ESS Shielded casks’ preliminary design and related monolith maintenance operations

Hotlab 2017, Mito, Japan

Lennart Åström¹, Magnus Göhran², Iñigo Ruiz de Olano², Riccardo Bevilacqua ²

¹ Fagerström Industrikonsult AB, La Cours gata 4, 252 31 Helsingborg – Sweden
² European Spallation Source ESS ERIC P.O. Box 176, 221 00 Lund – Sweden

www.europeanspallationsource.se
17-09-19
ESS site - Target station
Layout of the main components on the ESS site
Key features of the ESS Target Station

- Transport hall
- Active cells
- Utilities block
- Target monolith
- Beam expander hall
- High bay
- 130 m
- 22 m
- 37 m

ESS Spallation Source
Key features of the ESS Target Station

Target Safety System
- Monitors target coolant flow, pressure and temperature, monolith pressure, & target wheel rotation
- Prohibit beam on target if parameters are outside specified limits

Helium cooling of target material
- Mass flow 3 kg/s
- Pressure 11 bar
- Temperature inlet/outlet 40 °C/240 °C

Rotating solid tungsten target
- 36 sectors
- Mass, total 11 tonnes, whereof 3 tonnes of W
- Rotates 23.3 rpm, synchronized with pulsed proton beam 14 Hz

Moderators
- Provisional locations of moderators above and beneath the target wheel, i.e. monolith centre
- 1st MR plug exploits the upper space, offering:
  - Cold, 30 mm high, liquid H₂ moderators, 17 K
  - Thermal, 30 mm high, H₂O moderator, 300 K

Diagnostics and instrumentation
- Controlled and integrated commissioning and operation of the accelerator and target
- Fluorescent coating of PBW and target front face
- Optical paths, grid profile monitor, aperture monitor
- Wheel monitoring including position, temperature, vibration, as well as internal structure
Key features of the ESS Target Station
Casks - Interfaces

12.6.4 Casks and Associated Handling Devices

12.6.2 Active Cells
- Floor Valves
- Active Cells Mode Control System

12.5 Fluid systems
- 12.5.4 Target station HVAC

12.2 Target Systems
- 12.2.2 Target Wheel
- 12.2.3 Target (Drive) and Shaft
- Target Monitoring Plug

12.3 Moderator Reflector Systems
- 12.3.3 Moderator and Reflector Assemblies

12.4 Monolith System
- 12.4.2.2 Proton Beam Instrumentation Plug
- Target Monitoring Plug
- 12.4.2.4 NBEX (Note 1)
- 12.4.3 Confinement system
- 12.4.3.1 Proton Beam Window
- 12.4.3.2 Monolith Vessel
- 12.4.3.4 Covers and penetrations
- 12.4.4.2 Inner Shielding Systems

12.6.5.2 Mock-up and Test Stands
- Mock-up

Site infrastructure
High Bay Crane
High bay
Active cells facility
Mock-Up and Test stand
Target components to be handled by the Remote Handling System
Target components to be handled by the Remote Handling System
Operational functions

• The casks are required to constitute a **physical enclosure** as well as an interface to high bay crane, 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.

• The mechanical design of the casks shall be focused on **functionality and flexibility** and the main objective is to limit the number of specific casks to a minimum.

• The system shall be designed considering **recovery** and reverse processing order and shall cover all steps of the different handling procedures for all monolith components.
Safety functions

• Radiation shielding

• Confinement of radioactive substances

• Provide a level of safety that includes induced secondary effects from cask handling not would endanger any facility barrier.
Preconditions for lifting I

• The remote handling system shall safely maintain the load in different transport and handling situations is, according to the hazard analysis and shall be dependent on following three regulations that together govern the chain of lifting:

• Swedish Radiation Safety Authority’s:
  – Referral on lifting equipment and lifting operation
  – Special conditions for the ESS facility in Lund
  – Design Guide for Nuclear Civil Structures
Lifting and transportation of shielded casks in high bay will be performed with two electrically driven top running double girder bridge cranes with the capacity of 50 ton each. The two cranes can function in tandem for lifting operations over 50 ton which will be the case for the target wheel cask as for an example.
Integrated lifting devices - § 10 SSM

lifting guideline:

L1: Used nuclear fuel

L2: Risk of criticality event or release of radioactive substances outside the facility

High Bay crane

L3: Lifting where loss of load of radioactive material or other loads, would or might result in the release of radioactive substances within the facility presents a risk that the radiation dose to people exceed the dose limits for workers. → KTA 3902 and 3903

