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European Spallation Source (ESS)

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Note:

This statement given by a subgroup of the steering committee „Large research facilities for basic research“ of the German Science Council concentrates on the scientific and technical investigation of the project. The statement if the project should be funded or not is given by the Science Council itself by a final evaluation of all nine projects. This statement is given in a seperate report.

A. Introduction and background

A.I. Field of research

In the applicant's view, the use of neutrons is very well established in research areas such as physics, chemistry, material sciences, life sciences, engineering and earth sciences:

Physics: Solid State Physics

Magnetism and superconductivity are among the traditional areas of neutrons in condensed matter. The discovery of heavy fermions, of high-Tc superconductors, spin-Peierls transitions, C60 and all its derivatives, molecular magnets and the explosive growth of multilayer science have provided a plethora of new phenomena in the last decade that call for neutron techniques, including studies at very low temperature, now down to 500 pK, on nuclear spin ordering. The centre of activity has been in the study of systems exhibiting novel effects due to strong electronic correlations, such as high-Tc materials, heavy fermions or colossal magnetoresistance manganites. A recent example is the identification of structural and magnetic polarons in the manganites.

Physics: Liquids and Glasses

The scientific problem of liquids and glasses is to understand the atomic dynamics in the absence of long range order. Presently there is neither a satisfactory microscopic understanding of the low-temperature anomalies of glasses, nor of the nature of the glass transition. Neutron scattering is one of the key techniques applied in this area.

Physics: Fundamental Neutron Physics

Neutron physics has made major contributions to a better understanding of the constituents of elementary particles to the status of the universe. In particular, accurate measurements of neutron beta decay were instrumental in fixing the number of particle families at three. Moreover neutron experiments have made substantial contributions to our understanding of strong, electroweak and gravitational interactions. Neutron interferometry can be used to obtain non-classical states allowing us to check the very foundations of quantum mechanics.

Physical Chemistry: Soft Condensed Matter

Soft matter (polymers, thermotropic liquid crystals, micellar solutions, microemulsions, colloidal suspensions, membranes and vesicles) is one of the major growth areas of neutron scattering. The two crucial points for the application of neutrons in this area are: the ability for H/D labelling, and the fact that the slow time scales of molecular motions are within the range of observation of slow neutron techniques, especially of the spin-echo method. Neutrons have already played a major role in understanding polymer conformation and rheology as well as of surfactants and self-assembling systems.

Life Sciences: Biology and Biotechnology

Neutrons have an important role to play in determining the structure and dynamics of biological macromolecules and their complexes. The similar scattering signal from deuterium, carbon, nitrogen and oxygen allows the full determination of the positions and dynamics of the atoms "of life". In addition the negative scattering length of hydrogen allows the well-known contrast variation method to be applied to dissect the component parts of multimacromolecular complexes. In the post genomic era structure determining techniques are reaching towards high throughput and a high number of proteins to be investigated.

Chemistry: Chemical Structure, Kinetics and Dynamics

There is a vast range of different chemical reactions investigated by elastic and inelastic neutron scattering. Most of the work relies on the different scattering cross sections of H and D, and on the great sensitivity of neutrons to light elements such as H and O in the presence of heavy ones. A main activity in this field is connected with catalysts. Such materials range from complex zeolite templates to relatively simple molecules such as the transition-metal sulphides. In all cases the key aspect of the catalytic activity concerns the residence time and position of a hydrocarbon molecule, amenable to neutron scattering.

Earth and Environmental Sciences and Cultural Heritage

Recently neutron scattering has been added to the earth science portfolio of methods due to the latest generation of diffractometers and spectrometers. One of the most significant issues is related to the prediction of earth quakes and volcanic eruptions.

Materials Science and Engineering

Materials science is concerned with property control by influencing, or at least understanding, the microstructure. The use of neutrons at the microscopic and mesoscopic level is an important analytic tool. Also in the area of internal strains/stresses neutron diffraction is now being used extensively.

A.2. Availability of Neutrons

At present, Germany runs three medium flux reactors, the BER-II at Berlin, the FRJ-II at Jülich and the FRG-1 at Geesthacht. The last two were built between 1950 and 1960 while BER-II was refurnished around 1990. The FRJ-II and the FRG-1 are expected to be shut down within the next five years while BER-II is envisaged to be operational for another 20 years or more. A new reactor, about a factor two less neutron flux than the High Flux Reactor (HFR) at the ILL in Grenoble, the FRM II in Munich should become operational in 2001; however, due to a continuing retardation of the final operation licence by federal authorities its timely availability for scientific usage remains undecided.

Plans for investment into facilities for neutron scattering outside Germany exist in the following countries:

- United Kingdom, addition of a second target station to the 156 kW spallation source ISIS. This project is in the planning stage. It is driven by the fact that all neutron beam lines on the first target station are occupied with instruments, some of which do not make optimum use of the 50 Hz repetition rate. These instruments would benefit from the second target station with its lower repetition rate (10 Hz).

- France (European Collaboration), the ILL is preparing to realise its“Millennium Programme” of instrument and infrastructure renewal to make its high flux reactor most effective and to provide Europe’s neutron scatterers with cutting edge opportunities in next two decades.

- Austria, the AUSTRON project. The Austrian government is supporting a plan to build a 500 kW spallation neutron source with a strong emphasis on medical applications in Austria. Presently partners are being sought to support this project.

- USA, the SNS project. The US decided to fund construction of a 1-2 MW spallation neutron source. This facility is under construction and will, when completed in 2006, be the world’s most powerful neutron source.

- Japan, the JSNS project. Like the US, Japan has decided to build a next generation spallation neutron source. JSNS will be a 1 MW facility in it's first stage, which is presently funded, but will be upgradable to 5 MW in the second phase of the project.

In the applicant's view, justification for these parallel projects on a European as well as on a global scale stems from the fact that a very large and continuously increasing user community (presently about 4000 in Europe) faces a decreasing number of suitable research opportunities. This is due to the closure of research reactors, on the one hand and on the other, the new opportunities opened up by the development of high power spallation neutron sources bringing a new quality into this field of research. The recommendation of three major regional sources by the OECD report took this fact into account.

A.II. The facility itself

II.1. Scientific objectives and research prospects

II.1.1 Research program

The applicants consider the European Spallation Source to be a research infrastructure which plays an important role in strengthening the potential of Europe as a global research region. ESS will provide for an enhancement in source performance for the different applications by factors between 10 and 100. It is not designed and built to serve one or a few specific research programmes, but rather as a flexible tool that can be adjusted to the evolving needs of a large and ever changing scientific community. The use of neutrons continues to evolve in both traditional and new fields. Given the impact of new materials in technology, no predictable end to this process is seen. Given the existing and expected future demand in Europe, an invest in a new facility at the cutting edge of neutron science is necessary. The realisation of ESS would provide a centre of innovation and excellence for the scientific community in Europe and worldwide.

The fields in which ESS will be most relevant are described in detail in an extended study: Scientific Advisory Committee of the European Spallation Source and European Neutron Scattering Association: Scientific Trends in Condensed Matter Research and Instrumentation Opportunities for ESS (ESS/ENSA Engelberg workshop), Engelberg/Switzerland, May 2001(for the current use of neutrons see A.I.):[1]

- Physics,
- Chemistry,
- Materials Science & Engineering,
- Life Sciences,
- Earth & Environmental Sciences.

