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Instrument Construction Work Unit Document

Instrument LoKI

WU Choppers

Neutron Chopper Group

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DOCUMENT REVISION HISTORY

Revision	Reason for revision	Date
1.2	Adopted for baseline, for release	2014-12-08
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SUMMARY

This Instrument Construction Work Unit Document summarizes the Work Unit that a the chopper group will deliver to the construction of an Instrument Project. This will include all of the relevant project information available at the moment. The deliverable numbers refer to the elements described in the Product Breakdown Structure of the Instrument Project.

More information is available in the documents listed in section 9

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LIST OF ABBREVIATIONS

Abbreviation	Definition
ESS	European Spallation Source
STC	Steering Committee
SAC	Scientific Advisory Committee
TAC	Technical Advisory Committee
NSS	Neutron Scattering Systems
PCG	Project Coordination Group
DMSC	Data Management & Software Centre Copenhagen
R&D	Research and Development
HVAC	Heating, Ventilation, Air Conditioning

1. DELIVERABLES LIST

13.6.1.3 Chopper System

13.6.1.3.1 Pit assembly 1

13.6.1.3.2 Pit assembly 2

13.6.1.3.3 Pit assembly 3

13.6.1.3.4 Control System

13.6.1.3.5 Support System

1.1 Assumptions

In accordance with the 'NSS strategy for chopper delivery, the following assumptions are being made in this document:

Within the boundaries established within the project;

- The ESS chopper group has responsibility over the design choices and schedule for the delivery of the Loki chopper system
- The ESS chopper group has authority over the selection of partners for the delivery.
- The manpower estimations are based on previous experience of work being carried out in-house. Subject to the way the way the work is divided to In-kind partners, additional resources may be required and costs incurred.

All figures are indicated without contingency, and do not take inflation, overheads and administration expenses into account. It should be considered to have an error bar of ±25%.

2. DELIVERABLE: 13.6.1.3 CHOPPER SYSTEM

2.1 Deliverable General Description

Refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

2.2 Option Description

This deliverable is the overall integration, management, installation and commissioning of all the other deliverables.

2.3 WBS element values

2.3.1 Section 02 Project Management, Integrated Design and System Integration

Labour cost	66.6	k€
Duration	85	Months

Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

2.3.2 Section 03 Design Activities

Labour cost	16,8	k€
Duration	5	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

2.3.3 Section 04 Procurement, Fabrication and Validation Activities

Labour cost	0	k€
Duration	0	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

2.3.4 Section 05 Construction and Installation Activities

Labour cost	74,88	k€
Duration	14	Months
Non-Labour cost	23	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

2.3.5 Section 06 Cold Commissioning Activities

Labour cost	18,72	k€
Duration	7	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

2.4 Deliverable (Product) Scope

Refer to the “Scope Document – Loki – Chopper group document” for the scope of supply and work for this deliverable.

2.5 Deliverable Schedule

2.5.1 Schedule

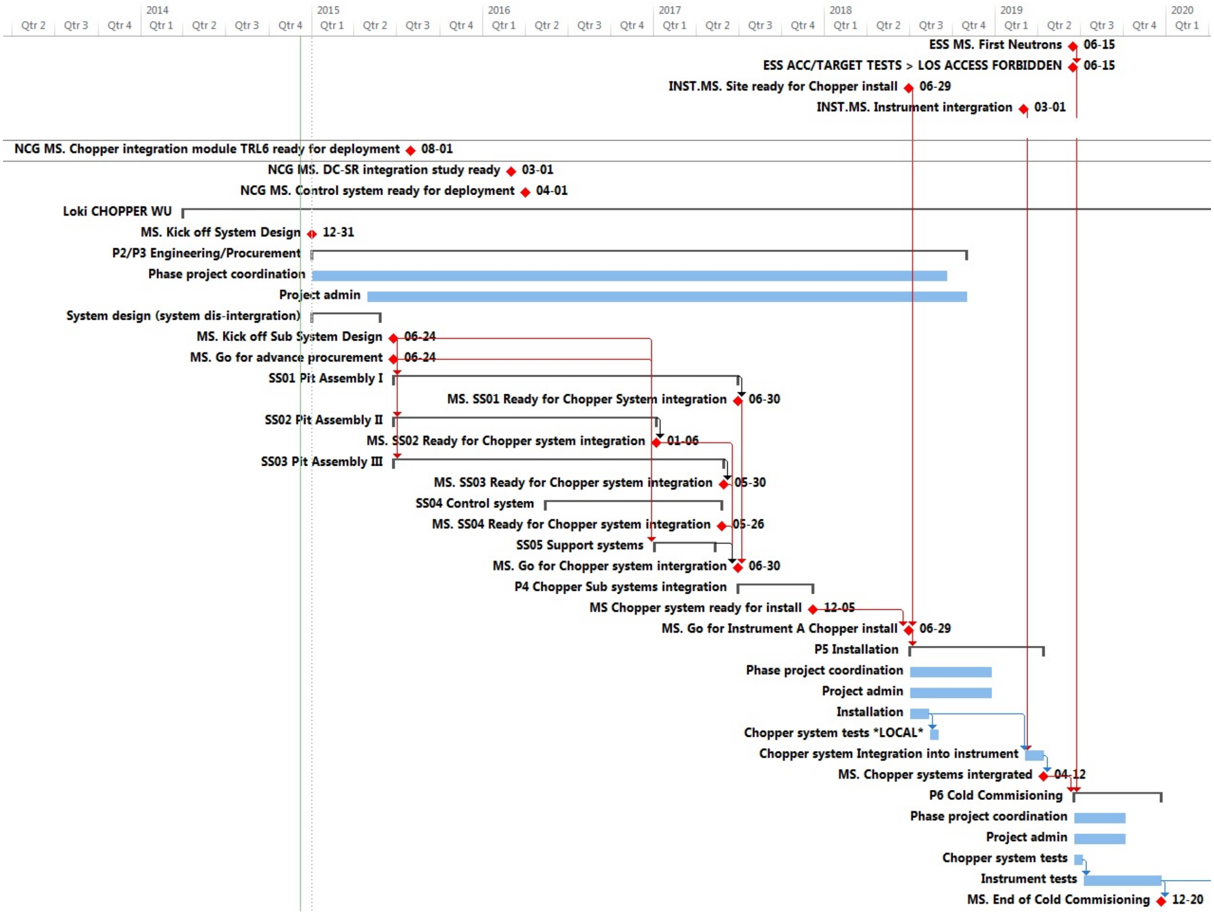

Figure 1 - Overall schedule

2.5.2 Milestone Connections

All major milestone connections are available in the figure above.

2.6 Work unit Risks

Refer to the “Loki_risklog” document for a full risk log of the work unit.

3. DELIVERABLE: 13.6.1.3.1 PIT ASSEMBLY 1

3.1 Deliverable General Description

Refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

3.2 Option Description

Refer to the "Conceptual design report NCG Loki" document for the description of this deliverable.

3.3 WBS element values

3.3.1 Section 02 Project Management, Integrated Design and System Integration

Labour cost	9.1	k€
Duration	21	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

3.3.2 Section 03 Design Activities

Labour cost	29.9	k€
Duration	9	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

3.3.3 Section 04 Procurement, Fabrication and Validation Activities

Labour cost	8,4	k€
Duration	23	Months
Non-Labour cost	165	k€
Number of Major Procurements	Spindles and drives – 120k€	
High Level Milestones	See schedule	

3.3.4 Section 05 Construction and Installation Activities

Labour cost	20,4	k€

Duration	9	Months
Non-Labour cost	5	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

3.3.5 Section 06 Cold Commissioning Activities

Labour cost	0	k€
Duration	0	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	None	

3.4 Deliverable (Product) Scope

Please refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

3.5 Deliverable Schedule

3.5.1 Schedule

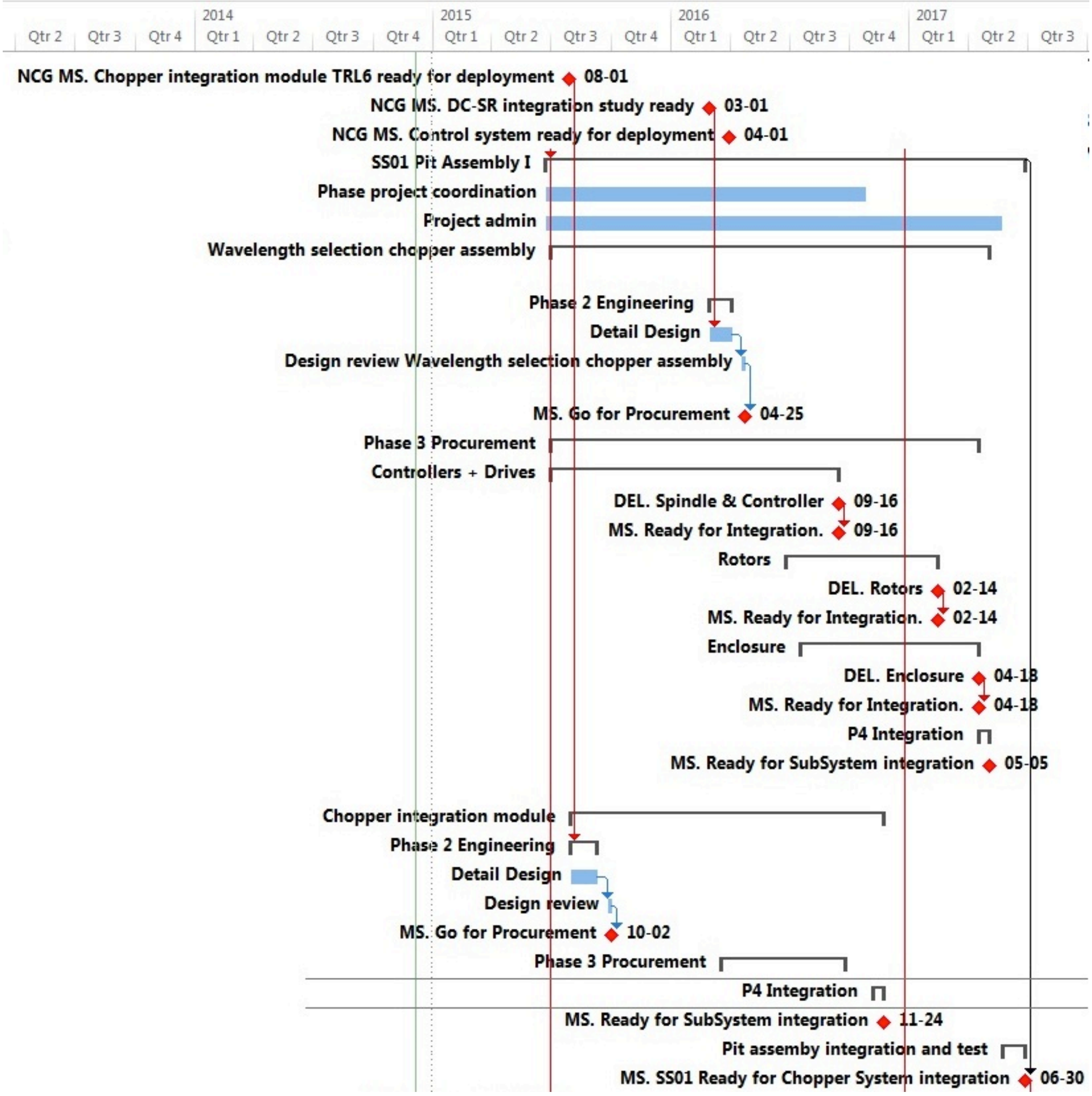

Figure 2 - Pit assembly 1 schedule

3.5.2 Milestone Connections

All major milestone connections are available in the figure above.

3.6 Work unit Risks

Refer to the "Loki_risklog" document for a full risk log of the work unit.

4. DELIVERABLE: 13.6.1.3.2 PIT ASSEMBLY 2

4.1 Deliverable General Description

Refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

4.2 Option Description

Refer to the "Conceptual design report NCG Loki" document for the description of this deliverable.

4.3 WBS element values

4.3.1 Section 02 Project Management, Integrated Design and System Integration

Labour cost	8.6	k€
Duration	16	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

4.3.2 Section 03 Design Activities

Labour cost	5.4	k€
Duration	1	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

4.3.3 Section 04 Procurement, Fabrication and Validation Activities

Labour cost	1.5	k€
Duration	7	Months
Non-Labour cost	44	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

4.3.4 Section 05 Construction and Installation Activities

Labour cost	7.7	k€

Duration	2	Months
Non-Labour cost	5	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

4.3.5 Section 06 Cold Commissioning Activities

Labour cost	0	k€
Duration	0	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	None	

4.4 Deliverable (Product) Scope

Please refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

4.5 Deliverable Schedule

4.5.1 Schedule

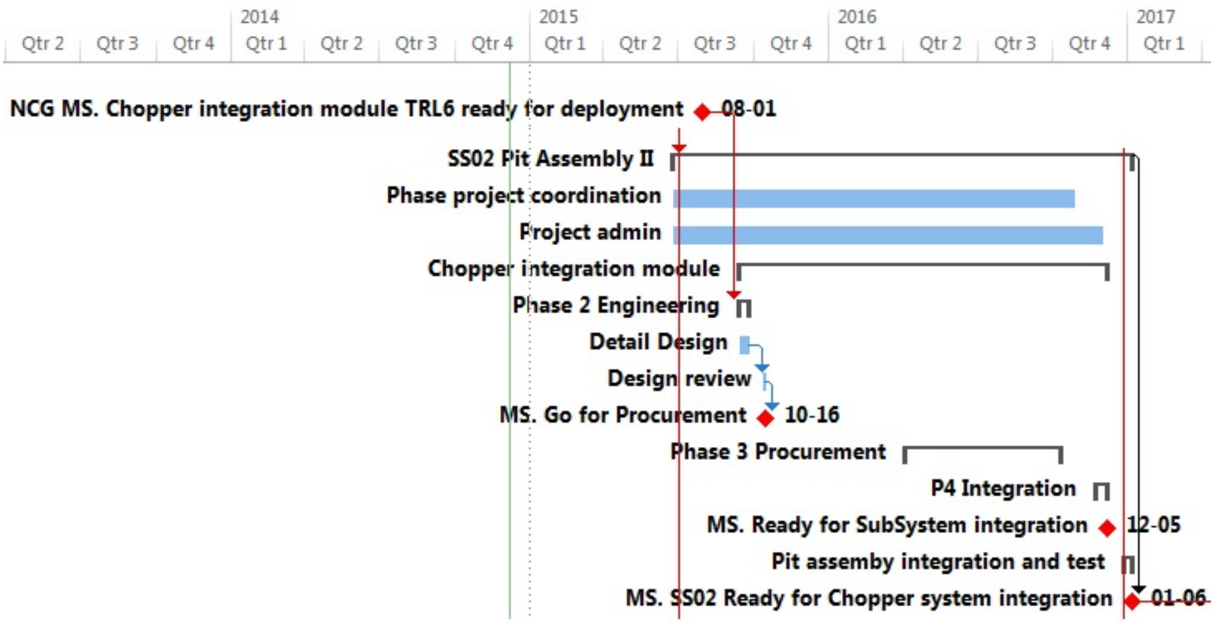

Figure 3 - Pit assembly 2 schedule

4.5.2 Milestone Connections

All major milestone connections are available in the figure above.

4.6 Work unit Risks

Refer to the "Loki_risklog" document for a full risk log of the work unit.

5. DELIVERABLE: 13.6.1.3.3 PIT ASSEMBLY 3

5.1 Deliverable General Description

Refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

5.2 Option Description

Refer to the "Conceptual design report NCG Loki" document for the description of this deliverable.

5.3 WBS element values

5.3.1 Section 02 Project Management, Integrated Design and System Integration

Labour cost	9.1	k€
Duration	25	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

5.3.2 Section 03 Design Activities

Labour cost	13.6	k€
Duration	6	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

5.3.3 Section 04 Procurement, Fabrication and Validation Activities

Labour cost	8.5	k€
Duration	23	Months

Non-Labour cost	165	k€
Number of Major Procurements	Spindles and drives – 120k€	
High Level Milestones	See schedule	

5.3.4 Section 05 Construction and Installation Activities

Labour cost	16.3	k€
Duration	6	Months
Non-Labour cost	5	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

5.3.5 Section 06 Cold Commissioning Activities

Labour cost	0	k€
Duration	0	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	None	

5.4 Deliverable (Product) Scope

Please refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

5.5 Deliverable Schedule

5.5.1 Schedule

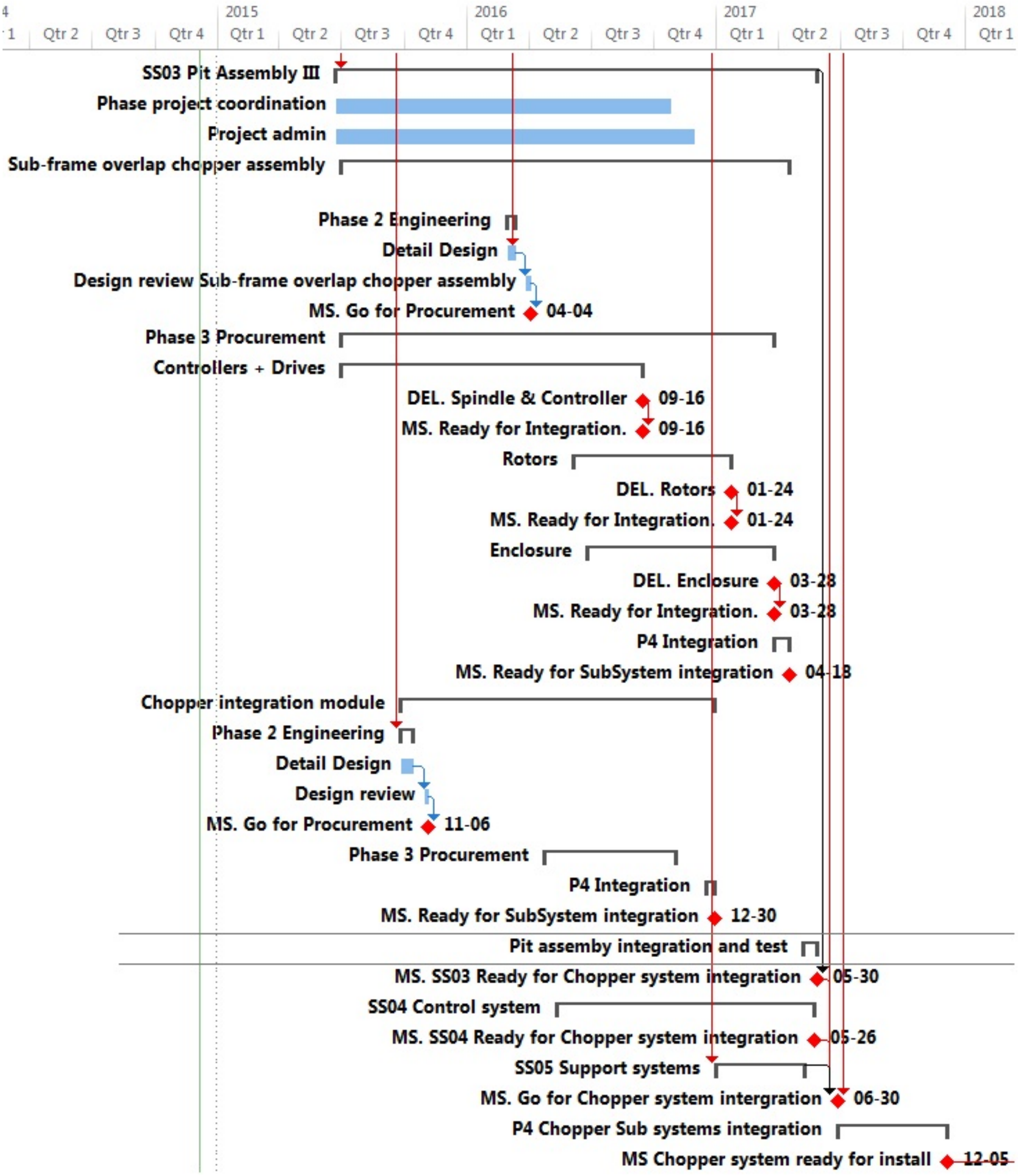

Figure 4 - Pit assembly 3 schedule

5.5.2 Milestone Connections

All major milestone connections are available in the figure above.

5.6 Work unit Risks

Refer to the "Loki_risklog" document for a full risk log of the work unit.

