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Preliminary System Design for the ODIN instrument

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DOCUMENT SCOPE

This document describes the preliminary engineering design of the Imaging beamline ODIN in detail. The document provides an overview of the instrument and describes technical solutions. The expected performance of the given technical solutions with respect to the functional requirements is discussed, followed by an evaluation of the scientific performance.

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1 INTRODUCTION

The Preliminary System Design Description document of the ODIN instrument describes the system architecture and the physical layout of the instrument. The descriptions arise from the design of the instrument addressing the functional requirements [1], as well as the constraint requirements that have been identified at this point. The purpose of this document, together with the Concept of Operations [2] and System Requirements [3] documents is to:

- provide a documented description of the design of the instrument that can be reviewed and approved by the stakeholders in a Tollgate 2 review
- provide a detailed enough description of the instrument so that its components can be designed in detail ("design-to specification")
- provide a description of the hardware and software solutions
- discuss the performance expectations of the instrument

2 SYSTEM DESCRIPTION

2.1 Purpose

ODIN is a multi-purpose imaging instrument intended to satisfy a wide range of scientific needs. The multi-purpose imaging capability provides spatial resolutions down to the µm-range enabled by the high brightness of ESS coupled with ongoing advances in detector technology. The pulsed nature of the source will give access to wavelength-resolved information, yielding a qualitative informational advance over current state-of-the-art. The full scope capability offers its users a variety of imaging techniques for the characterisation of objects with applications in virtually all natural science disciplines.

2.2 Overview

The instrument consists of three main technical subsystems: beam transport and conditioning system (BTCS), sample exposure system (SES) and scattering characterization system (SCS). In addition, as described in the instrument product breakdown structure (PBS), the instrument includes the structures that house and support these subsystems, the software to control the instrument and the software to process the data. The hardware description in this document does not strictly follow the PBS, but rather provides a functional breakdown of technical components along the neutron beam path. This makes it easier to map the specifications to the high level scientific requirements. The PBS numbers are given for reference where appropriate.

2.3 Layout

The instrument is located at beamport S2 and, as a bi-spectral instrument, it will view both the cold and the thermal moderators. All instrument components are located in Hall 1 (Figure 1). The first optical elements are located in the beamport

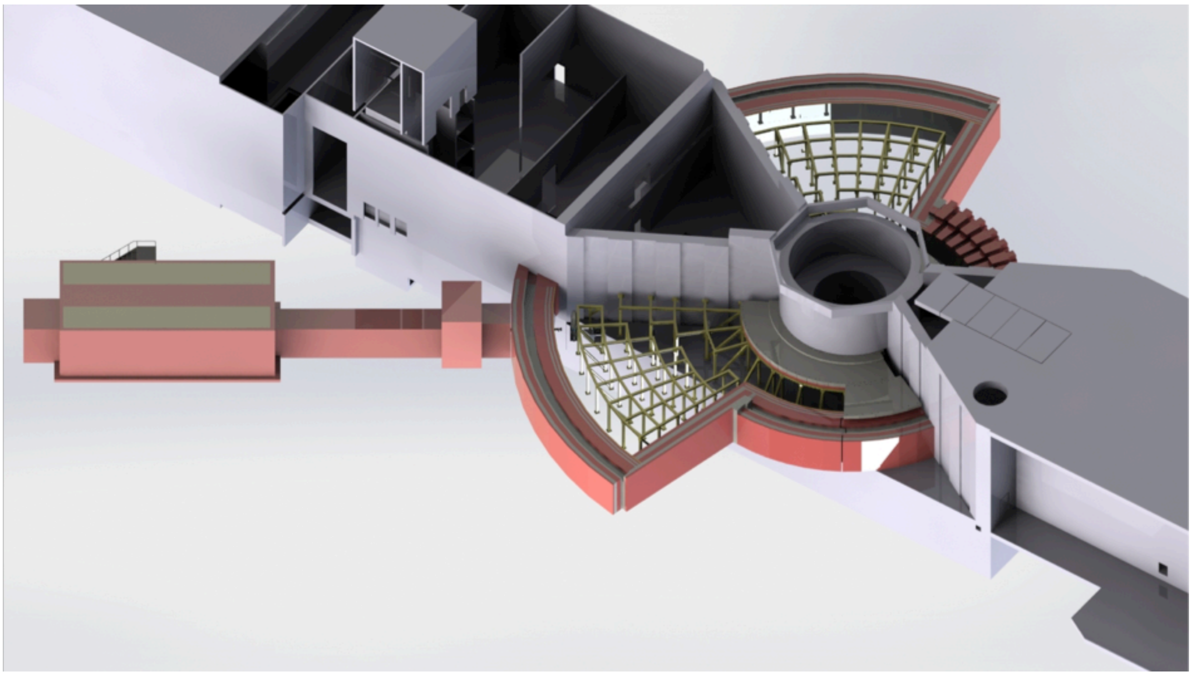

Figure 1. Current Beamport Allocation.

insert. The complete chopper system, with the exception of one chopper, is located inside the bunker, as is a heavy shutter. Apart from one chopper, the guide between bunker and experimental cave does not have any additional active components. The experimental cave will contain the sample area, detector system, slit system and beam stop.

3 SUB-SYSTEM DESCRIPTION

3.1 Neutron Optics

The neutron optics system has been optimized for the transport of a divergence of ±0.7° both horizontally and vertically in order to have a homogeneously illuminated area of up to 20x20 cm^2 at a sample position. Given the need to use the Wavelength Frame Multiplication concept to tune the energy resolution, an eye-of-the-needle approach in the horizontal direction has been applied, for a faster and more uniform chopping of the beam early on. That includes a focusing feeder that focuses the beam to 1.5 cm in the horizontal direction at the WFMC position followed by a ballistic guide with the first focus at the WFMC and the second focus at the cave entrance. Given the small size of the new moderator concept, matching the intended size of the pinhole at the entrance of the cave, a ballistic approach has been employed in the vertical direction.

The m-coating along the guide was optimized for efficient transport of neutron with a wavelength of 1Å through extensive McStas simulations.

A useful figure of merit of the ODIN guide system is the transfer function of the entire neutron guide system from source to cave. To assess the performance of the guide system after the first pinhole as compared to a more traditional neutron

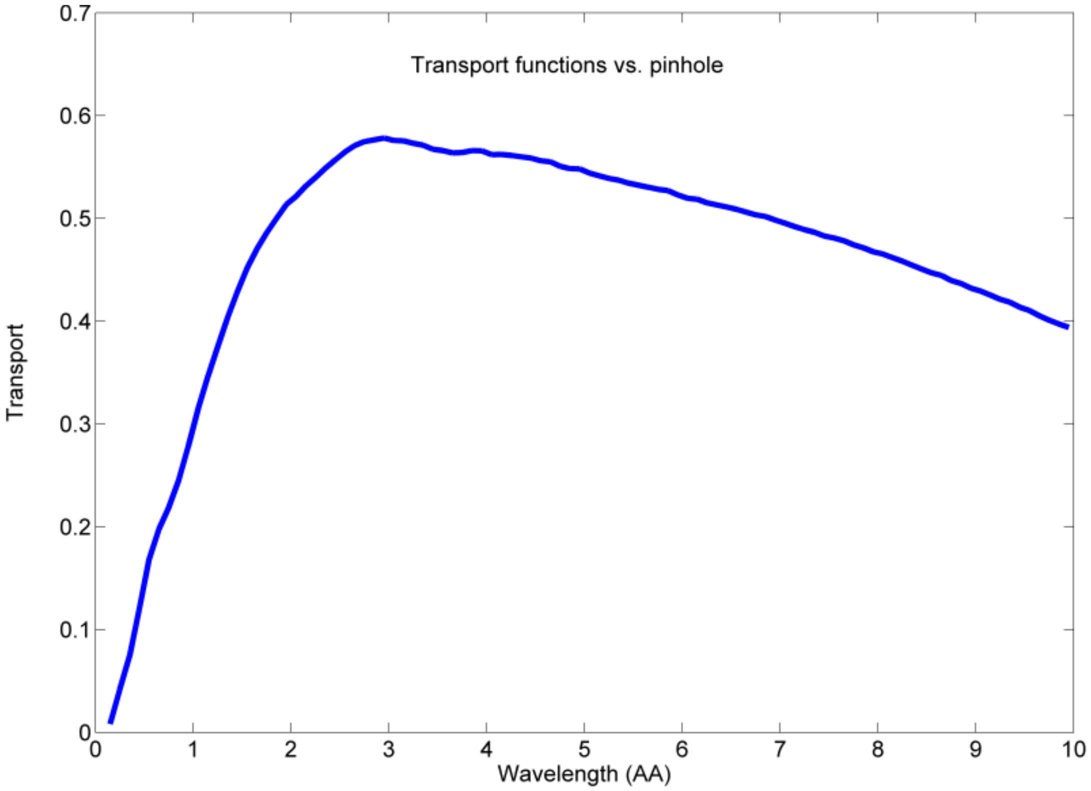

Figure 2. Transport function of the full ODIN neutron optics compared to a pinhole configuration.

