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Concepts of Operations for the ODIN Instrument

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1. INTRODUCTION

This ConOps provides a brief description of the ODIN, Optical and Diffraction Imaging with Neutrons, instrument. The basic instrument concept is introduced; this includes both a high level introduction to the science case of the instrument as well as the framework and context within which the instrument will be designed, operated and maintained through its life-cycle.

This document is mainly but not exclusively intended for everyone who is involved in the construction and operation of ODIN. It will also serve the function as a quick overview of the instrument's purpose, construction and operation not only for persons familiar with the field of neutron science and imaging in particular but also for those who are not.
The ConOps may be updated several times to ensure its actuality.

2. HIGH LEVEL SCIENTIFIC REQUIREMENTS

2.1. Background

The science case and hence the high level scientific requirements are based on the imaging modalities that shall be supported by ODIN. The chosen modalities are scientifically most advanced and promising while being able to best exploit the specific strengths of the ESS source. The basic scope that the instrument will fulfil in accordance with the scope setting meeting will not enable all envisioned imaging modalities. However, modalities not available in the basic scope will be implemented at a later point (staging). Therefore all modalities, basic and staged, are presented here. In addition to staged modalities, which are an integral part of the instrument, some potential upgrade options are described briefly as well.

I. White Beam Imaging with highest spatial and temporal resolution. ESS will provide a time averaged flux comparable to or outperforming current neutron sources. Therefore, ODIN can be enabled to provide the highest resolution for this most common and conventional form of neutron imaging. This will further widen the already broad range of applications in general and in industry in particular.

II. Time of Flight Imaging with adjustable wavelength resolution down to unprecedented accuracy and with adjustable wavelength range: The outstanding brightness of ESS combined with its tuneable time structure allows for tailoring the resolution of time-of-flight (ToF) imaging to specific applications. These techniques, as far as developed, are the main drivers for imaging at pulsed sources so far. This will enable advanced and *in-situ* studies of materials currently not amenable by any other technique or instrument.

2.1.1. Basic Scope

White Beam imaging for various scientific or industrial applications as outlined in [1]. The high flux at ESS will enable the study of fast, even non-periodic processes.

Bragg edge imaging for (1) strain mapping, (2) crystalline phase studies, (3) preferred orientation investigations, (4) microstructure studies and (5) grain mapping, which may be combined with diffraction (a potential update): The versatility in wavelength range and the achievable high wavelength resolution will enable advanced and *in-situ* studies of, among others, engineering and functional materials with unprecedented accuracy and detail.

2.1.2. Full Scope

I. Polarized neutron imaging (staged) for the investigation of magnetic fields and structures and phenomena in bulk materials: The required wavelength resolution provides ESS with a significant advantage as compared to short pulsed and continuous sources and the ToF mode enables otherwise not amenable quantifications, potentially up to the full reconstruction of magnetic vector fields in 3D. This will enable the characterisation of magnetic features, which are currently not amenable by any other technique or instrument in bulk condensed-matter.

II. Dark-Field neutron imaging (staged), which enables the observation of (ultra) small angle scattering features of structures beyond direct spatial resolution combined with image resolution: The required wavelength resolution provides ESS with a significant advantage as compared to short pulsed and continuous sources and the ToF mode enables otherwise not amenable small angle scattering quantification of microscopic structures. Two promising methodical approaches are envisaged with the potential to together cover structures from the nanometer to the micrometer scale in addition to the imaging resolution range. This will enable material science characterisations of a vast variety of materials from hard matter to soft matter even in the context of real systems and devices where these length scales and in particular variation of those are not amenable today.

III. Diffraction (potential upgrade) combining imaging with diffraction has the potential to enable advanced *in situ* studies as mentioned 2.1.2 above. However, given the high complexity and cost for a diffraction detector system, this technique is foreseen as a potential upgrade to be considered later.

2.2. Top-level requirements for ODIN

Corresponding to 2.1.1 above, the top-level requirements for the basic scope are[1]:

1. ODIN shall be capable of a direct spatial resolution down to 10 µm (3D).
2. ODIN shall allow for time resolutions below 70 ms in kinetic measurements, with a spatial resolution down to 50 µm.
3. ODIN shall allow time resolutions of the order of 1 µs in quasi-stroboscopic mode, with a spatial resolution down to 55 µm.
4. ODIN shall allow measurements of sample areas of up to 20×20 cm^2 at once.
5. ODIN shall allow the detection of contrast equivalent to 10 ppm H_2 in steel, with a spatial resolution down 100 µm.

[1] For more details on verification see [2].

6. ODIN shall be able to detect relative lattice distortions of the order of 10^{-5}.
7. ODIN shall be capable of visualising crystalline phases with a 3D resolution of at least 100 µm.
8. ODIN shall be able to observe structural phase transitions with a 2D resolution down to 300 µm with a time resolution of 10 s of seconds.
9. ODIN shall be able to observe grains and their orientations with a 3D resolution of at least 100 µm.
10. The System's design shall provide the space and flexibility necessary to host and drive future developments in the Neutron Imaging field, including the potential upgrade with diffraction detectors.
11. ODIN should serve the user and science community without interruptions during source operation; all components' service-cycles should be adaptable to the ESS maintenance cycle.

Additional top-level requirements for ODIN corresponding to staged imaging modalities, 2.1.2 above, are:

12. ODIN shall be able to detect and quantify structural features down to 10 nm from dark-field contrast imaging with direct spatial resolution of at least 1 mm.
13. ODIN shall be able to characterise magnetic fields and structures with accuracy better than 1 mT.
14. ODIN shall be able to provide complementary x-ray contrast with similar spatial resolution (10 µm) relatable to the neutron data with according accuracy.

3. SYSTEM CHARACTERISTICS

3.1. System purpose

Neutron imaging is a real-space technique examining the inner structure of potentially highly complex components by detecting the transmitted beam. ODIN's 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 instruments. The full scope capability offers its users a variety of imaging techniques for the characterisation of objects with applications covering, but not limited to, cultural heritage, energy materials and devices, magnetic phenomena, biology, geology, food science and in industrial applications e.g. fuel cell development, rechargeable battery development and non-destructive inspection of engineering components. Different imaging techniques, from traditional attenuation-based imaging to advanced dark field, polarized neutron or Bragg edge imaging, will be available within the full scope of ODIN with unprecedented efficiency and resolution. The instrument concept prepared to host the full scope takes full advantage of the flexibility made possible by the ESS time structure, allowing wavelength resolution, bandwidth and collimation to be tailored to each application.

As a multi-purpose imaging instrument ODIN is designed to satisfy a wide range of scientific needs. Given the plethora of applications in various scientific fields, only a few examples can be given here:

- Energy research and environment – e.g energy storage devices (batteries, fuel cells etc.), catalysis, nuclear energy materials.
- Magnetism and hard matter research – e.g high density data storage materials, energy efficient magnetic materials in engineering applications, superconductivity.
- Engineering materials – study of strains, stresses, textures and microstructures deep in metal components.
- Geology, earth and agricultural sciences – structural information in rocks, sands and soil. Allowing for studies of e.g water transport mechanism in ground fractures, CO_2 storage in the ground, compaction and movement of sandy grounds, soil transport characteristics in large-scale earthquakes and continental shifts, studies of root growth and function in soil.
- Soft matter and biology – e.g study microstructural details and transitions in biology along with soft matter investigations and externally triggered transitions in soft matter, study of systems like full plants.
- Archeology, Paleontology and Cultural heritage – enhancement of today's capabilities with respect to structures and microstructures of ancient tools, weapons, fossils and artworks. Providing better understanding of e.g ancient metallurgy and fabrication methods.
- Routine Non-destructive Evaluation of Material Reliability – e.g study of component failure and improved welding processes, product development and improvement, creep detection.

3.2. High Level System Requirements

In order to achieve the high level scientific requirements, to serve the outlined science case, and to take best advantage of the ESS source with the supported imaging modalities, the following high level system requirements have to be met. They are the central design requirements among the extensive functional requirements listed in the corresponding System Requirements Specification [3].

