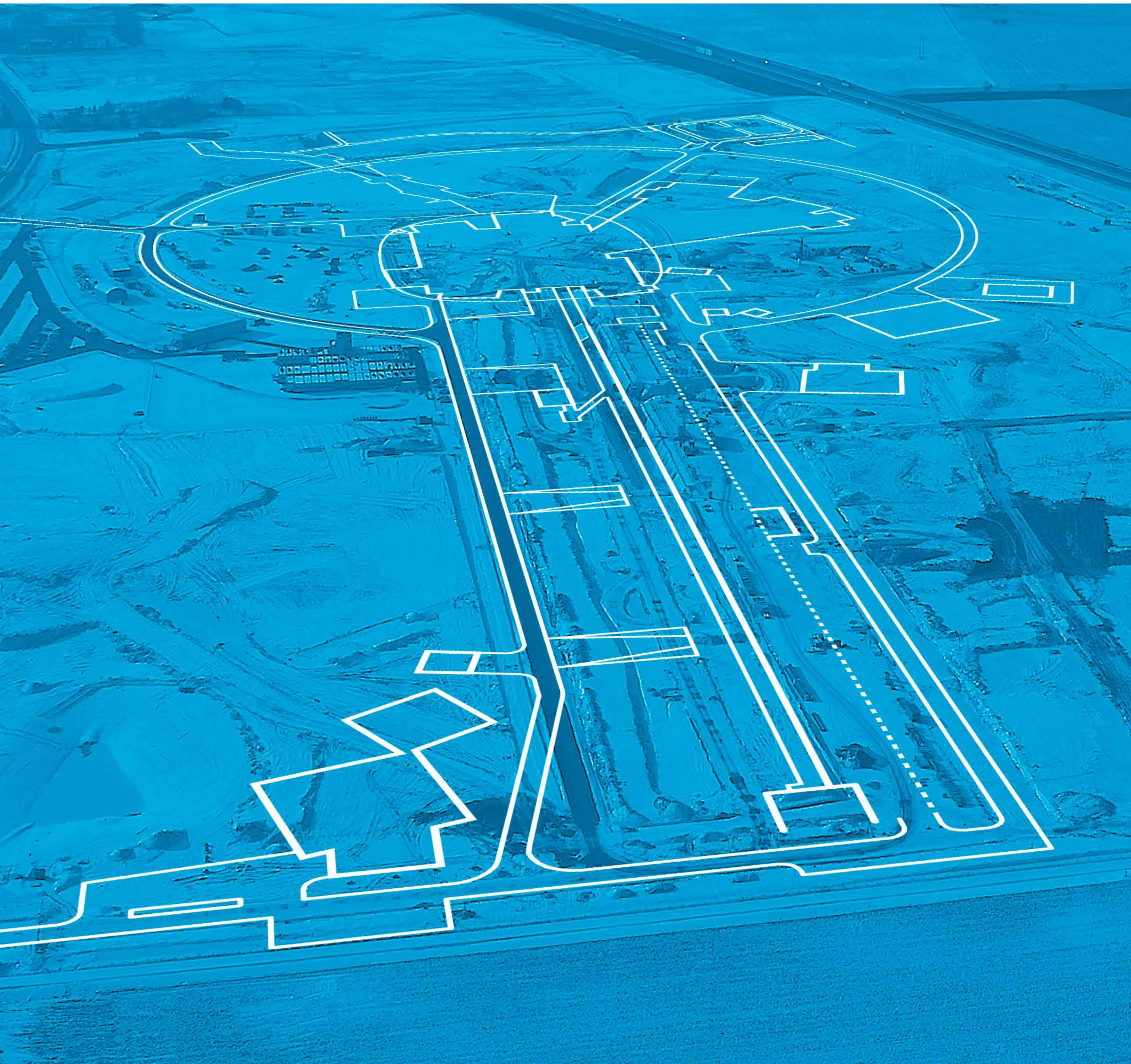
EUROPEAN
SPALLATION
SOURCE

Activity Report 2015



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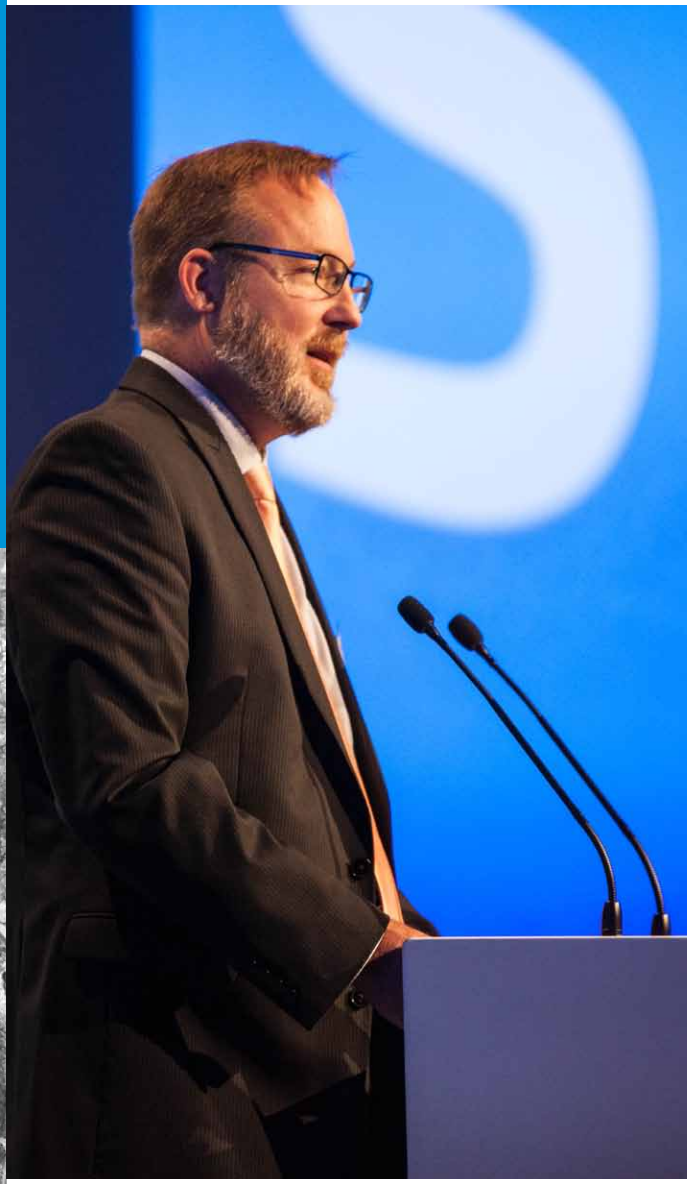
Architectural rendering of the ESS facility under construction in Lund, Sweden. (Image: Team Henning Larsen; Cover photo: Perry Nordeng)

The European Spallation Source in 2015

October 9, 2014, marked both the culmination of more than two decades of work dedicated to the realisation of the European Spallation Source and the beginning of a new set of challenges on the road to the same objective. On that day, several hundred members of the European science community came together at the ESS construction site in Lund to lay the foundation stone for the facility, to celebrate the work that made such an act possible, and to reaffirm the collective commitment to building the world's next-generation neutron science facility.



ESS Director General and CEO James H. Yeck addressing the crowd at the ESS Foundation Stone Ceremony in October 2014. (Photo: ESS)

Construction Drives the Schedule Forward

In the six months that have followed the ESS Foundation Stone Ceremony, the ESS project has progressed rapidly and the momentum built in that time can be felt across each area of the project.

With project funding secure, it is the civil construction on the site that is setting the pace for 2015. By next year, the site's buildings, tunnels and foundations will begin to be outfitted with the world-leading technology that will define ESS. The engineering, prototyping, testing and manufacturing of these components is also well underway, and the key to a successful 2015 at ESS is to secure the in-kind commitments of partner institutions and labs based throughout the project's 17 Member Countries and beyond.

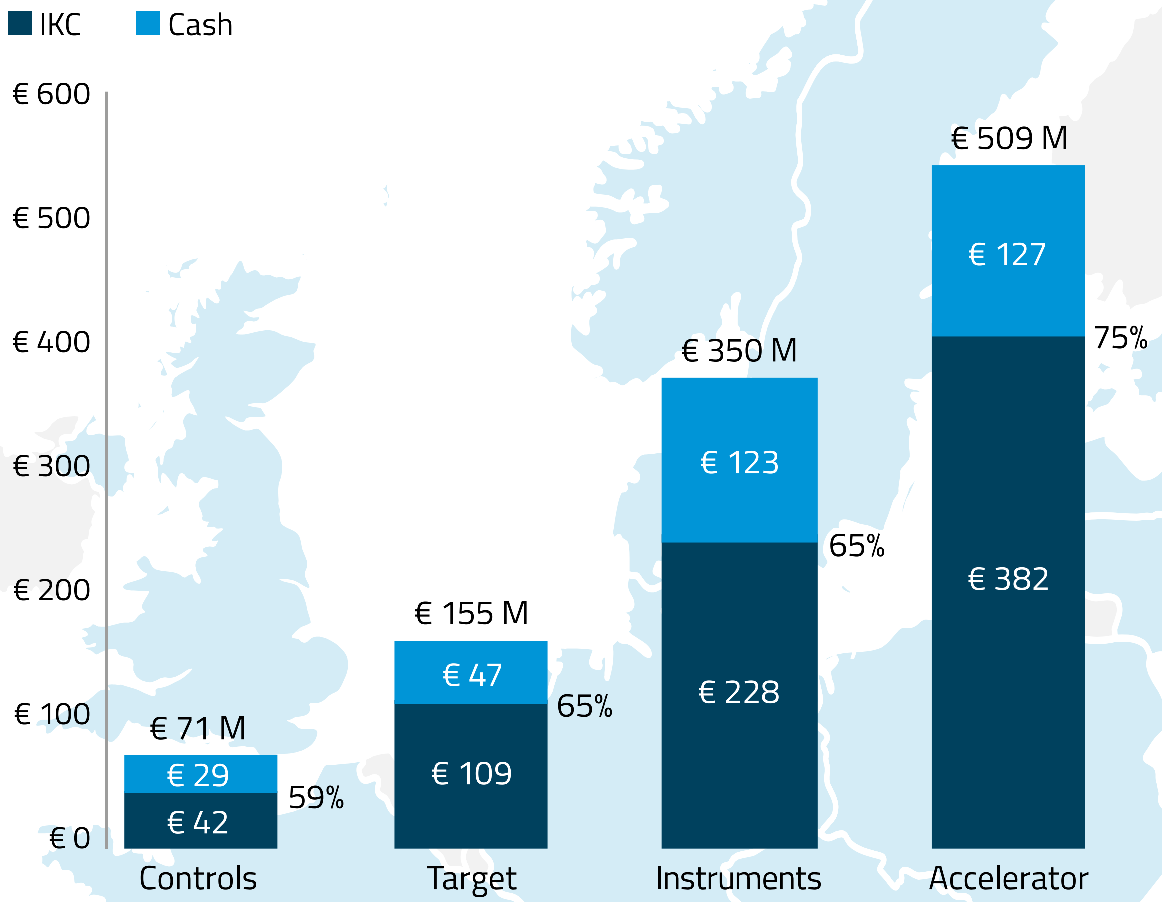
Establishing the In-Kind Model

An in-kind model on the scale of ESS has never been attempted in a European big-science project, and the challenges have been formidable. ESS nevertheless stands at the brink of establishing a breakthrough model for the collaboration. As of December 2014, 189 organisations from 24 different countries had expressed interest in making in-kind contributions (IKCs) to ESS. This number has been steadily growing, and is expected to increase even further. IKCs should peak in 2017, where an estimated 30% of the project spending profile for that year will come from in-kind agreements.

