WISSENSCHAFTSRAT

Drs. 5385/02
Berlin, 12 July 2002

Statement
on nine large-scale facilities for basic scientific research and on the development of investment planning for large-scale facilities

Part II: Statements by the sub-panels on the individual large-scale facilities

Preliminary remarks

In a letter dated 31 March 2000, the Federal Ministry of Education and Research (BMBF) asked the Science Council to comment on the further development and future structure of large-scale facilities for basic scientific research. The BMBF made its request more specific in a letter dated 31 October 2000, when it presented the Science Council with a list of large-scale facilities with an investment volume of more than € 15 million (DM 30 million at that time), which institutions of the *Helmholtz-Gemeinschaft Deutscher Forschungszentren* (HGF), the *Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz* (WGL) and the Max Planck Society – in some cases in cooperation with universities and European and international partners – were planning in the near future[1, 2], asking that the Council assess the planned facilities:

- TeV-Energy Superconducting Linear Accelerator (TESLA)
- TESLA X-ray Free Electron Laser (TESLA X-FEL)
- Soft X-ray Free Electron Laser (Soft X-ray-FEL)
- High Field Laboratory Dresden (HLD)
- High Magnetic Field Facility for Neutron Scattering Research
- European Spallation Source (ESS)
- International Accelerator Facility for Beams of Ions and Antiprotons
- European Drilling Research Icebreaker (Aurora Borealis)
- High Altitude and Long Range Research Aircraft (HALO)

The present statement drawn up by the Science Council concentrates on the project proposals forwarded by the BMBF.

The Science Council wishes to expressly acknowledge both the significance of the individual initiatives and the willingness and contributions of the institutions involved in this assessment process, which is also being noted and observed at an international level. However, it sees the submitted projects for large-scale facilities as merely one section of possible future research infrastructures and wishes to point out

1 In spring 2000, the BMBF asked the German scientific organisations to suggest large-scale facilities for basic scientific research.
2 Originally, the CO_2 satellite CARBOSAT was also included in the list. That project was withdrawn in October 2001.

that there are other areas of research, in which large-scale facilities are very important, which are not covered by the large-scale facilities in the list submitted by the BMBF. Examples worth mentioning are astrophysics and the processing and archiving of large quantities of data.[3] Regardless of the assessment and appraisal of individual large-scale facilities in the present paper, the Science Council will also continue to devote itself to basic questions relating to the further development and structure of large-scale facilities, not only for basic scientific research. In Section C of this statement requirements for the future assessment of large-scale facilities are therefore formulated.

In January 2001, the Science Council set up the working group "Large-scale Facilities for Basic Scientific Research". The group is composed of scientists from universities and other research establishments in Germany, the United States and Switzerland, plus individuals involved in and representing national and international scientific administration.

The working group arranged for the individual facilities to be assessed by experts. It then put these assessments into an overall science policy context. To accomplish all this a two-track process was chosen:

- The **expert assessment** of the nine individual facilities was carried out in the period between October 2001 and January 2002 by a total of six sub-panels. 57 external experts were involved in the assessments, including 37 from abroad.[4]

- The working group prepared a **science policy appraisal** of the large-scale facilities. This was based on the individual expert assessments of the scientific quality of each large-scale facility. By arranging for the members of each sub-panel to include at least two people who were also members of the working group – one of whom chaired the sub-panel – it was possible to ensure that the

[3] Based on the level of investment involved, supercomputers should also be included in the large-scale facilities being looked at here. The elaboration of investment and usage strategies for supercomputers is already the task of the Science Council's "National Coordination Committee for the Use and Procurement of Supercomputers".

[4] Eleven of the 37 foreign scientists came from the US, seven from Switzerland, six from England, four from France, two each from the Netherlands and Sweden and one each from Japan, Australia, Russia, Canada and Greece.

findings of the assessments by the sub-panels flowed directly into the appraisals carried out by the working group.

The Science Council has divided its statement into two parts:

Part I "Comprehensive Statement" is comprised of, in Section A, a science policy appraisal of the large-scale facilities under consideration here – **as a final vote on each respective initiative** – and, in Section B, recommendations on the structure and funding of large-scale facilities in Germany. Section C formulates requirements for the future assessment of large-scale facilities. Part I is preceded by theses for the present and for subsequent assessments, which address the significance of large-scale facilities for basic scientific research.

Part II consists of statements from the sub-panels on the individual facilities, although the Science Council's vote, which is what determines whether or not the project is to be promoted or realised, is only to be found in Part I.

The Science Council owes special thanks to the members of the working group and of the sub-panels who are not members of the Science Council. Thanks also go to the institutions that elaborated the plans for the large-scale facilities considered here. They prepared comprehensive background documents for the working group and the sub-panels, welcomed the sub-panels in an open manner when they made their site assessments and made themselves available for constructive discussions with the sub-panels.

The Science Council released the present statement on 12 July 2002.

This statement on nine large-scale facilities for basic scientific research and on the development of investment planning for such facilities concludes for the present the Science Council's expert assessment and science policy appraisal of the submitted proposals for large-scale facilities. At the time of the appraisal, the projects varied in scientific quality and technical maturity. Important points regarding the medium- and long-term funding conditions still need to be clarified. The Science Council regards the funding of facilities of this size as a continual process. Thus it considers this statement to be the basis for further necessary decisions on support. The Science Council will submit concrete recommendations on the priorities for implementation of the individual facilities which are based on the present statement and which take into account the subsquent science policy debate on the goals and the funding of the facilities. The Council offers to provide further advice in the future regarding the funding of the facilities which received positive appraisals and also to assess new or revised proposals for large-scale facilities.

Theses on the significance of large-scale facilities for basic scientific research

The present statement concentrates on the expert assessment and science policy appraisal of nine large-scale facilities, which were presented to the Science Council by the BMBF in October 2000. The Science Council does not see these nine facilities as a closed list, but rather as a starting point for the systematic planning of investment in large-scale facilities. That is why the Science Council has placed the following theses, which relate to these and to subsequent assessments of large-scale facilities, at the start of its statement:

1. Basic scientific research plays a key role in shaping the future worldwide. Scientific and technical developments for industry and society often start with the findings of basic research. They leave their mark on today's society, influencing cultural content and understanding.

2. The successes achieved by basic scientific research are not only the fruit of work carried out with no or relatively little equipment, or the result of spontaneous breakthroughs or serendipity, but are also the result of using large, complex facilities at national and international research centres. The opening-up or development of totally new areas of research is closely related to the availability of specific new facilities.

3. Large-scale facilities should stem from a broad initiative of scientific users with equal rights. That is why scientists from all areas of the system of science should be involved in the development, planning and construction of large-scale facilities. This is especially true for scientists from universities and for their essential involvement in the conception and development of large-scale facilities. Large-scale facilities on the scale with which we are concerned here must represent the distilled core of national and international research collaboration and scientific networks.

4. One essential task to be fulfilled in the operation of large-scale facilities is that of linking high-ranking scientific research closely with the training of junior scientists and including them in international research collaboration. The involvement of

junior scientists requires special efforts by the scientific leadership of the institutions involved. It is important to make very sure that future generations of scientists receive adequate, forward-looking training using the large-scale facilities. Besides questions relating to the financing of large-scale facilities, acquiring and promoting the next generation of scientists – a "resource" that is likewise not subject to unlimited availability and for which various scientific research disciplines, including ones making little use of large-scale facilities, are competing among themselves – is a central prerequisite for exploiting the scientific and technical potential of large-scale facilities. The Science Council expressly asks that all those involved from all areas of the system of science make special efforts to ensure that these requirements are met.

5. With large-scale facilities on the scale with which we are concerned here, there must be long-term scientific visions, and the prerequisites for technical innovations must be given. Only then can they play the role they merit in scientific progress and the application of new findings and act as a catalyst in whole areas of research. Large-scale facilities on the scale with which we are concerned here must be of outstanding significance for Germany as a scientific location.

6. Most large-scale facilities can no longer be planned and financed at a purely national level, because of the need for scientific potential to be brought together and because of the costs for setting up, maintaining and running the facilities. The facilities should be set up as research establishments organised under an umbrella of multinational European or international sponsorship and should be open to a broad European and international usership. In the medium term this will mean further developing the division of labour in Europe and throughout the world for the construction and operation of large-scale facilities. Including foreign partners in project preparation at an early stage, letting them participate in decision-making and be responsible for their own scientific or technological contributions are prerequisites. Large-scale facilities can also make an important contribution to the further internationalisation of the German system of science by promoting cooperation and mobility and can help in general terms to gradually open up national institutions to European and international involvement.[5] In order

[5] German Science Council: Theses on the Future Development of the System of Higher Education and Research in Germany, Cologne 2000, p. 5 ff.

to avoid the duplication of research infrastructures, which would be detrimental to the effective capacity usage of large-scale facilities, there should be no comparable rival projects at the national or European level that are already in the realisation phase.

7. Germany should – over and above individual cases which already exist – be the location for several multinational European or international large-scale facilities under the leadership of German scientists and should also be substantially involved in the planning, construction and operation of large-scale facilities located abroad. In accordance with the importance of Germany as a centre of scientific excellence and of German scientific work, the country should be entrusted with the scientific leadership for a significant number of large-scale facilities.

8. Large-scale facilities which, because of the costs involved, must be held available at a central location for users many of whom are not from the establishment operating the facilities, should be operated by an establishment that is very service-oriented in its approach. Major research establishments working on scientific and technical as well as on medical and biological research and development requiring the concentrated large-scale deployment of human, financial and material resources are obvious candidates. On the other hand, larger institutions of the *Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz* (WGL) and the Max Planck Society (MPG), working in cooperation with universities and other national and international research establishments, can also be suitable places for large-scale facilities.

9. Large-scale facilities must be centrally incorporated into the strategic planning and research programme of the institution(s) in charge and must be a core element of the spectrum of tasks. Profile building and concentration are crucial for achieving optimal allocation of resources. This may, and in some cases will definitely, mean that, if a facility is located at a certain institution, this institution will have to decide against continuing some of its ongoing research activities due to limited financial and personnel capacity. Generally, this will also mean that staff and resources have to be re-allocated.

10. It is universities that conduct basic research across the whole spectrum of disciplines. The intensive and often long-term investment of human and financial resources in a specialised field, or the particular organisational requirements connected with the construction and operation of large-scale facilities generally do not match the structure or scale of a university and may exceed the level of organisation which they can be reasonably expected to manage. In the field of apparatus and equipment, which includes large-scale facilities, cooperation between places of further education and major research establishments should be a matter of course. Scientists from universities are important users of large-scale facilities. Access to the facilities must be kept open for them in a systematic and pragmatic way, so as to allow them to carry out research projects.[6] To the same extent that German scientists have access to large-scale facilities abroad, foreign scientists should also be able to have access to large-scale facilities in Germany.

A. Expert assessment and science policy appraisal

A.I. Methods

The Science Council first carried out an expert assessment of each large-scale facility for basic scientific research listed by the BMBF and then, in a second step, placed the individual facilities and the respective expert assessments in an overall science policy context.

The individual expert assessments of the large-scale facilities were carried out by various sub-panels. The main focus of the assessments was on

- the probability of fundamentally new insights or the possibilities of decisive scientific advances which could only be achieved with the large-scale facility,
- the large-scale facility's technical feasibility and the degree of technical innovation,

[6] The Science Council has commented in detail on this matter elsewhere. See: German Science Council: Recommendations on cooperation between large-scale research institutions and higher education institutions, Cologne 1991, p. 40 ff., German Science Council: Systematic Evaluation of

- the scientific and technical competence of the institutions involved,
- the already existing or anticipated acceptance of the (potential) users from immediately relevant and from neighbouring areas of expertise, and
- the fulfilment of various objectives of importance for research (transfer, international perspectives, promoting young scientists).

A science policy appraisal of the large-scale facilities was carried out by the Science Council building upon the assessments of the scientific quality of the individual facilities and taking the following aspects into account:

- Scientific potential of the research programme

  As part of the science policy appraisal, the scientific objectives which were being pursued with each of the planned large-scale facilities were first considered. The focus was on the potential for producing outstanding scientific findings in relation to the present level of knowledge and already foreseeable future demand. The planned large-scale facilities had to be congruent with the long-term development perspectives of the corresponding field or fields of expertise. The scientific innovations had to be linked with a basic contribution to progress in the fields of expertise concerned. In addition, there had to be certainty that the desired insights can best be achieved with the large-scale facility, i.e. there should be no possibility that the insights being sought might be achievable elsewhere with existing or future facilities perhaps at a lower cost. Moreover, the large-scale facility should be potentially open to different scientific disciplines so as to allow knowledge to be gained by advancing into previously "unknown territory".

  The institutions making the applications had to have the necessary scientific and technical competence and give convincing assurance that the existing infrastructure can cope with building and operating the large-scale facility. The focus to be achieved with the large-scale facility also had to be clearly recognisable and to contribute towards raising the profile of the respective research institution further in the long term.

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the HGF – Statement by the Science Council on the *Helmholtz Gemeinschaft Deutscher Forschungszentren*, Cologne 2001, p. 52 ff.

- Fulfilment of science and technology policy goals as formulated in the theses (see page 7 ff.)

- Degree of maturity of the technical concept and, linked to it, the possible timeframe for implementing the individual facilities

  The Science Council feels that a formal minimum requirement should be the extent to which the concept is ready for a decision (see Section C). A fully developed technical concept is a crucial prerequisite for implementing the planned large-scale facility within a short time. It must be a project that can hold its own against similar or rival initiatives which either already exist or which are planned, and it must be based on a solid cost estimate. The technical feasibility should be adequately proven through test systems or in the technical design report.

Taking the individual expert assessments by the sub-panels as a basis, the Science Council considered the facilities along with their strengths and weaknesses in the context of further national and international scientific development of the research fields they belong to and assessed their interaction with other disciplines. As a result, the facilities have been divided up into three groups:

- The first group includes facilities which, when implemented, would provide a research infrastructure of a new quality, which would contribute decisively to the development of the research field concerned and which promise new scientific knowledge. The Science Council believes that the facilities in this group merit unconditional support. Convincing scientific programmes and technical design reports are available for these projects. They should be tackled soon and funding partners sought without delay (see Chapter A.III.).

- The second group includes facilities which, when implemented, would also give rise to research infrastructure of a new quality, which would contribute decisively to the development of the research field concerned and which promise new scientific knowledge. Scientific programmes and technical design reports are available and are well developed. However, specific points have yet to be clarified, and this fact stands in the way of unconditional support. The Science

Council has formulated the requirements that need to be met and requests the Federal Government to keep it informed about the clarification of the individual points and to re-submit the parts of the project proposal conceptually revised according to the requirements so that, if appropriate, they can also be confirmed as being worthy of unconditional support (see Chapter A.IV.).

- For the third group of facilities, the Science Council has drawn up specific statements for various scientific, technical or procedural reasons (see Chapter A.V.). Should continued work on the scientific programme and the technical design report for these facilities lead to more extensive insights and to a new project proposal, the Science Council would consider it necessary to carry out a new assessment, which may also have to compete with other initiatives for large-scale facilities (see Section C for details on the procedure for the future assessment of large-scale facilities).

In the following chapter an overview will first be given of the status and future outlook for the areas of research to which the planned large-scale facilities belong, and the significance of research infrastructure for the respective area of research (Chapter A.II.). The findings of the concluding science policy appraisal by the Science Council of the large-scale facilities under consideration and likewise brief outlines of the expert assessments of the individual facilities by the sub-panels can be found in chapters A.III. to A.V. The detailed statements by the sub-panels are gathered together in Part II of this statement; it should be pointed out here that only Part I contains assessments which have a bearing on the decision to support the projects.

A.II. Status and future outlook for the areas of research to which the planned large-scale facilities belong

The following large-scale facilities belong to the field of condensed matter physics

- TESLA X-ray Free Electron Laser (TESLA X-FEL)
- Soft X-ray Free Electron Laser (Soft X-ray FEL)
- High Field Laboratory Dresden (HLD)

- High Magnetic Field Facility for Neutron Scattering Research
- European Spallation Source (ESS)

Condensed matter physics is concerned with the structure and dynamics of solids and their surfaces, the electronic and magnetic characteristics of all kinds of systems, and the construction and behaviour of macro-molecules under different conditions. The investigative procedures are mainly carried out using charged particles, neutrons and synchrotron radiation. Important application-oriented questions are included from the fields of solid-state and material science and from life science areas.