3.2.1. Basic Scope

From the **white beam** mode follows that all standard imaging requirements have to be taken into account including beam homogeneity, large field-of-view, highest flux and variable collimation with the additional flexibility of spectral choice from the thermal to the cold region i.e. covering a wavelength range from 1 Å to 20 Å.

From the planned **Bragg edge** application follows that different wavelength resolutions and bandwidths have to be enabled: 10%, 1% down to below 0.5% wavelength resolution for spectra between 1 Å and about 9 Å and variable bandwidths up to about 4.5 Å.

3.2.2. Full scope

The requirements regarding imaging modalities to be implemented later are listed below for completeness; they are less stringent than the already imposed requirements and will be fulfilled within the basic scope already.

Polarized neutron imaging will require a wavelength resolution of about 1% and potentially a broad bandwidth up to a coverage from 1 Å to about 9 Å.

For **Dark-field imaging** applications a wavelength resolution of 10% suffices on a broad bandwidth also starting from about 1 Å up to 9 Å.

3.3. System Life-Cycle

The figure below is a schematic of the ODIN instrument life-cycle without the corresponding further detailed development phases. Each phase of the instrument development is concluded with a TG (toll-gate) review, with accompanying design review.

While TG reviews present a destinct separation between phases, there will actually be some overlaps between phases; these overlaps are indicated by triangular extensions in Figure 1. For example the design of details lingers on until very late, if not until the end of the construction and long lead time items have to start tendering and production in the design phase and have to be developed with companies hand in hand with the final design. The Instrument Development process provides the framework within which the instrument will be developed with timely milestones in order to measure progress, still allowing for the overlap to exist. The controlling document for the instrument development is ref. [4].

A specific addition to the general high-level phases in Figure 1 is the staging of instrument scope. It is implemented in the schematic and it is basically an extended construction, which is separated from the construction of the basic scope with respect to budget and realisation processes, which are not completely developed and hence hard to account for.

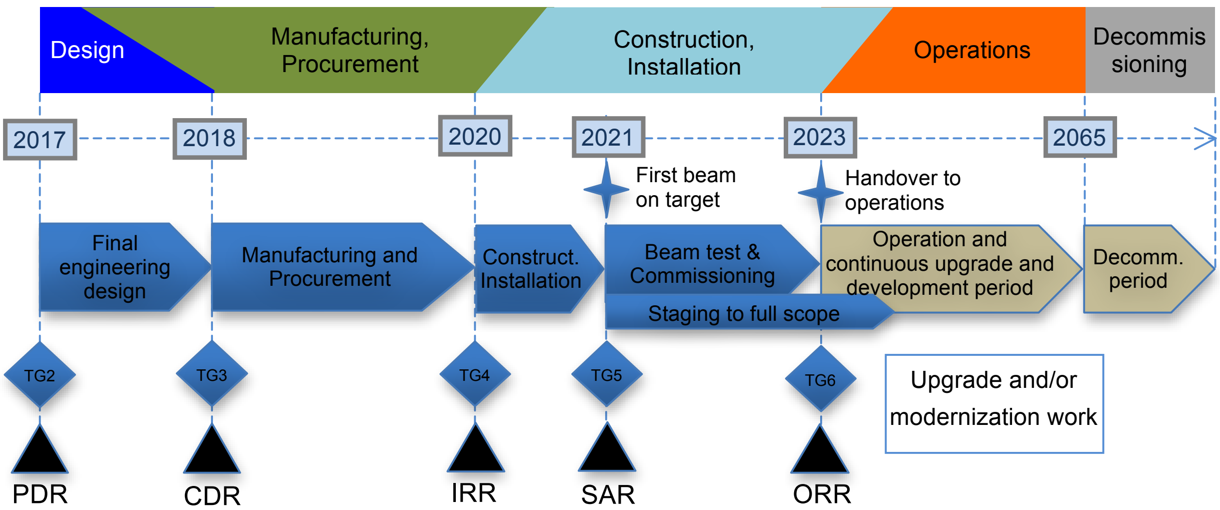

Figure 1. Instrument Development process and its related life-cycle

In the case of ODIN this means that the full scope of system described here cannot be realized within the currently assumed project. This implies that during the design and construction phase as outlined in the life-cycle diagram, only the agreed upon basic scope of ODIN can be realized. The basic scope will not fulfill the high level scientific requirements, but will encompass all essential components, with respect to the guide and chopper system, ensuring easy upgradeability to the full envisioned scope. The final (full scope) system will elevate the basic scope from a state-of-the-art instrument to a unique and pioneering system, which is its primary aim.
It is however currently not entirely clear when planning, design and budget security can be achieved for such a staging process to take place in time to assure scientific uniqueness and performance of the system.

3.4. System overview

3.4.1. General

The conceptual ODIN instrument, see Figure 2, is subdivided into the following generic main functional blocks:

- Neutron guide
- Prompt pulse suppression
- Shielding
- Chopper system
- Shutters
- Cave interior
- Beam manipulation and analyses equipment
- Detectors
- Beam stop
- Personnel Safety System, PSS
- Control hutch
- Instrument control

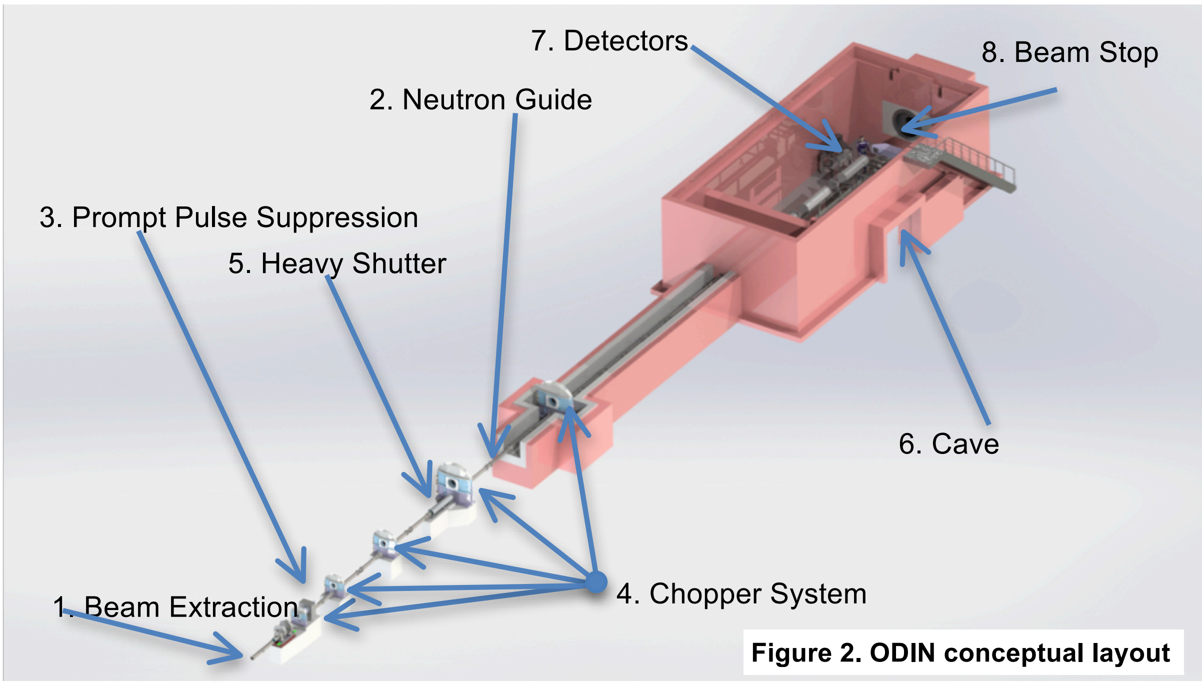

Figure 2. ODIN conceptual layout

All those have to be defined and designed such to enable to fulfill the high level requirements as the basis for the detailed functional and non-functional instrument and component requirements, see [3].

