ESS Vacuum System
A neutron facility

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Specialized Technical Service
Vacuum System Section Leader
European Spallation Source ERIC
- Neutron introduction,
- ESS Vacuum responsibilities,
- Vacuum Standardization, an Integrated Approach,
- ESS vacuum system Accelerator/Target/Instruments
- Vacuum Support.
Vacuum for what?

Why we need vacuum for a particle accelerator?

Why we need vacuum on a SRF LINAC?
Movie made by Neutron imaging and Activation Group, ICON Instrument. Paul Scherrer Institut, CH
X-ray interacts with electrons in the atoms. The heavier is the atom the larger is the absorption.

Neutrons interact with nucleus and have a very different absorption contrast.

MAX IV
Radiograph of an analog camera: by neutrons (top) by X-rays (bottom). While X-rays are attenuated more effectively by heavier materials like metals, neutrons make it possible to image some light materials such as hydrogenous substances with high contrast: in the X-ray image, the metal parts of the photo apparatus are seen clearly, while the neutron radiograph shows details of the plastic parts.
Reactor Sources

- X-10
- CP-2
- CP-1
- Berkeley 37-inch cyclotron
- 350 mCi Ra-Be source
- Chadwick

Spallation Sources

- ISIS
- IPNS
- SINQ
- IPNS
- SNS
- FRM-II
- ESS
- OPAL
- PIK
- J-Parc
- CSNS
- PIR

Effective thermal neutron flux n/cm²-s

ESS Long-pulse performance

Brightness (n/cm²/s/sr/Å)

\( \lambda = 1.5 \, \text{Å} \)

- ESS 5 MW
  - 2015 design
  - 2013 design (TDR)
- ISIS TS1
  - 128 kW
- ISIS TS2
  - 32 kW
- SNS
  - 1-2 MW
- JPARC
  - 0.3-1 MW
- ILL
  - 57 MW

Time (ms)

\( \times 10^{14} \)
Road to realizing the world’s leading facility for research using neutrons

- **2003**: First European design effort of ESS completed
- **2009**: Decision: ESS will be built in Lund
- **2012**: ESS Design Update phase complete
- **2014**: Construction work starts on the site
- **2019**: First neutrons
- **2023**: ESS starts user program
- **2025**: ESS construction complete

50+ Partners and growing

<350 Employees

48 Nationalities
The ESS organization charges the ESS Vacuum System team with the responsibility for all ESS vacuum systems including not only the Accelerator, but also Neutron Instruments and Target.

The main task of the team is to support the in kind contributions on the vacuum system and the integrated vacuum design of the ESS complex.
Vacuum Standardization
an Integrated Approach

Working closely with our partners across the project, one of our primary goals was to **promote** the use of **common vacuum equipment and standards**. As a result a Vacuum Standardization meeting was held in February 2014 where equipment suitable for Standardization was agreed and reflected in the ESS Vacuum Handbook.

An important element of this **standardization** is the Vacuum Procurement Policy. The primary objective of the program is to develop a list of standard vacuum equipment through a **Vacuum Framework Agreement (VFA)** for use project wide to minimize project costs, reduce spares holdings, training and achieve other benefits of standardization. The **VFA** was made in conjunction with **UK** and **France**.

https://europeanspallationsource.se/vacuum
Vacuum Control System

ICS team responsibility

Vacuum team responsibility
The European Spallation Source (ESS) is a multi-disciplinary research centre based on the world’s most powerful neutron source. ESS will give scientists new possibilities in a broad range of research, from life science to engineering materials, from heritage conservation to magnetism. ESS is a pan-European project, with Sweden and Denmark serving as host countries. The main research facility is being built in Lund, Sweden, and the Data Management and Software Centre (DMSC) is located in Copenhagen, Denmark.

The TARGET IS THE NEUTRON SOURCE
When the accelerated protons hit the rotating tungsten target wheel, spallation occurs and neutrons are scattered from the tungsten nucleus. The more neutrons produced and collected in the target, the „brighter” the neutron source. The neutrons are directed through moderators and neutron guides to the scientific instruments, where they are used for experiments. The Target monolith consists of the Target wheel, moderators, cooling systems and shielding and weighs approximately 5,800 tonnes.