As the success of ESS to a great extent depends on schedule performance, in-kind agreements are on the critical path. In total, it is estimated that more than 35% of the €1.843 B ESS construction cost will be supplied through IKCs. Work packages actively under discussion with potential partners amount to approximately €385 M, 55% of the total estimated in-kind value of ESS. At the moment there are 51 near-term agreements, totaling more than €100 M, expected to be signed during 2015.

ESS In-Kind Goals

Construction cost:	€ 1,84 Billion
In-kind:	€ 750 Million



In-Kind Contributions

What is an IKC?

An in-kind contribution is a non-cash contribution provided by a Member Country to ESS and may come in different forms. A typical IKC can be a technical component or system for the facility. Additionally, it is likely that the personnel, software, or hardware needed to perform the testing, installation, and/or integration of the component are a necessary part of the agreement. R&D itself is another important part of ESS's in-kind partnerships, forming agreements that drive innovation and the project forward.

The IKC Process

An IKC begins with an Expression of Interest (EoI) from an institute or supplier, and can be separated into three fundamental phases.

Phase 1: The received EoIs are evaluated. This phase ends with the signing of a contract with a partner institution. In case there are multiple interested parties, the ESS team will coordinate in assessing the best-valued proposal and select it as the one to be contracted.

Phase 2: The delivery of the contracted work, services, materials, etc., is tracked.

Phase 3: A final evaluation of the performance of the IKC collaboration. The IKC value is defined and credited to the ESS member country.

ESS ERIC

A key element to ESS's trailblazing collaboration model will be the July 1, 2015, organisational transition from ESS AB, a Swedish- and Danish-owned limited liability partnership, to a European Research Infrastructure Consortium, or ERIC. The European Union created the ERIC framework in order to facilitate the formal establishment and operation of European-wide research infrastructures.

ESS host countries, Sweden and Denmark, along with Spain, Hungary, and Norway, applied to the European Commission (EC) on behalf of ESS to establish the ERIC. Once established, ESS member countries and observers will join the ERIC and will thereby be enabled to directly fund the ESS project. EC approval of the transition is expected in May 2015.

The ERIC transition will grant ESS status as an international organisation with respect to certain tax and procurement laws, easing some of the bureaucratic and financial burdens that accompany cross-border collaboration. Additionally, the ESS ERIC Council will replace the ESS Steering Committee, though in name only, as the partner representatives that comprise the committee will remain in place. The ESS AB Board of Directors will be dissolved.

Preparations for the ESS ERIC transition began over two years ago and it has long been envisioned as the way forward for the project and its in-kind model. The European Spallation Source is being built in the spirit of cooperation, sourcing the knowledge of Europe's leading experts and institutions. In the pages that follow, updates on progress made throughout the project over the last two years will present a clear picture of the worldwide collaboration required to integrate the Greenfield ESS project with the greater neutron science establishment. ☐

Construction Investments by ESS Partner Countries*

Sweden	35.00 %
Denmark	12.50 %
Germany	11.00 %
United Kingdom	10.00 %
France	8.00 %
Italy	6.00 %
Spain	5.00 %
Switzerland	3.50 %
Norway	2.50 %
Poland	2.00 %
Czech Republic	1.00 %
Hungary	1.00 %
Estonia	0.25 %
Observers: Netherlands, Greece, Belgium, Latvia, Lithuania, Iceland	2.25%
Total	**100.00%**

*Includes pre-construction costs.

The ESS Foundation Stone Ceremony, October 9, 2014. (Photo: ESS)

ESS Site Development and Facilities

Test piling of the ESS construction site during early site works in 2014. (Photo: ESS)

Move into Construction

Conventional Facilities (CF) at the European Spallation Source refers to the spaces required to house ESS's research equipment, machines, instruments, and people. Various types of accommodations will be necessary for those who will either make use of ESS directly, or who will support its operation and maintenance, be they ESS staff, guest researchers, or visitors. CF is also responsible for the mechanical and electrical services necessary for the proper functioning of the facility.

The overall goal of the CF project is to deliver the physical space for a sustainable research facility in a sustainable way, within budget, according to schedule and with the proper function and quality.

The work in CF over the last two years is marked by the following major activities: the licensing process, building design, procurement of the construction contract, site investigations, construction works, and development of the energy concept.

Licensing Process

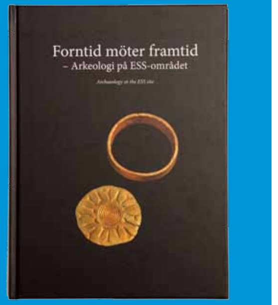
To build and operate ESS, licenses from the Land & Environment Court and the Swedish Radiation Safety Authority are needed. In the verdict delivered by the Environmental Court in June 2014, ESS was granted permission to build the research facility. Final approval for operation of the facility will be dealt with in a follow-up hearing in 2017. The application process according to the Radiation Protection Act is carried out stepwise, aligned with the design and construction process of ESS. Accordingly, the Swedish Radiation Safety Authority has, through a decision in mid-2014, granted ESS a first permission.

The acquisition of these two licenses, along with the building permits from Lund Municipality, allowed construction on ESS to begin in 2014.

Building Design

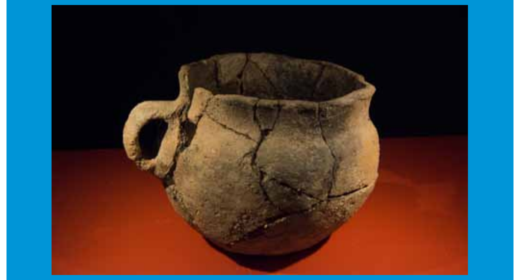
In February 2013, as the result of a design contest, a consortium led by Henning Larsen Architects was selected to develop the final architectural design under the leadership of the ESS design team. Wide flexibility and variation, a strong campus concept, a strong link to

Archaeology and Cultural Heritage



An extensive programme of archaeological investigations was carried out at the ESS building site in 2013, prior to construction. A team of more than 30 archaeologists, managed by the Swedish National Heritage Board (Riksantikvarieämbetet), performed the work.

An unexpected discovery was that of a large Stone Age settlement, evidence that people have been living in the area longer than previously known. The findings were exhibited in 2015 at the Lund University Historical Museum, and a book was published to accompany the exhibit. *Antiquity Meets the Future—Archaeology at the ESS Site*, describes life on the ESS construction site as it was 5,000 years ago and presents the numerous Iron Age and Stone Age artefacts retrieved from the earth northeast of Lund.



The field of archaeology and cultural heritage science is one of the science drivers for ESS, and instruments are being developed here that will open up the next generation of research in this field. Neutrons provide a non-destructive way of probing the material composition and complex structures of artefacts and specimens, increasing our knowledge of manufacturing techniques, agricultural practices, and even evolutionary biology. (Photos: ESS)

Concrete Works through March 2015

Accelerator Tunnel

Excavation and blinding: 315 m (E04-E18)

Base slab cast: 280 m (E04-E16)

Walls cast: 70 m (E10-E07b)

Vaults cast: 39 m (E10-E09)

Cryo-Transfer Line Tunnel

Base slab cast: all sections

Walls cast: 5 of 7 sections

Stubs

E7 and E8 cast

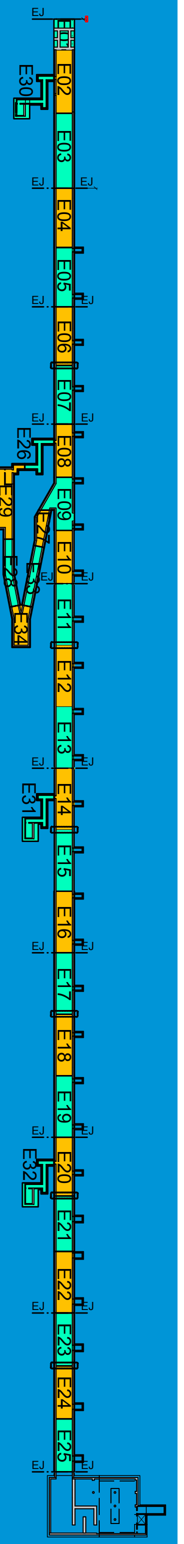
Building H05

Base slab cast (192 m^2)

Totals

2,847 m^3 of concrete

364 tonnes of steel reinforcement



Science Village Scandinavia, and a symbolic use of the roof structure are all key features of the concept by Team Henning Larsen.

The design of ESS has been developed from a feasibility study, through preliminary design, and is now in the detailed design phase for most areas of the project. Furthest developed are the Accelerator buildings and the earthworks, where drawings and specifications are now regularly issued for construction.

In the design process many different requirements are taken into consideration, for example user requirements, technical requirements, sustainability, quality, and occupational health and safety. These requirements will be continuously verified during construction and commissioning. The major focus within the design process is on delivering documents for construction, so as to keep the construction works on schedule.

Procurement of Construction Contracts

Procurement work has focussed on procuring a contractor for the construction of the "industrial" parts of ESS—the Accelerator buildings, Target building, Experimental Halls, Central Utility Building, and auxiliary buildings—and for earthworks. Prequalification of interested construction companies was completed during summer 2013, and tenders were received in December 2013. In the beginning of 2014, a thorough evaluation of the tenders was carried out, and Skanska emerged as the strongest partner. The contract between ESS and Skanska is called C101, and the work is executed through a collaboration organisation including personnel from both Skanska and ESS.

The collaboration contract with Skanska was signed on February 18, 2014. This form of contract was chosen in order to ensure the preparation and completion of the contract in the most cost and time efficient way possible. The joint project organisation's work and approach is characterised by complete openness, constructiveness, proactivity, responsiveness, respect, pragmatism, and professionalism.

Site Investigations

In November 2013, a series of extensive archaeological field surveys were completed on the ESS site. Archaeologists led by the National Heritage Board examined the ground at the site in three phases (see sidebar, page 7). Following completion of the archaeological field investigations, ESS test piled the site in order to evaluate the current ground conditions and to select an optimal foundation method. Several additional geotechnical investigations have taken place during 2013 and 2014 in order to assess the elevation and quality of the groundwater, as well as to further ensure a secure foundation.

