THE ESS IRRADIATED TARGET WHEEL HOT CELL OPERATIONS FOR HANDLING, DISMANTLING, SEPARATION AND PREPARATION FOR FINAL DISPOSAL

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ABSTRACT

The European Spallation Source (ESS) facility which will be built in Lund, Sweden is a long pulsed spallation source (5MW, 2GeV) and planned to be commissioned by 2019 [1]. The project includes a hot cell facility that is equipped with several systems fulfilling various functions. One of the functions shall cover the complete dismantling, separation and preparation for final disposal of the irradiated tungsten target wheel. The wheel disc has a diameter of 2.5 meter and a height of 8 cm. The spallation material within the target is tungsten. A stainless steel shroud, including slab supports encloses the tungsten. The shroud is connected to a shaft via a central hub. The total height of the assembly is 5.3 m weighting in total 14.5 tons.

The process of safe handling, dismantling, separation and preparation for disposal of the target wheel parts, needs a set of functional prerequisites such as; lifting, fixation, cutting devices, camera systems etc. The dismantling procedure needs to be well predefined to enable optimized packaging in relation to volume, materials, weight, radiation level, etc. A transport cask system adapted to the specific needs of ESS, able to meet the requirements of the ADR-S regulations is also needed [2].

This paper describes the specific ESS hot cell facility functions covering the processes from the separation of the parts of the irradiated target wheel to the preparation of the waste for the off-site transportation.

INTRODUCTION

The European Spallation Source (ESS) is a multi-disciplinary research centre based on the world’s most powerful neutron source. This new facility is around 30 times brighter than today's leading facilities, enabling new opportunities for researchers in the fields of material characterisation, biology, chemistry, life sciences, energy, environmental technology and fundamental physics.

ESS is one of the largest science and technology infrastructure projects being built today. The facility includes a linear proton accelerator, a tungsten target station, a large array of neutron instruments, laboratories, a data management and software development centre.

Europe's need for an advanced, high-power neutron facility was articulated 20 years ago. The European Spallation Source is a pan-European project. It is built by at least 17 European countries, with Sweden and Denmark as host nations. The ESS facility is built in Lund, while the ESS Data Management and Software Centre is located in Copenhagen, Denmark. Approximately two to three thousand guest researchers will carry out experiments at ESS each year. Most of the users is based at European universities and institutes, others within industry.

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 of the hot cell facility 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 crane for the transport of the irradiated components is 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.
ACTIVE CELLS

The active cells consist of a series of different areas having the main purpose of receiving, processing, interim storage and preparation for shipping of obsolete highly activated components. The main elements of the active cells are: process cell, maintenance cell, post irradiated experimental (PIE) cells, storage pits, technical galleries and transfer zone. An interior view of the process cell which is a part of the active cells is shown in Figure 1.

Figure 1: Interior of the process cell

MAIN COMPONENTS INSIDE THE SHIELDING MONOLITH

There are three main components placed within the shielding monolith that have to be periodically processed in the active cells. These are the target wheel including the shaft, the Moderator and Reflector (MR) plug and the Proton Beam Window (PBW). The degrading processes caused by irradiation and thermal environment determine the lifetime of those components.

REMOTE HANDLING CONCEPT

The concept rests on a high degree of modularity, where the modules constituting the remote handling system are easily replaceable.

Maintenance and handling of the target station machine equipment shall be performed remotely. Wear and tear parts of structures and machinery is designed for remote replacement. The processes of remote handling is designed so reversing of the process is possible if any failure occurs along the way. The operation of the active cells equipment will be carried out in a HMI central outside the confinement including visual surveillance by camera systems and with overlay VR possibilities.

The concept naturally also includes manual operation possibilities with through wall manipulators.

