

ESS Engineering Days

ESS neutron chopper group

Information for Instrument teams commencing Phase 1

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Group leader,
on the behalf of the Neutron Chopper Group

www.europeanspallationsource.se

2 June 2015

Presentation Plan

- Intro
- Work flow in Phase I
- Engineering activities
- Project activities
- Interfaces
- Standards
- Wrapping up

ESS Instrument technologies

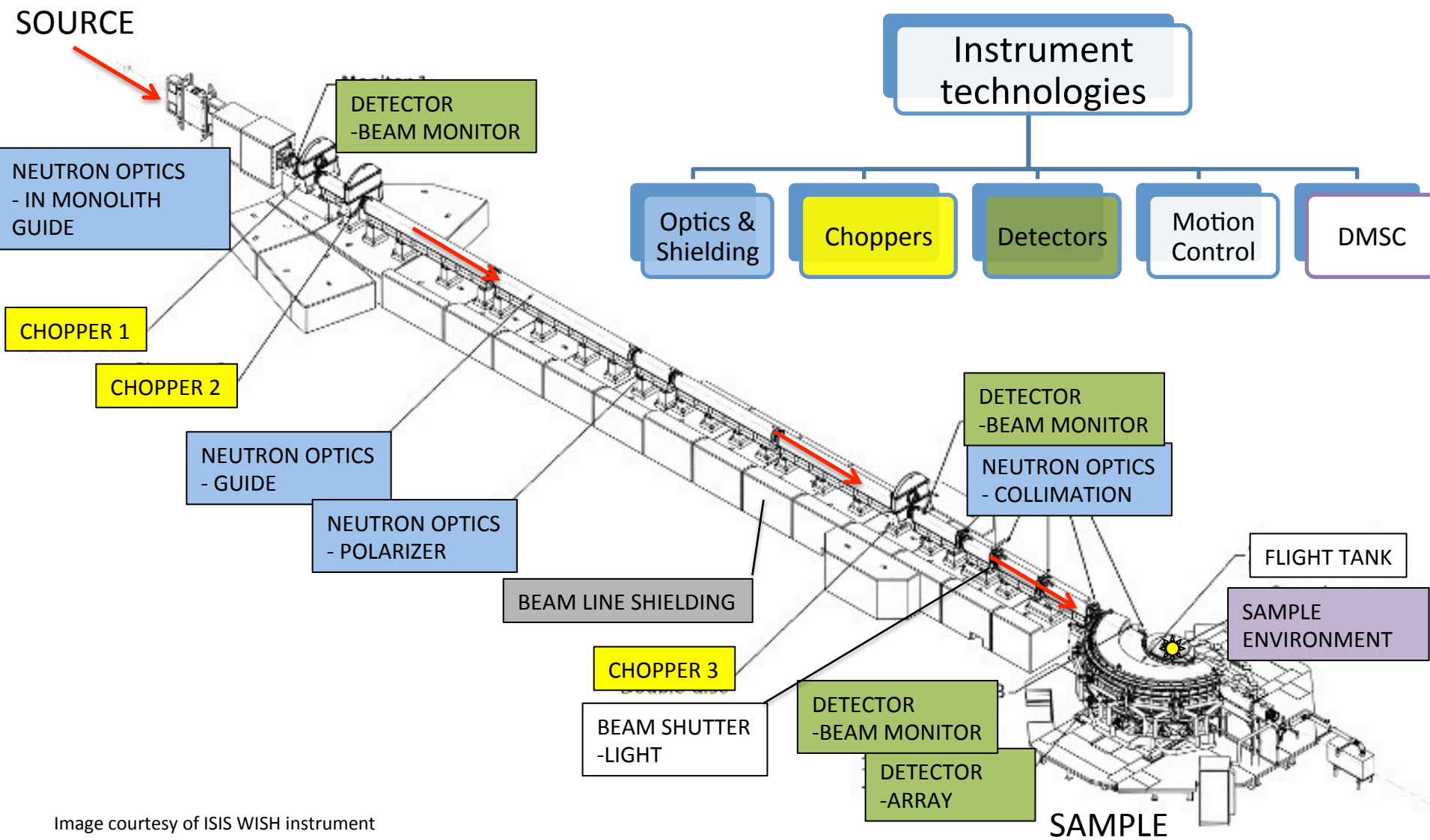


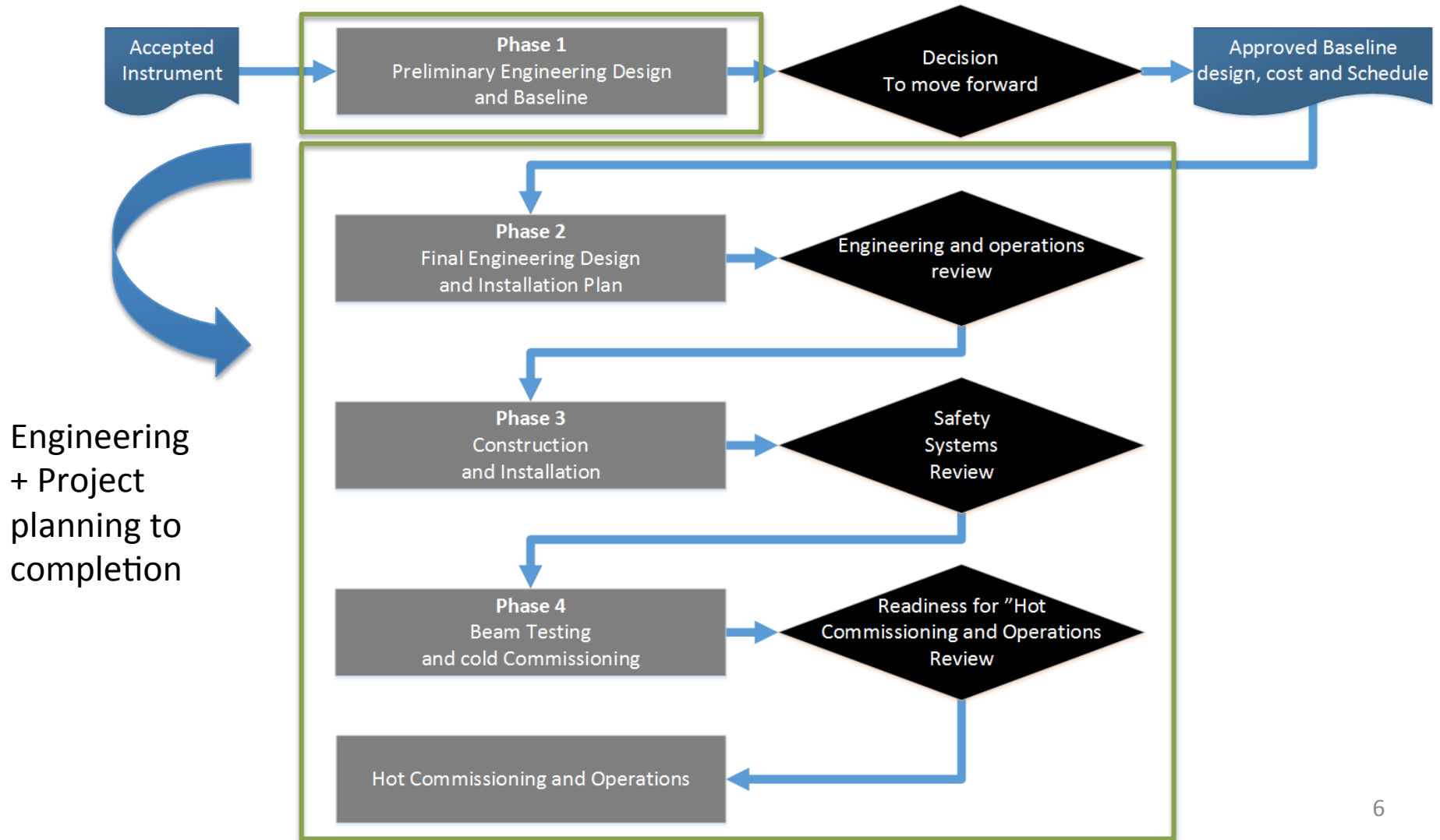
Image courtesy of ISIS WISH instrument

SUPPORT ENABLE INTEGRATE



DAREK PPSc	ERIK Mech integration	NICKLAS Control Eng	IAIN Paperwork	MARKUS Disc Choppers	NIKO Hybrid	GABOR Mech Eng
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The Instrument Construction process



Phase I - Preliminary design from proposal to project...

PRELIMINARY DESIGN PHASE

<TG2>

Exploration of Requirements

Functional analysis

Concept generation and evaluation

Concept development

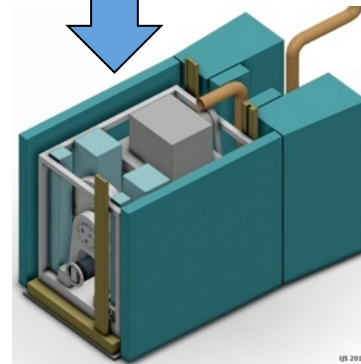
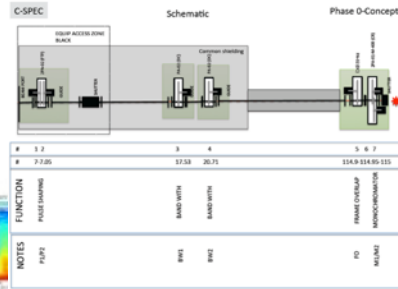
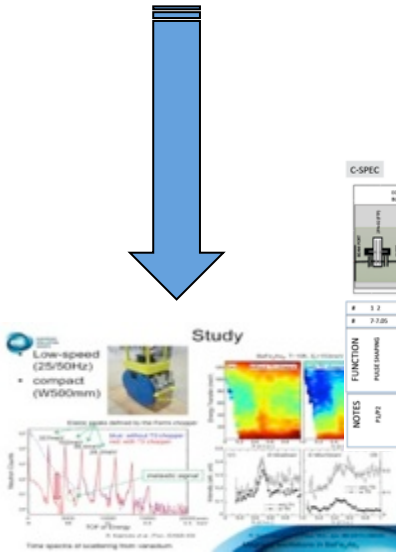
Design report
Project plan
Toll gate 2



ESS Instrument Construction Proposal CAMEA

Please read the call for instrument proposals found at www.esrf.eu/proposals and the "Preparation and Review of an Instrument Construction Proposal" to guide you in preparing your instrument construction proposal.

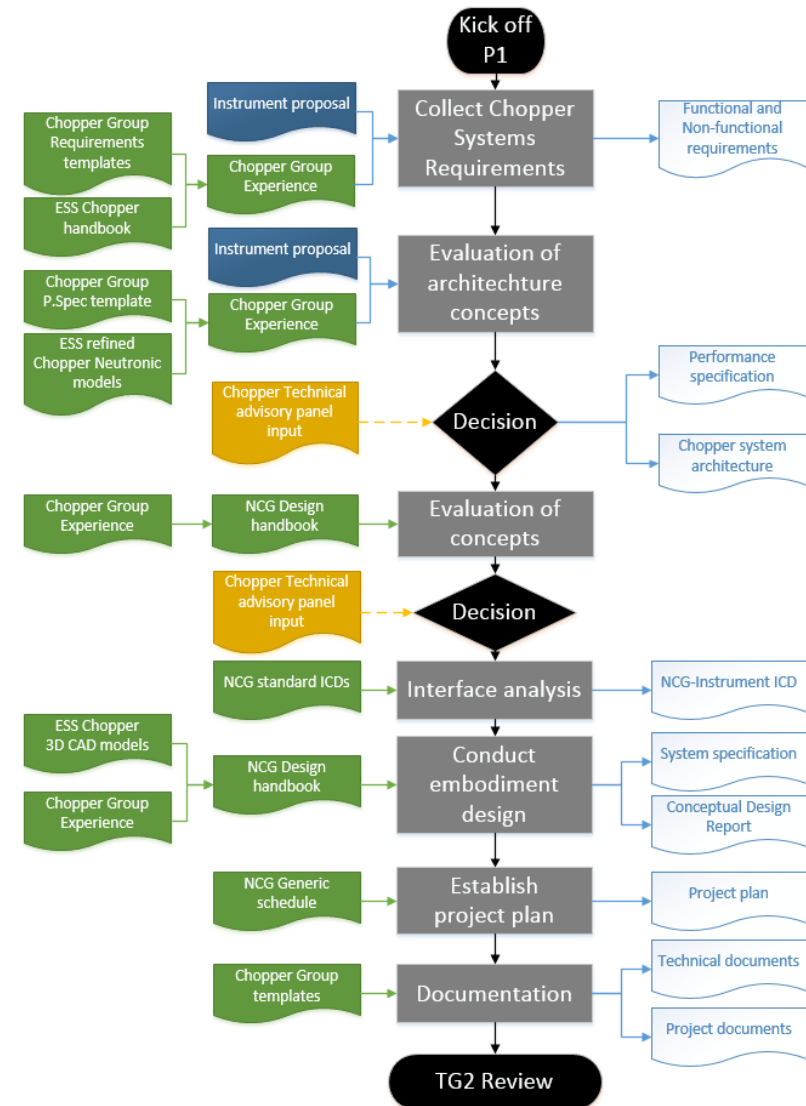
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Phase I Workflow