Construction workers casting a section of the Accelerator tunnel concrete vault. (Photo: ESS)

Construction Works

With the environmental license and the building permit in place, preparatory earthworks could commence during Summer 2014. These works included excavations and backfill, as well as development of the construction site office infrastructure.

The official ESS groundbreak in September by representatives of the host countries Denmark and Sweden, and the foundation stone laying ceremony in October, featuring representatives from the 17 Partner Countries, marked the starting point for more intense construction works.

The construction works progress well and according to schedule. The major part of the property has been excavated and backfilled, the construction site office has been established, and the ESS Accelerator tunnel is well into construction. A major milestone was achieved in December 2014 when the first concrete for the tunnel's base slab was cast nearly a month ahead of schedule.

Energy Concept

The ESS energy strategy—"Responsible, Renewable, Recyclable"—means that the facility will be energy efficient, supplied with electricity from renewable sources, and that the surplus heat will be recycled.

At the end of 2013, local agreements were signed regarding both the electrical grid connection and the connection to the district heating grid.

With the grid connections under construction, the main focus of the energy group's work during 2014 has been the update of the energy inventory, development of a concept for procurement of renewable energy for the operations phase, and development of an alternative low-temperature recycling solution for the facility's surplus heat.

Plans for 2015

The licensing process for the Radiation Protection Act is ongoing within ESS's Environmental Health and Safety division.

Building design work will focus on completion of the major parts of the Conventional Facilities design—the Accelerator buildings, earthworks, the Central Utility Building, and main utilities will be finalised during the year. The detailed design of the Target building and Experimental Halls will continue into 2016. The main focus of the design is to issue drawings and specifications for construction in time for the construction works to proceed according to schedule.

Procurement activities now focus on the procurement of a partner for the development of the campus area, which contains the main part of ESS's offices and labs.

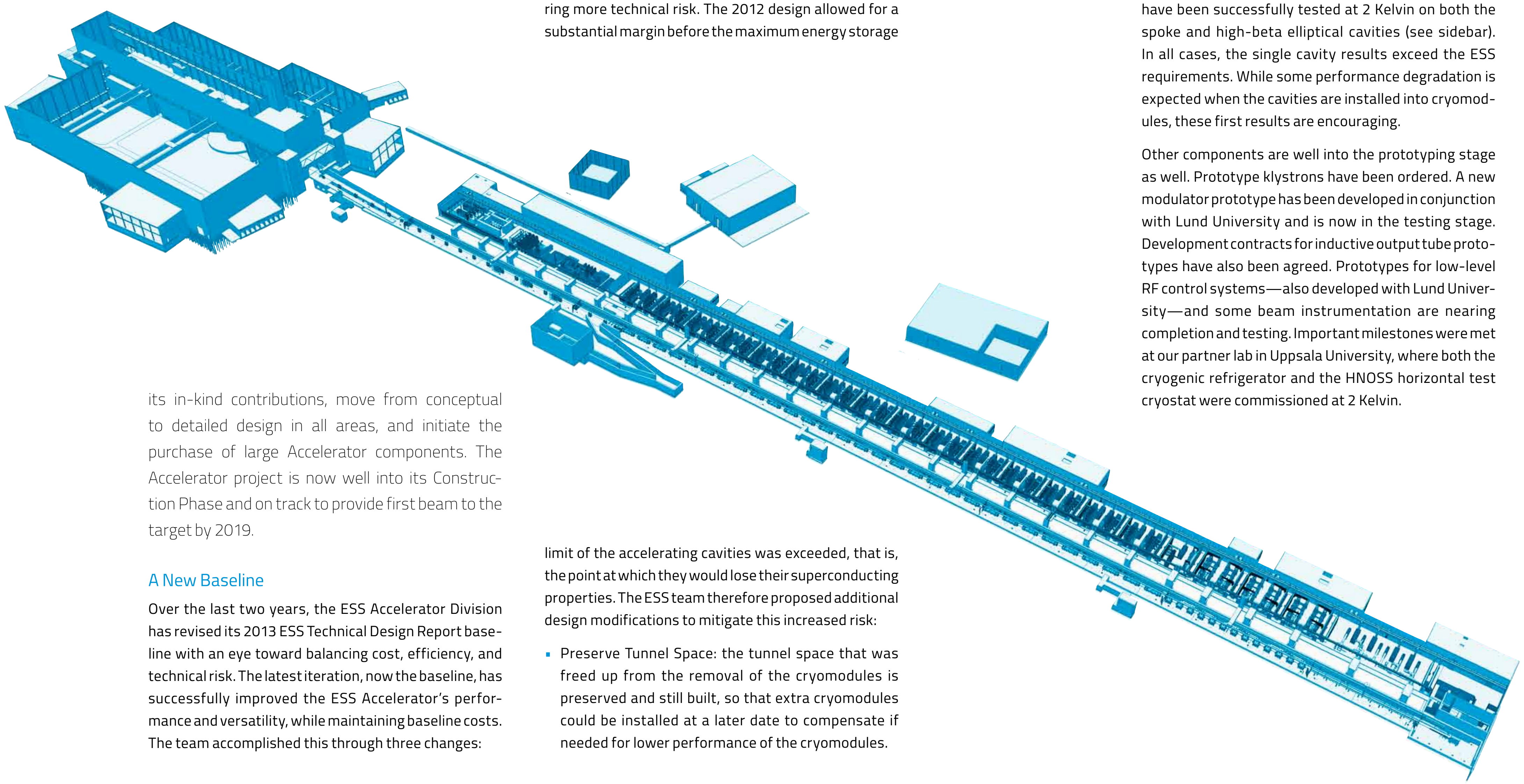
The concept for procurement of renewable energy for the Operations Phase will be finalised during the year, as well as the development of an alternative recycling concept for the surplus heat. More energy audits will be carried out, and the energy inventory further updated.

Excavations and piling for the ESS Target Station building and the Experimental Halls will begin this year, and construction of the Central Utility Building and electrical substations will also commence. Construction of the ESS Accelerator tunnel and other Accelerator buildings will continue during 2015, allowing for installation of the first cryonic components in 2016. ☐

The ESS Accelerator:

Redesign Complete and Under Construction

The ESS Accelerator will produce the intense proton beam required to initiate the spallation process and deliver neutrons to be used in experiments at ESS. To provide the world's next-generation neutron source, the ESS Accelerator will be the most powerful linear proton accelerator (linac) in the world, with an average proton beam power of 5 MW. The last two years have seen the Accelerator project execute a redesign of the Accelerator itself, advance prototyping and R&D efforts, greatly increase and formalise its in-kind contributions, move from conceptual to detailed design in all areas, and initiate the purchase of large Accelerator components. The Accelerator project is now well into its Construction Phase and on track to provide first beam to the target by 2019.



A New Baseline

Over the last two years, the ESS Accelerator Division has revised its 2013 ESS Technical Design Report baseline with an eye toward balancing cost, efficiency, and technical risk. The latest iteration, now the baseline, has successfully improved the ESS Accelerator's performance and versatility, while maintaining baseline costs. The team accomplished this through three changes:

- Increase the stored energy in the superconducting cavities by 25%
- Increase the beam current by 25%
- Increase the power handling of the superconducting cavity couplers by 25%

These changes led the team to reduce the number of high-energy cryomodules by 33%, resulting in a savings of about €90 M. The energy of the linac in the 2013 design has been reduced from 2.5 GeV to 2 GeV, but beam power has been preserved by compensating with an increase in beam current, to 62.5 mA.

Of course, these changes did not come without incurring more technical risk. The 2012 design allowed for a substantial margin before the maximum energy storage limit of the accelerating cavities was exceeded, that is, the point at which they would lose their superconducting properties. The ESS team therefore proposed additional design modifications to mitigate this increased risk:

- Preserve Tunnel Space: the tunnel space that was freed up from the removal of the cryomodules is preserved and still built, so that extra cryomodules could be installed at a later date to compensate if needed for lower performance of the cryomodules.
- Uniform Tunnel Design: the design of the accelerating cavities is tailored to match the changing beam velocity along the length of the linac. To save space, the tunnel layout matches the accelerating structures. If the tunnel layout is uniform, more space is required (about 5-10%), but a uniform layout preserves flexibility in changing the types of structures that can be installed in the tunnel at a later date.
- Universal Cryomodule: If the length of all superconducting cavities is required to be the same, a universal cryomodule can be designed to accommodate a variety of design energies. This also saves money and time in the prototyping phase of the cavity construction because just one type of cryomodule needs to be prototyped.

Hands-On Work with In-Kind Partners

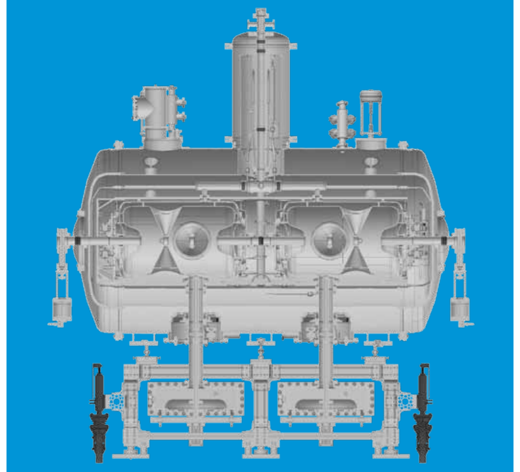
Development work is well underway on the superconducting radio frequency (SRF) cavities, a series of complex metallic structures that serve as the tunnel's superhighway for the accelerating protons. Prototypes have been successfully tested at 2 Kelvin on both the spoke and high-beta elliptical cavities (see sidebar). In all cases, the single cavity results exceed the ESS requirements. While some performance degradation is expected when the cavities are installed into cryomodules, these first results are encouraging.

Other components are well into the prototyping stage as well. Prototype klystrons have been ordered. A new modulator prototype has been developed in conjunction with Lund University and is now in the testing stage. Development contracts for inductive output tube prototypes have also been agreed. Prototypes for low-level RF control systems—also developed with Lund University—and some beam instrumentation are nearing completion and testing. Important milestones were met at our partner lab in Uppsala University, where both the cryogenic refrigerator and the HNOSS horizontal test cryostat were commissioned at 2 Kelvin.

Particle Acceleration Basics

The basic goal of the ESS Accelerator design is to deliver the protons as efficiently as possible in order to maximise the production of neutrons. The most efficient way to accelerate protons is to "surf" them on electromagnetic (RF) waves. The electrical properties of a proton interact with a radio wave similar to how a surfer interacts with, and gains energy from, a wave on the ocean.

To enhance the value of the experiments conducted at ESS, neutrons will be packaged in bursts or pulses, a conversion performed by devices called modulators. The pulsed electric power released from the modulators is then used to energise very powerful RF amplifiers known as klystrons.



The high-power wave is then guided to the accelerator through a specially sized tube called a waveguide. In the Accelerator tunnel, the waveguide couples to a sequence of complex metallic structures, called cavities, that store the electromagnetic energy. As the proton beam makes a pass through each cavity, these stored electromagnetic waves then couple to the protons, transferring their energy to the beam. The proton beam is thus accelerated toward its target.