6. DELIVERABLE: 13.6.1.3.4 CONTROL SYSTEMS

6.1 Deliverable General Description

Refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

6.2 Option Description

Refer to the "Conceptual design report NCG Loki" document for the description of this deliverable.

6.3 WBS element values

6.3.1 Section 02 Project Management, Integrated Design and System Integration

Labour cost	10.6	k€
Duration	14	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

6.3.2 Section 03 Design Activities

Labour cost	7,2	k€
Duration	1	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

6.3.3 Section 04 Procurement, Fabrication and Validation Activities

Labour cost	4,2	k€
Duration	10	Months
Non-Labour cost	77	k€
Number of Major Procurements	Rack, cables, monitoring – 53k€	

	CHIC, epix, instr control – 60k€	
High Level Milestones	See schedule	

6.3.4 Section 05 Construction and Installation Activities

Labour cost	14,4	k€
Duration	2	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

6.3.5 Section 06 Cold Commissioning Activities

Labour cost	0	k€
Duration	0	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	None	

6.4 Deliverable (Product) Scope

Please refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

6.5 Deliverable Schedule

6.5.1 Schedule

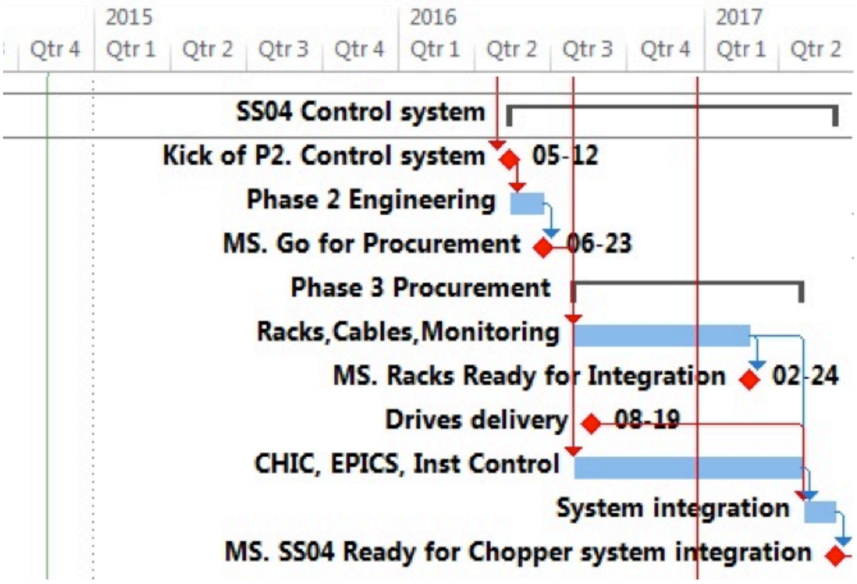

Figure 5 – Control system schedule

6.5.2 Milestone Connections

All major milestone connections are available in the figure above.

6.6 Work unit Risks

Refer to the "Loki_risklog" document for a full risk log of the work unit.

7. DELIVERABLE: 13.6.1.3.5 SUPPORT SYSTEMS

7.1 Deliverable General Description

Refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

7.2 Option Description

Refer to the "Conceptual design report NCG Loki" document for the description of this deliverable.

7.3 WBS element values

7.3.1 Section 02 Project Management, Integrated Design and System Integration

Labour cost	4	k€

Duration	0	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

7.3.2 Section 03 Design Activities

Labour cost	0	k€
Duration	0	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

7.3.3 Section 04 Procurement, Fabrication and Validation Activities

Labour cost	8,6	k€
Duration	5	Months
Non-Labour cost	30	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

7.3.4 Section 05 Construction and Installation Activities

Labour cost	0	k€
Duration	0	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	
High Level Milestones	See schedule	

7.3.5 Section 06 Cold Commissioning Activities

Labour cost	0	k€
Duration	0	Months
Non-Labour cost	0	k€
Number of Major Procurements	None	

High Level Milestones None

7.4 Deliverable (Product) Scope

Please refer to the "Scope Document – Loki – Chopper group document" for the scope of supply and work for this deliverable.

7.5 Deliverable Schedule

7.5.1 Schedule

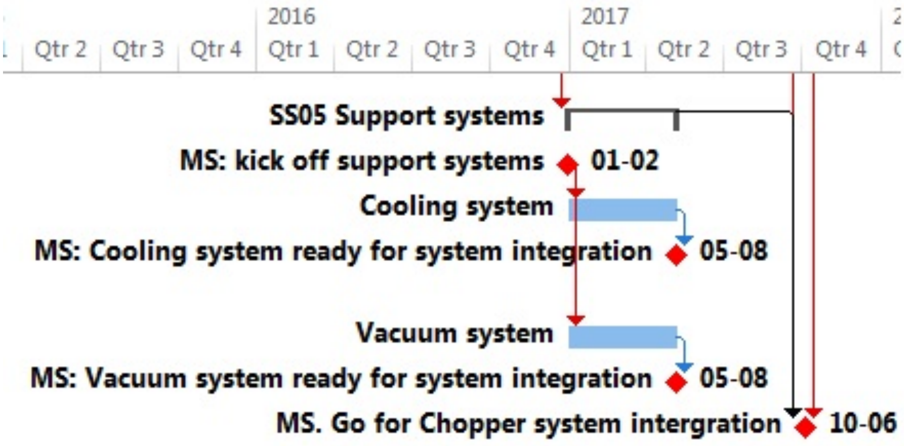

Figure 6 – Support system schedule

7.5.2 Milestone Connections

All major milestone connections are available in the figure above.

7.6 Work unit Risks

Refer to the "Loki_risklog" document for a full risk log of the work unit.

8. OTHER MATTERS

None applicable

9. REFERENCES

List of Chopper system Loki documentation to be considered part of this documentation:

- "Functional requirements Loki – Chopper group"
- "Non functional requirements Loki – Chopper group"
- "Scope Loki – Chopper group"
- "NCG to Loki ICD"
- "Conceptual design report NCG Loki"
- "In-kind plan Loki – Chopper group"
- "Instrument work unit spreadsheet"

- “Loki chopper system layout”
- “Loki PBS release”
- “Loki schedule_release”
- “Loki risklog”

EUROPEAN SPALLATION SOURCE

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Conceptual design report
Neutron chopper system
Loki

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TABLE OF CONTENT

1. INTRODUCTION

1.1 Purpose of the document

This documents describes the various concepts generated for the preliminary design of the Loki instrument chopper system the ESS. It descries three different variant and their pros and cons. Finally it describes the preferred solution, as recommended by the ESS chopper group, together with an estimated costing and PBS.

1.2 Requirements and other design constraints

Full functional requirements and non-functional requirements for the Loki chopper system can be found in their respective documents. Bellow is some additional requirements, not directly related to the performance of the chopper system, especially important for the design choices made in this document.

1.2.1 Common vacuum

The Loki instrument requires a common vacuum, that means there can be no neutron windows, separating the chopper units to the guides. This is due to the expected losses in the beam extraction together with the Hi-flux demands of a SANS instrument.

1.2.2 Declining guide

The Loki instrument is using a declining guide system to move the instrument out of direct line of sight. This has implications on the chopper system. Through the chopper pits the guide is declining around four (4) degrees. No bends are to be integrated into the chopper pit assemblies.

1.3 Chopper system layout

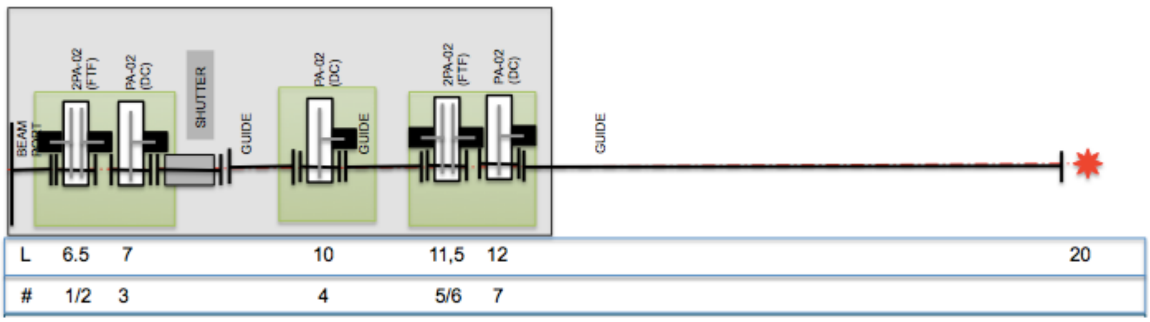

Figure 1 - Loki chopper system initial schematic

The Loki chopper system comprises of seven chopper axis. Axis are grouped intro five assemblies in three separate chopper pit assemblies. All chopper pit assemblies are within the common bunker shielding.

1.3.1 Pit assembly 1

Pit assembly 1 consists of three chopper axes, the Wavelength selection double disc chopper assembly and the resolution enhancement chopper assembly 1. They are positioned at 6.5 and 7 meters from the moderator.

All components related to the chopper assembly, the chopper pit, the connection to the chopper pit head box and the chopper pit box is part of the pit assembly 1.

1.3.2 Pit assembly 2

Pit assembly 2 consists of a single chopper axis, the resolution enhancement chopper assembly 2. It is placed at 9 meters distance from the moderator.

All components related to the chopper assembly, the chopper pit and the connection to the chopper pit head box, and the chopper pit box is part of the pit assembly 2.

1.3.3 Pit assembly 3

Pit assembly 3 consists of three chopper axes, the sub-frame overlap double disc chopper assembly and the resolution enhancement chopper assembly 3. They are positioned at 11,5 and 12 meters from the moderator.

All components related to the chopper assembly, the chopper pit, the connection to the chopper pit head box and the chopper pit box is part of the pit assembly 3.

1.3.4 Control system

The local chopper control system consists of three chopper standard control racks, each containing the chopper drives, the power electronics, the ICS interface and the CHIC. Cabling from the pit head box to the chopper racks are part of the control system. The actual routing of those cables is part of the instrument scope of work. Final placements in the instrument hall of the chopper racks are not part of the conceptual design report, and will have to be decided during detail design.

1.3.5 Support system

All non-pit equipment not part of the control system is part of the support system. Loki has a common vacuum system, with the intention for connections through the choppers. The interface to the vacuum is at the pit head box, and is handled extensively in the NCG-Vacuum ICD.

2. CONCEPT GENERATION

Three different overall system concepts where generated. One was designed for easy maintenance access, one for fewest neutron windows and one to be as compact as possible.

2.1 Module variant

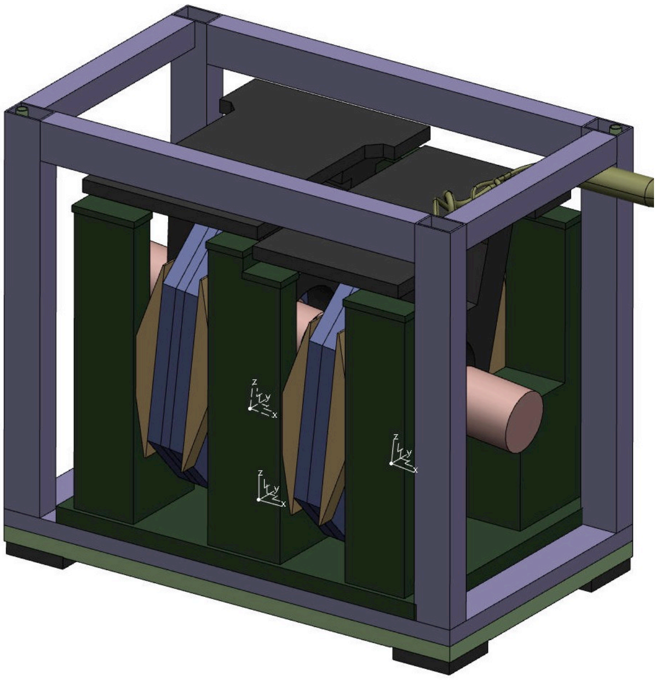

Figure 2 - Module variant, ISO view

This concept is based on the previous standard ESS chopper module. It has a face-to-face chopper assembly followed by a single disc chopper assembly.

All of the chopper assemblies are mounted inside a cradle. This cradle is removed in its entirety, leaving only the light green base plate shown in the figure above. Sections of guide are mounted inside the module and will be removed together with the chopper module.

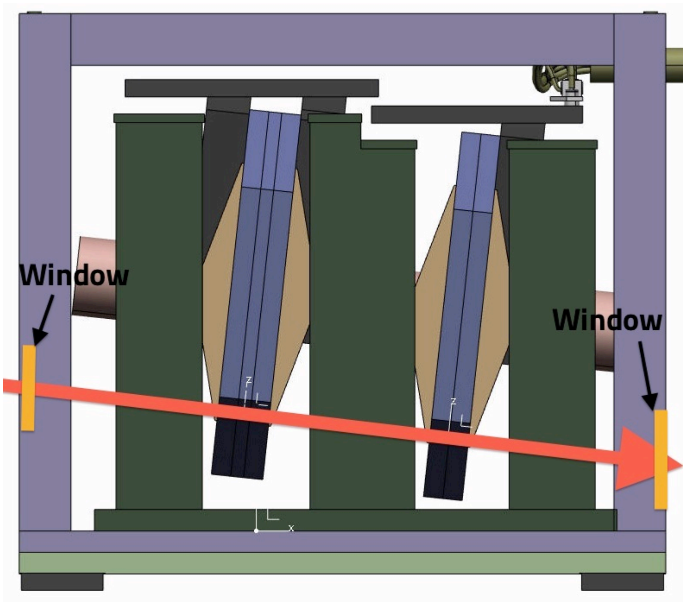

Figure 3 - Module variant, side view

The main advantage of this variant is ease of maintenance. It also allows for easy pre-alignment

The variant does not permit a windowless solution.

2.2 Horizontal cut variant

The horizontal cut variant is based on the requirement for a common vacuum. The chopper enclosure is split horizontally between the guide opening and the rest of the chopper. When you extract the chopper units the bottom support, containing all optics components, will be left in the pit. The bottom frame is acting as both the chopper support and the lower vacuum enclosure. Making the split flange design accessible remotely is an engineering challenge and risk, with potentially intervening structures and components.

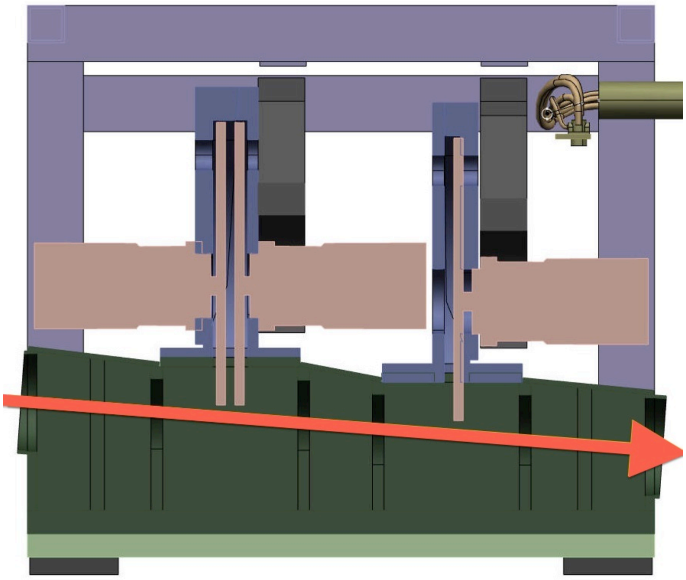

Figure 4- Horizontal cut variant, section view

There is no need for windows with this chopper installation, unless later safety analyses require them for target monolith integrity reasons. Gate valves are required if smaller sections are to be pressurised during maintenance.

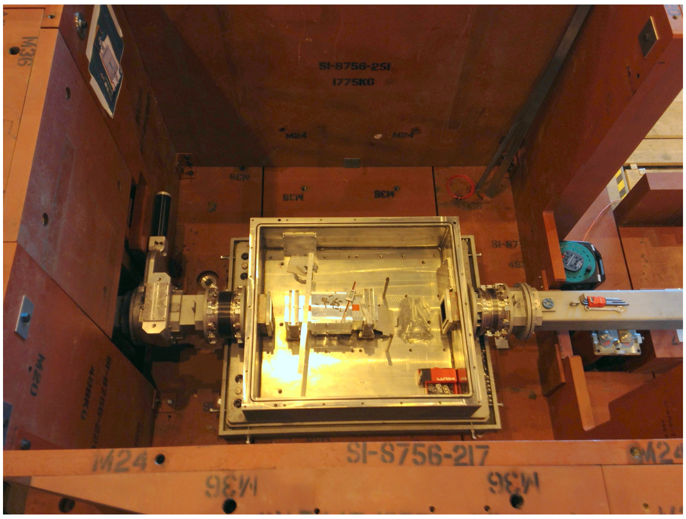

Figure 5 - IMAT chopper pit, TS2, ISIS

A lifting frame and alignment system ensures the chopper equipment can be reinstalled safely and maintaining alignment after maintenance.

The advantages of this concept include the possibility for a common vacuum, easy access to the guide components and possibility for a modular design, fitting all pits.

The disadvantages are the potentially difficult design making the split remote access friendly and the need to evacuate a large volume for chopper extraction.

2.3 Compact variant

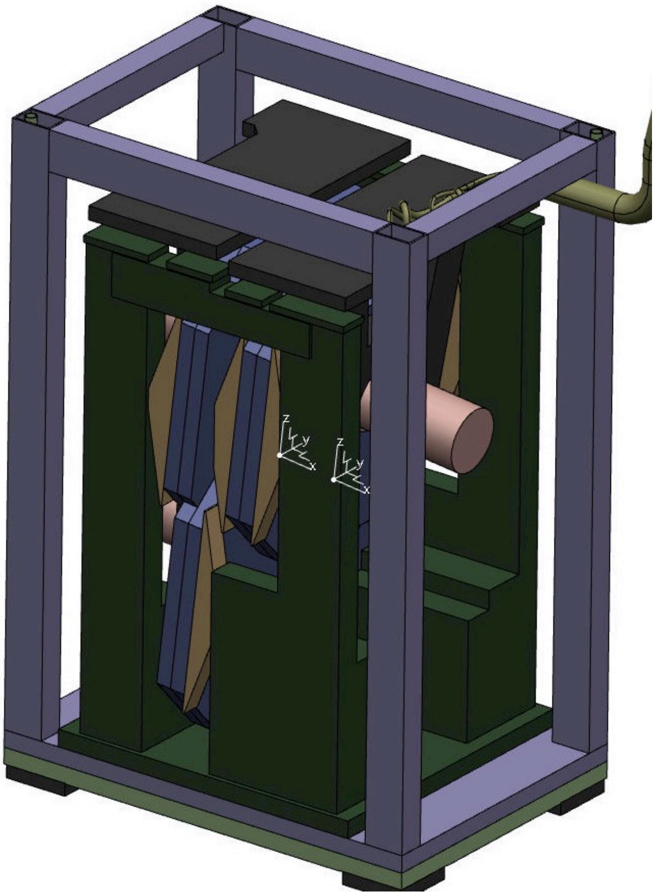

Figure 6 - Compact variant, ISO view

The compact variant is based on an over/under chopper followed by a single disc chopper. This reduced the total length of the installation from 1.5meters to about 1m. To be able to install and vertically extract this installation, windows are needed. The relative complexity of the over/under design increases cost.

Sections of guide are mounted inside the module and will be extruded together with the chopper module. The guide installation is also more challenging due to the need of larger support structures and the higher level of integration.