3.4.2. Neutron Optics System (PSI WP)

The neutron guide system has to fulfil strict requirements concerning the efficient transport of a large spectral bandwidth and divergence in order to enable a homogeneously, in space and spectrally, illuminated large field of view at the detector plane position, which varies between 1 m and 14 m downstream of a pinhole at 50 m, see [5] for a detailed discussion. These guide system requirements have to be met within the boundary conditions of facility and wavelength resolution requirements. The former include the moderator design but also monolith and service shutter designs while the latter require limited guide dimensions in some specific locations of choppers. The guide has the usual requirements of evacuation, alignment as well as of minimization of windows and interruptions on its way stretching from 2.12 m to nearly 50 m from the target centre. The guide is foreseen to enable direct line of sight between moderator and detector. The first approximately 3.5 m of guide are inserted in the monolith, an additional 0.5 m will be in the service shutter and another 0.5 m downstream; this 4.5 m long section is referred to as beam extraction guide. About 20 m of guide starting 0.5 m downstream the extraction section are installed in the shielding bunker and its wall, while the last approximately 20 m up to the pinhole are hosted in instrument owned shielding. The extraction guide section includes a bi-spectral extraction mirror system, which is key for some high level requirements of the instrument and allows combining the thermal and cold neutron spectra in one imaging instrument for the first time. Only very few facilities own a thermal and a cold neutron beamline, which are complementary for many applications. Combining both, cold and thermal spectra increases the cost-benefit of ODIN enormously. The guide system outside the monolith requires a vacuum system and potentially a ventilation system for dry Nitrogen. The guide system is in principle a non-moving fixed installation, which in the best case does not require any maintenance but potential settling of the ground calls for re-alignment options.

Other parts of the optics system are:

Filters: several filters shall be usable in order to tune beam characteristics. These include but are not limited to graphite and/or SiO_2 powder diffusers of different thicknesses, Cd, Bi and Pb filters of different thicknesses. These shall be remotely usable at the end of the guide system, while one Cd filter in a failsafe mode (normally open) shall be installed at 7 m in order to measure the fast neutron background and also to reduce potential activation of components.

Pinhole: a rotary pinhole system combined with an 8-blade slit system, to create a resizable octagonal pinhole, is to be installed at the 50 m position.

Beam Scrubbers/Slits are to be installed in various sizes along the optical bench between pinhole and sample position to limit the beam to the required size.

Flight tubes are used to bridge the distance from pinhole to detector as much as possible avoiding air scattering by either evacuated or He filled modular tubes.

3.4.3. Prompt pulse suppression – T0 Chopper (TUM WP)

Prompt pulse suppression is achieved by one or potentially two T0 Choppers located around 9 m from the target centre. The location is optimized with respect to the spectral requirements, while the final design depends on current developments but has an impact also on the guide design with respect to interruptions. It is currently expected that the instrument can be operated in most modes also in case of a functional T0 chopper system being missing. This adds to the robustness of the instrument system.

The T0 chopper will be connected with its vacuum housing directly to the guide system, hence sharing the same vacuum system. For removal of the T0 chopper(s) for maintenance and in case of failures the state of the art approach of split-housings is foreseen.

3.4.4. Shielding (TUM WP)

The instrument operates with a very intense beam and in direct line of sight. Corresponding shielding requirements apply not only with respect to safety but also with respect to neighbouring instruments with high background sensitivity. Shielding optimisation is key and still on the way both with respect to cost and safety. The instrument shielding stretches from the bunker wall to the end of the instrument in the beamstop and includes the optical and experimental Caves. Given the direct line of sight of ODIN, the beamstop has to be designed carefully. Combining a get lost tube with a heavy beamstop structure such as is implemented at J-PARC, RADEN instrument, is under consideration. However, corresponding input and simulations are not yet available.

3.4.5. Chopper System (TUM WP)

The chopper system is a central and maybe the most significant part of the instrument: it has to fulfil the requirements allowing the outstanding flexibility and efficiency of the instrument. This concerns mostly the requirements for wavelength bandwidth, wavelength range and resolution and their various combinations.

The choppers can be classified by their function into prompt pulse suppression chopper (T0), bandpass chopper (BP), wavelength frame multiplication choppers (WFMC, 1 pair, i.e. 2 single discs) and frame overlap choppers (FOC, 5 single discs). Together they form a complex wavelength frame multiplication (WFM) chopper system enabling several operation modes with respect to the parameters mentioned.

The chopper system is being optimized and specified with respect to the boundary conditions of the source time structure, the guide system, technical feasibility and failure modes and maintenance requirements. The system has two peculiarities: the wavelength frame multiplication choppers, closest to the source, between 6.75 and 7.25 m are placed on translation stages allowing to remotely change the distance between their discs and several of the FOCs have diameters significantly larger than state of the art. However, the large chopper size is balanced by their very low operation frequencies and hence does not pose a notable technological risk or development effort.

As an additional boundary condition, the choppers close to the monolith require integration with neighbouring beamlines with respect to the space and access constraints in this region.

All choppers except the last FOC are placed inside the bunker, see Figure 3. The realisation of the BP sharing housings with FOC 2 in the form of double disc choppers in a standard face-to-face configuration is envisioned. Advantages and disadvantages have to still be judged carefully for a final decision. In general independence of the systems is an enormous advantage for operations in case of chopper failures and maintenance.

Except for the case of the movable WFMCs the choppers are foreseen to be connected with their vacuum housings with no windows to the guide system, hence sharing the same vacuum system. For removal of choppers for maintenance and in case of failures the state of the art approach of split-housings is foreseen.

Figure 4 illustrates the basic operational modes of the chopper system. In panels a) and b) the natural resolution mode is shown, using each source pulse or every other pulse respectively. In this mode a wavelength resolution of about 10% can be achieved. However, the resolution is not constant over the whole wavelength range due to the lack of WFMCs. Grey areas indicate undesired signals from the rising and falling flank of the neutron pulse. In panels c) and d) the whole chopper system is utilized to achieve a wavelength resolution of about 1% homogenously over a wavelength range of 4.5 Å and 8 Å respectively. Panels b) and d) show how the BP chopper is used to block every other pulse in order to increase the accessible wavelength range.

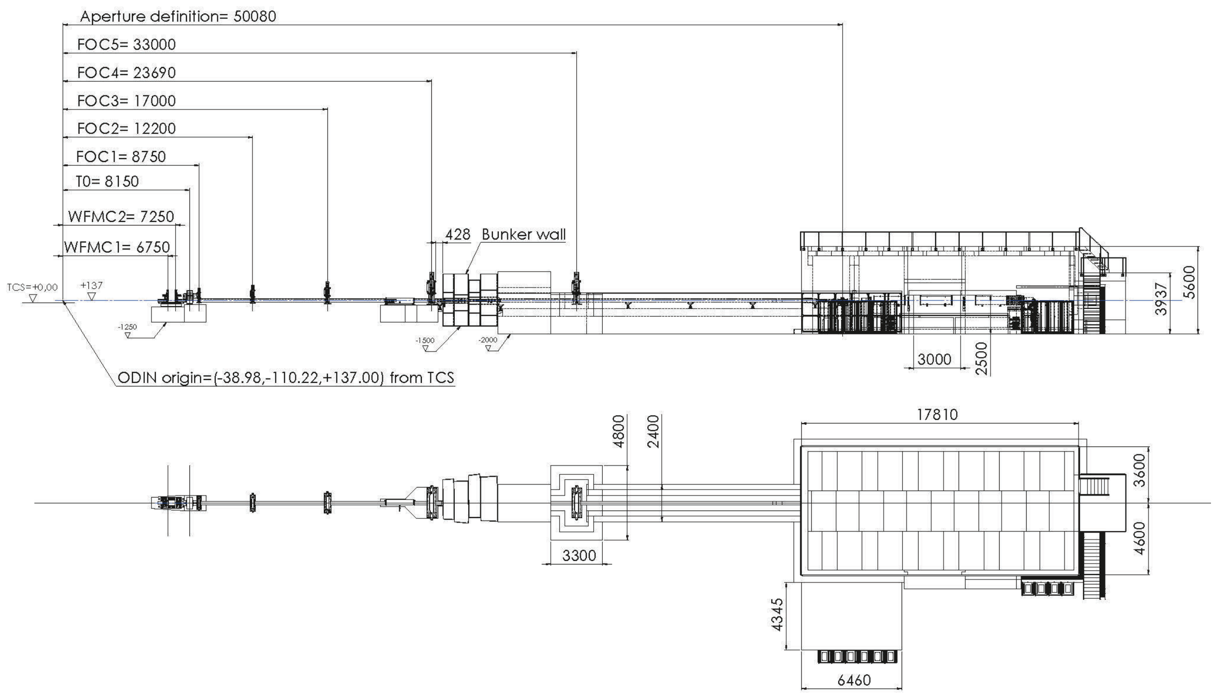

Figure 3. Chopper System overview.