Solid-state and material science is concerned with high-grade materials, which are an essential prerequisite for the technical developments our civilisation has achieved so far, whether in the field of energy supply, transport, communications or health. In the same way that these materials have a key role to play, the development of future-oriented technologies is unthinkable without advanced material research. State-of-the-art knowledge enables the hand-tailored manufacture or improvement of materials for specific needs. A distinction is made here between structural materials, which are characterised by desired mechanical properties such as firmness, stiffness, ductility, high levels of resistance to wear and to environmental influences, and functional materials, which are characterised by their electrical, magnetic, acoustic, optical and biological properties. Typical of most classes of material is that they can generally be used as structural and functional materials.

Clarifying the links between the microscopic structure of the materials and the properties which result from that structure is a subject of intensive research worldwide, and is as yet only partly understood. Crucial contributions to state-of-the-art knowledge have been provided by research with x-rays, neutron scattering, synchrotron radiation and other spectroscopic methods. The development of new materials remains a great challenge. Hi-tech materials require the exact monitoring of their structure over wide size and time scales, from nanometers to macroscopic dimensions, from picoseconds to hours or even years. This wide range and the variety of interesting characteristics pose a great challenge and to analyse them a number of different effective measuring techniques which are coordinated with and complement each other are required. Reliable measurement data and more and more high-powered computers are the basis for the growing importance of computer simulation.

Generally speaking, in the nanometer range the manufacture of new materials requires new strategies to link self-organisation with the ability to form hierarchical structures. A particularly high degree of inter-disciplinary cooperation is needed here in order to link approaches from the fields of physics, chemistry, biology and engineering.

Numerous challenges are posed by the characterisation of materials and the next generation of large-scale facilities needed for this, particularly the need to be able to handle ever smaller quantities of substances, right down to individual molecules or even individual atoms. This demands increasingly high-performance measuring equipment and methods. Many of the materials we are concerned with here do not have a crystal structure in the usual sense, so that their structures are not directly accessible to effective traditional methods as x-raying or neutron scattering. New approaches are required in structural research and close coordination of the use of large-scale facilities with the laboratory methods which are constantly being developed further for different kinds of microscopy, spectroscopy and computer simulations. The synergies that result here already indicate possibilities for a new quality of use for large-scale facilities in this field.

In this century **life sciences** will be as important as micro-electronics in the last century. The reasons for this great leap are varied: a new dimension of what is generally understood by life sciences has come about because the workings of primary biophysical and biochemical processes have been explained (eg. the explanation of basic mechanisms of photosynthesis; the extensive decoding of the human genome). The interest in themes relating to health and quality of life has grown enormously among a large section of the population and this is reflected in a marked increase in funds being spent in this sector of the economy.

Explaining structures by using x-rays can be seen as a decisive step on the path of scientifically explaining biological processes. This method has been used to explain not only the structure of the DNA double helix but also the structure of the photosynthetic reaction centre. In both cases a new quality of x-ray structure data at the particular time made the decisive step towards new insights possible. However, the clarification of these biological basic structures is still in its infancy. According to what we know today, the processes by which life is preserved in all organisms are controlled by dynamic processes conveyed by proteins. Very complex, dynamic molecular structures, some of which are made up of more than 1,000 amino acids, are waiting to be explained. These biological macro-molecules are based on primary structures (chains of amino acids), some of which are very well understood. When these chains of amino acids are folded, however, very complex secondary and tertiary structures arise, whose construction and function in living organisms have yet to be grasped. The dynamic interaction between large bioproteins (up to 100.000 Dalton) and molecules with a pharmacological impact can only rarely be explained using conventional x-ray methods. To explain this interaction, nowadays newer methods of NMR (particularly multi-dimensional NMR), spectroscopy and microscopy are used.

Initial data from experiments with neutron scattering already exist, data describing the dynamic characteristics of bioproteins. One disadvantage of neutron scattering is that so far it has only been possible on a few occasions to manufacture single crystals of a sufficient size for scattering experiments. In future it is expected that progress in clarifying structure will be achieved using extremely high intensity x-ray lasers. Using such lasers it should be possible to determine the structure of individual bio-molecules through experiments "with one shot". Although the molecule is then vaporised by the high input of energy, the structural data are registered instantaneously and permit the reconstruction of the complex molecular form. Initial, very promising results are available. Experiments still need to be carried out, however, to demonstrate the effectiveness of the method.

Parallel to the experimental techniques, another line of research is pushing ahead with the use of computer methods which first calculate amino acid sequences from known sequences of nucleotides, which should then lead, via folding algorithms, to three-dimensional protein structures. However, the suitability in principle of the algorithms currently available for this purpose is still a matter of scientific debate.

Since the methods which rely purely on theoretical findings for understanding bio-molecules and developing pharmaceuticals are relatively slow, and the pressure from the market to develop successful blockbuster substances is very great, many empirical testing methods are currently being developed. With these methods large numbers of known chemicals are characterised within combinatory test programmes and using mostly optical testing methods (high rapid throughput screening). Using these methods it is possible to examine more than 1,000 test substances a day. This has often meant in the past that pharmaceuticals were developed using purely empirical methods, with their function first being clarified in molecular terms later. The different bits of information about structures from scattering data, spectroscopy and computer simulation have to be combined systematically. To do this cooperation between the different disciplines needs to be strengthened.

In the past, scientific advances in life sciences have come more often from using "small facilities" than through research with large-scale facilities. There is a basic difference here to elementary particle physics or hadron and nuclear physics for example. Large-scale facilities like x-ray lasers or neutron sources, which can also be used in parallel by various scientific disciplines such as high-energy physics, nuclear physics, biophysics and certain areas of micro-electronics, will also be important in the future for further developments in the field of life sciences.

One of the facilities belongs to the field of **elementary particle physics**:

- TeV-Energy Superconducting Linear Accelerator (TESLA)

Elementary particle physics is devoted to the study of the smallest particles of matter and the forces working between them. Although, in terms of appearance, matter takes many forms in our world, it is made up of just a few basic components, between which four different forces are at work. A concrete model of this simple image is provided by the standard model of particle physics – albeit with the exception until now of gravitation.

The elementary nature of the components of matter and their forces becomes evident in the field of the micro-cosmos, at dimensions that are a fraction of the size of the protons and neutrons which make up the nuclei of atoms. Since all nuclear physics and atomic laws can be derived from this model, it is also a basis for understanding the macro-cosmos. Its applicability at extremely short distances leads to an understanding of the emergence and temporal development of the universe (Big Bang). The model thus represents a link between particle physics and cosmological developments.

The standard model forms a framework for the structures and laws of the micro-cosmos, whose applicability at wide ranges has been confirmed experimentally with an extremely high degree of accuracy. Experiments with particle accelerators have made decisive contributions here. Yet there are phenomena, like the small differences between matter and anti-matter and above all the mechanism for generating particle mass, which have not yet been investigated and understood sufficiently through experimentation. They include the very topical question about the nature of neutrinos, which are being investigated by measuring the neutrino flows from the sun, cosmic radiation and reactors, and by measuring double beta decay.

The standard model parametrises the characteristics of the fundamental components and forces without explaining them in physical terms. An explanation of why the electrical charge of the elementary electron is exactly identical to that of the proton, which is made up of quarks, remains to be found, likewise an answer to the question as to why six quarks and three charged leptons paired with three neutrinos exist. It does not show the origin of the four fundamental forces either. So far only three of the four forces, the electromagnetic, the weak and the strong interaction have been unified as gauge field theories. The inclusion of the fourth force, gravity, to derive a quantum theory has still to be achieved. It is widely assumed that this will only be possible by finding a more comprehensive theory.

In the standard model, particle mass is generated through the Higgs mechanism, i.e. through an interaction with a background field, the so-called Higgs field. This field manifests itself in the existence of an electrically neutral particle, the Higgs boson. The existence of this particle and the proof of the Higgs mechanism are seen at the present time as probably the most urgent questions needing to be solved by experiments. Other questions point beyond the framework of the standard model. The theory of matter can only be seen as complete once it traces all forces back to a common origin, which explains the spectra and mass of fundamental particles and integrates gravity, linked with the structure of space and time, in a quantum theory.

Unifying the electroweak interaction with the strong interaction at high energies to form one fundamental uniform interaction is a generally accepted concept. Starting with the very precise measurements of coupling constants at low energy levels it seems possible to realise this concept, as long as the standard model is complemented by supersymmetry. Supersymmetry widens the spectrum of known particles by giving each particle a partner whose intrinsic angular momentum (spin) differs by half a unit. Supersymmetry also offers a physical explanation of the Higgs mechanism. Moreover, supersymmetric particles could explain a large amount of the mass of the universe in the form of invisible "dark matter".

The development of the standard model has taken place in interaction between theory and experiments. For decades experiments using particle accelerators of various kinds were very important. Through the discovery of heavy quarks and leptons, of gluons, and of W and Z mesons, precision measurements have consolidated the model. The just recently acquired proof of the violation of the symmetry between matter and antimatter (CP) in B mesons is further confirmation of what the standard model tells us. The search for the Higgs particle remains the most important experimental question. Despite great efforts, the search for the Higgs boson using existing particle accelerators has been without success, although its properties are defined in the standard model, with the exception of its mass. Experiments on the proton storage rings – currently under construction – of the Large Hadron Collider at the European Organisation for Nuclear Research (CERN) in Geneva should be able to safely prove the existence of the Higgs particles up to a mass of 1 TeV (corresponding to one thousand proton masses) or rule it out with certainty. What is more, detailed investigations are planned, which should give signs of structures beyond the standard model in an energy field in which the model is not able to make consistent predictions. High-energy physicists all over the world are convinced that high-energy electron-positron collisions are best suited for such investigations. Whilst protons are extremely complex particles, whose interactions are influenced by many side-effects, the annihilation of electrons and positrons (matter and antimatter) is a simple process, which allows new-style phenomena to be clearly recognised and measured with precision. The energy intensities arising in the case of extremely high energies correspond to those during the first billionth of a second after the Big Bang, so that the beginnings of the cosmos could be duplicated in an experiment. All particles that were present at the beginning of the universe should emerge under these conditions in the experiment. If the idea of super-symmetry is relevant, it should be possible to observe the series of new particles it predicts. They are a new kind of matter, that forms no atoms and therefore does not form planets or galaxies either. They could be dark matter, whose existence is postulated from astronomic observations. Investigations of the processes that occur only with the highest levels of energy require enormous technical innovation in the construction of accelerators of the highest energy and intensity. In the past few decades the effective energy of particle accelerators has been increased by a factor of more than fifty with a relatively low increase in costs. The essential innovation was the introduction of storage rings, in which high-energy particle beams collide, in contrast to conventional accelerators, where a beam hits a stationary target. Parallel to that, the development of new methods of proof and of fast electronics led to the construction of large, very complex, high-performance detectors. Requirements for the selection, transport and storage of very large quantities of data and the need for world-wide communications have furthered new developments in these fields.

Research in the field of particle physics has been carried out in international cooperation for decades now. This cooperation not only enables the construction of large-scale facilities by using joint financial resources; it leads in particular to coordinated and therefore optimum use and to a considerably better quality of scientific and technical projects. A successful example is the European Research Centre CERN, which has become more and more of a global centre for scientific cooperation over the years. CERN is not just supported by its European member states, but also by a growing number of associated countries, whose scientists are involved in the construction of the LHC and the experiments. Thanks to bilateral agreements, DESY has received substantial contributions to the construction of HERA and experiments, both in terms of the development and supplying of components as well as through the involvement of foreign staff.

In the future, efforts will be made to find models for this type of global cooperation, which allows the participating scientists to be actively involved in the planning, construction and operation of a large-scale accelerator and the experiments whilst they are based in their own institutes, by using modern methods of communication. The implementation of this Global Accelerator Network is an objective for the future electron-positron collider. Scientists from three regions of the world, Europe, Japan and the US, are involved in developing a machine of such technical sophistication. It is to be expected that high-energy physics will not only explore new technical territory with such a machine and get closer to the fundamental scientific questions of the micro and macro-cosmos, but will also be able to contribute towards furthering global cooperation.

Hadron and nuclear physics is the area of research dealt with by the large-scale facility

- International Accelerator Facility for Beams of Ions and Antiprotons

The main topic of nuclear physics over the last 80 years was investigating phenomenological bases: determining the properties and structure of stable and almost stable nuclei, their excitation mechanisms and the reactions between nuclei. All descriptions of the properties of nuclei were based on the model of nucleons as nuclear building blocks which are subject to a strong phenomenological interaction. These discoveries delivered the basic foundations for the many practical applications of nuclear physics. At the same time, the phenomenological model made it possible to understand the energy sources and development of the stars in quantitative terms and also, later, to describe the zoo of mesons and nucleon excitations. Today it is understood that the true components of nuclear matter are quarks, which interact with one another through the exchange of gluons. The basic and, in principle, exact theory of the strong interaction is quantum chromodynamics (QCD). QCD contains mysterious, new properties which set it apart from the theories of the other basic interactions of nature. The most important difference is so-called quark confinement. This states that quarks can never occur alone, but only in connection with other quarks (or antiquarks). Accordingly, modern nuclear physics has divided into the pursuit of three important branches:

One of these is concerned with researching the basic characteristics of nuclear matter, consisting of quarks and gluons, as predicted by QCD. The aim here is not just to find new forms of strong-interaction matter, but also to understand confinement as such. In order to manifest the quark characteristics, reactions between nuclei or between nuclei and electrons at high energies are needed. On the one hand, very high nuclear densities can be generated here, so that the quarks (and gluons) can move quasi freely through part of the nuclear volume, and confinement can be briefly overcome. With higher collision energies the local energy intensity grows so much that a large number of quarks, anti-quarks and gluons is generated from the vacuum. This situation corresponds to that of the cosmos about 10 microseconds after the Big Bang. Under such circumstances QCD states that a new phase of nuclear matter arises: quark-gluon plasma (QGP). The transition from normal nuclear matter to QGP (or vice versa) is very important: the quarks lose more than 99% of their mass. In reverse this means that more than 99% of all mass in our world was generated by the transition from QGP to normal nuclear matter. QCD as a fundamental multi-particle theory predicts other forms of quark-gluon matter as well: the most interesting one is a gluon condensate which corresponds to the Bose-Einstein condensate of the electromagnetic interaction.

Other fundamental questions derive from the construction of nucleons and mesons from quarks and gluons: the proton is an agglomerate of quarks and gluons, all with their own spin and angular momentum, which must add up to a total of ½h-bar exactly. How does that happen? Quarks and gluons can also generate far more complex mesons than so far observed. What does the complete spectrum of mesons look like? By providing special supercomputers for so-called lattice calculations theoretical predictions will soon be made available for all these questions.

The second area, the nuclear physics of lower energies, seeks to extend the determination of unstable nuclei up to the fundamental limits of stability. Nuclei can only hold together a limited number of neutrons and protons, even for a short time. The limit is determined by so-called driplines. The properties of the nuclei at the proton dripline determine the development of stellar matter and the generation of the chemical elements from the original fuel, hydrogen, up to the most stable elements around iron and nickel. The still heavy elements then arise explosively through neutron deposit along the neutron dripline. The quantitative understanding of these supernova explosions and thus the occurrence of the heavy elements requires measurements of nuclei far from the stability valley. Towards the super-heavy nuclei, their stability limits are still unknown despite great research efforts. Reliable model calculations predict that nuclei with more than 180 neutrons and 126 protons, i.e. a nucleon mass of 306, should have practical lifetimes. Such nuclei would have a practical significance because of their exceptionally large fission probabilities. All this research requires accelerators with low to medium energy levels.