imaging beamline layout without guide, we compare the spectrum of the beam 10 m after the 1st pinhole without any additional neutron optics to the full guide system sample position, which is 10 m after the second pinhole. This comparison can be found in Figure 2.

As can be expected, the substantial length of the neutron optics hinders the transport of low-wavelength neutrons compared to a ~18m long instrument (without guide), but of course with the added benefit of higher useable ToF resolution and wavelength bandwidth.

In the following sections, each part of the guide is described in greater details and all the positions are relative to the Beam Port Coordinate System (BPCS) of beamport S2.

3.1.1. Overall neutron optics alignment

In order for the guide system to point to the desired region of the moderator within the geometric constraints of the monolith insert, the optics axis is shifted 2.6 cm towards S3. Should the design of the monolith insert change in the future, or irreparable conflicts with neighbouring beamline be found due the limited space in the monolith, slight adjustment of this value is possible.

3.1.1 Bi-spectral mirrors

Due to the scientific requirement of having a wide usable spectral band extending up to 10 Å or more, the neutron optics element nearest to the moderator will be an ensemble of 12 single-coated m=5 super-mirrors on a silicon substrate. These mirrors will be parallel to each other and composed of 5 straight sections of equal length for a total of 30 cm length. We will avoid using a bent substrate in order not to incur in significant extinction effects due to the smoothly-varying lattice spacing in bent silicon.

The mirrors will be pressure mounted via slots precisely made in the vertical mirrors of the feeder and glued with radiation-hard glue.

The choice of Silicon has been made due to its transparency to low wavelength neutrons coupled with its radiation hardness.

The temperature expected at the very entrance of the monolith insert is ~60° C according to the calculation presented at IKON 10, making a special cooling of this component not strictly necessary. Should a refined calculation show a higher temperature, a possibility would be to mount them inside the target area, before the entrance window of the beamline in order to take advantage of the contact cooling given by the He atmosphere inside the target area.

To assess the performance of the bi-spectral mirror arrangement, we compare the current version of the ODIN neutron optics (including bi-spectral extraction) to two fictitious instruments, a “thermal” and a “cold ODIN” each pointing respectively to the thermal and cold moderator only, without bi-spectral extraction but having all the remaining optics untouched. This comparison is shown in Figure 3.

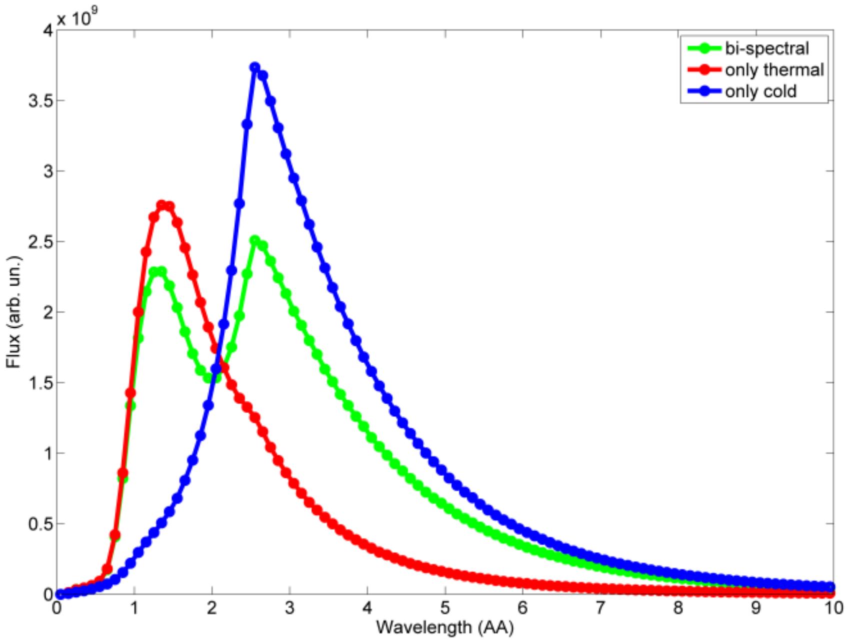

Figure 3. Comparison of the spectra of the current bi-spectral optics to a thermal only and cold only version.

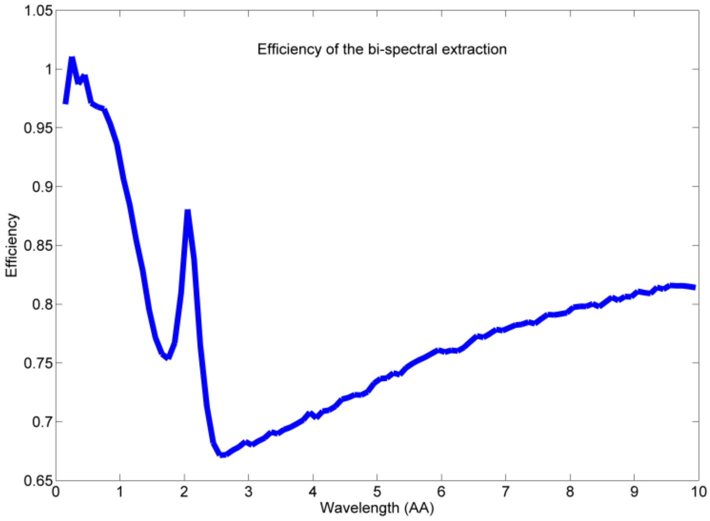

Figure 4. Efficiency of the bi-spectral extraction system vs. ideal case

An ideal dual beam extraction would provide a spectrum equal to the maximum of the two fictitious instruments for each wavelength. When comparing the resulting spectrum of ODIN with such an ideal extraction, we obtain Figure 4.

In this figure we see that for short wavelengths we have a high efficiency of more than 80%, decreasing as the wavelength increases due to the more efficient reflection of neutrons coming from the thermal moderator on the “wrong” side of the bi-spectral mirrors. As the wavelength increases, we reach the crossover point where the thermal and the cold moderator have the same intensity, after which the extraction efficiency has a discontinuity given by the binary nature of the max function, and as expected for colder regions the current extraction performs at a satisfactory level of about 75% of a “pure cold” instrument.

The gain in having a bi-spectral extraction is apparent in Figure 5, where the expected ODIN spectrum is compared to either the spectrum of the “thermal ODIN” or the “cold ODIN”.