Key areas of support & guidance

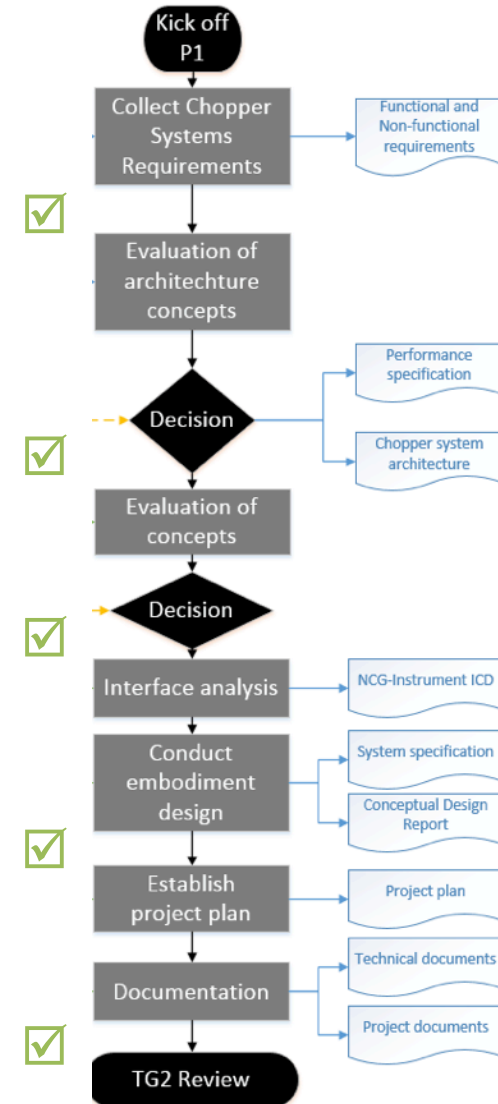
- Chopper documents
 - Standards & requirements
 - Interfaces
 - Strategies
 - Guidelines
- Design support
- Basic CAD models
- Neutronic Simulation



'check points'

- Regular meetings to coordinate with internal activities and receive input.
- Check points along the design process at major decisions to ensure that chosen solution is compatible with ESS standards & requirements.

ESS coordination 'check points'



Answer the question !

- Is it technically feasible to construct a chopper system meeting the stated performance requirements and which can be operated and maintained during the service life of the instrument ?

Design report

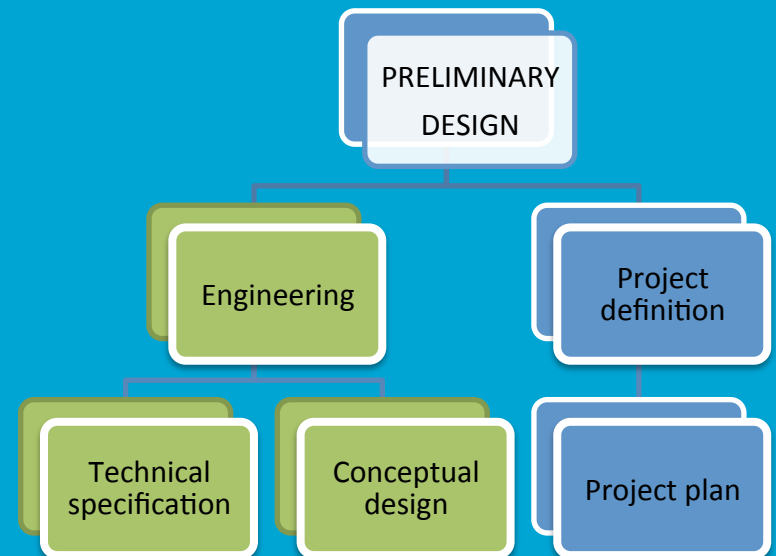
- Can this be done with the instruments budget and schedule constraints and at an acceptable level of risk ?

Project plan

SUPPORT
ENABLE
INTEGRATE

- SUPPORT to INSTRUMENTS

Preliminary Design Phase
- Engineering support



Activity 01

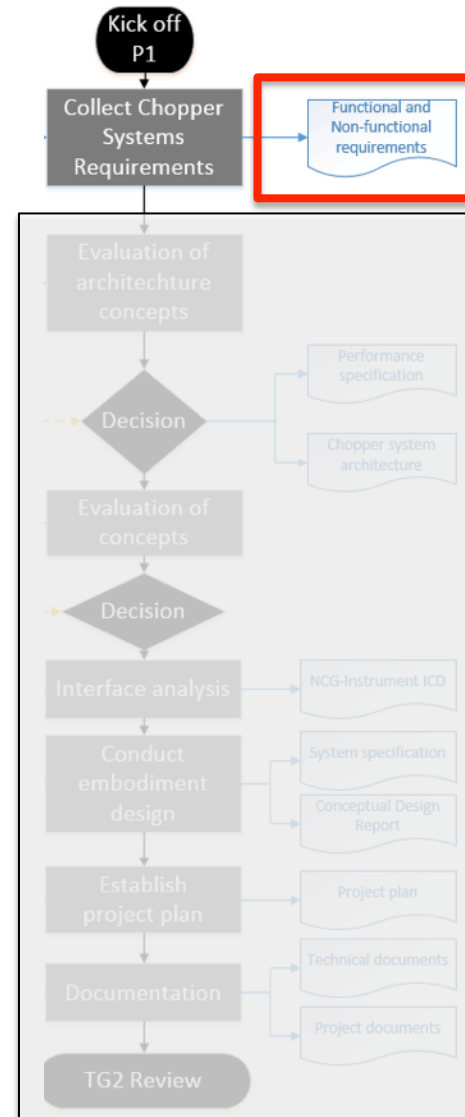
Requirements collection

FUNCTIONAL REQUIREMENTS

- 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 attenuate the transmission of neutrons outside of selected wavelength band.

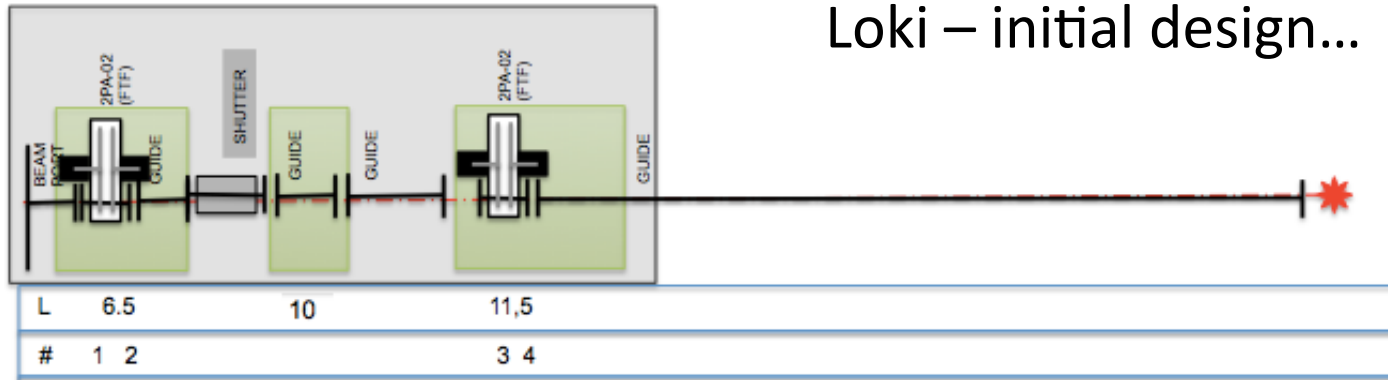
OPERATIONAL REQUIREMENTS

- The chopper system shall be functionally and operationally compatible with chopper support systems at the facility.
- Compatibility with ESS interfaces
- Equipment accessibility
- Equipment RAM
- Certification
- Compatibility with target operating costs
- Environmental protection
- Decommissioning



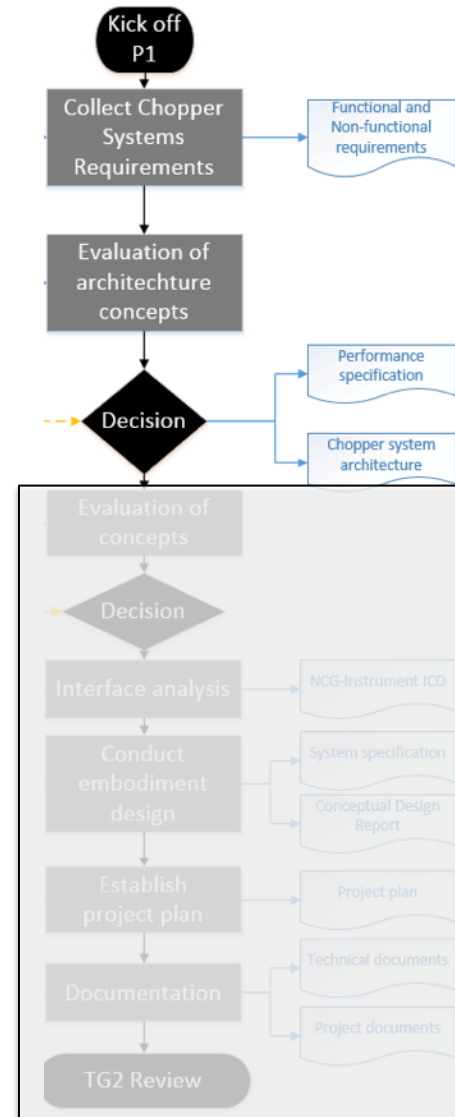
Activity 02

Establish of a baseline architecture



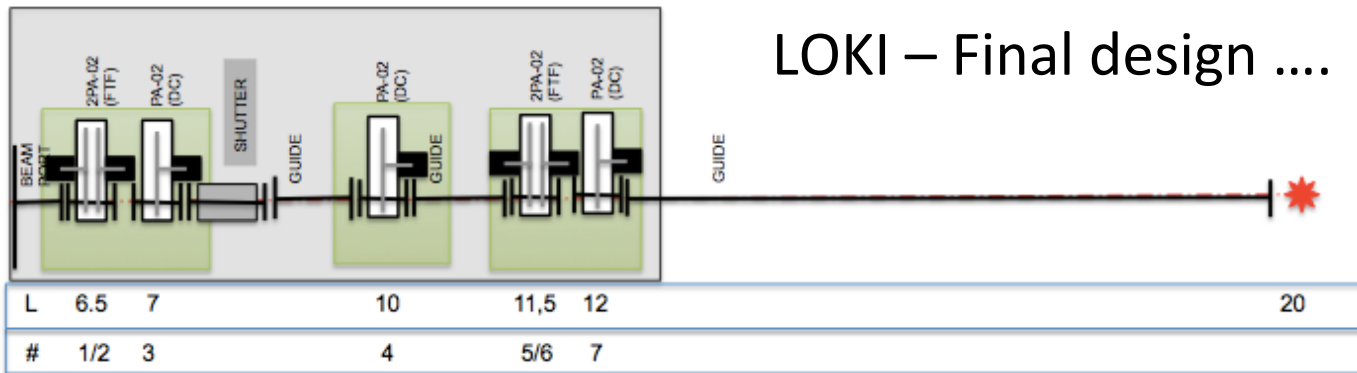
Establish the ‘architecture’ of the instrument chopper system such that it may be

- A common reference for all parties
- Simulated
- Explored and Improved!