The third area of nuclear physics concentrates on the properties of electron-neutrinos as generated in beta decay in the laboratory, in nuclear reactors or in stars, such as the sun. This research is carried out in laboratories far under the ground, often with large-volume detectors. For example, the detector at the Sudbury Neutrino Observatory (SNO) in Canada showed recently that electron-neutrinos change into other neutrino forms on their way from the sun to the earth. This has, at the same time, confirmed the standard model of the sun in quantitative terms. Explaining the combustion processes in stars and the explosion processes of supernovae leads to a quantitative prediction of cosmological neutrinos.

These three areas of research in nuclear physics today have led to an international consensus regarding the necessary new accelerators and detectors. Investigating QCD matter at the highest energy intensities requires heavy ion beams of at least 100 GeV/Nucleon. These are available today at the Relativistic Heavy Ion Collider (RHIC) in Brookhaven National Laboratory (BNL) and will be available at the large Hadron Collider (LHC) in CERN once it is completed. To generate nuclear matter of the highest mass density, i.e. the greatest nuclear compression, heavy ion beams with medium energy levels are needed, about 30 to 50 GeV/Nucleon.

Investigating quark distributions and cold QCD matter requires electron-proton collisions, such as the Hadron-Electron Ring Accelerator (HERA), or electron-proton collisions, such as planned at the Thomas Jefferson National Accelerator Facility (Jefferson Lab). Proton-antiproton or photon-nucleus facilities are currently being considered for QCD spectroscopy.

The production and investigation of radioactive nuclei at the driplines requires beams from nuclei that are themselves already radioactive. Powerful two-phase facilities are under preparation in the US, Japan and Germany.

Questions from the fields of **environmental and geo-research** are to be addressed with these large-scale facilities:

- European Drilling Research Icebreaker (Aurora Borealis)
- High Altitude and Long Range Research Aircraft (HALO)

Modern **environmental and geo-research** sees the Earth as a dynamic planet which is in a state of constant change and which represents a system the understanding of which is of essential importance in making provision for human existence. Environmental and geosciences are therefore becoming increasingly committed to the systematic observation of the Earth, which is the foundation for the preservation of the habitat Earth and a prerequisite for successful Earth management. Besides the preservation and sustainable use of natural resources such as fossil fuels, mineral raw materials, drinking water and biomass, making provisions for and dealing with natural disasters (floods, mass movements, earthquakes, volcanic eruptions) and, in particular, the impact of human activities on natural cycles (eg. climate impact and use of resources) and on terrestrial and aquatic eco-systems are two topics at the centre of research activities. All the areas mentioned are of high economic and social relevance and require process-oriented approaches. Environmental and geo-tasks for the 21st century are in detail:

- developing and testing integrated models which observe the atmosphere, hydrosphere, pedosphere, biosphere and lithosphere as a system,
- recognising and evaluating the processes of movement in the Earth's crust,
- analysing and evaluating environmental and geo-risks like earthquakes, volcanic activity, mass transfer, floods, climatic anomalies (global change), air pollution, soil degradation, water damage and changes in biodiversity, and drawing up prediction and management strategies,
- recognising and making sustainable use of essential natural resources such as water, raw materials and biomass,
- judging the interaction between people and the environment and drawing up and carrying out geo-ecological, environmental/geological, geo-technical and environmental protection measures.

Global climate change and the changes in the troposphere and stratosphere which are linked with climate change and which – as far as they can be judged from the state of knowledge today – are critical for climate change, are still too little understood. To construct reliable climate models and predictions, data about the Earth's climate in the fairly recent past is needed as is information about the current status of the upper layers of air above the Earth and about the relevant interactions between the atmosphere and eg. the biosphere and hydrosphere. This data can only be gained through deep sea drilling in all parts of the oceans, but particularly in regions of the Arctic and Antarctic waters, where the knowledge we have so far is patchy and incomplete, and through direct measurements in the troposphere and lower stratosphere, all of which is of essential importance for long-term strategies.

Large-scale facilities in the fields of environmental and geo-sciences, which are necessary for solving the aforementioned long-term tasks, are – apart from analytical institutions – in particular research platforms such as mobile deep drilling stations (eg. the Continental Deep Drilling Programme of the Federal Republic of Germany, the International Continental Drilling Programme), multi-purpose and polar research ships (the research ship Sonne, the research ship Meteor and the polar research ship Polarstern), and geo-scientific drilling ships (DRV Joides Resolution: Ocean Drilling Programme, Integrated Ocean Drilling Programme). Moreover, research aircraft and Earth observation satellites are used to analyse the atmosphere continuously and to measure the gravitational field and the Earth's slowly changing magnetic field. Whilst land-based deep drilling facilities are important for topography and three-dimensional explorations of the upper strata of the Earth's crust with regard to tectonic processes, volcanic activity and minerals and energy raw materials, on the other hand, research and drilling ships in combination with remote controlled robot systems and manned research submersibles are the only way to investigate the ocean floor with a view to decoding climate archives and exploring minerals (massive sulphide) and energy raw materials (crude oil, natural gas, gas hydrates). In the long term, ocean floor observatories will be used for monitoring submarine volcanic activity and the hydrothermal systems connected to them (discharges of hot seawater with temperatures of up to 400°C). The hyperthermophile chemosynthetic bacteria which occur at deep sea hydrothermal springs are currently being examined for possible use in the pharmaceutical industry and represent an important geo-bio interface.

A.III. Group of large-scale Facilities which merit unconditional support

The Science Council considers that

- the High Field Laboratory Dresden (HLD) and
- the High Altitude and Long Range Research Aircraft (HALO)

merit unconditional support. Convincing and well developed scientific programmes and technical design reports are available. Both facilities should be set in motion and financed quickly.

High Field Laboratory Dresden (HLD)

Brief description of the facility[7]

Magnetic fields are a parameter comparable to the parameters temperature and pressure and are therefore of importance for many areas of research. When field strengths are raised beyond what has been accessible until now, new and individually unforeseeable scientific insights relating to solid-state physics and material research can be expected.

An initiative by Dresden physicists and material scientists, headed by the *Forschungszentrum Rossendorf* (FZR) and the *Institut für Festkörper- und Werkstoffforschung* (IFW) in Dresden, is planning to install a high magnetic field laboratory with a magnetic field strength of up to 100 Tesla and a pulse duration of about 10-20 milliseconds. In order to be able to use the laboratory for a broad spectrum of experiments, three groups of different magnets are envisaged, each with different combinations of pulse duration (between 10 and 1,000 ms), maximum field (between 60 and 100 Tesla) and bore diameter (between 20 and 50 mm bore diameter of sample space).

[7] For details see Part II of this statement.

The Dresden initiative's scientific programme covers semiconductor physics and low-dimensional systems, magnetism and metal physics, superconductivity, nuclear and molecular physics, complex fluids and special questions of chemistry. Besides the significance of high, quasi-static magnetic fields for basic research, technology transfer between science and industry, for example in the application and manufacture of superconducting permanent magnets or the development and manufacture of high-strength superconducting coils, is anticipated.

A detailed scientific programme and a well-developed technical design report are available. The investment costs for the construction of the facility are estimated at €24.5 million including staff costs, the annual staff and operating costs at €3.7 million. For the construction phase up to the start of operations in the laboratory, 4 years are envisaged. The planned location is the *Forschungszentrum Rossendorf*.

Outline of the sub-panel's findings[8]

The planned laboratory for long-pulsed, i.e. quasi static, very high magnetic fields up to 100 Tesla will, in the opinion of the sub-panel, permit novel new investigations in condensed matter physics and material science. In addition, the linking of 100 Tesla magnetic fields with the infra-red FEL of the ELBE radiation source, which will come into operation in 2002 at the FZR, opens up unique research prospects in various fields, mainly in the area of the magnetism of materials and nanostructures, but also in the fields of chemistry and bio-technology.

The cooperation between experimental physicists, theoreticians and engineers from several Dresden institutes is extremely productive. The institutions involved in the project are noted for the high level of their scientific qualifications, especially in the areas of material research and solid-state physics. A 50 Tesla/1 MJ pilot facility has been successfully demonstrated at the *Institut für Festkörper- und Werkstoffforschung*. Moreover, significant progress has been made in developing high-strength superconducting composites, material development being a crucial prerequisite for the high fields the researchers are striving to achieve.

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8 For details see Part II of this statement.

Intensive use by Dresden scientists and other German research groups is to be expected for the high magnetic field laboratory, which has been conceived as a national-use laboratory. It will, however, also be highly attractive for European and international groups. Dresden as a location offers a splendid possibility to develop a laboratory which is a world leader for pulsed high field magnets with great potential for developing into a central European laboratory for this field. The scientific programme and technical design report are convincing.

Concluding science policy appraisal

The high magnetic field laboratory in Dresden, with its maximum achievable field strengths, the available bore diameters and high field homogeneity, plus the combination with spectroscopic procedures, offers new research possibilities which have yet to be realised in this quality anywhere else in the world. The use of high magnetic fields has developed into an important area of research in the past few years, especially for solid-state physics and material science. High magnetic fields permit the non-destructive tuneable modification of the electronic states of a system. They are, for example, a prerequisite for investigating semiconductor and magnetic nanostructures, for research into spin influences on chemical reactions and molecular magnetism and for investigating magnetomechanical orientation effects.

The planned high field laboratory is based on a high level of technical competence on the part of the establishments involved. The preparatory technological work is considerable, a coherent scientific programme and a convincing technical concept were first presented in 1999. The research activities in previous years, in particular by the leading institutions involved, show a high level of scientific profile and consistent progress towards research with high magnetic fields. The planned high field laboratory is decisively embedded in the strategic orientation of the establishments involved.

The Science Council underlines the high innovative potential which is linked to the investigation of the magnetic properties of solids and their behaviour in very high magnetic fields. Already in the past significant technological innovations with far-reaching economic impacts have been achieved, for example for the development of new materials for data storage. This is all the more remarkable given the fact that investigating materials using magnetic fields is not a wide area of research and the number of institutions and scientists involved is limited to a narrow circle.

The Science Council supports the plan to develop and operate the high field laboratory as a national facility. In the Dresden area in particular, with its high concentration of research institutes for solid-state physics and material research, the inadequate level of access to very high magnetic fields until now has had a negative impact. However, the Science Council is of the opinion that the global consensus that high magnetic fields up to 100 Tesla should be made available for scientific research means that the Dresden initiative should be opened more for European users. Further objectives should be more intensive cooperation with other German and European scientists and institutions and making the training of the next generation of scientists more international. An important step towards achieving these objectives is getting recognition as a European Large-scale Facility as quickly as possible, which is what the Dresden scientists are trying to do.

High Altitude and Long Range Research Aircraft (HALO)

Brief description of the facility[9]

Despite considerable progress in the past few decades, many of the significant processes and systematic changes in the Earth's atmosphere are still not fully recognised and understood, which is due, inter alia, to the fact that there is a lack of suitable platforms for large-scale measurements of the free atmosphere.

Representatives of German atmospheric research based in and outside universities, led by the *Deutsches Zentrum für Luft- und Raumfahrt* (DLR), Oberpfaffenhofen, and the Max Planck Institute for Chemistry in Mainz, are planning to procure a research aircraft – for further investigation of the troposphere and lower stratosphere and for earth observation – which will meet wider specification requirements in terms of range, altitude ceiling, payload and usable area. The planned research aircraft is to replace the Falcon 20 that has been in service for over 25 years and help strengthen German and European atmospheric research in the international context.

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9 For details see Part II of this statement.

The priority areas of research with the aircraft are to be:

- the chemistry and transport of trace components in the troposphere and lower stratosphere,
- ozone destruction in the stratosphere,
- integrated investigations of the interactions between chemistry-climate-biosphere-human activity,
- transport and chemistry in convective and turbulent systems,
- investigations of the distribution of sea ice within the framework of polar research,
- research into the impact of air transport on the tropopause region,
- earth observation and remote sensing with particular emphasis on the carbon cycle.

The scientific goals and measuring tasks are documented in a scientific programme. The required technical and scientific specifications are met by two aircraft that are commercially available. The total investment costs are estimated at €97 million, the annual operating costs – calculated for the first six years – at €3.8 million. After a procurement and modification phase of 3 years operational research flights can begin.

Outline of the sub-panel's findings[10]

The transition layer between the troposphere and the stratosphere is an essential region for understanding the global climate system. The sub-panel sees the research aircraft HALO with its more extensive possible applications compared with the research aircraft currently in service as a significant contribution to international global change research. Going beyond atmospheric research, it is also a valuable tool for other disciplines, for example for geophysical research. The availability of a high-performance research aircraft for use primarily by German scientists can also serve to secure the leading position of German atmospheric research in international and inter-disciplinary cooperation for years to come.

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[10] For details see Part II of this statement.

At present there is no other aircraft operating anywhere in the world which corresponds entirely to the specifications which HALO is intended to meet in terms of payload, cabin volume, range and altitude. Alternative platforms for measuring instruments like balloons or commercial aircraft can complement the work of the research aircraft in part very well, but are no substitute for it. Comparable scientific questions are being pursued only by the planned US research aircraft HIAPER (High-performance Instrumented Airborne Platform for Environmental Research). During the first five years after completion, however, HIAPER will not be offering any free capacity for international projects. The sub-panel is of the opinion that there is no possibility of German scientists subsequently being able to share in the use of the facility for purely European-oriented research projects.

The sub-panel welcomes the fact that the scientific and technical concept for the planned research aircraft is backed by a broad base of scientific disciplines and almost all the institutions in Germany that are working in the field of atmospheric research and earth observation and that take a common interest in further developing a question which is also of societal importance. The availability of measuring time for universities will considerably increase the attractiveness of atmospheric research and earth observation for students and scientists.

The research aircraft is to be available primarily for German atmospheric research and earth observation. The sub-panel considers that it is necessary for the aircraft to be integrated more strongly into international networks and international research with complementary instruments as well.

At Oberpfaffenhofen, where the aircraft is to be located, there are qualified personnel with a wealth of experience in the procurement and aeronautical operation of research aircraft. The sub-panel considers that the research flight activities carried out by the DLR, which is located there, make it the most suitable place for the research aircraft in Europe.

Concluding science policy appraisal

The research aircraft HALO will permit a further decisive step to be taken towards implementing systematic earth observation. Recognisable climate anomalies and the significant changes in the troposphere and atmosphere that are linked to them are still too little understood. To develop and calibrate reliable climate models and predictions which consider the individual layers of air as a system, information about the current status of the upper layers of air above the Earth and about the relevant interactions between the atmosphere and the biosphere and hydrosphere are essential. Getting this information can only be done by direct measurements, such as will be possible with the research aircraft HALO, measurements which have not yet been made anywhere in the world. The research possibilities this will open up are not only very attractive in scientific terms for numerous specialist disciplines – such as atmospheric chemistry, climate research, polar research and earth observation – they are also of very high societal relevance.

Germany leads the world for the atmospheric research being carried out at universities and other establishments, research that is marked by its variety and scientific quality. Aerosol research, which is being pursued at the highest level in Germany, deserves particular mention. The research aircraft HALO, as a "community research aircraft", can help secure and further develop Germany's position in atmospheric research. HALO offers ideal conditions as a platform for integrated research and for universities to promote future generations of scientists.

There are many possibilities for work arising from carrying out scientific experiments using the research aircraft, all with a high practical relevance; the preparatory scientific work is characterized by a similar, equally advanced state of preparation. The aircraft which come into question for use as research platforms are available commercially and present no technological challenges. To reduce costs the possibility of procuring the same type of aircraft as for the planned US initiative HIAPER (High-performance Instrumented Airborne Platform for Environmental Research) should be examined in liaison with the US project. Given the experience of the institutions involved, it is to be expected that the modification of the aircraft to meet the specifications of research flights and the adaptation of the instruments to be carried on board will proceed successfully.

The *Deutsches Zentrum für Luft- und Raumfahrt* (DLR) has a well coordinated, expert team for the management of research aircraft that is familiar with the scientific experiments.