Pictured above is a cut-away view of the prototype ESS spoke cavity cryomodule. The view shows two double-spoke cavities surrounded by their helium vessels, magnetic shielding, and thermal shielding within a vacuum vessel. The proton beam passes through the centre. These cryomodules are designed and provided by ESS partner lab IPN Orsay, in France, as part of an in-kind contribution. The group will produce a total of 13 cryomodules for ESS.

(Image: IPN Orsay)

Efforts to secure in-kind contributions (IKCs) continue with an increased emphasis on writing final technical appendices and the signing of contracts. Currently, the Accelerator Systems Project (ACCSYS) is discussing IKCs with 28 different institutions in 12 countries, amounting to roughly 50% of the project cost. Together with the long-standing collaborations at CEA Saclay and IPN Orsay in France, INFN/Catania in Italy, ESS-Bilbao in Spain, and Aarhus University in Denmark, ACCSYS is anticipating contributions from Elettra in Italy, Daresbury Lab, Rutherford Appleton Lab, and the University of Huddersfield in the UK, and Wroclaw University in Poland.

ESS Proton Source Development at INFN-LNS Catania

The National Southern Laboratory of Italy's National Institute of Nuclear Physics, INFN-LNS Catania, is an ESS partner institution working on the ESS Accelerator and Integrated Control System projects.

In the photograph are, from left, David Mascali and Lorenzo Neri, who are working on components for the plasma-based proton source for ESS. Here they are performing on-site acceptance tests for ESS components delivered to Catania, including the red 3-coil magnetic system and the high-voltage power supply cabinet.

(Photo: INFN-LNS Catania)

Construction and Component Production

The end of 2014 saw the casting of the first concrete base slab for the Accelerator tunnel, and a significant activity in 2014 was to bring the project into construction. This meant establishing the precise layout of equipment in the RF Gallery building and the tunnel, including checking for and responding to interferences and other issues. A full-scale physical mock up of the stubs connecting the gallery with the tunnel was built to establish the instrumentation and cabling layout prior to construction.

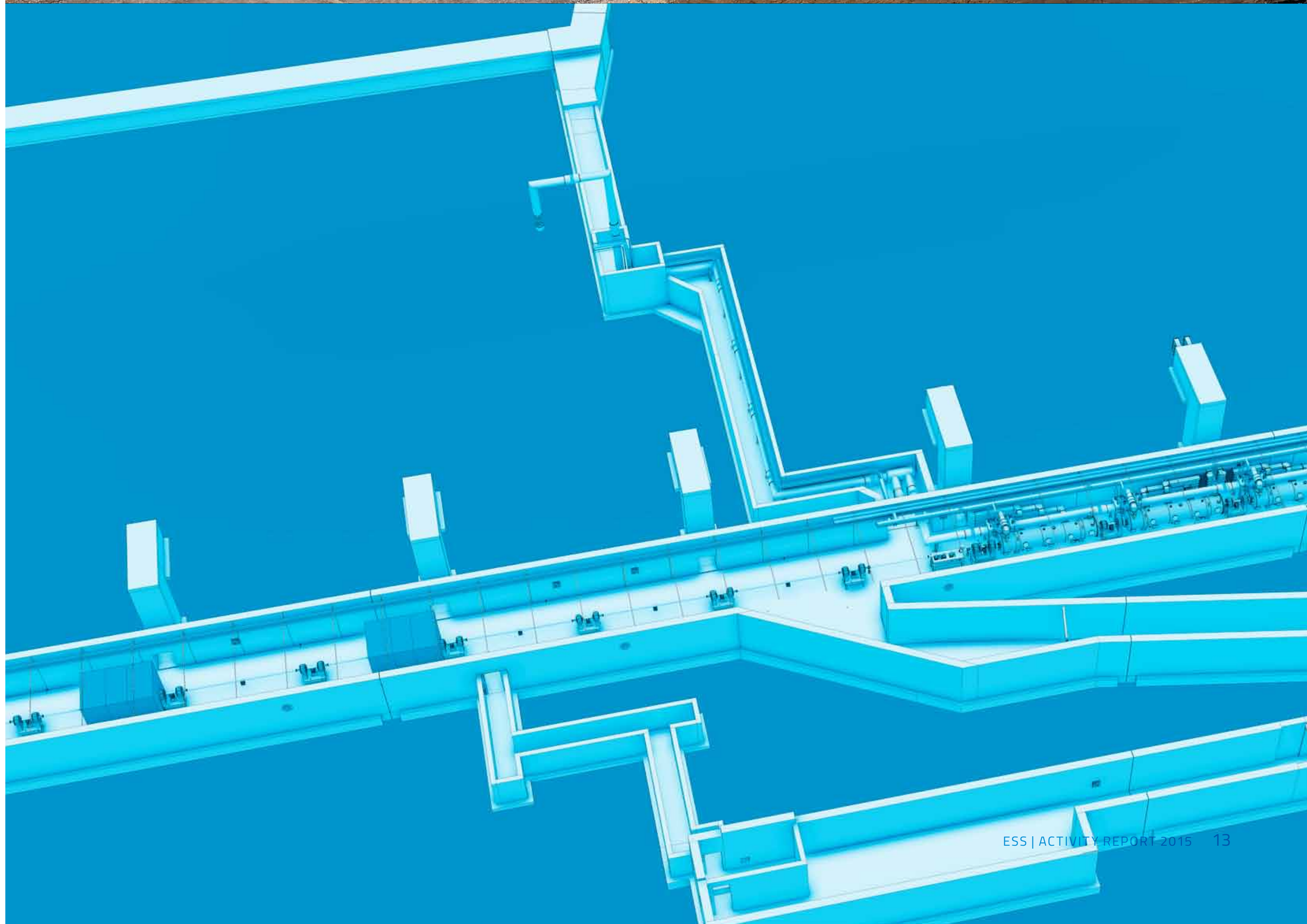
Procurement of Accelerator systems has begun. A vendor has been chosen for the Accelerator Cryoplant, and components for the first proton source and Low-Energy Beam Transport (LEBT) have also started to arrive in Italy at ESS partner institution INFN-LNS Catania. Collaboration with experts from a number of operational facilities—including ESS partners STFC in the UK, CEA in France, and CERN, as well as the DESY Laboratory in Germany and the Jefferson Laboratory in the USA , among others—is assisting ESS in developing documentation and management procedures for the production of the ESS SRF cavities.

Finally, an optimised and integrated component installation schedule is under development at ESS, updated to account for new IKCs and evolving knowledge of the work to be accomplished.

The ESS Accelerator will be the most powerful linear proton accelerator in the world, powering the ultimate neutron source. The design of the Accelerator is also required to be sustainable, cost effective, and technically versatile. To meet these goals, ESS has now completed several design iterations, resulting in the best possible balance of its original mandates. The project is currently on schedule to meet the Summer 2019 beam-on-target milestone. ☐

From Concept to Reality

An aerial photograph of the ESS construction site in Lund, taken March 9, 2015. The photograph shows excavation and concrete works in progress on the ESS Accelerator tunnel (horizontal); the cryotransfer line tunnel (top), which will connect the Accelerator to the cryogenics plant; and the beginnings of the high-energy beam transport (HEBT) loading bay (bottom), the principal access point for installation and maintenance of the Accelerator's components. Below the photograph is the ESS Plant Layout (EPL) view for building works in the same area. The EPL is a 3D CAD model that integrates all systems and sub-systems of the entire ESS facility. (Photo: Perry Nordeng; Image: ESS)



ESS Target Station Optimised for More Neutrons

The ESS Target Station team has made a concerted effort over the past two years to update both the organisational and technical aspects of the project. In optimising the project's organisation, the team has incorporated systems engineering formality into the project, and undertaken a review of the project's scope, cost, and schedule. The Target Station project has engaged potential partners throughout Europe to design, build and deliver Target Station hardware "in kind." The Target Station design has been optimised with an eye toward increases in performance and reliability.

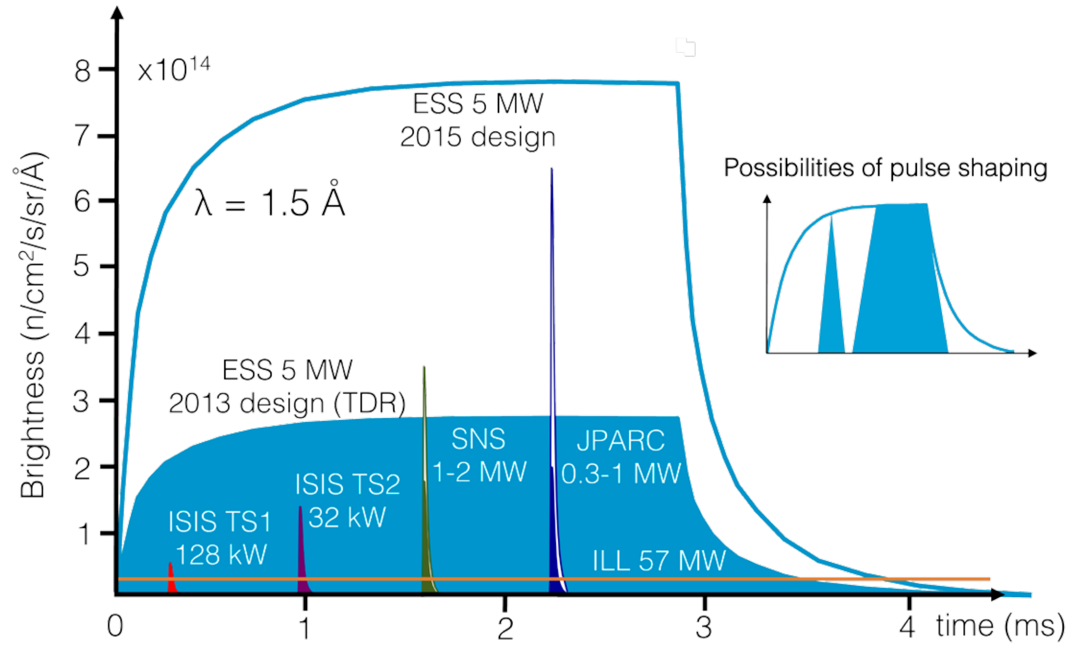
Target Station Components

The Target Station is the birthplace of the neutrons delivered to the neutron scattering instruments. It receives the high-power proton beam produced by the linear accelerator and uses it to produce neutrons via spallation. Spallation is the nuclear process whereby energised protons strike the nuclei of tungsten atoms and knock out neutrons. The neutrons released in this process are moving too fast and must be slowed down to speeds appropriate for neutron scattering research. The neutrons' speed is controlled by colliding them with different media in what is called a moderator-reflector system. A very small fraction of these moderated neutrons then enters the various neutron beam lines that direct them toward the instruments used in scientific research.