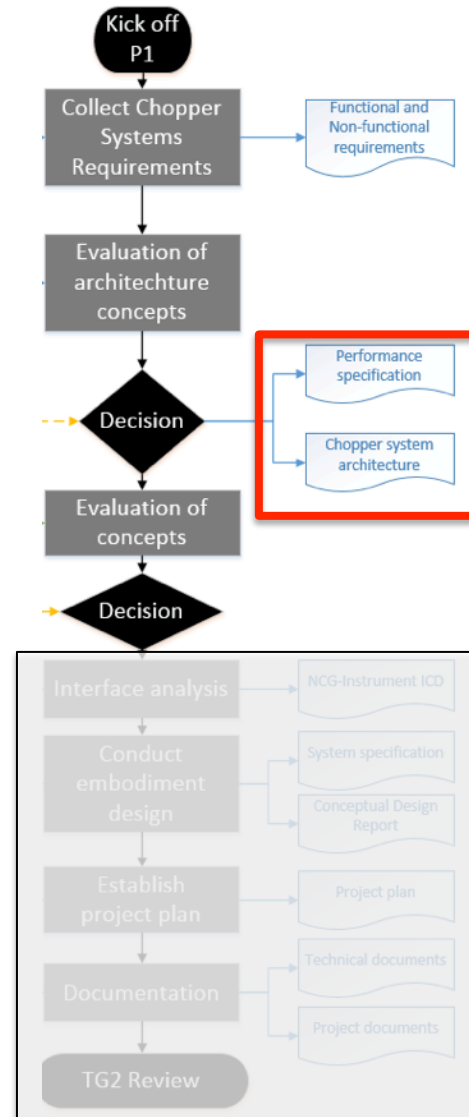
Activity 03

Evaluation of functional variants



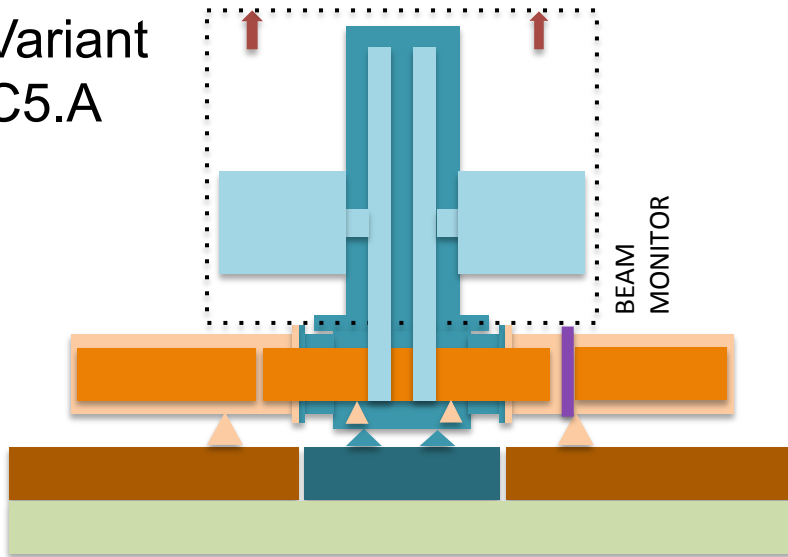
- Explore variants
- Include facility operational requirement and constraints
- Interfaces
- Explore instrument upgrade & staging approaches
- Develop rough costing
- Establish performance specification
- Simulate performance

Evaluate & select within the team the best overall concept for instrument overall.



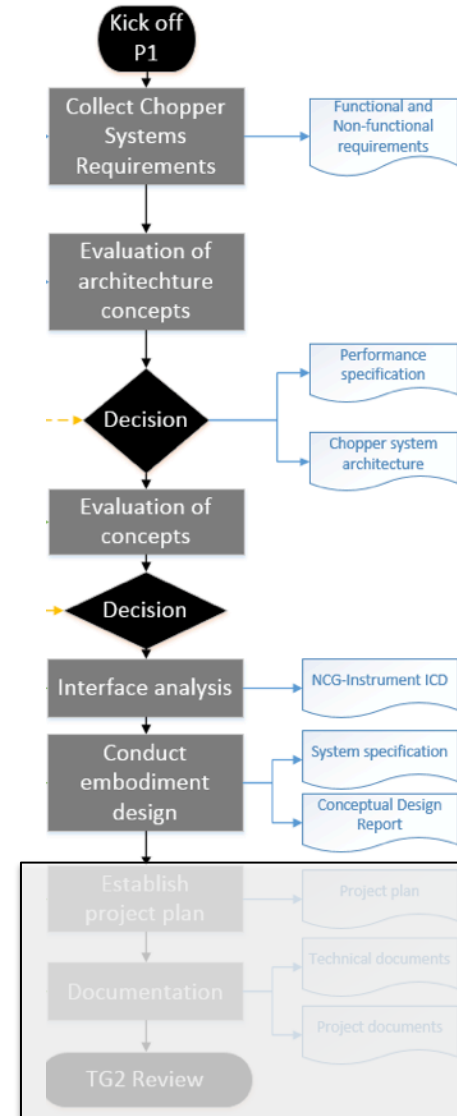
Activity 04 Implementation

Variant C5.A

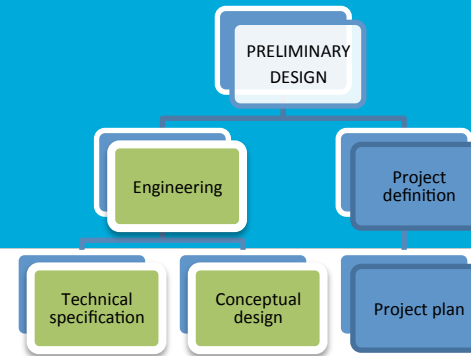


EXAMPLE of C5A from ILL IN5

- Consider 'operational aspects'
 - Installation
 - Maintainability
 - Mechanical and service interfaces
- Packaging
- Failure & Spares



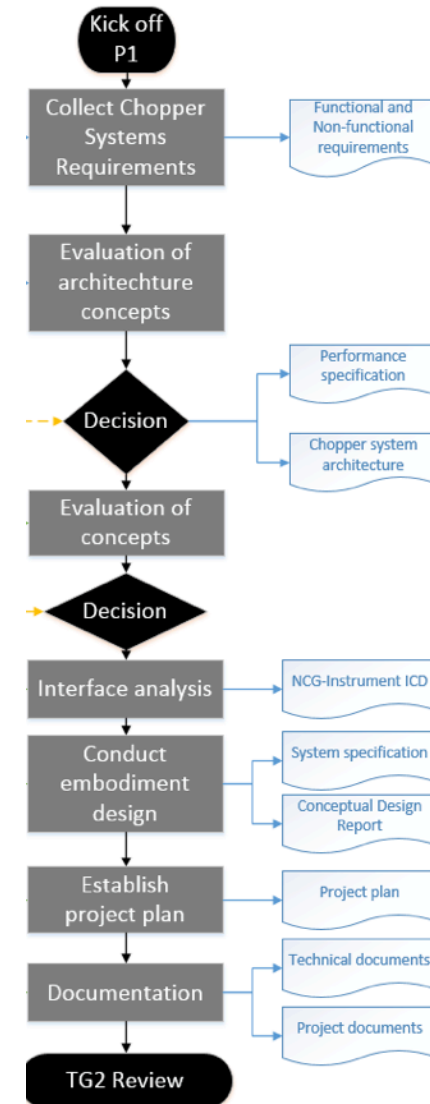
Activity 05 Documentation



- Chopper System Overview
- Chopper System Functional Requirements
- Chopper System Operational Requirements
- Chopper System Specification
- Chopper System Conceptual Design Report
- Chopper System Supply Project Plan
- Chopper System Risk Analysis

- A1 - Product Breakdown Structure (PBS)
- A2 - Project Schedule
- A3 - Work Unit Spreadsheet
- A4 - Chopper Work Unit Definition

