# THE ESS ACCELERATOR: MOVING INTO CONSTRUCTION

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*Abstract*

The ESS accelerator construction has started and the tunnel and RF gallery will be handed over to the accelerator division in 2016 with the installation of the cryoplant starting in early 2017. Beam should be delivered in June 2019 at 570 MeV and 1.5 MW with full 5 MW capability being available in 2023. The project is a highly contributed project with more than 50% of the total budget being contributed IK by more than 25 IK partners. This paper will review the project status reflecting the IK nature of the project with the many partners' contributions and with some focus on the cryogenics systems.


## INTRODUCTION

The European Spallation Source (ESS) is a new facility currently under construction in Lund, Sweden. Upon completion, ESS will be a neutron source providing world-class capabilities for research in a wide range of topics in materials science and physics.

The neutrons at ESS will be generated via the spallation process when a high power proton beam, produced by a linear accelerator, collides with a rotating Tungsten target. The resulting neutrons then travel to up to 23 instruments where they are use in scientific studies. The overall ESS project is well described in [1].

The ESS proton linac is required to produce a beam of 2 GeV energy with a current of 62.5 mA, a pulse length of 2.86 ms and a repetition rate of 14 Hz. This results in an average beam power of 5 MW with a peak beam power of 125 MW. This will constitute the world's most powerful proton linear accelerator. Figure 1 is a schematic of the ESS accelerator. Additional details on the accelerator may be found in [2 -3].

The ESS accelerator is moving out of the design phase and into construction with almost all of the accelerator components being under construction by May of 2017. This paper will describe the current status of the ESS accelerator components with additional emphasis on the accelerator cryogenics system. A brief overview of the status of the accelerator buildings and tunnel is also presented.

## IN-KIND PARTNERS

A significant feature of the ESS project is the use of In-Kind partners. More than 50% of the accelerator project, including almost 100% of the beam line components are provided by 27 different institutions throughout Europe.

The current distribution of In kind partners is shown in Fig. 2. Effective communication and coordination with these partners is a vital aspect of the ESS project. These institutions are not subcontractors but rather are full partners in the ESS project. The In-Kind partner institutions, for example, all have representation on the Accelerator Technical Board which oversees and directs the construction of the accelerator.

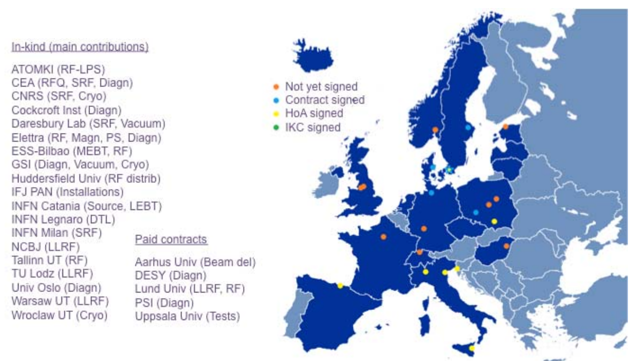


Figure 2: Current In-kind partners for the ESS accelerator.

## DESIGN REVIEWS

In order to ensure proper performance, all accelerator components, regardless of their origin, undergo at least one Preliminary Design Review (PDR) and one Critical Design Review (CDR). These reviews examine all aspects of the design including performance, safety, quality and reliability. The review committees consist of members of the ESS project along with external experts when required. Generally speaking, once a component has completed its CDR, it moves from design into procurement and construction. This year represents the peak for accelerator component design reviews at ESS with roughly 50 reviews being held in 2017.

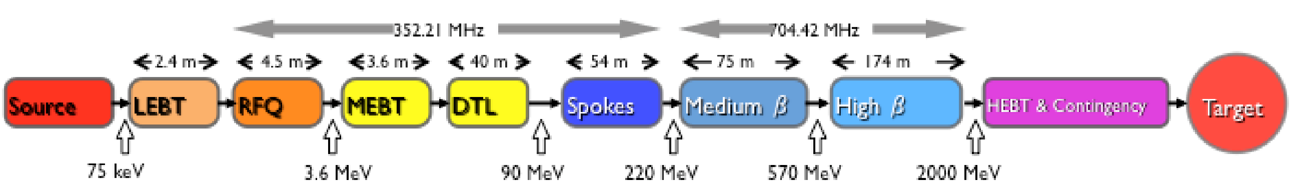


Figure 1: Schematic of the ESS accelerator.

