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Scope Setting Report
Instrument : HEIMDAL

SUMMARY

The purpose of this document is to describe the possible baseline options for the HEIMDAL instrument project and how the instrument performance will be upgraded over time after the construction project to get from the day-one scope to the full-scope as envisaged in the original instrument proposal.

HEIMDAL has been assigned to cost category B (12M€). The conclusion from analysing the costs is that it is only possible to deliver a very limited scope within cost category B. HEIMDAL is a long thermal instrument with relative high cost for guide and shielding. The cost category B only leaves sufficient funding for building a relative simple straight guide, and only very limited detector coverage can be afforded. The cost category B (12 M€) is not upgradable to full scope.

The three possible baseline options are presented along with a discussion of the cost implications. In summary:

Option 1 cost category B (**12 M€**) is an instrument with one backscattering detector module with an area of 0.5 m^2 resulting in coverage of ~0.2 sr. The instrument is not upgradable to full scope. Upgrade to reasonable diffraction performance with 1.3 sr coverage is presented.

Option 2 World leading powder diffractometer, here the cost is **14.9 M€** and the instrument has all the necessary cold guide components installed in the monolith and bunker area, for upgrading the instrument to full scope and the diffraction detector coverage reaches 1.3 sr (2.1 m^2). The upgrade to full scope is presented.

Option 3 World leading multi-length scale instrument, cost is **18.6 M€** and it encompasses the full instrument scope with diffraction, SANS and imaging options. The diffraction detector coverage reaches 2 sr (3.2 m^2). The SANS detector is placed 10 m from sample and covers 0.5 m^2 and the imaging detector has a coverage of 28x28 mm^2, with resolution of 55x55 μm^2.

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1. OVERVIEW

1.1. Science Case

The purpose of this introduction is to provide a brief description of the HEIMDAL instrument and the science case associated with the instrument. HEIMDAL combines thermal neutron powder diffractometer (TNPD) with small angle neutron scattering (SANS) and neutron imaging (NI). The instrument represents a novel design, where the cold beam for SANS bypasses the pulse-shaping chopper for the thermal beam. In the following the high-level introduction to the science case of the instrument is given.

HEIMDAL is designed to use a narrow wavelength band coinciding with the maximum brightness from the thermal moderator. The pulse-shaping chopper controls the pulse length and facilitates data collection in two modes: 1) high-resolution (short pulse, lower intensity) and 2) high-rate (long pulse, lower resolution). Conventional facilities typically have to build both a high resolution *and* a high flux instrument. A significant benefit of the HEIMDAL design is the simple peak profile functions describing the data. The high angular coverage and relatively short wavelength will allow collection of data suitable for low-resolution pair distribution function (PDF) analysis.

Thermal neutron powder diffraction (TNPD) is a technique applied across a wide range of scientific disciplines, crystallography, chemistry, physics, materials science, engineering and geoscience. The capability of switching between high resolution mode and high speed mode will allow HEIMDAL to cater for all these scientific disciplines. However, HEIMDAL is designed with the purpose of making *in situ* or *in operando* investigations of highly complex and multiphase systems. There is a growing community with interest in following processes as function of time. In the years to come the demand for performing *in situ* studies will also include a request for probing multiple length scales simultaneously. The field of neutron scattering is moving away from idealized samples towards real systems close to applications. This increases the complexity as the systems of interest become multi-component systems, which need to be studied as a function of multiple environmental conditions e.g. pressure, temperature, gas atmosphere, electric and magnetic field, etc. In order to examine the possible parameter space, a combination of powder diffraction, small angle scattering, and imaging is mandatory. The ambition is to build a world-leading instrument combining TNPD, SANS and NI in a single almost uncompromised setup.

HEIMDAL will serve the conventional powder diffraction community both in its desire for resolution and speed, while spawning an entirely new user community focused on its new capabilities for multiple length scale studies.

1.2. Requirements

The high-level requirements for HEIMDAL define the target scope for the instrument construction project. They have been formulated to capture the key aspects of the instrument proposal science case:

I. **Thermal Neutron Powder Diffraction (TNPD):**
The powder diffraction setup of HEIMDAL will have a tuneable resolution, allowing HEIMDAL to utilize the long pulse structure of the ESS for high-speed measurements. High-resolution

mode can be obtained at the expense of flux using the pulse shaping chopper. The length of HEIMDAL allows best usage of the long pulse in a single detector frame. The wavelength band is Δλ = 1.7 Å and centred around 1.5 Å coinciding with the maximum flux from the thermal moderator. HEIMDAL will cover the following high-level requirements;

HEIMDAL will:

1. be capable of powder diffraction with high Q resolution to ~21 $Å^{-1}$.
2. allow high peak resolution with Δd/d ~ $4{\cdot}10^{-4}$.
3. have a high flux mode with time resolutions below 10 s for kinetic measurements.
4. allow time resolutions around 10 µs in quasi-stroboscopic mode down to mg samples.
5. be capable of performing diffraction tomographic measurements within a 1 day of specimens with dimensions of 5x5 cm.
6. in high flux mode allow *in situ* total scattering experiments with high time resolution <60s.