The Science Council welcomes the emerging coordination of flights by research aircraft in which Germany, France, Great Britain, Italy and the Netherlands are leading by example, with aircraft being deployed or due to be deployed in different atmospheric corridors. The Council considers it to be acceptable that the concept for a new research aircraft will be primarily a national initiative, with the facility mainly being used by German scientists. Globally relevant questions from the fields of climate and environmental research require the most intense efforts by individual states coupled with coordination at the European and international levels. The Science Council sees a need for the research aircraft HALO to be integrated closely into European atmospheric research, for its use to be coordinated closely at the international level and for it to be incorporated into the exploration of the entire atmospheric system.

A.IV. Group of large-scale facilities which merit conditional support

The Science Council considers

- the TeV-Energy Superconducting Linear Accelerator (TESLA),
- the TESLA Free Electron Laser for X-ray applications (TESLA X-FEL) and
- the Accelerator Facility for Beams of Ions and Antiprotons

to be worthy of conditional support. The scientific programmes and technical design reports that are available for these facilities are at an advanced stage. Nonetheless certain points still have to be clarified, a fact which, at present, stands in the way of unconditional support. The Science Council has drawn up various requirements in this regard and requests the Federal Government to keep it informed about the clarification of the individual points and to re-submit the parts of the project proposal conceptually revised according to the requirements so that, if appropriate, they can also be confirmed as being worthy of unconditional support.

TeV-Energy Superconducting Linear Accelerator (TESLA)

Brief description of the facility[11]

Initiated and managed by *Deutsches Elektronensynchrotron* (DESY - German Electron Synchrotron) in Hamburg, a TeV-Energy Superconducting Linear Accelerator (TESLA) using energy of up to 800 GeV is in the process of being developed within the framework of global cooperation.

The energies and intensities made available by TESLA promise answers to fundamental, unresolved issues of elementary particle physics, such as proof of the Higgs mechanism, the detailed examination of the properties of Higgs particles and the experimental proof of supersymmetry, which is currently favoured as a fundamental theory. Furthermore, it is hoped that new knowledge about the question of the unity of gravitation and quantum physics will lead to the convergence of particle physics and cosmology.

The TESLA scientific programme and a detailed technical design report for TESLA with integrated X-FEL has been available since March 2001. The technical concept proposes two superconducting linear accelerators of a total length of 33 km in which electrons and positrons are accelerated in opposite directions in high electromagnetic fields and made to collide within a detector with a beam as small as possible in size and as high as possible in intensity. In conjunction with industry, accelerator components are to be produced which achieve gradients above 25 MV/m.

It is planned that the linear collider will be implemented and operated as part of a Global Accelerator Network. The estimated investment cost for construction of the 500 GeV TESLA collider including personnel costs totals € 3,450 million, the annual personnel and operation costs amount to € 135 million. A total period of 8 years is envisaged for the construction phase. The proposed location is at DESY in Hamburg.

[11] For details see Part II of this statement.

Outline of the sub-panel's findings [12]

The sub-panel stresses that the proposed linear collider will help to provide answers to fundamentally important questions in elementary particle physics and cosmology and that the collider is expected to play an important, if not decisive, role in improving understanding of the development of the cosmos and the nature of dark matter. The TESLA scientific programme complements the Large Hadron Collider (LHC) currently being built at CERN, since it is expected that the phenomena which will be demonstrated by the LHC in the future will be able to be explained in detail using the high measurement precision of TESLA. For this reason it is hoped that operation of both facilities will overlap.

Given the high concentration of international competence required for a research infrastructure of this size and the high overall investment and operation costs, it would seem imperative that only one collider of this kind be implemented worldwide. The sub-panel endorses the efforts of the TESLA collaboration to build, operate and use the linear collider within a global accelerator network. As an outstanding example of international cooperation, TESLA will develop a worldwide appeal for the field of high energy physics. The sub-panel welcomes the global consensus among high energy physicists, who agree that a positron-electron linear collider should be at the top of the list of most desirable large-scale facilities in elementary particle physics.

The TESLA collaboration leads the world in the research and development of superconducting cavities. The TESLA Test Facility (TTF) provided convincing proof that the superconducting accelerator components fulfil the requirements with regard to beam energy and intensity, thus testing and verifying the basic feasibility of the TESLA technology.

DESY, the most important European large-scale research institution apart from CERN, has excellently demonstrated its capability as the leader of the international TESLA collaboration. For DESY, the planned linear collider is the product of the systematic development of large-scale facilities successfully operated for many years, such as DORIS, PETRA and HERA. The experience gained over the past 30 years in the research and development, construction and operation of large-scale

[12] For details see Part II of this statement.

accelerator facilities provides a solid basis for successful implementation of the TESLA project.

Concluding science policy appraisal

The Science Council believes that an enormous amount of knowledge about fundamental questions concerning the micro- and macrocosmos will be gained from the scientific questions that will be examined using the TESLA linear collider. The existence of the Higgs boson and the verification of the Higgs Mechanism are considered at the present time to be the most pressing questions in elementary particle physics, which should be resolved via experiments. The idea is that precision experiments in an energy area for which the standard model does not provide any consistent information will reveal signs of structures beyond the model and that these will then be studied in detail. An electron-positron linear collider is the suitable facility in this case. Since it is only feasible to have one facility of this kind in the world, the decision to build the collider requires international agreement on the technology to be deployed and the location. An expert body from the International Committee for Future Accelerators (ICFA) is currently examining the possible technologies in detail.

The general feasibility of superconducting accelerator technology was convincingly demonstrated by the test accelerator (TTF) installed at DESY; however, some components which are based on extrapolations of hitherto existing storage rings, as well as on theoretical calculations and detailed simulations, have not yet been completely validated by experiments. Accelerator components with gradients of up to 25 MV/m can be reliably produced in cooperation with industry, and, on the basis of the current level of knowledge, they make further development to the target of 35 MV/m appear probable. This should make it possible to extend the energy range to 800 GeV in the long term. Extremely interesting is the transfer of superconducting accelerating structures for the construction of future generation synchrotron radiation sources.

Among the projects assessed here, the TESLA linear collider is the only facility that would be implemented with global participation. Accordingly, construction and operation of the facility should be carried out within the framework of international cooperation whereby, using modern communication methods and working from their respective institutions in their home country, the participating scientists would be actively involved in planning, building and operating such a facility as well as conducting the experiments.

The Science Council welcomes the intention of implementing a linear collider within a framework of international cooperation; this approach promises a fundamentally new, forward-looking quality of worldwide cooperation in science. If the facility is located in Hamburg, DESY will be able to further develop and strengthen its status as an internationally renowned research centre. However, the Science Council draws attention to the fact that this will require the institution to manage an unprecedented level of coordination, which also includes the important question of international funding. The Science Council sees the need for further clarification with regard to the issue of international funding and international provision of personnel and facility components, as well as clarification concerning the need to place international collaboration on a more formal footing, especially since scientists and engineers from the participating countries are to be involved in management of the project. The Science Council assumes that it will be possible to reach agreement on these aspects during the conception phase of the linear collider.

The Science Council requests the Federal Government to give its binding consent to German participation in the project as soon as possible after the project proposal has been submitted with specific details concerning international funding and international cooperation, since the partner countries are expected to give their binding financial consent only after implementation has been decided on at national level. The Science Council also considers it necessary to seek foreign funding partners very soon.

TESLA X-ray Free Electron Laser (TESLA X-FEL)

Brief description of the facility[13]

Knowledge about the structure of condensed matter and complex molecular systems has so far been gained primarily by examining matter in a state of balance. However, owing to its extremely high brightness and adjustable wavelength, combined with

[13] For details see Part II of this statement.

very short pulses and spatial coherence, the radiation of a free electron laser allows matter to be examined in a dynamic state, outside a state of balance, using atomic resolution. According to the technical design report submitted in March 2001, the first part of the TESLA superconducting linear accelerator is to serve as a driver for the X-ray Laser (X-FEL) with wavelengths of up to 0.1 nm.

Examples of new kinds of investigations in physics, chemistry, biology and the material and geo-sciences are studies of the formation of matter during the materialisation or melting of solids and liquids, insights into the timing of phase transitions and the changes in the bond configurations in chemical reactions, and the direct exploration of the function of biological macromolecules. Accordingly, an extensive national as well as international user community made up of scientists from different disciplines can be expected to emerge.

The laser light in the FEL occurs when high energy electrons are conducted through a special configuration of alternating magnetic fields. The purpose of the linear accelerator with its superconducting cavities is to generate electron beams of very low emittance and of a high current intensity, with narrow energy band and with temporal and spatial stability. In spring 2000, FEL laser light of wavelengths of less than 100 nm was generated for the first time using the Test Facility operated by DESY since 1997 (TTF 1, VUV-FEL).

According to the technical design report for the TESLA linear collider with integrated X-FEL, which was submitted in March 2001, the estimated additional investment cost for the construction of the X-ray laser including personnel costs totals € 673.4 million, the annual personnel and operation costs amount to € 36.1 million. If the facility is implemented as part of the TESLA linear collider project, the construction phase is estimated to be eight years.

Outline of the sub-panel's findings [14]

With respect to time resolution, brilliance and coherence, the radiation performance of FELs gives rise to new experimental methods which significantly expand the current examination techniques used in synchrotron research and open up

[14] For details see Part II of this statement.

interdisciplinary research fields. In the future, FELs will not replace, but complement synchrotron sources.

Both the technical properties of the X-FEL laser beam and the scientific programme proposed by DESY are unique in Europe. The hard x-rays of the TESLA X-FEL provide highly intensive radiation which, due to its wave length and ultra-short time resolution, is particularly suitable for time-resolved structure research. This allows new insights to be gained into material structures; and the possibility of three-dimensional representation of single molecules will open the door to completely new research possibilities in the bio-sciences. A major impact on basic research as well as on application-oriented research can be expected.

Using LINAC-driven X-FELs, it is possible to boost brilliance and coherence considerably and to shorten the x-ray pulses to femtoseconds. Collaboration on TESLA under DESY's management is the world's leading project in the development of superconducting LINACs. The feasibility of this technology for the vacuum ultraviolet (VUV) and soft x-ray range has been convincingly demonstrated by the TESLA Test Facility (TTF). The sub-panel believes that extension into the hard x-ray range is possible. Overall, the TESLA X-FEL project is the one which is the most advanced in the world.

For many years now, DESY has acquired a high level of competence in the construction and operation of large-scale research infrastructures, which means that it can be expected to provide the necessary prerequisites with regard to technology and know-how for implementation and operation of the X-FEL. DESY’s outstanding expertise in accelerator technology and in research using hard x-rays is a key advantage of the proposed location.

The sub-panel welcomes DESY’s intention to separate the linear accelerator and X-FEL, since a version in which the two are separate would guarantee greater flexibility and independence for the different groups using the TESLA collider and the X-FEL. It would also mean that any possible delay in the implementation of the international

TESLA linear collider would not also necessarily be an impediment to implementation of the X-FEL project.

For the joint statement on TESLA X-FEL and Soft X-ray-FEL, see p. 54.

Concluding science policy appraisal

The high luminosity and time resolution of the X-FEL promises a new quality of experiments for many areas of research in the natural, life, material and geo-sciences. Due to the high coherence of the photon radiation it will be possible for the first time to extensively analyse the structural and dynamic properties of matter. This destructive method of examination requires new methods for assessing femtosecond signals, and the necessary detectors must be developed. The particular scientific appeal of the X-FEL will soon attract a broad national and European user community.

DESY has already been able to boost its central position in European synchrotron and laser research through the results it achieved using the world's first VUV-FEL of the TESLA Test Facility (TTF 1). The expansion of the TESLA Test Facility (TTF 2), which, subsequent to optimisation of the accelerator components will also be used from 2004 for carrying out experiments, as user infrastructure in the spectral range of 20 eV to 200 eV, means that a high-performance VUV-FEL will be put into operation in the near future. However, the number of possible experiments in this case is limited. So far, use of the TTF has led to key theoretical and experimental developments as well as sweeping technological innovations, a trend that is expected to continue in the future. The Science Council acknowledges that this provides the necessary foundation for the successful implementation and operation of the X-FEL.

The Science Council believes that coupling the linear accelerator with the FEL is technically feasible and financially viable, but is nonetheless, from a scientific point of view, not an absolute precondition for implementation of the X-FEL. Separating the two facilities would not only allow more flexible use, but would also make the X-FEL more independent of the pending international decision on accelerator technology. Thus, the Science Council welcomes DESY's intention to separate the linear collider and the X-FEL. Since an increase in the investment costs must be avoided as far as possible, the Science Council endorses the DESY's proposal to initially aim for partial implementation of the X-FEL. A technical design report that is optimised for the X-FEL and modified in relation to the existing integrated technical concept should be submitted as soon as possible, together with a cost estimate. Furthermore, better use should be made of the complementary expertise of DESY and BESSY in order to increase the level of coordination between the scientific programmes and the technical R&D work of both FEL projects (TESLA X-FEL and Soft X-ray-FEL). For this reason, the Science Council recommends closer cooperation between both institutions. Coordinated scientific programmes presenting convincing arguments for the necessity of having two FELs laboratories at two locations should be submitted very soon.

The Science Council feels that a facility of this magnitude should only be implemented with European partners. The binding financial consent of the partner countries can, however, only be expected if there is a decision at national level on implementation of the TESLA X-FEL. Thus the Science Council requests the Federal Government to give its binding consent to German participation in the TESLA X-FEL project as soon as possible after the revised project proposal has been submitted. The Science Council also considers it imperative to seek foreign funding partners as soon as possible.

International Accelerator Facility for Beams of Ions and Antiprotons

Brief description of the facility[15]

In order to widen basic research in the fields of nuclear, hadron, atomic and plasma physics, and widen application-oriented research in the areas of material science, biophysics and radiation biology, the *Gesellschaft für Schwerionenforschung (*GSI - Heavy Ion Research Centre) in Darmstadt is planning to extend its existing accelerator facility on a large scale. At the centre of the planned facility is a superconducting double ring accelerator system SIS 100/200 with a maximum magnetic rigidity of approx. 200 Tm. The aim is to accelerate ion beams which are of a higher intensity by a factor of 100 to 1000 to 1-3 GeV/u and to achieve approximately 15 times higher energies for highly charged ions. For protons this is to

[15] For details see Part II of this statement.

lead to a maximum energy of 60 GeV. The synchrotron rings will be supplemented by storage rings and experimental facilities for the four proposed main scientific programmes:

- Nuclear structure physics and nuclear astrophysics: structure of exotic atomic nuclei far removed from stability, production paths of nucleosynthesis in the cosmos, tests on fundamental symmetries and interactions,
- Hadron physics with antiproton beams: quark-gluon structure and dynamism of hadrons, origin of confinement and hadron mass,
- Nuclear matter physics: cold nuclear matter at high densities, phase transitions of baryon-rich nuclear matter, origin of hadron mass, neutron stars,
- plasma research: macroscopic matter under extreme density, pressure and temperature conditions, properties of stellar plasmas.

The scientific programme is available and the technical concept is due to be completed in late 2003 / early 2004. The total cost for the accelerator facility and the experimental facilities is estimated to be € 675 million, the annual personnel and operating costs amount to € 79 million and the construction period is expected to be seven years.

Outline of the sub-panel's findings [16]

The sub-panel considers the proposed accelerator facility to be a central instrument in Europe for researching matter in the dimension range of atom/atomic nucleus/subnuclear particles and in the effective range of the strong force (quark matter, nucleons, atomic nuclei). The facility planned in Darmstadt will offer completely new kinds of research possibilities using ion and antiproton beams, which will allow new avenues to be pursued in basic research and application-oriented research. This particularly applies to the areas of radioactive nuclear beams, nucleus-nucleus collisions and hadron physics. The project will enable Europe to maintain the lead and reinforce its position in nuclear and hadron physics in the long term.

[16] For details see Part II of this statement.

The planned research activities in the field of plasma physics do not reach the same standard as that of the aforementioned areas. They are not sufficiently embedded in international scientific programmes and should not be intensified in the direction of application-oriented fusion research.

