Process for Neutron Instrument Design and Construction

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	Name	Affiliation
Authors	Rob Connatser, Oliver Kirstein	Science Directorate
Reviewers	Ken Andersen, Oliver Kirstein, Arno Hiess, Mark Hagen	Science Directorate
Approver	Dimitri Argyriou	Science Directorate

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	Name	Affiliation
Author	Shane Kennedy	Science Directorate
Reviewers	Oliver Kirstein, Gabor Laszlo, Peter Sångberg, Ken Andersen, Arno Hiess (Rev 8)	Science Directorate
Approver	Andreas Schreyer	Science Directorate

Distribution: NSS Project management team, Neutron Instrument Scientists and Neutron Instrument Engineers, Science Director, Director General

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1. PURPOSE

The Neutron Instrument Construction projects are the sub-projects of the Neutron Scattering Systems (NSS) Project of the European Spallation Source (ESS) that have the responsibility for producing the neutron scattering instruments. To this end the NSS Project has developed a process for running, reviewing, and tracking the individual Neutron Instrument Projects (aka Neutron Instrument Work Packages). This process is described in this document. It also provides a brief description of the hot commissioning phase of a Neutron Instrument after the completion of construction. The roles of the NSS Project support team, and the advisory and decision-making bodies are also detailed. The references listed provide more detailed descriptions.

This document supports the *Policy for Building Neutron Instruments* [1], approved by the ESS Steering Committee in February of 2013.

This revision (R8) of the document differs from the earlier versions mainly in the casting of the latter phases of the project (phases 3, 4 and 5), where the delineation between manufacturing, installation, integration and commissioning with neutrons has been more clearly defined. In addition some effort has been made to strengthen the definition of deliverables for all project phases. To that end Figure 1, which conveys the essential elements of the process, has been revised. Further updates to this document, particularly in the description of Tollgates 3-6, are foreseen as the NSS Project progresses.

2. PROCESS APPLICABILITY

This process applies to all Neutron Instruments that will be developed for ESS, both instruments developed internally by ESS and instruments developed by external entities, e.g in-kind partners. The process is written in a way that it covers both approaches and the differences, internal versus external, will be notified in the relevant section. Main differences are e.g. that externally supplied instruments will be utilizing administrative processes and procedures incorporated in the respective entity; such as procurement, planning etc.