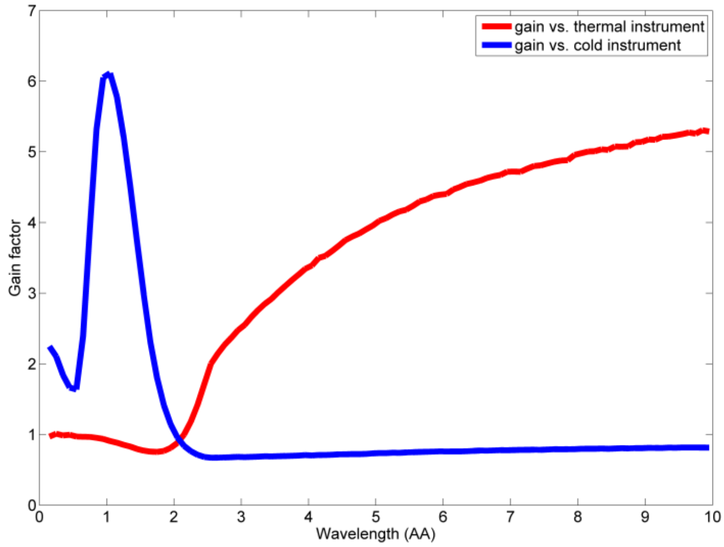

Figure 5. Gain factors by using a bi-spectral extraction on the purely cold and thermal instruments.

As can be seen, we can expect an order of magnitude increase in the intensity of region around 1 Å compared to a cold only instrument and a factor of 5-7 average for the cold wavelength compared to the case of a thermal instrument.

3.1.2 Monolith insert

The monolith insert will house the bi-spectral mirrors, most of the feeder and the light shutter. The feeder has a focusing shape in horizontal direction and defocusing in vertical direction. As mentioned earlier, the focusing part is needed to achieve proper chopping at the focal spot of the feeder itself, where the WFMCs will be placed. This is the part that has the highest m-coating after the bi-spectral mirrors.
The vertical direction is defocusing in order to relax the m-coating needs and increase the transported flux, without hindering the chopping.
In this section of the guide system, the curved guides will be approximated with straight segments of 30 cm in order to be able to use thicker substrates and improve the thermal stability of the whole structure.

The substrate of choice in this area, in accordance with the NOSG handbook [4], will be either Al or Cu, depending on the results of background simulations.

3.1.3 Main (transport) guide

The rest of the guide will be partly in the bunker and partly inside the instrument shielding. Until necessary, the substrate will be Cu or Al in accordance with the NOSG handbook recommendations, after which borfloat glass will be used for its superior lifetime and quality, still in accordance with the NOSG guidelines. 10-Boron plastic or otherwise 10-boron-containing materials will be used as guide shielding in order to reduce activation of the vacuum components and overall radiation level. For this part of the system, truly curved sections can be expected, in order to have the best homogeneity possible at the sample position.

3.1.4 Guide vacuum

The guide system will be operated in vacuum throughout the whole length of the system. In particular, the concept of “outside vacuum” will be employed, where the optics will be mounted and aligned inside long vacuum chambers, as opposed to “inside vacuum” where only the inner space within the guide system is evacuated and the guide substrate itself provides the vacuum chamber. This will ensure the least amount of deformation to the shape of the guide thus increasing its durability and performance, albeit at a slight cost penalty.

3.2 Chopper System

A schematic of the chopper system layout is shown in Figure 6. The complete chopper system is based on a Bachelor Thesis and a PhD Thesis, [5],[6]. Since a detailed description of the system is beyond the scope of this document, only a brief summary will be given. Mathematical background, disc design, performance and failure modes are all discussed in [6]. The chopper positions have been slightly adjusted as to not interfere with the bunker pillar-frame or the first chopper of the DREAM instrument. Some operational modes of the system are shown in Figure 7. Except for the WFMCs a split housing approach is planned for all choppers.

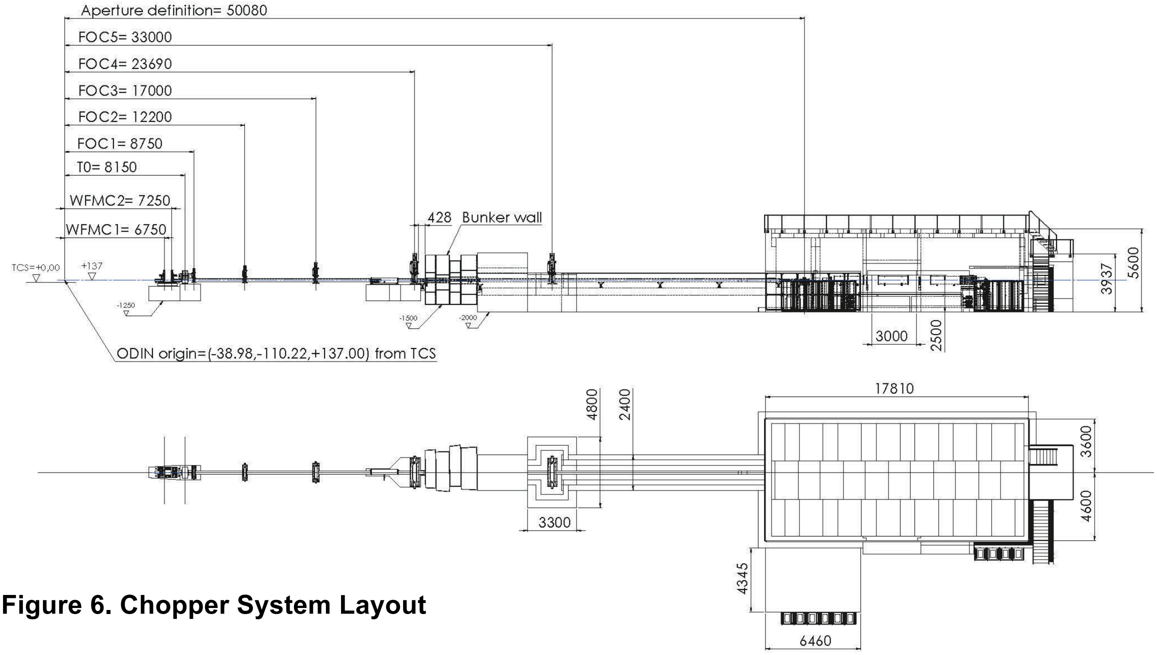

Figure 6. Chopper System Layout

3.2.1 T0 Chopper

Current simulations suggest that a few modes of ODIN, in particular such with high wavelength resolution, might profit from a T0-chopper. Therefore currently a T0 chopper is foreseen in the design of ODIN. There is one T0-chopper for attenuating the prompt pulse as well as thermal neutrons up to about 0.5 Å. A conceptual design has been studied for the DREAM instrument [7]. The performance with respect to fast neutron attenuation is described in [8]. This recent study indicates that a single hammer on one rotation axis should be sufficient for DREAM. It is hence expected that such solution is more than sufficient for the imaging instrument ODIN, with in general much lower background sensitivity. It is therefore also expected, that the requirements to the T0 chopper for ODIN are more relaxed than those for DREAM, which drive the development for ESS.

Preliminary T0 parameters:

Position:......... .... 8.15 m
Beam height: 6cm
r_0=................. .... 30 cm
Frequency: 28Hz
W-hammer length: ≤ 20 cm (plus B, Cu for thermal and cold neutrons – TBD)
Hammer section: .. ≈ 25°
Phase accuracy:.... 0.3°

ESS plans to develop a standard T0-chopper along the lines of the DREAM requirements [9]. ODIN will in case of a successful development use this ESS standard device. In case of failure of this development ODIN will use existing technology as used as other spallation neutron sources. This is possible because the requirements of ODIN do not have to be expected to exceed these of existing technological solutions.