The spallation target itself is a large, rotating wheel filled with tungsten and cooled by helium. The moderator-reflector system is situated next to the target. These components are encased in 6,000 tonnes of steel shielding to limit the radiation escaping from the target. The steel and its enclosing structure comprise what is called the monolith. Neutron beam line penetrations in the monolith couple the moderators to the neutron scattering instruments (see figure, page 17).

Neutronics Optimisation

The job of the neutronics team is to make the best use of the moderator-reflector system in order to most effectively deliver neutrons to the ESS instrument suite. Slowing down the liberated neutrons is an inherently inefficient process, with less than 0.001% of them reaching their intended destinations. This means there is significant opportunity to improve performance through innovative design. The scientists in the neutronics team have employed state-of-the-art radiation transport simulation tools and the ESS Data Management and Software Centre's (DMSC) large computing platform to optimise the Target performance.



Single-pulse source brightness as a function of time at a wavelength of 1.5 A at ESS, ILL, SNS, J-PARC and ISIS Target Stations 1 and 2. In each case, the thermal moderator with the highest peak brightness is shown.

Optimisation studies performed by the neutronics team have led to the development of a highly innovative moderator design, which for a large class of neutron scattering instruments yields as much as a three-fold increase in the expected neutron flux on sample (see figure, page 14). This large gain demonstrates the high payoff that can be realised from moderator optimisation studies. It is equivalent to boosting the beam power of the Accelerator from 5 MW to 15 MW, an expensive proposition. By contrast, the improvements in the moderator design are cost neutral.

Moderator-Reflector Plug

The moderator-reflector system is subjected to intense neutron radiation that limits its lifetime to about one year. Replacement of this highly radioactive component must be performed remotely. One of the moderators is situated under the target wheel, which is replaced much less frequently (every five years or so) than the moderator-reflector plug. To replace this section of the moderator-reflector plug without moving the wheel requires two-axis motion of the plug. In addition, optimum performance requires that the moderators be placed in their operating position with a high degree of accuracy. Engineers devised a clever solution to this problem, termed the "twister," whereby the moderators are mounted on a shaft that rotates them from their operating positions to their extraction positions such that they can be extracted vertically into shielded casks in a straightforward procedure. This innovation provides an elegant solution to a difficult problem, and assures improved maintainability of the Target Station over earlier concepts.

Target Wheel

As an example of in-kind participation in the Target Station project, ESS-Bilbao in Spain has responsibility to design, build and deliver the target wheel. This is a 2.5-meter-diameter, 4-tonne disc suspended from a 5-meter-long shaft. The spallation material is tungsten,

ESS-Bilbao Target System Collaboration

In November 2014, ESS-Bilbao was chosen as the In-Kind Partner for the ESS target system.

ESS-Bilbao is a centre for neutron technologies with a staff of 60 scientists and engineers based in Bilbao, Spain. It is a consortium in which the Spanish State Government and the Basque Autonomous Region each hold half a stake. A team of 10 is specifically dedicated to the target wheel systems.

The ESS target wheel will feature the novel design of a rotating tungsten target. The design makes it possible to distribute the high heat of the ESS 5 MW proton beam over a larger volume than what is irradiated by the proton beam in a single moment.

Pictured above with a prototype of the ESS target wheel are, from left, Gorka Bakedano, Javier Corres, Idoia Mazquiarán, and Carlos Cruz. They are focusing the camera that is used to test the rotating target. The prototype is housed in the ESS-Bilbao research and development facility in Zamudio, Spain. (Photo: ESS-Bilbao) and the ESS-Bilbao team has developed a robust design for the arrangement of tungsten blocks within the target wheel. The arrangement consists of some 7000 tungsten bricks distributed in about three dozen sectors that comprise the wheel. The bricks are configured in an offset grid pattern that assures adequate cooling by flowing helium. Thermal stresses and operating temperatures are lower than those of earlier designs, attributes that should improve target reliability.

Fluid Systems

There are a number of cooling loops associated with the Target Station. The largest is the helium loop that cools the target wheel, which carries away about 60% of the heat deposited by the proton beam. Recent design changes have resulted in increasing the pressure of this helium system from 3.5 to 10 bar, which allows the use of a much less expensive pump. In addition, a better understanding of the sources of contamination has led to a simplified helium purification system. Furthermore, the coolant in the secondary loop of this system has been changed from nitrogen to water, yielding about €3 M in cost savings.

Monolith

The monolith, 11 meters in diameter and 7 meters tall, is composed mostly of large steel blocks that shield the radiation produced when the intense proton beam hits the target. In the last year, the monolith design has incorporated changes that yield significant cost savings relative to earlier concepts. The base of the monolith must shield downward-directed radiation and provide a stable foundation for the internal structures. Earlier designs employed custom-built stacked steel blocks. The current design employs a series of concentric rings filled in between with low-cost steel or iron mixed with concrete, a much lower cost solution. The monolith vessel has been reduced in diameter to include only actively cooled steel. This change reduces cost and improves reliability.

Neutron Beam Extraction

The neutron beam extraction system captures and delivers neutrons to neutron scattering instruments. The design of this system is done in close collaboration with the Science Directorate, who have responsibility for neutron instrument design. Recent efforts have focused on developing innovative "double-decker" beam extraction ports that allow any of the 42 beam lines to view either the upper or the lower moderator. Concepts for servicing these in-monolith components have been developed.

Remote Handling

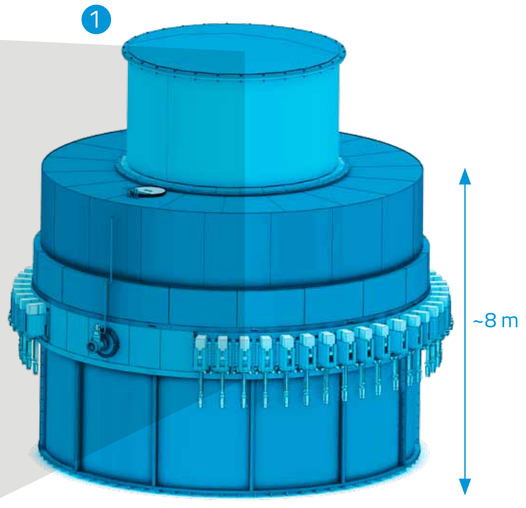
Significant progress has been made in establishing the functional requirements for the active cells and remote handling systems. This work has led to a robust, flexible design of the active cells that emphasizes robotic manipulation of highly radioactive components instead of the more traditional manual remote manipulation. Working with staff from the ESS Environment, Safety and Health Division, procedures for dismantling the target wheel have been developed, and concepts for the storage and packaging of radioactive components for off-site transport have been incorporated into the design.

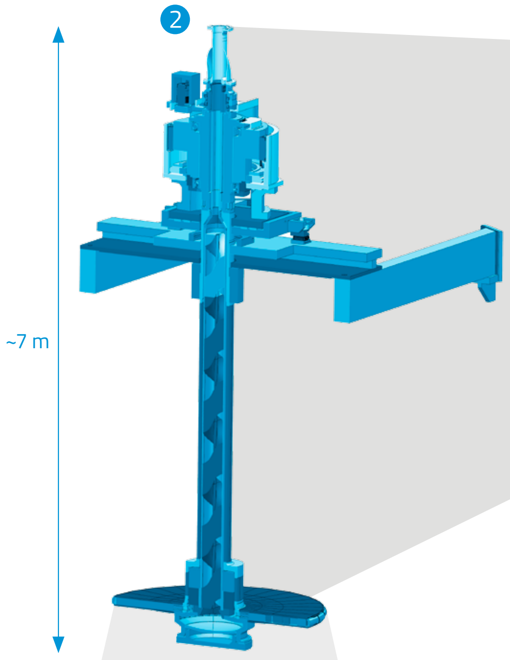
Looking Forward

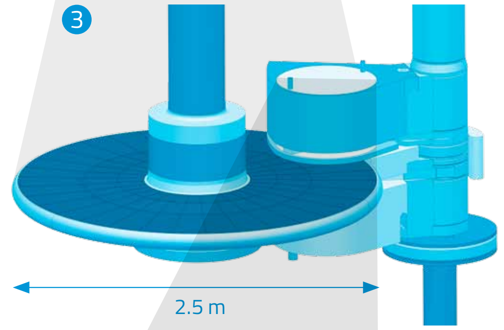
In 2015, the Target Division will focus on completing the preliminary design for essentially all systems comprising the Target Station, and will continue to seek in-kind partners to design, procure and deliver Target Station hardware. Right now on the construction site, the sounds of pile drivers can be heard preparing the foundation for the Target Station building. With the pouring of its base slab, portions of the monolith support structure are due to be installed this year. □

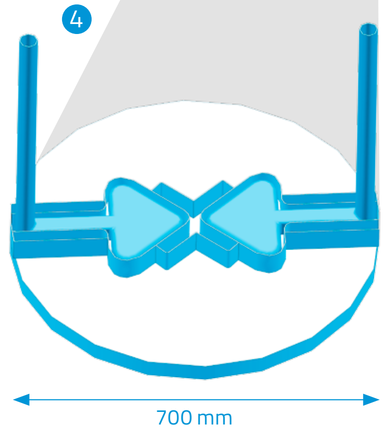
The ESS Target Station site being excavated. The first Target installations are scheduled for later this year, when specially engineered structural steel embedments will be anchored in the concrete slab. The MAX IV synchrotron, to be commissioned next year, is visible on the horizon. (Photo: ESS)

Target Station Components









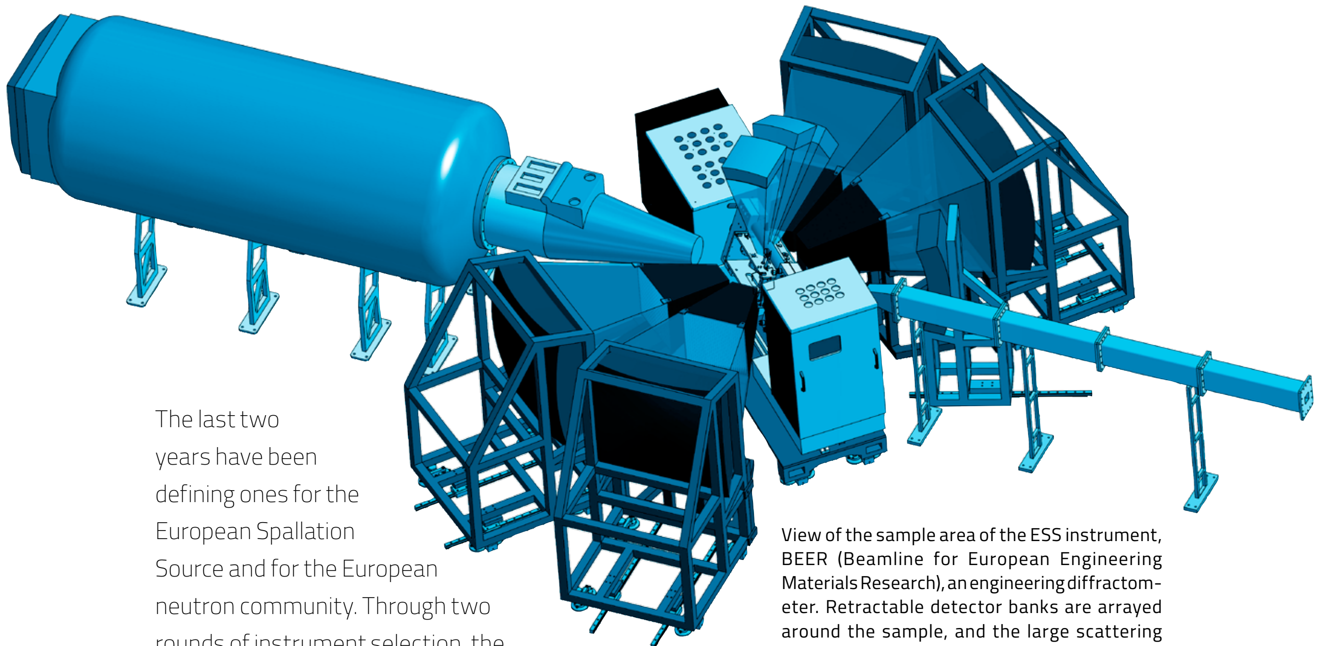
1. The Target Station monolith, including 6,000 tonnes of steel shielding. The view shows the aperture where the proton beam enters the monolith horizontally, as well as some of the 42 double-decker neutron beam line penetrations.