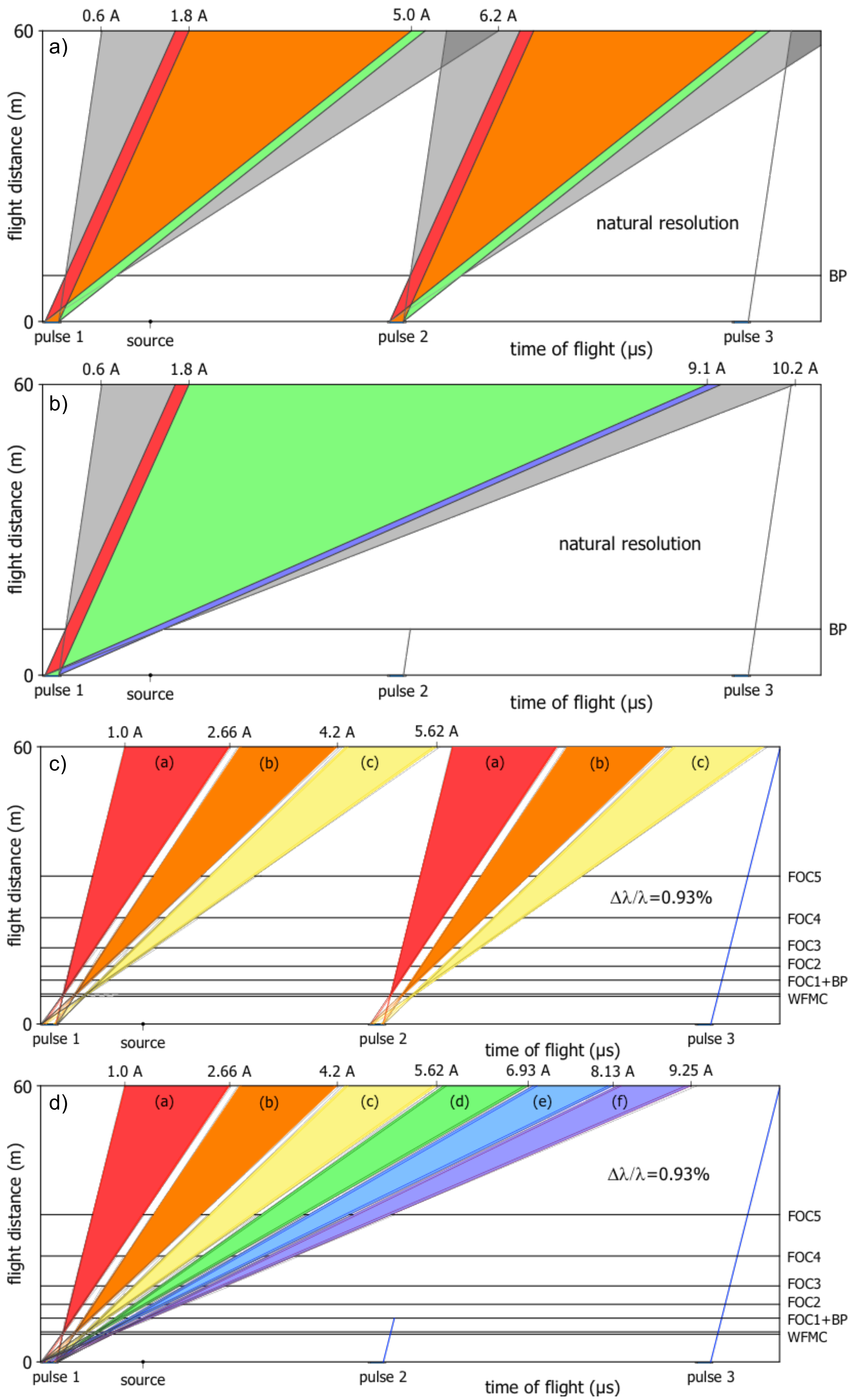

Figure 4. Impression of some possible operation modes

Figure 5. Proposed Heavy Shutter Concept.

3.4.6. Shutters (TUM WP)

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 up to 3 meters, requires to be fail safe and accurate as to carry a corresponding length of guide, which also requires to be evacuated. A proposed concept is shown in Figure 5.

3.4.7. Cave interior (PSI WP)

The cave is a massive shielding construction (TUM WP) and will largely resemble a full conventional imaging instrument. Its first but separated part (optical cave) hosts the filter and pinhole exchanging system defining the imaging geometry. The very spacious second and main part (experimental cave) hosts a very flexible set-up along an optical bench and modular structures like flight tubes, sample stages and detector positioners for various detector systems and sample sizes. In addition the potential for a large number of auxiliary equipment to be flexibly installed with high precision has to be provided. This includes not only sample environment but also installations of beam manipulation devices for a number of sophisticated measurement techniques included in the full scope of the instrument. This is, however, state of the art for imaging instruments, though some improvements based on gained experiences shall be considered, in particular with respect to short turnover times between different measurements. The cave also requires various utilities for gas, exhaust, electricity and corresponding surveillance equipment installations also state of the art for this kind of instruments at other sources. The anticipated inner dimensions of the cave, which starts at about 50 m, will be 16 m in length, 6 m in width and 5 m in height. The exact dimensions may have to adapt to the requirements of neighbouring beamlines; the height of the cave has to be decided with the height of the experimental hall and crane access in mind as well as taking into account the weight and bulkiness of equipment that will be added and removed through the top. Access to the cave is currently foreseen through the sidewall as illustrated in Figure 2. However, also this depends on boundary conditions and interfaces with neighbours and the facility in general.

The experimental cave is the main part of the cave that is accessible for standard operation, while the optical cave will be only accessed for pinhole system maintenance.

3.4.8. Beam manipulation and analysis equipment (out of scope, prepared for staging)

A wide range of beam manipulation devices is required for different imaging techniques and needs to be specified for efficient state of the art ToF methods. These include polarisers, analysers, spin manipulation devices such as flippers, v-coils, guide fields with the corresponding remotely controlled electric supplies, but also grating interferometers, the auxiliary x-ray set-up, lens systems etc. A large coverage diffraction detector system is also planned as later (final) addition.

3.4.9. Detectors (PSI WP)

Imaging stations are normally equipped with a range of specialised detectors used for specific purposes and exchanged on the fly between measurements. Apart from conventional scintillator and CCD or CMOS based imaging detectors (PSI), ODIN will also require ToF detectors with high spatial resolution (ESS). While there are already existing, high-performance detectors of this type most are currently limited to a relatively small FOV. However, development to overcome limitations is well underway at and for other ToF imaging instruments that are coming online in the near future: IMAT at ISIS, RADEN at J-PARC and VENUS at SNS. While technical solutions fulfilling the basic requirements are available now, expected progress will benefit ODIN. Detector footprints may be designed with portability to other beamlines in mind.

Basic Scope: A first set consisting of one scintillator based detector and one ToF detector is included in the basic scope.

Full scope: More specialized detectors (white beam and ToF) will be added.

Potential Upgrade: Some high performance scattering detectors might also be relevant for an ODIN upgrade as mentioned above and in 3.4.13 below.

3.4.10. Personnel Safety System, PSS (ESS WP)

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.

