ESS Cask Assembly and Systems Engineering Methodology

Hotlab 2018 - Helsinki
Dr Carwyn Jones\textsuperscript{1}, Magnus Göhran\textsuperscript{1}, Lennart Åström\textsuperscript{2}, Prof Jon Holt\textsuperscript{3}

\textsuperscript{1}European Spallation Source ERIC
\textsuperscript{2}Fagerström Industriksultant AB
\textsuperscript{3}Scarecrow Consultants Ltd

www.europeanspallationsource.se
17-09-2018
Overview

• Introduction
• ESS Overview
• Cask Assembly
• Systems Engineering Methodology
  – Approach – Model Based Systems Engineering
  – Framework
• Current Status – Competitive Tender
Science Drivers for the Reference Instrument Suite

**Large-Scale Structures**
- Multi-Purpose Imaging
  - ODIN
- General-Purpose SANS
  - SKADI
- Broadband SANS
  - LOKI
- Surface Scattering
- Horizontal Reflectometer
  - FREIA
- Vertical Reflectometer
  - ESTIA

**Diffraction**
- Thermal Powder Diffractometer
  - HEIMDAL
- Bispectral Powder Diffractometer
  - DREAM
- Monochromatic Powder Diffractometer
- Materials Science Diffractometer
  - BEER
- Extreme Conditions Diffractometer
- Single-Crystal Magnetism Diffractometer
  - MAGIC
- Macromolecular Diffractometer
  - NMX

**Spectroscopy**
- Cold Direct Geometry Spectrometer
  - C-SPEC
- Wide Bandwidth Direct Geom. Spectrometer
  - VOR
- Bispectral Direct Geometry Spectrometer
  - TREX
- Cold Crystal-Analyser Spectrometer
  - CAMEA
- Vibrational Spectrometer
  - VESPA
- Backscattering Spectrometer
  - MIRACLES
- High-Resolution Spin-Echo
- Wide-Angle Spin-Echo

**Fundamental & Particle Physics**

**Life Sciences**

**Magnetism & Superconductivity**

**Soft Condensed Matter**

**Engineering & Geo-Sciences**

**Chemistry of Materials**

**Archeology & Heritage Conservation**

**Energy Research**

**Fundamental & Particle Physics**
Construction plan

- **2003**: European Design of ESS Completed
- **2009**: Decision to Site ESS in Lund
- **2012**: ESS Design Update Phase Complete
- **2014**: Construction Starts on Green Field Site
- **2022**: Machine Ready for 1st Beam on Target
- **2023**: ESS Starts User Program
- **2025**: ESS Construction Phase Complete
ESS employees (as of 31 Oct. 2017)

- **426** Employees
- **50** Nationalities
- **> 45** Collaborating Institutions
Target station
Monolith Systems

Monolith vessel

proton beam instrumentation plug

Moderator reflector plug

proton beam window

Monolith inner shielding (~1000 tonnes of steel)

Monolith vessel connection ring

Proton Beam Window
Remote Handling Systems

Active Cells Facility:
- Length: 30 m
- Depth: 12 m
- Height: 15 m

Casks
Mock-Up and Test Stand
Target components to be handled by the Remote Handling System

<table>
<thead>
<tr>
<th>Component Mass (ton)</th>
<th>Component</th>
<th>Cranes in scope of handling</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
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<td>2</td>
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<td></td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>

- **Temporary shielding ring for TW**: 28.6 ton
- **Target Wheel**: 13.1 ton
- **Target Wheel Cooling Unit (ESS-0041622)**: 48.2 ton
- **West Inner Block, Level 6 (ESS-0039593)**: 54.9 ton
- **West Inner Block, Level 5 (ESS-0039594)**: 62.8 ton
- **Target Wheel Shaft Shielding (ESS-045135)**: 2.4 ton
- **Target shaft shielding (ESS-0039390)**: 0.6 ton
- **East Inner Block, Level 6 (ESS-0039390)**: 14.2 ton
- **East Inner Block, Level 5 (ESS-0039390)**: 13.4 ton
- **Moderator Cooling Unit (ESS-047843)**: 13.2 ton
- **Moderator reflector plug**: 6.1 ton
- **Proton beam window plug**: 14.3 ton
- **Proton beam instrumentation plug (ESS-0008848)**: 19.4 ton
- **PBIP Support Structure (ESS-0037900)**: 8.3 ton
- **PBIP Optics Block A (ESS-0051480)**: 2.2 ton