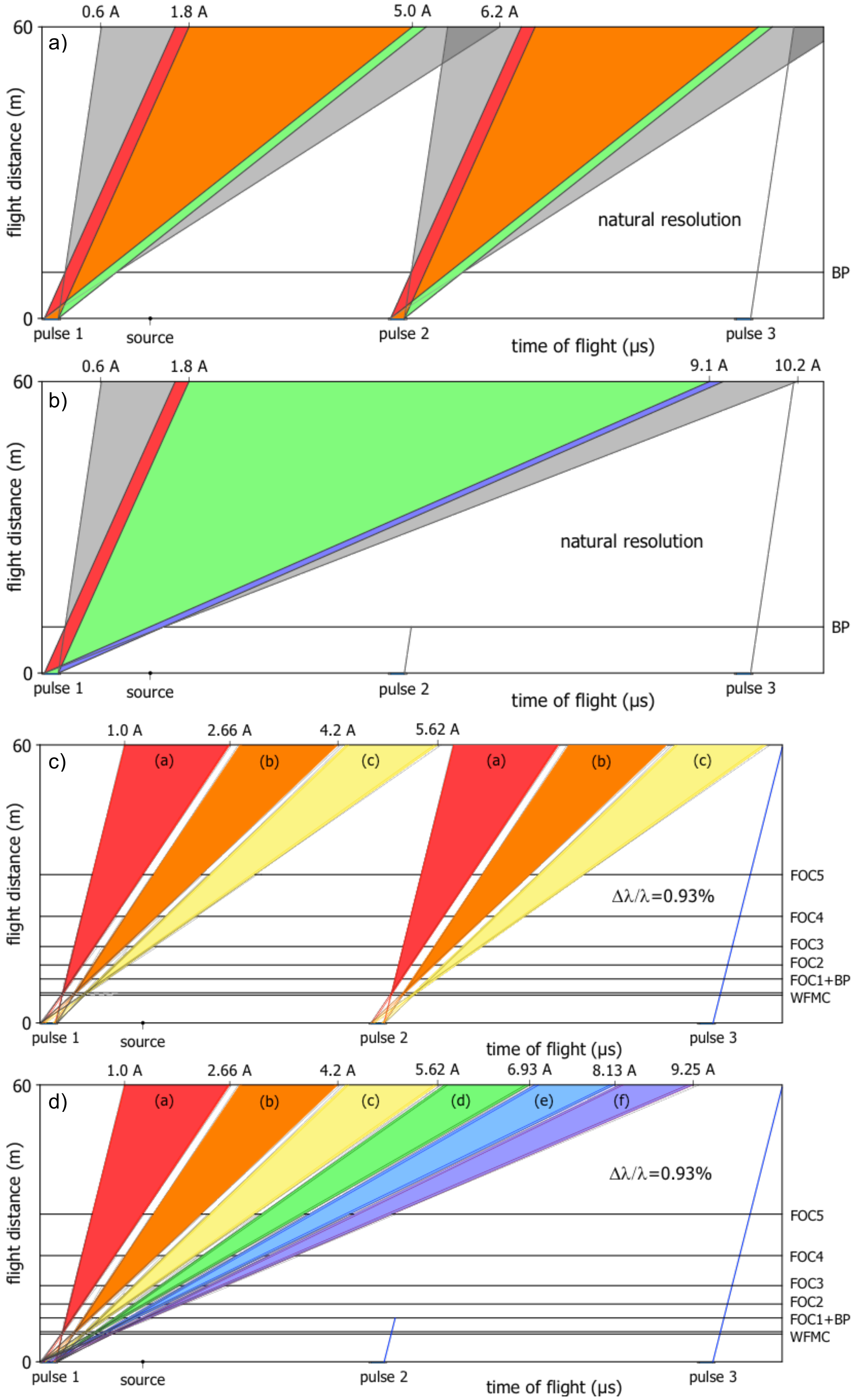

Figure 7. Impression of some operational modes with and without chopper system.

3.2.2 Wavelength Frame Multiplication Choppers

A pair of wavelength frame multiplication choppers will be placed closest to the source, between 6.75 and 7.25 m, centred at 7.00 m are on translation stages allowing to remotely change the distance between their discs. Both discs will be 700 mm in diameter and have 6 windows in order to “cut” the beam into 6 frames. The housings will be mounted according to the CHIM pillar variant [10].

3.2.3 Bandpass Chopper

The BP chopper can be used to block every other pulse in order to increase the accessible wavelength range as compared to normal operation where every pulse is used. The disc has a diameter of 800 mm and one window. By adjusting the chopper frequency to 28 Hz or 14 Hz every, or every other pulse is allowed to pass, respectively. The BP will share a housing with Frame Overlap Chopper 2.

3.2.4 Frame Overlap Choppers

The main characteristics of the 5 Frame Overlap Choppers (FOC) are shown in Table 1. With increasing distance, the disc diameters increase as well, while the rotation speed decreases (this is calculated in detail in [6] and can be deducted from Figure 7).

Chopper	Position (m)	Disc Diameter (mm)	Frequency (Hz)
FOC 1	8.5	800	42
FOC 2	11.84	1000	42
FOC 3	16.49	1200	28
FOC 4	22.97	1800	14
FOC 5	32.0	1800	14

Table 1. Frame Overlap Chopper Summary

3.3 Beam Cut off

3.3.1 Heavy Shutter

Due to the line-of-sight baseline the instrument requires a heavy shutter for access even in conventional operation. It is currently expected that a shutter would have a length of 2.5 to 3 m, requires to be fail safe (either spring-loaded or gravity driven) and accurate as to carry a corresponding length of guide, which also requires to be evacuated. A proposed concept is shown in Figure 8.

Figure 8. Heavy Shutter, preliminary design

3.3.2 Beam Stop

The Beam Stop has to be able to accept the full beam assuming all choppers and shutters are in the full open position. The Stop is cup like with its axis parallel to the incoming beam, its inner core is iron. The iron core is 720mm long and radius 250 mm, the void sections are 500 mm and 700 mm and are surrounded by 200 mm steel, see Figure 9. An additional “get lost” tube is considered.

3.4 Shielding

The shielding has to absorb the radiation to fulfil the dose requirements of 1.5 µSv/h in the supervised area. The design also has to limit the background for the instrument.

3.4.1 Inside Bunker

The bunker in D01 contains all instrument components up to 25 m distance from the surface of the moderator. This includes 8 of the 9 ODIN choppers. The instrument team will provide the boron based shielding, surrounding the neutron guide. To reduce streaming and background three tungsten collars around the guide of about 5 cm thickness are considered, alternatively steps in the metal substrate of the guide could be used for that purpose.

3.4.2 Outside Bunker

The neutron guide has to be shielded from the bunker to the cave; this will also include FOC 5 at 32 m. The shielding outside the bunker is based on Summary of a preliminary analysis of the ODIN shielding requirements, [11]. In order to reduce activation of shielding material by thermal neutrons, almost all the shielding will be clad with about 10 mm of borated rubber or PE. Shielding integration around the feed-through in the currently flat bunker wall should be carefully considered.

3.4.2.1 Guide and FOC 5 Shielding

I. Guide from Bunker to FOC 5: This is a short section of guide shielding material currently is 350 mm steel and 550 mm concrete.
II. FOC 5 Pit: Due to scatter from the chopper itself the pit will also consist of 350 mm steel and 550 mm concrete. Guide from FOC 5 to Cave: A lower level of scatter allows shielding to be down to 250 mm of steel and 350 mm of concrete. A concern is the m5 guide close to the cave as this produces high energy photons, this may increase the concrete thickness or require additional lead shielding.

3.4.2.2 Cave

The Cave comprises two chambers, the optical cave, which will house the collimator wheel and the experimental cave, where the actual experiment will be housed. The optical cave walls will contain 300 mm steel, 50 mm lead and 350 mm concrete. The separated experimental cave will have walls of 150 mm steel and also 350 mm concrete. As mentioned above, both cave will be clad in about 10 mm of borated rubber or PE.