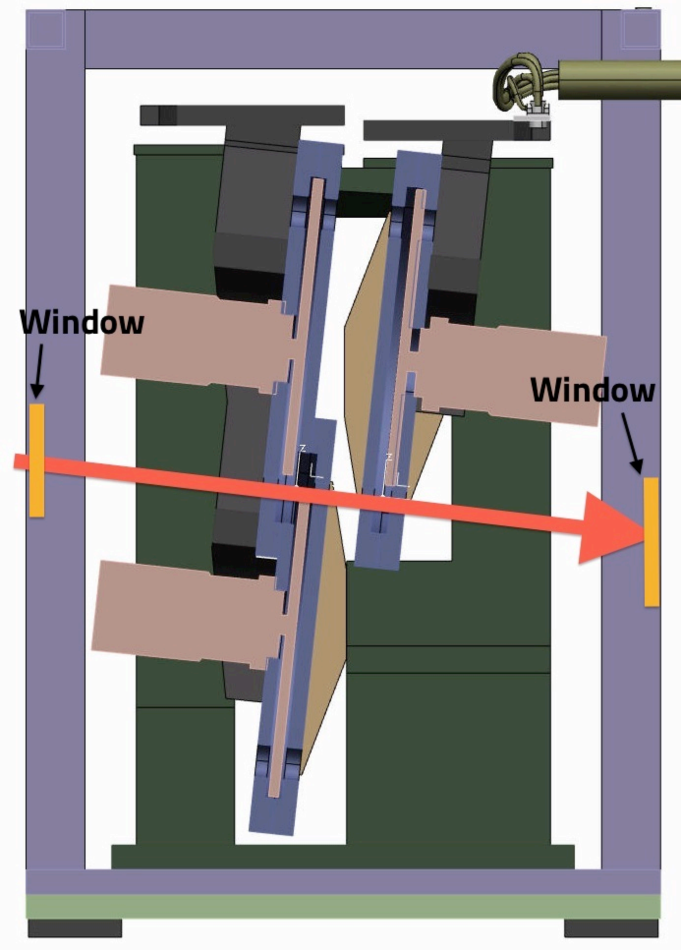

Figure 7 - Compact variant, section view

3. CHOSEN SOLUTION

The described solution bellow meets the requirements for all three chopper pit assemblies, with minor modifications, and is therefor presented as one. Modifications to the solution will be done to incorporate the different set ups in the different assemblies.

3.1 Evaluation

Based on the need for a common vacuum with no windows, the only solution that met the requirements where the horizontal split variant. The module variant is the alternative solution possible. The least favourable solution is the compact variant, due to the complex support paths and the more expensive solutions needed.

The horizontal cut variant is the preferred solution. Bellow is a more detailed study of its main components.

3.2 Chopper assembly design

The chopper assembly consist of one or two chopper axis, enclosure, support structure and harness. All components will meet the design guidelines in the ESS chopper handbook. The key components are described bellow.

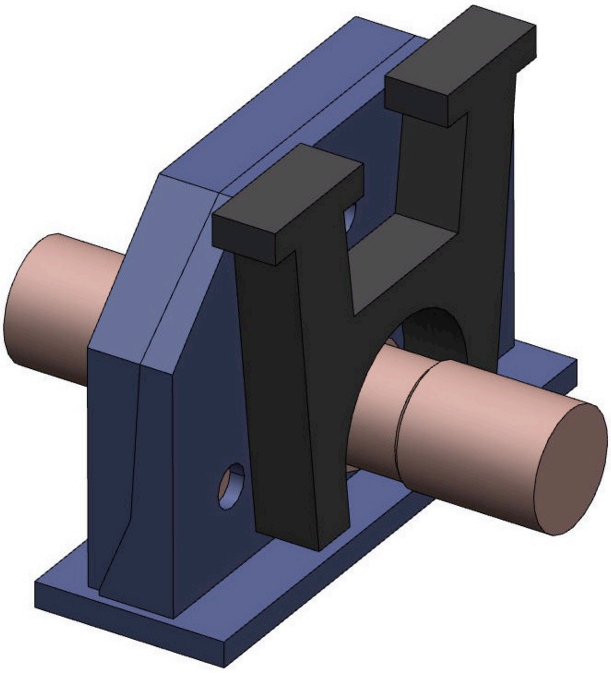

Figure 8 - Conceptual chopper assembly design

3.2.1 Chopper axis

3.2.1.1 Rotor design

The Loki rotors will be based on the standard ESS low speed aluminium rotor. It is a sturdy reliable rotor design with B4C-epoxy attenuators. Total weight of a single rotor is about 15kg.

All Loki rotors will be able to implement the same rotor design. The attenuator is preliminary calculated to be the equivalent of 2.43mm of B4C.

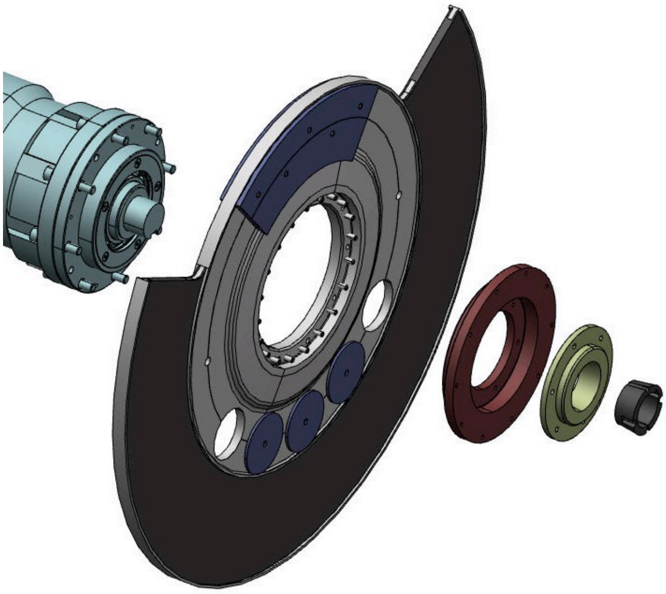

Figure 9 - Current rotor concept

During detailed design, full engineering simulations and tests will be performed on the chosen rotor design.

3.2.1.2 Spindle unit

Due to the low maintenance requirements of the areas where the Loki choppers will be installed, a magnetic bearing drive system is required. It shall be able to handle the relatively low speeds the choppers are running at, but still meeting the required values for accuracy.

3.2.2 Enclosure

The enclosure is built up of two main halves, with a diagonal split. The diagonal split allows the two units (in case of a face-to-face chopper assembly) to be disassembled separately. The housing and all main components are built out of aluminium. Detail design will dimension the thickness of the enclosure to withstand the impact of a raptured disc.

Spare ports for post-installation extra diagnostics are available on the enclosure.

Simple and reliable vacuum seals are ensured by keeping the mating surfaces as simple as possible and by having the O-ring joint in the extracted part.

3.2.3 Support structure

The chopper unit is placed directly on to the chopper pit support through a flanged plate. The support structure is highly integrated into the enclosure design.

A secondary support connects the enclosure to the cradle. This is not loadbearing during operation, and only intended to support the structure during extraction and installation. The current secondary support design is conceptual.

3.2.4 Chopper unit harness

The chopper unit harness consists of all cables, pining and sensors that goes from the chopper unit, or its spindle, to the chopper connection plate. The connection plate is the interface component between the part of the pit system called the umbilical and the chopper assembly.

3.3 Pit system design

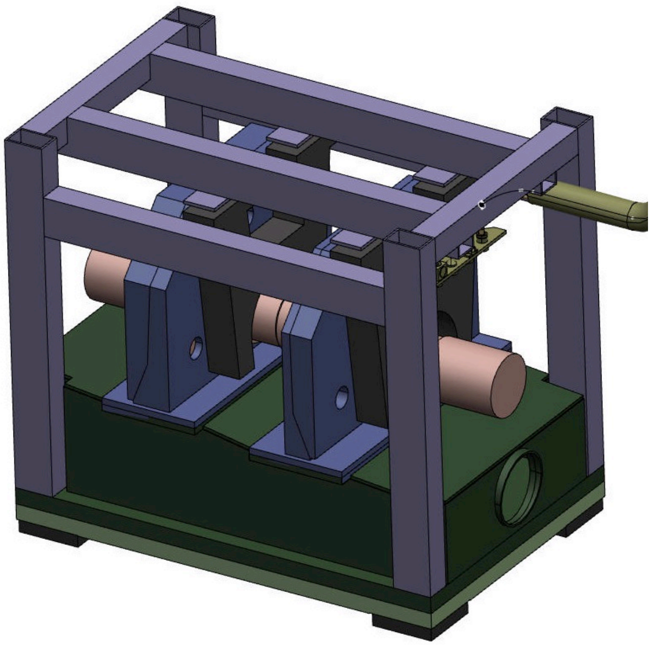

Figure 10 - Conceptual pit module design

The horizontal cut approach dictates some pit system solutions. All components will meet the design guidelines in the ESS chopper handbook. The lower part of the chopper enclosure is also used as the support for the chopper units, the base for some guide installation and the part vacuum seal. The multipurpose use of this components means it needs to be sturdy and rigid. The detailed design and thickness of this component will be decided during detailed design.

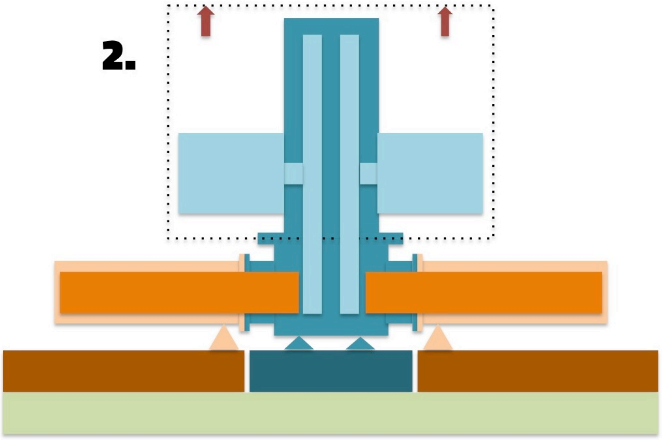

Figure 11 - Installation variant chosen

The choppers will be installed on a chopper base plate. This plate is levelled and grouted to the CF base plate. The chopper assembly will be aligned and then fixed with pins, on both the base plate and between the chopper assembly and the pit system. This results in a good alignment precision and repeatability without loosing flexibility during installation.

3.3.1 Extraction method

The chopper equipment installed within the common shielding bunker is designed for vertical extraction. The bottom section of the enclosure/support stays in the pit, together with the guide components, while the top assemblies are being lifted up.

The chopper assemblies will be fitted to a lifting frame, which is compatible with extraction tooling and methods. The lifting frame ensures the guidance during removal operations and reduces the risk of accidental collisions.

3.3.2 Beam monitors

After each chopper assembly there shall be a provision for the installation a beam monitor. Beam monitors are not part of the chopper work unit. They will be used during commissioning and operation of the instrument. In the pit system design, there is room for implementation of beam monitors. The cabling for the beam monitors can be done through the chopper umbilical.

3.4 Control system approach

Individual chopper axis from suppliers will be integrated through the chopper integration control (CHIC). The CHIC will interface with the ESS integrated control system and receive control commands from DMSC instrument control software.

The Loki chopper control system will be compatible with the ESS integrated control system. This includes one CHIC system for each rack and individual drives for each axis. All components will meet the design guidelines in the ESS chopper handbook.

Three racks are expected, one for each pit assembly. Every rack will have power distribution, low voltage distribution, fuses, CHIC, EPICS IOC and one or more chopper drives, see figure

12. Currently, it is not decided whether the UPS will be located in- or outside the control rack.

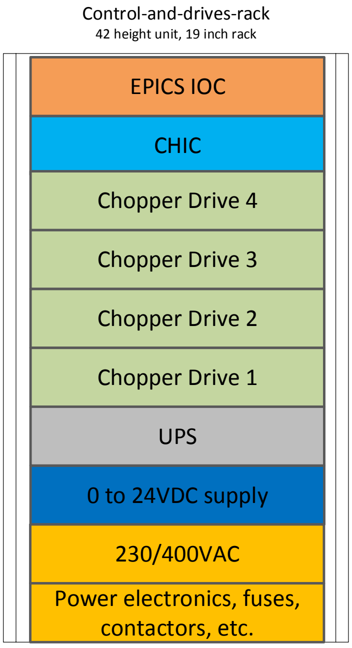

Figure 12 - Standard 19" chopper control rack

Every control rack is a standalone unit with no hardware communication connection between the different Chopper drives. A control rack fits into the ICS as shown in figure 13.

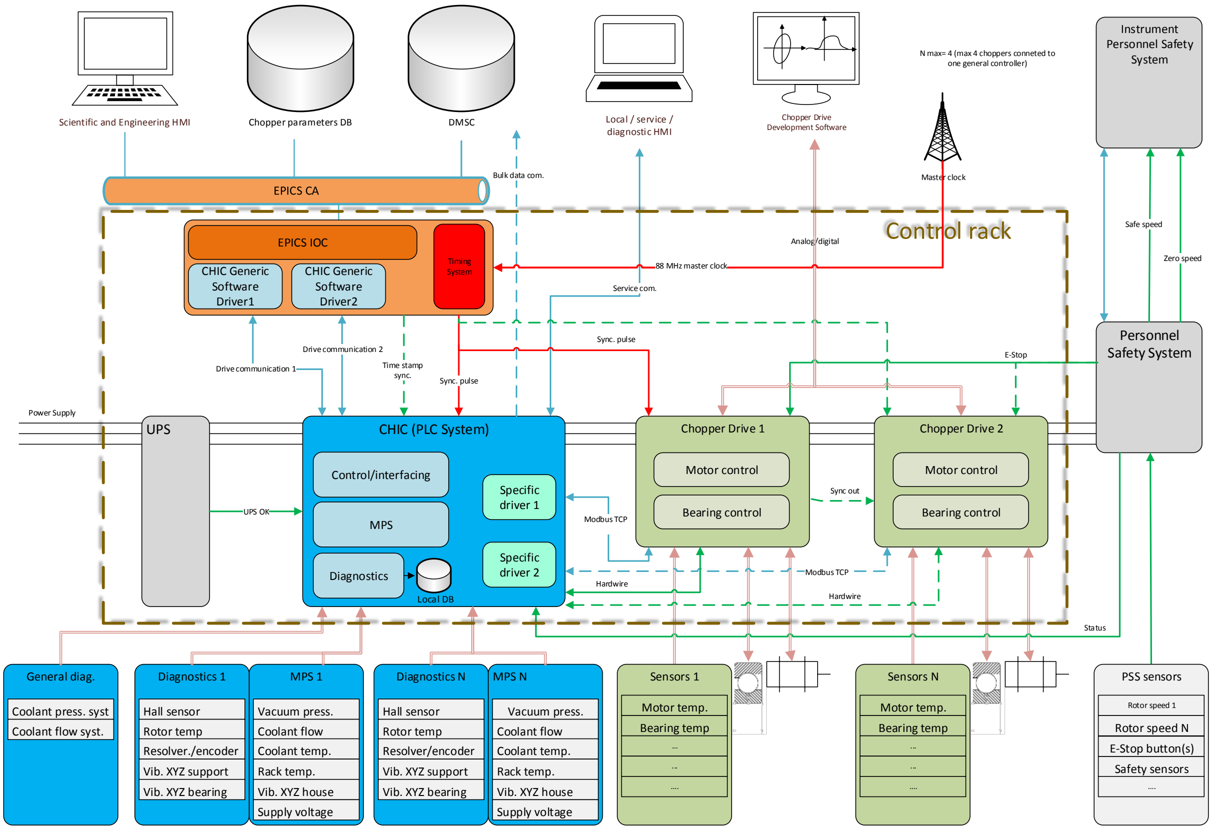

Figure 13 – System layout of a single chopper control rack and the connections to it

3.5 Support systems

The Loki instrument uses a common vacuum system. The guide system will be evacuated through the one of the choppers per pit and routed through the umbilical. Standard chopper-vacuum ICD will be implemented. The system is designed for 10^-3 mbar.

Currently no need for cooling is foreseen. If the need for a cooling circuit is realised during detailed design, this will follow the chopper-cooling ICD and be routed through the umbilical.

4. PBS AND COSTING

4.1 PBS

The Loki chopper system PBS can be seen bellow. It is a preliminary PBS and will be changed and sufficiently detailed during detailed design and the progress of the generic systems development at the ESS.

Name	Instrument	Sub system	Sub Sub system	Sub assembly	Component	Detail
Loki chopper system	**13.6.3.1.3**	**0**	**0**	**0**	**0**	**0**
Pit Assembly 1	13.6.3.1.3	1	0	0	0	0
Wavelength selection chopper assembly	13.6.3.1.3	1	1	0	0	0
Chopper axis 1	13.6.3.1.3	1	1	1	0	0
Spindle	13.6.3.1.3	1	1	1	1	0
Rotor	13.6.3.1.3	1	1	1	2	0
Disc	13.6.3.1.3	1	1	1	2	1

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Coating	13.6.3.1.3	1	1	1	2	2
Coupling	13.6.3.1.3	1	1	1	3	0
Chopper axis 2	13.6.3.1.3	1	1	2	0	0
Spindle	13.6.3.1.3	1	1	2	1	0
Rotor	13.6.3.1.3	1	1	2	2	0
Disc	13.6.3.1.3	1	1	2	2	1
Coating	13.6.3.1.3	1	1	2	2	2
Coupling	13.6.3.1.3	1	1	2	3	0
Chopper enclosure	13.6.3.1.3	1	1	3	0	0
Front Enclosure	13.6.3.1.3	1	1	3	1	0
Back enclosure	13.6.3.1.3	1	1	3	2	0
Chopper support	13.6.3.1.3	1	1	4	0	0
Chopper support base plate	13.6.3.1.3	1	1	4	1	0
Chopper unit harness axis 1	13.6.3.1.3	1	1	5	0	0
Connection plate male	13.6.3.1.3	1	1	5	1	0
Motor cable	13.6.3.1.3	1	1	5	2	0
Machine cable	13.6.3.1.3	1	1	5	3	0
Vacuum assembly	13.6.3.1.3	1	1	5	4	0
Sensor harness	13.6.3.1.3	1	1	5	5	0
Chopper unit harness axis 2	13.6.3.1.3	1	1	6	0	0
Connection plate male	13.6.3.1.3	1	1	6	1	0
Motor cable	13.6.3.1.3	1	1	6	2	0
Machine cable	13.6.3.1.3	1	1	6	3	0
Vacuum assembly	13.6.3.1.3	1	1	6	4	0
Sensor harness	13.6.3.1.3	1	1	6	5	0
Resolution enhancement chopper assembly 1	13.6.3.1.3	1	2	0	0	0
Chopper axis 1	13.6.3.1.3	1	2	1	0	0
Spindle	13.6.3.1.3	1	2	1	1	0
Rotor	13.6.3.1.3	1	2	1	2	0
Disc	13.6.3.1.3	1	2	1	2	1
Coating	13.6.3.1.3	1	2	1	2	2
Coupling	13.6.3.1.3	1	2	1	3	0
Chopper enclosure	13.6.3.1.3	1	2	2	0	0
Front Enclosure	13.6.3.1.3	1	2	2	1	0
Back enclosure	13.6.3.1.3	1	2	2	2	0
Chopper support	13.6.3.1.3	1	2	3	0	0
Chopper support base plate	13.6.3.1.3	1	2	3	1	0
Chopper unit harness axis 1	13.6.3.1.3	1	2	4	0	0
Connection plate male	13.6.3.1.3	1	2	4	1	0
Motor cable	13.6.3.1.3	1	2	4	2	0
Machine cable	13.6.3.1.3	1	2	4	3	0
Vacuum assembly	13.6.3.1.3	1	2	4	4	0
Sensor harness	13.6.3.1.3	1	2	4	5	0
Chopper integration module	13.6.3.1.3	1	3	0	0	0
Pit structure	13.6.3.1.3	1	3	1	0	0
Pit base plate	13.6.3.1.3	1	3	1	1	0
Alignment plate	13.6.3.1.3	1	3	1	2	0
Alignment plate	13.6.3.1.3	1	3	1	3	0
Alignment plate	13.6.3.1.3	1	3	1	4	0
Alignment plate	13.6.3.1.3	1	3	1	5	0
Position bar	13.6.3.1.3	1	3	1	6	0
Position bar	13.6.3.1.3	1	3	1	7	0
Cradle	13.6.3.1.3	1	3	2	0	0
Cradle frame	13.6.3.1.3	1	3	2	1	0
Pit chopper support	13.6.3.1.3	1	3	3	0	0
Chopper support	13.6.3.1.3	1	3	3	1	0
Guide fastening components	13.6.3.1.3	1	3	3	2	0
Umbilical	13.6.3.1.3	1	3	4	0	0
Connection plate female 1	13.6.3.1.3	1	3	4	1	0