3.4.11. Control Hutch (TUM WP)

A control hutch will host remote control equipment, computers and the experimentalists during measurement times. The hutch will be adjacent to the cave; its final design depends on space boundary conditions not yet fully determined.

3.4.12. Instrument control (TUM WP)

Most instrument components will require remote control through specific electronics placed outside the shielding but connected to the components inside and to the control computers.

3.4.13. Future upgrade possibilities

Diffraction detector options

Due to specific applications in e.g. engineering materials and strain investigations, complementary detector coverage in scattering geometry is an important option as can also be seen in the concept of the IMAT instrument at ISIS. Hence 90° detector banks with collimators as well as further detector coverage for complementary scattering experiments shall be considered an up-grade option in the moment and considered in detail later based on experiences at e.g. IMAT. Implementation of these additional detectors is straight-forward possible with additional collimation through the foreseen slits and wavelength resolution options of the instrument. This was also taken into account in the design and layout of the instrument cave size, shielding and installations. Variable positions of diffraction detector along the beam from the 60 m to pinhole might be considered (e.g. rail system) in order to optimize performance.

Fourier/SPEED choppers

Fourier/SPEED choppers mainly applied or investigated for (engineering) diffraction could be an additional option also for Bragg edge investigations in transmission. This is currently not considered in more detail. However, since these chopper systems carry the potential of significantly higher performance for in particular *in-situ* diffraction and strain mapping applications for a number of important engineering materials, their potential implementation may be considered at a later point.[2]

Other upgrade options

Imaging instruments generally provide a high flexibility in their caves that allows to react to and host novel imaging approaches and technological developments. This is also the case for ODIN. In particular today the development of Wolter optics through MIT and NIST is under observation by the ODIN team and the length of the cave is well suited to host such a system for imaging with magnifying neutron optics in the future.

3.5. Key System Interfaces

Key interfaces have to be considered carefully in order to embed ODIN in an environment and context, which enables its optimisation and finally operation and efficient operation. Key interfaces are to the following systems outside the scope of ODIN:

- Target system: This interface concerns the beam extraction guide system and its interplay with the monolith in terms of geometry, cooling and atmosphere, the utilized moderator and its choice and influence on performance and guide optics as well as the service shutter as part of the target monolith hosting a piece of the guide system and performing vital function for the operation and maintainability of ODIN.

[2] Since the implementation is uncertain and the design of such a system is beyond the current scope no direct preparations for such a system are currently planned.

- Bunker system: A large number of key instrument components will be placed in the shared bunker which in ODINs instrument sector (south) extends from the monolith wall at 5.5 m out to 24.5 m with a wall thickness of 3.5 m, which implies that no choppers can be positioned between 24.5 and 28 m from the source. Interfaces with the structure, floor, columns, construction time plan etc. have to be considered and clarified with the bunker system in the design and construction phase.

- CF: CF defines parameters like the floor and ceiling heights, crane access, space for paths and instrument infrastructure etc., which are all of significant importance for the construction, operation and maintainability of the system.

- Neighboring instruments: There are significant physical interfaces with neighboring instrument systems in terms of space occupation, which in particular close to the monolith and in the area of the cave have potential impact on the performance, availability and maintainability as well as operational access of the involved systems.

- ICS: ICS is an important provider of key input and services for the instrument operation and in the current planning is hence vital to the instrument operation as it provides the source timing input as well as it takes up and transports key instrument data, without which the instrument becomes not operable.

- DMSC: The DMS centre also provides key services and systems for the instrument in the form of control, reduction and analyses software, without which the instrument cannot be operated and exploited for its central mission. It has to be hence guaranteed that the provided software and data solutions meet the requirements of the system to function in the foreseen and useful way also for third party users.

- SAD: The SAD provides the instrument with the indispensable services of the user office handling user requests and beamtime proposals, hence organizing the access of users required for the scientific productivity of the system according to its purpose. In addition SAD is administrating and maintaining the common sample environment, some of which will be required to perform specific experiments on ODIN and the applicability of it in the context with the ODIN system has to be ensured.

- Maintenance and Service Groups: The integration and application of standards and corresponding solutions as well as access strategies and maintenance requirements and schedules have to be agreed with technical groups as far as possible. This will ensure that services available through these groups can be used directly, which in turn guarantees a high availability of the instrument system.

- other: other interfaces of the system in construction (c) and operation (o) are amongst others with users (o), industry (c,o), public relations (c,o) and other instruments (c,o). Particularly important for an imaging instrument with very different users and applications is an interface with image analysis specialists (c,o), which can support the best possible exploitation of the recorded data. This is the reason why an image analysis lab and expert portal such as the DTU imaging portal and analysis lab bringing together x-ray, neutron and other imaging specialists to support users requires being prepared and is essential for the productivity of ODIN.

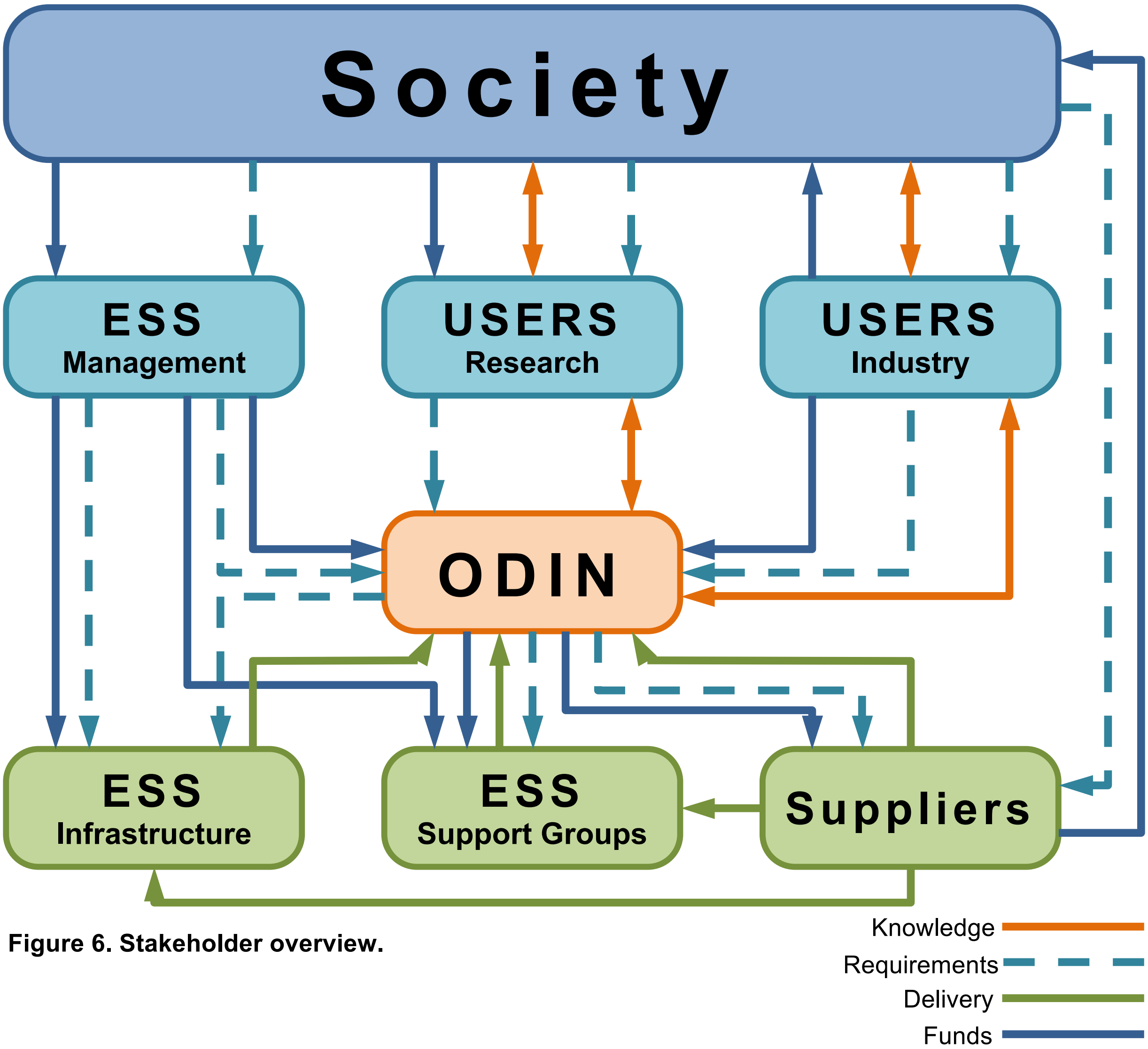

Figure 6. Stakeholder overview.