2. A cut-away view of the target wheel shaft assembly and target wheel. The 4-tonne, 2.5-meter-diameter target wheel is divided into 36 radial segments containing around 7,000 tungsten blocks. It is cooled via helium and rotates such that one proton beam pulse will strike each segment of the wheel over the course of a single rotation. The helium coolant passages are integrated into the shaft, as is the drive motor and support bearing for the wheel.

3. The moderator-reflector systems adjacent to the target wheel, one above the wheel and one below it. They can be rotated on their shaft and removed from the monolith for service or replacement.

4. The ESS "butterfly" moderator design. This is the low-profile (3-cm-high) moderator enclosed within the reflector situated just above the target wheel. To a large extent, this small device will determine how many neutrons the ESS target station will produce. Two hydrogen moderator cans, arranged as opposing "arrows", and one water moderator can, the "x" in the centre, contain the hydrogen and water media that "moderate" or slow down the neutrons released from the target. The neutrons then enter the beam lines at a speed suitable for experiments.

ESS Instrument Selection a Catalyst for European Science Community



View of the sample area of the ESS instrument, BEER (Beamline for European Engineering Materials Research), an engineering diffractometer. Retractable detector banks are arrayed around the sample, and the large scattering tube (left) is for optional SANS measurements. (Image: BEER instrument proposal)

The last two years have been defining ones for the European Spallation Source and for the European neutron community. Through two rounds of instrument selection, the community has converged on the first 12 instruments of the ESS suite, and the third round of proposals is in progress. As the foundations of the facility as a whole are being cast in concrete in Lund, the foundation of the ESS scientific user facility is also forming.

The Instrument Suite Takes Shape

The ESS instrument suite will have 22 state-of-the-art neutron instruments, designed to meet the needs of a wide array of scientific disciplines. These range from the conventional neutron science areas of condensed matter physics and physical chemistry, to emerging applications like structural biology. Industrial applications include engineering materials and smart materials.

The European neutron science community has worked hard to explore the future scientific possibilities that the high brilliance and long-pulse structure of the ESS neutron beams will enable. This has culminated in the maturity of instrument concepts purpose-built to ESS's advanced specifications in order to collaboratively address the most pressing questions in research and development. The first open call for such proposals was concluded in 2013, resulting in the selection of three instrument concepts, which are now on the path towards construction. The second call attracted 16 high-quality instrument proposals from different groups in the European collaboration, nine of which were selected in 2014 to be included in the ESS project.

Even as these concepts were being integrated into the construction plan, the third round of proposals opened. Twelve proposals were received, and are undergoing review for selection in 2015. In this way, the ESS instrument suite is being filled with instrument designs conceived and developed through ESS partnerships and selected through a peer-review process.

Advisory Partners

Key to defining the scientific future of ESS is our wide network of advisors. Each of the six instrument classes has a Scientific and Technical Advisory Panel (STAP) made up of experts from around the world. These panels directly support the instrument teams and provide a technical and scientific review of their proposals. This process ensures balance and complementarity in each instrument class. Similar panels advise each of the technical projects supporting instrument development as well as Science Support Systems and the ESS Data Management and Software Centre (DMSC).

The Scientific Advisory Committee (SAC), whose mandate it is to advise ESS management on the overall scientific development of the facility, has the important task of evaluating all instrument proposals from a facility-wide point of view. Together this amounts to more than 100 distinguished advisors worldwide assisting in the establishment of the ESS instrument suite.

Technical Advancements

Pivotal to the realisation of the instruments at ESS is continued progress in new neutron technologies. In collaboration with Institut Laue-Langevin (ILL) in France and Linköping University in Sweden, work on 10B detectors has moved significantly forward. A demonstration of new detector technology was made with the help of ILL's time-of-flight instrument IN6, and ILL has produced a full-size prototype of their *MultiGrid* detector. A dedicated ESS detector coatings workshop intended to fulfil ESS's boron-10 carbide deposition needs was inaugurated in late 2014 in Linköping (see sidebar, page 21).

Work is also progressing on radiation shielding solutions as part of collaborations with Switzerland's Paul Scherrer Institute (PSI), the USA's Spallation Neutron Source (SNS) and ORNL in Tennessee, MAX IV and Lund University in Sweden, ISIS in the UK, and CERN.

Additionally, work at ESS has resulted in a novel moderator design concept that results in increased neutron brightness and significantly enhanced instrument performance. This development, which has involved the reoptimisation of all instrument concepts, will result in even higher performance of the ESS instruments than previously expected, at least twice that presented in the 2013 ESS Technical Design Report.

Nurturing the ESS Science Community

Developing and selecting instruments for ESS is closely coupled to the work of exploring the scientific potential of the facility and building a strong future user community. ESS has always been a partner with its anticipated user base in the planning and construction of the facility, and has established a system of conferences to facilitate this partnership, complementing the many ongoing peer-to-peer collaborations.

The 3rd Science & Scientists at ESS conference took place as a satellite meeting to the International Conference of Neutron Scattering (ICNS) in Edinburgh in 2013. The meeting, held at the University of Edinburgh, attracted more than 130 neutron scattering researchers affiliated with the facilities and universities of 17 different nations.

ESS's semi-annual meeting of its in-kind instrument partners, known as IKON, was held four times in the last two years, and each meeting attracted well over 100 participants to Lund. The meetings focused on current

Instruments in Development

ODIN
a multi-purpose imaging instrument

LoKI
a small-angle neutron scattering (SANS) instrument

NMX
a macromolecular diffractometer

BEER
the beamline for European engineering materials research

CAMEA
a spectrometer with continuous angular and multiple energy analysis

C-SPEC
a cold chopper spectrometer

ESTIA
a focussing reflectometer

FREIA
a fast reflectometer for extended interfacial analysis

HEIMDAL
an instrument combining powder diffraction, SANS and imaging

DREAM
a powder diffractometer

SKADI
a small-K advanced diffractometer

VOR
a versatile, optimal-resolution chopper spectrometer

Instrument Collaboration Partners

The ESS Science Directorate is involved in many collaborative efforts, covering neutron instruments, intrument technologies, sample environment, support facilities and data management and software.

Czech Republic
Czech Technical University in Prague
Nuclear Physics Institute of the ASCR

Denmark
Aarhus University
Technical University of Denmark
University of Copenhagen
University of Southern Denmark

Estonia
University of Tartu

France
Institut de Biologie Structurale
Institut Laue-Langevin
Laboratoire Léon Brillouin

Germany
Forschungszentrum Jülich
Helmholtz-Zentrum Berlin
Helmholtz-Zentrum Geesthacht
Technical University Munich

Hungary
Wigner Research Centre for Physics at the Budapest Neutron Centre

Italy
Consiglio Nazionale delle Ricerche
Elettra-Sincrotrone Trieste
Università degli Studi di Perugia

Netherlands
Delft University of Technology

Norway
Institute for Energy Technology, IFE

Spain
ESS-Bilbao

Sweden
Linköping University
Lund University
Mid-Sweden University
University of Stockholm
Uppsala University

Switzerland
École Polytechnique Fédérale de Lausanne
Paul Scherrer Institute

United Kingdom
ISIS
University of Edinburgh

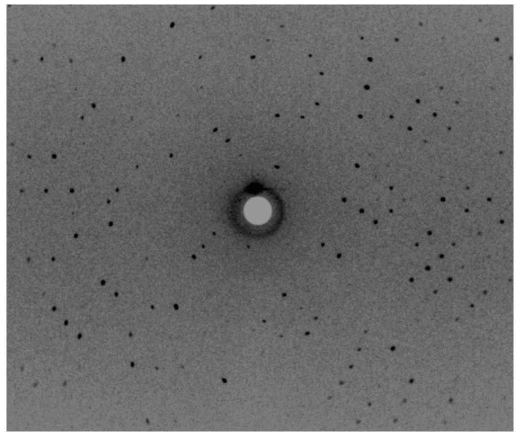
instrument proposals and provided opportunities for in-depth discussions between instrument developers and ESS's Instrument Technologies staff. There has been a progression of the conversation at these meetings towards more concrete issues pertaining to the actual construction and installation of instruments. As the partnership intensifies, the February IKON meetings will be hosted by ESS partner labs. The February 2015 IKON8 meeting was admirably hosted by ISIS in the UK.

The ESS Science Symposia is a successful series sponsored by ESS. Each meeting is organised by a different scientific community to address the potential of ESS in relation to the community's particular discipline. Eight of these were held over the last two years, covering a diverse range of topics, from life science to particle physics, and from green construction materials to engineering materials processing and testing. ESS benefits from each meeting by receiving a report in which scientific visions and ESS facility requirements from the different disciplines are specified.