In **Solid State Physics**, it will become possible to elucidate the magnetic structure and dynamics of new and more complex materials, in particular organic solids. Neutron scattering at the ESS is also expected to play an important role in research on nanostructured materials such as quantum dots and molecular magnets. The detection of single-particle spin-flip excitations in metals, which will become feasible at the ESS, is expected to open up a new domain of investigation.

In the area of **Liquids and Glasses** it is expected to better understand the atomic dynamics in the absence of long range order and to get a microscopic understanding of the low-temperature anomalies of glasses and of the nature of the glass transition. Of particular interest are first steps of crystallization in metals and alloys and liquid/solid interfaces.

In **Fundamental Neutron Physics** the following questions remain to be answered at a more powerful neutron source:

- elucidate the origin of the handedness of nature by looking for an exotic decay mode of the neutron;

[1] At the beginning of May 2001, in Engelberg (Switzerland), about 80 scientists gathered together from all fields of neutron science, encompassing solid state physics, material science and engineering, biology and biotechnology, soft condensed matter science, chemistry, earth and related sciences, the science of liquids and glasses and the physics of the neutron itself. They were to deliberate on the optimum choice for the neu-

- a two decades decrease of the present limit for the electric dipole moment of the neutron will supply information on the matter-antimatter asymmetry in the universe;
- a direct neutron-neutron scattering experiment will become feasible.

In **Soft Condensed Matter**, the ESS will allow to investigate almost any interface in contrast to reflectometry by which only a small class of interfaces or surfaces may be studied. Two areas of particular importance are the liquid/liquid interfaces, where adsorbed polymers or amphiphilics play a crucial role in determining the stability of emulsions and biolubrication, where the delicate control of environmental factors (pH, ion concentration, etc.) is used to manipulate the conformation of polyelectrolytes at the lubricated interface.

In **Life Sciences (Biology and Biotechnology)**, the ESS will offer major gains in neutron capability whereby smaller samples, smaller quantities and lower concentrations all become viable. Thus, the major structure and dynamics techniques of protein crystallography, small angle neutron scattering, inelastic scattering and membrane reflectometry will all benefit in a major way. The considerably reduced measuring times will allow native rather than artificial membranes to be probed by reflectometry, including membrane bound proteins at the surface of actual cells.

Structural biology, as well as biotechnology, will benefit from the powerful ability of neutrons to contribute to the location of hydrogen atoms and water molecules in biological systems. Thus it will contribute to the production of missing complementary data relevant for molecular modelling and to the strategy of rational drug design, in synergy with other biophysical approaches.

Materials for catalysis are one example of the various research opportunities in **Chemical Structure, Kinetics and Dynamics**. As far as reactivity of metal organic systems are concerned, the binding of organic ligands to metals and the electronic state of transition metals (X-ray and neutron Studies) are of primary importance. Heterogeneous catalysis is governed by the interaction between molecules and the surface of the material. As most of these molecules contain considerable amounts of

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tron parameters of ESS and to define the final ESS layout on scientific grounds.

hydrogen, neutrons are particularly suited to study both structure and dynamics. Here the ESS would enable in-situ measurements on a real time scale and thus allow insight into the mechanisms of the catalytic reaction and into the continuous degradation process of the material.
One of the most significant issues in **Earth and Environmental Sciences** is related to the prediction of earth quakes and volcanic eruptions. The reliability of the relevant models crucially depends on the knowledge of the physical and chemical properties of the materials involved (oceanic crust, upper mantle, continental crust). Frontier applications of an ESS class neutron source are in-situ studies, where mineral structures and material behaviours are investigated under extreme temperature and pressure conditions to simulate the real situation deep in the earth. These experiment would be complementary to synchrotron diffraction and would allow especially to elucidate the role of water inclusions in minerals. Maintaining such conditions in the laboratory usually requires massive sample environment, which can, however, be penetrated by neutrons.

The ESS as a next generation of high power pulsed neutron sources will alter the nature of the experiments in **Material Science and Engineering**, allowing for the first time investigations of materials in real time, with realistic dimensions and in real conditions. The ESS will be a powerful tool for the analysis of both functional and structural advanced materials. Thus nanopores or inclusions in ceramics are detectable by SANS (Small Angle Neutron Scattering) or the motion of ions in battery materials will be followed on the microscopic scale. In the area of internal strains/stresses neutron diffraction could lead to reduce the sample volume by three orders of magnitude, the technique would be of great interest in a large range of engineering problems, such as the remaining lifetime in turbine blades and the strains in and around rivets and welds.

II.1.2 Services

ESS will take into account that as the size of the science community using neutrons grows, many of the users will be less expert in planning and performing neutron scattering experiments as well as in extracting the relevant information from the measured data. According to the applicants the user-concept of ESS will include in particular:

- Use of the facility free of charge if there is a commitment to publish all results in the open literature.
- A wide range of different instruments designed to cover all aspects of neutron use in science that can be met with a pulsed spallation neutron source.
- Opportunities to participate as a Collaborating Research Group (CRG) with a purpose-designed instrument under the Group's control.
- Free use of standardised sample environment equipment.
- Limited support with special, user designed sample environment equipment.
- Laboratory space to prepare short lived or difficult to transport samples on site.
- Scientific and technical support in planning, performing and evaluating the experiment by local instrument responsibles and technicians. (Depending on the extent of this support, joint publication may be considered.)
- Use of ESS computing facilities and data reduction software.
- Office space during the stay at the facility, i.e. in general during the measurement period and a few days before and after the measurement.
- Limited on site accommodation for experimenters whose frequent presence at the instrument is required over several days.
- Help with travel and local arrangements.
- 24 hour food and beverage service (cafeteria and vending machines) on site.
- A friendly and open, science oriented atmosphere.

II.1.3 National and International networks and programs

The present European research base of neutron sources consists of several reactors and 2 spallation sources:

Czech Republic	- LVR-15 Prague (Research Reactor 10 MW, 1 x 10^{14} n/cm^2/sec)
France	- ILL Grenoble (Research Reactor, 52 MW, 1.2 x 10^{15} n/cm^2/sec) - LLB-Orphée Saclay (Research Reactor, 14 MW, 3 x 10^{14} n/cm^2/sec)
Germany	- FRJ-II Jülich (Research Reactor, 23 MW, 2x 10^{14} n/cm^2/sec)

	- BER-II Berlin (Research Reactor, 10 MW, 2x 10^{14} n/cm^2/sec) - FRG-1, Geesthacht (Research Reactor, 5 MW, 8 x 10^{13} n/cm^2/sec) - FRM-II Munich (Research Reactor, 20 MW, 7 x 10^{14} n/cm^2/sec) under construction
Hungary	- BRR (Research Reactor, 10 MW, 1.6 x 10^{14} n/cm^2/sec)
Netherlands	- HCR Delft (Research Reactor, 2 MW, 2 x 10^{13} n/cm^2/sec)
Norway	- JEEP2 (Research Reactor, 2 MW, 2.2 x 10^{13} n/cm^2/sec)
Russia	- IBR-2 (Pulsed Reactor, 2 MW, 1 x 10^{16} n/cm^2/sec peak)
Sweden	- NFL R2 (Research Reactor, 50 MW, 1 x 10^{14} n/cm^2/sec)
Switzerland	- SINQ Villigen (Continuous Spallation Source, 1 MW, 2 x 10^{14} n/cm^2/sec)
UK	- ISIS Abingdon (Pulsed Spallation Source, 156 kW 2-10 x 10^{15}n/cm^2/sec, peak)

In the applicant’s view the success of the existing network is based on the complementarity between the two high performance sources, ILL and ISIS and the regionally distributed series of medium and small flux laboratories. The medium and small flux laboratories have also the role to prepare the scientific communities, junior researchers or new users to make the best use of the bigger and more costly facilities, which have a limited and highly competitive access. Most of these regional medium flux facilities have been open to international users, supported by the EU-“Large Scale Facility” programme.