3. PROCESS FOR INSTRUMENT DESIGN AND CONSTRUCTION

3.1 Process Map

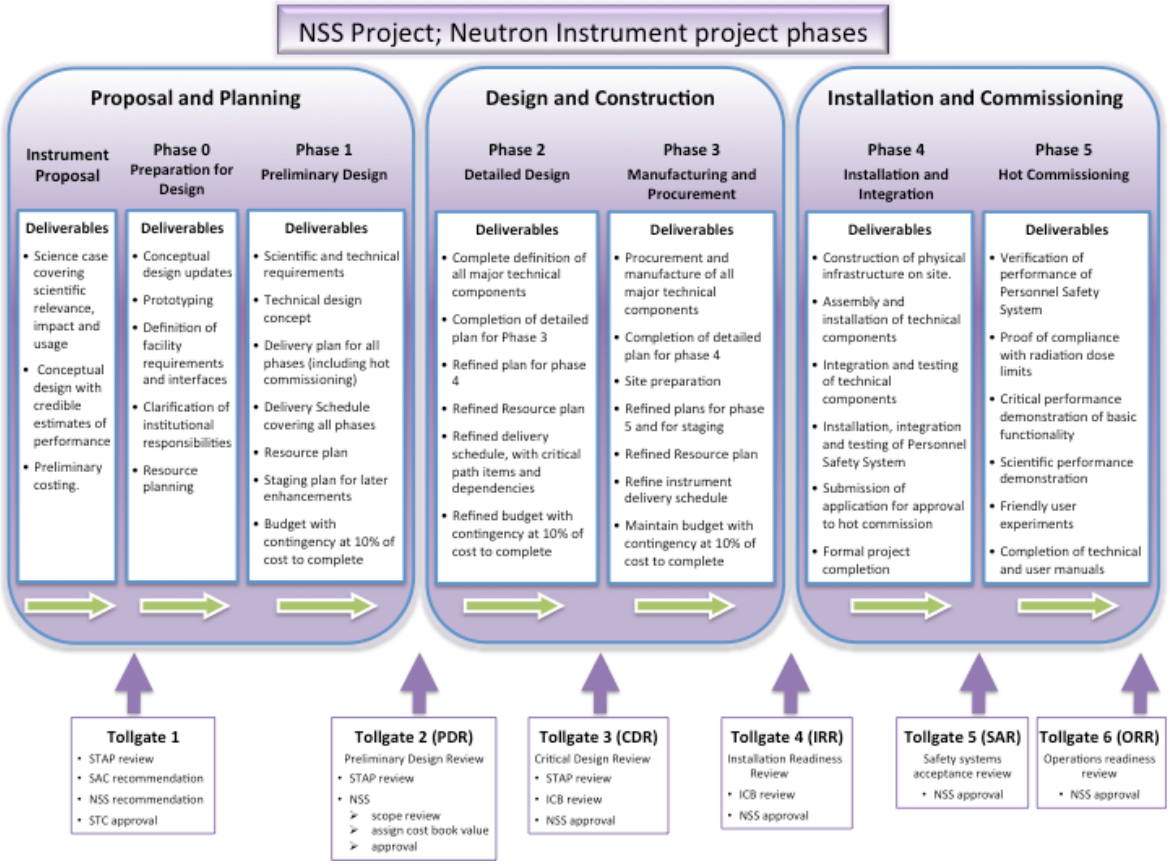

Figure 1. Overview of the ESS Neutron Instrument development process

3.2 Input

The stipulated input to this proposal is an expressed interest to develop a Neutron Science Instrument that will accommodate one or more science cases that would benefit from the long pulse and high brilliance source that will be provide by ESS.

This expressed interest is formalized in an Instrument Proposal and thus, by referring to Figure 1, the input is actually provided in the first phase of the Proposal and Planning stage, see 3.3.1.1, below.

3.3 Process

Neutron Instrument Projects will have three significant stages. They are: Proposal and Planning; Design and Construction; and Installation and Commissioning. On completion of these stages the Neutron Instrument will be ready to commence user operations. Each stage has two or three phases that are generally separated by Tollgate decisions, which involve critical reviews.

Each Neutron Instrument Team is supported by a Scientific and Technical Advisory Panel (STAP), which provides advice on the scientific and technical direction of the Neutron Instrument Project. Generally a STAP provides advice to several instruments within an instrument class. More information can be found in Roles of STAPs to support instrument construction, [2].

Once a neutron instrument project moves into phase 1, the Neutron Instrument team is supported by the NSS Project, primarily through the Neutron Instruments Lead Engineer and Neutron Instruments Lead Scientist. Together they will ensure timely delivery of support from the ESS and are responsible for integration, coordination and facilitation of synergies between the Neutron Instrument Project and the other parts of the NSS project.

Phases 1 through 4 are funded by the NSS Construction Project. Phase 5 is funded by ESS Operations. All phases of Neutron Instrument construction projects can be provided as in-kind contributions from partners.

3.3.1 Proposal and Planning

3.3.1.1 Neutron Instrument Proposal

A detailed description of the instrument selection process is given in the forthcoming procedure for Selection of Neutron Instruments for ESS [3]. A Neutron Instrument proposal is created to promote a scientific case for a Neutron Instrument, covering the scientific relevance, impact and usage. It also presents a conceptual design for the Neutron Instrument with some estimates and modelling of its performance. A preliminary costing is included in the proposal.