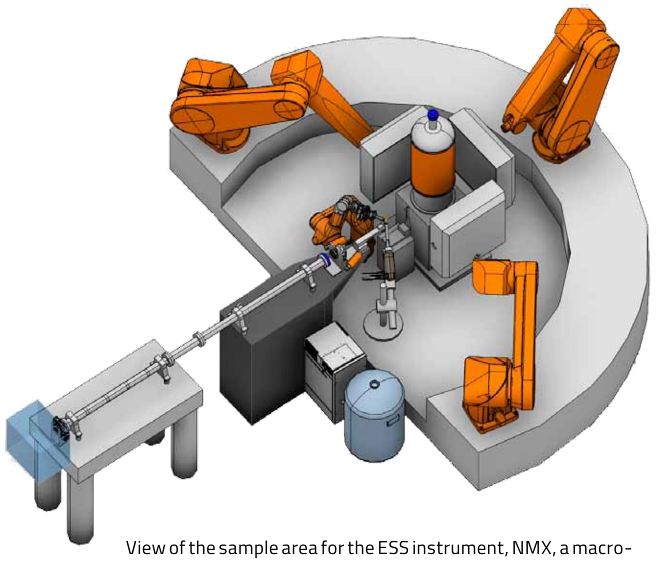
Locally, collaboration has intensified between ESS and MAX IV, the next-generation synchrotron source expected to be commissioned next year. The two organisations are working together with other regional actors to plan for Science Village Scandinavia, a hub of scientific and recreational facilities to be situated geographically between ESS and MAX IV, offering space for outstations and companies that wish to benefit from a location near both facilities.

Looking Forward

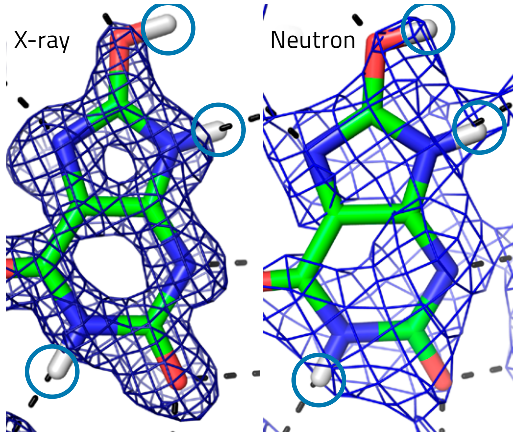
Like the entire ESS organisation, the Science Directorate has aligned its efforts in preparation for construction, marked by an intensifying engagement with partners to reach a high level of in-kind cooperation, and also by the recruitment of key competences to the team. Personnel have been appointed to the newly created Division of Scientific Projects in order to manage instrument construction and other scientific construction projects. These projects will be distributed across Europe, and a collaboration and delivery model for NSS has been developed. The Instruments Collaboration Board (ICB) is where representatives from all contributing labs work together to optimise resources for delivering the world-leading instrument suite. Together with its many partners, ESS looks forward to the continued realisation of the ESS neutron scattering systems. ☐



Detail of the neutron diffraction pattern of a protein crystal prepared by the ESS Biocrystallization Lab. The diffraction experiment was conducted on the BIODIFF instrument at FRM II near Munich, Germany, by ESS support scientist, Zoë Fisher, who also prepared the sample. (Photo: ESS)



View of the sample area for the ESS instrument, NMX, a macromolecular diffractometer with detectors mounted on robotic arms. In this view, the detectors are arranged around a cryostat for a materials science experiment. (Image: ESS)



X-ray crystallography (left) cannot usually determine the positions of hydrogen atoms (blue circles) in proteins. The neutron crystal structure (right) of urate oxidase (Oksanen et al. 2014) shows an unexpected proton that unveiled a new mechanism for the action of this enzyme. The X-ray data were collected at the ESRF synchrotron and the neutron data at the Institut Laue-Langevin, both located in Grenoble, France. (Image: ESS)

The ESS Detector Coatings Workshop in Linköping

ESS and Linköping University (LiU) inaugurated the ESS Detector Coatings Workshop in Linköping, Sweden, in November 2014. The workshop is a production facility used to apply thin films of boron-10 carbide (10B4C) onto neutron detector substrates, such as aluminum. The use of boron carbide film is a new technique for detectors, and the coated aluminum plates will serve as the neutron impact point on the new *MultiGrid* detector designed at Institut Laue-Langevin (ILL) in Grenoble, France. This is the design ESS intends to use for its first large-area detectors.

The coatings production facility is about the size of a large home and includes a single off-the-shelf, industrial-scale sputtering machine named Chewbacca. It has the capacity to produce 1000 square meters of coated plates annually. This will be enough to supply ESS with its estimated requirement of around 5000 square meters by 2020, when its first instruments and their detectors will go online.

The photograph shows Carina Höglund, a researcher in neutron detection at ESS, preparing aluminum substrate samples at Linköping University.

(Photo: ESS)

Data Management and Software Centre Key to Early Instrument Success

As the European Spallation Source instrument suite has been taking shape over the last two years, there has been a parallel acceleration in the growth and visibility of the ESS Data Management and Software Centre (DMSC). This has been evident both at the DMSC offices in Copenhagen, and in the development of potential in-kind partnerships.

The DMSC is a division of the ESS Science Directorate, and its scope includes the development of both software and hardware for:

- the experiment control interface;
- the experimental data capture, streaming, file creation, and cataloguing;
- the reduction, analysis, modeling, and visualisation of the experimental data;
- and the capabilities for ESS users to remotely analyse and download their data.

The DMSC management has been established over the last two years and the staffing of the division's five groups is ongoing in parallel with discussions on in-kind funding between the DMSC and its key institutional partners.

Data Management

This group, which is responsible for both data streaming and data file writing and cataloguing, is actively planning a schedule for instrument operations in 2019. This area is a key horizontally integrated component of instrument development and operation for ESS.

Instrument Data

This group is discussing architecture designs for the experiment control system with in-kind partners at the Paul Scherrer Institute (PSI) in Switzerland and the Science and Technology Facilities Council (STFC) in the UK.

Experiment control is a mission-critical system for ESS. The DMSC is currently engaged in defining interface controls with key ESS stakeholders and planning a development and deployment strategy that will deliver the integrated system required for operations in 2019. The key strategy in this area is to ensure that ESS has a modular system architecture that allows sufficient customisation for individual beam line requirements.

Live data reduction and visualisation is also critical to the early success of the ESS instruments, and DMSC is working with STFC to develop the software framework that will realise this objective. To this end, ESS formally joined the Mantid open source development project in October 2014. Mantid is the backbone of the software architecture that will deliver real time data reduction from the ESS data stream.

Data Analysis

This group has for a number of years been actively developing key software code for McStas and SASview, the primarily tools used for the analysis and simulation of neutron data. One key achievement is the coupling of the well-known McStas code, which simulates neutron instruments, with the reduction framework Mantid.

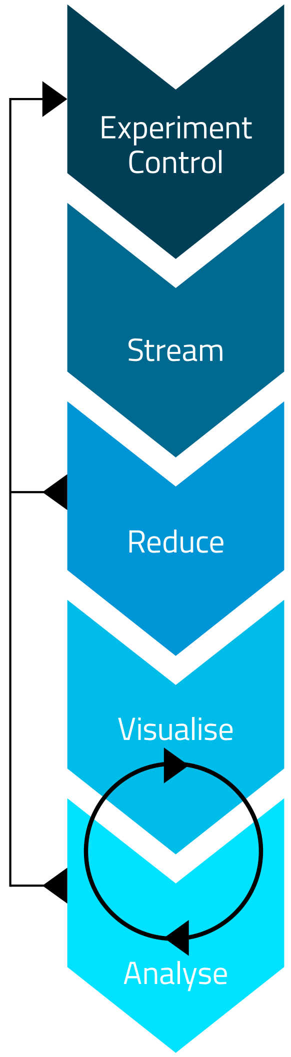
An important ethos for the DMSC is that it foster a Europe-wide collaborative network between ESS and other neutron science facilities to accelerate software development for the community. The SASview and McStas collaborations, ESS joining the Mantid collaboration, and the recent success of the Sine2020 grant proposal, which has resulted in multi-institution data research activity to be coordinated by ESS partner Institute Laue-Langevin (ILL) in France, are further evidence of this progress.

Data Systems and Technologies

This group will provide, deploy, and maintain DMSC's hardware infrastructure on which its software systems will operate in Lund and Copenhagen. This group will also be responsible for the network link passing both over and beneath the Öresund waterway between Sweden and Denmark.

From Lund to Copenhagen, and Back Again

The figure illustrates a typical data flow for a neutron scattering experiment. Each arrow in the graphic corresponds to a key area of scope within the DMSC.



The team of users configure the components of the instrument and sample environment using an experiment control system that interfaces with the neutron instrument components through the ESS EPICS network.

Data are taken in event mode whereby the individual detector counts are tagged with useful experimental metadata to create a dataset. The list of events and metadata are aggregated in software and broadcast over a network in a continuous stream of data that external software systems can utilise.

The raw data are transformed and corrected from the base unit of the instrument to a data type that is scientifically useful and valid. One of the key objectives of ESS is to take the large volumes of data and process them in as near to real time as possible.

The representation to the beamline users of a scientifically meaningful display of the corrected data.

A scientific model is generated in order to scientifically interpret the experimental data.

Data Flow / Experiment Control

A key objective is to build in from the start the capability for the interconnected software systems to control the experiment. The lines connecting parts of the data flow to the experiment control represent this functionality.

Iterative Workflow

The circle in the graphic represents the iterative workflow of scientific modelling and visualisation of model and experimental data that is often used.

Looking Forward

In 2015 the DMSC will continue to advance its development and deployment strategy. As more instrument projects move into preliminary engineering design, there will be increased focus on software requirements from instrument teams at in-kind partner facilities.

Development of the core ESS experiment control system and aspects of the core Mantid framework will begin in the third quarter of 2015. The end of 2015 will see a completed set of interface documentation for the experiment control development as well as a defined architecture and development plan.

Much of the development effort at the DMSC will come from in-kind contributions (IKCs), and the DMSC is working towards finalising these IKC agreements by the third quarter of 2015.

Lund Controls Lab

The ICS lab at the ESS offices in Lund. Urša Rojec, a contractor in the Hardware and Integration group, is shown here doing development work on a digitiser board for the Low-Level Radio Frequency (LLRF) controller to be used in connection with the ESS Accelerator. The MTCA.4 development crate includes three digitiser boards, for LLRF, the Beam Current Monitor, and the Beam Position Monitor, as well as generic digitiser functionality. (Photo: ESS)

The Integrated Control System Brings the ESS Project Together

In June 2013, what was then a group of seven staff members known as the ESS Controls Project Team, a part of the Accelerator Division, was reorganised into the ESS ICS Division. Over two years, the team has grown rapidly to a staff of 23, and is expected to reach 35 people in 2015. Additional personnel for controls are provided through framework agreements procured under European tendering rules. Three companies—Cosylab from Slovenia, Evorpo from Hungary, and Vitrociset from Italy—have been awarded contracts and will be working as partners with ICS to deliver the Control System.

The ESS Control System is a complex network of hardware, software, and configuration databases that integrates the total operations of the ESS Accelerator, Target, Neutron Instruments, and Conventional Facility infrastructures. The system is essential for the synchronisation and day-to-day operation of all equipment responsible for the production of neutrons for the experimental programs. The Integrated Control System (ICS) Division manages the activities involved in the design, construction, installation, and commissioning of the ESS Control System.