## ACCELERATOR STATUS

### *Normal Conducting Front End*

**Ion Source** The Ion Source and associated Low Energy Beam Transport (LEBT) system is provided by INFN Catania. Construction of the first ion source is near completion with the first plasma generated in the source, see Fig. 3, and the first beam extraction expected before October 2016. Installation of the Ion Source and LEBT in the ESS tunnel is expected in the third quarter of 2017.

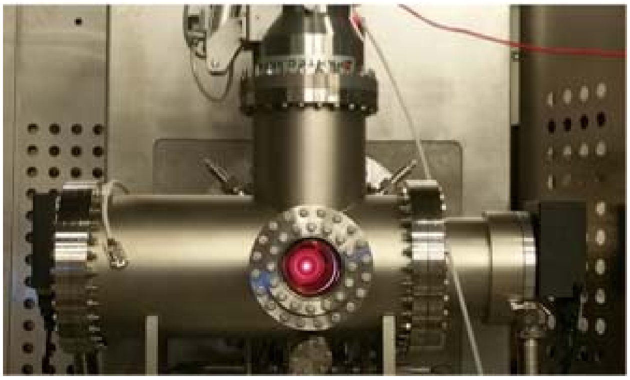

Figure 3: First plasma in the ESS Ion Source. Photo courtesy of INFN Catania.

**Radiofrequency Quadrupole (RFQ)** The RFQ is provided by CEA Saclay and completed its final CDR in December of 2015. The copper for the RFQ has been procured and has undergone hot isostatic pressing. Machining of the RFQ will begin shortly with final assembly at the ESS site in Lund scheduled for Q2 2018.

**Medium Energy Beam Transport (MEBT)** This device is being contributed by EES Bilbao with additional beam instrumentation contributions from a number of contributors. Prototype bunchers and magnets have been built and tested. The bunchers, magnets and beam instrumentation have all completed preliminary design reviews with a CDR of the complete MEBT planned for early 2017. The MEBT is scheduled to be installed in the ESS tunnel in mid 2018

**Drift Tube Linac (DTL)** The DTL is provided by INFN Legnaro. The CDR for the DTL was finished in June 2016 and procurement of the DTL has started. Prototype Beam Position Monitors have been built and various construction techniques, such as e-beam welding, have been qualified. Assembly of the 5 DTL tanks is planned to start at the ESS site in Mid 2018

### *Superconducting Linac*

The superconducting portion of the linac provides roughly 90% of the beam acceleration and consists of 3 types of superconducting cavity cryomodules: double spoke, medium beta elliptical and high beta elliptical. All the superconducting cavities operate at 2 K. Linac Warm Units (LWUs) separate each cryomodule. The LWUs operate at room temperature and contain correction, steering and focusing magnets, beam instrumentation and vacuum pumping ports. Details on the superconducting linac may be found in [4].

**Spoke Cryomodules** The spoke cavities and their cryomodules are being provided by IPN Orsay. Tests of prototype cavities has demonstrated that they exceed ESS requirements and a test of the complete prototype spoke cryomodule is planned for early 2017. The completed spoke cryomodules will start to arrive at the ESS site in 2018.

**Medium Beta Elliptical Cryomodules** The medium beta elliptical cavities will be provided by INFN Milano. A test of a prototype cavity (based on a CEA Saclay design) showed that it exceeded the ESS requirements. Tests of prototype cavities based on an INFN design are expected in the fourth quarter of 2016.

Both the medium beta and high beta cavity cryomodules will be assembled at CEA Saclay. The cryomodule design was produced by IPN Orsay. A prototype medium beta cryomodule will be tested by the end of 2016. Medium beta cryomodules will start to arrive at the ESS site in Q4 2017.

**High Beta Elliptical Cryomodules** These crymodules will be added to the linac after 2019 to boost the beam energy from 570 MeV to the final 2 GeV ESS requirement. Tests of high beta prototype cavities designed by CEA Saclay show that they exceed ESS specifications. The production high beta cavities will be supplied by STFC Daresbury. A prototype high beta cavity cryomodule will be tested in 2017.