TOTAL BUILDING AREA 65 000 m²
The ESS facility will be approximately 650 metres in total length. The target building will be 115 metres long, and about 30 metres high. The 537-meter-long accelerator tunnel is built underground and will be covered with soil.

PROTONS GENERATED IN AN ION SOURCE
In the ion source protons are generated and guided into the linear accelerator, the Linac. The first part of the Linac is used to focus the proton beam while it accelerates.

CAVITIES ACCELERATE THE PROTONS
Electromagnetic fields are used to accelerate the protons to approximately 95% of the speed of light. The second part of the accelerator consists of superconducting cavities which are cooled to ~2 K using liquid helium. After traveling 602.5 m the protons hit the target wheel.

PILES TO AVOID MOVEMENTS
The heavy Target building and experimental halls are resting on a total of 6,600 piles of different types, in order to avoid unwanted movements in the structure.

ESS will have 22 tailor-made instruments located in three experimental halls. Neutrons are excellent for probing materials on an atomic and molecular level — everything from motors and medicine, to plastics and proteins. The neutrons hit the sample and detectors register the neutron scattering, giving precise information about the material’s structure and dynamics.

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Warm LINAC overview

**Source+LEBT:**
- Designed at INFN Catania
- ESS reviews vacuum system, procedures and supplies Vacuum instrumentation.

**RFQ:**
- Designed at CEA
- ESS reviews vacuum system, procedures and supplies Vacuum instrumentation

**MEBT:**
- Designed at ESS Bilbao
- ESS reviews vacuum system, procedures, in-kind supplies Vacuum instrumentation

**DTL:**
- Designed at INFN Legnaro
- ESS reviews vacuum system, procedures and supplies Vacuum instrumentation
Warm LINAC: Ion Source (IS) + Low Energy Beam Transport (LEBT)

Present design of P.S. and LEBT: pumps, gauges and

Expected Operative Pressures

BEAM OFF – Static Vacuum
P.S.  range 10E-6 mbar
LEBT  range 10E-7 mbar

BEAM OFF – Gas IN
P.S.  range 10E-3 mbar
LEBT  range 10E-5 mbar

By Marletta, S. et all
Warm LINAC: Ion Source (IS) + Low Energy Beam Transport (LEBT)

Vacuum diagram

CATANIA ONLY

by H. Spoelstra
ESS/Vac
Warm LINAC: Ion Source (IS) + Low Energy Beam Transport (LEBT)

Vacuum wiring diagram and logic (interlock system)

Vacuum WP is responsible to interface Vacuum Control and ICS (PSS and MPS).
Warm LINAC: Radio Frequency Quadrupole (RFQ)

Pumps, gauges and valves
- 2 dry pumps (12.5 m³/h)
- 6 cryo-pumps 200 L/s
- 2 sets of turbo-pumps 150 L/s
- 26 couples of gauges «Pirani - Penning»
- 14 valves
- 2 gauges Bayard-Alpert

Contributions
- gas load from LEBT due to differential pressure
  - mainly H₂
  - other gas: Kr, Ar for SCC2
- out-gassing of copper
  - copper inner surface
  - RF loops due to RF
- desorption due to beam collision
  - depends on the history of the heat treatment
  - only the second half of the RFQ

Design pressure: $5 \times 10^{-7}$ mbar
- minimization of the scattering between accelerated particles and gas species
  - high transmission
  - high quality beam
- minimization of the probability of discharge between surfaces

By Poton, A.
Warm LINAC: Radio Frequency Quadrupole (RFQ)

Vacuum components
- Rough vacuum system
- Turbomolecular pumps
- Gauges
- RGA

Outgassing and pumps:
- OGR: 5E-10 mbar l/s/cm²
- Gas: 50% H₂ and 50% N₂
- Pumping speed: 345 l/s (H₂) ; 340 l/s (N₂)

Interfaces:
- Upstream: LEBT collimator
  Gas in: 2E-05 mbar l/s
- Downstream: MEBT
  Gate valve on RFQ
- Implementation gate valves on TMPs ports TBD.

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Warm LINAC: Radio Frequency Quadrupole (RFQ) status

- **TUNERS**: Definition on He leak check procedure on the brazing connections (lessons learned from SNS and SLAC).