II. **Small angle scattering (SANS)**:
The SANS setup is unconventional as the wavelength resolution is high (Δλ/λ~1%) and the wavelength band is relative narrow (Δλ = 1.7 Å), due to the instrument length. Using a dedicated SANS detector together with diffraction detectors it will allow a single shot spatial coverage of >3 orders of magnitude in reciprocal space (~10^{-3} – 1 $Å^{-1}$). The cold beam designed for SANS has the following capabilities:

A) **Convention SANS:** Measurements of high-resolution SANS, combined with TNPD.

B) **Low-resolution powder diffraction:** The cold neutrons in combination with the diffraction detectors can be used for very high-intensity low-resolution powder diffraction.

C) **Imaging:** The cold beam can be used for a number of imaging techniques. Imaging and SANS cannot run simultaneously.

In this way, HEIMDAL will be able to:

7. quasi-simultaneous collection of small angle scattering data with a q-resolution covering three orders of magnitude from 10^{-3} to 10^{0} $Å^{-1}$.
8. match the time resolution of SANS and NPD to collect quasi simultaneous data with a time resolution of 10 s.

III. **Neutron imaging (NI)**:
The cold beam takes the full pulse and is very useful for some neutron imaging techniques including contrast imaging, Bragg edge imaging and tomographic reconstruction.

HEIMDAL will:

9. allow the measurement of samples with cross section areas up to 5x5cm with cold beam.
10. provide a pixel resolution of about 50x50 µm.
11. be capable of performing Bragg-edge imaging with potential of doing 3D phase reconstruction.

1.3. Configuration options

Three configuration options are presented:

1. **Cost category B** (12M€). The aim was to meet the cost category. **Cost : 12.1 M€**

2. **World leading powder diffractometer:** (option 2) Instrument manages to meet scientific requirements with reasonable performance and is upgradable to full scope.
   Cost: 14.9M€
3. **Full technical scope.** This is a refinement of the scope presented in the original proposal.
   Cost: 18.6 M€

A schematic illustration of the full scope instrument is seen in Figure 1. The moderator is shown and how the thermal and the cold guide initially takes different paths, but are combined into the same guide, before exiting the bunker.

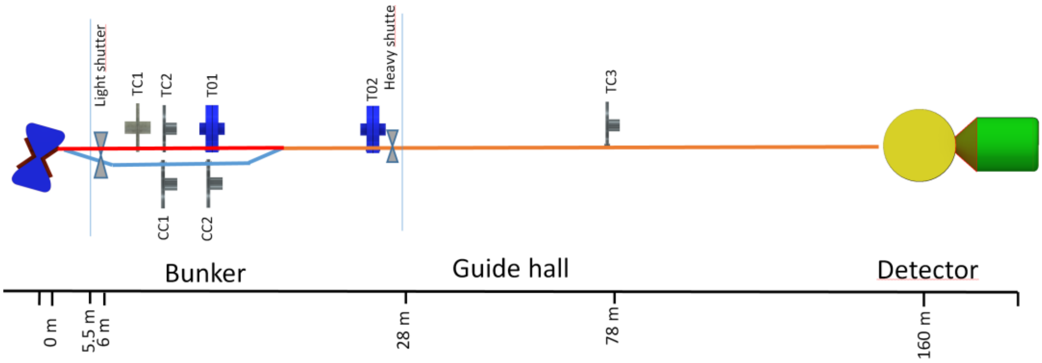
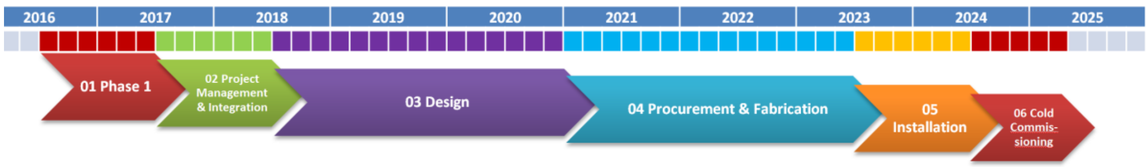


Figure 1: Layout of HEIMDAL instrument situated at W8, along with various items of the instrument.