**Linac Warm Units (LWUs)** These are being supplied by STFC Daresbury with the magnets supplied by the Elettra Laboratory and beam instrumentation supplied by a variety of sources. The LWUs and magnets have both completed their CDRs and procurement and construction of these components has started. The first prototype LWU has been delivered to ESS. See Fig. 4.

Figure 4: Prototype LWU (with mock-ups of magnets) at ESS.

**Beam Delivery System** The final stage of the accelerator is the beam delivery system that moves the beam across the target surface to prevent overheating. This is accomplished by a rastor magnet system provided by Aarhus University. A solid model of this system is shown in Fig. 5. Procurement of this system has begun with first article production underway.

**Beam Instrumentation** A complex suite of beam instrumentation is distributed throughout the accelerator. These devices come from a number of in-kind partners, and vendors. PDRs and CDRs have been completed for many of these devices with prototypes already delivered for inclusion in the ion source and LEBT.

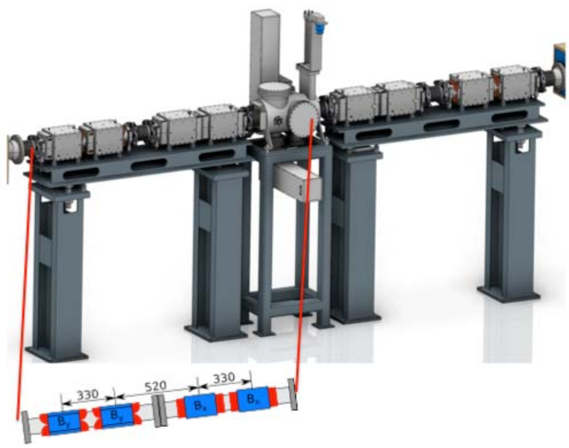


Figure 5: Beam delivery system.

### *RF Sources and Modulators*

The systems providing the radiofrequency power to the accelerator components are some of the most complicated and expensive parts of the accelerator project. A variety of RF sources, some provided by In-Kind Partners and some purchased directly are used in the design. These are summarized in Table 1.

Table 1: ESS RF Sources

| Frequency | Component | Solution | In-Kind? |
|---|---|---|---|
| 352.2 MHz | RFQ/DTL | Klystrons | Yes (ESS Bilbao) |
| 352.2 MHz | MEBT Bunchers | Solid State | Yes (ESS Bilbao) |
| 352.2 MHz | Spoke cavities | Tetrodes | Yes (Elettra) |
| 704.4 MHz | Medium Beta Elliptical Cavities | Klystrons | No |
| 704.4 MHz | High Beta Elliptical Cavities | Klystrons or IOTs | Possible |

A number of prototype sources have been ordered and manufacturing will be fully underway in 2017.

An innovative 660kVA modulator [5], that will power most of the RF sources, has been designed by a collaboration of ESS and Lund University. A reduced scale prototype has been successfully tested and the PDR has been completed. The CDR and start of production of these modulators is expected in late 2016 to early 2017.

## CRYOGENIC SYSTEM

Ninety percent of the beam acceleration is accomplished by superconducting RF cavities. The operating temperature of these cavities is 2 K. Thus, a significant cryogenic system is required for ESS. The cryogenic system consists of three cryoplants; one to cool the accelerating structures, one to cool the 20 K hydrogen moderator surrounding the target and one to provide liquid helium for the neutron instruments. These cryoplants are supported by distribution systems and by an integrated helium recover, purification and storage system. Details on the complete ESS cryogenic system may be found in [6].

The Accelerator Cryoplant (ACCP) [7] provides up to 3 kW of cooling at 2 K with an additional 11 kW of cooling at 50 K for the cooling of the thermal shields in the cryomodules and distribution line. This plant is under construction by Linde using a detailed technical specification provided by ESS. The final CDR for this cryoplant was completed in September 2016. Figure 6 shows the solid model of the ACCP cold box and Fig. 7 shows the completed, machined top plate for that cold box All helium compressors (made by Aerzen) for the ACCP have passed their factory acceptance tests. An example of one of these tests is shown in Fig. 8.

Delivery of the first ACCP components (the helium compressors) to the ESS site will start in March 2017.