The sub-panel welcomes the offer by the state of Hessen to enhance GSI's scientific competence in the field of astrophysics by jointly appointing a professor for astrophysics at the University of Frankfurt/Main. The planned accelerator and detector system is unrivalled in the world and is technologically of a very high calibre. Technological innovations necessary for construction of the facility will be developed, such as fast cycling superconducting magnets and the system of collector ring and cooler storage rings. The numerous parallel technological tasks yet to be performed, such as construction and testing of the superconducting magnets could, however, lead to a delay in the whole project.

In the thirty years of its existence, GSI has evolved into a top international centre of nuclear physics and heavy ion research. GSI’s long-term planning and prospects hinge on the accelerator facility. This will mean internal re-orientation of specialised fields and the restructuring of personnel.

Concluding science policy appraisal

The establishment of the GSI accelerator facility for basic research in the fields of nuclear, hadron, atomic and plasma physics would allow a deeper understanding of the most fundamental aspects of the structure of matter, leading to greater knowledge of the structure of surrounding matter and the various hierarchical levels of matter, especially nucleons and nuclei.

The versatility of the accelerator facility means that different related areas of research - strong interaction, many-body aspects, phase transitions in dense, hot nuclear matter and in macroscopic matter - as well as the different user groups involved could be served by one central facility. The combination of the double ring and the storage rings allows the efficient parallel operation of up to three or, in special cases, four experiments in the four research fields of nuclear structure physics and nuclear astrophysics, hadron physics with antiproton beams, nuclear matter physics and plasma research. This gives rise to a wide range of synergies in terms of methods and instruments as well as from an economic point of view. The scientific programme of the planned accelerator facility thus complements the issues of particle physics, the focus of which is on the examination of the basic building blocks of matter and their fundamental interactions.

For GSI, implementation of the scientific programme would involve a process of extensive reorientation. The Science Council feels it is necessary to examine the technical possibilities for developing the existing accelerator facility in stages in order to be able to tackle the scientific programme gradually. Step-by-step implementation should included funding in stages.

GSI can look back on a whole series of excellent results in its research on the structure of matter. For example, GSI has over the years been single-mindedly improving its capabilities for observing superheavy nuclei. Scientifically and technologically, the proposed accelerator is the logical development of the investigations which the organization has successfully carried out for years in the fields of nuclear and hadron physics as well as plasma research at high pressures and densities.

The scientific importance of the GSI accelerator facility is undisputed. However, the numerous parallel technological developments still required could lead to a delay in the whole project. Appropriate project management should be able to prevent this problem from occurring.

At present, GSI is a user laboratory primarily for external and national users, who form a sizeable, powerful user community. As a consequence of the extension of the existing accelerator facility, GSI will also become highly attractive to top international scientists, which should be reflected by a growth in user numbers, not least as a result of the newly opened field of antiproton physics. GSI is expected to blossom into the key European research centre for nuclear physics.

In the opinion of the Science Council, a facility of this magnitude should only be implemented with European participation. Binding financial consent, however, will most probably only be given by the partner countries when implementation has been decided at national level. Thus, the Science Council requests the Federal Government to give its binding consent to German participation as soon as possible after the step-by-step concept for developing the accelerator facility has been submitted. The Science Council also considers it necessary to seek foreign funding partners very soon.

A.V. Group of large-scale facilities for which specific statements have been drawn up for various reasons

For various scientific, technical and procedural reasons, the Science Council has drawn up specific statements for the following facilities:

- Soft X-ray Free Electron Laser (Soft X-ray-FEL),
- European Spallation Source (ESS),
- High Magnetic Field Facility for Neutron Scattering Research and
- European Drilling Research Icebreaker (Aurora Borealis).

Should continued work on the scientific programme and the technical design report for these facilities lead to more extensive insights and to a new project proposal, the Science Council would consider it necessary to carry out a new assessment, which may also have to compete with other initiatives for large-scale facilities (see Section C for details on the procedure for future assessment of large-scale facilities).

Soft X-ray Free Electron Laser (Soft X-ray-FEL)

Brief description of the facility[17]

Following the demonstration of the SASE principle[18], the foundation has been laid for a light source in the spectral range of vacuum ultraviolet (VUV) to soft x-ray. As a member of the international TESLA collaboration, the *Berliner Elektronenspeicherring-Gesellschaft für Synchrotronstrahlung* (BESSY) is planning to upgrade the synchrotron radiation source BESSY II by adding an FEL for the soft x-ray spectral range (1.2 to 60 nm) with the aid of the TESLA superconducting cavities. The increase in peak brilliance by up to a factor of ten and the ultra-short micro-pulse

[17] For details see Part II of this statement.
[18] The SASE principle (Self Amplified Spontaneous Emission) was successfully demonstrated on the Low-Energy Undulator Test Line (LEUTL) of the Advanced Photon Source (APS) at the Argonne National Laboratory, Illinois, and on the VUV-FEL of the TESLA testing facility (TTF) at DESY.

time structure of the Soft X-ray-FEL will open up new possibilities in the field of spectroscopy.

The Soft X-ray-FEL will open the door to new kinds of experiments using the highest spectral, time and spatial resolution in the bio-sciences, femtochemistry, atomic and molecular physics, solid-state and surface physics research, and in the field of time-resolved processes used to investigate reactions, catalysis processes and to precisely examine the dynamics of nanostructures in electromagnetism.

A detailed scientific programme is available, and the technical design report is to be completed later during the course of 2003. The estimated investment cost for construction of the facility including personnel costs totals € 148 million, the annual personnel and operation costs amount to € 12.4 million. After completion of the technical design report, the construction period is expected to take four years. The proposed site is BESSY in Berlin-Adlershof.

Outline of the sub-panel's findings[19]

The BESSY Soft X-ray-FEL has soft, laser-like x-ray beams with considerably improved peak brilliance compared to synchrotron sources and lasers, whose extremely short pulses allow greater spatial and time resolution in spectroscopic and structural investigations. The technical properties of the BESSY Soft X-ray-FEL enhance the existing range of examination techniques offered by synchrotron sources and conventional lasers by offering the unprecedented possibility of precisely analysing electronic processes and properties in a dynamic state. This also provides the basis for spectroscopic experiments never before conducted in the field of femtochemistry, for the study of non-linear processes and for the targeted modification of matter. A huge impact can be expected on both basic research and application-oriented research. Compared to the TESLA X-FEL, the spatial resolution of the Soft X-ray-FEL is lower. Since the photon energy is also lower, it is easier to follow chemical processes within an individual molecule using the Soft X-ray-FEL.

The proposed Soft X-ray-FEL is based on the TESLA superconducting technology. As a member of the TESLA collaboration, BESSY is taking part in the development

[19] For details see Part II of this statement.

of beam lines and injectors for the TESLA X-FEL as well as in the preparation of pump and probe experiments. BESSY has many years of experience in the development and design of accelerators, undulators and beamlines for research using synchrotron radiation. The sub-panel regards BESSY's outstanding expertise in VUV and the soft x-ray range and the opportunity to operate the Soft X-ray-FEL in parallel with the BESSY II synchrotron source as an enormous advantage offered by the proposed location.

Joint statement by the sub-panel on TESLA X-FEL and Soft X-ray-FEL

Both the TESLA X-FEL and the BESSY Soft X-ray-FEL will lead to a fundamental leap in quality with regard to coherence, time resolution, wavelength and laser beam intensity. This will open up new avenues of broader, interdisciplinary research which reach far beyond the opportunities offered by the present synchrotron research activities. The scientific programmes of both Free Electron Laser projects are, by international standards, of the highest scientific level. The FELs proposed in Hamburg and Berlin should provide the future scientific user community with complementary research infrastructures, which benefit from each other with regard to the scientific goals and the development of FEL technology and which could secure Germany's and Europe's leading position in this field in the long term. In order to achieve this, the sub-panel recommends closer cooperation between DESY and BESSY and a more convincing use of the complementary expertise of both institutions. In addition, it should be examined whether it would make more sense from the point of view of costs and benefits to implement two FEL laboratories, each specialised to cover a certain spectral range, or just one FEL laboratory that covers the entire spectrum.

Concluding science policy appraisal

The Soft X-ray-FEL will open up completely new fields of activity, in particular in the material and life sciences, for research using synchrotron radiation. The laser-like coherent short pulse radiation will allow above all the dynamism of the electronic, chemical and magnetic properties of matter to be examined time-resolved in a new quality.

Although European funding should be the aim for Soft X-ray-FEL, this will be difficult to realise given the other comparable FEL projects at the preliminary planning stage in Europe. Despite the fact that the Soft X-ray-FEL will also be attractive to an international user community, the Science Council assumes that the facility will be primarily used by German research groups working in various fields.

The competence which BESSY has demonstrated in the construction of the high brilliance synchrotron radiation source holds the promise of further successful technological development in the future. Nonetheless, there is still a substantial amount of preliminary work to be done to produce a fully-fledged technical design report, since all that is available at present is a concept study without any preliminary experiments. The Science Council believes that if work on the technical concept is continued at a fast pace, it will be possible to develop an important research infrastructure for the targeted spectral range that can take the lead in European competition.

In order to increase the level of coordination for the scientific programmes and technical R&D work in both FEL projects and to make better use of the complementary expertise offered by DESY and BESSY, the Science Council recommends that there be closer cooperation between the two organisations. Coordinated scientific programmes presenting convincing arguments for the necessity of setting up two FEL-laboratories at two sites should be submitted very soon.

High Magnetic Field Facility for Neutron Scattering Research

Brief description of the facility[20]

Both neutron scattering and the use of extremely high magnetic fields are among the key methods employed for researching magnetic phenomena. By combining both methods, the Berlin Neutron Scattering Centre (BENSC) of the *Hahn-Meitner-Institut* (HMI) in Berlin is seeking to increase the possibilities for neutron scattering experiments with very high magnetic fields.

The combination of neutron scattering and high magnetic fields allows further-reaching material science experiments in solid-state physics to be conducted, eg. on magnetic materials such as intermetallic compounds with rare earths or actinides, on magnetic anisotropes in technical materials or on magnetic double- or multi-layered systems. In the case of soft materials, high magnetic fields can cause changes of state in non-magnetic substances as well. Structural determination using neutron diffraction is expected to make an important contribution to experiments on fully-oriented macro-molecular structures or crystals.

The concept for the High Magnetic Field Facility proposes that continually-operated, resistive magnets - a (horizontal) solenoid for 40 Tesla, in which the probe for the neutron beam is accessible to the coil in longitudinal direction, and a vertical split-pair magnet for 30 Tesla, where the probe is mounted vertically in relation to the coil axis between the two parts of the coil and is thus accessible for the neutrons - be built in a high magnetic field laboratory according to the specifications of a neutron scattering instrument to be built at HMI. Unlike conventional arrangements, the high magnetic field system is to be designed as a stationary facility complemented by mobile neutron scattering instruments.

A technical design report is not available at present. The estimated cost of the R&D work, construction of the magnets and provision of power supply, including the necessary cooling systems, and personnel costs totals € 48.5 million; the estimated annual personnel and operating costs amount to € 4.3 million. The investment costs for the neutron scattering instruments are to be financed by HMI’s regular budget. According to the current plans, three years are proposed for the construction period. The proposed location is HMI in Berlin.

Outline of the sub-panel's findings[21]

The sub-panel believes that the High Magnetic Field Facility proposed by the *Hahn-Meitner-Institut,* which is to combine static magnetic fields of 20 - 40 Tesla with neutron scattering, offers unique opportunities worldwide to carry out important measurements in the fields of condensed matter physics and the material sciences. The possibility of conducting neutron scattering experiments in magnetic fields much

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[20] For details see Part II of this statement.
[21] For details see Part II of this statement.

higher than the current fields of 17 Tesla presents a new attractive research option for both national and international users.

The planned magnet technology is based on the expertise of foreign high magnetic field laboratories, where the technology is already fully established. The sub-panel is convinced that the first-class equipment developed by HMI (instruments, neutron conductors) would allow experiments to be carried out which could compete with the existing neutron intensity of the currently most high-powered high-flux reactor at the Laue-Langevin Institute (ILL) in Grenoble. The sub-panel welcomes HMI's high magnetic field project, also in view of the plans for the European Spallation Source (ESS), since HMI's development work could be used as preparation for the establishment of an ESS high magnetic field laboratory.

The sub-panel believes that the scientific goals linked with the high magnetic field facility, namely the concept of combining the methods and technologies of two large-scale facilities, set the course for the future. However, these goals have not yet been translated into a concrete scientific programme and efforts in this direction must be stepped up.

The technical concept and a detailed cost calculation for the proposed High Magnetic Field Facility has not yet been elaborated. Neither, so far, has HMI presented a convincing strategic plan which places the facility on a sound institutional footing in the long term.

Concluding science policy appraisal

The combination of neutron scattering and very high magnetic fields offered by HMI's High Magnetic Field Facility is unrivalled worldwide and promises numerous new research prospects in condensed matter physics and the material sciences.

For the first time, it would be possible to perform neutron scattering experiments in static magnetic fields well above 17 Tesla. For high field technology itself, the exploration of superconductors, in particular the generation of superconducting matter of extremely high critical current density, is especially promising.

The Science Council considers the proposed High Magnetic Field Facility to be a national facility, the aim being 2/3 national and 1/3 international use. The combination of neutron scattering with high magnetic fields constitutes a tight, focused scientific approach, which will attract modest numbers of national and international users. Furthermore, due to the limited number of experiments possible per year, only a small number of users will be catered for.

The Science Council emphasises the unique character of the facility, which lies in the combination of the two different research instruments. However, a systematic scientific programme is still lacking, as is a detailed technical concept for the magnet facility, its power supply and the proposed neutron instruments. More preparatory work must be done. If the project is developed fully, it will be necessary to carry out a new assessment.

European Spallation Source (ESS)

Brief description of the facility[22]

The natural sciences and their application in medicine and technology are based to a considerable extent on knowledge about the atomic and molecular structure of the matter being examined. In the past, the use of neutrons for studying the structure and dynamics of solid and liquid matter has often proven effective. To date, research reactors have served as neutron sources; however, their technical limits for usable neutron flows have been reached. As a pulsed 2 x 5 MW spallation neutron source, the European Spallation Source (ESS) is to offer peak fluxes up to 100 times greater than the currently most high-powered high-flux reactor, which is located at the Laue-Langevin Institute (ILL) in Grenoble.

It is expected that the high intensity of the ESS will allow the implementation of kinetic experiments on the smallest time scales, the identification of polymer chains, protein complexes and hydrogen bonds in biological and pharmaceutical substances, innovations in protein crystallography and real time recordings of phase diagrams in multidimensional parameter spaces.

[22] For details see Part II of this statement.

The technical concept of the ESS proposes a particle accelerator which generates high-intensity proton pulses on energies in the GeV range required for effective neutron production, as well as various target reflector units, in which the neutrons, generated by proton bombardment of heavy target nuclei, are slowed down in moderators to thermal or sub-thermal energies and finally conducted to the scattering experiments in beamlines.

The ESS project is currently at the planning stage, due to be concluded in mid-2003. The R&D work is being carried out by 15 European institutions from 10 countries, with the *Forschungszentrum Jülich* (FZJ) as the leading institution for the “target” and the *Hahn-Meitner-Institut* in Berlin (HMI) as the leading institution for the “instrumentation”, and is being coordinated by the European Research and Development Council. The estimated investment cost including the personnel costs for the R&D work totals € 1,390 million, the annual personnel and operating costs amount to € 144 million. The first neutron production is planned after a construction period of seven years.

Outline of the sub-panel's findings [23]

The sub-panel stresses the need for a high-power neutron source like the one provided by the European Spallation Source (ESS) in order to maintain and bolster Europe’s leading position in neutron research. The much higher performance capability compared to existing research reactors promises novel research possibilities in the fields of solid-state physics, chemistry, biology, material sciences and engineering. The sub-panel considers a neutron source based on the spallation principle to be basically technically feasible and considers the currently known performance and design parameters of the ESS to be well-chosen.