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Connection plate female 2	13.6.3.1.3	1	3	4	2	0
Connection plate female 3	13.6.3.1.3	1	3	4	3	0
Motor cables	13.6.3.1.3	1	3	4	4	0
Machine cables	13.6.3.1.3	1	3	4	5	0
Vacuum assemblies	13.6.3.1.3	1	3	4	6	0
Sensor harnesses	13.6.3.1.3	1	3	4	7	0
Pit head box	13.6.3.1.3	1	3	5	0	0
Pit services	13.6.3.1.3	1	3	6	0	0
Pit Assembly 2	13.6.3.1.3	2	0	0	0	0
Resolution enhancement chopper assembly 2	13.6.3.1.3	2	1	0	0	0
Chopper axis 1	13.6.3.1.3	2	1	1	0	0
Spindle	13.6.3.1.3	2	1	1	1	0
Rotor	13.6.3.1.3	2	1	1	2	0
Disc	13.6.3.1.3	2	1	1	2	1
Coating	13.6.3.1.3	2	1	1	2	2
Coupling	13.6.3.1.3	2	1	1	3	0
Chopper enclosure	13.6.3.1.3	2	1	2	0	0
Front Enclosure	13.6.3.1.3	2	1	2	1	0
Back enclosure	13.6.3.1.3	2	1	2	2	0
Chopper support	13.6.3.1.3	2	1	3	0	0
Chopper support base plate	13.6.3.1.3	2	1	3	1	0
Chopper unit harness axis 1	13.6.3.1.3	2	1	4	0	0
Connection plate male	13.6.3.1.3	2	1	4	1	0
Motor cable	13.6.3.1.3	2	1	4	2	0
Machine cable	13.6.3.1.3	2	1	4	3	0
Vacuum assembly	13.6.3.1.3	2	1	4	4	0
Sensor harness	13.6.3.1.3	2	1	4	5	0
Chopper integration module	13.6.3.1.3	2	2	0	0	0
Pit structure	13.6.3.1.3	2	2	1	0	0
Pit base plate	13.6.3.1.3	2	2	1	1	0
Alignment plate	13.6.3.1.3	2	2	1	2	0
Alignment plate	13.6.3.1.3	2	2	1	3	0
Alignment plate	13.6.3.1.3	2	2	1	4	0
Alignment plate	13.6.3.1.3	2	2	1	5	0
Position bar	13.6.3.1.3	2	2	1	6	0
Position bar	13.6.3.1.3	2	2	1	7	0
Cradle	13.6.3.1.3	2	2	2	0	0
Cradle frame	13.6.3.1.3	2	2	2	1	0
Pit chopper support	13.6.3.1.3	2	2	3	0	0
Chopper support	13.6.3.1.3	2	2	3	1	0
Guide fastening components	13.6.3.1.3	2	2	3	2	0
Umbilical	13.6.3.1.3	2	2	4	0	0
Connection plate female 1	13.6.3.1.3	2	2	4	1	0
Motor cable	13.6.3.1.3	2	2	4	4	0
Machine cable	13.6.3.1.3	2	2	4	5	0
Vacuum assemblies	13.6.3.1.3	2	2	4	6	0
Sensor harnesses	13.6.3.1.3	2	2	4	7	0
Pit head box	13.6.3.1.3	2	2	5	0	0
Pit services	13.6.3.1.3	2	2	6	0	0
Pit Assembly 3	13.6.3.1.3	3	0	0	0	0
Sub-frame overlap chopper assembly	13.6.3.1.3	3	1	0	0	0
Chopper axis 1	13.6.3.1.3	3	1	1	0	0
Spindle	13.6.3.1.3	3	1	1	1	0
Rotor	13.6.3.1.3	3	1	1	2	0
Disc	13.6.3.1.3	3	1	1	2	1
Coating	13.6.3.1.3	3	1	1	2	2
Coupling	13.6.3.1.3	3	1	1	3	0
Chopper axis 2	13.6.3.1.3	3	1	2	0	0
Spindle	13.6.3.1.3	3	1	2	1	0

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Rotor	13.6.3.1.3	3	1	2	2	0
Disc	13.6.3.1.3	3	1	2	2	1
Coating	13.6.3.1.3	3	1	2	2	2
Coupling	13.6.3.1.3	3	1	2	3	0
Chopper enclosure	13.6.3.1.3	3	1	3	0	0
Front Enclosure	13.6.3.1.3	3	1	3	1	0
Back enclosure	13.6.3.1.3	3	1	3	2	0
Chopper support	13.6.3.1.3	3	1	4	0	0
Chopper support base plate	13.6.3.1.3	3	1	4	1	0
Chopper unit harness axis 1	13.6.3.1.3	3	1	5	0	0
Connection plate male	13.6.3.1.3	3	1	5	1	0
Motor cable	13.6.3.1.3	3	1	5	2	0
Machine cable	13.6.3.1.3	3	1	5	3	0
Vacuum assembly	13.6.3.1.3	3	1	5	4	0
Sensor harness	13.6.3.1.3	3	1	5	5	0
Chopper unit harness axis 2	13.6.3.1.3	3	1	6	0	0
Connection plate male	13.6.3.1.3	3	1	6	1	0
Motor cable	13.6.3.1.3	3	1	6	2	0
Machine cable	13.6.3.1.3	3	1	6	3	0
Vacuum assembly	13.6.3.1.3	3	1	6	4	0
Sensor harness	13.6.3.1.3	3	1	6	5	0
Resolution enhancement chopper assembly 3	13.6.3.1.3	3	2	0	0	0
Chopper axis 1	13.6.3.1.3	3	2	1	0	0
Spindle	13.6.3.1.3	3	2	1	1	0
Rotor	13.6.3.1.3	3	2	1	2	0
Disc	13.6.3.1.3	3	2	1	2	1
Coating	13.6.3.1.3	3	2	1	2	2
Coupling	13.6.3.1.3	3	2	1	3	0
Chopper enclosure	13.6.3.1.3	3	2	2	0	0
Front Enclosure	13.6.3.1.3	3	2	2	1	0
Back enclosure	13.6.3.1.3	3	2	2	2	0
Chopper support	13.6.3.1.3	3	2	3	0	0
Chopper support base plate	13.6.3.1.3	3	2	3	1	0
Chopper unit harness axis 1	13.6.3.1.3	3	2	4	0	0
Connection plate male	13.6.3.1.3	3	2	4	1	0
Motor cable	13.6.3.1.3	3	2	4	2	0
Machine cable	13.6.3.1.3	3	2	4	3	0
Vacuum assembly	13.6.3.1.3	3	2	4	4	0
Sensor harness	13.6.3.1.3	3	2	4	5	0
Chopper integration module	13.6.3.1.3	3	3	0	0	0
Pit structure	13.6.3.1.3	3	3	1	0	0
Pit base plate	13.6.3.1.3	3	3	1	1	0
Alignment plate	13.6.3.1.3	3	3	1	2	0
Alignment plate	13.6.3.1.3	3	3	1	3	0
Alignment plate	13.6.3.1.3	3	3	1	4	0
Alignment plate	13.6.3.1.3	3	3	1	5	0
Position bar	13.6.3.1.3	3	3	1	6	0
Position bar	13.6.3.1.3	3	3	1	7	0
Cradle	13.6.3.1.3	3	3	2	0	0
Cradle frame	13.6.3.1.3	3	3	2	1	0
Pit chopper support	13.6.3.1.3	3	3	3	0	0
Chopper support	13.6.3.1.3	3	3	3	1	0
Guide fastening components	13.6.3.1.3	3	3	3	2	0
Umbilical	13.6.3.1.3	3	3	4	0	0
Connection plate female 1	13.6.3.1.3	3	3	4	1	0
Connection plate female 2	13.6.3.1.3	3	3	4	2	0
Connection plate female 3	13.6.3.1.3	3	3	4	3	0
Motor cables	13.6.3.1.3	3	3	4	4	0
Machine cables	13.6.3.1.3	3	3	4	5	0

Vacuum assemblies	13.6.3.1.3	3	3	4	6	0
Sensor harnesses	13.6.3.1.3	3	3	4	7	0
Pit head box	13.6.3.1.3	3	3	5	0	0
Pit services	13.6.3.1.3	3	3	6	0	0
Control system	13.6.3.1.3	4	0	0	0	0
Rack Assembly 1	13.6.3.1.3	4	1	0	0	0
Rack	13.6.3.1.3	4	1	1	0	0
Rack component	13.6.3.1.3	4	1	1	1	0
Epics control unit	13.6.3.1.3	4	1	1	2	0
CHIC	13.6.3.1.3	4	1	1	3	0
Power assembly	13.6.3.1.3	4	1	1	4	0
0-24VDC supply assembly	13.6.3.1.3	4	1	1	5	0
UPS	13.6.3.1.3	4	1	1	6	0
Chopper drive assembly 1	13.6.3.1.3	4	1	1	7	0
Chopper drive	13.6.3.1.3	4	1	1	7	1
Sensors	13.6.3.1.3	4	1	1	7	2
Chopper drive assembly 2	13.6.3.1.3	4	1	1	8	0
Chopper drive	13.6.3.1.3	4	1	1	8	1
Sensors	13.6.3.1.3	4	1	1	8	2
Chopper drive assembly 3	13.6.3.1.3	4	1	1	9	0
Chopper drive	13.6.3.1.3	4	1	1	9	1
Sensors	13.6.3.1.3	4	1	1	9	2
Cabling	13.6.3.1.3	4	1	2	0	0
Cable trays	13.6.3.1.3	4	1	3	0	0
Rack Assembly 2	13.6.3.1.3	4	2	0	0	0
Rack	13.6.3.1.3	4	2	1	0	0
Rack component	13.6.3.1.3	4	1	1	1	0
Epics control unit	13.6.3.1.3	4	2	1	2	0
CHIC	13.6.3.1.3	4	2	1	3	0
Power assembly	13.6.3.1.3	4	2	1	4	0
0-24VDC supply assembly	13.6.3.1.3	4	2	1	5	0
UPS	13.6.3.1.3	4	2	1	6	0
Chopper drive assembly 1	13.6.3.1.3	4	2	1	7	0
Chopper drive	13.6.3.1.3	4	2	1	7	1
Sensors	13.6.3.1.3	4	2	1	7	2
Cabling	13.6.3.1.3	4	2	2	0	0
Cable trays	13.6.3.1.3	4	2	3	0	0
Rack Assembly 3	13.6.3.1.3	4	3	0	0	0
Rack	13.6.3.1.3	4	3	1	0	0
Rack component	13.6.3.1.3	4	1	1	1	0
Epics control unit	13.6.3.1.3	4	3	1	2	0
CHIC	13.6.3.1.3	4	3	1	3	0
Power assembly	13.6.3.1.3	4	3	1	4	0
0-24VDC supply assembly	13.6.3.1.3	4	3	1	5	0
UPS	13.6.3.1.3	4	3	1	6	0
Chopper drive assembly 1	13.6.3.1.3	4	3	1	7	0
Chopper drive	13.6.3.1.3	4	3	1	7	1
Sensors	13.6.3.1.3	4	3	1	7	2
Chopper drive assembly 2	13.6.3.1.3	4	3	1	8	0
Chopper drive	13.6.3.1.3	4	3	1	8	1
Sensors	13.6.3.1.3	4	3	1	8	2
Chopper drive assembly 3	13.6.3.1.3	4	3	1	9	0
Chopper drive	13.6.3.1.3	4	3	1	9	1
Sensors	13.6.3.1.3	4	3	1	9	2
Cabling	13.6.3.1.3	4	3	2	0	0
Cable trays	13.6.3.1.3	4	3	3	0	0
Support system	13.6.3.1.3	5	0	0	0	0
Power systems	13.6.3.1.3	5	1	0	0	0
Supply	13.6.3.1.3	5	1	1	0	0

Distribution	13.6.3.1.3	5	1	2	0	0
Fluid systems	13.6.3.1.3	5	2	0	0	0
Hutches	13.6.3.1.3	5	3	0	0	0
Service package	13.6.3.1.3	6	0	0	0	0
Transportation cask	13.6.3.1.3	6	1	0	0	0
Maintenance shielding	13.6.3.1.3	6	2	0	0	0
Tooling	13.6.3.1.3	6	3	0	0	0
Spares	13.6.3.1.3	6	4	0	0	0
Pit lift	13.6.3.1.3	6	5	0	0	0

4.2 Hardware cost

The hardware cost shown here is estimated on previous tenders and experience. In accordance with the 'NSS strategy for chopper fulfilment', the following assumptions are being made in this section:

- The ESS chopper group has authority over the design choices and schedule for the delivery of the Loki chopper system
- The ESS chopper group has authority over the selection of partners for the delivery.

All figures are without contingency, and do not take inflation, overheads and administration expenses into account. It should be considered to have an error bar of +20/-10%. Spare parts are part of the hardware cost estimation. It is broken down to the level of sub deliverables.

Name	Instrument	Sub system	Sub Sub system	Sub assembly	Component	Detail	Estimated cost (k€)
Loki chopper system	**13.6.3.1.3**	**0**	**0**	**0**	**0**	**0**	**763.5**
Pit Assembly 1	13.6.3.1.3	1	0	0	0	0	247
Wavelength selection chopper assembly	13.6.3.1.3	1	1	0	0	0	126.5
Resolution enhancement chopper assembly 1	13.6.3.1.3	1	2	0	0	0	70.5
Chopper integration module	13.6.3.1.3	1	3	0	0	0	50
Pit Assembly 2	13.6.3.1.3	2	0	0	0	0	112.5
Resolution enhancement chopper assembly 2	13.6.3.1.3	2	1	0	0	0	70,5
Chopper integration module	13.6.3.1.3	2	2	0	0	0	42
Pit Assembly 3	13.6.3.1.3	3	0	0	0	0	241
Sub-frame overlap chopper assembly	13.6.3.1.3	3	1	0	0	0	126.5
Resolution enhancement chopper assembly 3	13.6.3.1.3	3	2	0	0	0	70.5
Chopper integration module	13.6.3.1.3	3	3	0	0	0	44
Control system	13.6.3.1.3	4	0	0	0	0	113
Rack Assembly 1	13.6.3.1.3	4	1	0	0	0	41
Rack Assembly 2	13.6.3.1.3	4	2	0	0	0	31
Rack Assembly 3	13.6.3.1.3	4	3	0	0	0	41
Support system	13.6.3.1.3	5	0	0	0	0	30
Power systems	13.6.3.1.3	5	1	0	0	0	10
Fluid systems	13.6.3.1.3	5	2	0	0	0	10
Hutches	13.6.3.1.3	5	3	0	0	0	10
Service package	13.6.3.1.3	6	0	0	0	0	20

DOCUMENT REVISION HISTORY

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1.3	Small changes and release	2014-12-08
1.2	Small changes	2014-11-06
1.0	Draft for release	2014-10-17

Resolution Improvement for the LOKI ESS SANS Instrument

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Goal of the resolution improvement method

The LOKI instrument will offer to measure SANS on samples with an unprecedented high flux, with a broad simultaneous Q range. In order to make use of a broad wavelength range and also each ESS pulse, the total length of the instrument is moderately short (32.5 m), and – in order to reach high Q values - short wavelengths (~ 2 Å) are also used. As a consequence, at high Q values the resolution of the instrument in the originally proposed setup is ~ 30 %.

With the use of a set of three choppers we plan to reduce this resolution to ~ 10 %. The choppers are placed at 7, 10 and 12 m from the moderator surface. Each chopper has 4 openings.

As a short summary, the chopper openings are distributed such, that the first 3 openings are “focusing” to the start of the ESS pulse (where the short wavelength neutrons are expected to be more abundant). In other words, for any detector time point to where neutrons are arriving from these three wavelength bands the virtual source length is shorter than the full ESS pulse length.

The optimization of the chopper layout was performed in an idealized case, where infinitesimally small guide cross-section is considered. In the end of this document, we also demonstrate how the layout has to be modified to be suitable for the case of guides with finite width.

The idealistic neutron time of flight diagram for sample to detector distance (SD) of 10 m is shown in Figure 1 and for sample to detector distance of 2 m in Figure 2.

The setup is optimized to be able to fill the available timeframe for SD=10 m (Figure 1) and also for SD=8 m (Figure 3). As demonstrated in Figure 2 for the case of the shortest available SD of 2 m, the wavelength resolution is kept under 10 %. The number of long wavelength neutrons (above ~ 5 Å) is not influenced by this setup.

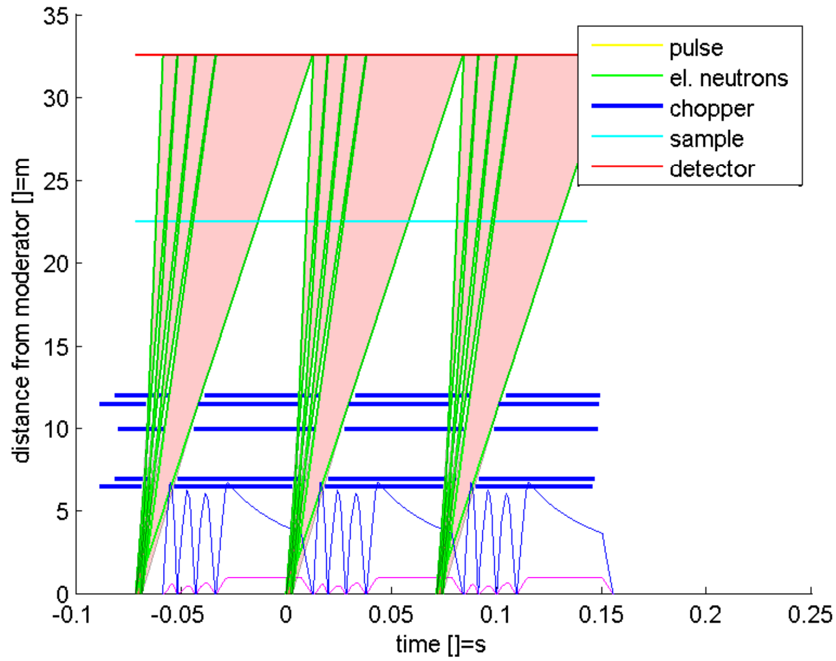

Figure 1 Time off flight diagram showing the resolution improvement chopper system with a 10 m sample to detector distance. The long wavelength limit is defined via the frame overlap choppers. The calculated results (on the same y axes) are shown for wavelength resolution in % (blue line) and flux ratio relative to the case where only the bandwidth choppers are running (magenta line).

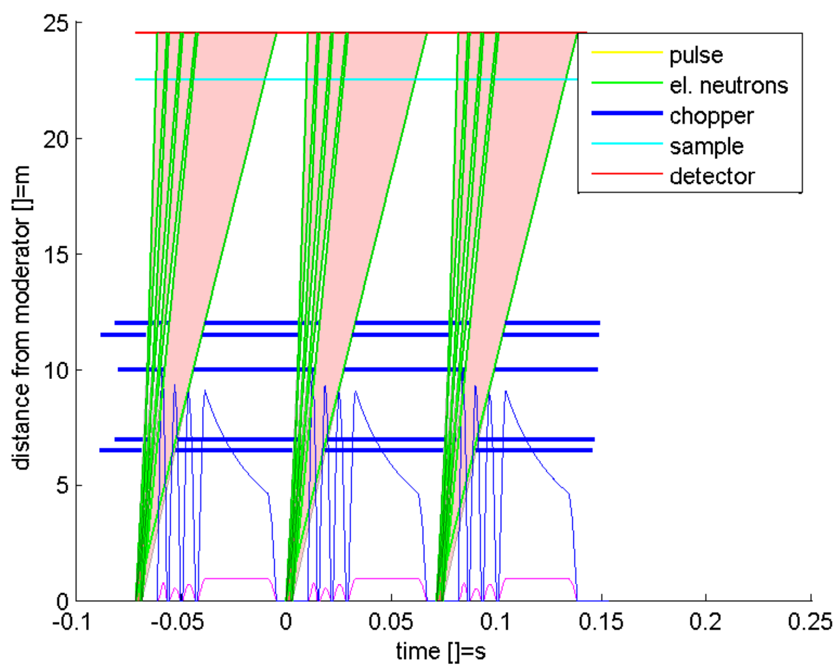

Figure 2 Time off light diagram showing the resolution improvement chopper system with a 2 m sample to detector distance. The long wavelength limit is defined via the resolution improvement choppers. The calculated results (on the same y axes) are shown for wavelength resolution in % (blue line) and flux ratio relative to the case where only the bandwidth choppers are running (magenta line).