The neutron facilities are seen as an important and integrated part of the European Research Area. Neutron scattering science has therefore developed, as defined by the Research Area Initiative, into a multidisciplinary research activity between physicists, chemists, biologists and engineers and between academic research and industry.

On a national level in Germany, the Forschungszentrum Jülich (FZJ), the Hahn-Meitner-Institut (HMI), and the Forschungszentrum Geesthacht are members of the Helmholtz-Centres (HGF).

II.2. Technology

The ESS accelerator complex features an 1.3GeV proton LINAC providing 10MW beam power and accumulator rings, which compress the 50 Hz, 1 ms LINAC pulses to 1 µs, in order to supply a 5 MW short pulse target station. A second 5 MW long pulse target station is directly fed by the LINAC delivering ~ 2.5 ms pulses at a repetition rate of 16 2/3 Hz.

Accelerator: The normal conducting Linac

A normal conducting linac system was chosen for the acceleration of H^- ions up to the final energy of 1.334 GeV. The design is optimised for very low beam losses (< 1 nA/m) in order to allow hands-on maintenance and repair even at the high energy part. Stripping injection (charge exchange $H^- \rightarrow H^+$) is used for filling the accumulator rings, thus requiring the H^- linac beam. Space charge problems and low injection losses require the use of two compressor storage rings, one on top of the other, operated in parallel to store 5×10^{14} protons. With a ring revolution period of 600 ns in total 1000 turns are accumulated in each ring. Subsequent single turn extraction from both rings forms two macro bunches to be delivered to the target with 1.2 µs pulse width and a repetition rate of 50 Hz.

The linac design has evolved to a normal conducting coupled cavity linac (NCCCL) operating at 560 MHz. Studies of the beam funnel showed that the beam energy had to be increased to 20 MeV to obtain short enough bunch lengths for effective funnelling. The reduction in operating frequencies from 175, 350, 700 to 280, 560 MHz is a good compromise for various linac stages. The peak bunch current in the main part of the accelerator is reduced by a factor of two compared with the original reference design as each rf cycle now contains beam. Complete beam tracking with space charge effects has now been carried out from the RFQ to the exit of the CCL. The final beam emittances are a factor of two lower in the transverse planes and a factor three lower in the longitudinal plane in comparison with the earlier design. The Compressor Ring design has also evolved to reduce the very high temperature predicted for the H^- to proton beam stripping foil. In the current reference design the chopping duty factor has been increased from 60% to 70% and the circumference has been increased by 34.6% compared with the original reference design.

Accelerator: Superconducting Linac

The main motivation for analysing a superconducting option for the ESS Linac is the expectation of a significant cost reduction. This assumption is based on the reduced length of the superconducting linac, its reduced investment costs in the RF system and lower operating costs. These savings should overcompensate for the additional costs of refrigeration and the more expensive superconducting cavities.

Accelerator: Ion source

The ESS requires about 140 mA of H^- beam. Two ion sources, each delivering a pulsed 70 mA H^- beam with a pulse length of 1.2 ms and a repetition rate of 50 Hz are being considered. At the University of Frankfurt an H^- volume source based on the HIEFS (High Efficiency Source) principle has been developed and tested. The source consists of a caesium seeded multicusp plasma generator, in which negative ions are produced via volume and surface processes. Due to improvements of the caesium injection method, the beam current density has been enhanced up to 153 mA/cm^2. Thus an H^- beam current of 120 mA has been extracted using an aperture radius of 5 mm.

Accelerator: Funnel device

The front end of the ESS linac has to provide a bunched high current H^- beam with a special time structure for injection into the following Drift Tube Linac. To achieve the required beam current, of more than 100 mA, two identically bunched beams have to be combined into a single beam with twice the frequency, current and brightness. This so called funnelling has to be done with a well bunched beam, which is needed for low emittance growth in a system of dipoles, quadrupoles, rebunchers and a deflector. Although not yet fully demonstrated, several studies underpin the feasibility of this concept.

Target

The ESS pursued the idea of a flowing liquid mercury metal target. This would not only solve the heat removal problem but also avoid the presence of an excessive amount of cooling water in the beam interaction region, with its associated radiolytic problems and generation of spallation products, that would be transported throughout the cooling loop. Mercury (melting point –38°C, boiling point at ambient pressure 350°C) has several advantages; such as the possibility of operating the loop at or near ambient temperatures and the fact that no alpha-active spallation products are generated. While there are no basic feasibility issues, development of the mercury target technology is seen as a major technical innovation which the project team continues to work on. The main problems whose significance and possible remedies are presently being assessed are: the generation of pressure waves due to the pulsed power input in the liquid and the effect of irradiation under stress on the interaction between the liquid metal and its solid container.

Instruments and modes of operation

ESS will take full advantage of the opportunities of pulsed source operation by incorporating two target stations with different pulse lengths and different modes of utilisation. ESS will employ and further develop latest instrumentation concepts based on extensive application of neutron optical components, new detector and data collection systems and simultaneous coverage of large ranges of scattering angles.

On a pulsed source, neutrons with different energy (velocity) arrive at the sample one after another, and thus typically 50% of the neutron spectrum can be used if the pulse repetition rate is well matched to the experiment considered. This condition cannot be fulfilled with a single repetition rate. Faster (hot and thermal) neutrons can take advantage of pulses closer to each other (5-20 ms) than the slower cold neutrons, for which at least 50 ms is optimally needed between subsequent pulses. The combination of a 50 Hz short pulse and a 16 $^{2}/_{3}$ Hz long pulse target station allows ESS to cover the whole range of neutron energies for condensed matter research with an efficiency 2-5 times superior to the single target short pulse approach followed by existing pulsed spallation sources and the facilities currently under construction. The long pulse source as well as the high power short pulse source require new developments in experimental techniques, such as phased chopper systems, new neutron optical components based on the recently developed supermirror technology and others. There are many activities in the ESS partner labs aiming at this kind of improvements.

Active pulse shaping techniques by choppers and neutron guides are seen as an important innovation in the instrumentation concepts of ESS. By now the duration of the neutron pulses emerging from short (1-2 µs long) proton pulses could only be controlled by introducing neutron absorbers in and round the moderators. These are not only difficult to realise at the ESS power level, they also reduce the peak intensity in the pulse by roughly a factor 0.6. Relying on external pulse shaping where required will not only allow to optimise the moderators according to simple criteria, it will also give unprecedented flexibility, in particular since pulses of naturally different lengths (ca 0.2 ms and 2-3 ms) will be available to start with. Nevertheless, it will be possible to produce 2-10 µs short neutron pulses for high resolution work with the help of fast rotating mechanical chopper devices.