The thermal guide is a straight guide, with double ellipses starting at the monolith wall and ending at the bunker wall and starting again after the bunker and ending before the instrumental cave. In the full scope instrument the cold beam is extracted through the monolith at angle both horizontally and vertically with respect to the thermal beam. The cold beam bypasses the thermal pulse shaping and pulse selection chopper. A band definition chopper is placed in the cold beam together with a frame overlap chopper placed 18 m from the sample. Approximately 20 m from the moderator the cold beam is reflected into the thermal guide and the cold and thermal beam is transported by the same beam transport system.

1.4. Time Schedule:

The timeline is seen below. There will be a significant overlap between some of the phases, e.g. the guide and chopper setups need to be installed in the bunker before the end of 2019. Therefore will procurement and installation be ongoing during the design phase (03 Design). In general procurement of certain long lead time items like guides, detectors and choppers need to be aligned with the procurement of the other instruments to minimize potential delays in installation. The crane for placing a guide shielding may also become an issue.



2. OPTION 1: SCOPE WITHIN COST CATEGORY B (12M€)

2.1. Scope

- Straight double pinhole thermal guide
- All necessary associated infrastructure (shielding, cabling, cabins etc)
- Thermal choppers
  - o Double counter rotating disk at ~6.5 m (Pulse shaping chopper)
  - o Pulse selection chopper at 7.0 m
  - o Two T0 choppers will suppress the prompt pulse, placed within the bunker
  - o Frame overlap chopper at 78 m
- Backscattering detector
- No dedicated sample environment can be afforded

The very low detector coverage (~0.2 sr) obviously makes it impossible to realize a world leading instrument even for diffraction. The top level requirements meet with this scope is 1) and 2), as it will be capable of measuring the large scattering vectors at Q_{max}~21 $Å^{-1}$ and with high resolution for the long wavelength neutrons. The setup is upgradable to fulfil requirement 3)-6).

The science case of HEIMDAL is based on being a multi length scale instrument capable of following TNPD, SANS and NI with a high time resolution. Thus, this scope **does not fulfil** the science case for HEIMDAL, as accepted by the SAC and reconfirmed by the STAP on June 22nd-23rd 2016. The cost category B does not allow the instrument to be upgraded to full-scope as all cold guide components are excluded.

2.2. Costing

The costing is based on bottom-up calculation of the procurement costs and manpower required for the tasks needed to deliver the higher level requirements items.

	01 Phase 1	02 Project Management & Integration	03 Design	04 Procurement & Fabrication	05 Installation	06 Cold Commis-sioning	Total
01 Shielding	€ 0	€ 0	€ 604,470	€ 1,610,209	€ 402,509	€ 0	**€ 2,617,188**
02 Neutron Optics	€ 0	€ 0	€ 1,156,800	€ 850,000	€ 425,000	€ 0	**€ 2,431,800**
03 Choppers	€ 0	€ 0	€ 979,728	€ 189,184	€ 0	€ 4,608	**€ 1,173,520**
04 Sample Environment	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	**€ 0**
05 Detector and Beam Monitors	€ 0	€ 0	€ 128,000	€ 21,216	€ 2,304	€ 0	**€ 151,520**
06 Data Acquisition and Analysis	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	**€ 0**
07 Motion Control and Automation	€ 0	€ 0	€ 0	€ 313,432	€ 4,608	€ 0	**€ 318,040**
08 Instrument Specific Technical Equipment	€ 327,400	€ 270,720	€ 714,240	€ 737,280	€ 276,480	€ 207,360	**€ 2,533,480**
09 Instrument Infrastructure	€ 0	€ 0	€ 483,400	€ 786,032	€ 314,048	€ 0	**€ 1,583,480**
10 Vacuum	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	**€ 0**
11 PSS	€ 0	€ 12,500	€ 25,000	€ 50,000	€ 25,000	€ 12,500	**€ 125,000**
12 Contingency							**€ 1,214,892**
Total	**€ 327,400**	**€ 283,220**	**€ 4,091,638**	**€ 4,557,353**	**€ 1,449,949**	**€ 224,468**	**€ 12,148,920**

Labour included in above (Person-Years)	**3.0**	**2.3**	**8.3**	**8.4**	**3.7**	**1.7**	**27.3**

Table 1 Costing for HEIMDAL in Cost Category BUpgrade/Staging plan

The upgrade to full scope is not possible as this requires installing a new beam plug into the monolith to allow extraction of the cold guide.

Upgrade to a full functional thermal neutron powder diffractometer requires a minimum of angular coverage from 10-170°. The instrument is a narrow band width thermal diffractometer, designed for 2D Rietveld refinements. Figure 2 shows the detector coverage for option 1 and the upgrade path with the cylindrical detectors covering from 10-150°. The gray area shows the position of the detectors in the original proposal. To reduce the cost the cylindrical detectors have been moved from a distance of 1.5 m to a distance of 1.25 m and reduced to half height, hereby reducing the detector area from 3.7 m^2 to 1.5 m^2. Cutting the detector cost by a factor of 3, while maintaining about 60% of the original coverage. The reduced distance degrades the resolution on the cylindrical detectors, but as the backscattering detectors are maintained at a distance of 1.5 m this will only have minor impact on the maximum resolution obtainable with HEIMDAL.