4. SYSTEM STAKEHOLDERS

At this early stage, the governance structure for the ODIN instrument is not yet defined. Subsequently, the current stakeholder analysis is more generic and most likely very similar to that of other instruments. At a later stage this ConOps stakeholder analysis will reflect the individual structure of the instrument in more detail.

The color scheme in the schematic overview (Figure 6) reflects the main requirements/deliverables as seen from the instrument. The instrument and knowledge transfer is shown in orange. Turquoise represents stakeholders that mainly postulate requirements towards the instrument, while light green represents stakeholders that mainly deliver goods and services to the instrument. While society (blue) is the ultimate source of funds and requirements, both are usually routed through ESS management and users to the instrument.

A more detailed list of stakeholders is shown in Table 1.

Table 1. Stakeholder list with respect to the three main life-cycle phases

		Design and Construction		Operation		Decommisioning		
Stakeholder Category	Stakeholder	provides	receives	provides	receives	provides	receives	Documents, Comments
System Purpose	(1) Society, Funding Agencies	Research Requirements/ Needs, Funding	Research Infrastructure	Research Requirements/ Needs, Funding	Research Infrastructure, Research Results incl. New Materials and know-how	Funding	Clean Site	ESS 00012345
System Purpose	(2) Management	Budget handling, oversight	Funding, Instrument, Infrastructure	Budget handling, oversight	Funding, operational Instrument, upgrades	Budget handling, oversight	Funding, Policy requirements from (11)	
System Purpose	(3.1) User Research	Science Requirements, Science Case, Advice	Instrumentation and Infrastructure for Science Case	Science Case and Requirements, Advice, scientific results/publications	Beamtime, scientific and technical support, data	N/A	N/A	
System Purpose	(3.2) User Industrial	Science Requirements, Science Case, Advice	Instrumentation and Infrastructure for Science Case	Science Case and Requirements, Advice, scientific results/publications or funding	Beamtime, scientific and technical support, data	N/A	N/A	
System Purpose and Support	(4) Instrument Scientists	Instrument following accepted specifications	Budget from (2) and funding from (1)	Operation, user support, upgrades, scientific results/publications	operational support and budget, system upgrade(s)	N/A	N/A	
Support	(5) Instrument Engineer(s)	Engineering support throughout the process	Requirements from (4) following accepted specifications/boundary conditions	operational Support	budget, technical requirements for equipment upgrades	N/A	N/A	
Support	(6) Support Groups (Hardware)	Infrastructure development, support and advice	Budget, requirements from (2)	Maintenance	Budget from (2)	N/A	N/A	
Support	(7) DMSC	Software development for (3)-(6)	Budget from (2) , requirements from (2) and (4)	Maintenance	Budget from (2)	N/A	N/A	
Support	(8) ES&H	Standards and Policies regarding environment, safety and health, PPS design	Budget and requirements from (2) and (11)	Maintenance	Budget from (2)	Standards and Policies	Budget and requirements from (2) and (11)	
Support	(9) Facility Infrastructure (CF, User Office, etc.)	Planning, coordination respecting requirements and needs	Budget and requirements	System maintenance	Budget and Requirements			
Support	(10) Suppliers	Components, products, services for Facility and instruments	Payment, requirements and specification from (2), (4) and (5).	Components, products, services for Facility and instruments.	Payment, requirements and specification from (2), (4) and (5).	Components, products and services.	Payment, requirements from (2) and (11).	
Support	(11) Regulatory Authorities	All relevant policies and requirements, licenses	Funding from Government, system specifications from (2)	Oversight	Budget from (1), (2)	All relevant policies and requirements, licenses	Funding from Government, system specifications from (2)	

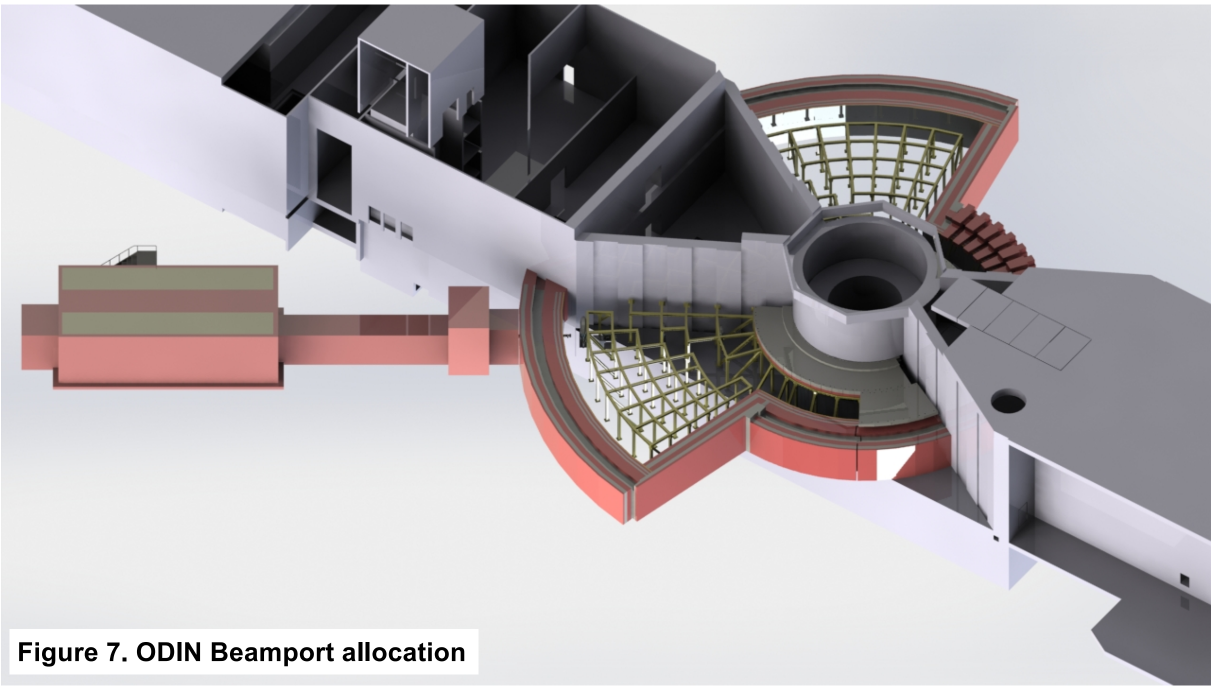

Figure 7. ODIN Beamport allocation

5. OPERATIONAL CONCEPTS

5.1. Operational environment

ODIN is located at beamport S2 in experimental hall 1, building designation D01.

The instrument will be operated in a controlled environment with a temperature of 22±2 °C all year round. The floor height in experimental hall 1 is 2 m below the target centerline. Free height to lifting hook of the overhead gantry crane is maximum 12 m [6]. Floor loading in experimental hall 1 must not exceed 20 ton/m^2. Floor stability in the hall is specified to be maximum 3 mm elastic movement and another maximum 3 mm due to creep/deformation [7].

Utilities and media are brought to the instrument from the gallery. Media include: DIH_2O, N_2, instrument grade compressed air, cooling water flow. Utilities include: office IT, office comms, power, MPS, PSS, DMSC and ICS. Details for e.g maintaining the stable temperature in the experimental hall are still in development. This could have an impact on possible locations for high power, high heat load, equipment; considerations for this need to be made.