Nevertheless, the sub-panel did not come to a conclusion as to whether the scientific issues arising from the aforementioned application fields of neutron research, which are the object of the proposed ESS scientific programme, will still be topical enough and will justify the need for a new generation neutron source at the time when the ESS is realistically expected to go into operation. All in all, the sub-panel did not reach a complete consensus on the assessment of the scientific programme. Thus the sub-panel recommends that the scientific goals of the ESS be revised and the work on the research programme be continued at the same intensity. At the same time, there should be greater acknowledgement of the alternative and complementary developments in the field of synchrotron radiation and of alternative laboratory methods of structural research such as microscopy, optical spectroscopy, NMR or computer simulation, and scientific expertise should be sought from outside the existing circle of neutron researchers. For a facility of this size and scope of application, the sub-panel feels it is crucial that the ESS be firmly embedded in the strategic orientation of the participating institutions.

The sub-panel expressly emphasises the European character of the ESS and regards the intention to include a large number of scientific institutions from various European nations as exemplary, as it illustrates the application of the European idea to the realm of science at the institutional level. These advantages, however, can only have the desired effect if the ESS has a clear project structure involving transparent decision-making in the project planning and the implementation phase and if the role distribution of the partners together with their scientific and technological contributions are clear-cut.

The sub-panel welcomes the European competition for the location of the ESS and feels it is imperative that Germany, on account of its major tradition of neutron research, be represented by a strong candidate.

Concluding science policy appraisal

Neutron scattering has become well-established as an important method of experimenting in diverse areas of research on condensed matter. By using this method, it has been possible in the past to fundamentally contribute towards the microscopic understanding of matter. Neutron scattering not only offers significant potential with regard to investigating fundamental areas such as phase transitions, magnetism or quantum liquids and studying technologically important materials such as magnets, superconductors, ceramics, polymers or liquid crystals, but is also an important method of characterisation for biological systems. The fact that a broad spectrum of scientific questions can be answered through research using neutron

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[23] For details see Part II of this statement.

scattering is due not least to the physical properties of the neutron itself. Another consequence of these properties is the complementary nature of the experimental methods using neutrons or photons, as is the effectiveness of these methods.

High-performing neutron sources must be available to German and other European scientists in the future too. However, the Science Council believes it is important that the necessity of building a new neutron source such as the European Spallation Source (ESS) should hinge on future need for research using neutrons. In the case of a new investment on this financial scale, the priority must be to open up new research areas for neutron scattering rather than to develop neutron sources solely on the basis of foreseeable technological limitations of the neutron sources currently operated in Germany and elsewhere in Europe (so-called “neutron gap”).

Furthermore, the Science Council considers it necessary to link the identification of neutron requirements closely with the examination of alternative and complementary (laboratory) methods in the field of structural research. For example, synchrotron radiation, microscopy, optical spectroscopy, NMR and computer simulation provide techniques which, in the case of some of the ESS-related research issues, could provide comparable results while requiring less equipment and lower investment costs.

Even though, compared to the other facilities under appraisal, the Science Council does not consider the location of a neutron source to be of particular relevance to Germany's status as a hub of scientific activity, it would nonetheless welcome the location of the ESS in Germany for general science policy reasons. Germany has a large and active user community both in the research fields in which neutron scattering traditionally plays a key role (solid-state physics, material sciences and crystallography) and in research areas in which neutron scattering has come to play a role more recently, such as biology or soft matter, which account for an important part of the user community internationally as well.

However, the Science Council points out that although German demand for high power neutron sources has been fulfilled hitherto by a European neutron source situated in France, this has not led to any structural disadvantages for German neutron research. Thus it is important for the Science Council that there is European competition for the location of the ESS. The Council regards this as the only suitable way to select the optimal location.

When assessing the ESS, the Science Council was presented with a concept for installing the facility at the *Forschungszentrum Jülich* and with a joint declaration by the *Länder* of Saxony and Saxony-Anhalt stating their interest in locating the ESS in the region of Halle and Leipzig.

The Science Council emphasises that a traditional focus of the research work performed at the *Forschungszentrum Jülich* is the application of neutrons in solid-state research. The research centre has an experienced and tried and tested infrastructure in the construction and operation of large-scale facilities. Situated within the triangle formed by the cities of Aachen, Düsseldorf and Cologne, Jülich is surrounded by a dense network of universities, research institutes and companies.

Should the *Forschungszentrum Jülich* be identified in European competition as being a suitable site for the ESS, the Science Council points out that the facility, owing to its size, ought to be made a central element of the strategic planning and research programme of the *Forschungszentrum Jülich* and should be a core task in its spectrum of activities. At the research centre, this institutional incorporation should be more obvious than it was at the time of the assessment.

As far as the region of Halle and Leipzig is concerned, the Science Council stresses that the dynamic scientific environment consisting of universities and non-university research institutions provides an important basis for offering the scientific connections need by a facility of this size. At present the Science Council cannot make a concluding appraisal with regard to location of the ESS in the region of Halle and Leipzig since no pertinent documents have been submitted yet.

Finally the Science Council draws attention to the fact that if the ESS was located in Germany, the investment costs would be higher for the German side than if Germany participated in the construction of the spallation source elsewhere in Europe. Irrespective of location, Germany's financial participation in the ESS must not be an obstacle to implementation of the facilities which are considered in this statement to be worthy of support.

European Drilling Research Icebreaker (Aurora Borealis)

Brief description of the facility[24]

An international consortium led by the Alfred Wegener Institute for Polar and Marine Research (AWI) is planning to develop a Drilling Research Icebreaker that allows expeditions during any season up to the central Arctic Ocean and which will be equipped with deep-sea drilling facilities.

The purpose of this Drilling Research Icebreaker is to fulfil the research needs of marine polar research and geo-research. In climate research as a part of marine polar research the focus is on questions relating to physical oceanography, marine research and meteorology. Biological research has chosen to focus on the study of life communities in the hitherto unexplored key region of the Arctic, on a systematic establishment of a time series for life cycles and winter-over strategies of Arctic organisms and on biochemical studies of substance cycles in the Arctic. The geo-scientific research will centre on the study of the scientifically largely unknown Arctic deep-sea floors in permanently ice-covered ocean areas.

The technological innovations of the Research Icebreaker are the dynamic positioning of the mobile drilling rig in drifting sea-ice, the containerized mobile laboratory concept and the two so-called moon pools, which allow deep-sea drilling and the deployment of remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV).

At present national and European working groups are pushing ahead with the planning activities, which are closely coordinated with the progress of the existing international ocean drilling programme. The estimated total cost is € 250 million, the estimated annual operating costs amount to € 20 - 25 million. The first research expedition will take place after a four-year period of construction and initial operation.

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[24] For details see Part II of this statement.

Outline of the sub-panel's findings[25]

The ocean basins of the most northern and southern latitudes play a key role in investigations of the possible changes in oceanography and the climate of the world's oceans. The Arctic Ocean is the only sub-basin of the global ocean that has not been able to be reached by international research programmes since none of the ships deployed have had the capability of deep-sea drilling in ice-covered areas. So far, only insufficient data has been available on the Arctic region, which is a highly-sensitive and climate-determining ecosystem - for example data on geological and climate issues and on development of the oceanic crust.

The sub-panel believes that the research icebreaker opens up new, unprecedented possibilities for conducting expeditions during all seasons right into the central Arctic Ocean while at the same time, due to its design as a drilling icebreaker, offering the facility for carrying out deep-sea drilling. The research goals concern scientifically and socially topical questions. However, they have yet to be condensed into a concrete scientific programme.

The Drilling Research Icebreaker is built on ambitious technical innovations such as dynamic positioning of the ship in drifting sea-ice and the so-called moon pools, which offer the possibility of all-year observation below the sea-ice. The implementation of these innovations could also lend significant economic impetus to the fields of mechanical and nautical engineering as well as drilling technology. The cost estimate is not yet reliable, particularly in view of the technical challenges facing the nautical engineers working to design a combination of research vessel and icebreaker.

In the past, the Alfred Wegener Institute has acquired a prominent international reputation in the provision of scientific and logistic support for Arctic expeditions. The sub-panel regards the AWI as the only institution in the world which currently has the personnel and technological capacity to supervise the construction and operation of a drilling research icebreaker. Aurora Borealis should be designed as a European large-scale facility.

[25] For details see Part II of this statement.

The location of Bremerhaven offers the ideal prerequisites for the operation of research vessels; with the aid of the proposed Drilling Research Icebreaker, the scientific competence available in Bremerhaven could help it blossom into a centre of excellence for polar research.

Concluding science policy appraisal

Research and drilling vessels combined with robot systems and research submarines, as proposed in the plans for the research icebreaker Aurora Borealis, are currently the most promising possibility for examining the ocean floor as an important climate archive. As yet, the Arctic and Antarctic sea regions have only been partially explored for the study of the impact of human activity on natural cycles and on terrestrial and aquatic ecosystems; only incomplete data is available for elaborating viable long-term strategies. The research possibilities which would be offered by the Drilling Research Icebreaker would not only serve to considerably advance national and international polar research and the geo-sciences, but are also very relevant to society.

German polar research internationally enjoys an outstanding reputation. One of its particular strengths is the Alfred Wegener Institute for Polar Research in Bremerhaven, which is in charge of the project and, also participating in the project, the Research Centre for Marine Geo-Science at Kiel university (GEOMAR). In the past, German marine research has often demonstrated with its research vessels *Sonne*, *Meteor* and *Polarstern* that it is capable of building and operating a ship of the size of Aurora Borealis.

The Science Council stresses the topicality and importance of the scientific questions which the proposed Drilling Research Icebreaker could help to solve. However, a concrete scientific programme has not yet been presented. The technological requirements have been clearly defined, namely the dynamic positioning in the moving ice systems, the mobile drilling rig, the mobile laboratory concept and the two so-called moon pools. So far technical feasibility has not been examined; as yet no technical concept has been submitted for the research icebreaker. Furthermore, the absolute necessity of combining deep-sea drilling and icebreaking capability in one vessel has not yet been sufficiently justified. The Science Council feels it is not yet in a position to properly assess the project due to the fact that no concrete scientific programme[26] or technical concept has been available so far. Should the project be developed fully, a new assessment will be necessary. The project proposal, which must be elaborated further, must include a reliable cost calculation for the Drilling Research Icebreaker and must examine technological alternatives which could lead to equally valuable scientific results involving less equipment and lower investment costs.

The Science Council considers international cooperation in marine and polar research to be an absolute prerequisite. As an alternative platform, the Drilling Research Icebreaker Aurora Borealis could provide a European contribution to the Integrated Ocean Drilling Programme (IODP) and should definitely have an unmistakably European character as far as the cooperation partners and the scientific user community are concerned.

[26] In a letter to the Science Council of June 2002, the Alfred Wegener Institute for Polar and Marine Research announced that the scientific programme would be published this month or in the coming month.

B. The structure and funding of facilities

Background

This section does not attempt to present data on the structure and funding of all large-scale facilities in the various fields of research in Germany or data on German participation in facilities abroad. It limits itself to facilities in areas of physics and environmental and geo-research which are comparable to the nine facilities under scientific appraisal in this statement. The Science Council sees this as a good starting point for general considerations about the structure and funding of facilities.[27]

The thematic focus of the large-scale facilities used in physics research in Germany is on fundamental questions concerning the structure and properties of matter and its smallest building blocks, extending to research on galaxies and the development of the cosmos (particle accelerators with their detectors, telescopes and satellites) as well as to the structure and dynamics of condensed matter (neutron, ion and synchrotron radiation sources).

Large-scale physics research using large-scale facilities takes a variety of different forms, and is conducted at the non-university institutions *Deutsches Elektronen-Synchrotron* (DESY), *Gesellschaft für Schwerionenforschung* (GSI), *Hahn-Meitner-Institut* (HMI), at the research centres in Jülich, Karlsruhe and Geesthacht, and at larger Blue List institutes such as the *Berliner Elektronen-Speicherring-Gesellschaft für Synchrotronstrahlung* (BESSY) and *Forschungszentrum Rossendorf* (FZR).

[27] The Science Council points out that other research areas in which large-scale facilities play a key role are not covered by the list of facilities passed on to the Science Council by the Federal Ministry of Education and Research. The Science Council has set up a national committee to coordinate the use and procurement of supercomputers.

The following table shows the fields of research in which the above mentioned research centres are engaged.

Research centre	Condensed matter physics			High energy physics	Hadron and nuclear physics	Astro-physics
	Synchrotron radiation	Neutron radiation	Ion radiation			
BESSY	X					
DESY	X			X	X	X
FZ Jülich		X			X	
FZ Karlsruhe	X				X	X
FZ Rossendorf			X			
GKSS		X				
GSI			X		X	
HMI		X	X			

The construction and operation of large-scale facilities at universities is, by comparison, on a much lower scale. The Technical University of Munich is setting up a new high-flux neutron source (FRM II) on the campus at Garching near Munich, financed by the Federal Government and the state of Bavaria within the framework of the joint task of university construction. This facility will replace the FRM research reactor that has been run since 1957, and will be available for research in physics, chemistry and material, engineering and life sciences.

Germany is in some cases a key funding partner in the various European research institutions. Its financial participation in international physics research includes funding for the European Organization for Nuclear Research (CERN), the European Synchrotron Radiation Facility (ESRF) and the Laue-Langevin Institute (ILL).[28]

[28] In addition, Germany provides funding for the European Space Agency (ESA), the European Southern Observatory (ESO), the European Molecular Biology Laboratory (EMBL), the European Centre for Medium-Term Weather Forecasts (EZMW), the European University Institute (EHI), the

- European Organization for Nuclear Research (CERN), Geneva
  CERN conducts basic research in the field of elementary particles of matter (high energy physics), focusing on examining the elementary building blocks of matter using particle accelerators, as well as in nuclear physics. The Large Hadron Collider (LHC) is in the process of being built and is due to be completed by 2006. The work is financed by the member states, each of whom contribute a percentage of the total costs calculated on the basis of their respective GNP. The German share is currently about 23%.[29]

- European Synchrotron Radiation Facility (ESRF), Grenoble
  ESRF, which has the legal status of a company under French private law, builds and operates synchrotron radiation facilities for research in the field of condensed matter. Germany's contribution to the operating costs is 25.5%.[30]

- Laue-Langevin Institute (ILL), Grenoble
  ILL, which has the legal status of a company under French private law, operates a high-flux reactor together with its instruments. The work is financed by the member states, each member contributing the agreed amount. Germany's share is currently 37%.[31]

German-Dutch Wind Tunnel Foundation (DNW), the European Transonic Wind Tunnel (ETW), and the German-French Research Institute Saint-Louis (ISL).

29 The member states of the research facility, which has the legal status of an international organisation, are Austria, Belgium, Britain, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Italy, the Netherlands, Norway, Poland, Portugal, Republic of Slovakia, Spain, Sweden and Switzerland, with Israel, Japan, Russia, Turkey and the USA as observer countries.

30 The member states are Britain, France, Germany, Italy, Spain, Switzerland, Nordsync (Denmark, Finland, Norway, Sweden), Benesync (Belgium and the Netherlands); Portugal and Israel are scientific members with limited rights. The German partner is *Forschungszentrum Jülich*.

31 The member states are Britain, France and Germany; Austria, the Czech Republic, Italy, Russia, Spain and Switzerland are scientific members with limited rights. The German partner is *Forschungszentrum Jülich*.

The following table shows the fields of research in which the above mentioned research centres are engaged.

Research centre	Condensed matter physics			High energy physics	Hadron and nuclear physics
	Synchrotron radiation	Neutron Radiation	Ion radiation		
CERN			X	X	X
ESRF	X				
ILL		X			

In Germany, the facilities in use in the environmental and geo-sciences notably include research platforms such as mobile deep drilling facilities (funded, for example, as part of Germany's Continental Deep Drilling Programme), research aircraft, multi-purpose and polar research ships and supercomputers.[32]

The objective of the Continental Deep Drilling Programme (KTB) was to open up a temperature range of approx. 300 °C at a depth of 10,000 m and rock pressures of almost 3000 bar. The KTB programme, which is part of an international programme for exploring the lithosphere, was financed by the former Federal Ministry of Research and Technology (BMFT) during the period 1983 to 1994, with a total funding volume of DM 528 million. After completion of the drilling, the aim will be for German geologists to participate in the International Continental Drilling Programme (ICDP), which proposes direct participation in internationally funded drilling programmes along the same lines as the Ocean Drilling Programme (ODP).