A post upgrade to detector coverage from 10-170° will cause following added cost:

Upgrade with diffraction detectors 10-150		
Detectors, including support	1.55	M€
Manpower	0.25	M€
Radial collimator	0.25	M€
Manpower	0.05	M€
Reopening Shielding	0.06	M€
Contingency	0.24	M€
Total cost	2.40	M€

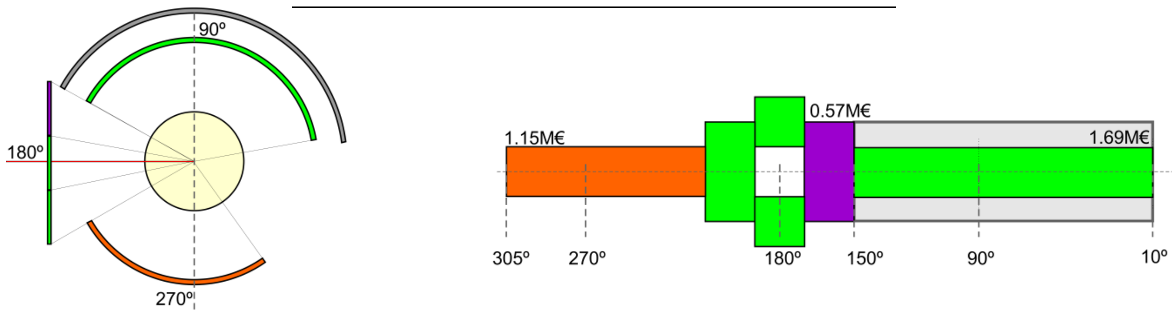


Figure 2: The configuration of the diffraction detectors (*left*) the diffraction detectors seen from above, – the beam enters from the left-hand side. (*right*) the diffraction detectors unfolded and seen horizontally. The purple colored detector is installed in option 1, while green is high priority for the upgrade, while orange is long term upgrade.

2.3. Risk

The lack of detectors makes it impossible to deliver a competitive day-1 instrument. The instrument will fail to deliver the science case that was presented to the STAP and SAC.
Below are top 5 risks rated high using ESS risk measures (impact x likelihood).

Table 2 Top 5 risks for Option 1

Risk level	RISK	TREATMENT NAME	Treatment	CATEGORY	TREATMENT PLAN
High 5x5	Failure to deliver proposed scientific performance	Lower expectations	Mitigate	Budget, quality and function	Communicate with stakeholders the lowered performance expectations. Begin planning for upgrade and seek funding. Responsible: HEIMDAL Team, ESS management
High 4x3	Conventional facilities delay	***CF LEVEL ESS-0019533***	Observe	Schedule, budget, quality and function	Access to bunker is a milestone for HEIMDAL schedule. Responsible: CF
		External areas like labs and workshops	Mitigate		External areas will give the opportunity to start pre-installations Responsible: CF
High 4x3	T0 choppers are currently high risk, due to concurrent development.	Change of guide design	Mitigate	Schedule, budget, data quality	Delayed installation, higher cost and high background are to be expected. A kinked guide solution may solve the problem.
High 3x5	Proper design according to instrument requirements and delay in monolith insert design	Schedule for external milestone	Observe	Schedule, budget, Quality and function	Follow the progress of the design and project schedule. HEIMDAL Team Responsible: target
		TARGET LEVEL ESS-0019533	Observe		Focus on Safety, feasibility and requirements Responsible: target
High 3x4	Detector, failure in meeting requirements, failing to deliver.	Detectors: Action plan and schedule with mitigation plan	Mitigate	Schedule, budget, quality and function	Following the progress of other instruments, coordination with other instruments using CDT detectors, DREAM and MAGIC. Responsible: CDT, Detector Group

3. OPTION 2 : WORLD CLASS SCOPE MEETING REQUIREMENTS

3.1. Scope

The scope for cost option 2 is:

- Straight double pinhole thermal guide
- Cold guide insert in the monolith for extraction of cold beam.
- All necessary associated infrastructure (shielding, cabling, cabins etc)
- Thermal choppers
    - Double counter rotating disk at ~6.5 m (Pulse shaping chopper)
    - Pulse selection chopper at 7.0 m
    - Two T0 choppers will suppress the prompt pulse, placed within the bunker
    - Pulse overlap chopper at 78 m
- Cylindrical detector in the range from 10-150°
- Back scattering detector from 150-170°
- Robotic sample changer and multiple low temperature sample changer.
- Cold and thermal guide installed in the light shutter (γ-shutter)

- This scope fulfil the requirement 1)-5). However the lack of high angle coverage prevents high speed total scattering data collection 6).