The ESS facility has 5 different operating modes, see [8]: Shutdown, Studies, Studies on Target, Startup and Production. These modes have various impacts on instrument operations. Pure experimental work can only be conducted during ESS-mode Production. Access to instrument equipment for maintenance, calibration, cold commissioning is mainly done during shutdown, studies and studies on Target – naturally after due safety assessment and possibly with some restrictions especially during studies on Target where neutrons will be present. During start-up instrument operations is limited to alignment, commissioning and calibration runs.

When ESS has entered into a steady-state operations phase the following principal schedule is currently expected to apply:

- 200 days/year of neutron Production for the ESS users after 2026,
- Proton beams will be on target for ~225 days/year,
- Two long Shutdowns, one in winter (~6 weeks) and the other in summer (~10 weeks) followed by Studies and Studies on Target periods,
- 3 Optional Studies Days every second week to avoid long down time of instruments due to failures of activated components, followed by 2 days for Studies and Studies on Target,
- A series of Studies days to allow for fine-tuning of accelerator and target systems.

One goal of ESS is to ensure that at least 90% of the users receive a neutron beam allowing them to execute the full scope of their experiments. This is in accordance to the availability and reliability assessments made in refs [10],[11].

The ODIN instrument will be managed and operated by a team of scientist and engineers. ESS will be manned 24 hours/day, 7 days a week, not in all categories but such that flexibility for users when conducting experiments and making preparations or analyzing results is ensured.

5.2. Operational scenarios

Although ODIN can be operated in a vast variety of modes (possible modes, which have a large number of combinations in terms of wavelength resolution, bandwidth, spatial and temporal resolution, imaging modality etc., can be deduced from the proposal and functional requirements in more detail) the following principal generic steps are required performing a measurement:

I. instrument preparation and cold verification (beam on or off, shutter closed, cave accessible)
- setting the primary instrument parameters for a specific experiment including choppers, slits, pinhole etc. remotely via control computer and software
- installing the specific required detector solution at the specific required position and focusing it (remotely) using light and the detector specific software. The detector set-up might require changing optics, scintillators etc. on the detector system itself manually.
- setting up and connecting all auxiliary equipment required for a specific measurement modality within the cave. This might involve flight tubes, spin manipulation devices, gratings, polarisers, analysers, sample environment etc.
- Controlling all functions of the set-up devices as far as possible without beam.

Required staff: instrument scientist & technician (if available), potentially also: technician(s), user

II. hot set-up verification (cave closed/opened, shutter open/closed, beam on)
- checking spectra, flux and beam position by recording neutron images
- checking alignment and functionality of auxiliary equipment in the beam, scanning parameters etc.
- re-aligning remotely and manually when required
- calibration and characterisation of auxiliary equipment for readiness to measure (polarization quality, spin turn efficiency, modulation visibility etc.
- note these processes can be repetitive

Required staff: instrument scientist & technician (if available), potentially also: technician(s), user.

III. prepare sample for measurement
- given the large range of different samples that can be measured in imaging the offline but on-site sample preparation can take from no time to seconds, minutes, hours, days to weeks and can be as different as ranging from wet-chemistry to biological growth to mechanical or thermal processes; hence a script of required steps cannot be provided.

Required staff: user, potentially some specific support personal or instrument scientist.

IV. sample set-up (cave closed/opened, shutter open/closed, beam on)
- sample(s) mounting on beamline
- sample(s) position check and potential correction remotely
- potential realignment manually
- signal check by recording images
- decision on measurement protocol including exposure times – potential additional check with beam

Required staff: user, first time(s) also instrument scientists, potentially also technical support staff.

note: III and IV can change order if e.g. samples have to be prepared or mixed directly at the beamline in order to not loose time between preparation and actual measurement, step 4 would relate in such case to the installation of a part of the sample or a corresponding container or dummy only.

V. measurement (cave closed, shutter open/closed, beam on)
- the sample is exposed to the beam
- data is collected
- a script is controlling the measurement parameters, which can be a single exposure or a complex scan of various parameters like positions or sample environment settings, but also only elapsing time
- the collected data of each individual step is stored and displayed quasi-live on the computer screens in the control hutch or on whatever device connected
- the feedback of displayed or subsequently examined data is suited to change the

measurement steps or to interrupt a measurement to make changes with respect to one of the previous described steps and to reenter the here described process at the corresponding point
- between exposures, when setting are changed according to the script remotely an instrument shutter might close to reduce radiation exposure (cold/thermal) and corresponding sample activation as part of the measurement script or routine
- long measurement will run for significant times unobserved
- exposure and data collection are interrupted in most cases when the source has downtimes but resumes when the source reaches a threshold neutron production again
- at the end of a script the shutter closes as last step of the script and data collection stops

Required staff: user, potentially in many cases and first runs also instrument scientist.

VI. sample removal (cave open, shutter closed, beam on/off)
- the sample is scanned for activation
- potential waiting time for sample cool down under threshold activation
- sample removal, by hand or with remote tools (activation)
- sample storage (activated/non-activated)
- (at a later stage sample screening by radiation safety staff to decide upon sample removal from site)

Required staff: user, potentially in first runs also instrument scientist.

note: in most cases a measurement is followed by a series of similar measurements on different but similar samples in which case the process is re-entered at step III or IV, potentially earlier if settings or environment need to be adapted

VI. data analyses
Note: preliminary analyses might take place during a measurement campaign however,
typically the real data analyses takes place elsewhere and is in its procedure and resources independent of the instrument system, though the requirements are set by the instrument team and provisions are taken by the instrument team during the construction and operation phase to ensure the tools and infrastructure to do so for the specific data are installed and available.

Primary instrument modes (excluding the specific modes of set-ups in the cave, which are supported by these primary modes) are summarized in Table 2. They are optimized for and combinable with a number of measurement modes that are realized by corresponding set-ups in the cave, like different detectors, polarization manipulation, diffraction gratings etc.

Table 2. Primary instrument modes with respect to chopper operations.

Mode	Wavelength — λ				Resolution-characteristic	BP Chopper Status	WFMC System		Optimized for:
	Range	Minimum	Maximum	Resolution			Status	Distance	
White Beam	unlimited	~ 1 Å	N/A	N/A	N/A	Off	Off	N/A	Conventional
	limited*	1 Å	20 Å	N/A	N/A	Off	Off	N/A	Conventional
Low Resolution ToF	4.5 Å	1 Å	20 Å	20%-1%	λ-dependent	On: 14 Hz	Off	N/A	Bragg Edge (qualitative), DFI
	9 Å	1 Å	20 Å	20%-1%	λ-dependent	On: 7 Hz	Off	N/A	SEMSANS
Medium Resolution ToF	4.5 Å	1 Å	20 Å	1%	constant	On: 14 Hz	On	0.5 m	Bragg Edge (phase, texture) Polarized
	9 Å	1 Å	20 Å	1%	constant	On: 7 Hz	On	0.5 m	Polarized
High Resolution ToF	4.5 Å	1 Å	20 Å	1%-0.3%	constant	On: 14 Hz	On	0.5-0.1 m	Bragg Edge (strain) Grain Mapping
	9 Å	1 Å	20 Å	1%-0.3%	constant	On: 7 Hz	On	0.5-0.1 m	Grain Mapping
Calibration, Diagnostic	flexible	flexible	flexible	flexible	flexible	flexible	flexible	flexible	N/A

5.3. Maintenance Concepts

5.3.1. Levels of maintenance

Within ESS there are three identified levels of maintenance, (see [8]):

1. Organizational maintenance: maintenance performed on site where the element is normally being operated,
2. Intermediate maintenance: maintenance performed on site at a dedicated workshop,
3. Supplier maintenance: maintenance performed off site at the supplier premises.

The term supplier includes In-Kind partners.

5.3.2. Maintenance categories

Maintenance can be divided into two categories: Corrective and Preventive. Preventive maintenance is part of scheduled maintenance, which also includes maintenance work to be conducted on equipment where condition based monitoring cannot be achieved. Performed instrument reliability analysis, part of RAMI work, aims to ascertain that preventive maintenance on this type of equipment/components could be limited to periods of scheduled shutdown of the facility. Only in rare cases when instrument reliability and availability are impaired, an immediate intervention outside scheduled shutdowns may be required. Maintenance and monitoring requirements of critical components will be taken into account in design and procurement of equipment from the beginning; this will minimise disruption to user operation.

