ESS PROGRESSING INTO CONSTRUCTION

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Abstract

The construction of the European Spallation Source, ESS, started in summer 2014. At the site in Lund, the accelerator tunnel will be completed at the time of IPAC16, while prototyping and manufacturing or preparations for manpower contributions are going on in more 23 laboratories distributed over the 12 European countries collaborating on the accelerator project. Major technical milestones have been reached include the testing of superconducting cavity prototypes of two families to values above design gradients, the first ESS modulator has been tested to 90 kV and the first klystron prototype has been received in April 2016. Equally important developments are taking place at many partner laboratories. The presentation will summarize the status of the ESS accelerator project by the time of IPAC16.

INTRODUCTION

The European Spallation Source (ESS) [1] has a long history with many re-incarnations. ESS is now finally under full construction in Lund in Sweden with 15 countries being founding members or observers of the European Spallation Source European Research Infrastructure Consortium (ESS ERIC), which now is the owner of the construction project and the future ESS neutron research facility.

The design of a 5 MW European spallation source [2] started in the early, in 2003 a site competition was initiated and in 2009 14 European countries decided to build the facility in Lund. Since the site decision the project has gone through a design update, an in-kind construction model has been agreed, financial and organisational matters have been resolved, an organisation with more than 350 employees from more than 45 countries have been set-up at a green-field site and the construction has started. In this paper I will report on the present status of ESS.

ESS IN BRIEF

The ESS facility will be the first long-pulse neutron spallation source in the world. The long pulse concept was first proposed by F. Mezei [3] and takes advantage of the relatively long moderation time for the creation of cold neutrons to relax the requirements on the pulse length from the accelerator. The main parameters of ESS can been seen in table 1. The neutron pulse length is 2.86 ms (see Fig. 1) with a repetition rate of 14. The neutron pulse length is set by the proton pulse length and for 5 MW average power (125 MW peak power) it is possible to create the proton pulses directly from a linear accelerator avoiding an accumulation ring. This is important as an accumulation ring for 5 MW is very challenging to construct and a target for very short 125 MW pulses is difficult to conceive even conceptually. The longer ESS pulses can be created with state of the art linear accelerator technology and with the longer pulse rastered over the target surface the target design is very feasible. The target at ESS will be a rotating helium gas cooled Tungsten target rotating at about 0.4 Hz. The resulting neutron pulses requires new instrument designs and concepts to fully benefit from increased brightness at ESS and today 11 instruments projects are already agreed with new and exciting designs for the future science program. Another instrument design is under way and within the construction budget in total 16 instruments will be built. Furthermore, a new flat moderator design pioneered at ESS will increase the brightness of the facility making it up to in total 100 times more powerful than existing neutron sources. Supporting facilities for sample preparation and data management are also being set-up as part of ESS. The data management facility will be located in Copenhagen.

Table 1: ESS Accelerator Main Parameters

Average beam Power	5 MW
Peak beam power	125 MW
Pulse Length	2.86 ms
Peak beam current	62.5 mA
Repetition rate	14 Hz
Duty cycle	4%

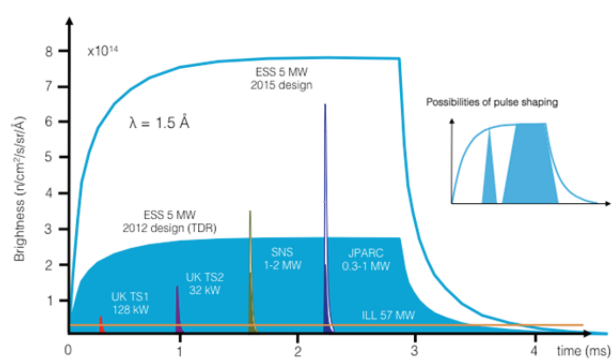

Figure 1: The ESS neutron pulse compared to other neutron research facilities.