Moderators

Cryogenic moderators are an essential ingredient for pulsed spallation neutron sources, because they (a) provide the much demanded long wavelength neutrons in sufficient quantities and (b) generate short pulses in the thermal neutron energy regime by shortening the life time of the neutrons in this interval by continued slowing down to lower energies. (Presently short pulses at ambient temperature moderators are generated by adding absorbing material into the moderator, which is at the expense of 40% of the peak intensity). The only currently viable cryogenic moderator material is liquid or supercritical hydrogen, because more favourable materials such as solid methane suffer too much from radiation effects. The ESS team has proposed to develop a system which would continuously transport pellets of methane or a similarly effective material through the moderator vessel and allow them to be annealed from the accumulated radiation damage off line. The anticipated gain in source performance from this development is of the order of a factor 2 on average. This work is ongoing.

The institutions involved in ESS do not see any serious shortcomings. The described technical innovations and the “green field design” will allow the project to offer unprecedented opportunities to the users within feasible technology. No boundary conditions (e. g. use of existing assets) exist, to force the need for compromises upon the project.

According to the applicants, a possible weakness of ESS could be its relatively high power consumption of an estimated 90-110 MW (assuming a superconducting accelerator and two target stations). A consequence might be that the operating schedule could be dictated by seasonal differences in energy costs rather than by scientific or technical efficiency.

Several conceivable ways in which the facility could be enlarged or upgraded in the future are seen as follows:

Addition of parasitic users requiring only a small fraction of the current accelerated

- Use of the unstripped fraction of hydrogen atoms at the injection to the ring(s), which will be dumped into a beam catcher
- Thin target placed in the beam transport line at an appropriate location, e.g. for pulsed muon production
- Construction of an Ultra Cold Neutron (UCN) source

Additional main users requiring a significant increase of the current accelerator

- Multipurpose facility (CONCERT) designed to the capability of delivering a total of 25 MW of beam power

Incorporation of irradiation facilities, e.g. for test irradiation of materials for nuclear fusion technology, in the long pulse target station

Upgrade for the main purpose of the facility

- Increasing the power of the short pulse target station by going to a repetition rate of 100 Hz
- Increasing the pulse current in the linac above 100 mA
- Increasing the linac energy by raising the accelerating gradient

II.3. Transfer of the research results

ESS will contribute to optimise

- materials for industrial applications (e.g. through deeper knowledge about the structure and behaviour of solids, complex fluids, polymers, lubricants etc.);
- therapeutic measures (e.g. through deeper knowledge about structure and behaviour of biomolecules, proteins, membranes etc.);
- the efficient use of and exploitation of energy resources (e.g. through better understanding of geological structures).

The applicants conclude that the influences on the business sectors were manifold, as nearly all manufacturing industries are expected to benefit from the research results of the facility. Some of the most promising fields of industrial application are seen for:

- manufacture of chemicals and chemical products,
- manufacture of pharmaceuticals,
- manufacture of refined petroleum products,
- manufacture of plastic products, manufacture of rubber products,
- extraction of crude petroleum, natural gas,
- manufacture of glass and glass products,
- manufacture of office machinery and computers,
- manufacture and optimisation of structural materials for ground based and air borne traffic as well as for energy systems.

In the applicant's view transfer of research results is a crucial concern during the construction and operation of the facility. Technology transfer will take place at all stages of research and development and has to be continuously supported. Due to the international (European) character of the facility and its use as a multi-purpose measuring instrument, decentralised forms of technology transfer have to be developed as well as a central one.

More possibilities to encourage applied research and economic exploitation of research results by the ESS are seen for example in programmes which could be implemented to stimulate the submission of proposals for applied research projects. A proposal for an innovative industrial co-operation model is currently being developed. It will consider the gain experiences of facilities similar to the ESS, the demands of the scientific community and needs of industry.

Spin-offs may arise during construction and operation of the facility. Spin-offs during the construction phase can be expected at a regional scale. In principle two different kinds of spin-offs during the operation phase are possible. The first being firms based on product innovations originating from research performed at the facility. The second being firms based on R & D-related services, e.g. commissioned R & D, software development, data processing and analysis. The ESS believes the second type of spin-offs to be more likely than the first.

The ESS will aim to implement policy concerning spin-offs, based on general and legal recommendations for large-scale research facilities, to include:

- sharing of know-how and providing access to the ESS for spin-offs;
- flexibility in employment contracts for potential founders of spin-offs among the personnel of the ESS;
- provision of information and consulting services for potential founders.
- To ensure a maximum use of the spin-off and transfer potentials of ESS, the project will seek to build close co-operation with existing firm incubators and technology transfer agencies. For this the facility has to be viewed in the regional context.

Both possible location for the ESS in Germany (Jülich or near Halle/Saale) offer a supporting infrastructure for spin-offs.

A.III. The institutions participating in the project

The Forschungszentrum Jülich (FZJ) with its interdisciplinary and international character is working in five major research areas:

- Structure of Matter,
- Information,
- Life Sciences,
- Environmental Research,
- Energy Technology.

FZJ has experience in planning and operating large scale facilities, three reactors (FRJ-I, FRJ-II and the gas-cooled high temperature reactor HTR) have been planned and operated, two of which have already been decommissioned (FRJ-I, HTR), the Tokamak facility TEXTOR-94 and the Cooler Synchrotron COSY are still in use.

Impact on re-orientation of research activities in case of implementation of the ESS:

- In 1998, the programme on nuclear safety, reactor technology and nuclear waste management was drastically reduced. A considerable amount of the then available resources has been transferred to increase the FZJ R&D efforts for ESS.

- In essence, based on current strategic planning for the next ~ 6 years to come, the main activities within the five major research areas sketched above will be pursued.
- Within the condensed matter programme, the studies of anorganic/biological interfaces and related topics are being intensified by shifting priorities within the programme. This will increase the demand for additional neutron beam time at the then available prime neutron sources.

The planned shut-down of the FRJ-II ("DIDO") reactor in May 2006 will represent a drastic upheaval:
- The FZJ will no longer provide neutrons to external users and for its in-house research.
- Some of the instruments at DIDO which are of paramount interest for FZJ in-house research will be transferred to the FRM-II.
- the large number of neutron scattering experiments performed by FZJ scientists, which relate to user service must – most likely significantly – be reduced because of the lack of beam time.
- Most of the staff of about 120 engineers and technicians presently necessary for the operation of the FRJ-II must reorient themselves in new areas.

If the ESS will be built in Jülich the FZJ will

- allocate resources currently spent for the operation of the FRJ-II to ESS;
- offer to take responsibility for the project management during the construction period;
- take over responsibility for design, construction and commissioning of the two ESS target stations;
- for synergetic reasons, offer to integrate the technical infrastructure (e.g. machine and electronic workshops) into the existing one;
- take over responsibility for the design and construction of several instruments;
- operate and provide the staff for several CRG (Collaborative Research Group) instruments for its in-house research and for external users;
- strengthen its in-house neutron research by appointing institute directors who will benefit from the near-by ESS.

If the ESS is to be built at some other location in Europe FZJ will support the project and offer to

- redirect some of the resources currently spent for the operation of the FRJ-II to ESS;
- become task leader for the design, construction and commissioning of the two ESS target stations;
- provide its experience to construct and commission generic instruments;
- operate several CRG instruments for its on-going in-house research. This requires the delegation of a considerable number of staff to the ESS.