TARGET WHEEL

Figure 2 shows the global picture of the target wheel and associated shaft. The wheel disc has a diameter of 2.5 meter and a height of 8 cm. The spallation material is cooled by a continuous flow of helium during operation. In the figure, the blue zone represents the spallation material, tungsten. With brown depicted, the stainless steel structure through which the helium coolant is distributed. The target is split in 33 segment sectors arranged in a structural casing of austenitic stainless steel (see Figure 3). Each segment consists of 13 tungsten slabs as is shown in Figure 4. Each tungsten sector absorbs, as the wheel rotates, synchronized proton beam pulses from the accelerator and transforms it through the spallation process into neutrons as the final and desired product. The spallation process generates a significant amount of heat, radioactive isotopes and direct radiation. Cooling channels around the tungsten slabs are designed to provide an adequate helium cooling. Several factors have been taken into account in the arrangement of the spallation material. The proton beam will deposit most of its heat in the region near the outer rim of the target, while the coolant is brought through the shaft from the back of the target. Channels is used to move the coolant towards the outer rim where the spallation material is located. The maximum temperature of the spallation material is kept as low as possible, and the surfaces of the tungsten slabs will not exceed 500 °C [1]. The beam entrance window is as thin as possible to minimise proton loss at the point of beam entry into the target material.

Figure 2: Target Wheel and Shaft
Therefore, the beam entrance window also will require substantial cooling so that its local maximum temperature can be kept low enough during beam operation.

Tungsten slabs are arranged in three groups. The first group is located at the outermost radial part of the target wheel, where the highest heat load is expected. It will consist of six slabs, which will cover the area facing the two moderators. The tungsten slabs in this group are between 12 and 14 mm thick, and are separated from one another by 2.5 mm wide cooling channels.

The second group of tungsten slabs is located just interior to those of the first group. It will consist of four slabs, which will form the transition area between the outer rim portion of the target wheel with highest heat load, and the inner rim portion with lower heat load. The tungsten slabs in this second group will have rectangular cross sections with thicknesses between 14 and 32 mm.

The third group of tungsten slabs is located at the innermost radial part of the target wheel. It will consist of three thick slabs with rectangular cross sections. These three groups inside each of the 33 sectors is cooled in series, using helium flow entering the target wheel, with mass flux of 3 kg s\(^{-1}\) total (or 91 g s\(^{-1}\) per sector) and inlet temperature of 25 °C. In the so-called “S-channel” arrangement, the coolant will flow in a serpentine pattern through the tungsten slabs.

**Figure 3: Sections of Beam entrance window reveals segment.**

**Figure 4: Segment with tungsten slabs**

The target wheel is connected to an approximately 5 m long vertical shaft. The shaft is manufactured of two concentrically arranged pipes for separating the inlet and outlet helium flows.

As is shown in Figure 2, the shaft contains helical inserts which are designed to shield the neutron streaming through the pipes. The shaft and the target wheel is handled as a single unit during installation and dismantling.

**DISMANTLING TECHNIQUES**

Several techniques were investigated to understand how to manage the dismantling of the target wheel. The logistics of disassembling this complex device was developed accounted for the specific geometry of the target but letting room for the updates expecting to occur both in terms of the target design as well as the development of the handling concepts and its associated tools.

Important factors determining the choice of dismantling/cutting and handling procedures are the requirements for the waste form and shipping occurring downstream the hot cells activity.

Other parameters analysed for the choice of the cutting methods are: cutting speed, maintenance frequency, maintainability, emissions and secondary waste.

A summary of all potential technical dismantling techniques is provided in Table 1.

There are two major technique groups: i) mechanical and ii) thermal dismantling. Since the wheel and shaft solely are constructed from metal, thermal cutting might be the preferred option.

In this respect laser cutting is the most favourable method, among the thermal methods, for the austenitic steel shroud. This technique provides strict control of avoiding heat near the tungsten zone by restricting the cutting only to zones of steel and the need of collection of melt material.

Advantages of the laser technique is fine tolerance cutting, low heat distribution, and relative low amount of secondary emissions. Theoretically, with precise control of supplied energy, the laser beam can remove weld seams without burning through the underlying structures using a suction device to collect molten material.

