ESS Shielded casks’ preliminary design and related monolith maintenance operations

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Abstract

The European Spallation Source (ESS) in Lund, Sweden will be a 5 MW long pulsed neutron spallation research facility with planned commissioning 2020. The ESS Remote Handling System within the Target Station will be equipped with several different systems and functions. One of the systems, the shielded casks, shall ensure the safety, protection of workers, property and the environment from the effects of radiation during target monolith maintenance and the internal transport of irradiated monolith components.

Transports will be performed by the shielded casks system in the so called high-bay between foremost the main docking positions on the monolith and the active cells where the irradiated components will be further processed through operations as dismantling, separation and preparation for disposal.

The complete functionality of the shielded casks encompasses many subjects which include among others; radiation shielding, logistics, mechanical design and external and internal lifting equipment. All of which, must be compliant with regulations in terms of handling of long-lived low and intermediate level waste.

The casks are defined as physical enclosures with their mechanical and electrical interfaces to high bay crane, active cells, mock-up and test stands as well as all internal target components within the monolith.

Target monolith components that will be handled by the shielded casks system are: proton beam window, moderator reflector plug, target wheel and shaft, proton beam instrumentation plug and the target monitoring plug. In order to access the components, adjacent internal shielding blocks must also be handled by the casks system.

Cask’s internal remote handling and lifting devices includes a design with adequate precision to facilitate installation and removal of monolith components. Also, the different operations must be carried out in a specific and well planned sequential order.

This paper will mainly describe the preliminary design of the casks system. The paper will also present an overview of the concept for operational sequences for the ESS remote handling, internal transports and handling of irradiated target components.

1. Introduction

The purpose of the preliminary design package of the Shielded Casks is to establish requirements and concept solutions related to mechanical and electrical design of casks and their internal transport systems to ensure the safety and protection of persons, property and the environment from the effects
of radiation during the internal transport of radioactive (non-fissile) monolith components within the Remote Handling System - Casks and Associated Handling Devices. The Casks system has passed a Preliminary Design Review (PDR) and is posted as open for in-kind contribution as the detailed design can commence.

2. Target station

The ESS target station is designed to fulfil the main functions: i) producing spallation within the tungsten target based on the high-energy protons from the ESS accelerator, ii) converting the high energy produced neutrons to cold and thermal neutrons and iii) delivering these neutrons to the scientific instruments placed around the target station building. The achievements of the above-mentioned functions require proper functioning of the supporting systems such cooling or shielding but also adequate maintenance systems and logistics. The remote handling systems are therefore, an essential element of the target station that provide the fulfilment of the top-level requirements. The target station building is about 130 m long, 20 m wide and 35 m high. It consists of: i) the accelerator-to-target zone, ii) the shielding monolith containing the target-moderator-reflector assembly, iii) the utility rooms that contain the cooling and filtering systems, iv) the high bay where the cranes for the transport of the irradiated components are placed, v) the active cells, consisting of the hot cells and supporting remote handling structures and vi) the transfer area used for transport of components to and from the target station building.

3. Target components to be handled by the Shielded Casks

Spent, but also new components that primarily are handled by the system are: target wheel and shaft, moderator reflector plug, proton beam instrumentation plug, proton beam window plugs and target monitoring plug.

The system shall also handle all internal shielding blocks and temporary shielding blocks necessary to be removed or handled for accessing the above-mentioned monolith components.

Handling within the Neutron beam extraction system is independent from Casks and associated handling devices but, is on a functional and a safety level connected to requirements within the shielded casks system. This document focuses specifically on the target wheel cask. However, the same approach has been given the other casks of the system.

4. Operational functions

The systems, included in casks and associated handling devices are required since radioactive spent components and tools will be handled by the system. Hands-on human interaction or handling of the radioactive materials inside casks is neither possible nor permitted. 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.

All functions with a bearing on motion, position and coordinates shall be operated by a control system. 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.
5. Safety functions

The design of the Casks system shall ensure or contribute to the achievement of the following safety functions:

• Radiation shielding in normal modes and in conditions within the stipulated design basis
• Confinement of radioactive substances in normal modes and in conditions within the stipulated design basis
• Protection of the facility against external natural and human induced events. The protection of the facility from the systems’ perspective is to provide a level of safety that external natural and human induced secondary effects from cask handling not would endanger any facility barrier.