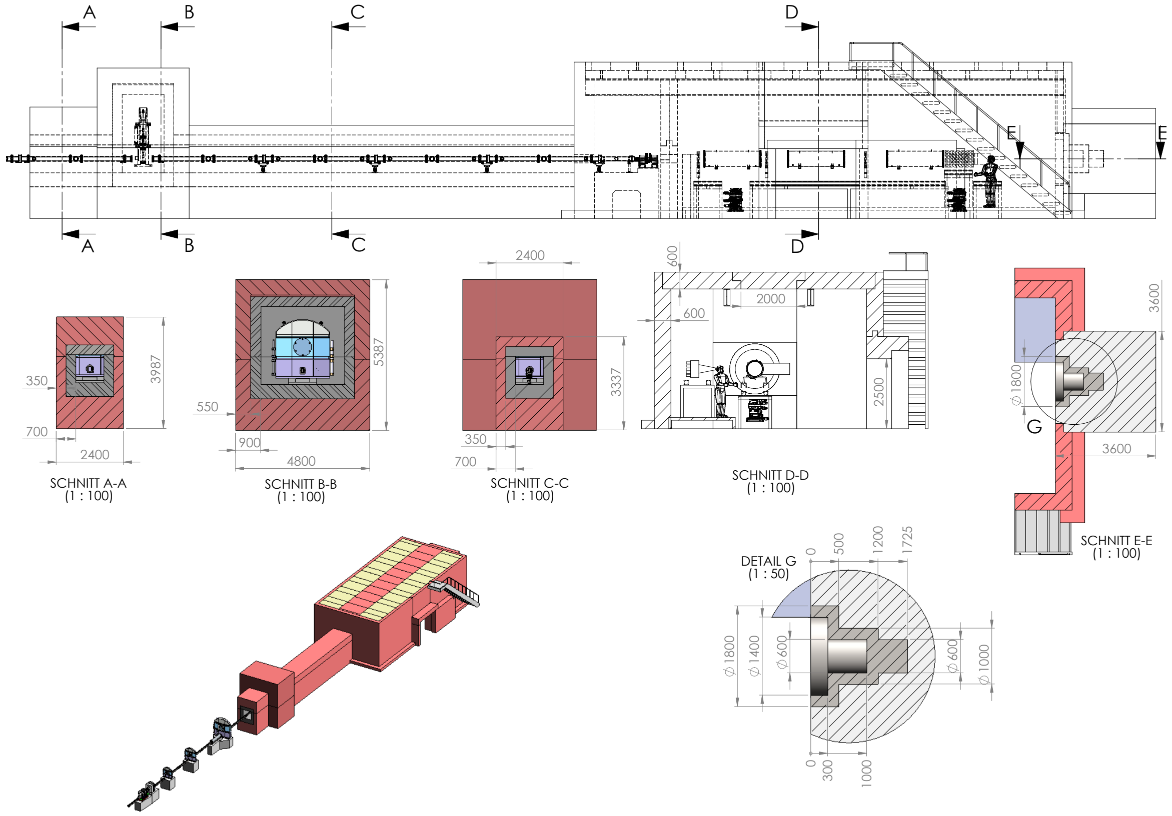

Figure 9. Summary of shielding from bunker to beam stop.

3.4.3 Summary of Shielding Dimensions

Figure 9 shows the dimensions of the guide shielding before (cut A-A) and after (cut C-C) the FOC 5 pit (cut B-B). The experimental cave and beam stop are shown in cut D-D and E-E, respectively.

3.5 Cave

3.5.1 Overview

The cave will be an assembly of standard and heavy concrete as well as steel, borated poly-ethylene and lead for shielding purposes (see 3.4.2.2 in this document). It will have a footprint on the floor of 18.7x9.1 m^2 plus an extension in beam direction of 2.5x3.6 m^2 for the beam stop. Its height will be 5 m internally.

Loading and storage areas for bulky samples and experimental devices and for off-line sample preparation will be situated around the cave as well as at both sides of the neutron guide, without impinging on the DREAM instrument, see Figure 10. The temporary storage area next to the guide shielding on the S1 side will be vacated when needed for an S1 instrument. A control hutch will be adjacent to the cave entry. The area in front of the cave provides enough space to host an additional frame overlap chopper if needed. Refer to Figure 10 for more precise shape and dimensions.

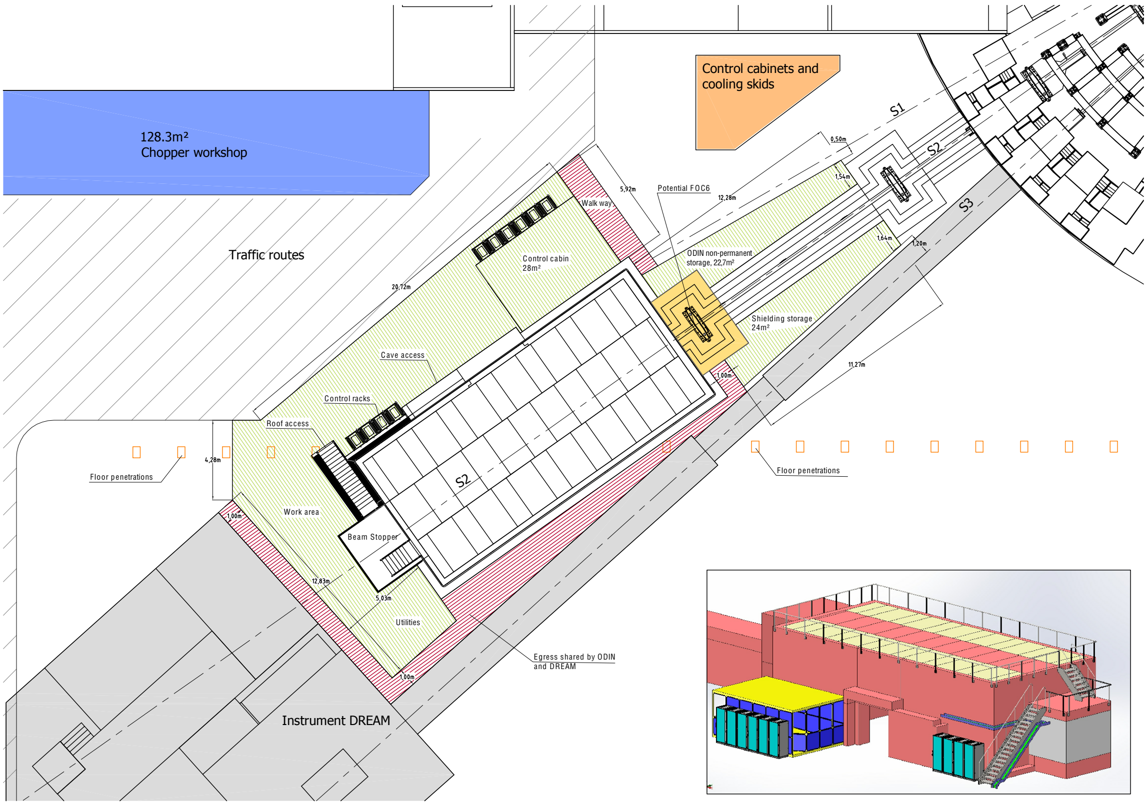

Figure 10. ODIN general layout and floor space plan.

Access around the cave will be possible thanks to a walkway of width 1 m running around the aforementioned loading areas and in the space between ODIN and DREAM.

The planned footprint does not interfere with traffic routes, chopper workshop or other areas needed for general operations. Shielding for FOC 5 will be modular to allow for easy integration with shielding for a future instrument at S1.

At least one portion of the roof will be removable by one of the crane in the hall to allow for installation of particularly bulky samples, sample environment or upgrades.

The cave itself is divided into two sections, a small one upfront (the optical cave) for beam manipulation and the main experimental area downstream.

3.5.2 Optical Cave (Collimator partition)

The optical cave will be accessible from the experimental cave via an interlocked door and will house mainly a collimator wheel integrated with a filter exchanger.

3.5.2.1 Collimator

The collimator system will be situated at the neutron entrance of the cave. In Figure 11 its preliminary design is shown.

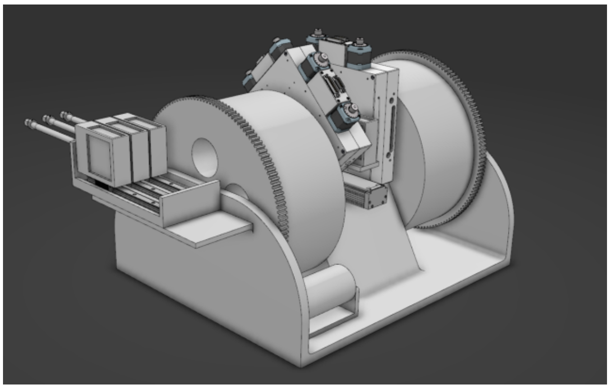

Figure 11. Drawing of the pinhole exchanger.