The Hahn-Meitner-Institut, Berlin (HMI), is an international centre of competence in solid state physics and materials sciences. The R&D-activities are grouped in structural research and solar energy research. The structural research is focused around the large scale facilities

- BER II, a 10 MW research reactor with a widely diversified instrumentation for neutron scattering
  The research with the reactor BER-II is co-ordinated by the Berlin Centre for Neutron Scattering, BENSC, in the HMI. Every year, around 400 visiting scientists use approximately 70% of the measuring time at some 16 instruments for both thermal and cold neutrons, studying a wide spectrum of problems from solid state physics over materials sciences to biology. Further, a Neutron Activation Analysis (NAA)-Laboratory is available for the analysis of chemical elements with neutrons.

- ISL, a combination of accelerators providing high energy ions
  The Ion Beam Laboratory, ISL, offering a wide variety of ion beams over a range of energies up to some hundred MeV, is dedicated to the application of ion beam techniques in solid state physics, material science and biological science. For medical applications a 70 MeV proton beam is used for the therapy of ocular melanomas in co-operation with the Universitätsklinikum Benjamin Franklin in Berlin.

- BESSY II, a third generation synchrotron source
  Whereas BER II and ISL are operated by the HMI, the synchrotron facility is run by the BESSY GmbH. Here HMI, in close collaboration with BESSY, is responsible for the installation of insertion devices and beam lines currently under progress and especially designed for structural research and complementary use closely synchronised with the user programme at BER II and ISL.

The solar energy research is focussed on photovoltaics and photochemistry, studying the direct conversion of sunlight into electrical or chemical energy. Central tasks are the development of concepts, materials and processing technologies for high efficiency thin film solar cells.

With respect to ESS

- the essential research fields of the Institute described will continue to develop.
- The research projects using neutrons are expected to benefit greatly from the proposed new neutron source and a strong interaction between both facilities can be expected independent of the location of ESS in Europe.
- The activities for development and design of neutron instruments and methods at HMI will support actively the new facility as done before with the engagement of the Institute at ILL (e.g. IN 15) or FRM-II (e.g. stress spectrometer). These activities will be enlarged with a location of ESS within Germany, especially in case of a possible location near Halle/Saale (Sachsen-Anhalt).

According to the applicants, the establishments involved into the ESS project can be divided into four groups:

1. The institutes represented on the ESS council – signatories of the ESS-MoU

   The ESS council has representatives from operators of Large Scale Infrastructures across Europe, national research organisations, universities/university institutes. The European Neutron Scattering Association (ENSA) is being represented by its chairman. The ILL at Grenoble is an observer to the Council.

The institutions represented are: the Hahn-Meitner-Institut Berlin, the Forschungszentrum Jülich, the Paul Scherrer Institut, Switzerland, CLRC represented by Rutherford Appleton Laboratory, UK, the Risø National Laboratory, Denmark, the Joint Institute for Nuclear Research (also representing the Institute of High Energy Physics), Frank Laboratory of Neutron Physics, Dubna and the Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, CNRS from France has become an observer with the intention to sign the new MoU as a full member.

The national research organisations from 4 major European countries are: INFM and CNR (Italy), CEA (France), CIEMAT (Spain) and EPSRC (UK). The Universities/university institutes all heavily involved in developing components of instrumentation for large scale facilities are: Frankfurt University, Institut für Angewandte Physik; Atominstitut der TU Wien, Austria; Uppsala Universitet, The Svedberg Laboratory, Sweden and the Interfaculty Reactor Institute, Delft University of Technology, The Netherlands.

2. Lead laboratories for the ESS tasks

For each of the major units of the ESS a European institution is assigned as the lead laboratory, i.e. this laboratory provides the task leader of the project and has the main responsibility for the development of this unit.

- The lead laboratory for the accelerator and ring is Rutherford Appleton Laboratory in the UK.
- The lead laboratory for instrumentations is the Hahn-Meitner-Institut in Germany.
- The lead laboratory for the target stations is Forschungszentrum Jülich.
- CEA in Paris is responsible for the superconducting Linac design and infrastructure (buildings etc.).

3. Other institutions and universities contributing to the development of the science case or to the tasks co-ordinated by the institutions above.

University scientists play a key role in the development of the scientific case for the facility and in developing neutron scattering instruments. University institutes are also partners in the accelerator parts of the project (University of Frankfurt, Dortmund, Wuppertal and Uppsala). In the other technical areas university scientists are involved on lower but growing level. In particular discussions are now in progress between FZJ and RWTH Aachen about possible task sharing in particular engineering work between the two institutions in the ESS project.

A.IV. Users of the Research Facility

About 4000 scientists in Europe – more than 800 in Germany - use neutrons in their field of research. According to a study by the European Neutron Scattering Association (ENSA) in 1996 the neutron users were distributed over the different disciplines of science in the following way:

Physics	46 %
Chemistry	26 %
Material Science	20 %
Life Sciences	4 %
Engineering Sciences	3 %
Earth Sciences	1 %

Since the publication of the ENSA study, the application of neutron scattering methods has grown particularly in the fields of Engineering and Material Science due to the recent developments in techniques like neutron tomography and internal stress measurements. The strongest increase in the number of experiments with neutrons is in the field of soft condensed matter, including biological systems: about 25 to 30 % of the entire requested beam time at the existing neutron facilities relates to soft condensed matter.

ESS will be a user facility catering to but also depending on scientists from many fields and coming from all over Europe and elsewhere. 2000 users are estimated to frequent ESS every year. More than half of them will be PhD students or postdoctorals. Future users have been involved in the planning from an early stage. A Scientific Advisory Committee representing those future users was established even before any Technical or Machine Advisory Committee has been called. The SAC will continue to guide and monitor the technical concept of the facility in terms of user needs.

Access to the ESS will be organised in three different ways:

- Open proposal system. Any user or user group can submit proposals for scientific experiments at an instrument at ESS. One or more selection committees nominated by the Scientific Council will evaluate the proposals and recommend beam time exclusively according to the scientific quality of the proposal.
- Collaborating Research Groups (CRG) – Groups operating an instrument at one of the target stations. These teams will be located at ESS but will be supported by different sources (see below) and be guaranteed a certain fraction of the beam time on the instrument for their research programme. 10 to 15 such CRG's are expected.
- Research groups of companies will be able to buy beam time for proprietary research: A small percentage of the beam time will be sold to companies or other interested users. The companies will be allowed to keep the results of their experiments at ESS confidential and unpublished but they will nevertheless be requested to comply fully with ESS safety rules, and standards.

ESS will provide scientific and technical support to user groups by maintaining a permanent staff of about 6 scientists and technicians per instrument at the site. The staff will also coach younger scientists, like diploma or PhD students, in the use of the instruments and will care for infrastructural aspects of the experiment.

According to the applicant’s view, ESS itself will provide opportunities for scientists in almost all fields in which its users will be active to secure continuity of qualified user support and instrument maintenance. Furthermore in the operation and development of ESS itself, good opportunities for academic staff are expected in the engineering and IT (Information Technology) disciplines (cryogenics, mechanics, electrical engineering, electronics, software engineering etc). Employment opportunities for young scientists out of ESS are seen as manifold as the disciplines in which neutron scattering is used. It is expected that the people will be highly qualified for academic positions in science, industry and management.-

The ESS has been extensively presented to the general public to different causes.

