of an *ENGIN-X* type instrument. This would be leading for the 5MW SPTS and be competitive for a 5MW LPTS. Both target stations of the full ESS are, therefore, required. With a 1MW SPTS competitiveness would be lost.

3. Maintaining the European lead

5MW stand-alone LPTS:
It is evident that only the full ESS will achieve the flagship goals and provide the European lead in these areas of science. The LPTS retains some lead in the field of methane clathrate research and the tomographic investigation of fluids and melts under earth mantle conditions as well as the tomography of archaeological materials.

1MW SPTS at 50Hz and 10Hz:
The 1MW SPTS offers little or no advantage over other planned sources.

Fundamental Neutron Physics

1. Outline of frontier research in term of flagships

Neutrons are a powerful tool for particle and nuclear physics and they are ideal probes for quantum investigations and gravitational physics. The related experiments depend on the availability of high densities and fluxes for cold and ultracold neutrons. The European Spallation Source is, therefore, of intense interest for fundamental studies in these fields. Contrary to the usual particle physics experiments, which take place at the highest possible energies of particles, these experiments with neutrons have energies, which are even much lower than those of ordinary gas molecules. Rather recently, new proposals for ultracold neutron sources using advanced moderation and pumping processes make density gains in the order of $10^3 – 10^4$ feasible. Also, β-decay experiments with cold neutrons can make use of the pulse structure of ESS for background suppression achieving a decay rate, which is 3 orders of magnitude higher than present experiments. As a consequence, experiments with cold and ultracold neutrons at the ESS opens the door for completely new investigations in this field concerning basic laws of physics. Some of them are mentioned below:

The exotic decay of a neutron into a hydrogen atom and an antineutrino can be measured for the first time and can help to find phenomena beyond the Standard Model of particle physics. The criterion for the finding of a neutrino with the wrong helicity would be the observation of a special hyperfine transition in the hydrogen atom. The branching ratio into the exotic hydrogen decay is 4×10^{-6} and therefore high density makes such basic investigation possible.

The question of the validity of the Standard Model can be tackled further by β-decay experiments, which allows to determine the quark mixing Cabibo-Kobayashi-Maskawa (CKM) matrix. The first matrix element has been derived from neutron β-decay and thus from particle physics for the first time. The presently not well satisfied unitarity condition for the CKM matrix presents a puzzle in which a confirmed deviation from unitarity is pointing towards new physics like super symmetry, right handed neutrinos or a forth quark generation.

The search for a non-vanishing electric dipole moment (edm) has reached an unpreceeded precision to be close to 10^{-26}ecm. The search for a final value will continue because a final value could explain the matter-antimatter asymmetry in the universe.

The density and fluxes available at the ESS make neutron-neutron scattering experiments feasible for the first time, which gives basic information about the strong interaction and the Pauli exclusion principle.

Tests of quantum mechanics including quantum state reconstruction and quantum gravity effects will become feasible. In this respect measurements of energy levels of bound neutrons above a reflecting surface are sensitive to a deviation from the Newtonian potential due to large extra-dimensions in modern string theories.

2. Preferred instruments

In order to achieve these high-density gains, a dedicated UCN target station is requested. Such a source will serve several UCN experiments. In addition, a high intense beam line for cold neutron at the cold moderator is needed. This beam line should be directed to the UCN station allowing higher neutron densities. The guide should be coated with supermirror with a cross section of minimum 6 cm width and 20 cm height. As phase space densities for the UCN source are concerned, a comparison in gain with other neutron sources is provided by a simple formula:

$$Gain\ \ factor = \frac{P_{ESS}}{P_{other}} \cdot \frac{\nu_{other}}{\nu_{ESS}}$$

with power P and repetition rate ν. As the SNS is concerned, the gain factor is 9 while in the AUSTRON case, the gain factor is 3.

3. Maintaining European lead

In order to achieve the required density of ultracold neutrons, a dedicated UCN target station is requested. In addition a high intense beam line for cold neutrons at the cold moderator is needed. Compared to such a potential UCN station at SNS the LPTS would gain a factor of 9. The 10Hz 1MW SPTS a factor of 3 while 50Hz 1MW station would fall behind. Similarly the required cold neutron beam would be most intense (factor 3 between them) AUSTRON at the LPTS.

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Annex 5 - Socio-Economic Impact

The aim of this appendix is to give a short outline of some findings in a fairly comprehensive literature on social and economic impacts of scientific activities. The impacts are discussed on several societal levels – from the global/European to the regional/local. In the end of the paper some short comments pertinent to the three scenarios in the main report will be presented.[1]

What is meant by socio-economic impacts?

The question of the socio-economic impacts, local and regional, of the location of new plants or the growth of existing production facilities have been of central interest in regional policy in European countries for a number of decades. This may be seen in the discussions and reports on the consequences of both the establishment and closure of industries and military regiments as well as in the relocation of central government offices. In recent years, the location of new universities and university colleges has attracted the greatest attention at the national, regional and local level.

The approaches and theoretical perspectives adopted in various academic disciplines during the 1950s and 1960s were characterised by a well founded belief that policy in the areas of economy, research, higher education and labour market should be largely conducted within national frameworks. Within the decision-making domain of the territorial state, both places and regions were not considered to be to any great extent *directly* dependent on conditions outside the boundaries of the country. In the few cases where this type of dependence could create problems, it was the duty of the state to intervene. During the past two decades, the growing direct cross-border dependences of places and regions have become increasingly evident. At the same time, the content of economic and working life has been subject to drastic change. Hence it is hardly surprising that the approach of social science researchers to social and economic problems has changed. At the same time, the character and content of impact analysis and effect models have been altered.

Traditional effect models are constructed in the following manner. Large investments in plant and machinery create a local and a regional demand for goods and services. The expansion of new and existing workplaces creates a larger labour market. The growth of employment together with family dependants leads to an increase in the population. The growth of purchasing power expands the retail trade and the market for household services in the area, which in turn generates higher tax revenues for the local authorities. These effects may be considered to be *direct* and are relatively easy to calculate.

Employment is not just created in new or expanding workplaces. There is a whole range of sub-contractors and service firms that also are able to increase their production as a result of the expansion of demand. Public authorities also find it possible to increase their investments and expenditure, which generates further expansion. It should be borne in mind that these multiplier effects do not only operate in a positive direction. Plant closures and the rationalisation of production units lead to consequences that operate in the opposite direction, albeit usually subject to a certain time lag.

There is considerable evidence to show that these effects have their greatest impact on places that have a small one-dimensional labour market and a highly restricted range of

[1] For a more exhaustive discussion see Gunnar Törnqvist: *Science at the Cutting Edge. The Future of the Øresund Region.* The Copenhagen Business School Press, Copenhagen 2002.

services. Large, diversified regions with dense supplier and customer networks will be least affected since there is usually a degree of more or less latent over-capacity among sub-contractors, retail trade outlets and service companies. Large regions are also more robust in relation to closures and layoffs since they are able to offer a wider range of employment alternatives than is possible in small. According to traditional studies, a multiplier of between 2-3 could be expected in larger regions i.e. 1000 new employment opportunities could raise the population in the area by between 2000-3000 persons. In smaller places with limited labour markets, the employment multiplier could be as large as 5-6. [1]

A well-known example from the extensive literature in this field is the description by the Swedish economist, Gunnar Myrdal, of economic progress and decline as a process of *cumulative causation* that is more or less self-generating and difficult to influence once it has started. Positive growth processes tend to become concentrated in a few central areas of expansion while backwash effects characterise many peripheral regions. Selective migration, capital movements and free trade favour the areas undergoing rapid growth while adversely affecting the areas experiencing slower growth. The free play of market forces tends to increase rather than reduce regional economic inequalities.

These backwash effects may be offset by positive spread effects, which would appear to be greater in countries that have attained higher levels of economic development. This is largely attributable to the fact that favourable economic conditions tend to generate improvements in communications, higher levels of education and an increased preparedness to remove obstacles to the spread of welfare.[2]

Numerous research reports have over the years followed the theoretical approach adopted by Francois Perroux who coined the concept of “pôle de croissance”. Initially this concept referred to sectors or groups of firms within an economy, which were strongly linked together. Growth in this type of sector could provide substantial spread effects. As the French term implies, the growth pole concept may be viewed as a crossing point between sectors (rows and columns) in an input-output table.

In relation to the analysis below, it is of particular interest to note that Perroux viewed growth not just as a quantitative process but also as a qualitative process characterised by transformation and renewal. The innovation processes (development of new products, new technology and new production processes) and the diffusion of innovations are seen as important driving forces in the economy.[3] Here there is a need en passant to remind us of the pioneering work of the Austrian economist, Joseph A. Schumpeter, on how innovations create business cycles of growth and depression in a sequential order. By means of “creative destruction”, development moves forward in waves in a capitalistic economy.[4]

Numerous authors among economists and geographers have given the concept of growth pole a purely geographic meaning. Growth poles are places where different types of growth become concentrated, either spontaneously or as a result of planning. These ideas were especially prevalent in the regional policy debate of the 1970s and helped to form many

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[1] A more detailed study of the earlier literature is available in for example Gunnar Törnqvist: *Arbetslivets geografi*, ERU rapport 3. Stockholm 1981.

[2] Gunnar Myrdal: *Rich Lands and Poor: the Road to World Prosperity*. Harper & Row, new York 1957. Gunnar Myrdal: *Economic Theory and Underdeveloped Regions.* Methuen and Co Ltd, London 1957.

