UPGRADING ODIN TO ENABLE FULL SCIENTIFIC SCOPE

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1. SCOPE

This document outlines the scientific prospects of rescoping ODIN, summarizing decision-making history, impact on the science case, cost estimates, schedule, and risk analysis.

2. INTRODUCTION

ODIN was conceived as a leading neutron imaging beamline for scientific research and industrial applications. [1] Adjustments were made due to evolving requirements and budget constraints [2], yet the instrument was designed to allow for rescoping all options later on, enabling ODIN to become and remain a world-leading neutron imaging beamline, capable of meeting the diverse and growing demands of its user community.

The STAP report in this phase (2015) already emphasized the importance of a fully featured ODIN to avoid a limited instrument: "STAP also believes that the original charter for ODIN to be the world's most advanced and leading imaging instrument is still the right approach. In that context, **STAP unequivocally states that in the long run strong commitment for a fully featured and adequately funded ODIN**, even when constructed initially to its minimally required potential, **will be more desirable than a crippled mediocre fully built instrument with limited scope**." This was re-emphasized in later STAP meetings as well as a recent exercise carried out by P. Deen et al. and presented to the Instrument Collaboration Board [4].

The success of neutron imaging heavily depends on the complexity of data analysis, which is greater than that of scattering techniques. Imaging datasets are large and unique, requiring custom algorithms and significant computational resources. To maximize the instrument's capabilities, especially regarding the proposed upgrades, proper staffing of the beamline is essential.

3. RE-SCOPING OPTIONS

Several key capabilities are currently missing from the scope of the ODIN neutron imaging beamline and hence not fully addresses the scientific needs of the user community. To fully realize the potential of the instrument, additional equipment and utilities must be installed in and around the experimental cave. These upgrades will not require access to the bunker or the shielded guide.

It is important to emphasize that the descoping of ODIN does not simply concern issues like detector coverage (which has an obvious impact on performance and scales approximately linearly with the area being added), but rather the exclusion of entire techniques. While descoped originally, the x-ray CT setup and grating interferometry have or will be recovered by external grants.

The following sections outline the key methodological upgrades that are planned to meet ODIN's scientific goals.

3.1. High Flux TOF Neutron Imaging Detector

Scientific Merit:

Currently, ODIN possesses only one TOF detector, namely the LumaCam [5], a novel scintillator-based event-mode imaging detector, which however is limited by its maximum neutron flux capacity. This restricts ODIN's potential benefits from being installed at the ESS before the user program begins. In contrast, facilities like RADEN (J-PARC) employ a range of imaging detectors for various needs, including energy-resolved imaging and traditional radiography.[6]

Technical Considerations:
The Micro-Channel Plate (MCP) detector, developed at UC Berkeley [7], is the most widely used TOF imaging detector and is employed at all major spallation sources (e.g., J-PARC, ISIS, LANL, SNS, PSI), delivering significant research output. It has been successfully used by ESS at the V20 testbeamline in collaboration with PSI and UC Berkeley.
Cost Estimates:
- **MCP detector:** 250 kEuro

3.2. High resolution setup
Scientific Merit:
Neutron imaging generally has lower spatial resolution than X-ray imaging, but many scientific fields require high-resolution neutron imaging for detailed structural information. Achieving this high resolution within reasonable acquisition times is essential and represents a crucial upgrade.
Technical Implementation:
Recent advancements have made high-resolution neutron imaging more affordable, particularly with standard scintillator-camera systems. Using infinity-corrected optics and specialized scintillators, spatial resolutions below 4µm can be achieved.[8] However, this high resolution reduces the field of view, limiting the size of objects that can be imaged. To address this, a larger camera chip, such as a tiled TPX3 camera, will be used. A dedicated high-resolution setup is recommended to streamline experiments.
Note: Neutron focusing optics, such as Wolter optics, are not being considered for this implementation, albeit their development needs to be followed.
Cost Estimates:
- **Camera box + optical lenses + scintillator (without camera):** 70 kEuro
- **Tiled TPX3cam/TPX4cam:** 300 kEuro

3.3. Diffraction-Supported Neutron Imaging
Scientific Merit:
Bragg edge transmission has limitations in selecting scattering vectors and gauge volumes, making complementary detector coverage in scattering geometry essential. Early installation of partial scattering detector coverage will enhance existing diffractometer setups and improve the quantification of transmission-based imaging data.
Technical Considerations:
ODIN's experimental cave is designed for future diffraction detector installations, with considerations for size, shielding, and infrastructure, similar to the approach at IMAT (ISIS). Two technical solutions are being considered: Traditional detector solutions based on established technology and Camera-based event mode detectors, which may offer unique advantages in functionality and cost.
Cost Estimates (for one 90° Detector Bank):
- Option 1: Traditional diffraction detector solution: 1.5 MEuro
- Option 2: Event mode imaging camera solution: 250 kEuro

3.4. Time-of-Flight Three Dimensional Polarimetric Neutron Tomography (ToF 3DPNT)
Scientific Merit:
3D-PNT is a novel technique for measuring and reconstructing three-dimensional magnetic field strengths and directions non-destructively, enabling the investigation of magnetic fields within bulk materials. While still under development, this technique is integral to the scientific case of ODIN.

Technical Considerations:
The ToF 3DPNT setup requires a dedicated polarimetric system for neutron instrumentation, which must be specifically designed. A robust reconstruction algorithm is essential for converting raw data into detailed 3D magnetic field maps.
Cost Estimates:

- **Polarimetric setup + development:** 600 kEuro

3.5. Spin Echo Modulated Dark Field Imaging (SEMSANS)

Scientific Merit:
SEMSANS is a Larmor labeling technique that uses a polarization and analysis configuration similar to polarized neutron imaging, enabling spatially resolved SANS studies in imaging geometry. It achieves resolutions between 10 nm and 100 nm, complementing the grating interferometry range of 100 nm to 1000 nm. Although still under development, it holds significant potential.
Technical Considerations:
Implementing SEMSANS on ODIN requires a dedicated setup, potentially based on RF technology. The reconstruction algorithms are critical and will necessitate dedicated effort, including post-doctoral support.
Cost Estimates:

- **SEMSANS setup + development:** 400 kEuro

4. CONCLUSIONS

The ODIN instrument is a key facility at the ESS, designed for exceptional performance in neutron imaging and related techniques. To achieve its potential as a world-leading instrument, it is crucial to address current detector limitations and enhance its capabilities. Prioritizing the proposed upgrades will enable ODIN to meet the diverse needs of its user community from the start of operations. Advisory bodies emphasize that completing the full range of upgrades is essential to maintain user interest and satisfaction, particularly during initial operations. Lessons from other facilities highlight the need for foresight in development to ensure seamless functionality. By strategically implementing these enhancements, ODIN will be well-positioned to attract a variety of scientific inquiries, reinforcing its status as a premier neutron imaging facility at the ESS.

5. REFERENCES

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