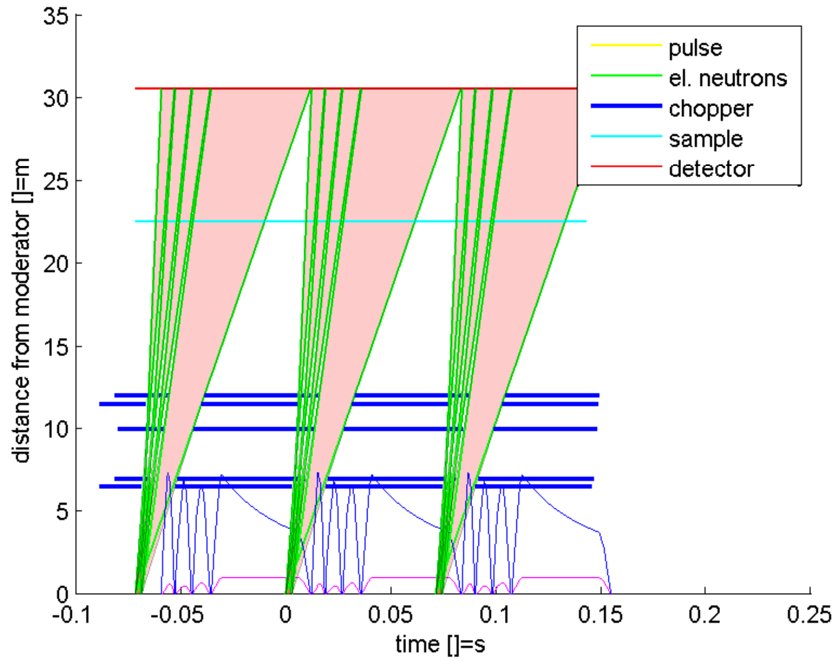

Figure 3 Time off light diagram showing the resolution improvement chopper system with an 8 m sample to detector distance. The long wavelength limit is defined via the resolution improvement choppers. The calculated results (on the same y axes) are shown for wavelength resolution in % (blue line) and flux ratio relative to the case where only the bandwidth choppers are running (magenta line).

Calculation of possible rotation speeds for different choppers

- One period of ESS is 71.4 ms
- The resolution improvement choppers are placed at 7, 10 and 12 m distances from the moderator surface
- The openings of the choppers in the idealistic case (infinitesimally small guide width) are detailed in Table 1.

Table 1 Opening and closing time of the choppers, optimized for an infinitesimally small neutron guide

	1st (ms)	2nd (ms)	3rd (ms)	4th (ms)		Full range (ms)	Full period/ range
Ch1 (7 m)	3.7451-4.5683	5.4713-6.6231	7.349 - 8.8695	9.3972-20.0276		16.2825	4.39
Ch2 (10 m)	5.2217-6.1933	7.6875-8.9244	10.37-11.9292	13.296-27.665		22.4433	3.18
Ch3 (12 m)	6.206-7.2767	9.165-10.4586	12.384-13.9691	15.8952-32.7568		26.5508	2.69

The resolution improvement choppers at 7, 10 and 12 m can rotate with 4, 3 and 2 ESS frequency, respectively.

Calculation of rising and falling times

In order to clarify the terms falling time and rising time, see Figure 4

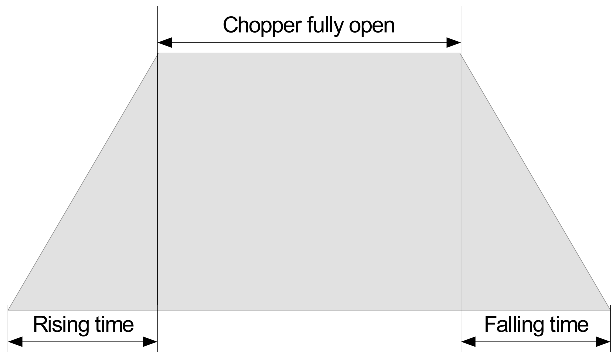

Figure 4 Time ranges, where the choppers are partially and fully open.

The width of the neutron guide is 25 mm for the resolution improvement choppers at 7 and 10 m, and 30 mm for the one at 12 m. The radius of the choppers is 350 mm. Considering a 30 mm high neutron guide, the smallest relevant radius is 320 mm.

Table 2 Rising and falling times for the different resolution improvement choppers in case of applying single or inversely rotating double choppers.

	Frequency	T (ms)	Guide width	Rising time Single chopper (ms)	Rising time Double chopper (ms)
Ch1 (7 m)	56 Hz	17.86	25 mm	0.222	0.111
Ch2 (10 m)	42 Hz	23.81	25 mm	0.296	0.148
Ch3 (12 m)	28 Hz	35.71	30 mm	0.533	0.266

We have two options for chopper choice: single choppers or inversely rotating double choppers. We compare below the two different options.

Consideration of rising and falling times in the chopper setup

In order to avoid any cross-talk between the different wavelength bends, we consider that the chopper times presented in Table 1 are the starting of the rising and the end of the falling times. To obtain the correct time points, when the choppers are half open and half closed, we need to use the correction values detailed in Table 3. To obtain the correct time points, when the choppers are fully closed, we need to use the correction values detailed in Table 4.

Table 3 Corrections for obtaining half opening and half closing times from Table 1.

	Required corrections			
	Use of single chopper		Use of double chopper	
	Half opening time	Half closing time	Half opening time	Half closing time
Ch1 (7 m)	+0.222/2	-0.222/2	+0.111/2	-0.111/2
Ch2 (10 m)	+0.296/2	-0.296/2	+0.148/2	-0.148/2
Ch3 (12 m)	+0.533/2	-0.533/2	+0.266/2	-0.266/2

Table 4 Corrections for obtaining times, when choppers are fully closed, from Table 1

	Required corrections			
	Use of single chopper		Use of double chopper	
	End of rising time	Start of falling time	End of rising time	Start of falling time
Ch1 (7 m)	+0.222	-0.222	+0.111	-0.111
Ch2 (10 m)	+0.296	-0.296	+0.148	-0.148
Ch3 (12 m)	+0.533	-0.533	+0.266	-0.266

We performed calculations with these three types of time values. We plotted the results for the case when single choppers are used (Figure 5), and when inversely rotating double choppers are used (Figure 6).

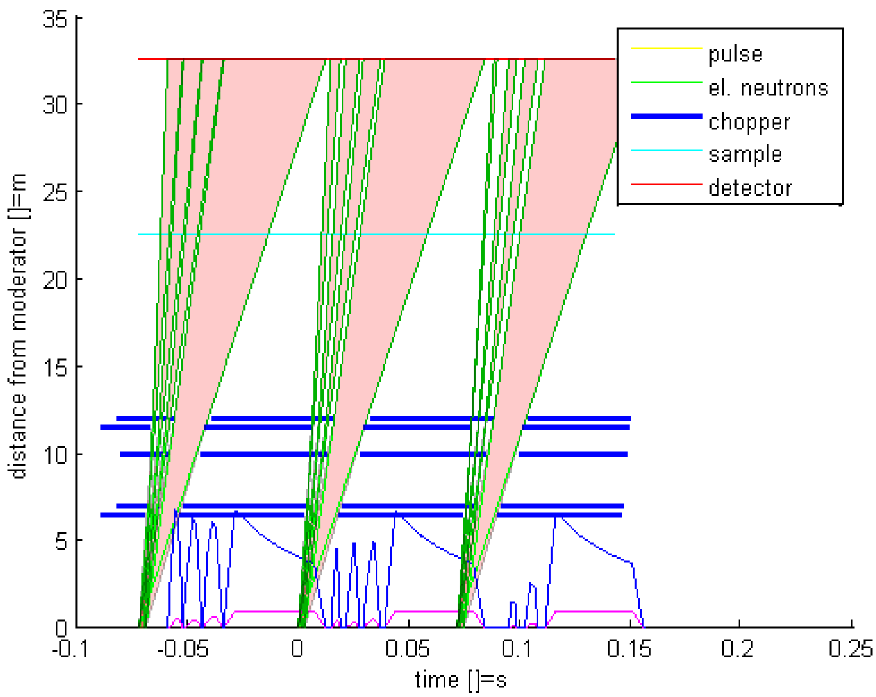

Figure 5 Case of single chopper. Simulation, performed with different time parameters of the applied wavelength resolution choppers. The first one with the start of rising and the end of the falling times, the second period with the medium time values, while the third period with the end of the rising and the start of the falling times. The calculated results (same y axes) for flux ration (magenta line) and resolution in percentage (blue line).

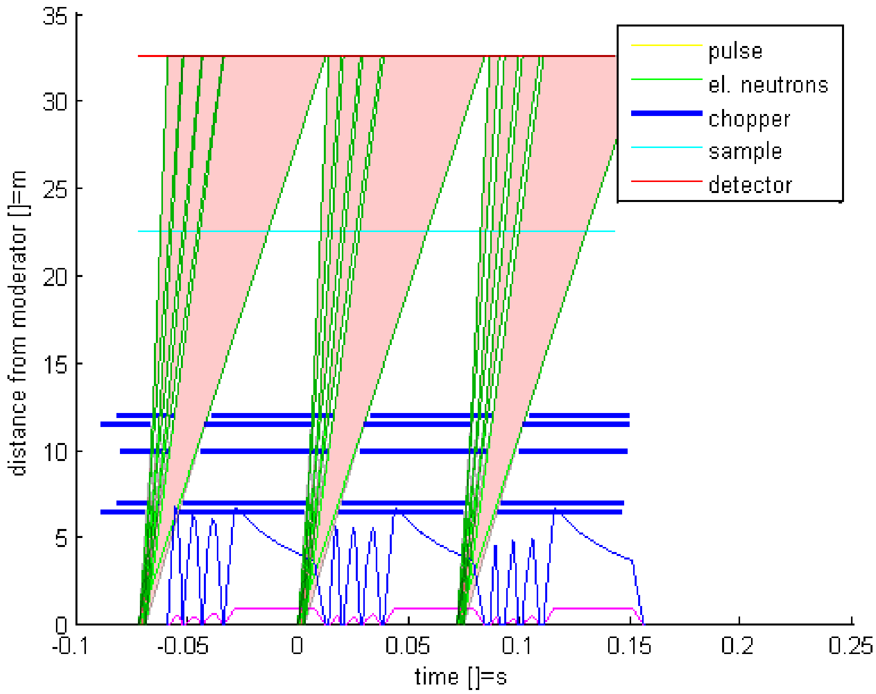

Figure 6 Case of double chopper. Simulation, performed with different time parameters of the applied wavelength resolution choppers. The first one with the start of rising and the end of the falling times, the second period with the medium time values, while the third period with the end of the rising and the start of the falling times. The calculated results (same y axes) for flux ration (magenta line) and resolution in percentage (blue line).

These two figures demonstrate that – due to the short opening times used by the resolution improvement method – the use of double choppers is highly preferred.

In Table 5 we show some calculated values for the flux preservation and for the minimal available wavelengths, for the case of single and double choppers and for the case of considering different time parameters.

Table 5 Minimal available wavelengthes and preserved flux ratios for the simulations presented in Figure 5 and Figure 6.

	1st period		2nd period		3rd period	
	Minimal wavelength (Å)	Fluxratio	Minimal wavelength (Å)	Fluxratio	Minimal wavelength (Å)	Fluxratio
Single chopper	1.3	0.5375	1.59	0.4361	1.89	0.3416
Double chopper	1.3	0.5375	1.44	0.4865	1.59	0.4362

Actual chopper layout

The chopper layout required for the inversely rotating double chopper setup is shown in Figure 7.

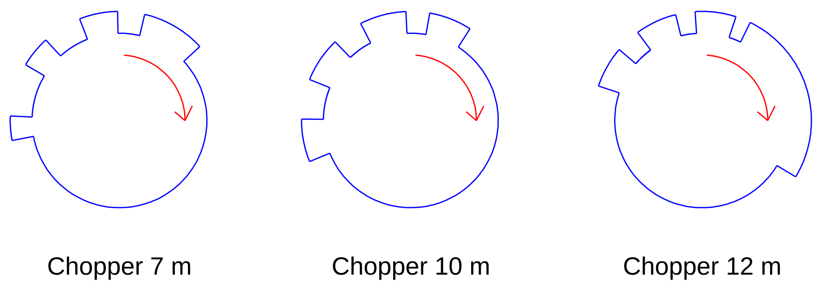

Figure 7 Schematic drawing of the resolution improvement choppers at 7, 10 and 12 m from the moderator surface, rotating with 4, 3 and 2 ESS frequency, respectively.

Required further studies

The setup in its present form relies on the precise starting time of the ESS pulse. Depending on the predictions, how this time point will be stable during the operation, refinement of the chopper setup may be required.

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Scope document
Loki
Neutron Chopper Group

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Version : 1.0

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Authors	Erik Nilsson		NCG
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Distribution: Iain Sutton, Andrew Jackson, Clara Lopez

1. DOCUMENT SCOPE

This document outlines the physical supply of choppers to the Loki beam line, as well as the scope of work being performed by the chopper group to reach that delivery.

2. NCG SCOPE OF SUPPLY IN THE LOKI PROJECT

2.1 Definition of the Loki neutron chopper system

The neutron chopper system (NCS) of the instrument consists of all components within the chopper pits, the chopper control system and support systems. Any special tooling for service is also part of the instrument's chopper system. Neutron guides, shielding and any other technical group specific components within the pit are excluded.

A chopper pit is a cavity within the shielding. It houses the chopper assemblies and any and all of its supports. Any extraction tools, alignment systems and so on is also part of the chopper system. All systems and components on the Loki chopper PBS are considered part of the chopper system and under the responsibility of the Neutron Chopper Group (NCG).

For descriptions on the interfaces between the chopper system and other system, please refer to chapter 2.3 in this document.

2.2 Deliverables

NCG will be responsible for and deliver all components included in the Loki chopper system. This includes any and all of the chopper assemblies, their mounts, support system and control system.

2.2.1 Not included in scope

The chopper group will not deliver any guide sections or shielding, or any other components as per the interface chapter below.

2.3 Interfaces

2.3.1 Optics

Please refer to the NCG-Optics interface control document for information on this interface.

2.3.2 Shielding

Please refer to the NCG-Shielding interface control document for information on this interface.

2.3.3 E&E

Please refer to the NCG-E&E interface control document for information on this interface.

2.3.4 ICS

Please refer to the NCG-ICS interface control document for information on this interface.

2.3.5 DMSC

Please refer to the NCG-DMSC interface control document for information on this interface.

2.3.6 CF

Please refer to the NCG-CF interface control document for information on this interface.

2.3.7 Health and safety

Please refer to the NCG-H&S interface control document for information on this interface.

2.3.8 Vacuum

Please refer to the NCG-Vacuum interface control document for information on this interface.

2.3.9 Cooling

Please refer to the NCG-Cooling interface control document for information on this interface.

2.3.10 Instrument team

Please refer to the NCG-Loki interface control document on information on this interface.

3. NCG SCOPE OF WORK IN THE LOKI PROJECT

3.1 Design, development and specification

The group activities and responsibilities include:

- The definition of the choppers system engineering performance and functionality requirements for the instrument.
- The production of technical specifications and guidelines for the purposes of system or subsystem design.
- The design functions required for the manufacture, integration and operation of the neutron chopper system.
- The validation of system performance and functionality, prior to realisation, through the employ of appropriate methods including measurement campaigns, computer simulation and the manufacture and testing of physical prototypes.

3.2 Procurement

The group activities and responsibilities include:

- Responsibility for procurement decisions and procedures of the neutron chopper system, components and associated spare parts according to the NCG procurement strategy.
- The production of technical documentation, as required, for the procurements and acceptance testing of components and systems.
- Documents will include technical specifications, verification and validation plans, test, and installation & operation manuals.
- Technical discussion with suppliers prior to order placement and during production.
- The selection and validation of potential equipment suppliers.

- Technical validation of procurement proposals and supplier tenders prior to order placement.
- The responsibility for inspection and test, as required, of material, throughout the procurement process.

3.3 Assembly, test and inspection

The group activities and responsibilities include:

- To conduct inspection and test functions throughout the procurement operations to ensure conformity of equipment to specification, including, as required.
- Verification & validation of all aspects of equipment performance, to specified values.
- Verification & validation of system safety requirements and compliance to the national and international standards in rigor.
- Authorization of equipment and components as 'fit for installation'.
- Responsibility for the implementation of features and/or procedures ensuring the safe operation of equipment.
- The validation of system the endurance and serviceability through the conduct of equipment 'endurance testing'.

3.4 Installation

The group activities and responsibilities include:

- The transport and installation, on site, of all systems and associated support equipment. Including: cables, services and dedicated handling equipment.
- The integration and set up of all supplied systems.
- The conduct on-site inspection and testing during system commissioning to ensure the conformity and safety of installed systems.
- The authorization of installed equipment as 'fit for operation'.
- Signing off of installed systems for service to responsible authorities or clients.
- Ensuring the safety of personnel and facilities during equipment operation and maintenance.

3.5 Commissioning

The group activities and responsibilities include:

- Commissioning of the neutron chopper system for Loki and its associated equipment so that they perform to agreed specifications.
- Consultation with associated groups, as needed during the commissioning phase.

3.6 Operations and maintenance

Operations and maintenance is not part of the Loki construction project but is part of the operation of the Loki instrument. The group activities and responsibilities include:

- Consultation on best operating procedures and practices.
- Consultation on the optimization of system performance.
- Routine inspection and programmed maintenance of installed systems.
- Timely response and assistance in the case of equipment breakdown.

Note: The responsibility for routine operation and upkeep of installed equipment are with the instrument scientist and their team.

- The development of a maintenance schedule for the components and systems included in the Loki chopper system to ensure the serviceability, safety and cost effective functioning of installed systems.
- The responsibility for the removal, and re-installation of systems for maintenance purposes.
- The responsibility for the transport to and from repair facilities, on site or external.
- The repair of all systems or components having suffered breakdown or having been subjected to accidental damage.
- The conduct of inspection and testing of repaired systems prior to installation to ensure the conformity, performance and safety of systems.
- The procurement and storage of spare components and tooling required to perform programmed maintenance operation within reasonable delay.
- The procurement and storage of critical and long supply delay machine components in provision for unscheduled repair.

3.7 Decommissioning and disposal

Decommissioning is not part of the Loki construction project but is part of the operation of the Loki instrument. The group activities and responsibilities include:

- Consultation on decommissioning issues, such as the safe removed and disposal of all equipment under the groups' responsibility at the end of the agreed service period.

4. ASSUMPTIONS

The group will be provided the resources by the instrument project, or provided the means of obtaining the resources, that are required to deliver the stated objectives with sufficient time to achieve the agreed scope by the agreed delivery date.

The group will be involved and/or kept informed of material developments and discussions relevant to the neutron chopper systems within the instrument in order to meet the agreed objectives.

The integration of the Loki chopper system into other chopper systems at the ESS is important for the maintainability and serviceability of the facility, therefor a large amount of standardisation is assumed.

5. LIST OF ABBREVIATIONS

Abbreviation	Explanation of abbreviation
NCG	Neutron chopper group
NCS	Neutron chopper system
E&E	Electrical engineering group
DMSC	Data management and software centre

ICS Integrated control system

CF Conventional facilities

DOCUMENT REVISION HISTORY

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Functional requirements of the Neutron Chopper System of the Instrument LOKI

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	Name	Date	Affiliation
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Approver	Andrew Jackson		Loki instrument team
Approver	Clara Lopez		Loki instrument team

Distribution: Iain Sutton, Andrew Jackson, Clara Lopez

TABLE OF CONTENT

1. INTRODUCTION

This document describes the functional requirements of the neutron chopper system of the Loki instrument proposed for construction at the European spallation source facility in Lund, Sweden.

Requirements are classified under two major headings, scientific and engineering.

Scientific requirements are loosely defined as those concerning the definition of system functions and levels of performance contributing to the achievement of the instruments scientific scope.

Engineering requirements are loosely defined as those concerning the definition of system functions and levels of performance contributing integration, safety, control and (all) other non-science driven requirements.

1.1 System description

The chopper system consists of all components, software and hardware needed to operate and maintain the chopper system.

The neutron chopper system of Loki is foreseen to consist of two double disc chopper assemblies and three single disc chopper assemblies. Seven chopper axis in total.

The double disc chopper assemblies are; the wavelength selection chopper assembly (WSC-A) and the sub-frame overlap chopper assembly (SOC-A). Both are considered to be face-to-face, counter rotating, double disc choppers, each containing two axis named axis 1 and axis 2. The single disc chopper assemblies form a resolution enhancement system (REC-1, REC-2 and REC-3).

The chopper assemblies will be installed in the neutron beam line within cavities in the shielding referred to as pits. Three pits are assumed and referred to as Pit 1 to 3, in order of proximity to the source.

- Pit 1 will contain WSC-A and the REC-1
- Pit 2 will contain REC-2
- Pit 3 will contain SOC-A and the REC-3.

For more information on the boundaries of the chopper system, refer to the interface control documents.

1.2 Assumptions

The following assumptions are being made.

- The location and packaging of all choppers systems is independent of the beam port on which the instrument will be situated.
- No neighbouring instruments are being considered.