[3] Francois Perroux: Note sur la notion de “pôle de croissance”, *Economie Appliquee 8*, 1955; Francois Perroux: *L’Economie du XXeme Siecle*. Paris 1961.

[4] Joseph Schumpeter: *Business Cycles: A Theoretical Historical and Statistical Analysis of the Capitalist Process*. McGraw-Hill, New York 1939.

of the growth related policy measures that were undertaken in the Nordic countries and in other parts of Europe.

With access to specific data on for example the establishment of a neutron facility – buildings, equipment, personnel and rates of utilisation by visiting researchers – it is entirely feasible to conduct an analysis of the impacts of the project. However, several factors would appear to suggest that we need *a wider perspective* and that we have to approach a complex of issues that need to be analysed step by step in future research.

The most immediate central question that arises is whether or not a major research establishment can be expected to play a more strategic role in its environment than for instance a regiment or a factory. The few thorough studies that have been carried out into the effects of newly established universities indicate that this is the case although the impact is not as great as the public debate would appear to suggest. This issue was examined by the Dutch economist, Raymond Florax, in his book *University: A Regional Booster?*. Here he analyses the extent to which universities may be expected to contribute towards radical changes and considerable development in a region.[1]

New universities unleash a wave of building activity. This can be seen throughout Europe. A university with its students, teachers and researchers form one of the largest workplaces in the region. Highly educated and well paid people create a particular type of demand for goods and services. The continuous turnover of young people creates a special dynamism in the region. A pool of well educated labour gathers around the university, people who are attractive to both private and public employers. From a Swedish perspective, these types of effects are easily observed in towns such as Lund and Umeå.

In many university towns, there is a strikingly large element of established cultural institutions and recurrent events. Computer and IT consultants, hi-tech firms and other specialist enterprises are attracted to university towns. Relative to their size, they also attract a considerable number of publishers and printers. In Lund for example, a town of around 100 000 inhabitants, there are more than one hundred publishers and a large number of printing business. The extent to which universities are both an expression of and an actor within the physical and cultural infrastructure is a question that has not previously received much attention. Currently it attracts considerable attention as part of an ongoing research programme.[2]

The second question is more difficult to examine in a strict research perspective but ought nevertheless to be raised. It concerns the *psychological impacts* of major physical infrastructure projects. As will be discussed below, research is currently surrounded by something of a halo, especially in the fields of science, medicine and technology. Places that are associated with successful research become renown as for example in the cases of CERN – the European centre for particle physics – and the Institute Laue Langvin in Grenoble.

With a neutron source in the centre

Figure 1 provides a simple illustration of how a neutron source may form the centre of a complex of activities. Around the central core, there is a ring of scientific spheres that are more or less dependent on the activities that are conducted at the neutron spallation source.

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[1] Raymond Florax: *University: A Regional Booster?* Avebury, Aldershot 1992

[2] This issue forms a central part of the research being carried by Kerstin Cederlund at the Department of Economic and Social Geography at Lund University. This work is part of a research programme entitled “The regional roles of universities. Swedish education, research and regional development in an international perspective”. It is financed by The Bank of Sweden Tercentenary Foundation.

Outside the ring of scientific spheres, there are several examples of technical applications and industries that can be considered to be more or less directly or indirectly related to these spheres.

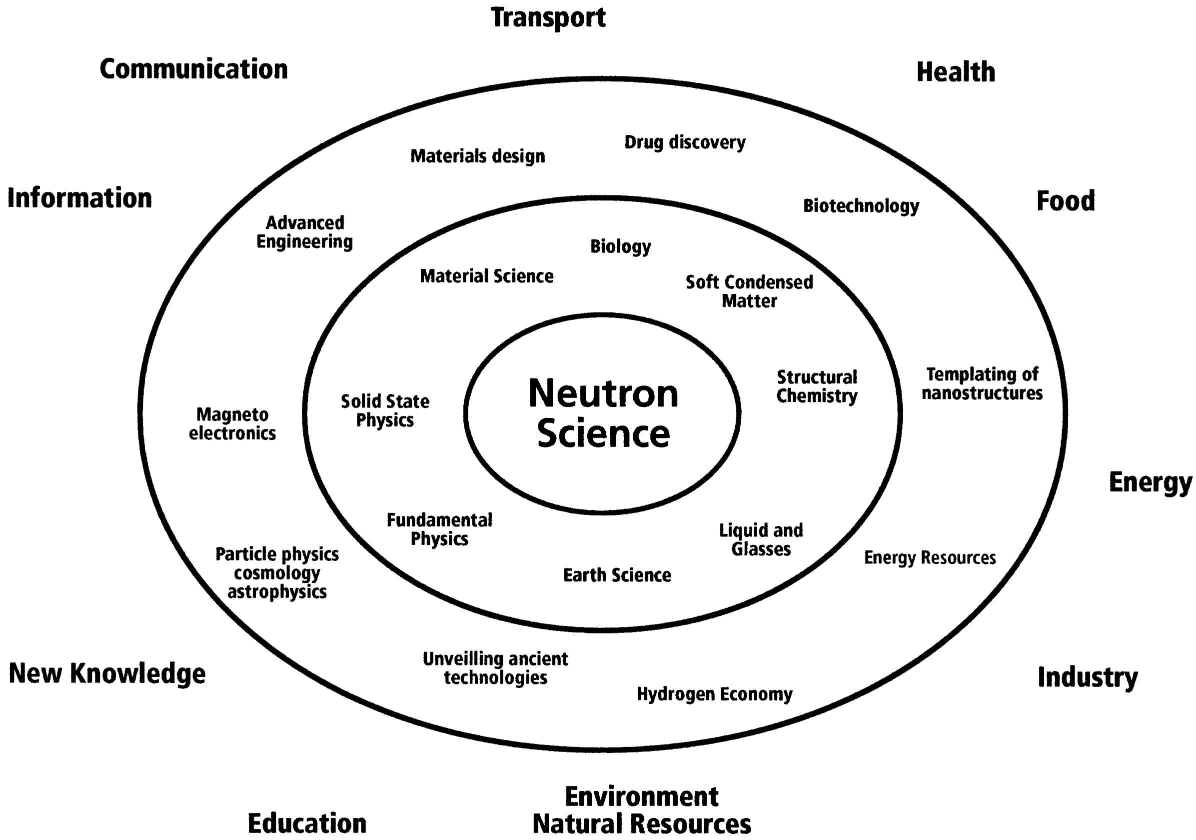

Figure A5.1. Influence of neutron science on other fields of research and industry.

The figure should not be interpreted as a map but as an illustration of how different activities are dependent on one another. The extent to which these dependencies exert an influence on the geographical location is a question that will be examined later.

In the majority of cases, the research findings are not likely to be directly applicable within industrial sectors without applied research and development of new products and processes. The extent to which this research is able to find practical outlets is likely to increase as one moves from the centre to the periphery of the figure. It is appropriate at this juncture to provide a brief definition of the innovation systems and technological clusters.

Our view of industrial location and economic competitiveness is based on the idea that a firm’s long term prospects are determined by its capacity to innovate. Naturally cost advantages are of importance. In the long run however, it is the ability to generate and utilise new knowledge which makes it possible to produce better products and employ more efficient manufacturing processes which in turn create the preconditions for survival and development.

Technological innovations apply to an entire range of processes from invention to the marketing of the finished product. What is termed product innovations may comprise new products or new variants of existing products. Process innovations lead to productivity gains as a result of a more rapid production process, new machines or new forms of organisation that allow the goods to be produced more efficiently and at lower cost.

The innovation concept does not have to be limited to the production of goods. It may also be applicable to new forms of service, distribution and administrative routines within both the private and public sectors. In recent years, the question of the relationship between institutional conditions and innovation processes has received particular attention.[1]

Isolated firms are seldom innovative. The majority of firms modernise their production process and develop new products and services by interacting with other firms and institutions – customers, competitors and suppliers of inputs and services. Laws and regulations together with different cultural patterns form the framework for this co-operation and interaction. Innovation processes in networks of relations may take considerable time to develop and they may be difficult to follow in detail. It is a question of evolution rather than revolution when research findings and inventions are developed into successful commercial products.

A *linear model* has previously been used to describe the role of university research in innovation processes. Here the chain of causality is simple and straightforward. Basic research is the first step. This type of research, especially in Sweden, is mainly conducted in universities and institutes of technology financed by government and special research foundations. Applied research involves the further development of the advances made by basic research. This may sometimes be conducted in university departments or increasingly, in the privately financed laboratories of firms and special research institutes. In a final stage, the firm develops new products and processes that are commercially viable and provide new employment opportunities and ultimately increased welfare.

In certain contexts, this linear model is still relevant. However it is limited in the sense that it provides an excessively schematic and simplified view of the complicated relations that often prevail in a knowledge based economy. More complex models have recently been developed in order to increase our understanding of the ways in which research may affect economies and welfare. Innovation processes are assumed to take place within a context of *interactive learning* involving a number of different actors. *Innovation system* is one of the names for the structures that have replaced the simple chain of causation provided by the linear model. The term system refers to a network that binds together institutions or actors that have mutual contacts and trust. This applies for instance to university researchers, decision-makers within public administration and various types of firm. Concepts such as *technological system* and *technological cluster* are used in relation to analyses of predominantly technical innovation processes.