It features two revolving drums with variable apertures in order to coarsely define the geometry of the beam and to shield the cave from and excessive amount of unwanted radiation. Between these drums two 4-blades variable slit systems (on of which will be offset by 45 degrees) will precisely define the geometry of the beam with all the degrees of freedom necessary.

After the second drum, a pneumatically-actuated filter bank will be able to remotely insert in the beam several filters to achieve different purposes such as smoothing the beam profile inhomogeneities, precisely cutting the beam to specific energies or block the beam altogether.

3.5.3 Experimental Cave

The experimental cave of ODIN will be accessible through a sliding door to the right (looking from the source). Two main measurement positions are foreseen, one at 52 m from the moderator and one at 60 m. The first one will be used for high flux measurements (for instance for dynamic processes with high temporal resolutions), while the last one will be used for the majority of applications Figure 12. When needed, the detector shall be movable to any desired position along the flight path to allow, for instance, for a wider field of view, more flux or for space considerations.

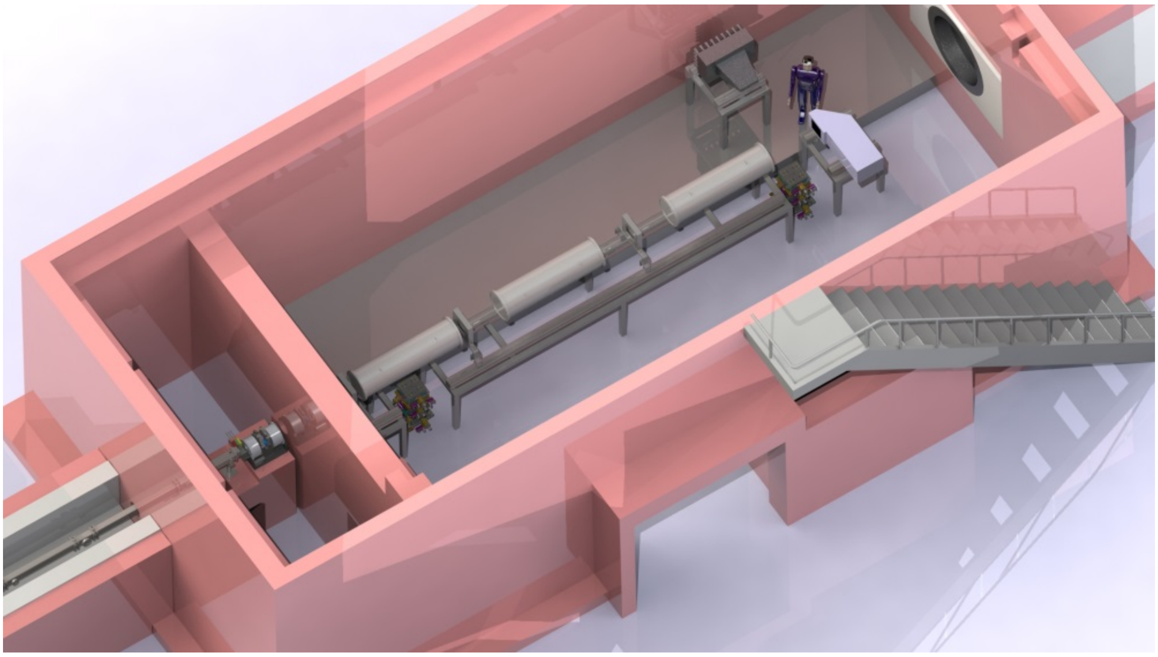

Figure 12. Sketch of the ODIN Cave.

3.5.3.1 Utilities Distribution

Utility distribution (power, network, cooling water, compressed air, gas, vacuum, dangerous gas detection systems and a fume hood) will be available as close as reasonable to the two main measurement positions.

3.5.3.2 Support Infrastructure

The experimental area will have a 1 t capacity crane attached to the ceiling support beams that can span the whole experimental space.

3.5.3.3 Sample Stages

The sample stages will be equipped with a 6-axes motorized sample stage (x, y, z, rotation and tilt in the remaining directions) with a precision in the order of 50 µm and with a capacity of 1 t.

A similar stage will also be used as detector stage, in order to allow for independent movement of the detector and sample for added flexibility. Additional motors will be needed in this stage for the focusing of the detector and for objective adjustments.

Additional ancillary linear and rotation stages will be available for specific needs.

For the specifications of each motor, refer to the table of motion, 3.9.1.

3.5.3.4 Optical Bench

An optical bench will run along the whole length of the flight path and precisely aligned with it. The detector stage will be mountable in any position of this bench by removing the sliding and evacuated flight tubes that are otherwise mounted to cover as much flight path as possible. In between sections of flight tubes, remote controlled 4-axes beam limiters will be installed to reduce component activation and to limit the background. Additional fixed beam limiters will be installed inside the flight tubes themselves.

3.6 Detectors

ODIN shall be able to perform state-of-the-art white beam imaging as well as pioneering ToF imaging techniques. Two different sets of detectors are necessary for such diverse applications. This is a common procedure in neutron imaging where the choice of detector is dictated by the specific experiment. Along the selection of the detector, also the sample position itself is dependent on the specific experiment (such as radiography, tomography, nGI and so on). For this reason we will not specify just one sample position and detector, but we will have available a portfolio of detectors and we will design the optical bench in the cave in order to offer all the flexibility needed to install it anywhere in the flight path (and for some applications on the side, too), while covering the rest of the neutron trajectory with flight tubes to reduce losses due to air scattering and unwanted irradiation in the cave.

3.6.1 White Beam

Neutron scintillators and camera-based detectors are a standard in all current white-beam imaging applications. They offer reliable operations, flexibility in choosing the necessary spatial resolution and FoV and, with recent developments, good time resolution for kinetic studies.

A portfolio of three cameras is foreseen as day-one starting kit, even though it's not necessary to define a specific one at this point in time. Camera technology is improving continuously, making a particular detector that can be purchased now already outdated for the date of initial operations. On top of that, cameras are off-the-shelves products that do not incur significant lead-time in procurement, allowing the choice of a specific set to be shifted to even just a few months before the starting date of cold commissioning.

At present time, ODIN would be operated with a 1MegaPixel - CCD camera for low light applications, a 4MP CCD camera for high resolution and low noise applications and a 4MP sCMOS camera for standard applications and for high time resolution. However, as mentioned earlier, the ODIN team is monitoring the current status of detector system development (naturally with running leading imaging facilities) and decisions for ODIN will be taken in due time without necessarily limiting the choice to cameras too early.

Scintillators are as well standard components that will be purchased in due time, since the lead-time of these components is negligible. A set of different materials and thicknesses can at present be foreseen, depending on the applications. 6Lithium Fluoride and Zinc Sulfide mixture are standard for big field of view (>5 cm) and relatively low resolution imaging (down to ~50 µm) and gadolinium oxysulfide is standard for resolution below ~30 µm and small samples (<3 cm). Relevant scintillator screens will be acquired by vendors when needed.

Since cameras are sensitive to radiation and are damaged by it, it is customary not to have them directly in-beam, looking at the scintillator, but rather have a mirror reflect the image of the scintillator perpendicular to the beam, where the objective will pick up the light and focus it onto the camera chip. This way, the camera does not experience the full direct beam, significantly extending its lifetime. On top of that, by varying the objective setting and correspondingly the camera-to-mirror-to-scintillator distance, one can also change the size of the recorded field of view and thus vary, within some boundaries, the resolution. This approach will also be followed by ODIN, where the camera will be situated either vertically or sideways to the beam, with either one or two 45° mirrors to have it outside of the direct beam. This optical arrangement will be housed in a light-tight box (camera box) where motors will allow for focusing the camera and for changing the objective settings. Similar systems already exist in almost all modern neutron imaging facilities and their design proved robust and reliable, while the exact details of the design will be worked out in due time, the ODIN team does not expect to deviate too much from this approach.