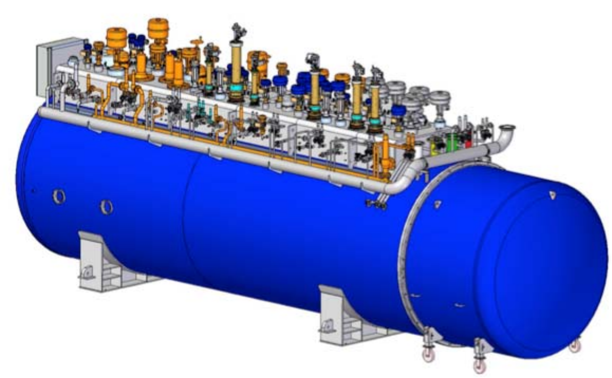

Figure 6: Solid model of the ACCP cold box.

Figure 7: Machined top plate of the ACCP cold box.

Figure 8: Factory acceptance testing of one of the ACCP helium compressors at Aerzen.

The ACCP is connected to the cryomodules in the accelerator tunnel via a Cryogenic Distribution System (CDS) [8]. The CDS permits independent warm-up and cool-down of cryomodules via a distribution line that runs parallel to the linac. Two In-Kind Partners provide the CDS. Wroclaw University of Science and Technology provides the elliptical cavity cryomodule distribution line, including the connection between the tunnel and the ACCP. IPN Orsay provides the spoke cavity cryomodule distribution line. The CDR for the elliptical cavity cryomodule line has been completed and this section is in procurement. The PDR for the spoke cavity cryomodule line has been completed with the CDR planned for February 2017. Additionally, a prototype valve box for the spoke cavity cryomodule distribution line has been constructed and will be tested soon. The elliptical cavity cryomodule distribution line design is shown in Fig. 9 and components for the prototype spoke valve box are shown in Fig. 10.

## CONVENTIONAL FACILITIES PROGRESS

Significant progress has been made on the ESS site since construction started in the summer of 2014. The accelerator tunnel is now complete and both the cold box Hall (which will contain the cryoplant cold boxes) and the helium compressor facility are nearing completion and will be partially turned over to the accelerator project in November 2016. The first significant installation of technical equipment, warm helium gas piping in the cold box hall and compressor building, will also start in November 2016. Figure 11 shows a view of the accelerator tunnel while Fig. 12 show the interior of the cold box hall. An aerial view of the overall ESS site is shown in Fig. 13.

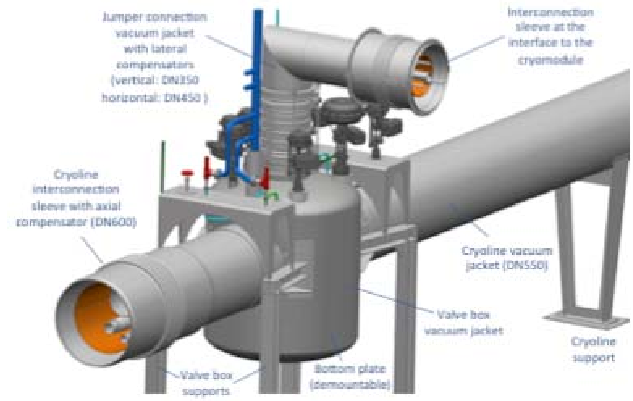


Figure 9: Design of elliptical cavity cryomodule distribution line.

Figure 10: Prototype spoke cavity cryomodule distribution line valve box under construction.

Figure 11: View of the ESS accelerator tunnel. The tunnel is 5 m wide by 3.5 m high

Figure 12: Cold box hall.


Figure 13: Aerial view of ESS site. The ion source of the accelerator is located on the far right of the photo.

## CONCLUSION

The ESS accelerator is moving from design into construction. The majority of design reviews will be completed in 2016 and production by in-kind partners and industry has begun on many important components. Accelerator buildings are nearly complete and will start to be turned over to the ESS in late 2016. Significant accelerator installation activities on site will begin in November 2016. The current goal is to have beam ready for the target by July 2019.

## ACKNOWLEDGEMENT

This work describes the efforts of more than 200 people working at ESS, in partner institutions and in industry. It is the talent and hard work of these people that will make the ESS accelerator a success.

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