<table>
<thead>
<tr>
<th>Component</th>
<th>Crane</th>
<th>Cask</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>2</td>
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<td>12.2.2</td>
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<td>3</td>
<td>12.4.4.2</td>
<td>12.4.4.2</td>
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<tr>
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<td>12.2.3</td>
<td>12.4.4.2</td>
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<td>12.3.3</td>
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<tr>
<td>7</td>
<td>12.4.2.2</td>
<td>12.4.2.2</td>
</tr>
</tbody>
</table>
Operational functions

• The casks are required to constitute a physical enclosure as well as an interface to high bay crane, high bay floor, active cells, mock-up and test stands and the monolith.

• The main system objective is to constitute a radiation shielding and a foundation for a safe functional process for remote handling and transports.
Safety functions

• Radiation shielding in normal modes and in conditions of off-normal modes

• Provide a level of safety to ensure induced secondary effects from cask handling does not endanger any facility barrier.
Requirements of radioprotection and shielding

• Casks system shall contribute to the protection of operators and the public from exposure due to direct radiation or any contamination contained within the casks.

• The design of the shielding functions limit dose:

  < 0.5mSv/h @1m from Cask Assembly

  < 2mSv/h @0.2m from Cask Assembly
Shielding vs total weight for TW Cask

A prediction of up to 2000 Sv/hr dose from the Target Wheel after a two week cool down
Estimation of Cask process

Cask usage over 5 years number of components

- Target wheel and shaft: 1
- Target monitoring plug: 1
- Moderator Reflector Plug: 5
- PBIP Slices: 10
- Proton Beam Window: 10
Cask Assembly Challenge

• Technical

• Slave of many masters
Concept designs
MCNP calculations
Concept designs 2
Key findings from initial Target Wheel cask shielding study

- Classification of lifting devices in harmony with design and functionality
- Interlocks between high bay crane, internal hoist and opening of active cells floor valves
- Weight optimization absolutely necessary to achieve required dose rate limit within maximum weight restriction.
- Complete shielding analyses needed for all cask configurations including temporary shielding ring when docked to monolith
• Since the mid-to-late 2000s MBSE has been increasingly prevalent in Systems Engineering literature

• Over the last five or so years, MBSE is becoming both common- and best-practice
What we model

- System
  - 1..* abstracts

- Model
  - 1

- View
  - 1..*
  - is consistent with
How we model

Framework

ontology

viewpoint

process set

1..* describes how to develop

1..* is based on
The spoken language

Diagram

Notation

1..*

Diagram

1..*

1

is consistent with
ESS Framework – MBSE

Approach

Framework

1

Ontology

1

Viewpoint

1..*

is based on

System

1..*

abstracts

defines template for

View

1..*

is consistent with

Model

1

Notation

1..*

is consistent with

Diagram

1..*

visualises

Visualisation

System
Visualisation

Approach

1..* visualises

1..* abstracts

1..* is consistent with

is based on

System

1..* defines template for

1..* is consistent with

Notation

is consistent with

Diagram
The 5 SysML structural diagrams

**BDD** [Package] Block Definition Diagram [Block Definition Diagram]

- **<block>** Block1
- **<block>** Block2
- PartB 1
- PartA 1..*
- **<block>** Block3
- **<block>** Block4

**PKG** [Package] Package Diagram [Package Diagram]

- **Package**
  - **<import>**
  - **PartA: Block4[1..*]**
  - **PartB: Block2[1]**

**IBD** [Block] Block1 [Internal Block Diagram]

- **PartA: Block4[1..*]**
- **PartB: Block2[1]**

**PAR** [ConstraintBlock] Parametric Diagram [Parametric Diagram]

- **Parameter1:** Real
- **ConstraintProperty1 : ConstraintBlock1**
- **Parameter2:** Real
- **Property4:** Real