- **Tollgate 1**

The STAPs and the Scientific Advisory Committee (SAC) review all of the proposals in any proposal round and makes an endorsement to ESS management for proposals it considers should move into construction. ESS management takes in the advice from all advisory bodies and, considering the needs of the project, makes a recommendation to the ESS Council (formerly known as the ESS Steering Committee (STC)) on which Neutron Instrument proposals should be moved into the next phase. The ERIC Council makes the decision on which proposals move into a planning phase and thus into the ESS project baseline.

3.3.1.2 PHASE 0 – Preparation for Preliminary Design

Phase 0 is a preparatory time when proposing teams continue the work on the proposal. Proposing teams will assemble a preliminary resource plan for executing the Neutron Instrument Project. This phase includes planning for phase 1, including preparation of a resource plan and costing for preliminary engineering design of the Neutron Instrument. The plan must be approved by NSS Project management, and the appropriate

agreements must be signed before Phase 1 can proceed. The documentation is to include a Memorandum of Understanding for the construction of the Neutron Instrument, and a Technical Annex for the In-Kind Collaboration Agreement, that defines the execution of Phase 1 of the project.

3.3.1.3 PHASE 1 – Preliminary Engineering Design

Phase 1 begins when a Neutron Instrument Project team is formed, the core of which is an instrument scientist and an engineer. The instrument scientist is the Scientific Project Leader and the engineer is the Project Engineer.

The objective is to turn the science case and conceptual design of the Neutron Instrument Proposal into a Neutron Instrument Construction project plan containing a baseline project specification, with a well-defined scope, budget and schedule. The specification is expected to include a fully developed concept of design, which is linked to the science case by the Instrument's Concept of Operations. Examples of the *Concepts of Operations* have been prepared by the NSS Project [4]. The budget should cover full cost of Phases 1 – 4 and include a 10% contingency. Ultimately the success of the project will be judged by verification of the instrument's ability to meet its critical performance criteria during hot commissioning (Phase 5). In this regard, care must be taken to define performance criteria in terms of measurable parameters. These *technical performance measures* (TPM) should be carefully selected to include only those requirements that are expected to have profound impact on the success of the instrument.

The Neutron Instrument Project team is given a cost category at the start of this phase, along with an appendix [5] outlining the support that the NSS Project will provide to the project. The cost category is the provisional budget, estimated by NSS management to meet the baseline requirement, and the support provided by NSS is estimated to be of order 2.7 M € in value. In order to produce the project specification, the Neutron Instrument Project team is also provided with detailed descriptions of the technical and operational requirements and standards that must be met in construction of the Neutron Instrument, along with detailed information on the process for completion of Phase 1 and preparation for Tollgate 2. A detailed description of the tollgate 2 procedure is given in *Instrument Construction Projects; Tollgate 2 Review and Decision* [6].

The Neutron Instrument scientist is the primary source for the functional requirements and provides the vision of the Neutron Instrument's operation, layout, and use. The engineer provides the technical project leadership, including management and integration of engineering effort. ESS technical teams support the project by contributing to the formal definition of the relevant functional requirements and suggesting technical solutions. As mentioned above the Neutron Instruments Lead Engineer and Neutron Instruments Lead Scientist will be the primary source of support for the Neutron Instrument Project.

- **Tollgate 2: Decision to move forward (Preliminary Design Review)**

The output of Preliminary Engineering Design is the Neutron Instrument Construction Project Plan. This proposal contains a baseline project specification, with a well-defined scope, budget and schedule for the delivery of the Neutron Instrument. In order to reach this point all possible instrument conceptual design options should have been evaluated (i.e. all alternate technical solutions for the major components of the instrument). This proposal is reviewed by the NSS Project Management according to the process defined in Instrument Construction Projects Tollgate 2 Review and Decision, with emphasis on

- **scientific parameters** -that it will meet the stated performance criteria (TPM),
- **engineering** -that it is feasible to build with all of the appropriate interfaces,
- **safety and licensing** -that it meets the requirements for safe operations and for licensing
- **budget** -that it can be built within the budget,
- **schedule** -that it can be built and made ready for hot commissioning within the required timeframe, and
- **management** -that the instrument consortium has the capability and sufficient resources to deliver according to their plan.
- **Operation and maintenance** – that it can be operated (incl. performing experiments using samples and sample environment) and maintained.