Corrective maintenance will mainly apply when an event happens, forcing maintenance to be done unscheduled. This occurs when either a critical component fails or an issue that requires immediate action is detected. The instrument will then have to stop user operations for the duration of repairs or maintenance.

Another key categorisation of maintenance is the distinction regarding to access requirements and limitations. Components can hence be categorised into easy maintenance access, limited maintenance access and difficult maintenance access devices. In the first category all devices and components can be placed in areas, which are located outside the radiation shield of the primary instrument, including such devices placed in the cave. These devices can be serviced anytime when required, though downtimes are used for preventive maintenance in order not to interfere with the scientific utilisation of the instrument. In the second category is the limited number of hardware components installed inside instrument shielding between the bunker shield and the cave, which are hence downstream of the heavy shutter system of the instrument. These components shall be accessible during source operation in case of required corrective maintenance. In the third category are components installed in the bunker area where access currently appears to be possible only during source downtimes and through remote handling. Access to components within the last two categories requires removal of shielding with the corresponding implications of crane use, space requirement and scheduling and additionally might also involve a required cool down time of components due to activation, which increases the time requirements.

Finally, as category of practically no access, the components of the extraction system in the monolith could be defined: access requires removal of significant parts of the instrument and its neighbours. Hence, no moving parts and components requiring maintenance can be placed there and the design of components installed there has to be especially robust.

5.3.3. Maintenance philosophy

ODIN's maintenance philosophy is in line with the approach of the facility to utilize condition based preventive maintenance as much as possible. In order to minimize resource requirements and potential instrument downtimes, inspectability and accessibility, but also failure mode instrument operation and application of facility standards are in the focus of a sustainable instrument design. However, performance and in particular cost against the background of a limited instrument budget are major constraints also in this regard and balanced cost-benefit solutions are indispensable.

As the most critical components with regards to maintenance all moving parts within the bunker and instrument shield upstream of the cave can be identified easily. For ODIN this covers choppers including the T0 chopper, the translation stage of the WFMC choppers, the heavy shutter and a potential filter system. The following philosophies apply to those in the ODIN design.

Choppers & T0 chopper:
- choppers are accessible and removable vertically from the top, and when required by remote handling; however, up to date there is no information available on expected activation and radiation situation within the bunker. Better knowledge of the situation to be expected is essential in order to plan resources efficiently and under correct assumptions. This is important in particular with respect for the remote

handling requirements that have to be met, designed and which impact cost, complexity, space demand etc.
- choppers are removable without impact on the guide system; this implies a state of the art split housing approach for choppers which are connected to the guide vacuum system, which is a design driver with respect to performance in order to keep guide interruptions as small as possible , which is in particular key for an imaging instrument like ODIN
- choppers are removable independently; This is important for ODIN as simulations clearly demonstrate that the vast majority of modes that ODIN enables stay functional in case any single chopper has to be removed for any kind of maintenance (according to current simulations this also applies to the T0), however, the impact is significantly more severe when any two choppers have to be removed, with only minor exceptions for certain combinations which are considered.
- chopper solutions with minimum maintenance requirement are preferred where affordable, final choice requires cost-benefit analyses; failure mode operation enables maintenance with certain frequency.
- choppers must be (remotely) moveable to an open position when failed, whenever possible to minimize instrument downtimes.

Translation stage of WFMCs:
- due to the independence criteria for chopper maintenance the translation stage is a separate component with respect to removal; however it can only be removed for maintenance if both choppers which it bears are removed too; therefore it is envisaged to potentially allow for a combined removal
- two independent stages can be considered, which could be removable with the respective chopper; it is, however, currently believed that this will increase complexity without significant advantage;
- ideally two choppers can be reinstalled in fixed positions when the stage is removed
- removal of the stage shall not affect the guide system
- vertical removal and remote handling has to be possible
- radiation hardness of motors and movability have to be considered carefully

Cd filter:
- the filter motion should be fail-safe, meaning in case of failure of the motion control, the filter is removed from the beam, a state which has no viable impact on instrument performance;
- a safe radiation hard solution is to be realized, likely pneumatic
- removal is remote, vertical and with no impact on other components

Heavy shutter:
- the heavy shutter has to be fail-safe; failure of the component disables any instrument function; hence, the design has to be extremely robust and reliable;
- removal of the shutter disables any instrument function, hence the component has to be designed as maintenance-free as possible
- removal is vertical, with remote handling as required

The guide system should not require maintenance, but in case of failures partial removal follows similar principles as for the choppers; gate valves will allow maintaining the vacuum in the remaining parts of the guide. Realignment requirements of the guide are to be considered in the general design of the system; due to the anticipated ground settlement, realignment will have to be as straightforward as possible. The guide design shall be as robust against misalignment as possible while affordable in terms of cost and performance.

All other components are accessible, should be easily replaceable (standards) or allow failure mode operation, partly through replacement by alternative components (e.g. different detector to be used). Regular maintenance and checks shall prevent failure.

6. CONSEQUENCES OF THE CONCEPTS

6.1. General design considerations

General design considerations concern all functional and non-functional requirements and are documented in detail in the corresponding documentation, the Preliminary System Design Description.

6.1.1. Upgrade options

Identified upgrade options shall be considered and be catered for as much as possible in the design solutions, see 3.4.13.

6.1.2. Robust design

The current preliminary design can be considered robust with respect to the scientific and technical aspects raised. This is supported by the flexibility and various available failure modes of the instrument, which allow for efficient operation in nearly all cases of single component failure. However, careful provisions have to be made especially during final design; in particular the performance and respective corresponding issues of the extraction guide and the heavy shutter have to be considered carefully. The final design of the guide including its alignment and support as well as choices still to be made on details of choppers and their support will be of significant importance.

However, robustness has to also be considered with respect to viable systems that ODIN is connected to and relying on. This concerns particularly the ICS and data streaming functions coupled with it. In order to guarantee best possible availability it is foreseen that ODIN is able to operate in a stand-alone mode in case of difficulties of the ICS and data streaming systems. The only precondition required for most instrument modes, namely time-of-flight modes is receiving a trigger signal from the source pulses, which ODIN consequently asks to get supplied with through a hardware solution. All choppers can usually, just like other motion control, be addressed locally either through an internal hardware connection or in the worst case by directly approaching the specific electronics or controls. Detector solutions currently considered for ODIN include a local data storage capability (indeed for limited volumes and time), allowing for standalone operation of the instrument for considerable downtimes of centralized capacities. Furthermore, considered detector systems are intended to be equipped with corresponding parallel data acquisition features as well, which imply minimum extra cost.

Better knowledge of the operational environment and interfaces like with the target but in particular also the conditions during access in the bunker are key boundary conditions to enable optimum choices and design. This information is key for robust design but at the time of writing this version of the ConOps, not yet fully available.

6.2. Training of personnel

Training of personnel will be further developed in future releases of this document when the design has matured enough for it to be included in a meaningful and contributing manner. Training will in general build on the basic ESS access requirements and safety classes.

GLOSSARY

Term	Definition
BP	Bandpass (-width) Chopper
CDR	Critical Design Review
ConOps	Concepts of Operations
FOC	Frame Overlap Chopper
IRR	Installation Readiness Review
ODIN	Optical and Diffraction Imaging with Neutrons
ORR	Operational Readiness Review
PDR	Preliminary Design Review
PPSC	Prompt Pulse Suppression Chopper
PSS	Personnel Safety System
SAR	Safety System Acceptance Review
T0	Pulse Shaping Chopper (t=0 chopper)
TG	Toll gate
WFMC	Wavelength Frame Multiplication Chopper

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[11] ESS-0008886

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
0	First issue	Markus Strobl, Peter Sangberg	2016-05-16
1	Second issue	Elbio Calzada, Michael Lerche, Manuel Morgano,	2017-01-18
2	Revision of TG2 panel implemented	Michael Lerche	2017-03-10