Studies of innovation systems and technological clusters are characterised by different approaches and perspectives dependent on the types of question that have been raised. Studies of the Swedish export industry represent almost a *sector perspective*. Here special studies have been devoted to transport related, wood products related, foodstuffs or pharmaceutical related industries. However, as is the case with many older studies, a *national perspective* is also present which indicates that networks and clusters are assumed to possess special national characteristics. Within the boundaries of territorial states, the legal and regulatory systems and the policy measures of central government are applied in a uniform manner. Within these boundaries there are also cultural patterns and institutions that have different characteristics and functions than elsewhere.[2]

Network is a concept on which there is considerable contemporary focus. The same could be said of the concept of *cluster*. This leads in turn to another related concept namely

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[1] The following section owes its inspiration to an article by Charles Edquist "Systems of Innovation Approaches - Their Emergence and Characteristics" which is available in Charles Edquist (ed.) *Systems of Innovation*: *Technologies, Institutions and Organisations*. Pinter, London and Washington DC 1997. Both the article and book contain a thorough discussion of relevant literature.

[2] Örjan Sörvell, Ivo Zander, Michael Porter: *Advantage Sweden*. Norstedts, Stockholm 1991.

development bloc. It was above all through the work of the American economist, Michael Porter, that the cluster concept attracted considerable attention following the publication of his major work in 1990.[1] Porter argued that it wasn't actually nations that competed with one another but rather firms. He then went on to use the cluster concept to describe how international competitiveness is created within a group of related firms.

The formation of clusters does not need to imply that the activities concerned are bound together by a close physical proximity. It is quite sufficient at least at the outset that the firms are part of a coherent, functioning system. Here it is appropriate to remind ourselves that Francois Perroux's concept of "pôle de croissance" referred primarily to sectors or groups of firms within an economy that have strong links to each other and that growth in this type of sector produced strong spread effects throughout the entire economy.

In recent years, it has become more common to refer to clusters within a specific geographical environment where related firms are localised and surrounded by supporting activities. The various actors – all of whom are linked together - may be subcontractors, customers, competitors, universities, authorities and organisations. There are numerous examples of geographical clustering such as Hollywood in relation to the film and entertainment industry, Silicon Valley within information technology, Detroit in relation to motor vehicles and the City of London regarding financial services. [2]

The arguments above bring us closer to the approaches and research findings associated with "The New Economic Geography". As the British geographer Ron Martin points out, it is really only the concept of cluster that can be said to be new. The underlying arguments and observations have been available in the economic literature for many years.[3]

Before proceeding with an analysis of the socio-economic impacts of the research centre, it is appropriate to examine some of the components that are part of what has become an increasingly complex effect model. At the same time it is essential to extend the socio-economic and geographical perspective.

It is above all two factors that make it vital to integrate the plans for the location of a future research establishment within a wider perspective. Firstly a neutron research centre takes on a strategic importance in what is termed a knowledge-based economy. Secondly the establishment of this research centre should not be seen as a local or regional concern only. In our discussions the European perspective will be essential.

The knowledge based economy

Whereas previous periods of modern history have been characterised by a relatively slow transition from agrarian to industrial forms of production and living conditions, the present transformation is unique in human history in terms of the pace at which technology, forms of production and economic, social political and cultural conditions are changing. At the same time the fundamental importance of the *growth of knowledge and diffusion of innovations* has become increasingly evident.

There are several signs of the emergence of a post-industrial society and knowledge-based economy. *Trade* between industrialised countries has changed character. A growing

[1] Michael Porter : *The Comparitive Advantage of Nations*. Simon and Schuster, New York 1990.

[2] Anders Malmberg, Örjan Sörvell, Ivo Sander: Spatial Clustering, Local Accumulation of Knowledge and Firm Competitiveness, *Geografiska Annaler* 78 B, No 2, 1996; Hans Tson Söderström red.: *Kluster.se. Sverige i den nya ekonomika geografin.* SNS Förlag, Stockholm 2001.

[3] Ron Martin, Peter Sunley: Deconstructing Clusters: Chaotic Concept or Policy Panacea? Submitted to *The Journal of Economic Geography*. December 2001.

proportion of the internationally traded goods comprise products whose high value has been created by inputs of highly skilled labour and advanced technology. The service content of these traded goods has increased while the pure material content has undergone a corresponding decline. *The content of work* and the production output have taken on new forms. Research has become the most expansive sector.

The important role played by research, especially the *practical importance* to a nation of research in the natural sciences has been widely recognised. The *status and prestige of scientists* has risen markedly and has come to encompass not only natural science and medicine but also research in general. At present there would appear to be a widespread impression that universities and research institutes are an important driving force underlying technological and industrial development and that there is a fundamental relationship between research and higher education on the one hand and the international competitiveness of firms. This relationship would naturally have important consequences for employment and wealth of nations.

It has long been known that that there are agglomerative forces that exert a major influence on the location of different types of production. Firms and institutions gain advantages from proximity, particularly in certain areas and in certain places. It is especially important to note in the light of the aims of this report that the tendencies towards agglomeration in certain regions are even more striking in the knowledge-based economy than in the traditional industrial society with its factory towns and mining communities. *Geographical clustering* is one of the most prominent features in the economic geography of the new millennium.

The geopolitical perspective

The future of the industrialised countries no longer depends to the same extent as in former days on natural resources and the diligence of inhabitants. The development and communication of knowledge together with a capacity to innovate have become vital factors in promoting economic and social change. The role of science and the practical importance of higher education has become increasingly evident. The universities and research institutes can be considered to act as a driving force for technological and industrial development. This perspective on the transformation of society achieved a breakthrough during and after the Second World War.

Geopolitical developments during the 1930s and 40s helped to accelerate not just the scientific breakthrough but also brought about a change in the geographic distribution of the production of knowledge and economic power. The United States emerged from the Second World War in a very strong position. On the other hand, its allies and the axis powers needed at least a couple of decades to recover. In relation to the Manhattan project, for instance, the military sector was able to mobilise vast resources. This expansion of American industry was given a further stimulus by the Marshall Plan to aid rebuilding in Europe, the space programme and not least the rearmament programme in the shadow of the Cold War.

Of perhaps even greater importance to the establishment of American predominance were the human resources that flooded the country. Skills and knowledge became concentrated in certain parts of the United States and made a notable contribution to the country’s remarkable technical, scientific and cultural development after the war. A database of nearly 700 biographies of Nobel Prize winners clearly shows how unique knowledge and expertise were transferred across the Atlantic. Many Noble Prize winners received their prize after being appointed to prestigious positions at universities and research institutes in the US. These scientists grew up in Europe, were educated in European schools and universities, and worked in European research environments where pioneering discovers were first made. Many well-known winners of the Nobel Prize in physics, for example, converged in Princeton. Of the over 40 economists from different parts of the world that have won the Bank of Sweden's Prize in Economic Sciences in Memory of Alfred Nobel since 1969, 16 have been active at the University of Chicago.[1]

As the European Union has developed, European countries have regained several of the leading positions in economics and research that they held prior to the Second World War. The present fifteen countries of the European Union have a combined economic and scientific potential that is comparable with that of the United States in the mid 1990s. Roughly speaking, the United States has 70 per cent of the population of Europe and slightly more than 80 per cent of its GDP. The United States has 29 per cent of world industrial production in terms of value added compared to 28 per cent for the EU. South East Asia has also a sizeable industrial production.

Regions in networks

Most of us would appear to be familiar with a focus on Europe divided into sovereign states the boundaries of which have established the framework for most political activity. By means of legislation and political action, governments have been able to exert control over economies and citizens have been able to see a relationship between their own welfare and the strength of the country's economy. Within these political frameworks, education and research have also been organised. People have lived with national identities that have been formed by upbringing, education and the information that is communicated in unison over wide linguistic areas by means of books, newspapers, radio and television. A uniform geopolitical order has become legitimised and commonly accepted. It has reached into all areas of modern social life, especially during the twentieth century.

In a new millennium, this type of framework is no longer quite as self-evident as it was a few years ago. During the short period that has elapsed since the fall of the Berlin Wall in the autumn of 1989, the role of the territorial state in the future of Europe has begun to be debated and questioned. Researchers and political commentators have pointed to a number of factors, which suggest that territorial states have played out the role that they have had for over a century or at least lost some of their traditional hegemony.

Networks have become a highly fashionable concept. The Spanish-American sociologist Manuel Castells uses the concept *Network Society* in order to characterise an emerging world. In this world, many of the most important functions are organised in networks. Networks constitute the new "social morphology" of our societies, and the diffusion of networking logic substantially modifies the operation and outcomes in processes of production, power, culture and human experience. Moreover he maintains that network not only impinge on the hegemony of states but also on other collective spheres of power such as political parties and trade unions. Work is in the process of losing some of its collective identity and by means of extensive specialisation has become more closely associated with the competence and knowledge of individual human beings. A cultural pattern of social communication and social organisation focused on the individual is gaining ground.[2]

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[1] Gunnar Törnqvist has worked on this material for the Nobel Foundation Jubilee Exhibition in 2001 together with two doctoral students, Niclas Olofsson and Ola Thufvesson. See *Cultures of Creativity. The Centennial Exhibition of the Nobel Prize.* Science History Publications, USA & The Nobel Museum 2001.