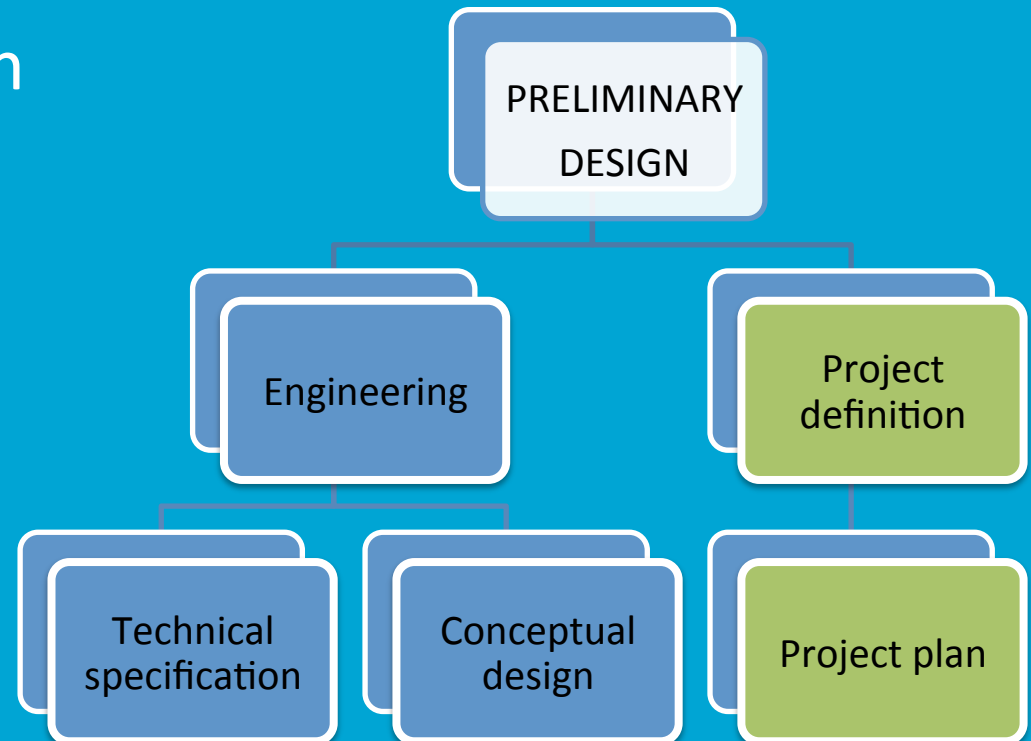
'Technical' documents



Phase I

Preliminary design

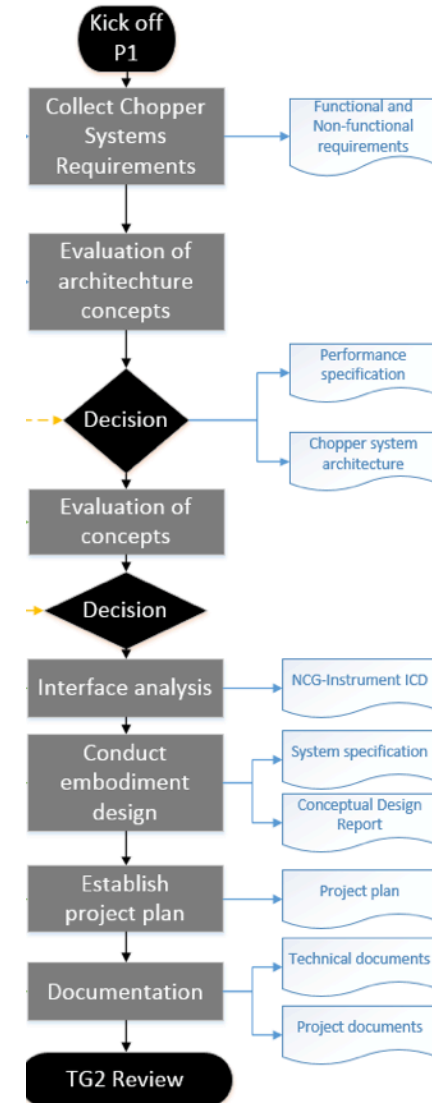
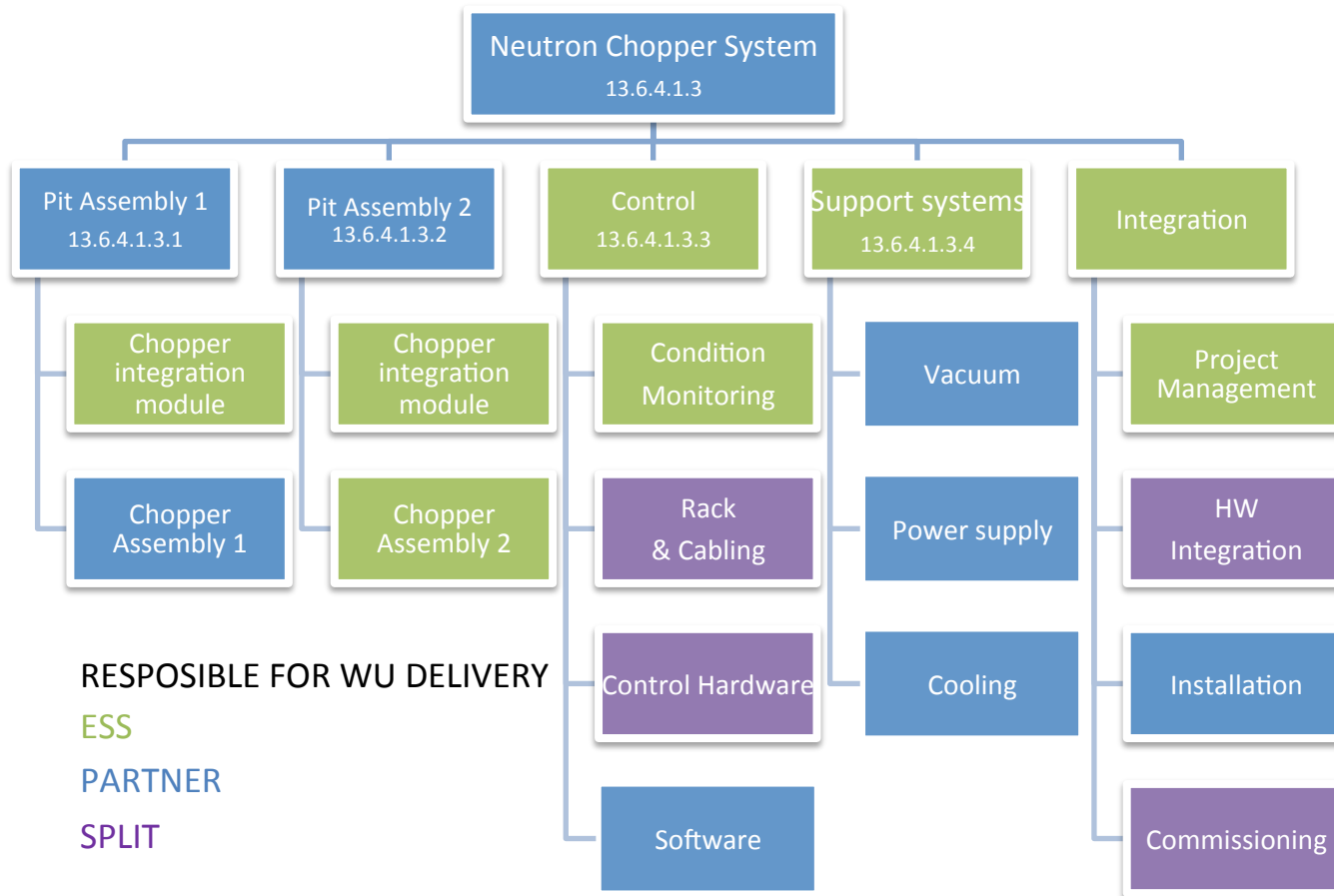
Project documentation



Phase I

Chopper systems Project plan

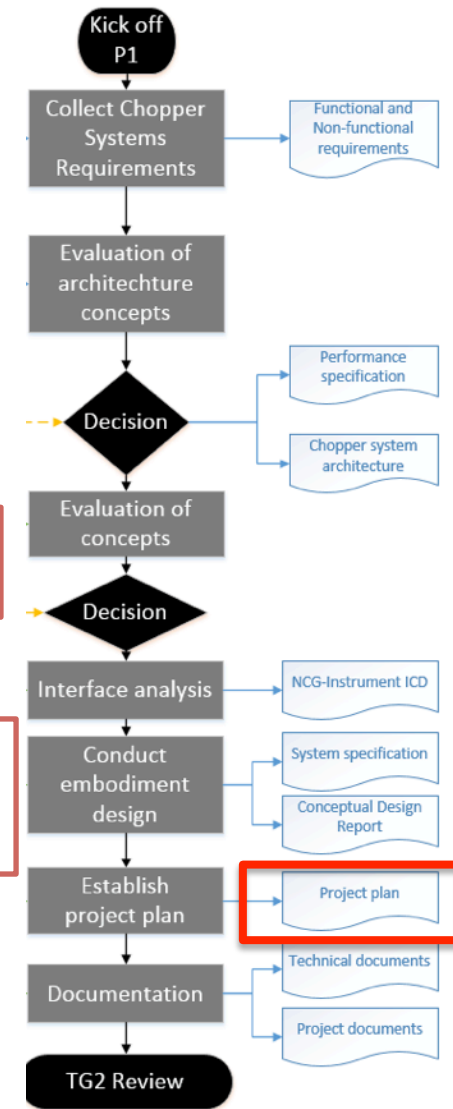
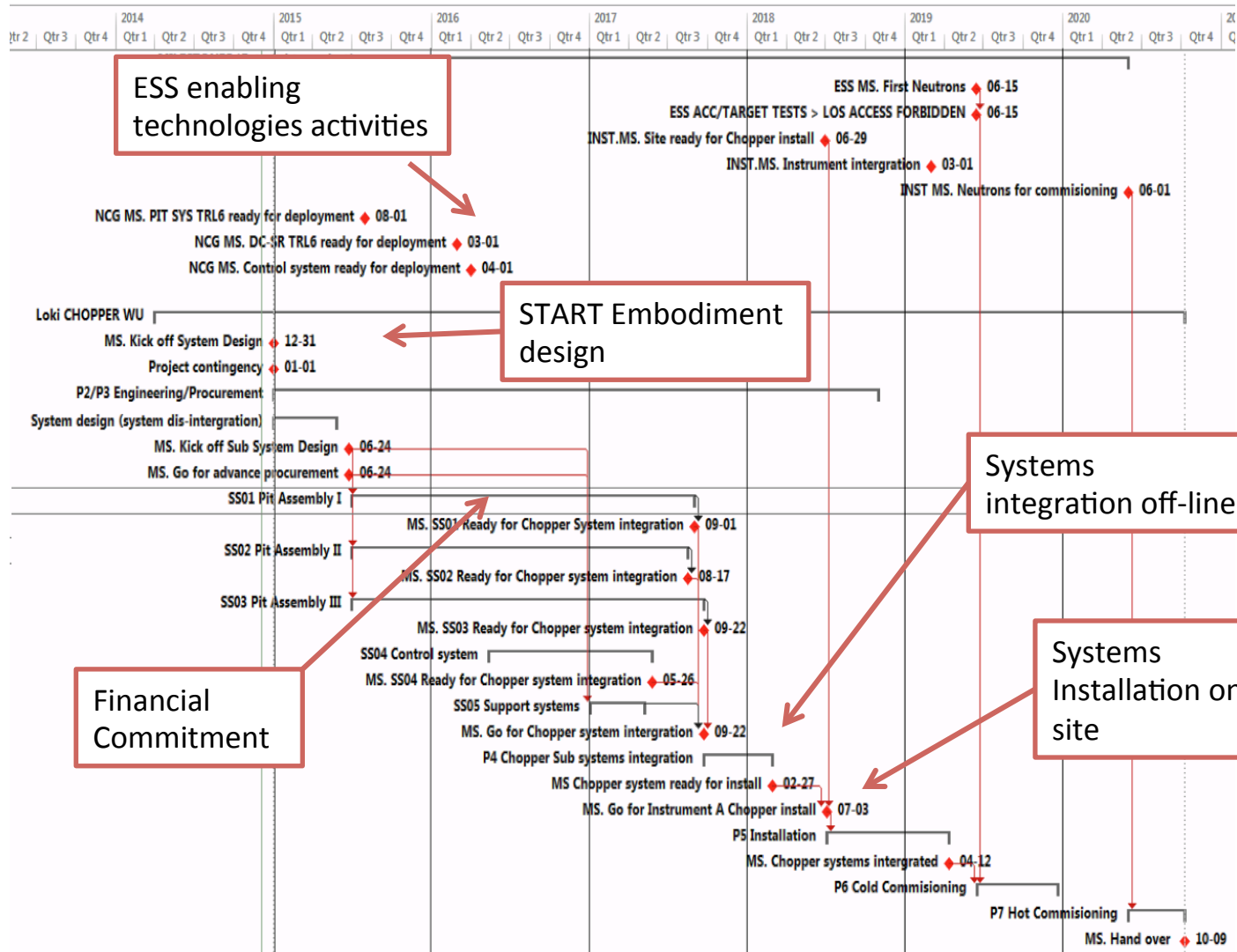
- WBS



Phase I

Chopper systems project plan

- Schedule till completion



Phase I

Chopper systems project plan

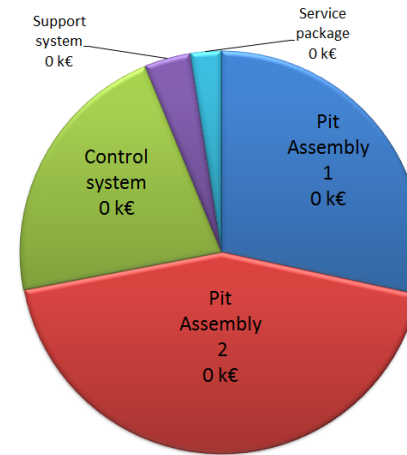
- resource estimates

Establish resource budgets

- Hardware cost estimates
 - Direct costs
 - Indirect costs
- Manpower estimates
 - Direct manpower
 - Indirect

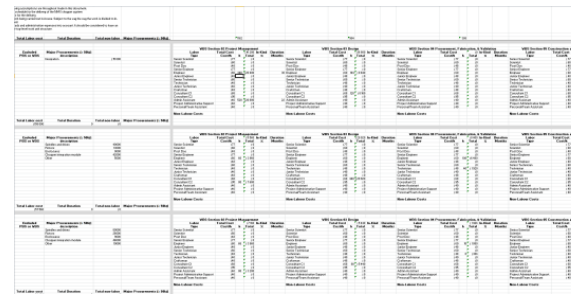
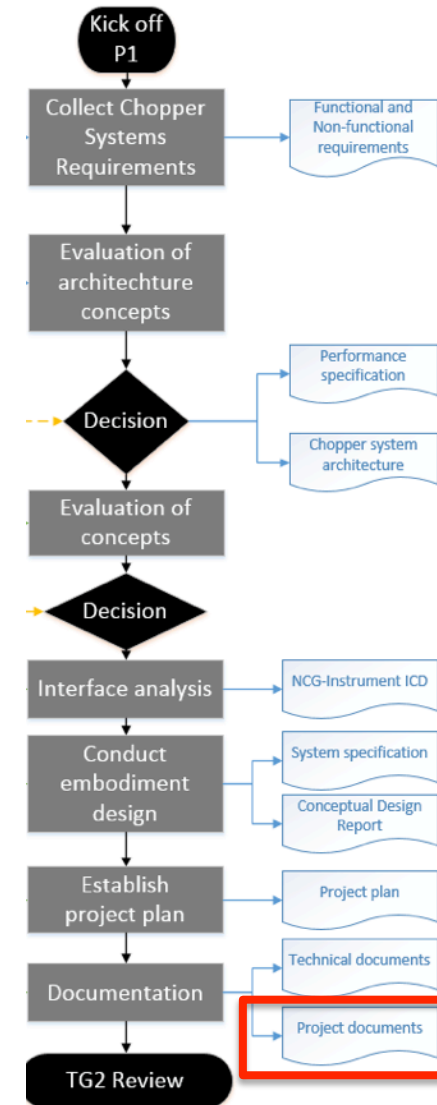
Including on-site activities!