The ESS Linear Accelerator

The ESS ion source produces a proton beam that is transported through a Low Energy Beam Transport

(LEBT) section to the Radio Frequency Quadrupole (RFQ) where it is bunched and accelerated up to 3.6 MeV. In the Medium Energy Beam Transport (MEBT) section the transverse and longitudinal beam characteristics are diagnosed and optimized for further acceleration in the Drift Tube Linac (DTL). The first superconducting section consists of 26 double-spoke cavities (SPK) with an optimum beta value of 0.50. The spoke cavities are followed by 36 Medium Beta Linac (MBL) elliptical cavities with β = 0.67 and 84 High Beta Linac (HBL) elliptical cavities, with β = 0.86. After acceleration the beam is transported to the target through the High Energy Beam Transport (HEBT) section and rastered on the target using an active fast magnet beam delivery system. A block diagram of the ESS accelerator design can be seen in Fig. 2.

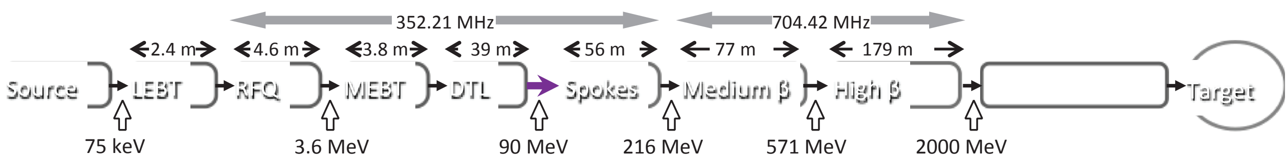

Figure 2: A block diagram of the ESS accelerator.

ESS - AN IN-KIND PROJECT

The ESS facility is being built by a collaboration of European laboratories with the major part of the contributions coming as in-kind. The host state contribution of the total budget of 1.843 M€$_{2013}$ is close to 50% and is all cash. For the budget distribution, see Fig. 3.

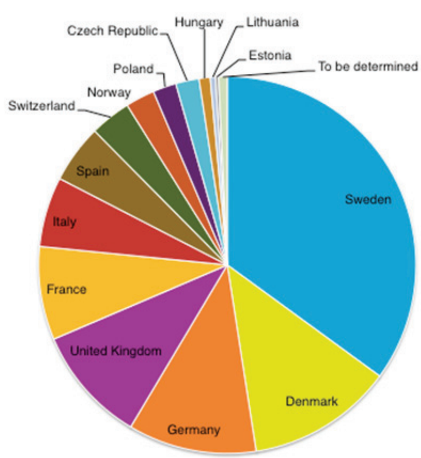

Figure 3: The total budget for ESS is 1.843 M€$_{2013}$ with Denmark and Sweden as host states contributing with almost 50% of the budget. Together with the 12 other countries some 99% of the construction budget is guaranteed today and more countries are planning to join.

The remaining 12 countries aim for some 75% of their contributions being in-kind (see Fig. 4) on how this target is distributed on in-kind goals for the main projects at ESS. This very large fraction of in-kind is a challenge for the project and every effort is made to learn from the experience of other in-kind projects to set up an efficient in-kind process and management. The European union has given a grant of almost 20 M€ (Brigthness under EC Horizon 2020) to help with the in-kind processes.

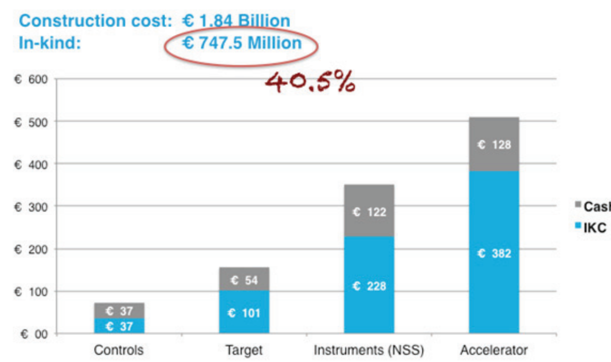

Figure 4: The in-kind goals for ESS for accelerator, target, integrated control system and instruments.