[2] Manuel Castells: *The Rise of The Network Society*, The Information Age: Economy, Society and Culture, Volume 1. Blackwell Publishers, Oxford 1996; *The Power of Identity*, The Information Age: Economy,

What is now happening is that different forms of cross-border network are growing in importance at the expense of territories. There is a growing tension and risk for conflict between the power associated with territories and the interests that find expression in networks. The huge growth of institutional networks provides the most marked examples. Company networks and scientific networks that have been of vital importance for economic progress have broken out of their traditional political and social limitations. It is no longer a question of simply adjusting to the size of the market and distant sources of raw materials. A complicated web of cross-border networks is developed as a result of foreign investments, take-overs, mergers, cross-wise ownership, business alliances and co-operative agreements. These arrangements are subject to floating ownership relations and patriotic loyalties. The stateless organisations of the present age can be only partly controlled and influenced within the territorial based decision-making systems. By evolving new strategies for co-operation and specialisation within networks, it is possible for firms to take advantage of differences in the conditions of production in several countries at the same time. The difficulties of conducting economic and labour market policies within national frameworks are one of the most profound challenges to national sovereignty in our time.

The expansion and importance of research is still discussed in terms of national priorities. At the same time, it is undoubtedly the case that research and development is predominantly conducted within international networks outside the control of individual states, despite the fact that many of them still finance a large part of their operations. Science has freed itself from national frameworks and increasingly operates within network structures, which are strikingly reminiscent of those that prevailed during the Middle Ages. An archipelago of universities and research institutions are bound together in a network of cross border relations. The scientific world is now more than ever part of a powerful system of communications. Research and the development of knowledge is based on the diffusion of ideas and the circulation of information. In a creative process, pieces of information are combined in new frequently surprising ways. Teaching conveys these new ideas to others. Scientific networks and communities are not just used for communicating ideas and viewpoints. They are also used for purposes of control, criticism and recognition.

At the same time as a network society with global dimensions attracts attention, the regional level in Europe has received a growing interest among researchers in the social sciences and humanities. The regional level refers to a level between the national and the particularly local.

In contemporary economy, globalisation goes hand in hand with regional revival. A regional recovery is close on the heels of global growth. “There is a indeed a rise of the regional in lockstep with the rise of the global.” This relationship has been tested and verified in a number of countries in the OECD.[1]

It has been well known for a while that forces of agglomeration exert an important influence on the location of different types of production. There are advantages from having production units close to one another, particularly in certain areas and places. The British economist, Alfred Marshall was one of the earliest proponents of the importance of neighbourhood for industrial development. A hundred years ago he observed that

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Society and Culture, Volume II Blackwell Publishers, Oxford 1997*; End of Millennium*, The Information Age: Economy, Society and Culture, Volume III. Blackwell Publishers, Oxford 1998.

[1] See for example Christopher Harvie : *The Rise of Regional Europe*. Routledge, London 1994; Jan deVet: Globalisation and Local and Regional Competitiveness, *STI Review*, 13, 1993, p. 89 –121; Philip Cooke: *Cooperative Advantage of Regions*. Unpublished paper, Centre of Advanced Studies, University of Wales 1994.

industrialised countries there were areas and places characterised by an industrial atmosphere. "Industry in the air" was his expression. Here similar and related industries congregated forming an archipelago of scattered islands. Marshall put forward three main reasons to explain these phenomena of industrial concentration and the creation of an industrial atmosphere in a specific place or region. The agglomeration of related firms produce external effects by the creation of a permanent labour market for skilled personnel within a limited geographical area. This area becomes attractive for both employers and skilled labour. The other factor in favour of agglomeration is the growth in the availability of specialised inputs and services. Thirdly agglomeration generates competence. [1]

The Canadian economist, Jane Jacobs, attracted considerable attention in 1984 with the publication of *Cities and The Wealth of Nations*. Here she put forward the view that nations were inappropriate territorial units for an understanding of the ways in which economies operate. Every state is comprised of a mixture of several regional economies. Rich and poor regions are to be found adjacent to each other. Without national policies of regional compensation, the gaps between regions would be unacceptably large. Despite these regional policies, the economic disparities between regions far outstrip those between national average levels. According to Jane Jacobs, the city region is the geographical unit that best provides insights into how economies basically operate. The city regions or urban regions are the proper units in a larger economic landscape. In urban regions, a remarkable amount of economic activity takes place within a small area. Between these agglomerations, the economic landscape is surprisingly empty.[2]

A leading contemporary economist, Paul Krugman, took up Marshall's ideas in his book *Geography and Trade* published in 1991. He argued that states have a role to play in the international economy simply because their governments undertake measures that affect the geographical mobility of goods and factors of production. As a result of political decisions, political boundaries may act as a barrier to trade and factor movements. However there is otherwise no inherent economic sense in drawing a line on the ground and stating that on either side of that line there are two independent economies. For a closer understanding of what is happening in a global economy we must observe what is taking place *within* the boundaries of individual states. If we wish to understand why growth rates differ between countries, we ought to begin by examining the differences in regional economic growth. As has been seen above, external effects and the advantages of agglomeration exert a decisive influence on the localisation of economic activities and the creation of centre-periphery relations. It is hardly likely that the political boundaries will define the space in which these external effects will operate. If we pause, take a step backward and reflect on the most striking feature of the geography of economic activity, we will quite quickly conclude that it is concentration. According to Krugman, the concentration of firms that arise in all industrialised countries may be explained in terms of a Marshallian trinity of factors: a common labour market, access to inputs and services and the transfer of knowledge. All of these factors presumably occur in a city or a small group of towns where people are able to change jobs without having to break up from a familiar environment, where regular face-to-face contacts can be made and where goods and especially services that are difficult to move may be supplied.[3]

A picture emerges here of a fragmented space, consisting of an archipelago of self-aware regions bound together by different types of network. Several different conditions have

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[1] Alfred Marshall: *Industry and Trade*. Macmillan, London 1919.
[2] Jane Jacobs: *Cities and the Wealth of Nations*. Penguin Books, Harmondsworth 1984.
[3] Paul Krugman: *Geography and Trade*. The MIT Press, Cambridge, Massachusetts 1991.

interacted to create this new map. The operation of modern transport systems tends to facilitate the development of a nodal settlement system. Strong forces of agglomeration encourage the concentration of productive activities. As we have seen above, firms and institutions within research and cultural life are embedded in regional environments where human beings live and work. However the lack of opportunities to exchange ideas, knowledge and capital over long cross-border distances would impede the growth of entrepreneurship, research and cultural diversity and threaten the individual region with stagnation. Extensive networks become established without an obvious connection to territorial boundaries. The interaction between global forces of change and regional ambitions that exerts such an important influence on our material prosperity is facilitated by the links that bring together a kaleidoscopic world of domestic bases and places of creativity. "*Regions and localities do not disappear but become integrated in international networks that link up their most dynamic sectors*". This is the view put forward by Manuel Castells in his books on the contemporary growth of network societies.[1]

Universities in particular act as strategic links between worldwide networks and local environments. These links communicate in two directions. The university links up a place and a region with centres of knowledge throughout the world. They act as international connection centres. At the same time, the university mobilises local and regional competence in different ways to create an attractive environment in those places where they are located.[2]

The mechanisms of regional success

What are the factors that generate success in a knowledge-based economy? Before continuing with a discussion of this question, it is appropriate to examine the experiences that can be drawn from the literature in this field. In our time, economic prosperity, innovative capacity and growth are positive value concepts that are accompanied by characteristics that are highly unevenly distributed throughout the world. Why are certain areas and places successful in certain respects while other regions and places not? Why are certain regions attractive to people and productive forces while others are not? Last but not least, what role does science and higher education play in this context?

There are several analytical studies of well-known regional environments in the United States, Europe and Japan. The environments have several common features. They are large population centres, contain large universities and research institutes and have a strong element of industrial activities based on high tech, electronics and information technology. On the basis of these studies, two different groups of environment may be clearly identified.[3]

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[1] Manuel Castells: *The Rise of The Network Society*, The Information Age: Economy, Society and Culture, Volume 1. Blackwell Publishers, Oxford 1996; *The Power of Identity*, The Information Age: Economy, Society and Culture, Volume II Blackwell Publishers, Oxford 1997*; End of Millennium*, The Information Age: Economy, Society and Culture, Volume III. Blackwell Publishers, Oxford 1998.

[2] Kerstin Cederlund: *Univesitet* - *Platser där världar möts.* SNS Förlag. Stockholm 1999

[3] The research reports that are summarised here are presented in the following:
Manuel Castells, Peter Hall: *Technopoles of the World: The Making of 21st. Century Industrial Complexes.* Routledge, London 1994;
E.Decoster, M.Taberies: *L'Innovation dans un Pole Scientifique et Technologie: Le Cas de la Cite Scientifique Ile de France Sud.* Universite Paris 1, Paris 1986;
Peter Hall*:* The University and the City, *GeoJournal* 41.4, 1997;
Peter Hall, M.Breheny, R.M;cQuaid, D.Hart D: *Western Sunrise: The Genesis and Growth of Britain's Major High-Tech Corridoor.* Allen and Unwin, London 1987;
David Keeble: High -technology industry and regional development in Britain: The case of the Cambridge phenomenon, *Environment and Planning C* 1989;

The first group comprises the *London-Heathrow-Reading corridor*, the *Plateau de Saclay*, south of Paris, *Sophia Antipolis* near Nice, the *Munich region* , the *Kista-Arlanda corridor* and *Tsukuba*, the science town near Tokyo. These areas are characterised by a heavy concentration of high-tech firms and easy accessibility to important universities and research institutes. However the studies that have been carried out have not provided any clear evidence of synergy effects between university research and entrepreneurial success. The contacts between them are few. Despite their close proximity, universities and research institutes live in one world, small, medium sized, and big firms live in another. Finally it should be borne in mind that the regions listed above have undergone rapid growth as a result of comprehensive planning and regulation.