- Integration
- Installation
- on-site service connections



Resource \ WBS Section	WBS S02 Prj Man	WBS S03 Design	WBS S04 Procurement	WBS S05 Install	WBS S06 Cold Comm	Total
Engineer (h)	000	000	000	000	000	0000
Technician (h)			0000	000	000	0000
Consultant (h)		000				000
Admin (h)	000					000
Total	0000 h	000 h	0000 h	000 h	000 h	0000 h
Manpower cost	00 k€	00 k€	000 k€	00 k€	00 k€	00 k€

Estimated error bar is -30% to +30%

Phase I

Chopper systems project plan

- RAM & Risk

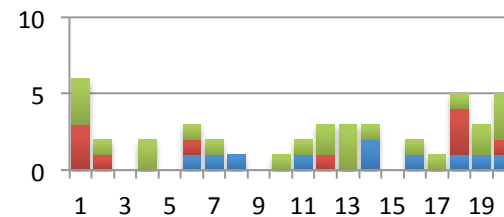
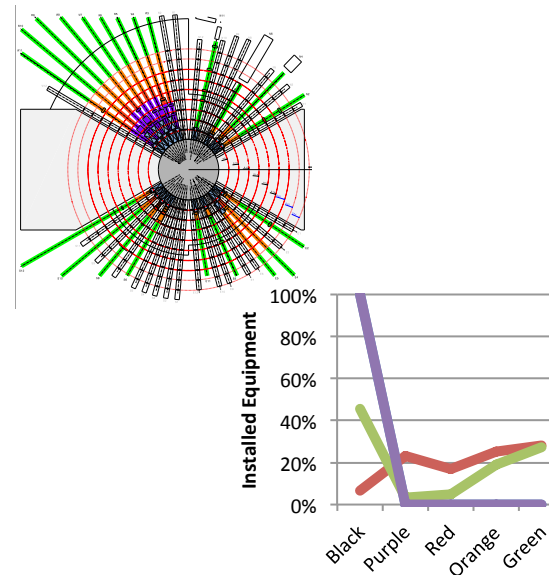
Technical risks

- Failure mode analysis
- Safety assessments
- Reliability-Availability & Maintainability assessments
- Operating strategy

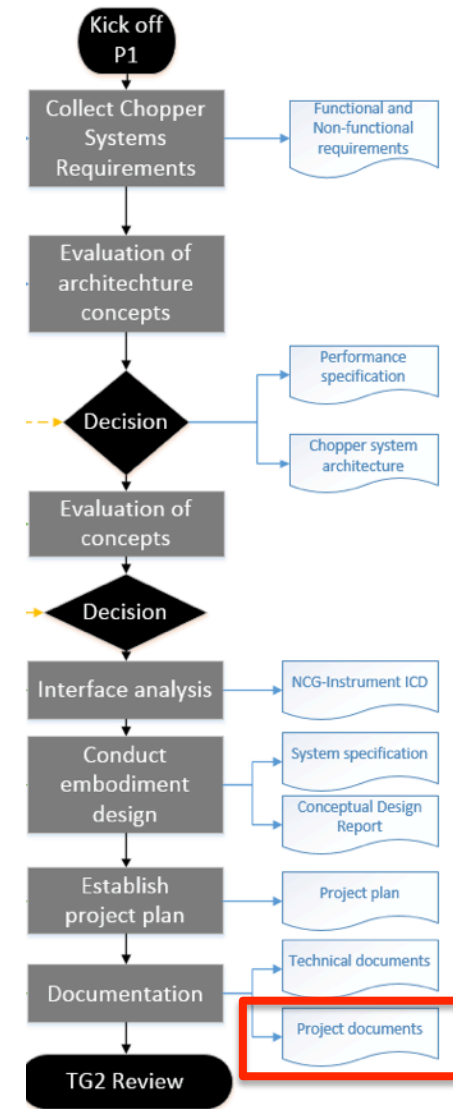
Project risks

- Schedule risk
- Critical component supply

Ensure compliance with operational requirements and strategies



RISK LIST LOKI CHOPPER SYSTEM										
ID	Source	Risk level	Category	Description	Pos.	Imp.	Score	Consequence	Active	Accepted
1 DR	SS2014	Design	Design	Design on basis of in-kind design partners	4	2	8	Design on basis of in-kind design partners	Yes	Yes
2 DR	SS2014	Design	Design	Design issues impacting access to horizontal light flange	3	4	12	Design issues impacting access to horizontal light flange	Yes	Yes
3 DR	SS2014	Design	Design	Design layout cost	4	3	12	Design layout cost	Yes	Yes
4 DR	SS2014	Design	Design	New rotor design failure	2	5	10	New rotor design failure	Yes	Yes
5 DR	SS2014	Design	Design	CS tool steel impregnation study delay	1	6	6	CS tool steel impregnation study delay	Yes	Yes
6 DR	SS2014	Design	Design	Interface and zipper of work in location	3	4	12	Interface and zipper of work in location	Yes	Yes
7 DR	SS2014	Design/Procurement	Design	Choice of final gearbox is determined from NCG	2	5	10	Choice of final gearbox is determined from NCG	Yes	Yes
8 DR	SS2014	Design/Procurement	Design/Procurement	Package assembly resource	2	5	10	Package assembly resource	Yes	Yes
9 DR	SS2014	Procurement	Procurement	Issues in the low temperature stack	4	3	12	Issues in the low temperature stack	Yes	Yes
10 DR	SS2014	Integration	Integration	Link space not available for integration	3	4	12	Link space not available for integration	Yes	Yes
11 DR	SS2014	Integration	Integration	Guides for chopper magnetron not delivered	4	3	12	Guides for chopper magnetron not delivered	Yes	Yes
12 DR	SS2014	Installation	Installation	Not enough installation personnel	5	3	15	Not enough installation personnel	Yes	Yes
13 DR	SS2014	Installation	Installation	Not enough tools for installation	5	3	15	Not enough tools for installation	Yes	Yes
14 DR	SS2014	Installation	Installation	No access to beam port on schedule	4	3	12	No access to beam port on schedule	Yes	Yes
15 DR	SS2014	Installation	Installation	Beam guide heat treatment	2	2	4	Beam guide heat treatment	Yes	Yes
16 DR	SS2014	Installation	Installation	Temperature sensor needs during installation	1	2	2	Temperature sensor needs during installation	Yes	Yes
17 DR	SS2014	Installation	Installation	Link release of impingement	2	2	4	Link release of impingement	Yes	Yes
18 DR	SS2014	Installation	Installation	Infrastructure failure during installation	1	4	4	Infrastructure failure during installation	Yes	Yes
19 DR	SS2014	Commissioning	Commissioning	CS control cabinet being tested	2	3	6	CS control cabinet being tested	Yes	Yes
20 DR	SS2014	Commissioning	Commissioning	DMC chopper control delay	4	1	4	DMC chopper control delay	Yes	Yes



Phase I

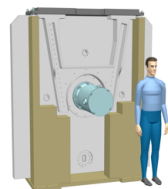
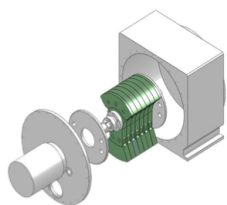
Chopper systems project plan

Procurement plan

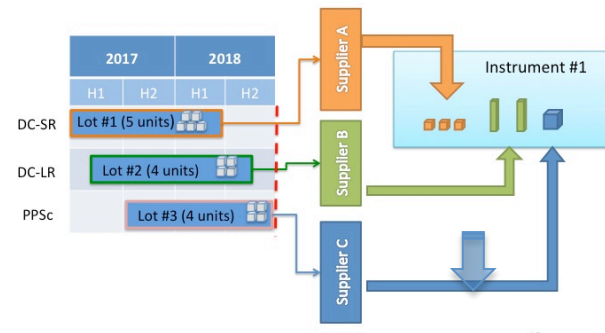
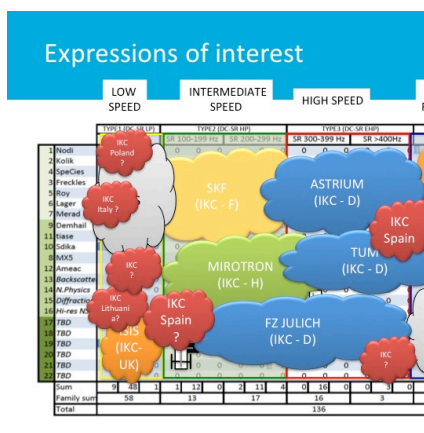
Finding the right partners for getting the job done

Horizontal in-kind

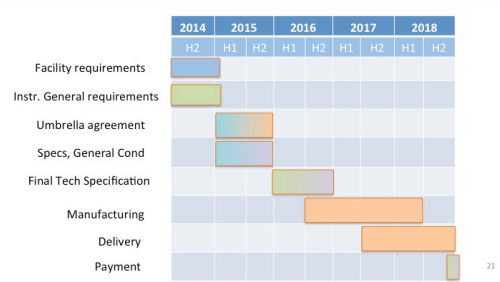
- Supplier framework agreements
- Access to mutualized development projects.
- Access to experience



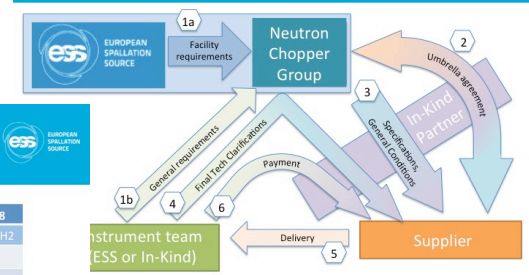
Multiple supplier to 1 Instrument



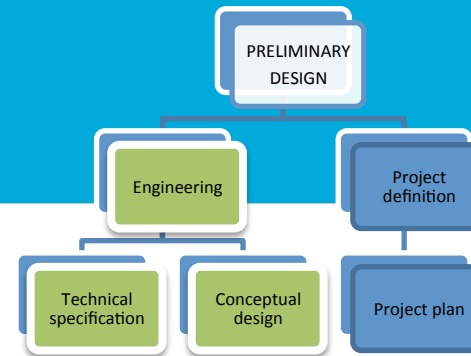
Procurement process timeline



Procurement process structure



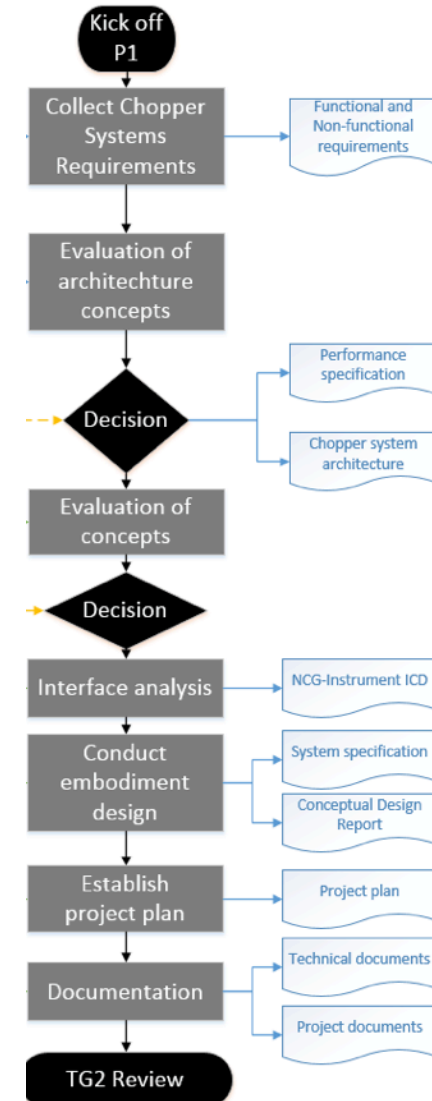
Project activities Documentation



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'project' documents



Instrument technologies integration layer

INSTRUMENT PROJECT TEAMS

DMSC

Instrument control Software

Chopper Hi level Control

ICS

Control Network HW / SW

Detectors

Data acquisition Software

Instrument #1

Instrument specific algorithms
chopper control parameters

Timing signals

Communication protocols

Motion Control

Electronic Hardware & Middleware

Instrument #2

Instrument specific instructions

Control Box Software (device driver)