6. Requirements of radioprotection and shielding

In normal modes and in conditions of off-normal modes, the Casks system shall contribute to the protection of operators and the public from exposure due to direct radiation from radioactive materials or any contamination contained within the casks and their interfaces to associated sub systems. 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. The integrated dose budget for the different operations on a case by case basis will be further elaborated.

7. Preconditions for lifting

The lifting devices used for casks can be divided into two separate functions: the high bay crane which lifts and transports a sealed cask and the different cask’s integrated lifting devices used when docked to corresponding confinement. Respective system’s responsibility to safely maintain the load in different transport and handling situations is, according to the hazard analysis, dependent on following three different regulations that together govern the chain of lifting:

• Lifting and lifting devices as cranes, wires, etc.: Referral SSM2014-4363-24, Guidance with the background and reasons for Radiation Safety Authority’s regulations on lifting equipment and lifting operations at nuclear facilities [1].
• Devices integrated in the load that constitutes a part of the load and crane runways are considered mechanical devices: Special conditions for the ESS facility in Lund [2].
• Provisions of anchorages in the concrete structure as well as attachment parts of crane runways in building structures: SSM 2015:24 Design Guide for Nuclear Civil Structures (DNB) [3].

The first regulation is valid for casks only and for the high bay crane, all three regulations are applicable. 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.

8. Shielding calculations for total weight estimation

Preliminary shielding calculations for the target wheel cask has been performed in Micro shield 10.03 [4]. Figure 1 shows the resulting dose rate at contact as a function of wall thickness. The main reason for shielding thickness calculations was to determine that the high bay cranes total capacity of 95 ton would be sufficient. The result of the calculations shows that the estimated steel thickness covering the lower part of the cask where the highly activated tungsten of the target wheel is situated should be approximately 250 mm.
The calculations include a 50-mm lead cover over the target wheel. The estimated thickness applied to the CAD geometry shows a plausible total weight including the cask lifting rig, shielding bottom valve and hoist, marginally under the limiting crane capacity as shown in Figure 2.

A more detailed and iterative design method using MCNP6 analysis has started prior to the detailed design phase.

9. Concept design study

The structural part of the casks envelope is a steel flask where the lowermost portion as shown in Figure 3 is provided with a connection to a bottom valve. The bottom valve is a horizontally operated hatch which enables opening and closing. For weight saving reasons and balance, it is advantageous to separate the bottom valve into two halves. Geometries close to all transitions between interfacing parts needs to be carefully designed to eliminate all possible shine paths.
The materials chosen for the casks shall have properties to resist brittle fracture and fatigue within the dimensioning temperature range. A surface protection system shall be used both inside and outside for provision of anti-corrosive protection and a decontaminable surface.

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

The different casks are designed and optimized for its shielding purpose in relation to its weight. The design solution is based on keeping the shielding structure as close as possible to the geometry of the monolith component and by that reducing the extra weight a larger diameter solution would inflict. For preventing displacement of monolith components inside casks during handling, an internal fixation function is provided. A mechanism fixates the component at three positions via a common actuator. Another mechanical locking mechanism is intended to offload the in-cask integrated hoist system during cask transport. Lifting with the in-cask integrated hoist is limited to operation when the cask is docked to its respectively counterpart and by that representing the perimeter of each confinement barrier. This solution implies reduction of the level of QA grading related to the in-cask integrated hoist to a certain extent.

All casks are equipped with lifting interface connection lugs for piecing together with the lifting rig of the high bay crane. The lugs, one at each side of the cask, are positioned so stability and optimal use of the high bay crane’s lifting height becomes obtained. The lugs are designed to guide the lifting rig to the correct position. The positioning of the lugs correlates with the lifting rig for balanced lifting and each cask’s center of gravity rests under the two high bay crane hooks. Figure 4 shows the full assembly of the cask, lifting rig and the divided bottom valve.

The radiation horizontally from the tungsten blocks of the lower part of the target system will show lower values in comparison with the vertical radiation due to self-shielding. This fact allows the outer
rim to be designed with a relative slimmer wall thickness than the walls shielding the vertical radiation. The lower part of the target wheel cask is designed as a flange for connection to the bottom valve.