In the other group, we find four different environments that have experienced substantial synergy effects: *Silicon Valley* with *Stanford University*, the *Highway 128 complex around Boston* with *MIT*, *Aerospace Alley* with the *California Institute of Technology* and finally *Cambridge* in Britain with its ancient, prestigious university. Here there are direct links and a substantial transfer of knowledge between university research and clusters of firms. There are numerous institutional and social networks. The networks are frequently held together by key persons who know each other well. The regulatory framework is minimal and the environments are relatively unplanned and have gradually emerged during a long time.

The researchers who have studied these environments suggest that the following factors have played an important role in explaining the remarkable differences between the two groups. It takes ten to fifteen years for synergy effects to appear. Here it is vital that university research is in tune with the needs of industry, as was the case with the space programme and the cold war military-industrial complex. Behind these successes are individuals whose early initiatives began a long run process, a spark that has ignited a chain reaction. Metaphorically speaking, there is a need for a “precision-tooled” interaction between researchers and entrepreneurs. This interaction presupposes mutual understanding and *trust*.

In 1994, the American researcher, AnnLee Saxenian presented an analysis of IT clusters in Silicon Valley and the Boston region. Her main argument was that it was basically “cultural” differences that explained the greater innovative capacity and growth of Silicon Valley than the high technology centres along Route 128 in the Boston region. The explanation is historical.

The prestigious universities of the Boston region – Harvard, Yale, Princeton and MIT – have for many years been able to take advantage of their well-established relationship with federal government in Washington. A stable contact network that is frequently formal and hierarchical has been developed within the academic world as well as with the public administration and industrial sectors in its vicinity. Developments in Silicon Valley on the other hand have been characterised by a pioneering spirit that to an outsider may appear disorganised, hazardous and unstable. This pioneering spirit in California has created a regional innovative environment and a development climate at the local level around the university that has stimulated small business enterprises in the IT sector. Risk capital has been available. Co-operation between universities and firms has developed rapidly without any obvious signs of prestige and a formal system of rules and regulations. The attitude towards

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AnnLee Saxman: *Regional Advantage: Culture and Competition in Silicon Valley and Route 128.* Harvard University Press, Cambridge, Mass. 1994;
Allan Scott: *Technopolis*: *High-Technology Industry and Regional Development in Southern California.* University of California Press, Berkeley 1993;
S.M.Tatsuno: *The Technopolis Strategy: Japan, High Technology, and the Control of the Twenty-first Century.* Prentice-Hall Press, New York 1986.

new businesses associated with the university environment has been encouraging and tolerant. At the same time, it should be pointed out that this environment comprises elements that are conceived as being economically and socially brutal.[1]

The case studies presented here indicate that there is no simple answer to the question regarding the role played by research and higher education in regional and local environments. The literature in this field provides many good examples of the dynamic role of the university in promoting regional development. However there are also numerous examples of universities and firms that are not dependent on each other at the local and regional level. The detailed studies that have been carried out provide fairly clear evidence that the relationships involved are highly complex and that the effects of higher education and research vary markedly between different places and regions.

If two phenomena occur in the same area – for example successful research and industrial expansion – this could not be seen as providing support for the hypothesis that there is a causal relationship between them. A combination of factors that appear to be successful in one region would not necessarily produce the same effects in another one.

But after all, the regional examples that have been presented so far are strikingly unanimous in one respect. The most creative economic environments in the knowledge-based economy have been developed on the basis of local and regional co-operation between qualified research and enterprising spirit. Individuals with unique skills may combine the roles of researcher and entrepreneur. They are able to move without restrictions between university laboratories research and development departments of the firm. However it is probably more common to establish this close relationship by means of the tightly drawn network of contacts that bind researchers in the academic world with key individuals in the business sector. Local and regional politicians may also play an important role in this context.

In another context, we have referred to the concept of *social web*, or social fabric in order to indicate a network structure that is local and tightly drawn.[2] We have also put forward the thesis that close, tight networks of this type are probably of strategic importance in milieux of creativity and places of creation.

Comments on the Working Group scenarios

The working group was mandated to review the following three scenarios for neutron scattering in Europe:

1. The full ESS project with both a 5 MW long pulse and a 5 MW short pulse target station;
2. A phased ESS with first the construction of a long pulse target station and the short pulse station at a later stage;
3. A 1 MW short pulse target station either as an upgrade of ISIS or as a new facility.

As can be seen from other parts of the Working Group Report, *Alternative 1* will give Europe unique scientific opportunities and an overall leading position in all fields of science where neutrons are important. It is also the most expensive and resource-consuming

[1] AnnLee Saxenian: *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Harvard University Press, Cambridge, Mass. 1994

[2] This concept has been put forward by Torsten Hägestrand in different contexts including Torsten Hägerstrand: Resandet och den sociala väven, *Färdande och resande*. KBF, Stockholm 1995. The concept has been further developed in Gunnar Törnqvist*: Renässans för regioner: Om tekniken och den sociala kommunikationens villkor*. SNS Förlag, Stockholm 1998; Sverker Sörlin, Gunnar Törnqvist: *Kunskap för välstånd. Universiteten och omvandlingen av Sverige.* SNS Stockholm 2000.

alternative concentrated in time. In the long term *Alternative 2* will give comparable scientific benefits, but in short term the benefits of this alternative are not in parity. Costs of comparable or higher magnitude than in alternative 1 can over time be split up. The establishment of a new neutron source can after a first stage be interrupted. With *Alternative 3* Europe will loos some of its leading position in neutron based sciences. The most striking argument for this solution is that it is cheap.

When approaching the socio-economic impacts of the alternatives there are some fundamental circumstances to consider. Neutron facilities are costly with long lead times in both planning and construction. Let us take ESS as example. Assuming that a decision to build is made in 2004, building and expending could start in 2005. The construction period has been assumed to end during 2012. Full scientific output will be reached sometime between 2015 and 2020. Lead times of other alternatives are comparable. As was pointed out under the heading "The mechanisms of regional success" above it often takes ten to fifteen years for socio-economic impacts of research activities to appear. This means that the total time span to be considered is 30 years or even more. For such a long time the scientific predictability is not good. Technologies will change. New scientific achievements will come in. And above all, economies, political state of things, institutional frameworks, and living conditions will probably change.

When we are going to discuss socio-economic impacts there is also another problem to consider. The location of a world-class neutron facility is important. As was discussed above, the physical, economical, institutional and cultural infrastructure in the environment is crucial.

"If two phenomena occur in the same area – for example successful research and industrial expansion – this could not be seen as providing support for the hypothesis that there is a causal relationship between them. A combination of factors that appear to be successful in one region would not necessarily produce the same effects in another one." Considering these problems with time and location let us discuss three types of socio-economic impacts.

A	Direct– Localised	Short-term
B	Indirect – Network-type	Long-term
C	Global diffused – Public-beneficial	Long-term

A-impacts can be expected to occur especially during the time of construction but also later. Here some of the traditional effect models former presented may be relevant. The demands on both material and intellectual resources certainly depend on which of the three alternatives we discuss. For the most advanced project, ESS, the need for land is estimated to be 1.3-2.0 sq. kilometres while the investment expenditure is expected to be in excess of 1.5-2.0 billion EUR. The personnel requirements are expected to be in the region of between 500 and 600 persons on a permanent round the clock basis. It is anticipated that as many as 4000 to 5000 scientists will make use of the plant every year. As already has been pointed out, these direct localised effects have their greatest impact on places that have a small one-dimensional labour market and a highly restricted range of services. Large, diversified regions with dense supplier and customer networks will be least affected since there is usually a degree of more or less latent over-capacity among building firms, sub-contractors, retail trade outlets and service companies.

Approaching B-impacts, technological clusters and innovations systems will be brought into focus. In a new millennium many of the most important functions are organised in networks. Networks constitute the new "social morphology" of our societies, and the diffusion of networking logic substantially modifies the operation and outcomes in processes of science, production, power, culture and human experience. Experiences from contemporary research clearly show the effects diffused in networks of our time are of Long-term type. *Geographical clustering* is one of the most prominent features in the knowledge based economy of the new millennium. Probably most of the B-impacts are localised (agglomerated) in environments where institutional frameworks and social web are tight. The most successful agglomerations are bound together by cross-border networks. A picture emerges of a fragmented space, consisting of an archipelago of scientific regions bound together by different types of network.

In an overall perspective the C-impacts are of most importance to discuss. The future of the advanced economies no longer depends to the same extent as in former days on natural resources and human diligence. Scientific excellence and communication of knowledge together with a capacity to innovate have become vital factors in promoting economic and social change.

Finally some comment of *human resources*. In the short term, a simple question arises: what about potential project teams? We have to take into account the quality and the availability of technical and scientific staff required to build the instruments for alternative 1, 2 and 3. Large fluctuations in instrument performances can be expected depending on the quality and motivation of the staff. Human resources cannot be stretched: the definition of the ESS projects (full ESS and phased ESS) has involved a large European team which should not be disbanded without putting the whole project at risk. Other projects such as AUSTRON and the 1 MW upgrade of ISIS will require further efforts to finalise these projects, which would require some time in order to build up the respective project teams.

In a long term European perspective we have to consider that knowledge based human capital and scientific excellence are the most important production factors of our time. Scientific competence is the foundation for the future wealth of nations. As mentioned above, historical experiences show that these human resources are rare and highly mobile. *Quo vadis Europa?*

Regional hot-spots in Europe

The process of globalisation is increasingly favouring regions that strive to become world leaders within a particular field. The growth impulses generated in such ‘hot-spots’ of expertise has become the main driving force in economic growth of all advanced nations.