Chopper Integrated Slow motion Control

Motion control software

Instrument # 22

Guide Chopper Interface

Personnel Access & capacity

Sample Environment

Alignment

Neutron optics

Optics & Shielding

Integrated Beamline shielding
Vacuum systems

Machine Protection Systems
Safety Systems

Operating schedule

Target

Monolith / instrument interface

Electrical Power & UPS

Cooling / heat recovery

Containment

Contamination

Facility

Ventilation

Safe working practices

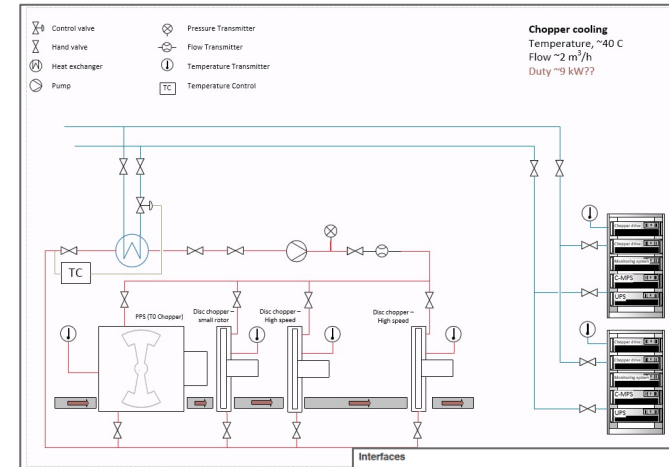
Building Services

Health & Safety

Neutron Chopper System

Interface configuration definitions

- ICD NCG-CF
- ICD NCG-Cooling
- ICD NCG-Motion Control and Automation
- ICD NCG-Health and safety
- ICD NCG-Optics
- ICD NCG-Shielding
- ICD NCG-Vacuum
- ICD NCG-DMSC
- ICD NCG-ICS EPICS SW
- ICD NCG-ICS Machine Protection System
- ICD NCG-ICS Personnel Safety System
- ICD NCG-ICS Timing System Network
- ICD NCG-CHiC-Drive
- ICD NCG-Detectors
- ICD NCG-Sample station
- ICD NCG-Target Station



ICS process variables per chopper axis

No.	Name	Source	Destination	Unit	Range	Sample rate	Type	Comment
1	Instrument wide person safety system	CHIC/IOC	Personnel Safety System	REL	NA	NA	REL	Labels generated on instrument avoid any triggering (200Hz, 700, 1400) Instrument pulse frequency of the instrument
2	High frequency support pulse signal chopper 1	CHIC/IOC	Timing card	REL	NA	NA	REL	High frequency support pulse
3	Chopper ID	CHIC	Timing card	REL	NA	NA	REL	if address or process variable name or other identification of chopper
4	Instrument ID	CHIC	Timing card	REL	NA	NA	REL	if address or process variable name or other identification of instrument
5	Motor speed support	CHIC/IOC	Individual	REL	NA	NA	REL	NA
6	Phase offset support	CHIC/IOC	JA	REL	0-360.0	NA	REL	0-360
7	Parking position support	CHIC/IOC	NA	REL	NA	NA	REL	NA
8	Request chopper start	CHIC/IOC	NA	BOOL	NA	NA	BOOL	NA
9	Request chopper stop	CHIC/IOC	NA	BOOL	NA	NA	BOOL	NA
10	Request chopper start stop	CHIC/IOC	NA	BOOL	NA	NA	BOOL	NA
11	Enable speed control	CHIC/IOC	NA	BOOL	NA	NA	BOOL	NA
12	Enable chopper	CHIC/IOC	NA	BOOL	NA	NA	BOOL	NA
13	Set chopper speed	CHIC/IOC	NA	REL	NA	NA	REL	REL
14	Phase error	CHIC	JA	REL	NA	NA	REL	Phase error Required for phase offset support
15	Phase error derivative	CHIC	JA	REL	NA	NA	REL	Phase error derivative Required for phase offset support
16	Actual Motor speed	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Actual speed feedback from motor
17	Actual Motor phase	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Actual phase feedback from motor
18	Actual Motor speed feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Actual speed feedback from motor
19	Actual Motor phase feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Actual phase feedback from motor
20	Actual speed feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Actual speed feedback from motor
21	Actual phase feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Actual phase feedback from motor
22	Motor position via set of frequency feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Motor position via set of frequency feedback
23	Motor speed feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Motor speed feedback
24	Motor phase feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Motor phase feedback
25	Motor speed feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Motor speed feedback
26	Motor phase feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Motor phase feedback
27	Motor speed feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Motor speed feedback
28	Motor phase feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Motor phase feedback
29	Motor speed feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Motor speed feedback
30	Motor phase feedback	CHIC/IOC	Instrument Control	REL	NA	1 sample/s	REL	Motor phase feedback

Interfaces

The timing system handles all synchronization in the entire facility and basically consists of a Master timing event generator and a number of event receivers, placed on the EPICS control box.

It also makes sure that all external clocks are synchronized accurately with a jitter less than 1ns. The heart beat frequency of ESS is very close to 1414.1, it is set to 1400000000Hz. All timing will be related and offset relative to this heart beat pulse train, i.e. if heart beat is triggered at 2.00s, the start pulse for ensuring that the process pulse reaches the target might be 7.00s and the end of the process pulse 7.01s.

Any device downstream will have to offset its timing in relation to the heart beat.

Search frequency	202101000	Hz
Stables per event clock period	4	
Event Clock Frequency	8000000	Hz
Event Clock Period	0.00000125000000000000	s
Event Clock rate per macrostructure pulse	4000000	
Stable macrostructure rep rate	0.017428568	s
Stable macrostructure rep rate	14.000000000	Hz
Event clock rate per macrostructure length	251800	
Stable macrostructure full length	0.002000000	s

Table 1: Description of the ESS timing system.

Master events sent to electrical output channels

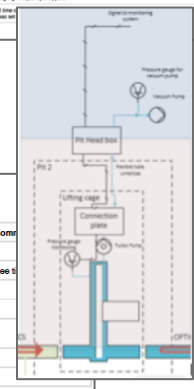
In every EPICS hardware rack there are several electrical I/O cards handling the Event receiver cards. Every Event receiver card will have several electrical output channels, which will be used as seen in Table 2.

Channel	Description
1	Master pulse and used as chopper reference pulse, 3.5Hz, 7Hz or 14Hz, depending on selected chopper in the instrument
2	50-100ns-1430Hz pulse for supporting high frequency choppers
3	Clock signal, signal in synchronous and time of frequency

Table 2: Channel usage of event receiver card

ICS electrical connections

No.	Name	Source	Destination	Unit	Type	Comments
1	Instrument wide Personnel Safety System OK	ICS MPS	Chopper drive		24VDC digital signal	
2	Reference pulse signal chopper 1	IOC Timing card	CHiC & Chopper drive		5VDC digital signal	See Table 2
3	High frequency support pulse signal chopper 1	IOC Timing card	CHiC & Chopper drive		5VDC digital signal	
4	Time synchronizing pulse signal	IOC Timing card	CHiC		5VDC digital signal	
5	EPICS Control box Ethernet connection	EPICS Control box	CHiC		Ethernet, RJ45	
6	Instrument wide Machine Protection System OK	ICS MPS	CHiC		24VDC digital signal	
7	CHiC MPS status signal	CHiC	ICS MPS		24VDC digital signal	

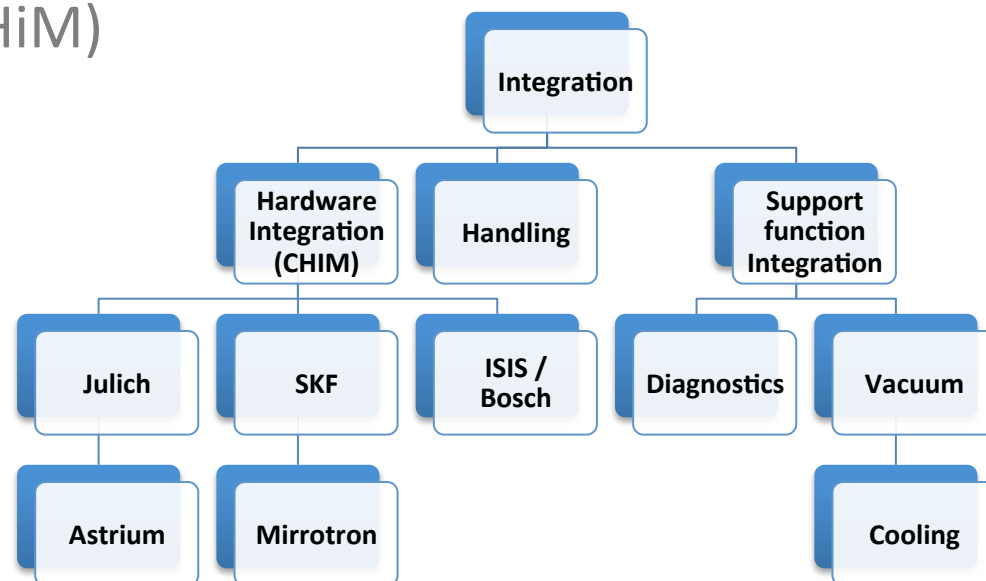


PHYSICAL INTEGRATION

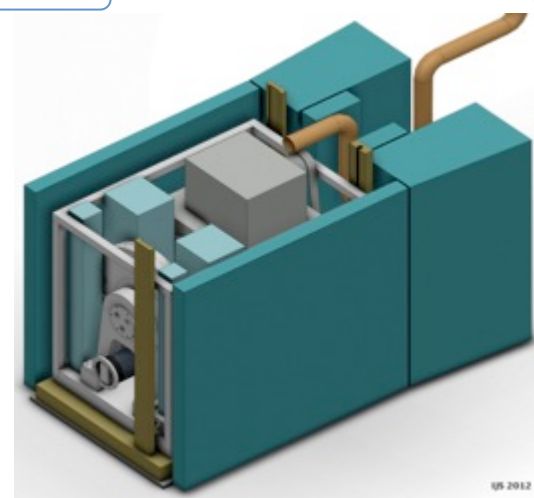
Chopper Integration modules (CHiM)

Includes elements of

- Services (Vac, Cooling)
- Neutron Optics
- Vacuum housings
- Local shielding
- Support structures
- Beam monitor
- Safety functions

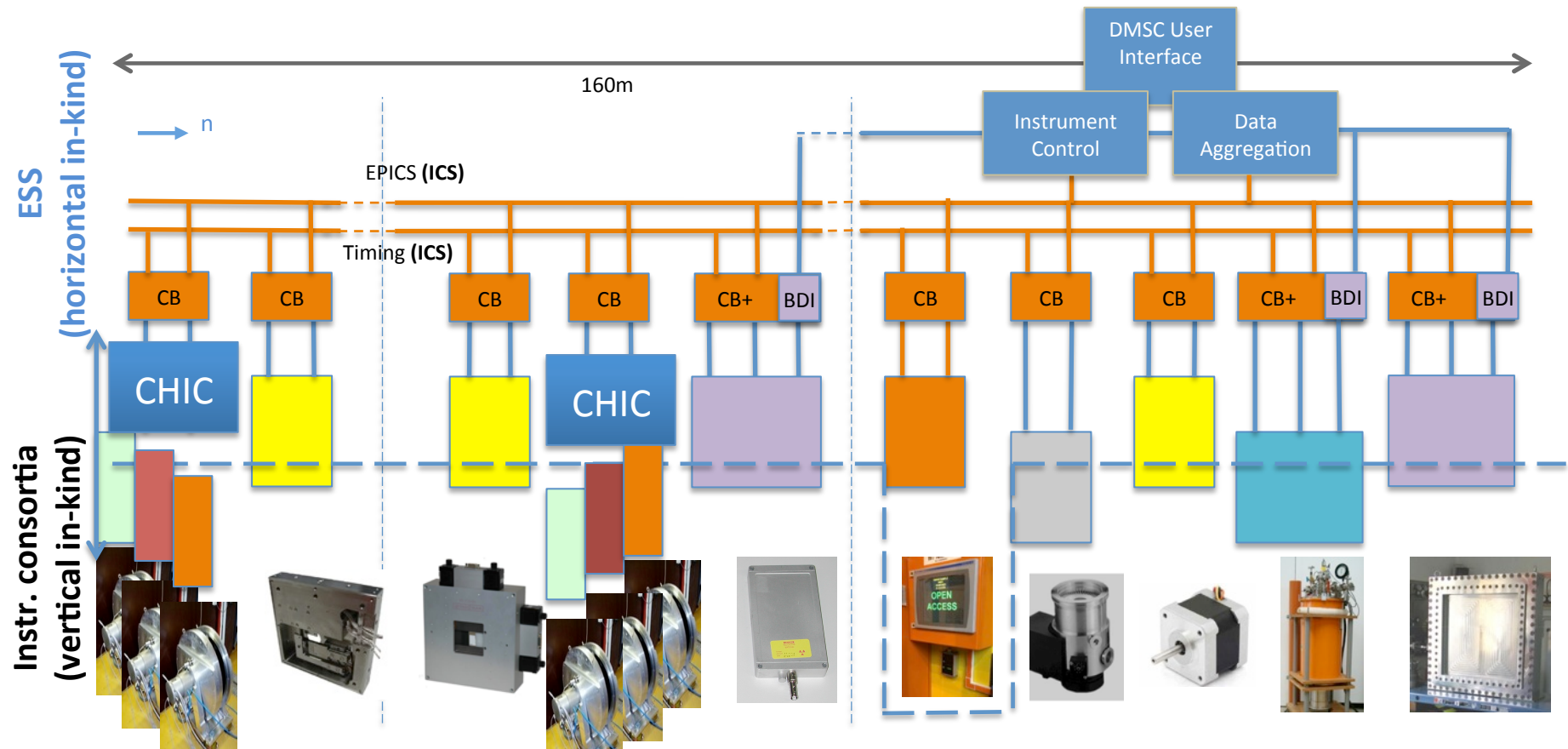


A coherent approach to implementation across the instrument suite, ensuring reliable high performance and operational serviceability