The setup is fully upgradable to achieve requirement 6)-11), within shutdown break of ESS

The absence of SANS and imaging detectors obviously makes it impossible to realize a multi length scale instrument. Perhaps an imaging detector for Bragg-edge imaging can be shared with ODIN (e.g. Timepix 1400 Hz, 28 x 28 mm^2 with pixel resolution 55 x 55 μm^2, price from ASI: 147.000 € or µPIC 300 x 300 mm^2 with resolution of 400 x 400 μm^2 estimated cost 300.000 € - J-Park development).

This scope **does not fulfil** the science case for HEIMDAL. The scope meets half of the high level requirements and is upgradeable to a configuration that provides the full scope.

Most of the thermal neutron powder diffraction (TNPD) science case 1)-5) will be met by this configuration, however the lack of backscattering detectors will significantly reduce the time resolution for total scattering experiments – requirement 6). The detector coverage sums to approximately 2 m^2 equivalent of 1.3 sr, which is about 60% of the original envisioned initial coverage. A 60% coverage will still produce a world leading instrument regarding *in situ* and time-resolved powder diffraction measurements, however, in high-resolution mode the instrument will only be on par with existing instruments. The detector configuration is shown in Figure 3 and represents the purple colour with a cost of 2.26 M€ plus installation. Cost given in Figure 3 is detectors without installation. Further upgrade includes the backscattering detectors in green and the orange detectors on the left-hand side from 210-305°, Figure 3.

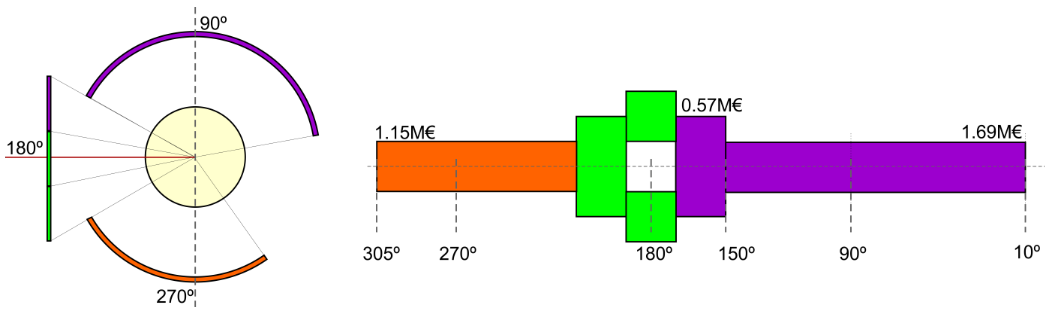


Figure 3:. The purple colored detector is installed in option 2, while green is high priority for the upgrade, and orange is long term upgrade.

3.2. Costing

The costing is based on bottom-up calculation of the procurement costs and manpower required for the tasks needed to deliver the higher level requirements items. Vacuum equipment is not included in the cost as this is expected to be delivered from outside the HEIMDAL budget.

Table 3 Costing for HEIMDAL Option 2

	01 Phase 1	02 Project Management & Integration	03 Design	04 Procurement & Fabrication	05 Installation	06 Cold Commis-sioning	Total
01 Shielding	€ 0	€ 0	€ 604,470	€ 1,610,209	€ 402,509	€ 0	**€ 2,617,188**
02 Neutron Optics	€ 0	€ 0	€ 1,411,800	€ 850,000	€ 425,000	€ 0	**€ 2,686,800**
03 Choppers	€ 0	€ 0	€ 979,728	€ 189,184	€ 0	€ 4,608	**€ 1,173,520**
04 Sample Environment	€ 0	€ 0	€ 0	€ 306,912	€ 20,736	€ 6,912	**€ 334,560**
05 Detector and Beam Monitors	€ 0	€ 0	€ 433,360	€ 618,742	€ 560,251	€ 0	**€ 1,612,353**
06 Data Acquisition and Analysis	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	**€ 0**
07 Motion Control and Automation	€ 0	€ 0	€ 0	€ 548,432	€ 4,608	€ 0	**€ 553,040**
08 Instrument Specific Technical Equipment	€ 327,400	€ 270,720	€ 714,240	€ 737,280	€ 276,480	€ 207,360	**€ 2,533,480**
09 Instrument Infrastructure	€ 0	€ 0	€ 618,400	€ 876,032	€ 314,048	€ 0	**€ 1,808,480**
10 Vacuum	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	**€ 0**
11 PSS	€ 0	€ 12,500	€ 25,000	€ 50,000	€ 25,000	€ 12,500	**€ 125,000**
12 Contingency							**€ 1,493,825**
Total	**€ 327,400**	**€ 283,220**	**€ 4,786,998**	**€ 5,786,792**	**€ 2,028,631**	**€ 231,380**	**€ 14,938,246**
Labour included in above (Person-Years)	**3.0**	**2.3**	**8.8**	**9.1**	**4.2**	**1.8**	**29.1**