  ESS requirements (ESS VHB):
  - Hydrostatic test (x1.5 maximum design pressure)
  - Baking to remove water from possible cracks,
  - Leak check

- **ACCT brake at RFQ exit plate.**
  - ESS proposal of a flat gasket accepted
  - Test to evaluate the required closing force to be executed envisaged at ESS
Warm LINAC: Medium Energy Beam Transport (MEBT)

By Zugazaga, A. et all

Average pressure
$10^{-8}$ mbar range

Mechanical Pump: TRIVAC D 65 B
Turbo Pump: HiPace 700
Ion Pumps: NexTorr D200-5
VAT Mini UHV Gate Valve 01022-CE44
VAT UHV gate valve 10844-CE44
PKR 251 / ITR 90

3.6 MeV
Warm LINAC: Medium Energy Beam Transport (MEBT)

ESS ERIC provides testing capabilities for outgassing.

- Test performed:
  - Black coating
  - Graphite
  - EMU grid
  - EPDM

ESS Bilbao responsible for vacuum design and MolFlow simulations.

Vacuum components:
- Pump-down system
- NEG pumps
- Gauges

Interfaces:
- Upstream: RFQ (valve sits on RFQ)
- Downstream: DTL (valve sits on DTL and it’s an insertable valve)
Warm LINAC: Drift Tube LINAC (DTL)

By Roncolato, C.

- Average pressure: $10^{-8}$ mbar range

PMQ = Permanent Magnets Quadrupole
In vacuum, Sm$_2$Co$_{17}$ magnets
Outgassing tests and Molflow simulations carried out at ESS. Critical tested components: PMQs and ACCT

Vacuum components per tank:
- Pump-down system (carts)
- NEG pumps (both in the tank and the intertank)
- Gauges

Interfaces:
- Upstream: MEBT (insertable gate valve on DTL)
- Downstream: LEDP (All metal gate valve on DTL intertank)

Due to high gas load of epoxy insulation, a pre-installation outgassing process is necessary.
Warm LINAC: Drift Tube LINAC (DTL)

- Black coating for NPM in the DTL inter-tanks: two different solutions depending on installation schedule of Faraday cup.

- Leak check procedure for the water cooled stems.
Cold LINAC

- 13 Spoke CM's
- 9 Elliptical MB CM's
- 20 Elliptical HB CM's
- 15 Elliptical WU's in HEBT
  - 6 in DogLeg
  - 3 WU's in A2T
  - 3 WU's in DMPL
Cold LINAC: Low Energy Differential Pump (LEDP)

Requirement of the differential pumping sections:

• HPR pressure / LPR pressure = 100 to protect superconducting RF cavity
• Molflow+ simulation with the following parameter set:
  • HPR facet desorption = 1
  • HPR facet sticking coefficient $S = 1$
  • LPR sticking coefficient $S = 1$
  • All simulations were run for mass 28
• The pressure ratio is calculated as the ratio between the adsorbed particles on LPR facet and the total desorbed particles

Simulation result: a 100:1 ratio across the section requires approximately 2000 l/s ($N_2$), transmission probability with the parameters listed is 0.008
Cold LINAC: Spoke cryo module

Legend:
- Two position valve
- Control valve
- Secondary vacuum pump
- Pressure safety valve
- Primary vacuum pump
- Pressure transmitter
- Pressure indicator

- Beam vacuum (p< 10^{-9} mbar)
- Insulation vacuum (p< 10^{-5} mbar)
- Cryogenic distribution

By Duthil, P.
Cold LINAC: LINAC Warm Unit (LWU)

Instrumentation need to satisfy pressure ($P < 10^{-9}$ mbar) and particle free requirements.

Two families: 13 x Spoke LWU (SWU) & 51 x Elliptical LWU (EWU)

Specific cleaning procedure for different instruments!!!
LWU’s provide vacuum continuations between cryo-modules and host beam diagnostic and magnets. Designed, built and processed for UHV and particle free operation (base pressure $5 \times 10^{-9}$ mbar, without beam).

Equipped with DN100 flange for UHV pump, DN40 manual valve, Pirani and cold cathode, burst disk.

LWU’s integrate quadrupoles and correctors.

Various flanges dedicated to diagnostics (e.g. Wire Scanners, BPM, BCM, Faraday Cup, Bunch Shape Monitor).