Chopper Control : Modular Instrument Control Concept

- Flexibility in how partners contribute to the instrument
- Flexibility in how instruments consortia distribute their shares
- Flexibility in how much in-kind partner contributes to the control electronics



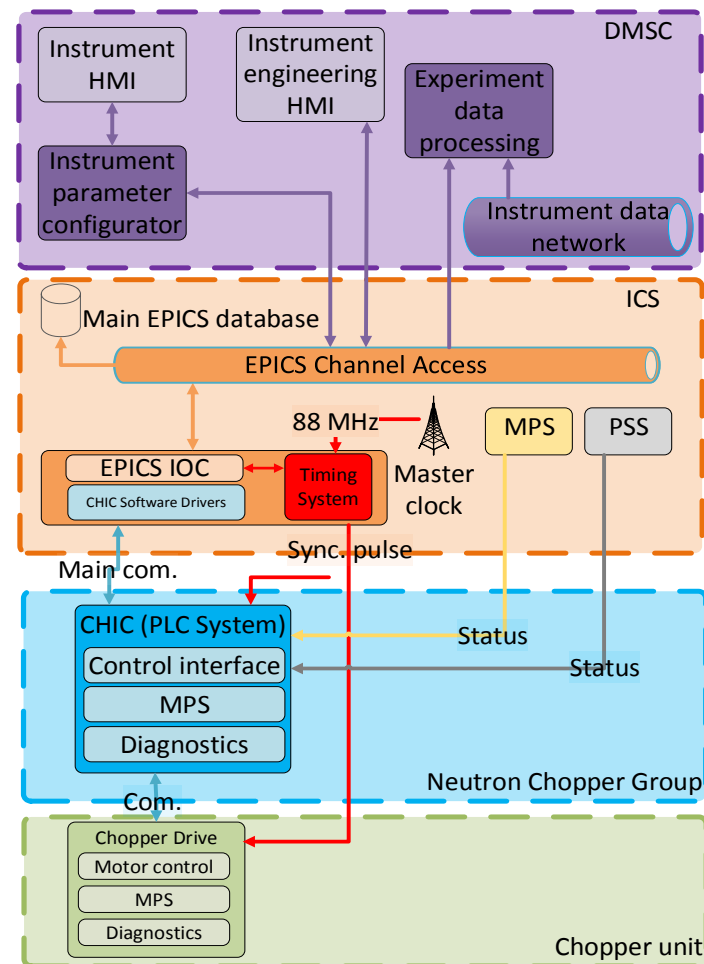
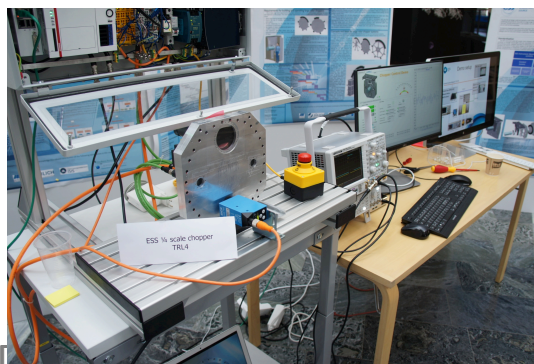
ESS STANDARDS

Chopper control systems & Condition monitoring

CHOPPER INTEGRATION CONTROLER (CHiC)
Hardware & Software Integration (EPICS)
between suppliers chopper units and 'the
facility'

- Instrument control system DMSC via ICS
- Instrument level Personal Safety Systems
- Machine Protection Systems

ESS Standard Condition monitoring &
Diagnostics system



Implemented through:

- Development of Integration
- Hardware & Software STANDARDS

ESS Technical standards, Neutron chopper systems

Chess #	Title
ESS-0034249	Neutron chopper systems, Guidelines
ESS-0034248	Neutron chopper systems, Concept of operations
ESS-0034247	Neutron chopper systems, Standards & Requirements
ESS-0034263	Neutron chopper systems, Strategy for design, manufacture and integration
ESS-0034262	Neutron chopper systems, Strategy for procurement
ESS-0034261	Neutron chopper systems, Strategy for installation, commissioning and early operation
ESS-0034260	Neutron chopper systems, Strategy for normal operation
ESS-0034259	Neutron chopper systems, Strategy for decommissioning and disposal
ESS-0034258	Neutron chopper systems, Standard component list

ICS TS Requirements

Program: ADU Work Package: WP2 Work Unit: WU.3

Author: Ian Stanford, Dan Kraljic Date: 2013-04-02

Version: 1.3

Approval Matrix

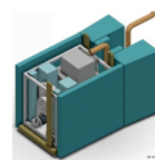
Role	Author	Reviewer	Stake Holder
Author	Ian Stanford	ICS	Gerry Trisham
Author	Dan Kraljic	SI	Andrew Lammiman
Reviewer	Dan Kraljic	SI	Andrew Lammiman
Reviewer	Mika Hultin	SI	Thomas Carl
Approver	Gerry Trisham	SI	Richard Paul Wilson
		SI	Janis Koppel
		Target	Francis Perrucci

ESS Vacuum Handbook
Part 1 – General Requirements for the
ESS Technical Vacuum System

Author: Name: Date: 21 May 2014

Author: Name: Date: Gerry Hultin

<<Instrument technologies>>
Guidelines,
for Neutron Chopper systems at the ESS facility.



Distribution: <<G4E names>>

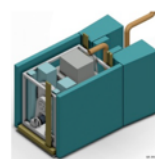
Name	Role
Ian Stanford	Neutron Chopper group leader
Dan Kraljic	
Andrew Lammiman	
Thomas Carl	
Richard Paul Wilson	
Janis Koppel	
Francis Perrucci	

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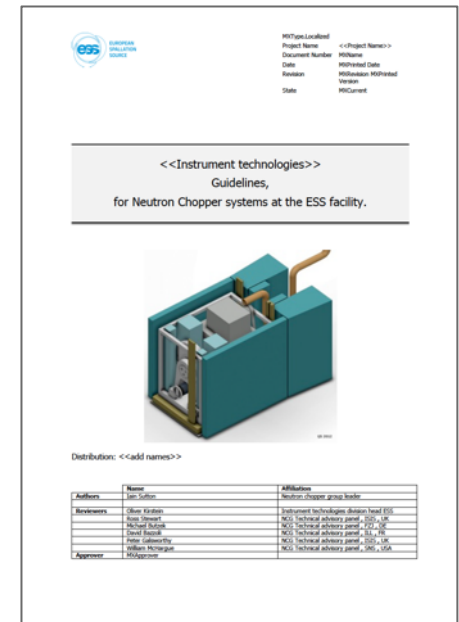


Distribution: <<G4E names>>

Name	Role
Ian Stanford	Neutron Chopper group leader
Dan Kraljic	
Andrew Lammiman	
Thomas Carl	
Richard Paul Wilson	
Janis Koppel	
Francis Perrucci	

ESS requirements, specification and equipment standards

- Facility requirements
 - Safety & security
 - Legislation
 - Certification
 - Quality assurance
 -
- Operational requirements
 - Reliability
 - Availability
 - Maintainability
 - Transportability
 -

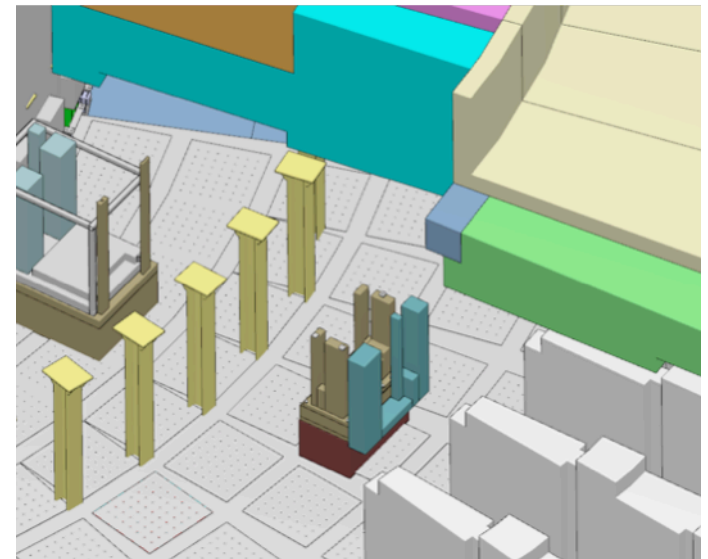


ESS Document :ESS0034247

Neutron chopper systems

Strategies

- Neutron chopper systems, during instrument design, construction and integration
 - ESS Document :ESS0034263
 - Draft release Q3 2015
- Neutron chopper systems, during instrument installation, commissioning and early operation
 - ESS Document :ESS0034261
 - Draft release Q4 2015
- Neutron chopper systems during instrument normal operation
 - ESS Document :ESS0034260
 - Draft release Q3 2015
- Neutron chopper system during decommissioning and disposal
 - ESS Document :ESS0034259
 - Draft release Q1 2016

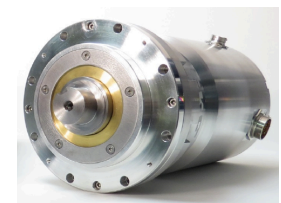
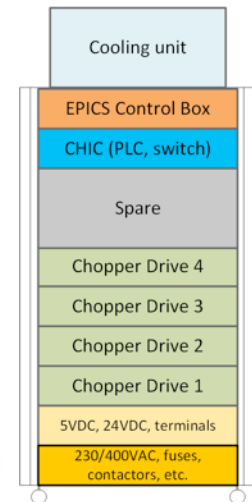
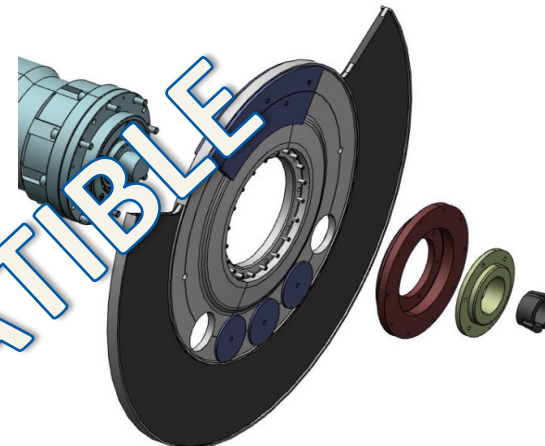


Standard components

- Component specifications
 - Control racks
 - UPS systems
 - Cooling systems
- Component recommendations
 - Sensors
 - Motors
 - Cables
 - Seals
- Material recommendations
 - Materials for construction
 - Beam windows
 - Pressure housings