Mechanical cutting methods include shear cutting, blade cutting, tearing and breaking.

For the shaft and the relative large supporting structures of the wheel, high speed circular sawing without coolants or lubricants might be another possible solution, at least in this stage of the design. Initial circular sawing tests has been performed by the ESS remote handling group with promising result. The tool used for these tests is presented in Figure 5. Based on the shape and size of the secondary waste from the circular sawing, it seems realistic and possible to collect the chips (see Figure 6).
Precise cuts near the sensitive target material could be carried out through end milling. The conclusions drawn from the pre-study undertaken, points in the direction of combining the two mechanical processing techniques of circular sawing and end milling for the dismantling of the wheel and shaft.

Development of coating techniques for the saw blade shows promising results for dry processing.

The relatively large chips from sawing shall be collected by guiding plates (hoods) connected to a vacuum system which in turn is connected to a waste drum. The sawing process shall as far as it is possible be covered by a temporary single layer plastic tent structure to limit the spread of chips and minimize decontamination to a smaller surface.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Applicability</th>
<th>Cutting thickness</th>
<th>Secondary Emission</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxy-fuel</td>
<td>Low carbon alloy steel</td>
<td>300 mm</td>
<td>Hot oxide, fumes, aerosols</td>
<td>Fast, Hot slag, Low degree tolerance.</td>
</tr>
<tr>
<td>Plasma</td>
<td>Electrical conductive materials</td>
<td>180 mm</td>
<td>Gaseous, dust and solid products</td>
<td>Low degree tolerance.</td>
</tr>
<tr>
<td>Laser</td>
<td>Most materials</td>
<td>20 mm</td>
<td>Gaseous, dust and solid prod.</td>
<td>Flexible, precise</td>
</tr>
<tr>
<td>Water jet</td>
<td>Most materials</td>
<td>150 mm</td>
<td>Abrasives, fluid and dust</td>
<td>Expensive decontamination operation</td>
</tr>
<tr>
<td>Mechanical</td>
<td>All materials</td>
<td>2000 mm</td>
<td>Scraps, burrs, dust</td>
<td>Collection of scraps necessary</td>
</tr>
</tbody>
</table>

Table 1: Dismantling techniques

AUXILIARY PROCESS CELL EQUIPMENT

Equipment within the active cells shall be designed to ensure a safe, robust and consistent handling and processing of the components. Electrical control
equipment shall be placed outside the active cells and as far as possible electronics shall me minimized inside the cells. Different tools needed for the disassembly of the target wheel are: overhead crane, dual power manipulator on telescopic mast, rotating table, circular saw, end mill, secondary waste collection system, lifting tools and camera system. The circular saw is remotely operated and driven by a fully automatic output regulated high frequency motor. Servo motors runs the linear rail system and all rotations of the saw assembly.

Advantages with the solution is a versatile function, yet space efficient. The dual arm power manipulator is shown in Figure 8.

![Figure 8: Dual arm power manipulator](image1)

Circular sawing shall allow both horizontal as well as vertical cutting. Cutting of the shaft shall be performed from the top to the bottom. The rotating table to be used is shown in Figure 9.

![Figure 9: Rotating table, vices and the lower centre piece of the shaft](image2)

**DISMANTLING OF THE TARGET WHEEL AND SHAFT**

The whole target wheel assembly is lifted from its transport cask to the rotating table and fixed to it. The rotating table provides precise rotation to various fixed angles or allows continuous rotation. The process cell’s overhead crane is thereafter docked to the assembly via a lifting tool with integrated scales for balancing the weight of respective piece of shaft to be cut. The saw in horizontal position starts to cut the outer pipe of the shaft while rotating the assembly. After the cut is completed the upper outer part of the shaft can be removed. (see Figure 10 and 11). Next step is to the remove the outer helical shielding, which in height corresponds with the predefined cut level.