Regions and places now compete intensely on the ability to identify and create new front-edge facilities that can attract new foreign investment and simultaneously strengthen the competitiveness of the existing knowledge intensive firms. A few examples of regional concentrations of scientific activities and localisation of knowledge-based manufacturing industries in Europe may conclude this overview.

The number of publications in approved academic journals and conference proceedings has been a widely used measure of performance in recent years. In *bibliometrical studies*, an estimate is made of the number of published articles in leading academic publications in different areas. The origin of the articles is recorded with the aid of the published addresses of the university departments and institutes where the authors work. This type of approach may be criticised on several grounds. At the same time, it is the only available means of carrying out these extensive quantitative comparisons.

Measures are available for the number of published research reports in relation to GDP for a range of countries. Here Sweden is in second place after Israel and on a level that is twice that of the USA and far in excess of the average for the industrialised countries. The academic journals studied here belong to the fields of science, engineering and medicine.[1] However these nationally based comparisons miss an important point. *There are actually only a very small number of regions in different countries that provide really high quality research*.

The data in Table 1 has been taken from a recently published study carried out by a couple of Danish researchers Christian Wichmann Matthiesen and Annette Winkel Schwarz. Here the bibliometric statistics have been collated on a regional basis. The table covers 39 urban regions (city regions) in Europe all of which have nationally important universities and research institutes. The source for the Danish study is a database containing data from 5 000 leading academic journals in natural science, engineering and medicine, The Science Citation Index (SCI). It has been developed by the Institute for Scientific Information (ISI) in Philidelphia in the United States.

[1] *Science and Engineering Indicators* **-** 1998

Table A5.1. Number of published academic articles 1994 –96, by urban regions.

Region	No. of articles	Region	Per 1000 inhabitants
London	64,742	Cambridge	81
Paris	45,752	Oxford-Reading	41
Moscow	39,903	Geneva-Lausanne	29
Amsterdam-Haag-Rotterdam-Utrecht	36,158	Basel-Mülhausen-Freiburg	20
Copenhagen-Lund	21,631	Bristol-Cardiff	15
Stockholm-Uppsala	20,195	Zurich	13
Berlin	19,872	Stockholm-Uppsala	12
Oxford-Reading	18,876	Helsinki	12
Edinburgh-Glasgow	18,688	Copenhagen –Lund	11
Manchester-Liverpool	18,653	Amsterdam-Haag-Rotterdam-Utrecht	10
Cambridge	17,764	Munich	10
Madrid	16,230	Edinburgh-Glasgow	10
Munich	15,947	Gothenburg	10
Dortmund-Düsseldorf-Cologne	15,716	Mannheim-Heidelberg	8
Milan	15,120	Oslo	8
Rome	15,088	London	7
Frankfurt-Mainz	14,512	Lyon	7
Basel-Mülhausen-Freiburg	13,918	Milan	6
Sheffield-Leeds	13,484	Frankfurt-Mainz	6
Geneva-Lausanne	13,405	Prague	6
Mannheim-Heidelberg	12,289	Dublin	6
Zurich	11,951	Paris	5
Brussels-Antwerp	11,786	Berlin	5
St. Petersburg	11,506	Rome	5
Barcelona	11,467	Brussels-Antwerp	5
Vienna	10,882	Sheffield-Leeds	5
Bristol-Cardiff	10,633	Vienna	5
Helsinki	10,287	Manchester-Liverpool	5
Birmingham	9,882	Barcelona	5
Aachen-Maastricht-Liège	9,705	Aachen-Maastricht-Liège	5
Lyon	9,175	Birmingham	5
Warsaw	7,966	Madrid	4
Prague	7,616	Warsaw	4
Hamburg	7,425	Stuttgart	4
Gothenburg	7,378	Moscow	3
Budapest	6,697	St. Petersburg	3
Oslo	6,466	Hamburg	3
Stuttgart	5,043	Budapest	3
Dublin	5,043	Dortmund-Düsseldorf- Cologne	1

Source: The Science Citation Index[1]

[1] The material has been taken from Christian Wichmann Matthiesen and Annette Winkel Schwarz: Scientific Centres in Europe: An Analysis of Research Strength and Patterns of Specialisation Based on Bibliometric Indicators, *Urban Studies*, Vol 36, No 3, 1999.

Annex 6 – Timelines of individual projects

1. Method and scope of the study

The Working Group was mandated to review three options for neutron scattering in Europe: the full ESS project (a 5MW LPTS and a 5MW SPTS are built at full speed); a phased ESS; a 5MW LPTS hypothetically followed much later by a 5MW SPTS, and finally, a new SPTS operating at 1 MW constructed either as an ISIS upgrade or as the AUSTRON project. These projects would develop at their own pace and would provide the European scientific community with new apparatus according to different time scales. How do these projects compare with the current situation in Europe? How will their relative scientific potentials evolve with time? It is the purpose of this annex to clarify the parameters and the observables used in such a comparison.

Neutron scattering facilities make available experimental devices, called instruments, where scientists carry out their research programmes. These instruments are more or less efficient depending on the neutron flux available and the technologies used. It has been agreed to compare the potential scientific output of the three options mentioned above to a currently operating facility, the ILL, the reference point being taken as the pre-Millennium ILL in year 2000.

These options should be contrasted with a baseline scenario, which includes the ILL in Grenoble and ISIS in Oxfordshire. In Europe, the ILL and ISIS have set standards in neutron scattering worldwide; the ILL is a multi-national European collaboration, while ISIS is partially supported by European funding. Other medium flux neutron sources, some of which will be phased out during the next twenty years [1], represent the first tier of the European landscape for neutron scattering [2]. The ILL and ISIS constitute the second tier of the European landscape [2]. The two facilities have undertaken major renewal programmes. In particular, the ILL will bring to fruition the entirety of or a fraction of the ILL Road Map; the resulting programme, the content of which is called the Millennium Programme, rests with funding decisions to be made by the ILL Associates. Furthermore, ISIS-2, the second target project for ISIS can be considered as approved and somehow well underway. These two programmes are included in the baseline timeline.

Europe has enjoyed the world-leader position in neutron scattering for more many years. However, both Japan and the USA have initiated major efforts to alleviate the need for more advanced neutron sources in their respective regions. In particular, the USA have launched the SNS project, a 1.4MW Short Pulse Target Station with potential upgrade towards 2 MW or higher, in order to regain worldwide leadership in neutron science. For this reason, the SNS project has been added in the baseline as a yardstick in order weigh the European output against the outside world.

1.1. Scientific Output

The potential scientific output of neutron scattering installations is related to the number of neutron instruments open to the scientific community. A simple counting of the number of instruments currently operated at present medium and high-flux neutron sources in Europe leads to 115 instruments (HMI in Berlin, IBR-2 in Dubna, ILL in Grenoble, ISIS in Abingdon and LLB-Orphée in Paris). New sources are still in project (ISIS-2 in Oxfordshire) or in development phase (FRM-2 in Münich, PIK in St-Petersburg) with 58 more instruments.

Based on the number of days-to-users delivered by each facility, the existing sources are delivering around 20,000 instrument-days per year today.

However, not all instrument-days are created equal. Setting aside experimentalists inventiveness and skills, instrument and source performance are the main parameters which confer value to beam time. A measure of the global value of research facility is the counting of research articles published in prestigious journals such as Nature, Science, the Physical Review Letters and the Journal of Molecular Biology.

Within 20 years, some of the existing sources will be closed [1] and hopefully will be replaced by new facilities corresponding to one of the three projects presented above; it can be anticipated that the number of instruments available would remain at best constant. However, the new facilities will have brighter sources and will produce more efficient neutron beams; furthermore, they will host more powerful instruments. It would be worth conducting some analysis at least to clarify the balance between scientific benefits and budgetary considerations when discussing costs associated with replacing and maintaining neutron facilities. Assuming the three already planned projects (ISIS-2, FRM-2 and PIK) come to completion, they would produce another 9,500 instrument-days. The total number of instrument-days available to each of the 4,500 European scientists using neutrons is around 7 days per year and per scientist. There is an urgent need to keep that number up.

The ILL Millennium Programme was launched in 2000 in order to optimise the scientific output of the High Flux Reactor of ILL. A careful mix of instrument upgrades and infrastructure renewal will lead to a gain factor of 11 over the present situation by the years 2010-2012 [3]. This includes in particular the increase in the number of operating instruments: in 2002, ILL delivered roughly 5,800 instrument-days to users on the ILL public instruments and the Collaborating Research Group (CRG) instruments; the ILL Road Map foresees that by 2010-2012, the ILL will operate 30 public instruments and 11 CRG instruments (equivalent to 38 instruments), delivering 7,000 instrument-days to users per year.

Turning to the ISIS-2 project, the second target will start operation in 2006 and will be completed by 2012. A suite of roughly 20 instruments will be constructed at a pace of 3-4 per year, paralleled with the progressive upgrade of the 20 instruments located at the present ISIS facility. The number of instrument-days available would be similar to ILL’s figure.

The options for the European third-tier scenario, the full ESS and the 5MW LPTS or any 1 MW SPTS with 20 instruments once fully completed will contribute to roughly 7,000 or 3,500 instrument-days, respectively, but with much higher efficiency than today’s machines. Comparison between the future scenarios and existing sources imposes the use of so-called gain factors that involve the source brilliance, the reliability of the source, the number of operation days, the number of instruments, and the efficiency of instruments. Less quantifiable factors, such as support facilities and staff, which also contribute to the impact of facility, have been ignored.