.

1.3 Definition of terms

The following definitions are used for chopper specific terms in this document.

1.3.1 Chopper system

Chopper system comprises all components and control system needed to safely operate and maintain the chopper assemblies, pit systems, cabling and so on.

1.3.2 Chopper assembly

1.3.2.1 Rotor radius

The rotor radius is measured from the centre of rotation to the outer edge of the disc.

1.3.2.2 Distance from source

Single rotor assemblies

The distance from source of a disc chopper assembly is defined as the distance measured from the axis of the moderator to the plane median between the outer surfaces of the absorber on the chopper disc.

Double rotor assemblies

The distance from the source of a double disc chopper assembly is defined as the distance measured from the axis of the moderator to the plane median between the outer surfaces of the absorber on the chopper discs.

Note: The gap between rotors is considered to be nominally 10mm. The thickness of the rotors will vary dependant on the level of attenuation required.

1.3.2.3 Sense of rotation (rotor)

The sense of rotation is defined with respect to the frame of reference of an emitted neutron.

1.3.3 Acceleration

1.3.3.1 Spin up

The spin up time is defined as the time it takes an axis to accelerate and acquire phase lock from full stop to any operating frequency.

1.3.3.2 Spin down time

The spin down time is the time it takes an axis to decelerate from any operating speed to full stop and park into specified position.

1.3.4 Phasing

1.3.4.1 Phase accuracy

Phase accuracy consists of Phase trueness (proximity of the actual rotor positions and the commanded position) and Phase precision (repeatability or reproducibility of the actual rotor positions).

1.3.4.2 Phase jitter

Phase jitter is the difference between two consecutive measured phase errors.

1.3.4.3 Phase resolution

The phase resolution is the value of the accuracy of the phase signal.

1.3.4.4 TDC – Top dead centre

Top dead centre is the zero position of the rotor.

1.3.5 Passing Bandwidth

The Passing bandwidth is defined as the range of different energies of neutrons transmitted within a single pulse by neutron chopper system. Bandwidth is often selectable.

1.3.6 Chopper states

1.3.6.1 Open

The device is considered open when the transmitted flux exceeds 99.98% of the maximum value.

1.3.6.2 Closed

A device is considered closed when the total transmitted flux over the wavelength band of interest is inferior to 0.02% of the maximum value in the open position.

1.3.6.3 Transition

The device is considered to be in the transition state over the period during which the transmitted flux is between the open and closed values.

1.3.7 Attenuation

Attenuation is defined as the instantaneous ratio of transmitted beam intensity in the closed position to that of the incident beam.

2. FUNCTIONAL REQUIREMENTS

2.1 Wavelength selection

The neutron chopper system shall transmit a wavelength band of neutrons selected from all incident wavelengths.

Wavelength shall be selectable within the range of 1.8Å to 22Å.

The neutron chopper system shall block transmission of all wavelengths of neutrons outside of selected wavelength band.

All non-selected wavelengths shall be blocked over the range of 1Å and 30Å.

2.2 Bandwidth selection

The neutron chopper system shall permit the selection of the width of the transmitted wavelengths (bandwidth).

The bandwidth shall be selectable within the range of 0.4Å and 20Å.

2.3 Resolution enhancement function

The chopper system shall provide a means of improving the resolution by providing a series of sub-pulses from the source pulse while using the full bandwidth available.

3. PERFORMANCE REQUIREMENTS

The following performance requirements are needed to fulfil the functional requirements.

3.1 Naming of axis

Axis is named sequentially with respect to its position from the neutron source.

Assembly	WSC-A		SOC-A		REC-1	REC-2	REC-3
Axis	1	2	3	4	5	6	7

3.2 Chopper assembly positions

In order to achieve the functions and performance indicated above, the neutron chopper assemblies shall be positioned in accordance with the design established.

The position of each chopper assembly is defined in the table below.

The tolerance on position shall be ±20mm.

Assembly	WSC-A		SOC-A		REC-1	REC-2	REC-3
Axis #	1	2	3	4	5	6	7
Distance (m)	6.5	6.5	11.5	11.5	7	10	12

3.3 Axis 1

3.3.1 Rotor geometry

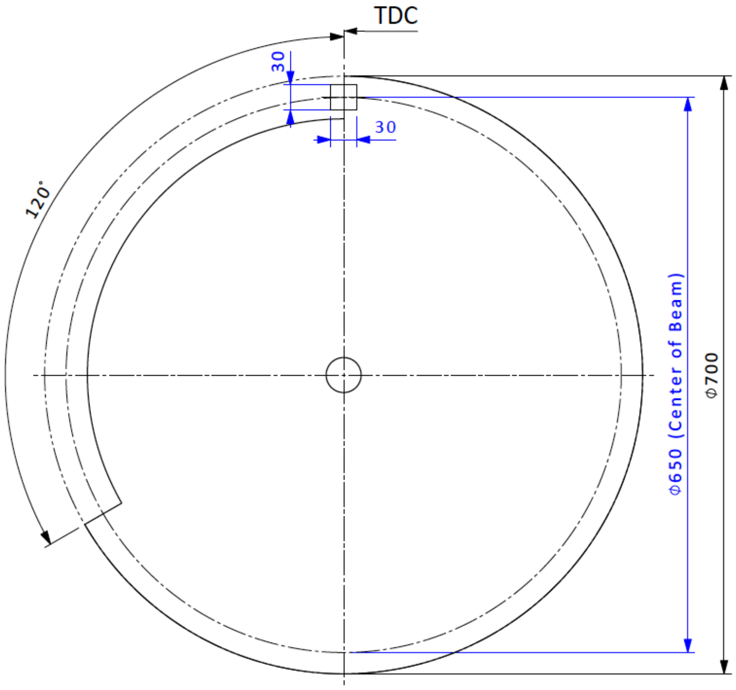

Figure 1 - Rotor 1 sketch

3.3.1.1 Rotor Diameter

The rotor diameter shall be 700mm.

The distance between the centre of rotation to centre of beam shall be 325mm.

3.3.1.2 Absorbing layer

The outer portion of all neutron chopper rotors shall be coated with neutron absorbing material such that the beam is interrupted in the closed position.

The height of the absorber shall exceed (vertically) by 10mm plus 10% of the optic interruption that of the incident beam at that position.

3.3.1.3 Windows

Absorber shall not be present in at certain positions in periphery of the rotor to permit the transmission of neutron. These positions are referred to as Windows.

Windows shall be 'fully open' i.e. without rotor material in beam in the open position.

Window height

Windows shall have vertical dimensions equal to or exceeding the height of the beam

Window width

The width and position of windows in the rotor are defined angularly with respect to the TDC. Se picture above for more information.

3.3.2 Operating frequencies and rotational direction

The rotor shall be operated at a selectable rotational frequency of 7Hz or 14Hz.

It shall be capable of rotating in both directions.

3.3.3 Beam geometry

The beam dimensions at the central plan of the rotor are 30mm high and 30mm wide.

3.3.4 Phase accuracy and jitter

The phase accuracy limits shall not exceed ±5µs at any operating speed.

The phase jitter shall not exceed 4µs at any operating speed.

3.3.5 Attenuation

The attenuation shall be 10^-6 or better, between 1Å and 30Å.

The attenuation shall be 1 or better, including and bellow 1Å.

The attenuation shall be 1 or better, including and above 30Å.

3.4 Axis 2

3.4.1 Rotor geometry

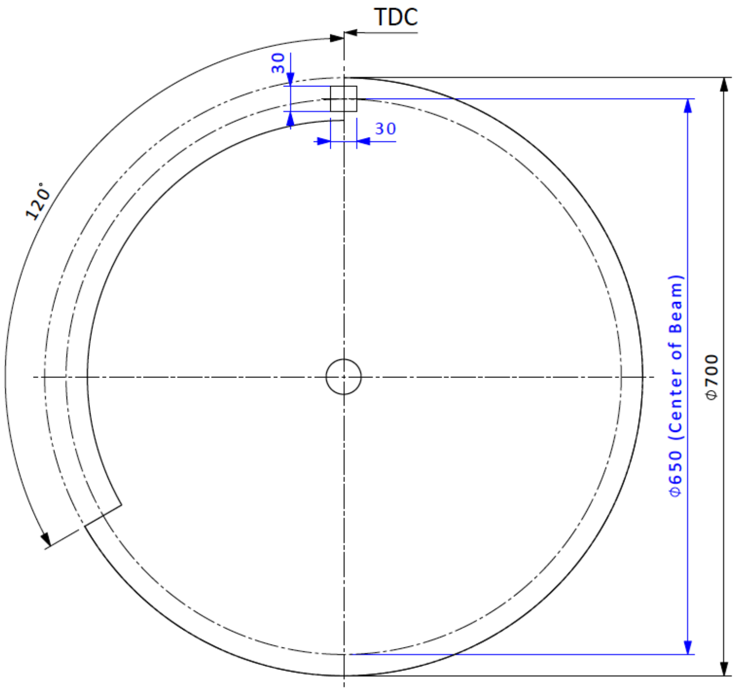

Figure 2 - Rotor 2 sketch

3.4.1.1 Rotor Diameter

The rotor diameter shall be 700mm.

The distance between the centre of rotation to centre of beam shall be 325mm.

3.4.1.2 Absorbing layer

The outer portion of all neutron chopper rotors shall be coated with neutron absorbing material such that the beam is interrupted in the closed position.

The height of the absorber shall exceed (vertically) by 10mm plus 10% of the optic interruption that of the incident beam at that position.

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Windows shall have vertical dimensions equal to or exceeding the height of the beam

Window width

The width and position of windows in the rotor are defined angularly with respect to the TDC. Se picture above for more information.

3.4.2 Operating frequencies and rotational direction

The rotor shall be operated at a selectable rotational frequency of 7Hz or 14Hz.

It shall be capable of rotating in both directions.

3.4.3 Beam geometry

The beam dimensions at the central plan of the rotor are 30mm high and 30mm wide.

3.4.4 Phase accuracy and jitter

The phase accuracy limits shall not exceed ±5µs at any operating speed.

The phase jitter shall not exceed 4µs at any operating speed.

3.4.5 Attenuation

The attenuation shall be 10^-6 or better, between 1Å and 30Å.

The attenuation shall be 1 or better, including and bellow 1Å.

The attenuation shall be 1 or better, including and above 30Å.

3.5 Axis 3

3.5.1 Rotor geometry

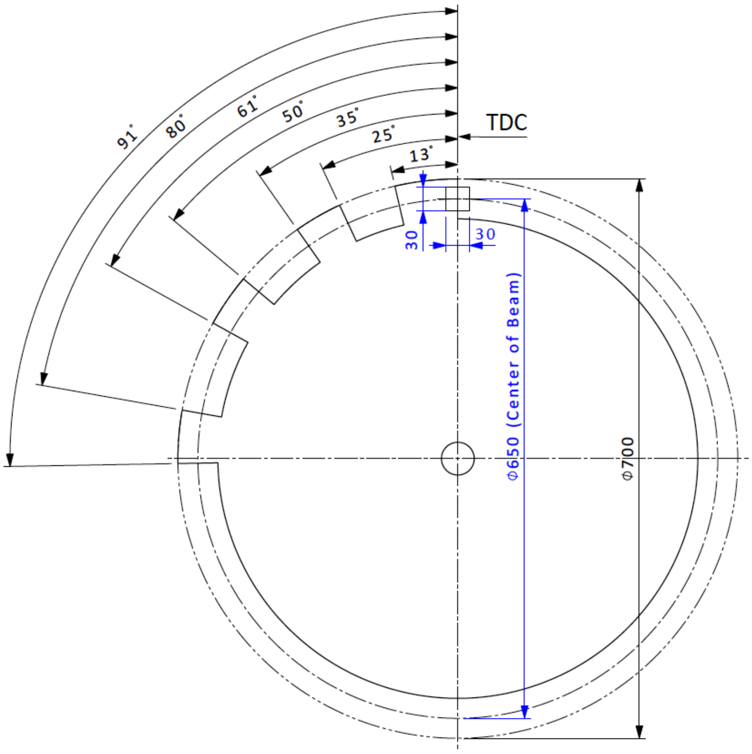

Figure 3 - Rotor 3 sketch

3.5.1.1 Rotor Diameter

The rotor diameter shall be 700mm.

The distance between the centre of rotation to centre of beam shall be 325mm.

3.5.1.2 Absorbing layer

The outer portion of all neutron chopper rotors shall be coated with neutron absorbing material such that the beam is interrupted in the closed position.

The height of the absorber shall exceed (vertically) by 10mm plus 10% of the optic interruption that of the incident beam at that position.

3.5.1.3 Windows

Absorber shall not be present in at certain positions in periphery of the rotor to permit the transmission of neutron. These positions are referred to as Windows.

Windows shall be 'fully open' i.e. without rotor material in beam in the open position.

Window height

Windows shall have vertical dimensions equal to or exceeding the height of the beam

Window width

The width and position of windows in the rotor are defined angularly with respect to the TDC. Se picture above for more information.

3.5.2 Operating frequencies and rotational direction

The rotor shall be operated at a rotational frequency 42Hz.

It shall be capable of rotating in both directions.

3.5.3 Beam geometry

The beam dimensions at the central plan of the rotor are 30mm high and 30mm wide.

3.5.4 Phase accuracy and jitter

The phase accuracy limits shall not exceed ±5μs at any operating speed.

The phase jitter shall not exceed 4μs at any operating speed.

3.5.5 Attenuation

The attenuation shall be 10^-6 or better, between 1Å and 30Å.

The attenuation shall be 1 or better, including and bellow 1Å.

The attenuation shall be 1 or better, including and above 30Å.

3.6 Axis 4

3.6.1 Rotor geometry

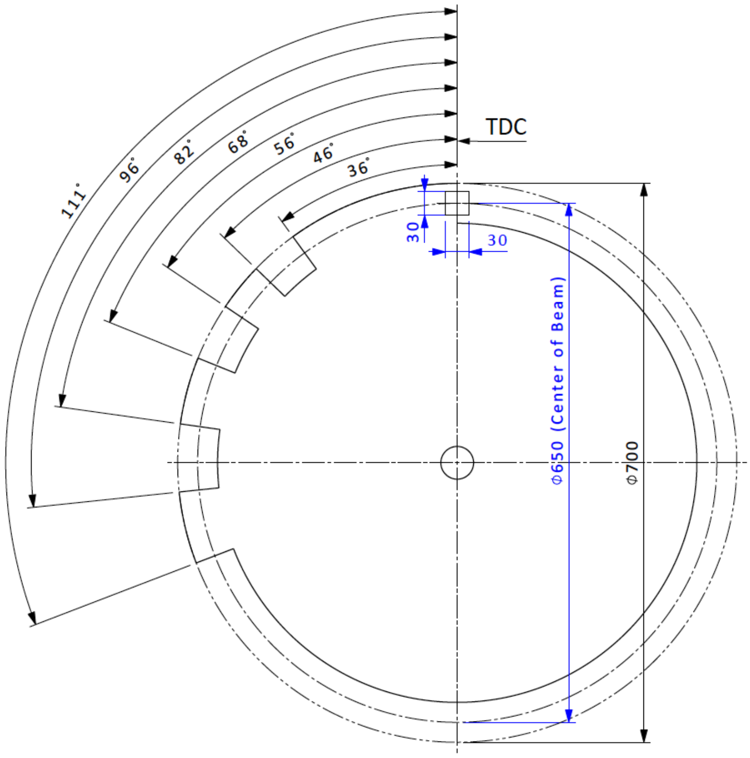

Figure 4 - Rotor 4 sketch

3.6.1.1 Rotor Diameter

The rotor diameter shall be 700mm.

The distance between the centre of rotation to centre of beam shall be 325mm.

3.6.1.2 Absorbing layer

The outer portion of all neutron chopper rotors shall be coated with neutron absorbing material such that the beam is interrupted in the closed position.

The height of the absorber shall exceed (vertically) by 10mm plus 10% of the optic interruption that of the incident beam at that position.

3.6.1.3 Windows

Absorber shall not be present in at certain positions in periphery of the rotor to permit the transmission of neutron. These positions are referred to as Windows.

Windows shall be 'fully open' i.e. without rotor material in beam in the open position.

Window height

Windows shall have vertical dimensions equal to or exceeding the height of the beam

Window width

The width and position of windows in the rotor are defined angularly with respect to the TDC. Se picture above for more information.

3.6.2 Operating frequencies and rotational direction

The rotor shall be operated at a rotational frequency of 28Hz.

It shall be capable of rotating in both directions.

3.6.3 Beam geometry

The beam dimensions at the central plan of the rotor are 30mm high and 30mm wide.

3.6.4 Phase accuracy and jitter

The phase accuracy limits shall not exceed ±5µs at any operating speed.

The phase jitter shall not exceed 4µs at any operating speed.

3.6.5 Attenuation

The attenuation shall be 10^-6 or better, between 1Å and 30Å.

The attenuation shall be 1 or better, including and bellow 1Å.

The attenuation shall be 1 or better, including and above 30Å.

3.7 Axis 5

3.7.1 Rotor geometry

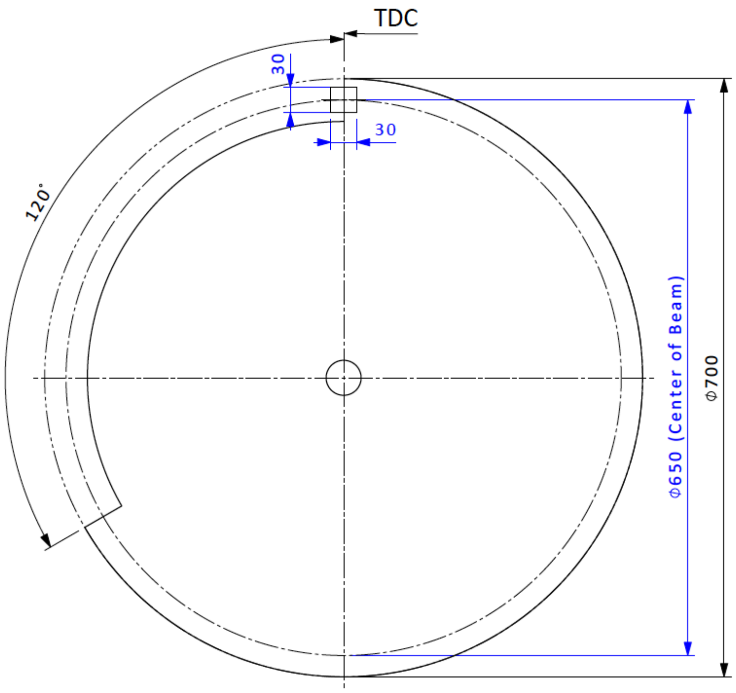

Figure 5 - Rotor 5 sketch

3.7.1.1 Rotor Diameter

The rotor diameter shall be 700mm.

The distance between the centre of rotation to centre of beam shall be 325mm.

3.7.1.2 Absorbing layer

The outer portion of all neutron chopper rotors shall be coated with neutron absorbing material such that the beam is interrupted in the closed position.

The height of the absorber shall exceed (vertically) by 10mm plus 10% of the optic interruption that of the incident beam at that position.

3.7.1.3 Windows

Absorber shall not be present in at certain positions in periphery of the rotor to permit the transmission of neutron. These positions are referred to as Windows.

Windows shall be 'fully open' i.e. without rotor material in beam in the open position.

Window height

Windows shall have vertical dimensions equal to or exceeding the height of the beam

Window width

The width and position of windows in the rotor are defined angularly with respect to the TDC. Se picture above for more information.

3.7.2 Operating frequencies and rotational direction

The rotor shall be operated at a selectable rotational frequency of 7Hz or 14Hz.

It shall be capable of rotating in both directions.

3.7.3 Beam geometry

The beam dimensions at the central plan of the rotor are 30mm high and 30mm wide.

3.7.4 Phase accuracy and jitter

The phase accuracy limits shall not exceed ±5µs at any operating speed.

The phase jitter shall not exceed 4µs at any operating speed.

3.7.5 Attenuation

The attenuation shall be 10^-6 or better, between 1Å and 30Å.

The attenuation shall be 1 or better, including and bellow 1Å.

The attenuation shall be 1 or better, including and above 30Å.