ESS ACCELERATOR COLLABORATION

Possible IK partners to the Accelerator project have been identified in Denmark, Estonia, France, Germany, Hungary, Italy, Norway, Poland, Spain, Sweden, Switzerland, and UK. Contract negotiations are going on with 23 partner organizations in these countries. A little over 40 IK Technical Annexes describing the scope of work are expected with these organizations.

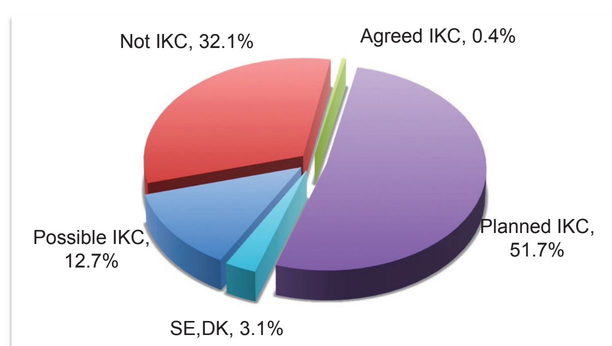

Figure 5: The ESS accelerator project has today secured 51.7% of the budget as In-Kind contributions. To that should be added 3.1% from the host states, which formally can't be counted as In-Kind.

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The process to formally sign complete in-kind agreements which includes both a general legal framework agreement for the country or research organisation in question and Technical annexes which regulates the scope of work, budget according to cost book values and schedule is lengthy and today full formal In-Kind Agreements have been signed with two partners for 0.4% of the accelerator budget. However, the value of planned agreements represents 51.7% (see Fig. 5) of the accelerator budget and work is progressing with so called heads of agreements (a form of letter of intent) while completing the full formal agreements. Host countries cannot formally give in-kind contributions and their share represent 3.1% of budget. There is still another 12.7% marked as possible in-kind in the accelerator project budget. It is important for ESS to find partners also for the ”possible” and work continues to secure that.

In brief and in alphabetic order here is a list of the main contributions from the IK partners: Aarhus university are delivering the beam rastering system which helps reduce the thermal stress on the target. Atomki in Hungary are delivering the interlock system for the RF sources. CEA-Saclay provides the RFQ, prototypes elliptical cavities, assembles the elliptical cryomodules and builds some of the beam instrumentation. The elliptical cryomodule design is a joint undertaking with IPNO-CNRS (see Fig. 6).

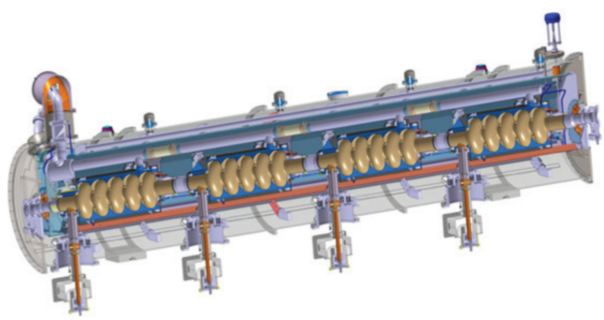

Figure 6: The elliptical cryomodule design is similar to the design is a joint undertaking by CEA and IPNO-CNRS. Picture courtesy of CEA and IPNO-CNRS.

The Cockcroft institute in Daresbury are contributing to the design of the imaging system. DESY is contracted to do beam diagnostics and support LLRF developments. Elettra in Trieste will deliver Spoke RF sources at 352 MHz, the magnets and associated power supplies for the linac and the beam transport together with electronics for beam instrumentation. ESS-Bilbao do the Medium Energy beam transport system (see Fig. 7) which is very important for controlling beam loss, the RF sources for the warm linac and some beam instrumentation and a beam dump. EPFL in Lausanne delivers the medium beta modulators. IFJ PAN in Krakow will do installation of the test stand for elliptical cryomodules and of the RF systems. INFN delivers the ion source (see Fig. 8), the Low energy Beam transport, the Drift Tube Linac and the medium beta elliptical cavities.