A.V. Project management, Location, Costs and Schedule

V.1. Project management

For the **present phase** (2000-2003) participating laboratories and organisations have concluded an Memorandum of Understanding in 1998, which is clarified by a Memorandum of Extension of May 2000. The existing MoU will be replaced by a new one in spring 2002. The purpose of the new MoU is to formalise the commitments of parties to strengthen central management and streamline COUNCIL decision making.

Overall responsibility rests with the COUNCIL consisting of a representative (Director/Board level) of each partner. The Project Director is responsible for supervising the management of the technical work. Management of the work packages in the three main areas (accelerator, targets, instruments) rests with a Task Leader coming from the lead laboratory for that particular task.

The Chairman of the COUNCIL, the Project Director, the Chairman of the Science Advisory Committee and the Secretary of the COUNCIL form the Executive Committee that coordinates all work in between COUNCIL meetings.

In the **construction and operational phase** (2004/5 onwards) ESS will closely follow the ESRF model. Governments (“Contracting Parties”) will sign a Convention that will entrust the construction and operation of ESS to a not-for-profit company or organisation ("the Company") subject to the law of the host country. Corporate members of the Company ("Members") will be appropriate bodies designated by the Contracting Parties.

The Company will be governed by a Directorate and a General Council, whose delegates will represent the Members, but will be appointed by the relevant Contracting Party. The Statutes of the Company, to be signed by the Members and by which act they agree to establish the Company, will be part of the Convention. The Convention details the responsibilities of the Directorate and the General Council. The Convention will also establish the financial contributions of the Members and the responsibilities of the Contracting Parties to make available annual grants to Members to cover their contributions.

Quality control will be organised at several levels:

- The ESF has been involved in the preparation of the scientific-strategic case for ESS and will formally review the expanded science case for ESS in 2002.
- The so far established Science Advisory Committee oversees all work leading to the definition of the scientific parameters of ESS, making sure that the users needs are met in the best possible way.
- A Technical Advisory Committee, involving experts from outside ESS and/or Europe, will be established to review all final technical work.
- A quality management system will be implemented for the detailed design and construction phase stating the codes and rules to be followed and defining the documents to be generated at all stages of specification, procurement, integration and testing.

Budget and personnel responsibility at present is largely decentralised, and based on the commitments of parties to make resources available to carry out the various tasks. Budget responsibility in the construction and operational phase according to statutory rules rests with the Directorate under the supervision from the Council. The same is true for personnel responsibility where the Council approves appointment of the Directorate only.

V.2. Location

There are currently two contenders offering to host the facility in Germany. The Forschungszentrum Jülich (Nordrhein Westfalen) advocates a site adjacent to its premises. The Hahn-Meitner-Institute itself does not apply to locate ESS. The HMI supports the proposal by the new Bundesland Sachsen-Anhalt to host ESS at the MicroTechPark Thalheim-Sandersdorf in the Halle/Saale region. On a European scale there are several locations that have expressed interest in hosting the facility, although only one of them, Rutherford Appleton Laboratory, has so far formally applied with the ESS Council. Other options discussed are Daresbury (UK), a consortium supporting a location in Southern Scandinavia and one or two sites in France.

V.3. Costs

The following table shows the costs that have been spent since 1997 for the preparation of the ESS (only the contributions by FZJ, HMI and the support of the EU are given):

	1997	1998	1999	2000	2001
Costs incurred for ESS ACCELERATOR development in Germany (in k€)					
FZJ [1]	750	1.300	1.000	1.300	1.600
Costs incurred for ESS TARGET STATION development in Germany (in k€)					
FZJ [1] [4]	2.850	2.200	3.950	5.250	7.400
HMI [1]	250	275	350	375	350
EU-TMR Contract TARGET ESS [2]		July 98 – Dec 02: 1.530			
EU-RTD Contract HINDAS [3]				Oct. 00 – Sept. 03: 1.625	

Costs incurred for ESS INSTRUMENTS development in Germany (in k€)					
FZJ [1]	150	150	150	150	300
HMI [1] [5]	500	550	650	650	650

[1] Full costs including personnel, capital expenditures, consumables and overheads.

[2] Total for 12 partners. FZJ is the co-ordinating institution and the largest recipient (450 k€).

[3] Total for 14 partners. FZJ receiving 154 k€

[4] FZ Jülich is the “Lead Lab” for the target stations is by far the largest contributor to R&D work in this field.

[5] HMI Berlin is the "Lead Lab" for the instrumentation.

For the period July 1998 – June 2001 the activities of FZJ and HMI were to a considerable part covered by the Helmholtz Gemeinschaft Deutscher Forschungszentren (HGF) through a joint “Strategiefonds-Projekt”. The means granted by the HGF-Senat are 3.27 Mio. € for FZJ and 1.08 Mio. € for HMI.

The number of scientists and engineering assigned in the participating institutions (status of December 2000) is

	Accelerator development	**Target stations**	**Instrumen-tation**	**Total**
RAL (UK) [1]	6.0	1.0	1.0	8.0
FZJ (D) [2] [4]	10.0	20.0	1.5	21.5
HMI (D) [3]		3.0	6.0	9.0
CEA Saclay (F)	3.0*			3.0
University Frankfurt (D)	5.5			5.5
TSL (S)	1.5		1.5	3.0
INFN (I)	2.0		1.5	3.5
CIEMAT (SP)	2.0			2.0
Paul-Scherrer-Institut (CH)		6.0		6.0
Universidad de Cantabria (E)		4.0		4.0
Universita di Ancona (I)		3.0		3.0
Technische Universität Graz (A)		2.0		2.0
CNR-IEQ (I)			1.0	1.0
IRI, TU Delft (NL)			1.5	1.5
Atominstitut (A)			0.5	0.5
Riso Nat. Lab. (DK)			0.5	0.5
Total				**83.5**

1) RAL, (UK) is a “Lead Lab” for the accelerator development.

2) FZJ is the “Lead Lab” for the target stations

3) HMI Berlin is the "Lead Lab" for the instrumentation.

4) By the end of 2001 it is anticipated a total of around 50 persons will be engaged in ESS-related work at Jülich.

* Without contribution by the CONCERT-Project which has been integrated into the ESS-Project.

The total number of staff required to run ESS as a user facility can at present only be estimated, based on the experience of existing facilities. Current estimates allowing for 3-shift operation on 6 out of 7 days and one day of maintenance and development per week are:

Accelerator operations and development	140 FTEs
Target systems operations and development (2 target stations)	70 FTEs
Instrument responsibility and technicians (40 instruments):	240 FTEs
General infrastructure and services	75 FTEs
Administration and user care	75 FTEs
Total ca.	**600 FTEs**

(FTE = full time equivalent one man year per year)

ESS cost planning includes a new and updated cost assessment by the end of 2003, taking into account the revised facility concept and bottom up estimates based on considerably better design detail than was available in 1996, when the cost was estimated on the basis of the feasibility study. The split of the total cost for development and construction is roughly as follows (the estimates are ±20%):

- 37 % for accelerator facilities
- 18 % for target systems
- 28 % for buildings and infrastructure
- 17 % for scientific utilisation.