The Project Teams

The ICS Project is organised in teams for Core Hardware, Core Software, Core Protection Systems, Infrastructure, and Integration Support. The engineers in the Core Hardware and Core Software teams develop the infrastructure for ESS Controls based on project-wide requirements gathered by the Integration Support team. The Core teams then provide the needed control system components to Integration Support, who in turn use these components to develop vertically integrated controls for the various sub-systems of the ESS facility.

The Core Protection Systems teams are developing two systems: the Machine Protection System (MPS) for protection of equipment in the event of beam failure conditions; and the Personnel Safety System (PSS) to prevent workers from oxygen deficiency or exposure to prompt radiation. Finally, the Infrastructure team will build the Control System networks as well as the ICS server hall and main control room.

Looking Forward in 2015

Presently ICS is working to establish in-kind partnerships for the delivery of control system integration. In particular, the controls group at CEA Saclay, in France, has been working with ICS for over a year to plan for the controls integration of the first Accelerator components, the Proton Source (PS), and Low Energy Beam Transport (LEBT). Other ESS partners that ICS has initiated discussions with include CNRS/IPN Orsay, in France, for cryo-distribution system control; ESS-Bilbao, in Spain, for Medium Energy Beam Transport (MEBT) controls; INFN-Legnaro National Laboratories, in Italy, for Drift Tube Linac (DTL) controls; Institute for Energy Technology (IFE)-Halden, in Norway, for the design of the main control room; and again with CEA Saclay for the Radio Frequency Quadrupole (RFQ) control.

In 2015, ICS expects to begin work with the Paul Scherrer Institut (PSI), in Switzerland, to convert a multi-purpose, high-performance electronic platform from its current VME form factor to one based on the uTCA.4 standard. The deployment of this platform at ESS on uTCA.4, already in use at PSI on the VME platform, will be developed as an in-kind contribution from Switzerland. Additionally, there will be work on the timing system in 2015. A native timing receiver for the uTCA.4 platform should become available for testing from our supplier, Micro Research Finland (MRF), later this year.

ESS Steering Committee

Sweden	Lars Börjesson (Chair)
Czech Republic	Petr Lukáš
Czech Republic	Ivan Wilhelm
Denmark	John Renner Hansen
Denmark	Bo Smith
Estonia	Toivo Räim
France	Christian Chardonnet
France	Philippe Ferrando
Germany	Sebastian Schmidt
Germany	Beatrix Vierkorn-Rudolph
Hungary	László Rosta
Iceland	Sveinn Ólafsson
Italy	Eugenio Nappi
Italy	Caterina Petrillo
Latvia	Leonids Buligins
Lithuania	Stanislovas Žurauskas
Netherlands	Nico Kos
Netherlands	Bert Wolterbeek
Norway	Bjørn Jacobsen (Vice-chair)
Poland	Bogdan Palosz
Poland	Marek Jezabek
Spain	José Luis Martinez
Spain	Inmaculada Figueroa Rojas
Sweden	Mats Johnsson
Switzerland	Joël Mesot
Switzerland	Martin Steinacher
United Kingdom	Neil Pratt
United Kingdom	Andrew Taylor

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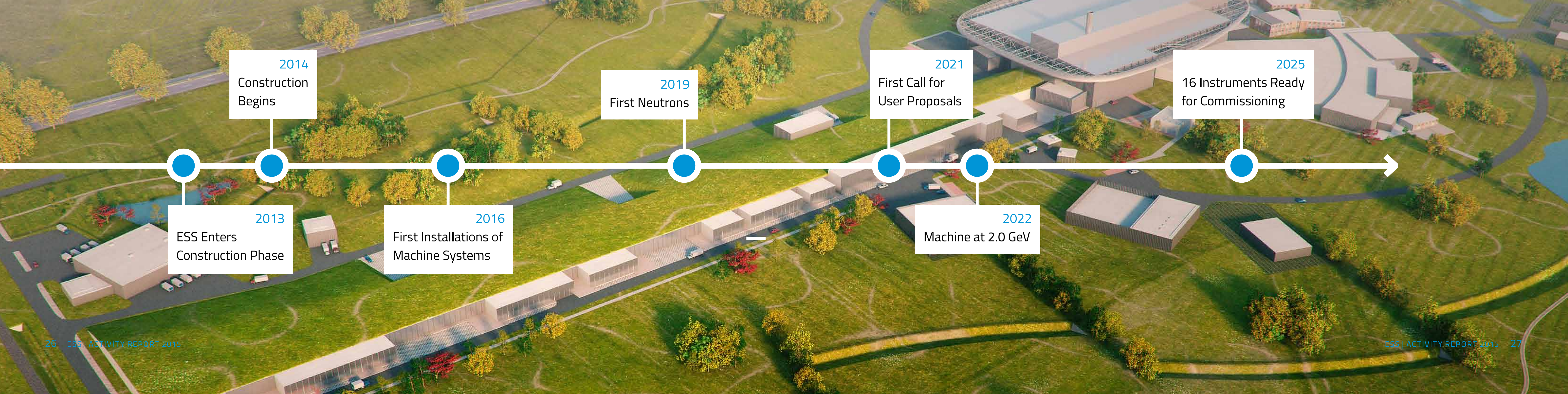
Sweden	Katarina Bjelke
	Lars Börjesson
	Per Eriksson
	Sven Landelius (Chair)
	Lena Gustafsson
Denmark	Kim Graugaard
	Hans Müller Pedersen
	Bo Smith (Vice Chair)
ESS employee representative	Mikael Palade

(Photo: ESS)

ESS Management Team

Director General & CEO	James H. Yeck
Director of Science	Dimitri Argyriou
Director of Technology	Roland Garoby
Director of Project Support & Administration	Matti Tiirakari
Deputy Director of Project Support & Administration	Therése Welander
Associate Director of Operations, Environment, Safety & Health, and Quality Assurance	Patrik Carlsson
Head of Conventional Facilities Division	Kent Hedin
Head of Communications & External Relations Division, and In-Kind Group	Allen Weeks
Strategic Project Advisor	Pia Kinhult

The ESS Timeline



2013
ESS Enters Construction Phase

2014
Construction Begins

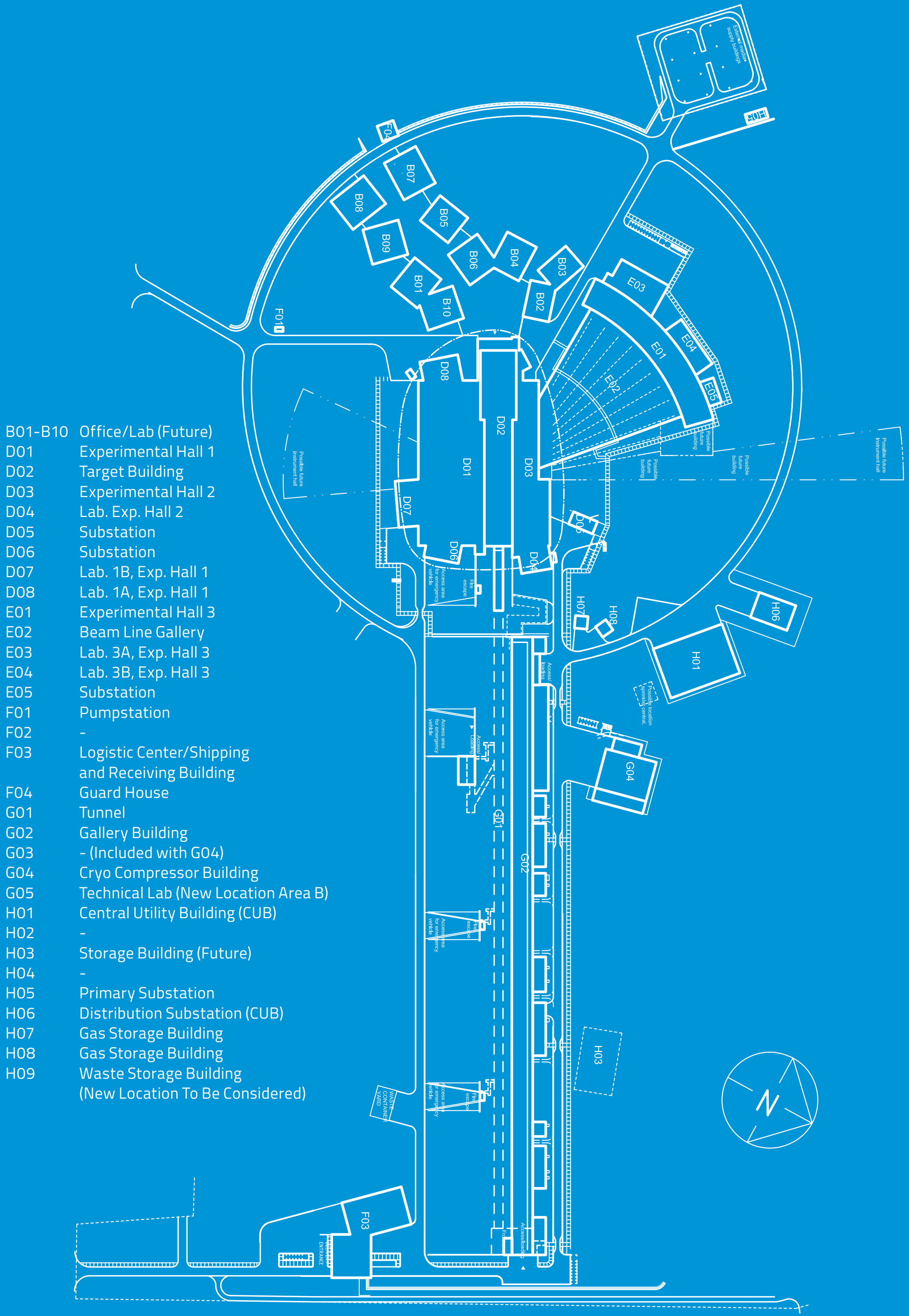
2016
First Installations of Machine Systems

2019
First Neutrons

2021
First Call for User Proposals

2022
Machine at 2.0 GeV

2025
16 Instruments Ready for Commissioning



B01-B10	Office/Lab (Future)
D01	Experimental Hall 1
D02	Target Building
D03	Experimental Hall 2
D04	Lab. Exp. Hall 2
D05	Substation
D06	Substation
D07	Lab. 1B, Exp. Hall 1
D08	Lab. 1A, Exp. Hall 1
E01	Experimental Hall 3
E02	Beam Line Gallery
E03	Lab. 3A, Exp. Hall 3
E04	Lab. 3B, Exp. Hall 3
E05	Substation
F01	Pumpstation
F02	-
F03	Logistic Center/Shipping and Receiving Building
F04	Guard House
G01	Tunnel
G02	Gallery Building
G03	- (Included with G04)
G04	Cryo Compressor Building
G05	Technical Lab (New Location Area B)
H01	Central Utility Building (CUB)
H02	-
H03	Storage Building (Future)
H04	-
H05	Primary Substation
H06	Distribution Substation (CUB)
H07	Gas Storage Building
H08	Gas Storage Building
H09	Waste Storage Building (New Location To Be Considered)

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