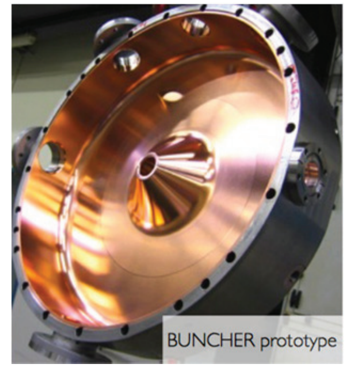

Figure 7: The buncher cavity for the Medium energy beam transport (MEBT) section. The complete MEBT is provide as an in-kind contribution from ESS-Bilbao. Picture courtesy of ESS-Bilbao.

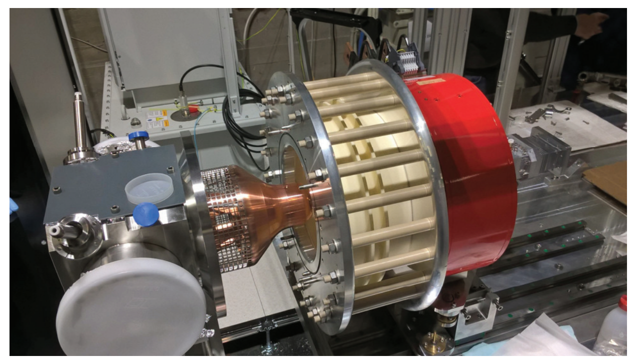

Figure 8: The ion source is a Microwave Discharge Ion Source and is designed and built by INFN in Catania. Picture courtesy of INFN-LNS.

IPNO-CNRS provides the complete spoke cavity (see fig. 9) part of the linac with the cryodistribution system.

Figure 9: A spoke cavity under chemical etching at INO-CNRS at the SupraTech facility. The complete spoke cryomodules with cavities are designed and built by IP-NO-CNRS. All three prototype double spoke cavities performed well above specifications in a vertical cryostat test. Picture courtesy of IPNO-CNRS.

Huddersfield University will deliver the RF distribution system. Lund University are contracted for support with modulator development and integration test stand and are developing the LLRF systems. Lodz University, NCBJ in Swierk and Warzaw Univeristy of Technology are providing the LLRF systems in a consortium between the three institutes and in collaboration with Lund University. Warzaw University of Technology also provides the phase reference line. Wroclaw University of Technology does the cryodistribution system. University of Oslo does the beam imaging system on the target and university of Bergen provides specialist support for the ion source. Uppsala University is contracted for testing and prototyping at 352 MHz with a new test facility – FREIA – now operational in Uppsala. STFC in Daresbury does the design and assembly of all the warm magnet sections in the linac, the differential pumping sections and provides all the high beta elliptical cavities. Finally, Tallin University are doing a design for modulators for the IOT tubes driving the high beta elliptical part of the linac.

ESS ACCELERATOR DIVISION

The Accelerator Division is recruiting according to plan and has grown from two people in early 2009 to some 84 permanent and contracted staff today. The main task is presently integration and coordination of the in-kind contributions to the ESS accelerator and preparations for installation, commissioning and operation phase. However, important efforts including new technical developments are also done at ESS.

The Specialized Technical Services (STS) Group provides cryogenics, vacuum, technical electrical and technical cooling support throughout the ESS project. Highlights for the last year include: ordering of all 3 helium cryoplants and completion of detailed design of the cryogenic distribution system, production of the linac warm unit prototype and the start of testing in the ESS Lund vacuum labs. Final designs of the technical cooling and electrical systems as well as the final design of the Lund cryomodule test stand were also accomplished. STS is also developing vacuum requirements and design options with the target and neutron science projects. The Linac group provides linac integration and develops interface requirements for both the linac itself but also for important systems such as the Machine Protection System and the Personal Protection System. It also coordinates all the linac in-kind contributions and trains and recruits future experts for all linac sub-systems. The Engineering Services group provides accelerator wide services such as system engineering, CAD model integration, interfaces to the conventional facilities, follow-up of conventional facilities construction and the construction of an integration test stand at ESS (see Fig. 10). The Beam Physics, Beam diagnostics and operations group leads the beam physics work, coordinates IK contributions to beam instrumentation and also provides some beam instrumentation as in-house developments. It also prepares the project for the commissioning and operations phase. The Safety group works on all safety aspects including shielding and activation calculations with Monte Carlo codes, industrial safety issues and oxygen deficiency studies for the cryogenic parts of the linac. It also does reliability and availability calculations for all of ESS, which is very important as the time for prototyping at ESS is short. The RF group has done the overall RF design work for ESS, manages the procurement of prototype klystrons and the industrial development of a high power multi beam IOT and coordinates all IK contributions for RF at ESS. It also develops the interlocks systems in collaboration with an in-kind partners and develops and manages power supplies for the accelerator. A unique development at ESS are the switched multi-level modulators which been designed and prototyped locally at ESS in collaboration with Lund Univeristy. This type of modulator has no impact on the local power grid thanks to the switched multi-level design and can be made very compact (see Fig. 11). The accelerator division also provides services for project wide quality assurance and control and administrative support.

