Developing a Target Imaging System for the European Spallation Source

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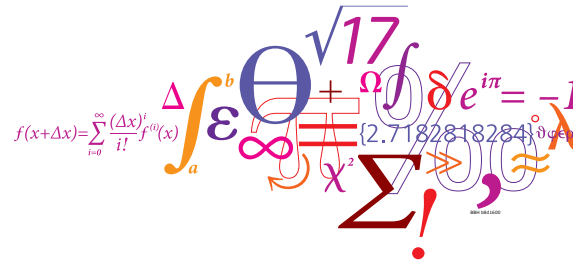

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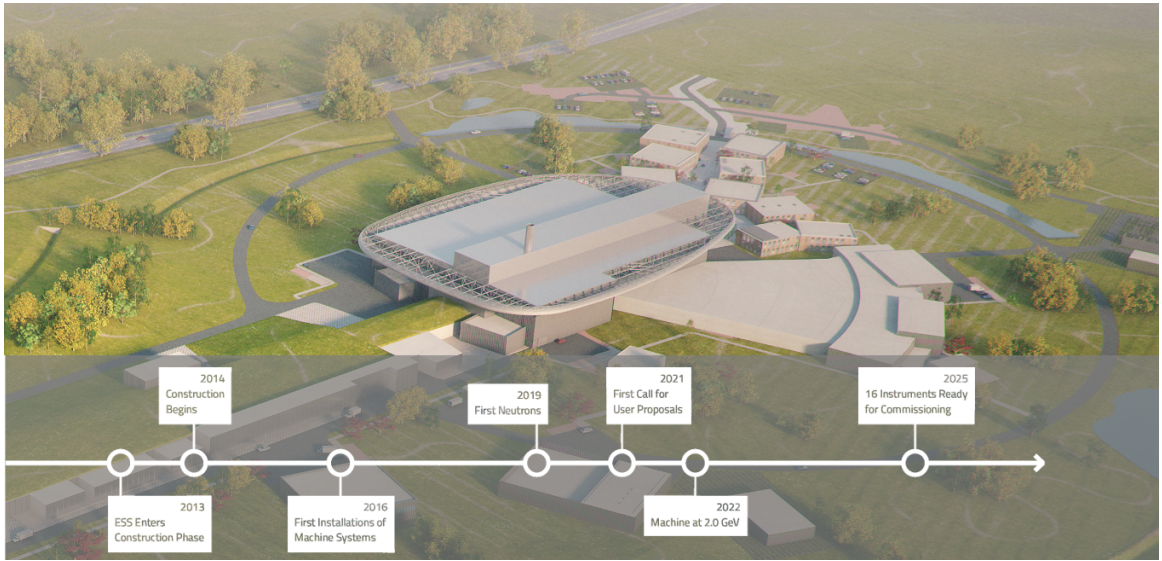
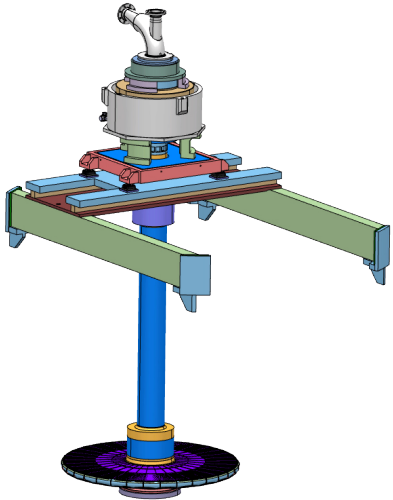
Center for Nuclear Technologies

Overview of the facility



The ESS target



The ESS Target Wheel…

- 2.5 m diameter
- suspended on a 6 m long shaft
- 36 sectors of 10° each
- 7000 tungsten bricks (3 tons)
- 2500 tons of shielding steel around

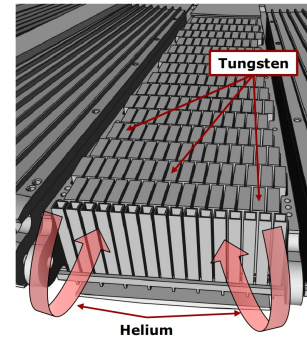
…will operate in extreme conditions

- 3 MW heat deposit from 5 MW proton beam
- 2.86 ms long proton pulses with 4% duty cycle
- 7 million 100°C thermal cycles per year