**REQ** [Package] Requirement Diagram [Requirement Diagram]

- **Requirement1**
  - **id = "001"**
  - **text = "The System shall ..."**
  - **<satisfy>**
  - **<block>** Block1
The 4 SysML behavioural diagrams
The ESS Ontology

Approach

Framework

Ontology

Viewpoint

is based on

1..*

Ontology

System

abstracts

1..*

System

Model

defines template for

1..*

View

is consistent with

1..*

Diagram

Notation

is consistent with

1..*

Visualisation

Diagram

Notation

is consistent with

1..*

Visualisation

System

Model

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The ESS Ontology – basic concepts
The ESS Ontology – Need concepts

[Diagram showing relationships between concepts such as Rule, Need Description, Use Case, and more, with arrows indicating constraints and associations.]
The ESS Model
Example System Overview
Example Subsystem Overview
Example Subsystem Overview
Example Subsystem Configuration View
Specification development

• The spec takes all of its info from the model
• All sources collated
• Needs mapped in context to use cases
• Provides traceability
  – From needs to concept designs
Cask Assembly Current Status:
Competitive Tender

Conceptual design

A
B
C

Specification development

Award contract

Detailed design, manufacture, test and install

March 2022 – Ready for Beam on Target
Thank you

Please, any questions?

My contact details, feel free to follow-up:

carwyn.jones@esss.se
+46721792442
European Spallation Source basics

High Power Accelerator:
- Energy: 2 GeV
- Rep. Rate: 14 Hz
- Current: 62.5 mA
- Pulse length: 2.86 ms

Target Station:
- He-gas cooled rotating W-target
- Average power: 5 MW
- Pulse power: 125 MW
- Neutron beam ports: 42

Target Station:
- He-gas cooled rotating W-target
- Average power: 5 MW
- Pulse power: 125 MW
- Neutron beam ports: 42

Environmental goal (“Sustainability”)
- Energy responsible
- Renewable energy
- Recyclable heat

High brightness and tunable resolution makes new measurements possible

Peak flux ~30-100 brighter than the ILL

Proton Source
Use cases created based on context

- **Stakeholder Role**: Operator
- **Stakeholder Role**: Public

**Context**: Casks Context

- **Capability Use Case**: Provide remote handling capability for Casks
- **Capability Use Case**: Provide functional operation capability
- **Capability Use Case**: Provide non-functional operation capability
- **Capability Use Case**: Provide Physical system

Relationships:
- Include
- Constrain
Focus on ‘Provide non-functional operation capability’
Focus on ‘Be safe’

- **Capability Use Case**
  - Identify safety functions
  - Protect facility
  - Provide radiation shielding
  - Confine radioactive substances

- **Capability Use Case**
  - For normal operation
  - For failure
  - For leakages
  - For events and circumstances
  - For human events
  - For environmental events

- **Components**
  - Cask

- **Stakeholder Roles**
  - Public
  - Operator
Traceability back to source elements

- «Cask Import Need» 001
- «Cask Import Need» 006
- «Cask Import Need» 088

«Capability Use Case»
- Provide radiation shielding
- Confine radioactive substances

- «Cask Import Need» 002
- «Cask Import Need» 120
- «Cask Import Need» 006
Weight reduction – Shielding calculations

Introduce integrated lead in cask

Optimize total weight <95 ton

Monte Carlo - Shielding Calculation

Dose rate

Above limit → Negotiate dose rate limit

Equal to limit → Approve design

Below limit → Gamma gate assembly

Temporary shielding ring
Financing

Host Countries Sweden and Denmark
Construction 47.5%  Cash Investment ~ 97%
Operations 15%

Non Host Member Countries
Construction 52.5%  In-kind Deliverables ~ 70%
Operations 85%

(Jan 2013 pricing)  M €
Conventional Facilities 531.9
Extra CF investment by host countries -93.0
Accelerator Systems 510.2
Target Systems 155.2
Integrated Control System 73.0
Design & Engineering 33.7
Neutron Scattering Systems 350.0
Project Support & Administration and Licensing 123.8
Contingency 158.2
Total Construction Budget 1843.0
In ESS, neutrons are produced (released) via nuclear spallation.

- Cascade stage produces high-energy neutrons that drive the shield design.
- Neutrons from the evaporation phase are similar to fission neutrons.