3.3. Upgrade/Staging plan

The option 2 is fulfilling high level requirement 1)-5). The upgrade staging plan is divided into different topics addressing different requirements:

TNPD: Two upgrades are foreseen of the diffraction detectors:

A) Upgrade to full backscattering capabilities, green detectors in Figure 3, cost 1.14 M€ + manpower, which is costed at 0.1 M€/m^2. The backscattering detectors add a detector coverage of approx. 1 m^2 and increases coverage to ~2 sr. The upgrade will significantly improve collection of high resolution and total scattering data allowing fulfilling the high level requirement 6).

B) Installation of detectors on left-hand side – orange in Figure 3. The detectors covers from 210-305° and covers an area of ~1 m^2 and increases speed for data collection in the high level requirements 1)-5).

SANS: The upgrade to SANS capabilities is also divided into different stage, where the first stage C) brings SANS capabilities with low angular coverage and at the second stage D), brings full q-coverage from small to wide angles. The position of the SANS detectors are shown in the Figure 4. The guide and chopper solution is assuming that the cold neutrons can be introduced into the thermal guide for most of the length of instrument.

C) This upgrade involves installation of choppers in the cold guide, installation of SANS tank and SANS detector, personal safety system etc, costs are estimated to:

Upgrade to SANS		
SANS Cave	0.26	M€
SANS Tank	0.80	M€
SANS Detector	0.50	M€
Cold chopper	0.31	M€
False floor	0.09	M€
PSS	0.05	M€
Manpower	0.26	M€
Contingency	0.25	M€
Total cost	2.52	M€

The SANS upgrade will provide the capabilities described in the high level requirements 7) and 8) however with a somewhat limited q-coverage compare with the original scope.

D) Installation of second detector to obtain full q coverage, Bandgem detector 1x0.5 m^2 0.5 M€, plus manpower estimated to 0.05 M€ as preparations for the detector will be made under configuration C) – (option D) is not a standalone option.)

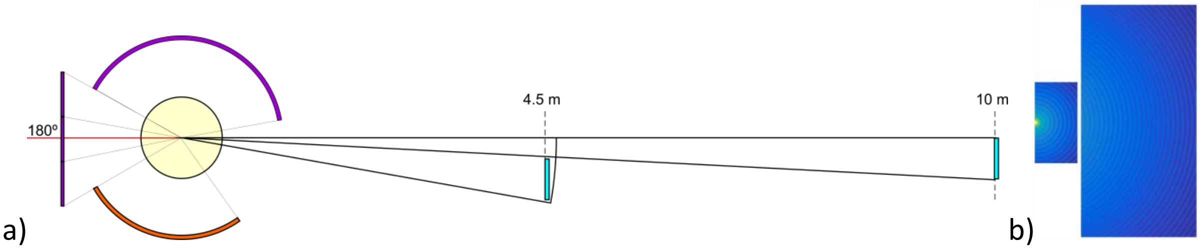


Figure 4: a) Detector view from above – the SANS detector are shown in cyan and are position 10 and 4.5 m from the sample to cover the angles between ~0° and 10°. b) Show a perspective drawing of the SANS detector arrangement seen from the sample.

The imaging capabilities for the most part needs an imaging detector if the instrument has been upgraded to the SANS capabilities C). However a standalone imaging upgrade could also be imagined, this would require installing the cold choppers 0.31 M€, and a detector e.g. Timepix from ASI 0.15 M€ - 28x28 mm^2. This detector could eventually be shared with ODIN for Bragg-Edge imaging experiments. If the SANS upgrade C) has already been installed, the cost would be limited to the detector and installation, which is estimated to 0.15 M€ + 0.01 M€ in manpower.

E) Installation of imaging capabilities without SANS – standalone imaging:

Upgradable for imaging		
Choppers	0.31	M€
Detector (Timepix)	0.15	M€
Manpower	0.05	M€
Contingency	0.06	M€
Total cost	0.57	M€

This upgrade would introduce capabilities covered by high level requirements 9)-11), without having the SANS installed, in other words an additional investment of 0.53 M€ would significantly broaden the scope of the instrument.