At present, Germany has a series of medium-sized research aircraft. The aircraft capable of the highest altitude and range is the FALCON research aircraft operated by the DLR, which, with a peak altitude of up to 13.7 km, a range of 3,500 km and a payload of approx. 1,200 kg, has been used since the mid-1970s for performing

[32] One important example of German participation in a European large-scale facility is its involvement in ENVISAT (ENVIronmental SATellite). Since 1991, the Federal Ministry of Education and Research has been supporting preparation of the satellite for the European Space Agency's mission with an annual sum of approximately € 5 million.

measurements with the aid of in-situ and remote reconnaissance sensors in the troposphere, and in medium and high latitudes, also in the lower stratosphere.

Germany has owned the research ship *Polarstern* since it was put into service in 1982. *Polarstern* is Germany's only research icebreaker and is deployed during the summer months in each hemisphere, i.e. in both the southern ocean around the Antarctic and the Arctic Ocean.

The *Meteor*, built in 1985/86, is also owned by Germany. It is operated by the *Deutsche Forschungsgemeinschaft* (DFG) and sails under the management of the *Reederei Forschungsschifffahrt* (RF). Expeditions on *FS Meteor* are planned and organized by the *Meteor* head office at Hamburg University on behalf of the DFG Senate Commission for Oceanography. In the last few years, the vessel has been mainly operated in the Atlantic, Mediterranean, Black Sea, western Indian Ocean and in the Caribbean.

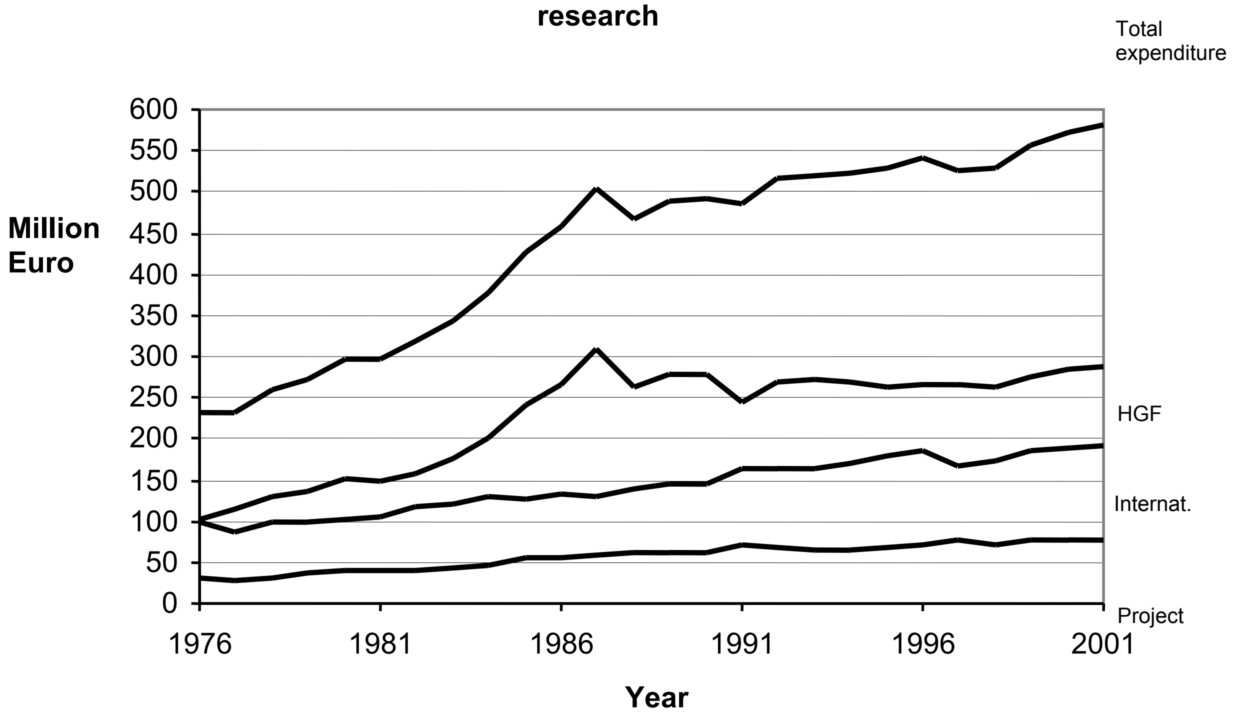
The research ship *Sonne* (built in 1969) is owned by *Reedereigemeinschaft Forschungsschifffahrt* (RF) and is chartered on a long-term basis (currently up to 2003) by the Federal Ministry of Education and Research for the purpose of marine research. The project sponsor BEO, with an office in Warnemünde, organizes the expeditions. In the past years, the research vessel *Sonne* has been deployed first and foremost in the Pacific and in the Indian Ocean.

Other European research ships are available for use by German scientists if German research ships compensate by providing the equivalent capacity.

Since mid-2001, a dedicated supercomputer installed at the *Deutsches Klimarechen-zentrum* (DKRZ) in Hamburg has been available to German scientists engaged in climate and earth system research. The investment costs total € 61.4 million over a period of 10 years.

In 2001 the Federal Ministry of Education and Research provided a total of € 582 million for the construction and operation of as well as research on national and international facilities.[33] This corresponds to about 1/12 of the Ministry's total budget. The lion's share was spent on institutional funding (€ 287 million , 49%), followed by participation in European Research Institutions (€ 192 million, 33%). € 78 million, or 13%, was spent on funding for projects. The Ministry's R&D expenditure on large-scale facilities for basic scientific research has ranged between € 516 and € 582 million per year since 1992 (see diagram below).

Actual expenditure by the Federal Ministry of Education and Research on large-scale facilities for basic scientific research



Source: BMBF

[33] According to the University Construction Act (Hochschulbauförderungsgesetz), investment in large-scale facilities for the purpose of research, teaching and health care is eligible for co-funding if the cost of the facility plus equipment, at universities, exceeds the minimal limit of € 125,000, or € 75,000 at other higher education institutions. The volume recommended by the Science Council for large-scale facilities (including the Computer Investment Programme CIP and office computers for scientists) has been on average € 370 million a year since 1991. Investments above € 10 million have been made in the past years for two supercomputers. The *Deutsche Forschungsgemeinschaft* has an annual budget for large-scale facilities of approx. € 15 million.

The majority of the facilities described here are installed at large-scale research institutions, which all belong to the *Hermann von Helmholtz-Gemeinschaft Deutscher Forschungszentren* (HGF). The 15 HGF centres have funds worth approximately € 2.2 billion, of which about € 1.65 billion is provided as institutional funding by the Federal Government and the *Länder* at a ratio of 90:10. The proportion of third-party funding, revenue (including from activities outside of research) and other grants amounts to just over € 0.5 billion. Approximately 35% of the € 4.6 billion (target for 2000) provided by the Federal Government and the *Länder* as part of their joint promotion of research goes to the HGF centres. The Federal Ministry of Education and Research spends approx. 27% of its research budget on funding for the *Helmholtz* centres. HGF's budget corresponds to a good 28% of the research expenditure of higher education institutions (from basic and third-party funding), which amounted to € 7.8 billion in 1999.[34]

Details on the investment and operating costs of the facilities being assessed and scientifically appraised are listed in the following table. These details are partly based on initial estimates. The individual plans are not based on any uniform funding models. The national, European and international funding arrangements proposed by the institutions in charge span a wide range of possibilities and are in some cases only initial suggestions rather than final decisions. Thus, at the present time, no conclusions can be drawn about the extent or timing of Germany's share in the financial burden.

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34 Federal Ministry of Education and Research: Report of the Federal Government on Research for the Year 2000, p. 96 ff.

	Investment costs (approx.)	Operating costs per year	Construction periods (planned)	Funding model
High Field Laboratory Dresden (HLD)	€ 25 million	€ 3.7 million	4 years	national
High Altitude and Long Range Research Aircraft (HALO)	€ 97 million	€ 3.8 million	3 years	national
TeV-Energy Superconducting Linear Accelerator (TESLA)	€ 3,450 million	€ 135 million	8 years	international
TESLA X-ray Free Electron Laser (TESLA X-FEL)	€ 673 million[35]	€ 36.1 million	8 years[36]	European
International Accelerator Facility for Beams of Ions and Antiprotons	€ 675 million	€ 79 million	7 years	European
Soft X-ray Free Electron Laser (Soft X-ray-FEL)	€ 148 million	€ 12.4 million	4 years	national
European Spallation Source (ESS)	€ 1,390 million	€ 144 million	7 years	European
High Magnetic Field Facility for Neutron Scattering Research	€ 49 million	€ 4.3 million	3 years	national
European Drilling Research Icebreaker (Aurora Borealis)	€ 250 million	€ 10-15 million	4 years	European

Source: Information provided by the various institutions

[35] Additional costs for installing the FEL facility. According to current plans, the X-FEL is to use the first three kilometers of the TESLA linear accelerator.

[36] The installation set up as part of TESLA.

Structural aspects

The majority of facilities of the size being examined here (see chapters A. III. to A. V.) require combined national and international scientific competence. They can no longer be planned and operated solely as national facilities and should be organized as research institutions with multinational European or international sponsorship catering not only for a German user community, but also for a broad European and international user community. In the medium term, this will lead to a further increase in the division of labour within the scientific community with regard to the construction and operation of large-scale facilities, both in Europe and worldwide. Foreign partners must be included in the preparation of projects as early as possible. This should also involve their participation in decision-making and the transfer of responsibility for their own scientific or technological contributions.

German scientists can look back on a long, successful tradition in the construction and operation of facilities in Germany. This tradition not only involves facilities which are largely nationally funded and nationally used, but also facilities receiving a substantial proportion of international funding and serving an international user community. The Science Council believes that Germany, in view of its importance and quality as a centre of scientific excellence and activity, should be the location for many European and international facilities under the supervision of German scientists - in addition to the few facilities it has at present. Furthermore, Germany should continue to play a key role in the planning, construction and operation of facilities located abroad; Germany should be in charge of at least some of the multinational European or international facilities.

A facility which, due to its costs, can only be implemented as one central facility and whose users generally do not come from the operating institution, should be run by an institution which is very much service-oriented in its approach. The appropriate type of organisation would be a large-scale research institution or scientific institution with a similar structure which carries out scientific and technical research and development requiring the concentrated use of human, financial and material resources on a large scale . The Science Council has already on other occasions spoken in favour of installing large-scale facilities in Germany first and foremost at large research institutions, which should also manage their operation.[37] However, the Science Council's statements regarding the HALO research aircraft and the High Field Laboratory Dresden also show that, in cooperation with universities and other national and international research institutions, larger institutions belonging to the *Wissenschaftsgemeinschaft Gottfried Wilhelm Leibniz* (WGL) and the Max Planck Society can be suitable locations for facilities.

It is universities that conduct basic research across the whole spectrum of disciplines. The intensive and often long-term investment of human and financial resources in a specialized field, or the particular organizational requirements connected with the construction and operation of large-scale facilities generally do not match the structure or scale of a university and may exceed the level of organization which they can be reasonably expected to manage. The Science Council considers the location of facilities of this size at universities to be an exception.

The Science Council has already emphasized in various past statements the importance of cooperation between higher education institutions and large-scale research institutions.[38] Such cooperation should be a matter of course when it comes to provision of equipment, including large-scale facilities. Through such a relationship the large-scale research institutions gain access to future generation scientists and thus to new creative potential, while students and scientists at the higher education institutions gain access to scientific, technical and complex logistical infrastructure.

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37 German Science Council: System Evaluation of the HGF - Statement of the German Science Council on the Hermann von Helmholtz Association of German Research Centres, Cologne 2001, p. 19.

38 German Science Council: Recommendations on cooperation between large-scale research institutions and higher education institutions, Cologne 1991, p. 40 ff., German Science Council: System Evaluation of the HGF..., Cologne 2001, p. 52 ff.

Funding

Basic scientific research plays a key role in shaping the future worldwide. The successes achieved by basic scientific research are not only the fruit of work carried out with no or relatively little equipment, or the result of spontaneous breakthroughs or serendipity, but are also the result of using large, complex facilities at national and international research centres. The Science Council underlines the fact that the location of facilities of this size in Germany will have enormous significance for the development of and increase in Germany's appeal as a hub of scientific excellence. At the same time, it points out that well qualified, creative experts are needed to be able to exhaust the scientific and technical potential of a large-scale facility. Apart from the issue of such funding for facilities, the recruitment and promotion of future scientists is the key prerequisite for the successful use of facilities. In order to make full use of the potential offered by Germany's system of science today, and thus at the same time to pave the way for the further involvement of Germany as a centre of scientific activity, all parties from all parts of the system of science must make a concentrated effort. Facilities which are highly attractive to national as well as international scientists can bring Germany a step closer to these goals.

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During the last decades, the Federal Government and the *Länder* have invested considerably in the expansion of the German system of science. This has led to the creation of a high-performance and internationally competitive infrastructure.

In the past years - the last time being in its theses on the future development of the system of higher education and research in Germany - the Science Council has repeatedly advocated that investment in science and research be significantly increased. It welcomes the present initiative of the Federal Government and a number of the *Länder* to provide financial resources for the construction of further large-scale facilities in order to promote basic scientific research. However, it is becoming apparent that the level of investment necessary for building the facilities considered worthy of support in this statement - in some cases after fulfilment of certain conditions (see A. III and A. IV.) - will be much higher than any single investment in facilities in Germany to date.

Before a facility is planned, it must first be established whether there is a scientific need for such a facility and whether it is technically feasible. If these considerations, which constitute the starting point for systematic investment planning, lead to a positive result, it must be examined whether and how the facility can be institutionally embedded in the funding structures of the existing system of science and what funding options are available.[39]

A variety of different possibilities are available with regard to funding the facilities deemed worthy of support:

- In the opinion of the Science Council, the Federal Government and the *Länder* should continue to provide substantial financial resources for the construction and operation of large-scale facilities in Germany and for German participation in facilities abroad. At the same time, however, the Federal Government and the *Länder* along with the research organizations and the relevant institutions must be prepared to make changes to their funding programmes and structures to accommodate new facilities.

- In addition to the possibility of restructuring, it should be examined - particularly in the case of large-scale facilities involving very high investment costs - whether more resources can be provided through public research funding to allow implementation of the facilities in the first place. EU (investment) resources or resources from European and international partners should be made use of wherever possible.

The Science Council takes the opportunity here to request the Federal Government, the *Länder* and the funding organizations to look in detail at the impact the funding of facilities of this size will have on the funding of the entire system of science. This applies in particular to the funding of higher education institutions - including support for the construction of universities, which is chronically underfunded, as repeatedly pointed out by the Science Council - and to the funding of non-university research institutions.

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[39] See Section C for requirements with regard to the future assessment of large-scale facilities.

The various initiatives towards building further large-scale facilities are supported both by scientists from universities and from non-university research institutions. It is becoming especially clear that higher education institutions and non-university research institutions need to work together for each other's benefit with regard to equipment, which includes large-scale facilities. This should also be reflected by appropriate financial participation[40] in the construction and operation of facilities by all institutions involved.[41]

Large-scale facilities must be centrally incorporated into the strategic planning and research programme of the institution(s) in charge and must be a core element of the spectrum of tasks. Profile building and concentration are crucial for achieving optimal allocation of resources. This may, and in some cases will definitely, mean that, if a facility is located at a certain institution, this institution will have to decide against continuing some of its ongoing research activities due to limited financial and personnel capacity. Generally, this will also mean that staff and resources have to be re-allocated.

The Science Council requests the *Länder* in which facilities are located to examine the possibility of providing additional funding commensurate with the scientific and economic impact resulting from location of the facility in the region in question.

The majority of the facilities of this size can no longer be planned and funded on just a national scale on account of the costs arising from installation, maintenance and operation. They should be designed as European or international facilities. Accordingly the construction of these facilities should be largely financed on a European or international scale. This could lead to the organization of European or international consortia. Investments could also be financed via European or international programmes, as is the case with the "Ocean Drilling Programme".