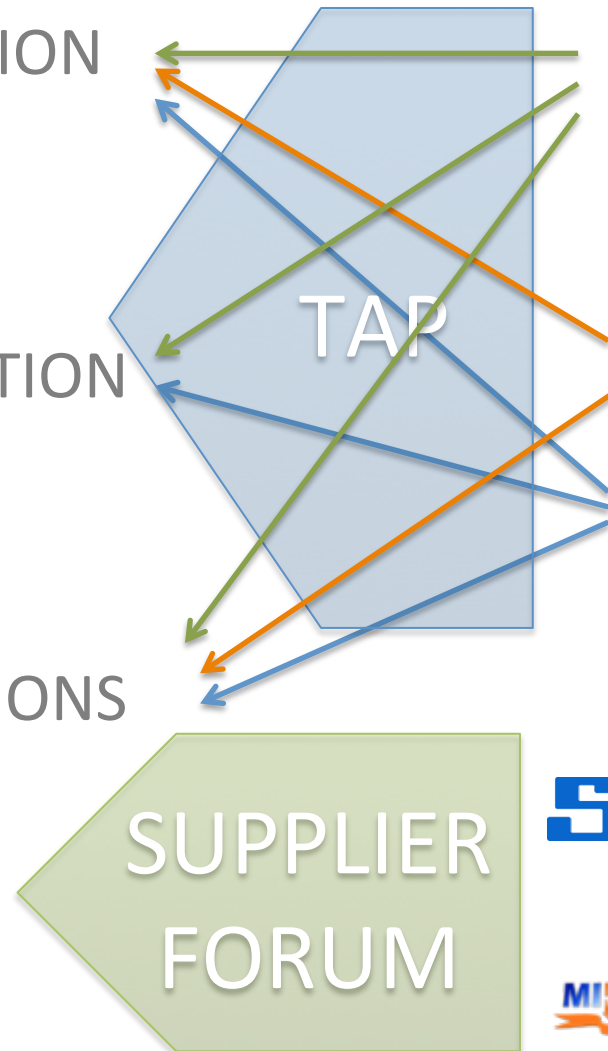
ESS Document :ESS0034258

ESS
COMPATIBLE

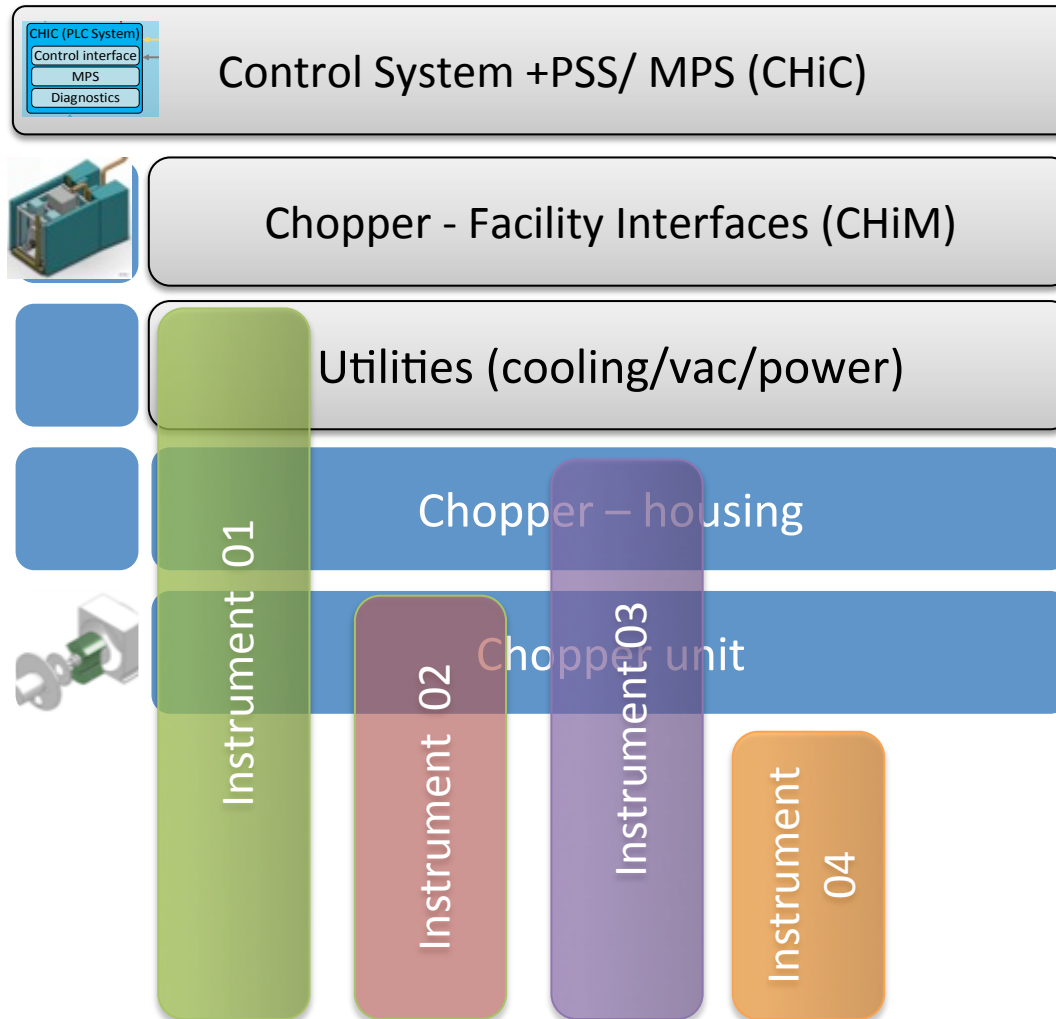


PARTNER PARTICIPATION

- STANDARDS DEFINITION
 - Test Protocols
 - Materials
 - Solutions
- EQUIPMENT VALIDATION
 - Performance
 - Irradiation
 - Endurance
- PROCUREMENT OPTIONS
 - Chopper units
 - Spindles
 - Rotors



HORIZONTAL & VERTICAL



< - ESS HW/SW

< - HW or Design

< - Interface Specification
Some ESS supply

< - ESS Interface
specification

< - ESS Equipment
standards & interface
specification

ESS INSTRUMENT TECHNOLOGIES

- SUPPORT
- ENABLE
- INTEGRATE

END

Thank you for your attention

Frame work agreement summary

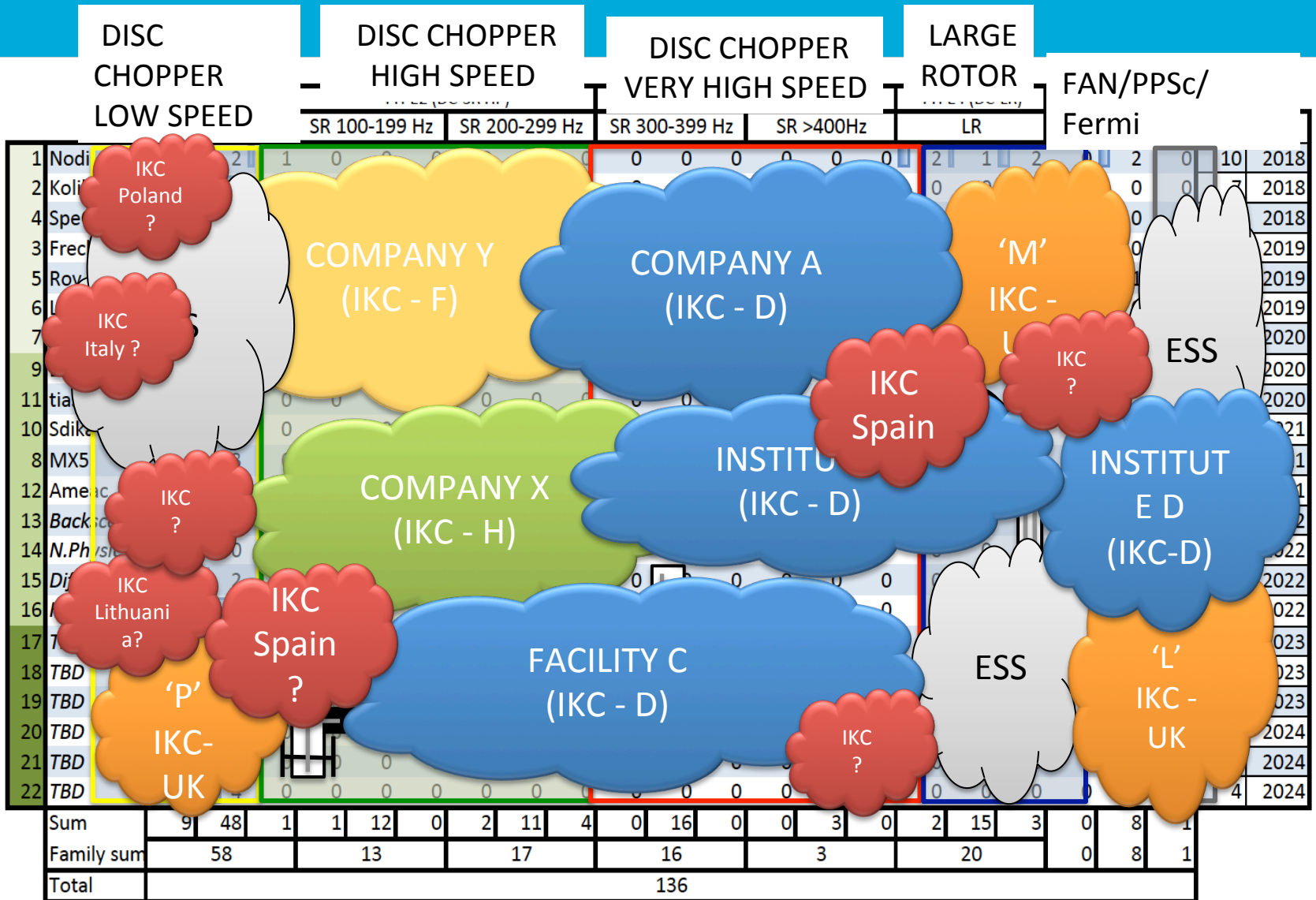
- ESS negotiates of framework agreement with suppliers and funding partners.
- ESS tenders and puts in place frame work agreements for batches of equipment in a strategic manner.
- Several sources would remain open for each type of equipment.
- Purchases under the negotiated conditions may be made by any instrument group within the project from suppliers under the frame work agreement.
- Payments are made by funding partners to the suppliers.

Overview of the suite of neutron choppers

	LOW SPEED			INTERMEDIATE SPEED				HIGH SPEED				LARGE ROTOR			FAN		PPSc								
	Hz	SR		Hz	SR	Hz	SR	Hz	SR	Hz	SR	Hz	SR	Hz	SR	Hz	SR								
1 Nodi	0	2	1	0	0	0	0	0	0	0	0	0	2	1											
2 Kolik	0	7	0	0	0	0	0	0	0	0	0	0	0	0											
4 SpeCies	0	3	0	0	2	0	0	0	0	0	0	0	0	0											
3 Freckles	0	2	0	0	0	0	0	0	0	0	0	0	0	0											
5 Roy	0	1	0	0	2	0	0	2	0	0	4	0	0	0											
6 Lager	0	5	0	0	4	0	0	2	0	0	0	0	0	0											
7 Merad	1	0	0	1	0	0	1	0	2	0	0	0	0	0											
9 Demhail	0	1	0	0	0	0	0	2	0	0	0	0	0	0											
11 tiase	0	1	0	0	0	0	0	0	0	0	0	0	0	0											
10 Sdika	6	0	0	0	0	0	0	0	0	0	0	0	0	0											
8 MX5	0	3	0	0	0	0	0	0	0	0	0	0	0	0											
12 Ameac	0	3	0	0	0	0	0	2	0	0	2	0	0	0											
13 Backscatte	0	0	0	0	2	0	0	0	0	0	6	0	0	0											
14 N.Physics	0	0	0	0	0	0	0	0	0	0	0	0	0	0											
15 Diffraction	2	0	0	0	0	0	0	0	0	0	0	0	0	0											
16 Hi-res NSE	6	0	0	0	0	0	0	1	0	0	0	0	0	0											
17 TBD	0	0	0	0	0	0	0	0	0	0	0	0	0	0											
18 TBD	4	0	0	0	0	0	0	0	0	0	0	0	0	0											
19 TBD	0	0	0	0	0	0	1	0	0	0	4	0	0	1											
20 TBD	4	0	0	0	0	0	0	2	0	0	0	0	0	0											
21 TBD	0	0	0	0	0	0	0	0	0	0	0	0	0	0											
22 TBD	0	4	0	0	0	0	0	0	0	0	0	0	0	0											
Sum	9	48	1	1	12	0	2	11	4	0	16	0	0	3	0	2	15	3	0	8	1				
Family sum	58			13				17				16			3			20			0		8		1
Total	136																								

6 'platforms' ~150 Choppers

A vision of 'Chopper systems' in-kind



22 Instruments ~ 145 axis