![Figure 10: Removal of one of the inner shaft parts](image3)
When the shaft is completely removed and transported either to the temporary storage pits or outside the active cells, the remaining whole wheel disc structure is transported in a lightweight stainless steel cover to a storage pit in the active cells area for allowing radioactive material decay. The wheel storage pit is designed to host 10 wheel discs. After the period of decay, the wheel is transported from the storage pit to the process cell. The dismantling process resumes with precise end milling of the stainless steel lateral surface of the wheel to uncover the tungsten slab sections within the cassettes. Once the cassettes are disconnected from the wheel shroud a power manipulator can separate and load the tungsten plates into thin wall baskets for further handling.

The remaining stainless steel support structure can then be cut by the circular saw and loaded by the dual arm power manipulator into other thin wall baskets. (see Figure 12).

WASTE HANDLING

Sealed baskets with its sorted and documented content shall pass a surface pre-decontamination stage in the process cell before it is moved into the maintenance cell. Monitoring, marking and final decontamination is then performed in the decontamination area of the maintenance cell. The baskets can thereafter be placed in storage pits for allowing radioactive material decay. Several handling alternatives are under analysis via a Best Available Technique (BAT) method in order to select the optimum solution for the handling of the waste downstream the active cells. The highly activated radioactive waste may be stored within a container, “waste tank” (see Table 2) and transported for further handling within the ESS waste temporary storage facility or shipped offsite via a “transport cask” (see Table 3) for further treatment, temporary storage or direct disposal.

ESS shall develop and design its radioactive waste handling system to align with Swedish nuclear waste management system. Since the waste acceptance criteria of the Swedish disposal facility able to host the long lived intermediate level waste (LLILW) is not finalized, the ESS waste forms are not yet defined. According with Swedish legislation ESS will develop the waste type description for each identified waste stream.

Until the final repository will start to operate (2045) solutions for temporary storage both on ESS site and offsite shall be analysed and decided.

Calculations show that the shipping container is a Type B cask in accordance with IAEA requirements for the transport of LLILW. [3]

The maintenance cell is directly adjacent with the transfer area which constitutes an air lock and thus a part of the static barrier of the confinement.

The transfer area in the active cells is equipped with a station for the waste tank. Outside the transfer area the, sealed tank is loaded into the offsite type transport cask.
The transport off-site shall be in accordance with ADR-S. 

<table>
<thead>
<tr>
<th>Tank wall thickness (mm)</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty waste tank weight (tons)</td>
<td>10</td>
<td>18.5</td>
<td>25.5</td>
<td>33</td>
</tr>
<tr>
<td>Basket/inter nal casings weight (tons)</td>
<td>3</td>
<td>3.5</td>
<td>5.5</td>
<td>6</td>
</tr>
<tr>
<td>Waste load, max. (tons)</td>
<td>11.5</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Total waste tank weight, max (tons)</td>
<td>25</td>
<td>34</td>
<td>43</td>
<td>51</td>
</tr>
</tbody>
</table>

**Table 2: Estimations of properties: Waste tank**

<table>
<thead>
<tr>
<th>Tank wall thickness (mm)</th>
<th>50</th>
<th>100</th>
<th>150</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste tank weight (tons)</td>
<td>25</td>
<td>34</td>
<td>43</td>
<td>51</td>
</tr>
<tr>
<td>Transport unit (cask and frame) (tons)</td>
<td>67</td>
<td>67</td>
<td>67</td>
<td>67</td>
</tr>
<tr>
<td>Total weight (tons)</td>
<td>92</td>
<td>101</td>
<td>110</td>
<td>118</td>
</tr>
</tbody>
</table>

**Table 3: Estimations of properties: Complete transport unit assembly (tank, cask and transport rack)**

**CONCLUSION**

The modular concept for the machinery and equipment in the active cells and an accurate mapping of the needed processes constitute the basis for the functional and reliable strategy of the remote handling activities in the active cells. The ESS radioactive waste handling approach with regard to obsolete monolith parts cover provisions in the active cells and facility infrastructure for complete preparation for final disposal.

**REFERENCES**