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40 In the case of the *Helmholtz-Gemeinschaft Deutscher Forschungszentren* (HGF), this may lead to re-evaluation of the financial weighting given to various programme areas as part of programme-oriented funding.

41 The Science Council realizes that the different funding modalities for the joint tasks in Germany do not at present allow for the joint funding of facilities by universities and non-university research institutions.

Facilities that are to be operated as a laboratory for national users but are also to be open to the international research community, should apply to the EU for recognition as a "Large-Scale Facility". This would pave the way for financial support for use of the facility by interested parties from the EU (and other countries) while also allowing the facility to be further developed into an international institution.

C. The assessment of large-scale facilities in the future

At the request of the Federal Ministry of Education and Research, a joint assessment of the proposed procurement of numerous large-scale facilities of different scientific institutions has been successfully carried out at one time. For the first time, the Science Council has appraised a wide range of such projects from a scientific and research-policy point of view.[42]

The Science Council believes that it is important to improve coordination of the procurement of large-scale facilities in the future too, and to review suitable initiatives according to uniform scientific and research policy criteria - in parallel with already established procedures. It is already becoming apparent that further initiatives - not just in large-scale research institutions - will be prepared after the assessment of these projects has been concluded.

In the case of this kind of nationally coordinated examination of projects which involve a considerable proportion of government funding, the following general objectives should be pursued:

- The projects should be examined on the basis of an increasingly networked higher education and science system, i.e. from a cross-institutional perspective.
- Decisions on large investments that are binding in the long term should become more transparent.

[42] Some years ago, the Science Council submitted a statement on the procurement of the research reactor in Munich. In the past, the Federal Ministry of Education and Research has repeatedly established special commissions for the assessment and the ensuing procurement of large-scale facilities primarily for large-scale research institutions.

- It should also be possible to discuss proposed international participation in facilities for which no location in Germany is planned; the goal should be to provide the scientific community in Germany with research infrastructure of a certain magnitude according to demand, including at locations outside the country.

A continuous, established procedure is required, which uses the available options for making assessments while avoiding new institutionalisation. Decisions on procurement above a cost limit of € 50 - 100 million which will be used by several institutions and are important for large sections of the scientific community must be based on funding recommendations made from a suitably broad perspective. For this reason, institutions or research organizations should not be able to opt for the procurement of large-scale facilities of supra-regional importance on the basis of internal decision-making processes. It makes sense to continue to entrust this task to the Science Council. The Science Council has relevant experience in the assessment of large-scale facilities and extensive investment projects (also in connection with the joint task of university construction and with supercomputers). All planned procurements of this magnitude and structure should be presented to the Science Council for appraisal from the point of view of science policy aspects.

When carrying out the appraisal, the following points should be taken into account:

- It is important to not only examine the procurement of specific facilities, but also to discuss the importance of and the prospects for the research areas concerned.
- Procurements should be considered that are not only supervised by universities but also by non-university research institutions.
- The expert assessment should be conducted in a structured framework that offers as much scope for comparison as possible.
- If necessary, the Science Council can continue to act in an advisory capacity beyond the initial assessment.

The Science Council will discuss the organizational and procedural aspects of the expert assessment, in particular its implementation, at a given time.
With respect to the procedure for examining the large-scale facilities for fundamental scientific research described here, the two-stage approach has proven effective,

namely the expert, detailed assessment of the individual projects by sub-panels from an expert point of view and the statement by the working group from an overall science policy perspective. Some of the staff involved were simultaneously a member of a sub-panel and a member of the working group. Equally successful was the international membership of the sub-panels and of the working group, since this permitted an "external viewpoint" in the sense of judging and comparing performance from an international point of view. The Science Council believes that both aspects should be retained as an indispensable element of future assessments of large-scale facilities.

This procedure has, however, also shown that a minimum formal requirement for the proposals should be the extent to which they are ready for a decision. This means that the facility nust have

- a scientific program,
- a technical design report.

However, experience has shown that those proposals which fall short of minimum requirements do not stand up to competition. In order to guarantee that only those proposals which are ready for a decision are assessed, the actual assessment procedure should be preceded by a preliminary examination of the submitted documents. The points that must be looked at above all are those in the introduction of the "Theses on the significance of large-scale facilities for basic scientific research".

D. Summary of the results of the science policy appraisal

At the request of the Federal Ministry of Education and Research, the Science Council carried out an expert assessment and a science policy appraisal with regard to the

- TeV-Energy Superconducting Linear Accelerator (TESLA)
- TESLA X-ray Free Electron Laser (TESLA X-FEL)
- Soft X-ray Free Electron Laser (Soft X-ray-FEL)
- High Field Laboratory Dresden (HLD)
- High Magnetic Field Facility for Neutron Scattering Research
- European Spallation Source (ESS)
- International Accelerator Facility for Beams of Ions and Antiprotons
- European Drilling Research Icebreaker (Aurora Borealis)
- High Altitude and Long Range Research Aircraft (HALO)

and drew up recommendations on the structure and funding of large-scale facilities in general as well as on their future assessment.

For this purpose, the Science Council established the "Working Group on Large-Scale Facilities for Fundamental Scientific Research". Various sub-panels carried out an expert assessment of the individual facilities. On the basis of each sub-panel's findings, the Science Council then carried out a science policy appraisal of all nine facilities.

The Science Council considered the facilities along with their strengths and weaknesses in the context of further national and international scientific development of the research fields they belong to and assessed their interaction with other disciplines. As a result, the facilities have been divided up into three groups:

- The first group includes facilities which, when implemented, would provide a research infrastructure of a new quality, which would contribute decisively to the development of the research field concerned and which promise new scientific knowledge. The Science Council believes that the facilities in this group merit unconditional support. Convincing scientific programmes and technical design reports are available for these projects. They should be tackled soon and funding partners sought without delay. This group includes the High Field Laboratory Dresden (HLD) and the High Altitude and Long Range Research Aircraft (HALO).

- The second group includes facilities which, when implemented, would also give rise to research infrastructure of a new quality, which would contribute decisively to the development of the research field concerned and which promise new scientific knowledge. However, specific points have yet to be clarified, and this fact stands in the way of unconditional support. The Science Council considers the facilities in this group to be worthy of conditional support. It requests the Federal Government to keep it informed about the clarification of the individual points and to re-submit the revised project proposals in time before the conclusion of negotiations so that, if appropriate, they can be confirmed as also being worthy of unconditional support. This group includes the TeV-Energy Superconducting Linear Accelerator (TESLA), the TESLA X-ray Free Electron Laser (TESLA X-FEL) and the International Accelerator Facility for Beams of Ions and Antiprotons.

- For the third group of facilities, the Science Council has drawn up specific statements for various scientific, technical or procedural reasons. Should continued work on the scientific programme and the technical design report for these facilities lead to more extensive insights and to a new project proposal, the Science Council would consider it necessary to carry out a new assessment, which may also have to compete with other initiatives for large-scale facilities. This group includes the Soft X-ray Free Electron Laser (Soft X-ray-FEL), the European Spallation Source (ESS), the High Magnetic Field Facility for Neutron Scattering Research and the European Drilling Research Icebreaker (Aurora Borealis).

The Science Council believes that in future, following the example of well-established procedures, the procurement of large-scale facilities must be better coordinated and that suitable initiatives must be assessed using uniform scientific and research policy criteria.

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This statement on nine large-scale facilities for basic scientific research and on the development of investment planning for such facilities concludes for the present the Science Council's expert assessment and science policy appraisal of the submitted proposals for large-scale facilities. At the time of the appraisal, the projects varied in scientific quality and technical maturity. Important points regarding the medium- and long-term funding conditions still need to be clarified. The Science Council regards the funding of facilities of this size as a continual process. Thus it considers this statement to be the basis for further necessary decisions on support. The Science Council will submit concrete recommendations on the priorities for implementation of the individual facilities which are based on the present statement and which take into account the subsequent science policy debate on the goals and the funding of the facilities. The Council offers to provide further advice in the future regarding the funding of the facilities which received positive appraisals and also to assess new or revised proposals for large-scale facilities.

Annex

- Questionnaire of the Science Council's Working Group on Large-Scale Facilities for Fundamental Scientific Research

Questionnaire of the Science Council's Working Group on Large-Scale Facilities for Fundamental Scientific Research

Foreword

The purpose of the following requests and questions is to provide the sub-panels of the Science Council Working Group on Large-Scale Facilities for Fundamental Scientific Research with key information on the planned large-scale facility for which they are responsible. The responses can be supplemented by additional documents and each institution may, if it so wishes, provide further details in addition to the information in the questionnaire or in the requested documents. As such, there is no restriction on the length of the responses; however, to facilitate further processing of the information, it would be preferable if the responses were kept brief and concise.

The reporting period covers the last five years (1996 up to and including 2000); all facts and figures provided should be those that were current on 1 January 2001. All financial data should be given in Euros.

Any further questions, particularly those concerning fundamental physical principles or the technology and operation of the large-scale facilities, will be dealt with in more detail during a visit of the sub-panel at the premises.

NB

Throughout this questionnaire, the term "field of research" refers to the field of research or fields of research in which the large-scale facility is or will be used.

A Executive summary

Please provide a brief summary of the facility project (scientific vision, strategic importance, scientific objectives and purpose, max. two pages).

B Questions regarding the field of research

B.1 How has your field of research developed over the last ten years and, in your opinion, how will it develop nationally and internationally in the coming years? (approx. 3-4 pages)

B.2 How do you assess the present situation with regard to Germany's participation in this field of research? From your institution's point of view, are there any fundamental qualitative or structural deficits in this field of research in Germany?

B.3 What alternative technologies exist for obtaining related or supplementary information? How have these developed at national and international level over the past few years? How do you think they will develop in the next few years? (Should there be more than one field of research involved, please answer these individual sub-questions separately for each field.)

C Questions regarding the facility itself

C.1 Scientific objectives and research prospects directly linked to the facility

C.1.1 Outline the planned scientific programme.

C.1.2 What range of services is the facility meant to offer scientists? How do these services differ from those of previous facilities?

C.1.3 In your view, what are the facility's main strengths and weaknesses? From a scientific or technological point of view, are there any serious shortcomings, and if so, please explain them.

C.1.4 Justify the feasibility of the facility and the state of affairs with regard to planning.

C.1.5 What impact do you expect the targeted research results to have on scientific, technological and social developments?

C.1.6 In what way does Germany as a centre of scientific activity and excellence stand to benefit from implementation of the facility, and to what extent is it likely to benefit the EU? Please outline alternative infrastructures (plans for new facilities or expansion / upgrading of existing facilities) should the planned facility not be implemented.

C.1.7 Please state the national and international networks and programmes into which the facility is to be incorporated.

C.1.8 Do your investment plans significantly overlap with those of other institutions? If so, how do you assess any possible overlaps (national, Europe-wide, overseas)? How do you justify these, and how can any possible negative effects be prevented?

C.1.9 What evaluations of the facility (assessment of concepts, preliminary work, etc.) have been carried out by external assessors in the last five years? What were the results and what was the impact? How and by whom were the evaluation groups named?

C.1.10 From the present point of view, what requirements could be set regarding the possibilities for enlarging / upgrading the facility?

C.2 Transfer of research results, importance of the facility for the economy

C.2.1 What importance do you attach to utilization of the knowledge that will be gained through research using the facility and research on the facility? Which business sectors and which key technologies could particularly benefit from the results and the development of the facility? Have appropriate transfer mechanisms been put in place for this purpose?

C.2.2 Are spin-offs expected to arise from this project, and if so, how are these being specifically supported?

C.2.3 According to your estimates, to what extent will regional, national and international businesses participate in the project by way of contracts awarded for planning and construction services as well as for services relating to further operation of the facility?

C.2.4 When the project is implemented, how will it affect the structure and priorities of extra-university research?

D Questions regarding the institutions participating in the project

D.1 Please list the establishments participating in the project and outline their contribution and specific competence. To what extent have university scientists participated in the planning?

D.2 Please describe the main focus of activities carried out by your institution and the other institutions involved in this research field. What do the participating institutions see as being essential aspects of their future activities? Which of these are directly linked to the facility? Which of the current or planned future key activities will be discontinued or re-oriented if the facility is implemented?

D.3 What experience do the institutions in charge have in planning and operating large-scale facilities?

D.4 Describe the research results of the past years achieved either a) at your institution, b) at one of the collaborating institutions or c) worldwide which were most important for implementation of the facility.

D.5 How many members of staff and what qualifications will be required for the appropriate use and operation of the facility? What is the personnel situation at the various participating institutions? How will additional staff requirements be met? Is it necessary to re-allocate some of the existing personnel?

D.6 What costs have been estimated so far for preliminary development work etc. for the facility, and how have these been financed? How much external funding (not including budgetary funds) has been obtained for this purpose by your institution (or its cooperation partners) in the last five years (broken down into funding from the Federal Government, regional government, the DFG, the EU, business and industry and other sources)? Please specify the fields in which this funding was used.

E Users

E.1 Which disciplines are dependent on use of the facility for research purposes and to what extent; which disciplines stand to benefit from it (main interested parties)? How can use of this facility reconcile the different needs of diverse groups of scientists?

E.2 What situation do you anticipate with regard to external users (duration and extent of use, origin of users)? How have potential users been taken into account in the planning for the facility? (If available, please enclose with your responses appropriate documentation on user meetings.)

E.3 How is access to the facility organized for scientists from universities and for other external scientists?

E.4 What role does the facility play in training and furthering the future generation of scientists (both guided and independent scientific work, seminars, postgraduate studies, etc.)?

E.5 In which fields of work and research can future scientists be employed following successful qualification?

E.6 How will the plans for the facility and the future research results be presented to the general public (i.e. not just the scientific community)?

E.7 To what extent do you expect the facility to be used by private-sector companies?

F Project management, location, costs and schedules

F.1 Project management

F.1.1 Please outline your approach concerning project planning and management and name your quality assurance procedures.

F.1.2 How is budget responsibility organized structurally and in terms of personnel?

F.1.3 Has an advisory board been established, or are there plans to do so? If so, please specify its functions and name its members.

F.1.4 Who has organizational responsibility for maintaining permanent operation of the facility?

F.2 Location

F.2.1 Please outline your locational planning of the facility.

F.2.2 Outline any general locational factors which, in your opinion, may be advantageous or disadvantageous to implementation of a large-scale facility at your location? What possibilities have been envisaged for a) a national location, b) a location elsewhere in Europe and c) a location overseas?

F.2.3 What would be the consequences for a) the research institutions currently involved in your project and b) for the national research institutions working in your field of research if the facility (or a similar facility) was implemented at another location and possibly by other (domestic or foreign) applicants?

F.3 Costs

F.3.1 Please detail the expected total cost broken down into investment, personnel and operating costs. How do you assess the long-term cost impact, and on what criteria is your assessment based?

F.3.2 How do you rate the status of the table of costs and how up-to-date is it?

F.3.3 How is the overall cost for the facility financed? Are there plans to involve foreign partners in the financing, and to what extent would this be realistic? What mechanism is used for apportioning overall costs (or parts thereof) to any foreign partners involved? Are there plans to involve industry? If so, what will be the modalities, and what kind of services will be provided?

F.3.4 What financial consequences do you expect if the project were to fall behind schedule?

F.4 Schedule

F.4.1 What is the schedule for implementation of the facility? Please provide the necessary details concerning planning, construction, time of commissioning and periods of use.

F.4.2 Specify the annual period of use for the facility and the total period of operation including / without any expansions to the facility.

G Additional information

The institutions involved are requested to provide, if applicable, the following additional documents in triplicate:

G.1 Proposal for the facility (if any);

G.2 List of publications (publications in renowned scientific journals, collections, monographs, textbooks) of the leading scientists involved in developing the facility;

G.3 Documentation of the evaluations carried out with regard to the facility (assessment of concepts, preliminary work, etc.) by external experts in the last five years;

G.4 Organizational charts of the scientific institutions involved.