	2001 estimate				
		A	B		note
Development	Total Staff [Sy]	Capital Cost [in k€]	Staff Cost [in k€]	Total Cost incl Staff [in k€]	
Accelerator facilities	131	9,119	15,720	24,839	
Target systems	113	4,061	13,560	17,621	
Scientific utilisation	20	14,933	2,400	1,.333	**C**
Total	**264**	**28,113**	**31,680**	**59,793**	
Construction					
Accelerator facilities	1,339	319,861	160,680	480,541	**D**
50 HZ target (SPTS)	403	47,406	48,360	95,766	
16 2/3 Hz target (LPTS)	600	69,840	72,000	141,840	**E**
Scientific utilisation*	373	179,200	44,800	224,000	**C,F**
General site and licensing	590	314,301	70,800	385,101	
Total	**3,305**	**930,690**	**396,640**	**1,327,249**	
Total development plus construction	**3,569**	**958,722**	**428,320**	**1,387,042**	**G**

Notes:

* Scientific utilisation is concerned with construction, maintenance refurbishing and running the instruments in user mode i.e. also providing standard sample environment etc.

Estimates are based on the original figures given in the 1997 feasibility study with the following adjustments made:

A: The overall European escalation of cost from 1996-2001 is 12% and all capital cost have been escalated by 12%

B: For the construction phase ESRF salary figures of 120 k€/Sy were used (no additional overhead)

C: the average cost per instrument is revised from 3M€ to ca. 8M€, based on recent SNS and ISIS estimates, all costs relating to construction of instrumentation have been scaled by 8/3 = 2.67

D: The power of the accelerator have been doubled from 5 to 10 MW

E: This target station replaces the 10 Hz SP target station in the 1996 proposal. No synergy can be counted on in the design of the SPTS and LPTS, the latter being more complex.

F: At the start of user operation 20 instruments are ready for immediate use and a further 16 during construction. The construction period for an instrument is 5 years and these instruments will be put into operation at a rate of 4 instruments per year.

G: Finishing the instruments mentioned in F and completing the full instrument suite will be part of the operational budget. If they were included in the construction budget this would add 96 M€ to the total construction cost for a facility.

During construction personnel cost accounts for roughly 1/5 of the total, whereas in operation more than 1/3 of the cost is for personnel, about half of which is needed to run and maintain the machine; the other half is for user support in the wider sense.

The estimated operation cost for ESS are as follows:

Operation	2001 estimate (all costs in k€)			
	see notes			
	A	K		note
	Capital Cost	Staff Cost	Total Cost incl Staff	
Staff (550 (+ 50 not paid by ESS))	0	66,000	66,000	H
Electricity	44.000		44,000	I
Linac	3,024		3.024	
Rings	168		168	
Controls	347		347	
Diagnostics	276		276	
Vacuum	394		394	
Site maintenance	2,912		2,912	
Water and air conditioning	504		504	
Cryogenics	1,400		1,400	
Target and beam stops	1,631		1,631	
Scientific utilisation*	24,128		24,128	J
Operation Total/a	**78,784**	**66,000**	**144,784**	

Notes:

* Scientific utilisation is concerned with construction, maintenance refurbishing and running the instrument s in user mode i.e. also providing standard sample environment etc.

H: out of the total of 600 staff working on ESS ca 50 will not be on ESS payroll

I: 100 MW power consumption for 10 MW linac was used relative to 78 for original 5MW linac

J: Instrument construction at a rate of 2 per year per target station included; (see note G above). For the first 5-10 years after start of operation this will enable to finish the instrument suite, after that the same resources will be used to renovate and replace old instruments. The total budget is 30,528 M€ and CRG's are expected to contribute 6.4 M€ per year for this.

K: For the operation phase average salary cost per year of 120 k€ was assumed as for the construction phase

ESS is expected to be used continuously over an estimated period of at the least 40 years. The annual operating time for the facility will be between 170 and 200 days per year, typically divided into three or four running periods.

The model for financing the facility will be part of the intergovernmental agreement prepared in connection with the decision to build the facility. Using a slightly modified ESRF model and the agreement in the MoU for the proposal phase, the following scheme can be drawn up.

Phase	General	Additional contributions
Proposal preparation phase	Each MoU partner contributes annually with a cash contribution to the Central project team and man-power to the project according to three different categories of participation (small, medium or big). Small: 15 k€ and 1.5 FTEs Medium: 45 k€ and 4.5 FTEs Big: 150 k€ and 15 FTEs Total: 1M€ and 100FTEs	Additional contributions by the partner institutions on a volunteer basis.
Construction	80-85% of the cost distributed among participating nations using a key to be negotiated in the Convention	The remaining 15-20% of the construction cost will be a site premium for the host country.
Operation	95-98% of the cost distributed among participating nations using a key to be negotiated in the Convention	The remaining 2-5% of the operating cost will be the site premium for the host country.

(FTE = full time equivalent = one man-year per year or additional 80 k€ in cash contribution)

There are currently no plans to involve industry in the direct running or financing of the facility.

V.4. Schedule

The proposed schedule includes:

Date	Phase	Deliverables
1992-1996	Feasibility study phase	Feasibility Report
1997-2001	R&D phase	Several R&D reports
2001-2002	Proposal Preparation phase	Project proposal
2002-2003	Project Assessment phase	Basic Engineering Design report
2004	Decision Phase	Project Approval and site design
2005-2010	Construction Phase	Facility built
2011-2012	Commissioning Phase	Facility ready for users
2013	Exploitation Phase	Science

B. Main Findings and Recommendations

B.I. Field of Research

The neutron scattering technique offers unique possibilities for the study of composite soft synthetic and biological materials (such as membranes, intracellular and extracellular macromolecular networks, and protein complexes), electronic materials (such as superconductors, magnetic materials, and nanostructured systems) as well as geological materials. It provides valuable information on the structural and dynamic properties of complex materials that complements other techniques such as X-ray scattering and Nuclear Magnetic Resonance (NMR). It also has a growing impact on materials engineering.

Europe has occupied the leading position in the application of neutrons to many fields of science. Currently, this position is assured by the Institut Laue-Langevin (ILL) in Grenoble until about 2010. The ESS as an European user facility can ensure future leadership in the field due to its superior performance. For Germany the FRM-II, at Munich is still needed, but could not substitute the ESS. The failure to build this facility expeditiously will seriously jeopardize the European position, as the competition of the Spallation Neutron Source (SNS) in the U.S. and the Japanese Neutron Source (JNS) in Japan would put Europe at a serious disadvantage. The capacity of the facilities in the US or Japan will definitely be insufficient to provide access for the European community of neutron scatterers.

B.II. Scientific Program

The increase of the neutron flux by nearly two orders of magnitude expected for the ESS will open up new directions in various fields of science such as solid state physics, chemistry, biology, and materials science and engineering. The ESS will generate new possibilities to gain insight into the structure and dynamics of soft, hard and composite materials.