Casks lifting devices

Integrated lifting devices - Regulation

Guidance with background and reasons for Radiation Safety Authority's regulations on lifting equipment and lifting operations at nuclear facilities SSM2014-4363-24, 2015-06-01

Special conditions for the ESS facility in Lund, SSM 15-36 Appendix 1. 2015-06-01. ESS-0018828 rev 3

Design of Lifting Equipment in Nuclear Power Plants, KTA 3902 Corrected 2014/04/08

Design Guide for Nuclear Civil Structures (DNB) SSM 2015:25, June 2015

Inspection, Testing and Operation of Lifting Equipment in Nuclear Power Plants, KTA 3903 Corrected 2013/03/28

High bay crane

Casks internal lifting devices

Mechanical devices/runway

Lifting devices

Building/attachments to building

EN 13001, Cranes – General design – Part 1: General principles and requirements

EN 1501:2011 Cranes – Bridge and gantry cranes
• Operators are allowed to be present in high bay during cask transport during normal operation if only the requirements of zoning are considered.

• High bay crane: SSM L3 and Section 4.2 of KTA 3902. (Impairment of safety relevant components can not be excluded)

• Casks: Industrial standard - Mechanical fixation of internal load during transport and docking of cask. (Cask hoist completely unloaded during cask transport. Lifting with cask hoist only when docked to confinement)
Estimation of processing time radiation and temperature (TW)

<table>
<thead>
<tr>
<th>Step</th>
<th>Duration</th>
<th>Radiation</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage of wheel disk</td>
<td>5 years</td>
<td>100 Sv/h</td>
<td>20°C</td>
</tr>
<tr>
<td>Transfer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing: cutting, packing</td>
<td>4 weeks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Docking, loading to cell</td>
<td>1 day</td>
<td>800 Sv/h</td>
<td>60°C</td>
</tr>
<tr>
<td>Separation, wheel and shaft</td>
<td>4 weeks</td>
<td>500 Sv/h</td>
<td>50°C</td>
</tr>
<tr>
<td>Opening of monolith</td>
<td>1 week</td>
<td>800 Sv/h</td>
<td>70°C</td>
</tr>
<tr>
<td>Decay in monolith</td>
<td>1 week</td>
<td>1000 Sv/h</td>
<td>600°C</td>
</tr>
<tr>
<td>Beam off</td>
<td>1 day</td>
<td>2500 Sv/h</td>
<td>15 kW</td>
</tr>
<tr>
<td>Beam on</td>
<td></td>
<td>10000 Sv/h</td>
<td>40 kW</td>
</tr>
</tbody>
</table>

Beam on
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 shall restrict the dose, 1 m from a cask, not to exceed 25 µSv/h and the contact dose is limited to not exceed 2 mSv/h. Both requirements need to be fulfilled.
Shielding calculations for total weight - first estimation

25 µSv/h 1 meter from cask requires a wall thickness of approximately 237 mm
Parameters for shielding design

Dose rate limit

Crane capacity

Costs

WE OFFER 3 KINDS OF SERVICES
GOOD-CHEAP-FAST
BUT YOU CAN PICK ONLY TWO
GOOD & CHEAP WON'T BE FAST
FAST & GOOD WON'T BE CHEAP
CHEAP & FAST WON'T BE GOOD
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

Temporary shielding ring

Gamma gate assembly
Ongoing dimensioning shielding thickness (TW cask)
Ongoing MCNP calculation
## Estimation- Weight of TW cask

<table>
<thead>
<tr>
<th>Part</th>
<th>m (kg)</th>
<th>m (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equipment</td>
<td>Assembly</td>
</tr>
<tr>
<td>Main shielding hull</td>
<td>36 840</td>
<td></td>
</tr>
<tr>
<td>Hoist, electrical cabinet, covers etc.</td>
<td>1 500</td>
<td></td>
</tr>
<tr>
<td>Target wheel and shaft</td>
<td>11 296</td>
<td></td>
</tr>
<tr>
<td><em>Spallation material</em></td>
<td>3 102</td>
<td></td>
</tr>
<tr>
<td><em>Cassettes</em></td>
<td>404</td>
<td></td>
</tr>
<tr>
<td><em>Target whell vessel</em></td>
<td>2 011</td>
<td></td>
</tr>
<tr>
<td><em>Shaft</em></td>
<td>5 780</td>
<td></td>
</tr>
<tr>
<td>Lead cover</td>
<td>5 299</td>
<td></td>
</tr>
<tr>
<td><em>Lead</em></td>
<td>4 608</td>
<td></td>
</tr>
<tr>
<td><em>Hull</em></td>
<td>691</td>
<td></td>
</tr>
<tr>
<td>Gamma gate</td>
<td>38 933</td>
<td></td>
</tr>
<tr>
<td><em>Hull</em></td>
<td>21 300</td>
<td></td>
</tr>
<tr>
<td><em>Gate</em></td>
<td>17 633</td>
<td></td>
</tr>
<tr>
<td>Lifting rig</td>
<td>1 000</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>94 868</strong></td>
<td><strong>Ok</strong></td>
</tr>
</tbody>
</table>
Target wheel cask shielding - conclusion