3.6.2 Time of Flight

Time-of-flight detectors for imaging, (i.e. featuring the corresponding spatial and time resolutions required for imaging and ToF with high wavelength resolution) are less standard and need for such detectors appeared only relatively recently with imaging applications at pulsed sources. However, also here development is relatively fast and, with the advent of imaging instruments at pulsed spallation sources, intense and manifold. Therefore, also in this case all relevant developments are closely observed, and leading developments continuously tested by the ODIN team. A decision for a corresponding detector (or detector suite) will be made in due time, based on the rich experience of the team and their collaboration partners in the field. The team is also intending to potentially contribute to developments and prototypes via third party funding, like this is usually and successfully handled in the imaging community. Should a favoured development or the specific know-how for such technology be within the range of potential in-kind partners of ESS, an in-kind solution for the ToF detector work-package will be assumed. Criteria for the selection of the used technology are the best compromise between reliability, efficiency (incl. background sensitivity), spatial resolution, time resolution, field of view and cost.

The currently broadly agreed leading system is the MCP-Timepix detector developed at UC Berkeley and the ODIN team has a very large experience in its application as well as a very close collaboration with the developers. If a decision were necessary to be taken today, such system would be acquired for ODIN through a collaboration with UC Berkeley. This system has been successfully integrated at beamlines at all major neutron sources (including the ESS testbeamline at HZB) by ODIN team members and a standardized integration is currently on the way at ISIS, so that no major effort and issues are to be expected in this respect. Data is available in time stamp format, but through included software also in image format, which the corresponding community (not only neutrons) is used to work with. In order to assure reliable, long-term integration into the ESS standardized readout an additional budget item for interface development was added.

3.7 Sample Environment

No specific sample environment is foreseen for day-one operation of ODIN within the construction budget. The cave will be however built in order to accommodate the highest possible number of relevant ESS-pooled devices.

3.8 Data Acquisition and Processing Software

From the point of view of the data acquisition software, camera integration is to be addressed with care, but as the software provided with the camera is a commercial one, collaboration with the vendor is to be anticipated. Nonetheless, as more and more cameras feature EPICS support, it is expected that a seamless integration following ESS requirements can be easily achieved.

Ideally, the data should run on two parallel tracks: a local storage and analysis system and the standard network-based DAQ. Over the years the users of current imaging beamlines have gotten used to be able to access, analyse and retrieve data locally, and the instrument team agrees with this approach. A more standardized version of the DAQ is to be anticipated across the ESS and is also seen as a very welcome addition to the local one. Given the risks associated to have this infrastructure in place for day-1 operations, we see the local solution as improving the robustness of the data acquisition chain.

For the data processing of white beam standard images, a number of commercially available software is currently a de facto standard among imaging beamlines around the world (OCTOPUS, VGSTUDIO, AVIZO, FIJI to name a few), so we foresee the same happening for the early stages of ODIN commissioning and operation. The ODIN team is however involved in many projects regarding data processing harmonization integration and development (e.g. SINE2020), and will keep monitoring the situation for possible more advanced or more standardized solutions.

Combined transmission and diffraction imaging is a technique still in its infancy, so no agreed upon software is currently existing and widespread. The ODIN team is closely monitoring (and is partially involved in) the development of such software for newly built facilities such as RADEN at JPARC and IMAT at ISIS.

There is currently no standard software specific for ToF imaging, but as already was the case for diffraction imaging, the ODIN team is well integrated in the neutron imaging community and hence well connected to corresponding developments. We do currently not foresee any specific problems to receive/develop the required software through close collaboration with the DMSC and other key players in place when ODIN will start operations.

ToF detectors for more advanced imaging techniques such as nGI, SEMSANS, polarized neutron imaging and their respective energy-resolved counterparts, will not discussed here as these techniques do not fall in the scope of the ODIN instrument construction budget. Nonetheless, the ODIN team is aware of, and also driving, in particular at ESS, the most recent developments and can therefore draw from the state-of-the-art in any moment.

3.9 Motion Control

As any other neutron scattering instrument, ODIN will have many movable parts especially in the experimental cave. Hardware and software solutions for motion control and automation will be developed in close collaboration with ESS Motion Control & Automation Group (MCAG) following standards and best practises for the key technologies and components used at ESS that are still being defined.

All motors and actuators are anticipated to be “off the shelf” products that can easily be controlled by commercially available components.

3.9.1 Table of Motion

Currently some 75 motors are planned for operation at ODIN. Crucial motions are all sample stages and the WFMC stage; the current requirements regarding load, range and accuracy are challenging but not unprecedented.

3.10 Personnel Safety System, PSS

A PSS system will be designed and provided by ESS and the instrument team to allow safe operation with regards to access to the instrument and its components.

3.10.1.1 Beam monitors

At least three ToF beam monitors will be installed along the neutron path of ODIN, for precise normalization of measurements. One will be installed after the second WFMC, one after the heavy shutter and the last after the collimator system. Currently gas electron multiplier (GEM) based monitors, that are under development at JPARC combined with neutron filters also developed at JPARC are forseen for implementation.

4 SYSTEM P&ID

The Process and Instrumentation Diagram (P&ID) is a schematic of all physical connections between the different subsystems of the instrument and between the instrument and the surrounding facility. A high-resolution version is provided in attachments.

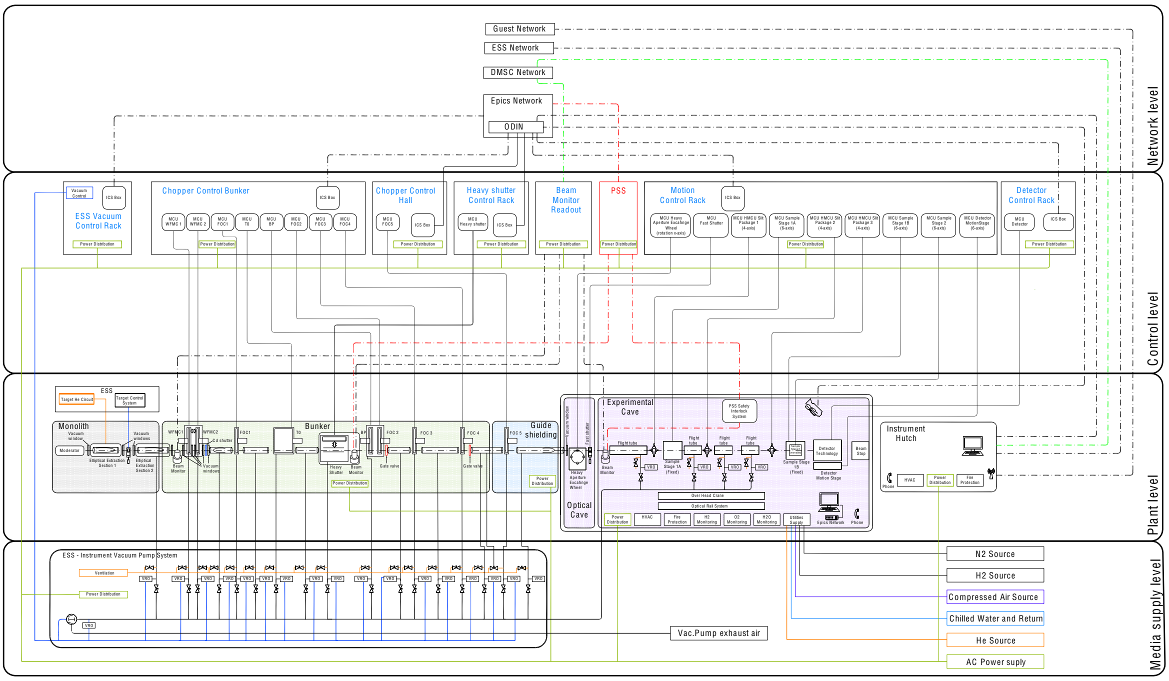

Figure 13. ODIN Process and Instrumentation Diagram

5 PRELIMINARY SAFETY ASSESSMENT

The main hazard present at all instruments is ionizing radiation. The shielding (see 3.4) protects personnel outside the instrument from radiation hazards. Users will need to have access to the experimental cave without being exposed to radiation. For maintenance purposes all parts of the instrument also shall be accessible to ESS staff. This is achieved with the heavy shutter, see 3.3.1. The light shutter (not part of the ODIN work package) located immediately outside the target monolith stops radiation emanating from the target, when the proton beam is not on target and allows maintenance work to be performed on downstream components.