The scientific case is documented in several studies (European Science Foundation (ESF): The Scienfitic-strategic Case for a Next-generation European Spallation Source for Science and Research (ESS Project), Interim report 2000; Scientific Advisory Committee of the European Spallation Source and European Neutron Scattering Association: Scientific Trends in Condensed Matter Research and Instrumentation Opportunities for ESS (ESS/ENSA Engelberg workshop), Engelberg/Switzerland, May 2001.).[2]

Among the highlights are experiments in the life sciences made possible by the broader length and time scales accessible at the long-pulse source and by the reduced sample size. This will allow studies of biological systems in their native environment beyond protein crystallography. Neutron reflectivity opens up new possibilities to study biofunctional surfaces (e.g. Complexes of DNA and RNA with membranes and proteins for gene-transfer technologies) on solid supports, thus allowing experiments with micrograms of materials in particular cases. Such studies are expected to give new insights into the physical basis of the self assembly of soft materials and into the underlying intermolecular forces. They are also expected to have an impact on the development of smart biosensors and other biofunctional surfaces for biotechnological applications. Real time investigations of soft and biological materials (e.g. enzymes) will also become feasible.

Another highlight will be experiments in solid state physics at the short-pulse source. Here, the magnetic dynamics of complex materials such as organic solids and nanostructured systems such as quantum dots and quantum wires will become accessible over a wide range of energies and length scales. New phenomena such as single-electron spin-flip excitations in metals will also become observable. These new experiments are expected to have an impact for the microscopic understanding of modern materials and their functional optimization for technological applications.

The range of instruments currently proposed is reflecting the needs of the European scientific community and appears appropriate to enable a strong scientific program. The development of instruments and the scientific program, however, should be bet-

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2 Since the given presentation on the occasion of the evaluation by the Science Council on December 10th to 11th, 2001, did not convey the full range of opportunities afforded by the proposed facility, these studies were also used as part of the evaluation of the scientific programme.

ter intertwined with the rapid development of other characterisation tools, for example synchrotron radiation, microscopy, spectroscopy (in particular Nuclear Magnetic Resonance (NMR)) and computer simulation. New ideas and developments also from outside the neutron scattering community should be integrated as the planning for instruments progresses.

B.III. Technology

The basic technologies of the proposed facility have been developed in existing laboratories around the world and are available and convertible. Given the status of technology, the competence of the groups involved and the envisaged R&D program, the ESS project is convincing and technically feasible. There is no alternative technology which would reach the specifications of the proposed spallation source.

The R&D initiated by the collaboration partners are appreciated Condiderable further efforts in R&D and prototyping is needed once the project is approved. The collaboration is encouraged to consider the application and further optimisation of the existing superconducting technology for the accelerating cavities of the linac as it holds the promise of cost reductions and high reliability. If the superconducting technology turns out to be superior, it should be considered for the construction of the linac from the beginning. These efforts are required to optimise the project and to provide a solid basis for the cost estimate which is a prerequisite for the continuation of the ESS initiative. The facility has to be top of its class on the European and even the global scale. To achieve this, technological competencies are being harnessed throughout Europe.

The options of a later upgrade considered by the proponents, like

- parasitic use of unstripped fraction of H^0 atoms, thin target for muon production, generation of Ultra Cold Neutrons,
- irradiation facility, isotope production for medical applications,
- higher repetition rate of linac, increasing linac pulse current, raising linac acceleration gradient

are recognised. In particular, upgrading to higher current will certainly occur as a natural development in the lifecycle of an accelerator. The target will be improved with time and experience, a process which is facilitated by the necessary regular replacement of the target. In order to create a potential for a later substantial upgrade, a longer tunnel could be built for the linac from the beginning but this would require design provisions in the transfer lines and compressor ring. The possibility to start with only one target could be considered with substantial implications for costs and the scientific potential.

B.IV. Project Management, Location, Costs, Schedule

The scientific and technological development of a new generation spallation source can only be carried out on an European level. Apart from the contentwise division of responsibilities in respect to the implementation a cost sharing between the countries involved should be aimed at. To coordinate the R&D - work which is carried out by 15 European institutions from 10 countries, the ESS requires a clear management structure with well-defined roles and responsibilities already in the R&D/Prototyping phase. The efforts to strengthen the European dimension and visibility at higher government levels need to be vigorously pursued.

As mentioned above, the failure to build the ESS will jeopardize the European position in neutron research. Thus, it is of high importance to build a new generation neutron source in Europe and a strong European effort is fully justified. The foreseen Europe-wide competition for the site with detailed comparison of all relevant aspects is considered effective and appropriate. It is important that Germany proposes a strong candidate in this competition. For the national site selection the proximity of universities is considered to be a strong asset. The potential for cost savings by using an existing site with relevant infrastructure is another important aspect. Irrespective of the site selection, German groups from universities and scientific institutions will continue to play a major role in the development of instrumentation and sample environments.

The ESS planning includes a new and updated cost assessment by the end of 2003, taking into account the revised facility concept and bottom up estimates based on considerably better design detail than was available in 1996, when the costs were estimated on the basis of the feasibility study. The collaboration partners are encouraged to continue to work as planned on the cost estimate in a bottom-up approach in order to make the estimate more precise and have it eventually confirmed by an External Review. Vigorous R&D and prototyping is supported as an important input for the cost estimate. The financing of construction and operation, the European Synchrotron Radiation Facility (ESRF) provides a proved model which works well.

At present, a network of neutron scattering laboratories is operating in Europe, which is based on several neutron sources including both reactors and spallation sources. The proposed facility is aimed to become the flag-ship of the European network of neutron sources. In order to realise this, a general decision on building and location by the end of 2003/beginning of 2004 should be made. This is a prerequisite for the completion and user operation start of ESS in 2012/2013. R&D and prototyping is to be organized in accordance with this goal since they are required for the cost estimate and facility optimization. Hence, they need strong support.

B.V. Users of the Facility

The ESS will play a leading role in the training of students in an international environment. The facility is expected to host about 2000 visitors per year for scientific experiments, a large proportion (about 1/3) of whom will be young scientists (at Ph.D. level). Graduate students will also be strongly involved in the research groups at the ESS. The overall user operation will follow the successful model of the ESRF and ILL.

B.VI. Transfer of Research Results

ESS will cover a broad spectrum of activities, ranging from basic to applied research and experimental product development. The impacts of the results on scientific and technological developments will be very positive as research with neutrons is and will remain a major advanced tool for materials and life sciences. A strong interaction with universities is expected, with a substantial impact on education and training.

ESS will advance accelerator technology which is a strategic core technology for e.g. nuclear waste transmutation, fundamental physics (ultra cold neutron and neutrino sources, radio-active ion beams), materials irradiation (e.g. for fusion facilities), medical accelerators and waste treatment. Industrial spin-offs can be expected, stemming from the impact described above.

C. Conclusion

The ESS is necessary to ensure the prominent position of Europe in research with neutrons. Moreover, due to the increase in primary flux compared to existing neutron sources, combined with new concepts for instrumentation, new research possibilities in solid-state physics, chemistry, biology, materials and engineering sciences are to be expected.

The technical feasibility is acknowledged. The scientific case has to be advanced intensively[3] and should be better intertwined with the rapid development of other characterisation tools, such as synchrotron radiation, microscopy, spectroscopy (in particular Nuclear Magnetic Resonance (NMR)) and computer simulation. New ideas and developments also from outside the neutron scattering community should be integrated as the planning for instruments progresses. The European site competition of the ESS is welcomed, Germany should participate with a strong candidate. The European dimension of the ESS, especially the roles of the several partners and their technological contributions, requires a clear management structure.

[3] This was agreed upon the majority of the panel. One member found this unacceptable and pointed out that the scientific case is strong. One member asked to add that the scientific case is acknowledged but has to be advanced intensively.