3.8 Axis 6

3.8.1 Rotor geometry

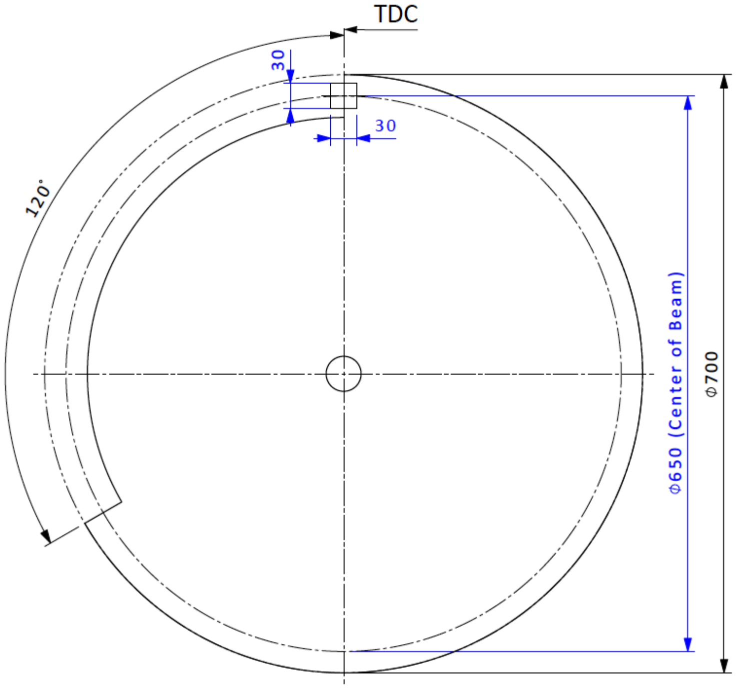

Figure 6 - Rotor 6 sketch

3.8.1.1 Rotor Diameter

The rotor diameter shall be 700mm.

The distance between the centre of rotation to centre of beam shall be 325mm.

3.8.1.2 Absorbing layer

The outer portion of all neutron chopper rotors shall be coated with neutron absorbing material such that the beam is interrupted in the closed position.

The height of the absorber shall exceed (vertically) by 10mm plus 10% of the optic interruption that of the incident beam at that position.

3.8.1.3 Windows

Absorber shall not be present in at certain positions in periphery of the rotor to permit the transmission of neutron. These positions are referred to as Windows.

Windows shall be 'fully open' i.e. without rotor material in beam in the open position.

Window height

Windows shall have vertical dimensions equal to or exceeding the height of the beam

Window width

The width and position of windows in the rotor are defined angularly with respect to the TDC. Se picture above for more information.

3.8.2 Operating frequencies and rotational direction

The rotor will operate at a selectable speed of 7Hz or 14Hz.

It shall be capable of rotating in both directions.

3.8.3 Beam geometry

The beam dimensions at the central plan of the rotor are 30mm high and 30mm wide.

3.8.4 Phase accuracy and jitter

The phase accuracy limits shall not exceed ±5µs at any operating speed.

The phase jitter shall not exceed 4µs at any operating speed.

3.8.5 Attenuation

The attenuation shall be 10^-6 or better, between 1Å and 30Å.

The attenuation shall be 1 or better, including and bellow 1Å.

The attenuation shall be 1 or better, including and above 30Å.

3.9 Axis 7

3.9.1 Rotor geometry

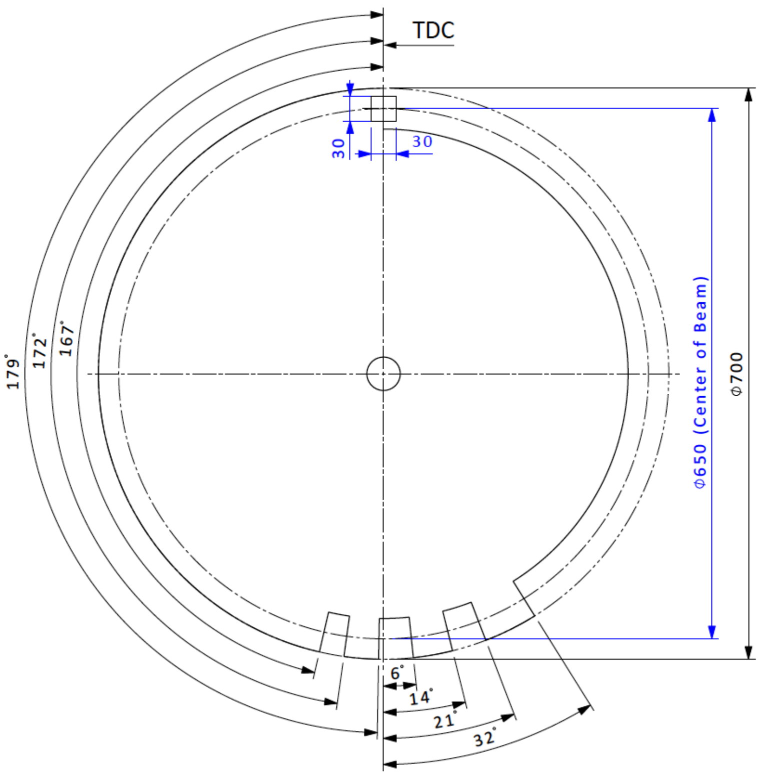

Figure 7 - Rotor 7 sketch

3.9.1.1 Rotor Diameter

The rotor diameter shall be 700mm.

The distance between the centre of rotation to centre of beam shall be 325mm.

3.9.1.2 Absorbing layer

The outer portion of all neutron chopper rotors shall be coated with neutron absorbing material such that the beam is interrupted in the closed position.

The height of the absorber shall exceed (vertically) by 10mm plus 10% of the optic interruption that of the incident beam at that position.

3.9.1.3 Windows

Absorber shall not be present in at certain positions in periphery of the rotor to permit the transmission of neutron. These positions are referred to as Windows.

Windows shall be 'fully open' i.e. without rotor material in beam in the open position.

Window height

Windows shall have vertical dimensions equal to or exceeding the height of the beam

Window width

The width and position of windows in the rotor are defined angularly with respect to the TDC. Se picture above for more information.

3.9.2 Operating frequencies and rotational direction

The rotor shall be operated at a rotational frequency of 14Hz.

It shall be capable of rotating in both directions.

3.9.3 Beam geometry

The beam dimensions at the central plan of the rotor are 30mm high and 30mm wide.

3.9.4 Phase accuracy and jitter

The phase accuracy limits shall not exceed ±5μs at any operating speed.

The phase jitter shall not exceed 4μs at any operating speed.

3.9.5 Attenuation

The attenuation shall be 10^-6 or better, between 1Å and 30Å.

The attenuation shall be 1 or better, including and bellow 1Å.

The attenuation shall be 1 or better, including and above 30Å.

3.10 Guide Interruptions

In order to reduce parasitic losses all length of interruption in the neutron optics required for choppers shall be reduced to the minimum reasonable possible.

The target value for the interruption in optics for a single rotor chopper assemblies is less than or equal to 50mm

4. LIST OF ABBREVIATIONS

Abbreviation	**Explanation of abbreviation**
ESS	European spallation source
NCG	Neutron chopper group
WSC-A	Wavelength selection chopper assembly
SOC-A	Sub-frame overlap chopper assembly
REC	Resolution enhancement chopper

DOCUMENT REVISION HISTORY

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1.4	Small changes and release	2014-12-08
1.3	New format	2014-11-05
1.1	Clarifications	2014-10-28
1.0	New draft for release	2014-09-25
0.4	Draft for release	2014-08-14
0.3	Draft	2014-06-06

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State	MXCurrent

Chopper system Non functional requirements

Generic instrument

Status : DRAFT version for discussion

Version : 0.1

Issue Date :

	Name	Date	Affiliation
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Distribution: Iain Sutton, Andrew Jackson, Clara Lopez

1. GENERAL REMARKS

1.1 Document scope

2. EXECUTION QUALITIES

Execution qualities are qualities, such as security and usability, which effect and are observable during the operation (and maintenance) of systems.

2.1 Equipment accessibility

2.1.1 Definition

Accessibility is defined as the degree to which a system or device, service is available to personnel to be installed, operated or maintained.

Accessibility may be quantified by, when starting from the normal operating configuration, the quantity of time or degree of effort required to achieve 'hands on access' to the system in question.

Many chopper components, such as chopper units and housings, will be installed within radiation shielding where access be restricted during the operation of the facility. In these areas accessibility will be very poor. Some chopper components, such as control equipment racks, will be installed outside of shielding within the instrument hall. In these areas accessibility will be good to poor.

Accessibility is strongly linked to equipment serviceability and availability.

2.1.2 Requirements

The following points have been identified as the general requirements for the accessibility of choppers.

Equipment accessibility zone classification

Black zone

- Direct access to systems and components shall be achievable within 8 hours.
- A clear access passage shall be provided vertically above equipment for all operational needs including the installation, adjustment, and removal.
- Human hands on access to equipment installed within the shielding following irradiation is prohibited.
- All installed equipment shall be
-

2.1.3 Associated requirements

- Chopper units shall be mounted above the guide
- All conections should runt through the connection plate and the pit head box.
- Hazardous maneuvers linked to the access of choppers shall be minimized to avoid both accidents and long-term damage.
- The disassembly of a chopper assembly to access its service parts should take no longer than one (1) hour.

- Access to the pit head should be possible within three hours after the source has shut down.

2.2 Equipment availability

2.2.1 Definition

Availability is defined as the degree to which a system, subsystem or equipment is in a specified operable and committable state at the start of a mission, when the mission is called for at an unknown, i.e. a random, time.

Simply put, availability is the proportion of time a system is capable of being used during a given interval of time.

To realize this the sub-systems need close to 100% availability.

Availability at the ESS is heavily dependent on four different factors;

- Schedule – If a breakdown occurs in an no access zone during the early part of a operation period, it could take a long time for it to be repaired.
- Shutter placement - Equipment placed upstream of adequate shutter can not be accessed for quick repair if broken. This means equipment can not be repaired until during a planned maintenance period, while the source is off.
- Beam separation - The tighter beams are bundled together the less independent they are. If the amount of lateral shielding is not sufficient to independently access an instrument, then its neighbours need to close down to gain access to the broken equipment. This lowers the facility availability.
- Instrument component reliability

2.2.2 Requirement

- The overall ESS goal is an availability of >95%.

2.3 Certification

2.3.1 Definition

Certification refers to the confirmation of certain characteristics of an object, person, or organization. This confirmation is often, but not always, provided by some form of external review, education, assessment, or audit.

In engineering terms the most common European certification is the CE-marking.

2.3.2 Requirement

Since the chopper system is not a commercial product available to the market, it will not need to be CE-marked.

The chopper components and system needs to be approved by appropriate internal safety and health standards available.

2.4 Compatibility

2.4.1 Definition

2.4.2 Requirement

Compatibility with facility systems such as

Equipment standards

Safety systems, MPS , PSS

2.5 Operating cost

2.5.1 Definition

In production, research, retail, and accounting, a cost is the value of money that has been used up to produce something, and hence is not available for use anymore. The cost does not only take in consideration the instant purchase cost, but should also include the cost of maintenance and decommissioning.

2.5.2 Requirement

2.6 Environmental protection

2.6.1 Definition

Environmental protection is a practice of protecting the natural environment on individual, organizational or governmental levels, for the benefit of both the natural environment and humans

The ESS has adopted an environmental protection policy that shall effect all parts of the company and the project, from development to operation and decommissioning.

The environmental protection regarding chopper systems can be split down into several different entities that all needs to be taken into account. These are:

- Energy consumption
  - Manufacturing
  - Operations
  - Maintenance
  - Decommissioning
- Radioactive waste
- Recycling of components
- Chemical waste
- Carbon emission
  - Manufacturing
  - Maintenance
  - Decommissioning

2.6.2 Requirements

The following environmental requirements have been identified for the chopper systems at the ESS:

- Each system shall undergo a life cycle analysis

2.6.2.1 Energy consumption

- During operations, according to the ESS energy plan, the total allocated energy consumption for chopper systems is 1,43GWh per year.
    - Based on 22 instruments, this transfers into an average of 64,9MWh per chopper system.

2.6.2.2 Radioactive waste

2.6.2.3 Recycling of components

2.6.2.4 Chemical waste

2.6.2.5 Carbon emission

3. EVOLUTION QUALITIES

3.1 Extensibility

3.1.1 Definition

Extensibility (not to be confused with forward compatibility) is a system design principle where the implementation takes future growth into consideration. It is a systemic measure of the ability to extend a system and the level of effort required to implement the extension. Extensions can be through the addition of new functionality or through modification of existing functionality. The central theme is to provide for change – typically enhancements – while minimizing impact to existing system functions.

Although forward compatibility and extensibility are similar, they are not the same. A forward compatible system can accept data from a future version of itself and pick out the "known" part of the data. An example is a text-only word processor ignoring picture data from a future version. An extensible system is one that can be upgraded to fully handle the new data in the newer input format. An example is the above mentioned word processor that can be upgraded to handle picture data or a browser that needs added functionality to successfully load and display certain document or file formats.

In systems architecture, extensibility means the system is designed to include hooks and mechanisms for expanding/enhancing the system with anticipated capabilities without having to make major changes to the system infrastructure. A good architecture provides the design principles to ensure this — a road map for that portion of the road yet to be built. Note that this usually means that capabilities and mechanisms must be built into the final delivery which will not be used in that delivery and, indeed, may never be used. These excess capabilities are not frills, but are necessary for maintainability and for avoiding early obsolescence.

Although usually applied to engineered systems involving software, it can be applied to any type of engineering. For example, houses can be built with future extensions in mind. The Prince Edward Viaduct located in Toronto, Ontario was built to accommodate a future subway line.

3.1.2 Requirement

The following extensibility requirements for chopper systems have been identified;

- During preliminary design, an upgrade plan should be made to plot potential instrument options.
- The system shall be designed to allow for these upgrades.
- The system shall allow for the replacement of obsolete components without altering the architecture of the system.

3.2 Failure recovery

3.2.1 Definition

3.2.2 Requirement

The following failure recovery requirements have been identified;

- In case of a failure, diagnostics and a complete system reset and restart shall be able to be executed from a remote location.
- In case of an emergency stop, remote restart is not required.
- Direct access should only be required in case of hardware failure.

3.3 Fault tolerance

3.3.1 Definition

Fault-tolerance or graceful degradation is the property that enables a system to continue operating properly in the event of the failure of (or one or more faults within) some of its components. If its operating quality decreases at all, the decrease is proportional to the severity of the failure, as compared to a naively-designed system in which even a small failure can cause total breakdown. Fault-tolerance is particularly sought-after in high-availability or life-critical systems.

A fault-tolerant design enables a system to continue its intended operation, possibly at a reduced level, rather than failing completely, when some part of the system fails.

Fault-tolerance is not just a property of individual machines; it may also characterise the rules by which they interact.

3.3.2 Requirement

- In case of a unit failure, the chopper system shall contain a limp-home function where the chopper can park in requested position to allow further use of the instrument.

3.4 Maintainability

3.4.1 Definition

In engineering, maintainability is the ease with which a product can be maintained in order to:

- isolate defects or their cause,
- correct defects or their cause,
- repair or replace faulty or worn-out components without having to replace still-working parts,

- prevent unexpected breakdowns,
- maximize a product's useful life,
- maximize efficiency, reliability and safety,
- meet new requirements,
- make future maintenance easier, or
- cope with a changed environment.

In some cases, maintainability involves a system of continuous improvement - learning from the past in order to improve the ability to maintain systems, or improve reliability of systems based on maintenance experience.

The chopper group at the ESS shall be able to perform the maintenance needed for the range of chopper systems in the facility. The capability is necessary to accommodate timeliness of repairs, work on activated equipment, transportation logistics, and the long-life nature of chopper systems.

3.4.2 Requirement

The following requirements have been identified:

- No in-pit equipment shall need maintenance more than once every five (5) years.
- No human access in the chopper pit should be allowed after installation is complete.
- Human access to the chopper pit during construction and installation is needed.
- Components should strive not contain materials with a cool down period of more than one week.
- All maintenance operations shall have a written and approved procedure.
- All systems containing fluids should have a leak tray or similar.
- All chopper assemblies should be able to be independently aligned.
- The alignment of equipment should be possible to adjust and control remotely.

3.5 Portability

3.5.1 Definition

Portability in high-level computer programming is the usability of the same software in different environments. The prerequirement for portability is the generalized abstraction between the application logic and system interfaces. When software with the same functionality is produced for several computing platforms, portability is the key issue for development cost reduction.

3.5.2 Requirement

The following requirements have been identified;

- The ESS chopper system needs to be able to integrate control systems from different suppliers
    - The integration should be made so different units could be swapped, changing as few components as possible.
- All same sized rotors shall have the same rotor/shaft interface.

3.6 Reliability

3.6.1 Definition

Reliability engineering is engineering that emphasizes dependability in the lifecycle management of a product. Dependability, or reliability, describes the ability of a system or component to function under stated conditions for a specified period of time. Reliability is theoretically defined as the probability of failure, the frequency of failures, or in terms of availability, a probability derived from reliability and maintainability. Maintainability and maintenance may be defined as a part of reliability engineering. Reliability plays a key role in cost-effectiveness of systems.

Reliability engineering is closely related to safety engineering and system safety, in that they use common methods for their analysis and may require input from each other. Reliability engineering focuses on costs of failure caused by system downtime, cost of spares, repair equipment, personnel and cost of warranty claims. The focus of safety engineering is normally not on cost, but on preserving life and nature, and therefore deals only with particular dangerous system failure modes. High reliability (safety) levels are also here the result of good engineering, attention to detail and almost never the result of only re-active failure management (Reliability Accounting / Statistics).

3.6.2 Requirement

3.7 Supportability

3.7.1 Definition

3.7.2 Requirement

3.8 Serviceability

3.8.1 Definition

In civil engineering, serviceability refers to the conditions under which a building is still considered useful. Should these limit states be exceeded, a structure that may still be structurally sound would nevertheless be considered unfit. It refers to conditions other than the building strength that renders the buildings unusable. Serviceability limit state design of structures includes factors such as durability, overall stability, fire resistance, deflection, cracking and excessive vibration.

For example, a skyscraper could sway severely and cause the occupants to be sick, yet be perfectly sound structurally. This building is in no danger of collapsing, yet since it is obviously no longer fit for human occupation, it is considered to have exceeded its serviceability limit state.

3.8.2 Requirement

- The chopper system should have an expected service life of 15 years.
- All electrical components should have been evaluated to plan for problems that render components obsolete.
- Upon delivery of system a complete spare parts list for the expected lifetime of the system should be provided.

3.9 Transportability

3.9.1 Definition

3.9.2 Requirement

The following requirements have been identified;

- No individual delivery unit shall be bigger than a standard EU-pallet, 1200mm*800mm
- Any individual delivery unit shall be movable by hand on a manual pallet truck and be liftable by a 1000kg crane.
- The maximum weight of an installation unit is 5000kg.
- All components heavier than 15kg shall have designated lifting points.
  - The only allowed lifting eyes are M12, M20 and M30.

3.10 Quality assurance

3.10.1 Definition

Quality Assurance (QA) is a way of preventing mistakes or defects in manufactured products and avoiding problems when delivering solutions or services to customers. QA is applied to physical products in pre-production to verify what will be made meets specifications and requirements, and during manufacturing production runs by validating lot samples meet specified quality controls. QA is also applied to software to verify that features and functionality meet business objectives, and that code is relatively bug free prior to shipping or releasing new software products and versions.

Quality Assurance refers to administrative and procedural activities implemented in a quality system so that requirements and goals for a product, service or activity will be fulfilled.

Two principles included in Quality Assurance are: "Fit for purpose", the product should be suitable for the intended purpose; and "Right first time", mistakes should be eliminated. QA includes management of the quality of raw materials, assemblies, products and components, services related to production, and management, production and inspection processes.

Suitable quality is determined by product users, clients or customers, not by society in general. It is not related to cost, and adjectives or descriptors such as "high" and "poor" are not applicable. For example, a low priced product may be viewed as having high quality because it is disposable, where another may be viewed as having poor quality because it is not disposable.