F) This upgrade is assuming the SANS option C) has been installed, this upgrade consists of detector and manpower i.e. 0.15 M€ + 0.01 M€ and would allow going to full instrument scope with multiple length scales covered from atomic to micrometer scale. All requirements 1)-11) are possible with the fully upgraded instrument.

3.4. Risk

The main risks for this configuration are delays in delivery of various ESS systems and HEIMDAL components, especially detectors and T0 choppers are high risk.

Below are top 5 risks rated high using ESS risk measures (impact x likelihood).

Table 4 : Top 5 risks for Option 2

Risk level	RISK	TREATMENT NAME	Treatment	CATEGORY	TREATMENT PLAN
High 5x5	Failure to deliver proposed scientific performance	Lower expectations	Mitigate	Budget, quality and function	Communicate with stakeholders the lowered performance expectations. Begin planning for upgrade and seek funding. Responsible: HEIMDAL Team, ESS management
High 4x3	Conventional facilities delay	***CF LEVEL ESS-0019533***	Observe	Schedule, budget, quality and function	Access to bunker is a milestone for HEIMDAL schedule. Responsible: CF
		External areas like labs and workshops	Mitigate		External areas will give the opportunity to start pre-installations Responsible: CF
High 4x3	T0 choppers are currently high risk, due to concurrent development.	Change of guide design	Mitigate	Schedule, budget, data quality	Delayed installation, higher cost and high background are to be expected. A kinked guide solution may solve the problem.
High 3x5	Proper design according to instrument requirements and delay in monolith insert design	Schedule for external milestone	Observe	Schedule, budget, Quality and function	Follow the progress of the design and project schedule. HEIMDAL Team Responsible: target
		TARGET LEVEL ESS-0019533	Observe		Focus on Safety, feasibility and requirements Responsible: target
High 3x4	Detector, failure in meeting requirements, failing to deliver.	Detectors: Action plan and schedule with mitigation plan	Mitigate	Schedule, budget, quality and function	Following the progress of other instruments, coordination with other instruments using CDT detectors, DREAM and MAGIC. Responsible: CDT, Detector Group

4. OPTION 3 : FULL SCOPE INSTRUMENT

4.1. Scope

The full instrument scope consists of the following items:

Diffraction setup:

- Straight double pinhole guide
- Thermal guide installed in light shutter
- All necessary associated infrastructure (shielding, cabling, cabins etc)
- Thermal choppers
  - Double counter rotating disk at ~6.5 m (Pulse shaping chopper)
  - Pulse selection chopper at 7.0 m
  - Two T0 choppers will suppress the prompt pulse, placed within the bunker
  - Pulse overlap chopper at 78 m
- Cylindrical detector in the range from 10-150°
- All backscattering detector from 150-190°
- Robotic sample changer and multiple low temperature sample changer.

Small angle setup:

- Cold guide insert in the monolith for extraction of cold beam.
- Cold guide feed back into the thermal guide at ~20 m.
- Cold guide installed in the light shutter (γ-shutter)
- SANS choppers
  - Pulse selection chopper 6.8 m
  - Pulse suppression chopper 14 m
- SANS cave
- SANS tank
- SANS detector (1 x 0.5 m^2)
- All necessary associated infrastructure (shielding, cabling, cabins etc)

Imaging setup:

- Imaging detector for Bragg-edge imaging

This scope meets all the high level requirements and fulfils the science case.

4.2. Costing

The costing is based on bottom-up calculation of the procurement costs and manpower required for the tasks needed to deliver the higher level requirements items.

Table 5 Costing for HEIMDAL Full Scope

	01 Phase 1	02 Project Management & Integration	03 Design	04 Procurement & Fabrication	05 Installation	06 Cold Commis-sioning	Total
01 Shielding	€ 0	€ 0	€ 604,470	€ 1,875,290	€ 421,018	€ 0	**€ 2,900,778**
02 Neutron Optics	€ 0	€ 0	€ 1,411,800	€ 850,000	€ 425,000	€ 0	**€ 2,686,800**
03 Choppers	€ 0	€ 0	€ 1,308,848	€ 189,184	€ 0	€ 4,608	**€ 1,502,640**
04 Sample Environment	€ 0	€ 0	€ 0	€ 306,912	€ 20,736	€ 6,912	**€ 334,560**
05 Detector and Beam Monitors	€ 0	€ 0	€ 633,520	€ 1,540,662	€ 982,171	€ 0	**€ 3,156,353**
06 Data Acquisition and Analysis	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	**€ 0**
07 Motion Control and Automation	€ 0	€ 0	€ 0	€ 548,432	€ 4,608	€ 0	**€ 553,040**
08 Instrument Specific Technical Equipment	€ 327,400	€ 270,720	€ 714,240	€ 737,280	€ 276,480	€ 207,360	**€ 2,533,480**
09 Instrument Infrastructure	€ 0	€ 0	€ 698,320	€ 1,849,840	€ 349,760	€ 0	**€ 2,897,920**
10 Vacuum	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	**€ 0**
11 PSS	€ 0	€ 12,500	€ 25,000	€ 100,000	€ 25,000	€ 12,500	**€ 175,000**
12 Contingency							**€ 1,860,063**
Total	**€ 327,400**	**€ 283,220**	**€ 5,396,198**	**€ 7,997,601**	**€ 2,504,772**	**€ 231,380**	**€ 18,600,635**
Labour included in above (Person-Years)	**3.0**	**2.3**	**9.8**	**9.9**	**5.0**	**1.8**	**31.8**