The target wheel cask is equipped with a hold/release mechanism for the lead blanket. The lead blanket is mechanically released when the target wheel is hoisted to a certain level just above the blanket level. When lowering the whole assembly, the lead blanket rest on the lower part of the target wheel rim and by that follow the target wheel and shaft when unloading the assembly to the active cells.

![Figure 4: Rendering of target wheel cask and valve](image)

A gripping tool constitute the link between the lifting ropes and the target shaft. It is designed to guide itself into position over the shaft. Gripping will be made by use of the openings on the envelope surface at the very upper part of the shaft. Rotational aligning can be adjusted after visual inspection of the direction of the shaft holes. An actuator performs the grip. When the gripping mechanism is activated in position for lifting it will remain mechanically locked until the weight of the target wheel assembly is completely unloaded to the receiving station in the active cells.

The hoisting assembly is mounted at the bottom part of the cask by the reason of easier access for maintenance and cask balance due to lowering the center of gravity.

The top of the cask is detachable through a flanged design. The pulley system which provides rope guiding at the top of the cask is able to compensate for angle changes that occur when the wire runs along the rope drum. Ropes are run through pulleys so radiation not can shine in a straight path.

An automatic cable reel at the top of the cask provide housing for a hybrid multicore, screened and jacketed signal cable combined with 1,5 mm jacketed power cables.
10. Control system

The casks and associated handling devices shall be equipped with all relevant instrumentation to ensure safe docking, lifting and transport.

Following requirements forms the preconditions for the design and function:
- Casks shall be powerless at all times except when docked to its counterpart
- Electrical power and signals shall be fed through the corresponding counterpart
- Any moving mechanical part shall keep its steady state when power is disconnected
- Maneuver of a counterpart floor valve or release of mechanical fixating functions without docked cask shall not be possible
- Both connected valves shall be maneuvered over one control system that shall be mounted on the cask bottom valve
- Cask operations shall be performed through specific control systems, individual for each cask type, mounted on respective cask.
- High bay crane shall have a restriction to lift casks unless signals indicating closed counterpart floor valves are verified.

11. Human-Machine Interface (HMI) design

The casks are, when docked to the active cells floor valves, controlled by the active cells control system. When docked to the monolith or the mock up, casks are controlled by a separate HMI. For operation of the casks and their integrated each cask, tool or equipment shall have a password protected dedicated screen for its operation. A camera system that shall be inserted from the outside of all casks allows the operator to follow the progression of the handling events.

Figure 5: Outline HMI concept
The outline HMI concept is shown in Figure 5. Operation of the floor valves and casks is possible when a cask is correctly placed on its counterpart and electrically connected. The cask system can either be controlled from the control room of the active cells or via the mobile HMI. The mobile HMI can be moved between the mock-up and the monolith depending on where the cask shall be docked.

12. Integrated lifting devices

This section treats only casks integrated lifting devices and thus not high bay crane for which separate requirements and solutions apply.

For the cask’s internal lifting devices, two separate lifting ropes connected to the gripping tool shall, each of another, independently be capable to retain all forces from the different monolith components including any offset forces incurred by a single cable failure. During transport from monolith to high bay floor or active cells the monolith parts shall be fixated and locked to the cask by a mechanical fixating device that will unload the in-cask integrated hoist. The mechanical fixating device shall be qualified to carry all loads and thus relieve the cask internal lifting devices from any safety function during the transport. When connected to the active cells or the monolith, the casks will be part of respectively confinement which means that the monolith component can be released from its fixation and the internal lifting device can be utilized safely.

13. Monolith maintenance

Remote handling of all monolith components has been investigated. One example focusing on target wheel handling is shown in Figure 6. Sequences of the remote handling operations for all different monolith components has been performed and at this stage been used as a basis for discussions with and writing interface documents for respectively stakeholder.
The need of tools for complete monolith maintenance is shown in Figure 7 and how the different tools are related for a specific remote handling operation is shown in Figure 8.

Figure 7: Casks system structure

Figure 8: Interdependencies of remote handling tools
References

[1] Referral SSM2014-4363-24, Guidance with the background and reasons for Swedish Radiation Safety Authority’s regulations on lifting equipment and lifting operations at nuclear facilities