Adjustment fixtures for the alignment of the girder, the chamber and the quadrupoles.
Installation of LWU to the cryo-modules require a particle free environment; portable modular clean rooms are designed by STFC/Daresbury for in-tunnel installation.

Three independent units with specific functions: gowning room, stock room for tools and components and working unit (ISO class 5 standard).

Prototype version installed at RATS for testing.
Cold LINAC: Mobile Clean room

by F. Ravelli
ESS/Vac
STFC is delivering in the timeframe October 2016 – October 2019.

We have received two elliptical WU prototypes (1st prototype is at the site, 2nd prototype at ESS new Receiving Facility in the picture) - the scope of the prototypes is to develop a procedure for ESS spool pieces on the production floor.
Cold LINAC: Elliptical cavity (medium/high Beta)

- Insulating vacuum pumping system: $P < 10^{-5}$ mbar
- Cavity string pumping through the gate valves. Particle free operation to connect components. $P < 1 \times 10^{-9}$ mbar
- 4 gauges for coupler protection and cavity vacuum monitoring

By Bosland, P. et al.
ESS Accelerator
Pressure requirement for (HEBT) < $10^{-4}$ Pa is sufficient from proton-beam interaction.
The **baseline** design for the **monolith vessel** includes operation from **1 atmosphere He, 1 mbar pressure (air or He)** all with Proton Beam Window (PBW) or **high vacuum** without PBW. The vacuum system can provides capabilities to reach rough vacuum for purging and purge, rough pressure solution or high vacuum. The purging system must be able to handle both He and H₂ as media in the system.

The vacuum for thermal insulation (moderator and target wheel) will be an active vacuum that will handle both the cryostat vacuum and the piping adjacent to the system. This vacuum might be contaminated by H₂O, H₂ and He.
Spallation is the process for producing neutrons by means of a particle accelerator and a heavy metal target. Protons derived from hydrogen gas are drawn through a linear accelerator to a velocity just below the speed of light, at which point they collide with the nuclei of the target metal, tungsten.
# Neutron Scattering Science (NSS): vacuum integrated approach

<table>
<thead>
<tr>
<th>Neutron Instrument scheduling</th>
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<tbody>
<tr>
<td><strong>NBi name</strong></td>
</tr>
<tr>
<td>Test Beamline</td>
</tr>
<tr>
<td>ODIN (S2)</td>
</tr>
<tr>
<td>BEER (W2)</td>
</tr>
<tr>
<td>DREAM (S4)</td>
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<tr>
<td>ESTIA (E1)</td>
</tr>
<tr>
<td>C-SPEC (W3)</td>
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<tr>
<td>BIFROST (W4)</td>
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<tr>
<td>T-REX (W7)</td>
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NSS: Instruments

- Proton beam window
- Moderator and reflector plug
- Target wheel
- Neutron beam extraction
- Target drive housing
- Neutron beam window
NSS: NMX instrument control diagram

Grounding Zones:
- Neel (C-1e and C-3e)
- NXS-2 (Blue)
- Detector with a Cave (Orange)
- Central Hub (Purple)

NMX FBID V.2.5 (preliminary)
15th Aug 2016
NSS: NMX instrument vacuum diagram

Preliminary
Vacuum support: RATS
Receiving/Acceptance test/Storage

Vacuum in RATS
- Clean room for assembling and testing components,
- Acceptance are for LWUs,
- Assembling area for vacuum chambers,
- Assembling area for Vacuum racks (share with ICS),
- Testing area for portable cleaning rooms,
Vacuum Integration Test Facility (VITF)
This facility will provide the capability for seamless integration of all vacuum systems used on the accelerator, target and neutron instruments with the ICS (ESS Integrated Control System).

Gauge Calibration Facility (GCF)
The GCF will be used to confirm the operation and calibration of all vacuum gauges and RGAs prior to installation, with calibration performed against a secondary standard.

Outgassing Test Facility (MTF)
This facility is designed to support the selection and approval of materials for use in vacuum environment in accordance with the requirements of the ESS Vacuum Handbook. Ex: selection of vacuum compatible cabling, to minimize the contamination of vacuum spaces.
Why we need vacuum for a particle accelerator?

Why we need vacuum on a SRF LINAC?
Thank you!

Tack!
Neutron Vision