4.3. Upgrade/Staging plan

Even in the full scope configuration there are foreseen upgrades. The full scope setup does not include left-hand side detectors given in orange in Figure 5, nor does it include the second SANS detector at 4.5 m. Therefore there are two upgrade paths available for the full scope instrument:

A) Full diffraction detector coverage – adding a detector area of approx. 1 m^2 of detectors with a cost of 1.15 M€ plus manpower.

B) Adding second SANS detector at 4.5 m, this would imply a cost of 0.5 M€ + manpower.

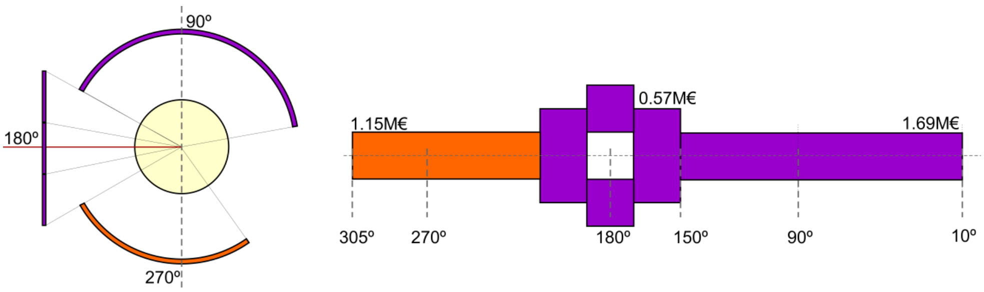


Figure 5: Diffraction detector coverage for the full scoped instrument (option 3). Upgrade is still foreseen of the left-hand side – orange detector area.

4.4. Risk

The main risks for this configuration are delays in delivery of various ESS systems and HEIMDAL components, especially detectors and T0 choppers are high risk.

Below are top 5 risks rated high using ESS risk measures (impact x likelihood).

Table 6 : Top 5 risks for Option 2

Risk level	RISK	TREATMENT NAME	Treatment	CATEGORY	TREATMENT PLAN
High 4x3	Conventional facilities delay	***CF LEVEL ESS-0019533***	Observe	Schedule, budget, quality and function	Access to bunker is a milestone for HEIMDAL schedule. Responsible: CF
		External areas like labs and workshops	Mitigate		External areas will give the opportunity to start pre-installations Responsible: CF
High 4x3	T0 choppers are currently high risk, due to concurrent development.	Change of guide design	Mitigate	Schedule, budget, data quality	Delayed installation, higher cost and high background are to be expected. A kinked guide solution may solve the problem.
High 3x5	Proper design according to instrument requirements and delay in monolith insert design	Schedule for external milestone	Observe	Schedule, budget, Quality and function	Follow the progress of the design and project schedule. HEIMDAL Team Responsible: target
		TARGET LEVEL ESS-0019533	Observe		Focus on Safety, feasibility and requirements Responsible: target
High 3x4	Detector, failure in meeting requirements, failing to deliver.	Detectors: Action plan and schedule with mitigation plan	Mitigate	Schedule, budget, quality and function	Following the progress of other instruments, coordination with other instruments using CDT detectors, DREAM and MAGIC. Responsible: CDT, Detector Group
High 3x3	Guide manufacturer fail to deliver, all instruments require significant amount of guides	Change of guide design	Mitigate	Schedule, budget, quality	Follow the manufacturer close and coordinate with other instruments.

SUMMARY

Table 7: Fulfilling science cases, costs, upgrade possibilities and upgrades costs

	Option 1	Option 2	Option 3
Science cases fulfilled	1-2	1-5	1-11
Costs (M€)	**12.1**	**14.94**	**18.60**
Science cases added with upgrade	blocked	7,8 (SANS) 9-11 (NI)	
Upgrade costs (M€)	blocked	(TNPD) (2.50 M€) (SANS) 2.52 M€ (NI) 0.16 M€	0 (All included)
Full costs (M€)	---	**20.12**	**18.60**

5. REFERENCES