ESS – Enabling discovery

Mats Lindroos
Head of Accelerator

Orsay EURISOL TM October 2014
A European research center

IDEON
Innovation
Environment
Incubators
Venture Capital
Marketing Advice

Neutron Source

Synchrotron Source

Copenhagen
Copenhagen University
CPH Airport

Bridge
SE-DK

MAX-lab

Science Village

Medicon Village

Eurosphere

Innovate

Environment

Incubators

Venture Capital

Marketing Advice

Ess

European Spallation Source
“Whatever the radiation from Be may be, it has most remarkable properties”

Neutrons

Its discovery
James Chadwick
1932
($\alpha$,n) reaction

![Diagram of Chadwick's neutron apparatus](attachment:chadwick_neutron_apparatus.png)
Neutrons are beautiful!

Wave  Particle  Magnetic moment  Neutral

Diffractometers - Measure structures – Where atoms and molecules are

10 Ångström

Spectrometers - Measure dynamics – What atoms and molecules do

1 - 80 meV
# Light and neutrons

<table>
<thead>
<tr>
<th>H</th>
<th>Li</th>
<th>C</th>
<th>O</th>
<th>S</th>
<th>Mn</th>
<th>Zr</th>
<th>Cs</th>
</tr>
</thead>
</table>

- **X-rays**
- **neutrons**

The table and diagrams illustrate the difference in interaction between X-rays and neutrons with various elements.
Non-destructive analysis of a steel armed concrete block with neutron imaging and X-ray tomography.

Source: PSI, CEMNET workshop 2007
Better drugs from detailed protein maps

This enzyme transports CO\textsubscript{2} and regulates blood pH.

It is a major player in some cancers, glaucoma, obesity and high blood pressure.

Neutron crystallography pinpoints protons and waters, showing how the drug Acetazolamide binds.
Whole-organism neutron imaging

Visualising water flow in a tomato seedling with neutron imaging.

Cross-section of plant roots in soil shows that plants collect

Red = high water content
Blue = low water content
Neutrons See the Light

Images from the NIAG group, PSI, Switzerland
ESS - Bridging the neutron gap

- Berkeley 37-inch cyclotron
- 350 mCi Ra-Be source
- Chadwick
- 1930 - 2020
- ISIS Pulsed Sources: ZINP-P, ZINP-P/KENS, WNR, IPNS, ILL, X-10, CP-2, CP-1
- Steady State Sources: HFBR, HFIR, NRU, MTR, NRX, CP-1

Effective thermal neutron flux $n/cm^2-s$


- FRM-II, SINQ, SNS, ESS
- J-PARC

Power

- $P = 1$MW
- $P = 100$KW
- $P = 10$MW

- Effective beam intensity $I_{beam}$ [mA]
- Energy of beam $E_{beam}$ [GeV]
The 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 on instruments

2023
ESS starts user program

2025
ESS construction complete
17 nations committed to build ESS

Cash contributions from Sweden, Denmark and Norway

50% of construction and 15-20% of operations costs

In-kind contributions from the other 14 nations

Construction cost: 1843 M €
Operation cost: 140 M €
Decommissioning cost: 177 M €

ESS AB 2014, ca 350 personer, 32 nationaliteter
Helicopter view of ESS

Instruments
22 Instruments in construction
budget
5 times more powerful than SNS
30 times brighter than ILL

Total Cost of Project
1843 (2013) Mil €
Build and operate a 5 MW SCRF linac

Design Drivers:
High Average Beam Power
- 5 MW
High Peak Beam Power
- 125 MW
High Availability
- > 95%

Key parameters:
- 2.86 ms pulses
- 2 GeV
- 62.5 mA peak
- 14 Hz
- Protons (H+)
- Low losses
- Minimize energy use
- Flexible design for future upgrades

Diagram showing the linac components and beam energy conversion:
- Source
- LEBT
- RFQ
- MEBT
- DTL
- Spokes
- Medium β
- High β
- HEBT & Contingency
- Target

Energy steps:
- 75 keV
- 3.6 MeV
- 352.21 MHz
- 90 MeV
- 56 m
- 179 m
- 704.42 MHz
- 2000 MeV
Collaboration During Pre-Construction

Sebastien Bousson

Pierre Bosland

CERN

Roger Barlow

Ibon Bustinduy

Søren Pape Møller

Anders J Johansson

The National Center for Nuclear Research, Swierk

Roger Ruber

Santo Gammino
And not to forget…

Many opportunities for new IK partners!
Titanium vessel with 4 ports on cavity end for high pressure rinsing.

7 to 13 MV/m

0.3 to 0.6 MV/m

13 cryomodules

26 spokes

LINAC 2014

FIRST CAVITY RECEIVED (October 13, 2014)
Potential partners identified for 46% of the total planned/potential in-kind value
Planned/potential in-kind is 78% of accelerator budget
Many activities start 2014, reflecting the importance of reaching agreements soon
New ACCSYS collaboration members soon: STFC (UK), Wroclaw (PL), Elettra (IT), LASA-INFN (IT)
Target station converts protons to “slow” neutrons

Functions:
- Convert protons to usable neutrons
- Heat removal
- Confinement and shielding

Unique features:
- Rotating target
- He-cooled W target
- High brightness moderators

- Diameter ~ 11 m; Height ~ 8 m
- Mass ~ 7000 tonnes (mainly steel)
Target Station includes systems that address nuclear hazards