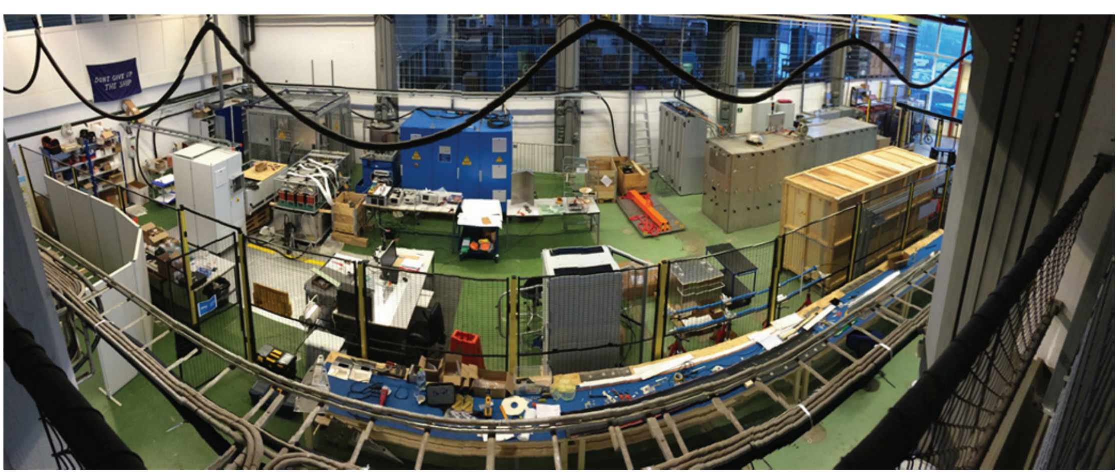

Figure 10: The ESS integration test stand with a modulator, a 352 MHz klystron and other RF equipment on loan from CERN. To the left the modulator test stand can be seen. Picture courtesy of David McGinnis, ESS.

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CONCLUSION

The project is now in the construction phase with prototypes being assembled and tested according and the low energy part under construction and is progressing according to plan towards first beam at 572 MeV in June 2019. The project has been made possible at a green field site hosted in a region with no or little previous experience of constructing a large accelerator based international facility thanks to in-kind contributions. The in-kind model for construction of such a facility is not only a financial model enabling countries to contribute through national institutes and universities but also a way to gather unique know-how for a larger common goal. The European Spallation source will give the global research community a unique facility for neutron scattering research and fundamental neutron physics and it will also enhance European capability for collaboration for future large scale research facilities.

Figure 11: The Switched multi-level modulator prototype design and built at ESS. The prototypes is built for 120 kVA but the operational modulators will be for 660 kVA and will be provided as in-kind. Picture courtesy of Carlos Martins, ESS.

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REFERENCES

[1] ESS, https://europeanspallationsource.se

[2] ESS Technical Design Report, ESS-2013.001, April 2013, Editor Steve Peggs.

[3] F. Mezei, "Comparison of neutron efficiency of reactor and pulsed source instruments", Proc. of ICANS-XII (Abingdon 1993) (RAL Report No. 94-025), I-137 and F. Mezei, "The raison d'être of long pulse spallation sources", J. Neutron Research 6 (1997) 3-32