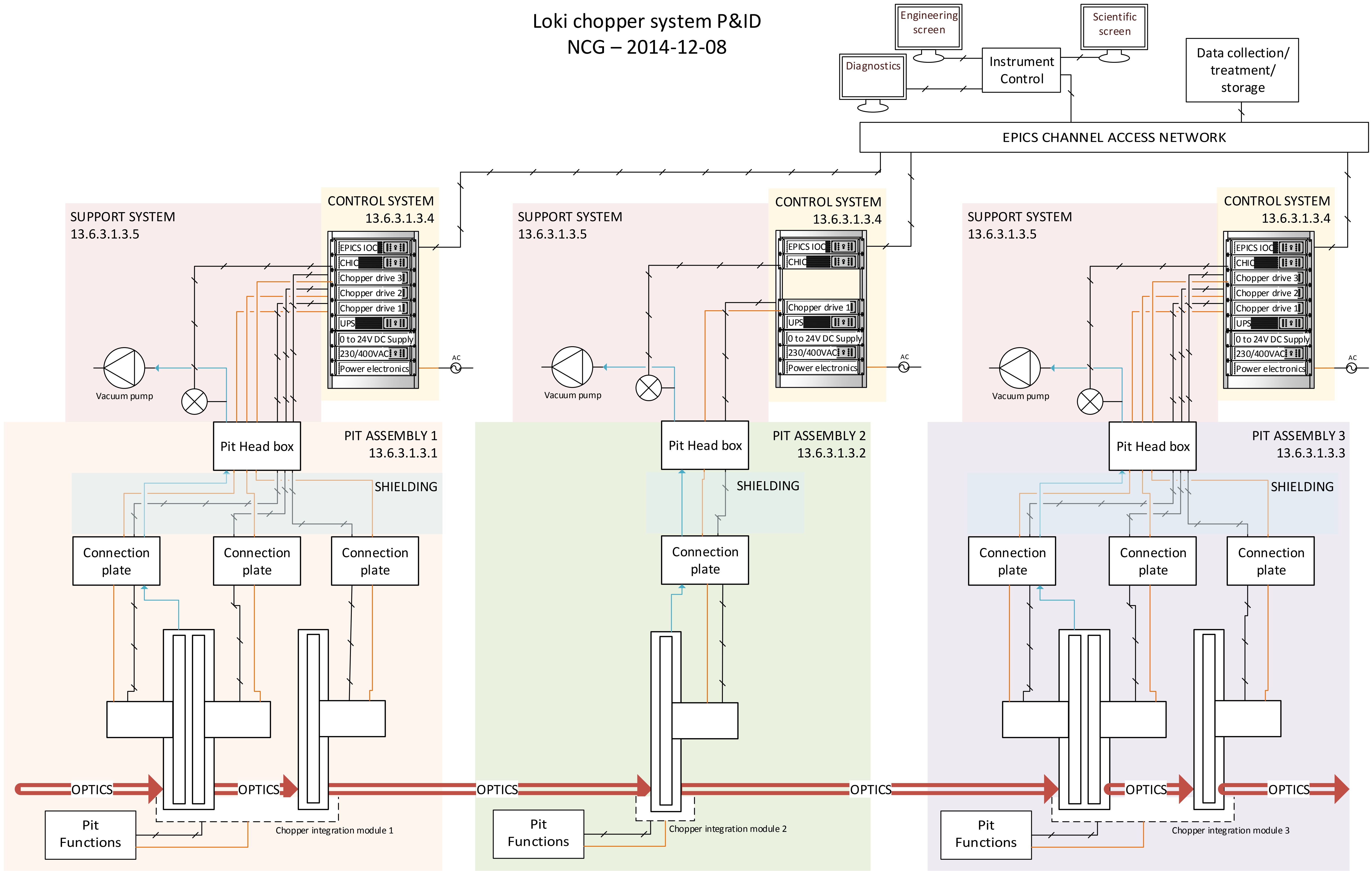
3.10.2 Requirement

3.11 Tracability

4. LIST OF ABBREVIATIONS

Abbreviation	Explanation of abbreviation
WBS	Work Breakdown Structure

WP	Work Package
WU	Work Unit
<<>>	<<>>



Loki chopper system P&ID
NCG – 2014-12-08
Engineering screen
Scientific screen
Diagnostics
Instrument Control
Data collection/ treatment/ storage
EPICS CHANNEL ACCESS NETWORK
SUPPORT SYSTEM 13.6.3.1.3.5
CONTROL SYSTEM 13.6.3.1.3.4
EPICS IOC
CHIC
Chopper drive 3
Chopper drive 2
Chopper drive 1
UPS
0 to 24V DC Supply
230/400VAC
Power electronics
AC
Vacuum pump
Pit Head box
PIT ASSEMBLY 1 13.6.3.1.3.1
PIT ASSEMBLY 2 13.6.3.1.3.2
PIT ASSEMBLY 3 13.6.3.1.3.3
SHIELDING
Connection plate
OPTICS
Pit Functions
Chopper integration module 1
Chopper integration module 2
Chopper integration module 3

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Document Number	MXName
Project Name	<<Project Name>>
Date	MXPrinted Date
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State	MXCurrent

NCG to Loki
Interface Control Documents

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TABLE OF CONTENT

1. INTRODUCTION

1.1 Purpose of the document

The Interface Control Document (ICD) between the Neutron Chopper System (NCS) and the Loki instrument collects and describes all the interfaces between these two systems. It is an agreed specification of the interface between the parties. It also lists the exceptions and amendments to the generic ICD to other stakeholders.

1.2 Definitions, acronyms and abbreviations

ICD Interface Control Document

NC Neutron Chopper

NCS Neutron Chopper System

NCG Neutron Chopper Group

ICS Integrated Control System

DMSC Data Management & Software Centre

E&E Electrical Engineering

CF Conventional Facilities

O&SG Optics and shielding group

2. CHARACTERISTICS OF THE SYSTEMS

2.1 NCS purpose

The neutron chopper systems task on an instrument is that together with the neutron optics shape the neutron pulse to fit the scientific experiment being excepted. The chopper system consist of one or several neutron chopper assembly. A neutron chopper assembly consist of one or several chopper axis. When rotating the axis shifts between absorbing and transmits neutrons, depending of its function and geometry.

A neutron disk chopper consists of a disc rotating perpendicular to the neutron flight path and has one or more apertures that allows neutrons to pass, while the reminder of the disc is coated with a neutron absorbing materials which attenuates the transmission of neutrons. All neutrons travel the same distance to the NC, but neutrons of different energies (and thereby velocities) will arrive at different times. Only neutrons of a certain velocity (energy) pass through the aperture (those that arrive when the aperture is aligned with the neutron flight path), while the others are absorbed by the NC. The NC will therefore be able to shape pulses differently depending on the scientific need.

2.2 Neutron chopper group role.

The ESS neutron chopper group is responsible ensuring the integration and operational support of all neutron chopper systems installed at the facility.

Integration and compatibility with the facilities infrastructure is managed through Interface control documents established between systems, in this case the neutron chopper system.

As part of the group's activities all the interfaces between chopper systems and the facility functions have been identified and parameterised in a suite of interface control documents for a generic instrument. These documents are customised to suit the specific requirements of instruments during initial phase of design.

2.3 NCS overview

Each beamline will have a NCS installed on it. Each beamline will specify its requirements for its NCS. Common for all is the large amount of integration needed. ESS will contain more chopper units then any other neutron source in the world. To be able to keep control and maintain this large amount of components, common interfaces, uniformly designed solutions and interchangeable components are key.

Installation requirements are influenced by available space; relationship to other beamline components such as neutron guides and shielding, but also to non functional requirements such as serviceability.

2.4 Generic systems schematic

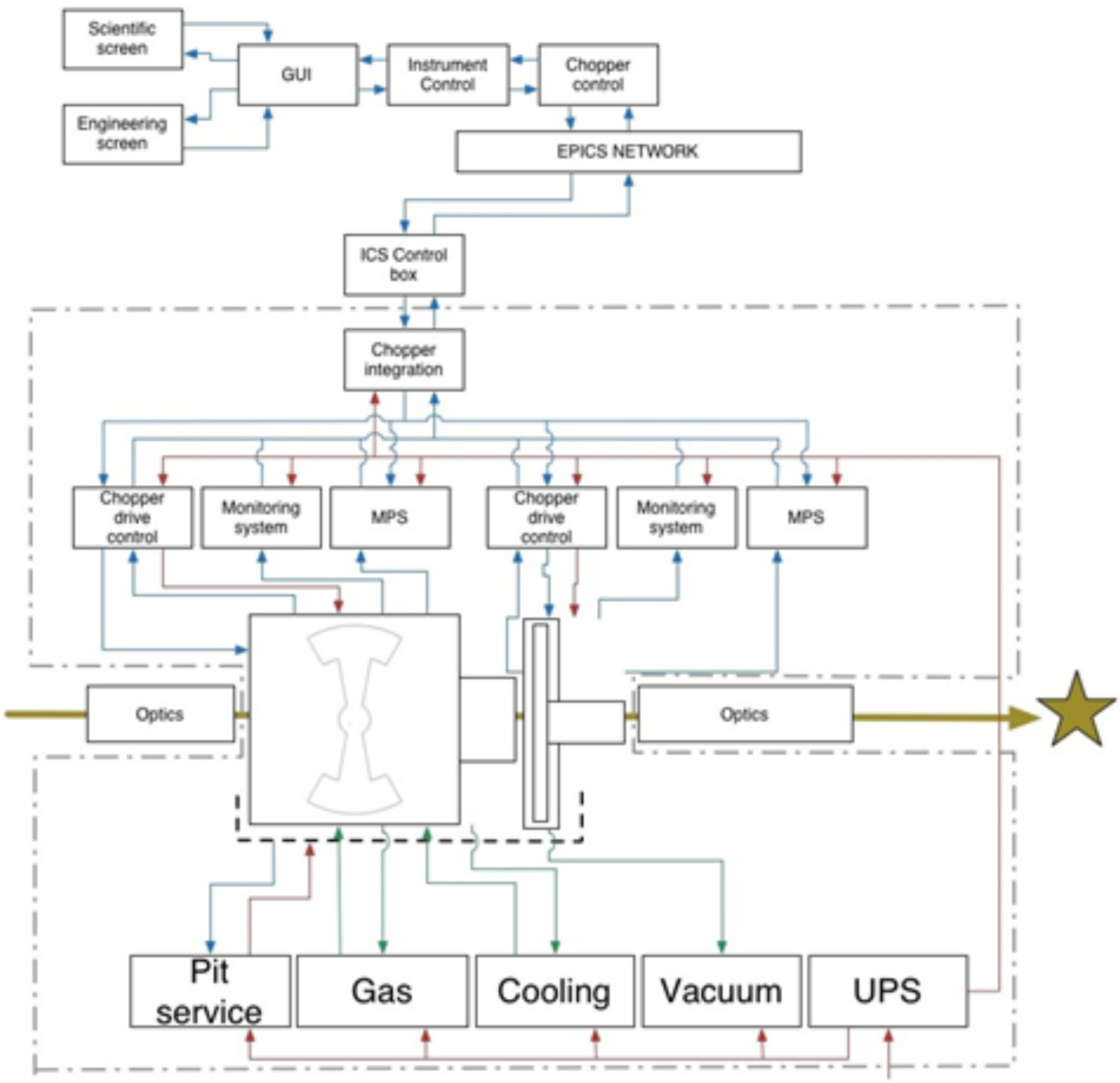

Figure 1. Generic system schematic

Shown above is an early draft of a system schematic and what systems the NC is interfacing with. As displayed the chopper system is composed of more than just the chopper assemblies. It this example a system of two units is combined in a single pit module. When the system complexity increases, so does the number of interfaces, especially the control system interfaces.

2.5 Instrument and instrument team

The instrument team is the team responsible for the overall delivery of the instrument. It usually consists of one or more scientists and one or more engineer. At the ESS the lead scientist is the project manager for the instrument project. An instrument consists of several work packages. The work packages that corresponds to the expertise of an ESS technical group falls into their respective scope of delivery, I.e. the chopper WP is part of the NCG scope and the optics WP part of the O&SG scope.

3. NCS AND LOKI INSTRUMENT INTERFACE

3.1 Relationship with other ICD

This ICD refers to the NCG ICDs to the other stake holders. It will list amendments and exceptions from those documents. Instrument unique interfaces are listed at the end of the document. These are interfaces not included in the generic documents, and that cannot be considered an amendment or exception from those.

3.2 Amendments and exceptions to ICD

3.2.1 NCG to Optics

All Interfaces between these functions are described and defined in the document.

XXX-YY-ZZZ v

3.2.1.1 Amendments

- Loki uses the type two installation configuration.

3.2.2 NCG to Shielding

All Interfaces between these functions are described and defined in the document.

XXX-YY-ZZZ v

3.2.2.1 Amendments

- Size of the extraction paths in the shielding shall be at least 1000mm wide, and enough length to extract the full chopper modules.

3.2.3 NCG to ICS

All Interfaces between these functions are described and defined in the document.

XXX-YY-ZZZ v

No amendments or exceptions.

3.2.4 NCG to DMSC

All Interfaces between these functions are described and defined in the document.

XXX-YY-ZZZ v

No amendments or exceptions.

3.2.5 NCG to Health and safety

All Interfaces between these functions are described and defined in the document.

XXX-YY-ZZZ v

No amendments or exceptions.

3.2.6 NCG to Vacuum

All Interfaces between these functions are described and defined in the document.

XXX-YY-ZZZ v

3.2.6.1 Amendments

- The Loki instrument will have an integrated vacuum system with extraction through the choppers. The pumps shall have sufficient effect to evacuate the system within 60 minutes to operating pressure.

3.2.6.2 Exceptions

- Vacuum control through the pit head box shall also be linked to the instrument control system.

3.2.7 NCG to Cooling

All Interfaces between these functions are described and defined in the document.

XXX-YY-ZZZ v

No amendments or exceptions.

3.2.8 NCG to E&E

All Interfaces between these functions are described and defined in the document.

XXX-YY-ZZZ v

3.2.8.1 Amendments

- Provisions for UPS equipment required to ensure chopper system operation is not included in the WU scope of supply. No space has been foreseen for the installation of UPS equipment within the Chopper racks.
-

3.2.9 NCG to CF

All Interfaces between these functions are described and defined in the document.

XXX-YY-ZZZ v

No amendments or exceptions.

3.3 Instrument unique interfaces

Routing of the cabling and piping between the pit head box and the chopper racks or other equipment is done by the instrument team. Specification and procurement of the cables and pipes is part of the Chopper group scope.

DOCUMENT REVISION HISTORY

Version	Reason for revision	Date
1.2	Document update for release	2014-12-08
1.1	E&E update	2014-11-06
1.0	Draft for release	2014-09-30

EUROPEAN SPALLATION SOURCE

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Document Number	MXName
Project Name	<<Project Name>>
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In-kind plan
Loki chopper system

Status : FINAL DRAFT for approval

Version : 1.0

Issue Date :

	Name	Date	Affiliation
Authors	Erik Nilsson		NCG
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TABLE OF CONTENT

1. INTRODUCTION

The neutron chopper group is responsible for the fulfilment of the facilities needs for neutron choppers systems and their support functions throughout the facilities construction and operation.

The following document describes the strategies for In-kind contributions for the Loki instrument chopper system

1.1 Document scope

This document describes the specific strategies and plans for the In-kind contribution to the Loki chopper system. This document will describe how to apply the strategies, for Loki, described in the document 'NSS strategy for chopper fulfilment'. Refer to this document for any general strategies and justifications.

1.2 Chopper system description

The neutron chopper system of Loki is foreseen to consist of two double disc chopper assemblies and three single disc chopper assemblies. The double disc chopper assemblies are; the wavelength selection chopper assembly (WSC-A) and the sub-frame overlap chopper assembly (SOC-A). Both are considered to be face-to-face, counter rotating, double disc choppers, each containing two axis named axis 1 and axis 2. The single disc chopper assemblies form a resolution enhancement system (REC-1, REC-2 and REC-3).

The system consists of three chopper pits. Pit 1 contains the WSC-A and the REC-1, pit 2 the REC-2 and pit 3 the SOC-A and the REC-3.

The chopper system consists of all components, software and hardware needed to operate and maintain the chopper system. For more information on the boundaries of the chopper system, refer to the interface documents.

1.3 Objectives

The following are the objectives of the delivery of the Loki chopper system, in the given order.

1. Deliver a functional chopper system that meets the instrument requirements, both functional and non-functional
2. Deliver the chopper system on time and budget for the Loki instrument
3. Maximise the In-kind contribution to the delivery

1.4 Assumptions

In accordance with the 'NSS strategy for chopper fulfilment', the following assumptions are being made in this document:

- The ESS chopper group has authority over the design choices and schedule for the delivery of the Loki chopper system
- The ESS chopper group has authority over the selection of partners for the delivery.

- The requested resources are available in the chopper group or its partners, at the time they are needed.

2. IN-KIND PLAN LOKI CHOPPER SYSTEM

The Loki chopper system will be a standard ESS chopper design. It will follow the guidelines and requirements in the ESS chopper handbook.

The detailed design adaptations the chopper system needs will follow the ESS chopper handbook guidelines and requirements. ESS chopper group approved equipment will be used. After the overall system design and choices, the detailed design and drafting can be performed by and outside partner, or in house at the ESS. An overhead ESS chopper group member needs to supervise the work.

Since the choppers and its pit system is design according to ESS chopper group standards and guidelines, an outside partner (build partner) can produce, assemble and do the initial sub-assembly verification and validation. The ESS chopper group will supply standard test procedures, this is a part of the ESS chopper handbook. Critical long lead-time component procurement and testing will be handled by the ESS chopper group and supplied to the build partner.

On site the ESS chopper group will do final integration of the full chopper system. This also includes the integration of the chopper system to the ICS control units. Temporary, short term, resources can be supplied by the partners for system integration, installation and commissioning.

It is not needed that the same partner performs all parts of the Loki chopper delivery. One partner can do the design and procurement of one sub-system while another is doing the integration and testing of another. Demands on capabilities and equipment will be different depending on what scope of work each partner takes on. This will be decided early in phase 2.

DOCUMENT REVISION HISTORY

Version	Reason for revision	Date
1.0	New Document	2014-10-23

RISK LIST LOKI CHOPPER SYSTEM

ID	Raised by	Date raised	Category	Description	Pro.	Imp.	Score	Consequence	Action(s)	Owner
1	EN	10/20/14	Design	Delays on choice of in-kind design partners	4	2	8	Delay to project	Early focus on design resources	NCG
2	EN	10/20/14	Design	Design issues getting access to horizontal split flange	3	4	12	Design change, potentially performance drop	Early design focus in detailed design	NCG
3	EN	10/20/14	Design	Design budget cut	4	3	12	Uncertainty in installed equipment	Front load detailed design	Instrument
4	EN	10/20/14	Design	New rotor design failure	2	5	10	Delay to project	Build prototype during 2015 and test on technology demonstrator	NCG
5	EN	10/20/14	Design	ESS small rotor integration study delay	1	5	5	Delay to project	Assist small rotor project	NCG
6	EN	10/20/14	Design	Interface and scope of work is unclear	3	4	12	Rework and/or duplication of effort	Push for finalisation of interface control documents early on 2015	Instrument
7	EN	10/20/14	Design/Procurement	Choice of in-kind partners is removed from NCG	3	5	15	Quality issues/standardisation issues	None	Management
8	EN	10/20/14	Design/Procurement	Package ownership removal	2	5	10	Installation/quality/standardisation issues	None	Management
9	EN	10/20/14	Procurement	Unable to buy key components in bulk	4	3	12	Extra cost	Decision for procurement early in project	Instrument
10	EN	10/20/14	Integration	Lab-space not available for integration	1	4	4	Delay to project	Move integration space to halls or other temp. space (tent?)	NCG
11	EN	10/20/14	Integration	Guides for chopper integration is not delivered	4	3	12	Delay to project/quality issues	Run integration without guides	Optics
12	EN	10/20/14	Installation	Not enough installation personnel	5	1	5	Delay to project/quality issues	None	Instrument
13	EN	10/20/14	Installation	No access to halls in time for installation	2	5	10	Delay to project/quality issues	None	CF
14	EN	10/20/14	Installation	No access to beam port on schedule	4	3	12	Delay to project/quality issues	None	Target
15	EN	10/20/14	Installation	Beam guide insert not ready	3	2	6	Delay to project/quality issues	None	Optics
16	EN	10/20/14	Installation	Target/accelerator tests during installation	1	2	2	Delay to project/quality issues	None	Target
17	EN	10/20/14	Installation	Late delivery of long-lead-time components	2	2	4	Delay to project/quality issues	Investigate long-lead-time purchases early	NCG
18	EN	10/20/14	Installation	Infrastructure failure during installation	1	4	4	Delay to project/quality issues	None	CF
19	EN	10/20/14	Commissioing	ICS control system/timing access delay	2	5	10	Delay to project	Have ICD ready	ICS
20	EN	10/20/14	Commissioing	DMSC chopper control delay	4	1	4	Delay to project	Have ICD ready	DMSC