- Remote Handling Systems including hot cells and associated equipment for maintenance and storage of irradiated components
- Target Safety System including credited controls to protect public and environment from radioactive hazard
- Fluid Systems including He and H$_2$O coolant loops, ventilation, filtering, etc.
### Science Drivers for the Reference Instrument Suite

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<th>Multi-Purpose Imaging</th>
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<td>Broadband SANS</td>
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<tr>
<td>Surface Scattering</td>
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<tr>
<td>Horizontal Reflectometer</td>
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<tr>
<td>Vertical Reflectometer</td>
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<tr>
<td>Thermal Powder Diffractometer</td>
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<tr>
<td>Bispectral Power Diffractometer</td>
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<tr>
<td>Pulsed Monochromatic Powder Diffractometer</td>
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<tr>
<td>Materials Science Diffractometer</td>
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<tr>
<td>Extreme Conditions Instrument</td>
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<tr>
<td>Single-Crystal Magnetism Diffractometer</td>
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<tr>
<td>Macromolecular Diffractometer</td>
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<th>Cold Chopper Spectrometer</th>
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<td>Bispectral Chopper Spectrometer</td>
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<td>Thermal Chopper Spectrometer</td>
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<td>Cold Crystal-Analyser Spectrometer</td>
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<td>Wide-Angle Spin-Echo</td>
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<td>Fundamental &amp; Particle Physics</td>
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</table>

- **life sciences**
- **magnetism & superconductivity**
- **soft condensed matter**
- **engineering & geo-sciences**
- **chemistry of materials**
- **archeology & heritage conservation**
- **energy research**
- **fundamental & particle physics**
The reference suite – a guide

These instruments are gradually being replaced by instrument concepts selected for construction.
Observing protons and neutrons decay into other particles

• Finding the anti-neutron will shed light on the anti-matter problem
• Another particle, the Majorana neutrino, has been theorised to be its own anti-particle

Finding the anti-neutron will help explain matter/anti-matter imbalance

ESS will enable
• Reliable production of many cold (slow neutrons)
• Unprecedented ability to find the anti-neutron
• State-of-the-art neutron optics technology instrument development for oscillation experiments
Neutron - antiNeutron oscillations

- Provided new physics occurs beyond the Standard Model at the mass scale of the order of $10^2$ to $10^3$ TeV the oscillation time could be in the region of $10^8$ s

- The experimental search for neutron-antineutron oscillations was done at the ILL high flux reactor at Grenoble (1994). No antineutron was detected in $2.4 \times 10^7$ s running time.
nnbar experiment @ ESS?

observe neutrons propagating in free space for a maximum of time without wall collisions

- Wide beam port
- Large moderator
- Horn-shaped supermirror reflector with a high m
- Long direct flight path (> 200m)
- High vacuum must be protected from magnetic fields + radiation

Detector
ESSnuSB

Before spring 2012  $\Theta_{13}=4^\circ$

After spring 2012  $\Theta_{13}=8.73^\circ$

- New accumulation ring with staggered beam extraction using solid state switch driven ILC like strip line kickers of up to 100 pulses to match pulse length to moderators and simplify target design
- Linac operated with H- and at 28 Hz to keep both target station operating at 5 MW
- Support (refunded) from ESS for Design study proposal
Previous Expertise

- ESSvSB
- EUROv (2008-2012)
- LAGUNA (2008-2010)
- LAGUNA-LBNO (2010-2014)
- ISS (2005-2007)
- BENE (2004-2008)
- SNS (USA)
1.8 Billion Euros:  
Biggest investment in Science ever in Scandinavia?

In modern time, definitely YES!

However, Tycho Brahe’s Stjärneborg costed the Danish king 1% of the state budget in 1580.

“With better measurements of the stars positions and movements I can make much better horoscopes for you, your majesty!”
• What has ESS got from EURISOL
  – Trained people
  – Spoke cavities and other equipment design
  – Collaboration model including accelerator
  – And much more

• What can EURISOL learn from ESS
  – A new major European facility can be built at an existing lab (FAIR at GSI) or at a Green field site (ESS)
  – Rigid industrial or DOE style project organization and execution is necessary to build trust in a European collaboration
  – Dreams come true but it requires a lot of work by persistent and visionary people!
Welcome!
Lund University Activities in Accelerator Development for ESS

- Development of the low level RF system for the ESS linear accelerator.
- Development of prototypes for high power high voltage pulsed modulators.
- Participates in cavity development for normal conducting accelerator.
- Total: 40 MSEK
- ESS AB: 27.5 MSEK

• Discussing future in-kind contributions for e.g. LLRF

LLRF system test bench and prototype.
**Design and specifications:**
- ESS and LTH;

**R&D and training of Highly Qualified Personnel:**
- LTH (3 MSc thesis, 5 Research associate, 1 PhD thesis starting Jan 2015);

**Control system hardware:**
- National Instruments AB, Skåne business center;

**Control system software:**
- Lund University Innovation System (LUIS) AB;

**Construction (Low Voltage part):**
- AQ Elautomatik AB, in Lund;
Existing contract:

- RF Design and FREIA
- SRF Test Facility

Total: 177 MSEK
- ESS AB: 60 MSEK

Proposed new contract:

- Detailed report on spoke cryomodule prototype tests
- Spoke cryomodule acceptance tests
- Spoke valvebox prototype tests
- Contributions to control system
- UU personnel working at ESS, Lund
- Test stand for klystrons and high power modulators.