1.2. Gain factors

Let us consider first the existing facilities, ILL and ISIS. In 2000, the ILL operated slightly more than 32 instruments (including CRG instruments) during an averaged period of 180 neutron-days supplied to users (this corresponds to 5,800 instrument-days). At the same time, ISIS has offered 162 days to users on a suite of 20 instruments (3240 instrument-days). Direct comparison to the numbers of scientific papers published in the highly visible and respected scientific journals leads to a gain factor in efficiency of 1.3 in favour of ILL over ISIS. This may reflect the particular selection of scientific journals but shows that the instrument suite implemented at ISIS is competitive with the ILL instruments. Therefore, a source-gain factor of 1 compared to ILL has been assigned to ISIS. However, a large fraction of ILL instruments have not been upgraded for years; furthermore, neutron guides at ILL were installed almost 30 years ago and the installation of modern guides (as foreseen in the ILL Millennium Programme) will bring a gain factor of 2-3 in neutron flux delivery at instruments: a fully refurbished ILL will be more than 1.4 times more efficient than in 2000, without counting the instrument gains which will be obtained by including new technological developments. Now let us turn to the neutron source at ILL. The power of the reactor at ILL cannot be increased, but improved moderators for the two cold sources could be installed. After 2012, ILL will improve the two cold sources it operates now by following methods used at pulsed sources which will lead source gain of 25-30% for the whole ILL. This potential source gain has not been included in the time charts below.

The ESS project team has produced documents [4] with source gains and instrument gains for each generic instrument compared to the SNS project and to the present ILL and ISIS; these quantities are very useful when optimising the best “location” of a given type of instrument and when selecting the best instruments at the best source to perform the best science.

When dealing with time planning, it is more appropriate to use an “average source gain factor” for a “standard” suite of instrument. The full ESS would provide two instrument suites optimised for both the 5 MW SPTS and the 5 MW LPTS, which maximises gain factors. However, a solution such as a single LPTS or a single SPTS (1.4 MW SNS and 1MW SPTS in Europe) would lead to a lower “average source gain factor” because all instruments will not be perfectly suited to the source. Spallation sources (ISIS and ISIS-2) coexisting with reactor sources can plan to host only the instruments that are perfectly adapted to their time structure, and therefore can lead to higher gain factors.

The total gains used here for pulsed sources (the full ESS, a 1MW SPTS at 10Hz or 50Hz and the 1.4 MW SNS) are based on ESS reports [4] presented at the Bonn meeting. The “average source gain factor” is given by the brilliance of the source for the suite of instruments, which are planned to be built on that source. The 1 MW SPTS options (where the instrument suites are not fully defined yet), have been taken as providing source gain factors of 5, as if the instrument suite will be fully optimised to a short pulse structure. In contrast, the 1.4 MW SNS does not offer equivalent gains because the non-fully-adapted instrument suite.

Instrument gains are defined by comparing the level of instrumentation concepts that could be achieved at the facilities to come compared to the situation of ILL instruments in 2000. An average factor of 2.5 for all instruments is attributed to all new facilities, including the post-Millennium ILL; another factor of 2 has been credited to the ILL corresponding to the refurbishment of ILL’s ageing infrastructure. The “average gain” is the product of the source and instrument gains.

The scientific output of any facility is taken as the number of equivalent instrument-days that is obtained by multiplying the “average gain” by the number of instruments and the number of effective operating-days. The number of effective operating-days depends on the total number of operating days of the accelerator and on the reliability factor. Reliability for continuous operation is mandatory for user service and is more easily achieved on reactor sources than pulsed sources (low power sources such as IPNS reach 92% but higher power sources may find it difficult to go beyond 0.9). The number of days given to users is further reduced due to provisions made for tests, commissioning, upgrades, and in-house research (fraction to users taken as 80% at all facilities).

The final gain factors are obtained by renormalising the scientific output of the different options to the ILL output of ILL in 2000, 5800 instrument-days. The last row of table 1 above lists the final gains, which are used to compare the different sources and options.

Table A6.1: Gain factors for the different options. The ILL's instrument-gain includes a factor 1.4 due to the refurbishment of infrastructure. ESS and ISIS-2 projects combine two options each.

SOURCE	ESS		LPTS 5MW	SPTS 1MW 50Hz	SPTS 1MW 10Hz	SNS 1.4 MW	ISIS-2		ILL after 2012
	LPTS 5MW	SPTS 5MW					2nd target	ISIS	
source gain	10	20	12	5	5	5	1	1	1
instrument gain	5	5	5	5	5	5	5	5	7
total gain	50	100	60	25	25	25	5	5	7
number of instruments	20	20	20	20	20	24	20	20	38
operating days	230	230	230	200	200	200	225	225	225
reliability	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	1
fraction to users	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
neutron-days to users	166	166	166	144	144	144	162	162	180
final gain	85		34	12	12	15	6		8

2. Timelines

The third-tier European scenario offers three options (the full ESS with two 5MW targets, the 5MW LPTS and the 1MW at 10Hz or 50Hz), which have their own time scales. The ILL Millennium Programme and ISIS-2 that constitute the second-tier of a hierarchy of European neutron scattering facilities are compared to the SNS project in the USA. The time charts below provide the evolution of the scientific output as measured in equivalent instrument-days as compared to ILL in 2000. A fixed time scale has been used for ILL and ISIS-2, the underlying baseline, and the SNS; in contrast, the three European scenarios have been put on a sliding time scale, with origin for the time axis defined as the time when the project is approved. Finally, the time span to be considered has been set to 20 years. Going any further would require to consider technical and political issues which are beyond our control today.

2.1. The baseline: ILL Millennium and ISIS-2 versus SNS

Figure A6.1 represents the comparison between the baseline option, ISIS-2 and ILL Millennium Programme and the already funded project SNS in the USA. It should be noted that upgrades of SNS up to 2 MW or higher are currently being considered, which would increase its performance by a factor of 1.4.

By the year 2015, the SNS at 1.4 MW will match ILL in terms of overall scientific output. However, some instruments will allow SNS to outperform European facilities as soon as SNS approaches the MW level. It is also likely the SNS power can be raised to 2 MW in the same timeframe. Furthermore, the USA will also continue to operate two powerful research reactors: HFIR at Oak Ridge and NIST near Washington. A comparison of scientific output (number of publications) indicates today that ILL is over-performing NIST by a factor of 2. However it can be expected that the NIST and the HFIR will follow more or less ILL's evolution in terms of gain in efficiency. It is therefore clear that, in the absence of a quick decision, the neutron scattering facilities in the USA will have the potential to overshadow the European scientific output of ILL and ISIS-2 in the next decade.

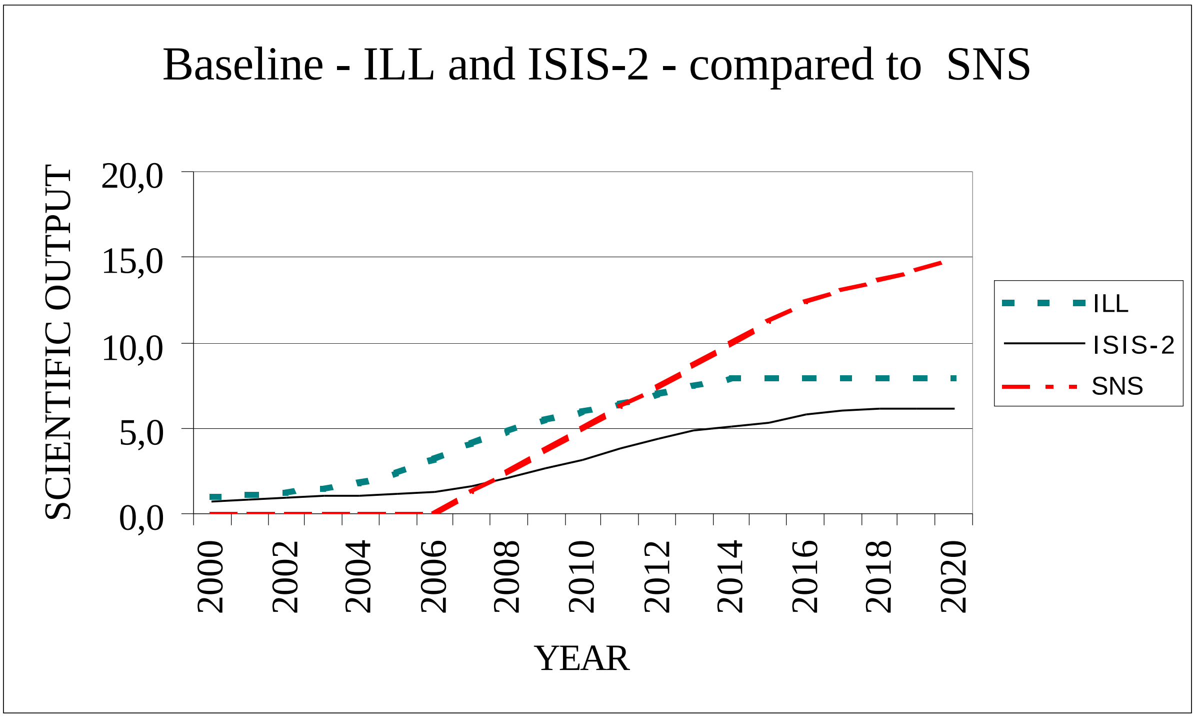


Figure A6.1: Timeline for the underlying baseline in the European landscape for neutron scattering (ILL Millennium and ISIS-2) compared to SNS.