The Personnel Safety System (PSS) interlocks the areas (such as the experimental cave) when the shutter is open. Additional radiation alarm will be installed inside the cave. It will also be connected to PSS to prevent personnel entering the experimental cave if a radiation leak has been detected.

A search procedure ensuring that no people are inside is required to close the interlock and open the shutter. All interlocked spaces shall have emergency stop buttons that close the appropriate shutter to prevent radiation exposure. All shutter systems are designed to fail closed.

Other safety systems which are not related to radiation hazard include: (i) oxygen deficiency sensor will be installed within the experimental cave; (ii) robot and sample table movement interlocks and/or emergency stop buttons will be installed in the cave to protect against injury.

Warning will indicate radiation, cryogenics and high magnetic fields hazards.

A first-aid kit will be available for users in the instrument hutch.

The administrative control will include training of all users and personnel working at the instrument. The training will include the walkthrough of the instrument, identification of all potential hazard situations and appropriate response. All instrument related training materials will be available on the instrument website. Hard copies of those documents will be available at the control hutch. ESS access training will have to be taken in advance as well.

5.1 Activated Samples

One of the risks for ODIN is handling of activated samples. After completion of the experiment, the radiation level of the sample will be measured. If activation is below a safe limit imposed by ESS, the sample can be transported outside of the experimental cave and handled by the user. The cabinets for temporary storage of activated samples will be provided. Information about sample composition, mass and exposure time shall be available during the temporary storage. When the radiation dose decreases to below the limits imposed by ESS than it can be returned to the user or placed in the common ESS storage capacity.

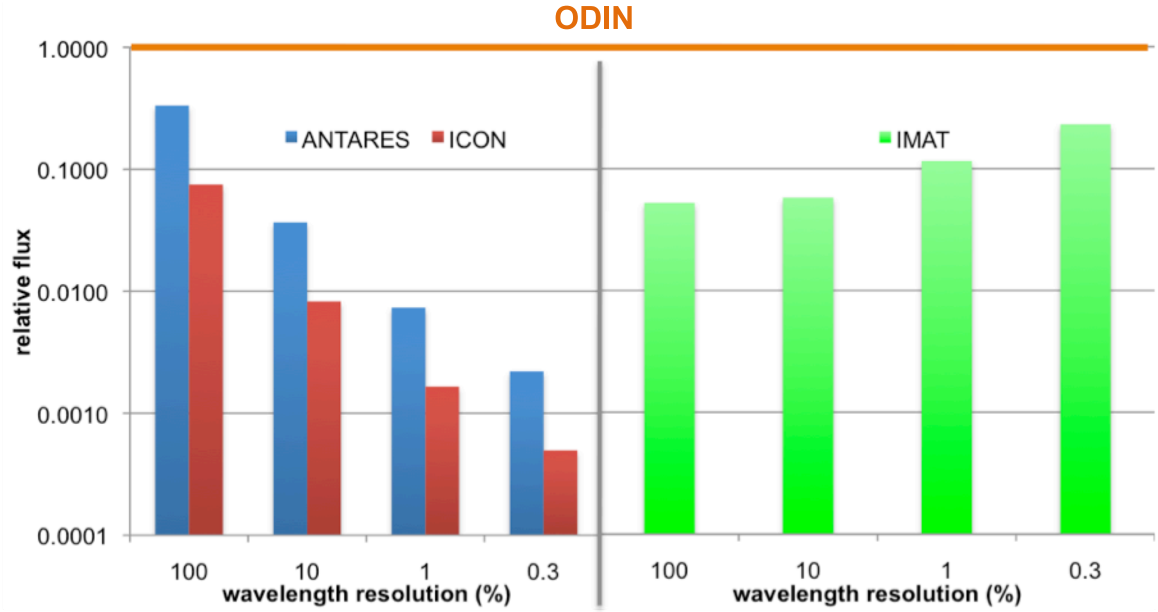

Figure 14. Relative flux comparison (estimated), ODIN vs. other state of the art beamlines.

6 PERFORMANCE EXPECTATIONS

The performance of an imaging instrument depends on flux, beam size, divergence and homogeneity and its detector suite. The available wavelength resolution is an additional important performance criterion for ToF based imaging. We expect ODIN to outperform current state of the art beamlines.

6.1 Neutron Flux

With its long pulse and high proton flux, the anticipated flux at ODIN sample position (at 2 MW) will be about 1.2×10^9 n/s/cm^2, this is three times higher than at current steady state sources and it outperforms other pulsed source even when conditioning the beam for high wavelength resolution as shown in Figure 14.

6.2 Beam characteristics

The neutron beam profile at the first sample position, about 10 m from the collimator is, as a simulation shows, homogeneous over a FoV of about 14×14 cm^2, (about 20×20 cm^2 at the second sample position at 14 m). The collimator wheel, see 3.5.2.1 will enable variable collimation up to L/D=10,000, which is unprecedented. For more details see [21].

6.3 Detectors

As described in 3.6 Detectors, the ODIN team is aware of new developments in both white beam and ToF detectors to ensure that once operational state of the (then) art will be used.

6.4 Wavelength resolution

The anticipated wavelength resolution of about 0.3%, [6] is ambitious but achievable due to the complex chopper system. Currently steady state sources offer about 10% resolution while Imaging Beamlines at SNS and JPARC anticipate about 0.5-1%.

6.5 Summary

With its high flux, high beam quality and high wavelength resolution ODIN has the potential of setting the state of the art in imaging when coming online. This will require a steady monitoring and development of all experiment components such as detectors but also equipment need for advanced techniques currently foreseen for staging (e.g. grating interferometry set ups). This is, however, an easy task given the collaborative nature of the neutron imaging community of which the ODIN team is an active part.

GLOSSARY

Term	Definition
BP	Bandpass (-width) Chopper
BPCS	Beam Port Coordinate System
BTCS	Beam Transport and Conditioning System
ConOps	Concepts of Operations
FOC	Frame Overlap Chopper
FoV	Field of View
GEM	Gas Electron Multiplier
L/D	Ratio of collimator sample distance (L) to collimator diameter (D)
MCAG	ESS Motion Control & Automation Group
MCP	Multi Channel Plate
nGI	Neutron Grating Interferometry
NOSG	ESS Neutron Optics and Shielding Group
ODIN	Optical and Diffraction Imaging with Neutrons
P&ID	Process and Instrumentation Diagram
PBS	Product Breakdown Structure
PE	Polyethylen
PSS	Personnel Safety System
SCS	Sample Characterization System
SEMSANS	Spin Echo Modulated Small Angle Scattering
SES	Sample Exposure System
T0	Pulse Shaping Chopper (t=0 chopper)
TG	Toll gate
ToF	Time of Flight
WFMC	Wavelength Frame Multiplication Chopper

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SUPPORTING DOCUMENTS

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[18] [11] Summary of a preliminary analysis of the ODIN shielding requirements
[19] ODIN Process and Instrumentation Diagram (P&ID)
[20] Table of Motion
[21] Optics Report for the ODIN Instrument: ESS-00100660

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
1	First issue	ODIN Team	2017-01-27
2	Revision of TG2 panel implemented	Michael Lerche	2017-03-16