The tungsten bricks

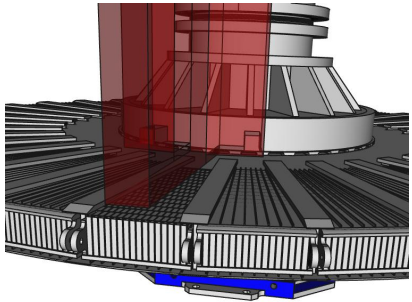
Tungsten bricks operate in a **brittle regime** after exposure to radiation

- Conditions may induce the **cleaving of the tungsten bricks**
- Local reconfiguration or accumulation of small debris may result in the **blocking of the coolant channels**
- **Thermal stresses may not be relieved**, thus affecting the lifetime of the target wheel



Important to know from an operations perspective if the tungsten geometry is preserved over the 5 years of expected lifetime of the target wheel

Principle of target imaging



Activation of the tungsten bricks is mainly due to hadrons.

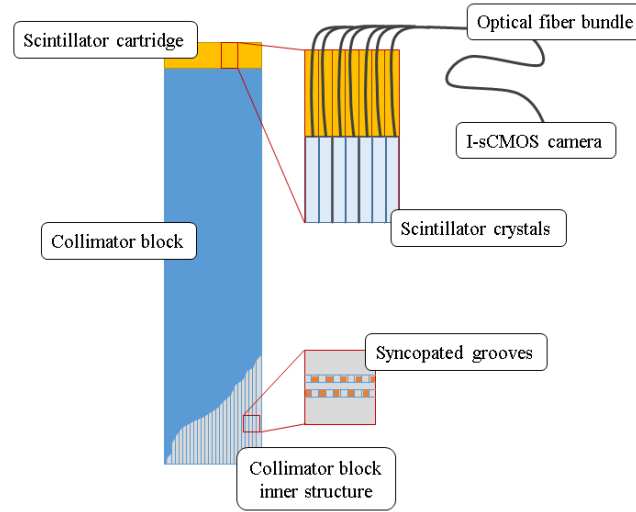
The **spatial distribution** of the decay gammas can be imaged through the target vessel.

The TIS is intended to provide high spatial resolution imaging of the decay gammas from the target wheel.

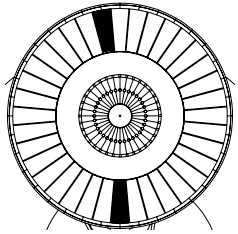
The image of the target **inner structure** can be used to confirm the **correct operation conditions.**

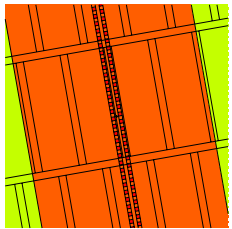
Proposed realization

- Brick size: $1 \times 3 \times 8$ cm^3
- Width of cooling channels: 0.2 cm
- Required maximum spatial resolution: 0.1 cm
- Gamma emission collimated by means of a **2.8 m steel block with syncopated 1x1 mm^2 grooves** to ensure complete radial coverage of the wheel
- **Azimuthal coverage** achieved by means of the wheel rotation
- **An array of scintillators** is placed on top of the collimator block
- Scintillators **coupled to optical fibers** to convey the scintillation light to a high-sensitivity I-sCMOS camera



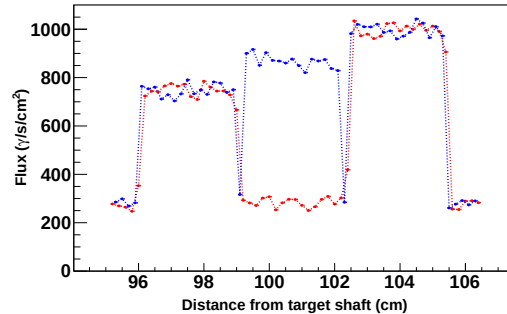
Gamma flux at scintillators



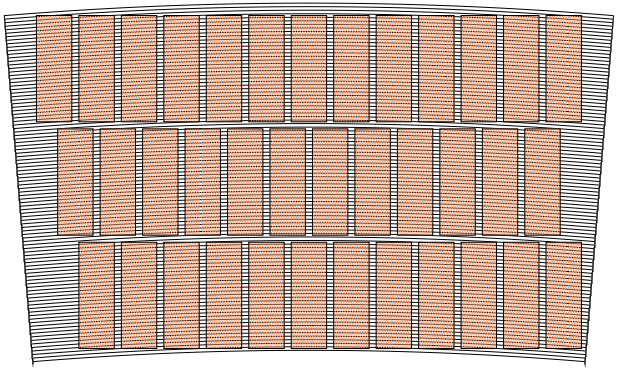


Simulation workflow:

- MCNPX simulation with **protons** on the first sector
- CINDER'90 to calculate **nuclide inventory after 1 s** on the **first sector**
- **Gamma source** (bricks+vessel) copied to the imaged sector
- MCNPX simulation to calculate the **gamma flux** at scintillators
- Independent MCNPX simulation for gamma and neutron **background** evaluation



Target Image Reconstruction



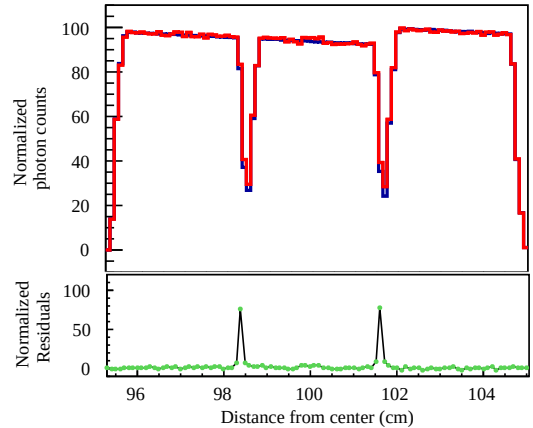
The first implementation of the code is based on **two assumptions**:

- **thin-layer (2D)**: given the attenuation length for 686 keV photons in tungsten, **only the top cm** is responsible for the measured signal;
- **cell rejection**: the collimator allows only gammas perpendicular to the target surface to reach the scintillators, so **no blurring** is included in the simulations.

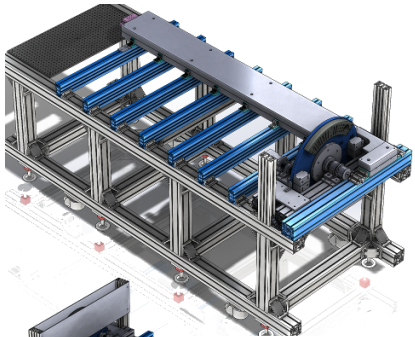
Error detection and location

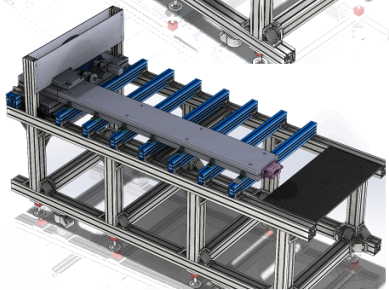
The images are compared by means of the **Pearson's χ^2 homogeneity test**, which calculates the probability for the **hypothesis of identity** to hold. The analysis of the **normalized residuals** locates the anomalous bins.

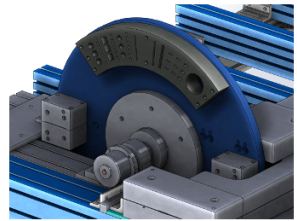
Increasing the number of angular bins and iterating the χ^2 test allows to **identify the location of the anomaly** and provides a **2D reconstruction** of the imaged target sector. The image spatial resolution is proportional to the number of angular bins.

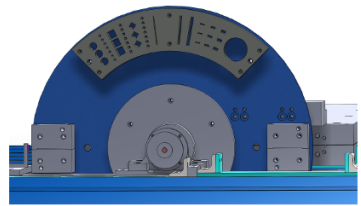


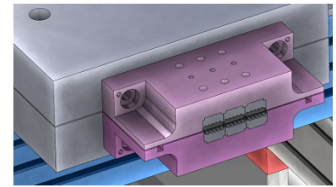
CAD Drawings

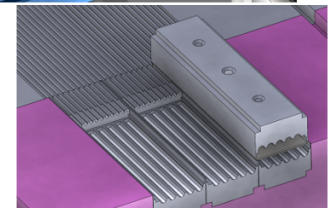












Status and outlook

The simulations provided **support to the feasibility** of the proposed TIS, and further studies are planned to characterize in detail the system:

- **background** from the activation of surrounding components will be included;
- the **gating capabilities** of the selected Andor I-sCMOS camera will be considered;
- **efficiency and losses** of scintillators, fibers and other optical components will be evaluated;
- **statistical evaluators** need detailed investigation to assess capabilities and limitations;
- extensive experimental studies will be performed to develop **software controls** and **image reconstruction procedures**, and to estimate the lifetime of the TIS components.

Thank you for your attention

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