2.2. The European third-tier scenario

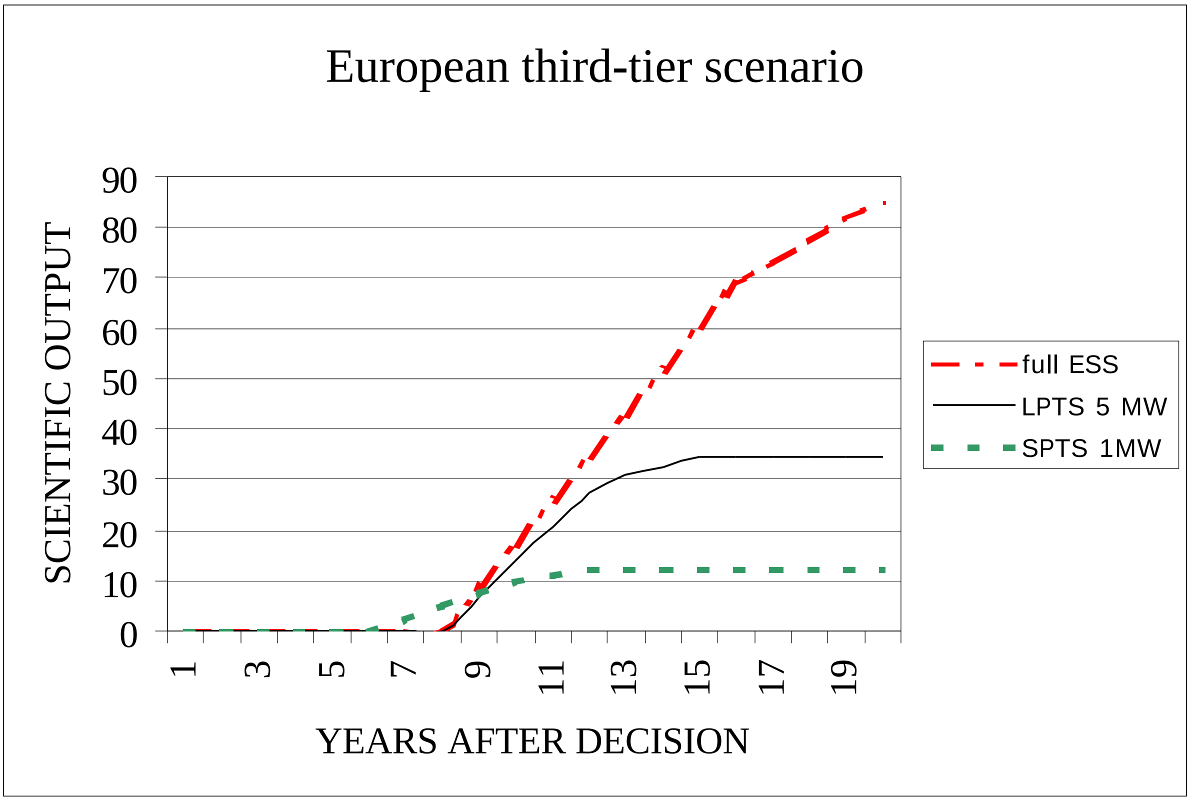
The three options for the front rank facility in the scenarios are compared in figure A6.2. The full ESS, with 40 instruments in operation on the two target stations 20 years after the decision for construction is made, will provide scientific output equivalent to 85 times that of ILL in 2000. The 5 MW LPTS project, with 20 instruments, will lead to a potential gain of 34, 15 years after the decision to build it is made. A short pulse target station at 1 MW with 20 instruments would lead to a long-term gain in scientific output of the order of 12 but with an earlier start.

In terms of scientific output, the full ESS project is obviously the most promising one. Looking at the time profiles above, it appears that, if the decision to build ESS were made in 2004, either the full ESS or the LPTS would reach the SNS level around 2012 and will be world-leading after 2015. A 1MW source will certainly be competitive with SNS but will not outclass SNS.

In the USA there are indications that as the SNS project with its current specification of 1.4 MW reaches maturity, potential future upgrades to 2-4 MW and the addition of a second target station may be possible.

If Europe intends to maintain its leadership in neutron scattering, it is therefore necessary to build the third-tier project. The time scale for such a decision is discussed in the main document. In any event, it would be highly desirable that the neutron scattering community in Europe co-ordinate the optimisation of instrument suites at the major facilities according to the adopted scenario once this scenario has been defined, approved and funded.

European facilities should focus on the best instrumentation optimised to their source characteristics, even if some niches could be found.



FigureA6.2. Timeline for the options in the European third-tier scenario for neutron scattering.

3. References

[1] "Survey of the Neutron Scattering Community and Facilities in Europe", European Science Foundation/ European Neutron scattering Association, IBSN 2-912049-02-4 (1998).
[2] "The ESS in the Context of an Evolving European Neutron Landscape: ENSA's Twenty Year Perspective", IBSN 3-89336-302-5 (2002).
[3] "The ILL Road Map", The ILL Millennium Symposium (April 2001). Download from http://vitrail.ill.fr/symposium/
[4] "Instrumentation Concepts: Advances by Innovation and Building on Experience", IBSN 3-89336-302-5 (2002).

Annex 7 – Costing

1. Assumptions

- The categories of comparison for both construction and operating costs are those developed for ESS. The ISIS costing has been worked out in the same categories. For AUSTRON the comparison is not perfect, but sufficiently good for the present purposes.
- In the end the choice of a site will determine, of course, not only the exact engineering and costing details of the conventional facilities, but also the costs of labour and the possibility of getting contributions in kind. Any such site-dependent cost differences might be a factor in a final decision. In order to compare likes to likes at this stage, these differences are not taken into account.
- Every target station has been taken to be equipped with same number of instruments of the same costs as was considered for ESS.
- ISIS operations costs are based on real data.
- Finally, cost estimates are in €'s of 2000, as this was the basis for the costing of ESS. Other estimates have been transformed to this basis by assuming an average inflation of 2.5% per year.

2. Cost comparison of different spallation neutron source proposals (M€$_{2000}$)

Table A7.1. Cost comparisons of spallation neutron source proposals.

Spallation neutron source Sub systems		ESS 5 MW SP/ 5 MW LP: 11.3% DC	ESS Staged		AUSTRON 1 MW*	ISIS 1 MW
			5 MW LP: 3.8% DC	5 MW LP/SP: 11.3% DC		
Instruments & Scientific Utilization		115	60	115	60	60
Target Systems		180	90	180	90	90
Accelerator Systems	Linac	370 (L_tot=500 m)	330[1] (L_tot=500 m)	410[2] (L_tot=500 m)	267	
	Achromat & Rings	85	0	85		390[6]
	Beam transfer to targets	20	10	20		
Conventional facilities		465	305	520[3]	260[4]	
Controls & networks		55	30	55	25[4]	
Management & admin. Support		60	35	60	24[4]	
Total estimated costs		1350	860	1445	726	540
Contingency (15%)		202	131	217	109	81
Total construction costs(including manpower)		**1552**	**991**	**1662**	**835**	**621**

1) Installation of all klystrons, but LP power supply only
2) Separated LP/SP power supplies instead of combined one
3) Klystron hall somewhat bigger to house separate LP and SP power supplies
4) These figures are scaled from the ESS 5 MW LP version; not all details are available.
5) 25% of conventional facilities to compensate for different labour cost rates, in order for total estimate to be site independent.
6) This figure includes the costs of the next four subsystems/categories.

*Extrapolated from the 0.5 MW AUSTRON costing using ESS methodology. This does not take into account local labour rate differences.

3. Operating costs in M€$_{2000}$

The annual operating costs for the full ESS option are taken from the Bonn proposal. The estimate for the staged ESS option is a straightforward extrapolation from that. For the AUSTRON 1 MW option and the ISIS 1 MW option, fewer details are available. The subdivisions are less accurate, but with total running costs of slightly less than 10% of the investment costs for a new facility, one is, generally, not very much off the mark.

It is important to realise that the ESS estimates include the costs for completing the full set of 40 instruments, and later on to continuously replace them. Underestimating or even ignoring these costs, for example by assuming that they will largely be borne from national sources, amounts to hiding from reality in the European situation. The same approach is used for the other options.

For comparison's sake the operating costs of the present two top facilities, ILL and ISIS, are also given.

Table A7.2. Summary of the operating costs.

	ESS 5 MW SP + 5 MW LP	**ESS 5 MW LP[1]**	**AUSTRON 1 MW[1]**	**ISIS Operations**	**ISIS +TgT II**	**ISIS 1 MW +TgT II**	**ILL now**	**ILL +Mill**
AC Power	107 MW	36 MW	24 MW	10 MW	13 MW	25 MW		
Energy costs	28	9.5	6.5	2	2.6	5	7	7
Other consumables	23	15	18	16[2]	21[2]	27[2]		
Personnel	(650 fte) 44	(412fte) 28	(358fte) 24	18	24	28		
Maintenance, spares	22	14	16.5					
Instruments	25	12.5	12.5	10	25	25		
Total	**142**	**79**	**77**	**46.5**	**72.6**	**85**	**60**	**63**

1) In a first approximation scaled from the full ESS by assuming an equal ratio between constructing and operating costs; estimating the AC power and the personnel; and adjusting the other two categories.
2) Includes the costs of maintenance and spares.