- Classification of lifting devices in harmony with design and functionality
- Interlocks between high bay crane, internal hoist and opening of active cells floor valves
- Additional safety features included based on hazard analysis
- Weight optimization absolutely necessary to achieve required dose rate limit within maximum weight restriction.
- Lead cover integrated in cask instead of a cover following the TW
- Gamma gate hatch manufactured lead instead of steel
- Temporary shielding inserts between casks gamma gates and monolith structure
Concept design study I
Concept design study II
A generic design philosophy is used. The lists in below section shows the features that are shared between the casks.

Uniform:

• geometry of lifting lugs for connection to the lifting rig
• size and shape of studs/screws
• guiding pin systems for casks, covers and interfacing valves
• electrical, I&C connection system
• flange patterns and hole distribution as far as geometrically possible
• internal camera support fixtures
Structure of Casks

- Lifting Beam for West Inner Shielding Blocks
- Lifting Beam for East Inner Shielding Blocks
- Lifting Beam for Proton Beam Window Shielding Blocks
- Lifting Beam for Target Monitoring Plug Shielding Blocks

ASSOCIATED HANDLING DEVICES

CASKS SYSTEM

CASKS

GAMMA GATES

- Target Wheel Gamma Gate for Casks C-TWGGC
- PBW and TMP Gamma Gate for Casks C-PBW/TMP-GGC
- MRP and PBIP Gamma Gate for Casks C-MRP/PBIP-GGC
- Target Wheel Gamma Gate for Monolith C-TWGGM
- PBW and TMP Gamma Gate for Monolith C-PBW/TMP-GGM
- MRP and PBIP Gamma Gate for Monolith C-MRP/PBIP-GGM

COVERS

- West Inner Block Covers Including Lids CO-WIB
- East Inner Block Covers Including Lids CO-EIB
- Proton Beam Window Shielding Block Covers CO-PBW
- TMP Insertion Plugs Covers CO-TMP
- PBIP cask adaptor plate A-PBIP
- MRP cask adaptor plate A-MRP
- Temporary Shielding Rings
- Temporary Shielding Ring for Target Wheel Cavity TSR-TW
- Temporary Shielding Ring for PBW TSR-PBW
- Target Wheel Shielding Block Cover CO-TW
- PBIP Shielding Block & Optics Blocks Cover CO-PBIP
- Proton Beam Instrumentation Top CC-PBIP
- Proton Beam Window Top CC-PBFW
- Target Monitoring Plug Top CC-TMP

CASKS

- Target Wheel Cask C-TW
- Moderator Reflector Plug Cask C-MRP
- Target Wheel Cooling Unit Cask C-TWCU
- Moderator Cooling Unit C-MCU
- TMP Insertion Plugs Cask C-TMP/IP

LEAD BLANKETS
- Lead Blanket for Target Wheel LB-TW
Interdependencies of remote handling tools
Concept of control interface
Monolith maintenance
Casks and monolith maintenance - conclusion

- Complete shielding analyses needed for all cask configurations and for all steps of monolith maintenance
- Shielding strategy also for temporary storage in high bay
- Complex and comprehensive package with many interfaces
Five-year averaged production of components

<table>
<thead>
<tr>
<th>Component</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target wheel and shaft</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>ESS-0030244</td>
</tr>
<tr>
<td>Moderator Reflector Plug</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Proton Beam Window</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>ESS-0059298</td>
</tr>
<tr>
<td>PBIP Slices</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ESS-0059296</td>
</tr>
<tr>
<td>Target monitoring plug</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ESS-0059300</td>
</tr>
<tr>
<td>Neutron Beam Guide plugs or inserts</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>ESS-0029936</td>
</tr>
<tr>
<td>Neutron Beam Shutters</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Bridge Beam Guide Holder</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Flange Assembly</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>