Once a Neutron Instrument Project team has satisfied NSS Project Management on these points, the project will be assigned a cost book value and move into Phase 2. The cost book value will cover the full assigned value for construction of the instrument, including all costs incurred in phases 1 through 4. As this value is specific to the design scope and the instrument concept, the concept must be fixed from this point forward. Instrument scope that has been identified as important to meet the full science case for the instrument, but which is beyond the value that can be assigned from the NSS Project budget, should be identified at this point. Such scope should be included in a staging plan for later enhancements if and when funds become available.

3.3.1.4 Internally developed Instruments

Internally developed instruments shall follow the relevant ESS processes as applicable, while external (through in-kind and other partners) instrument teams can opt to develop in accordance to respective entities processes as long as the requested information with respect to context and format is provided to ESS as per this process.

Applicable processes for internally developed instruments for the Proposal and Planning stage are:

- ESS Process for Stakeholder Requirements Definition, ESS-0015092
- ESS Process for Requirements Analysis, ESS-0015093
- ESS Process for Architectural Design, ESS-0015094
- ESS Process for Procurement, ESS-0019735

Other relevant ESS wide processes shall be followed as applicable as well.

Accompanying procedures, guidelines and handbooks are to be adhered to as applicable.

3.3.2 Design and Construction

3.3.2.1 PHASE 2 - Detailed Design

Final design of all portions of the Neutron Instrument are handled in Phase 2. Engineering and technical teams, following standard engineering practices, bring the design of the Neutron Instrument components to a state of readiness for manufacturing and procurement. The purpose of this phase is to complete detailed design of all major components of the instrument in a coherent manner so as to minimize risk of incompatibilities and the need for redesign work as the Neutron Instrument Project moves into Phase 3 (Manufacturing and Procurement). To that end this phase includes detailed planning for manufacturing and procurement. However, no manufacturing or procurement is to be done in this phase. The only exception to this rule is where long lead-time procurements are identified that are judged to add considerable risk to the project delivery schedule. In that case approval to begin manufacturing or procurement of these items comes from the NSS Project Office via the Neutron Instruments Lead Engineer.

Detailed planning for Phase 4 (Installation and Integration) also begins in this phase. Careful scheduling of Phases 3 & 4 should be done here to ensure that resource planning can be undertaken for manufacturing processes (such as factory and site acceptance testing), site preparation, installation and system integration, cold commissioning activities and licensing processes. Critical dependencies should be identified and a critical path analysis should be performed in this phase.

Support from the NSS Project Office will include construction managers under the leadership of the NSS Construction Engineer. The NSS Construction Engineer will develop and maintain an integrated installation plan that takes into account the procurement schedules for all Neutron Instruments, CF building schedules, and resource allocation.

- **Tollgate 3 – Engineering and Operation Review (Critical Design Review)**

Once the design has reached sufficient maturity to be ready to begin construction, a review is held of the Neutron Instrument Project. This review emphases engineering and operational details. Any re-baselining of the WBS elements happens in response to this internal review. Successful completion of this review is required to start procurement. There shall be no adjustment of the Neutron Instrument budget at this time

3.3.2.2 PHASE 3 – Manufacturing and Procurement

Neutron Instrument teams procure all of the major Neutron Instrument components, through in-kind agreements, standard procurements or internal manufacturing. In all cases care should be taken to ensure the quality of components, compliance with engineering tolerances and functionality prior to delivery to the ESS site. Factory

acceptance testing should be conducted in consultation with the NSS Project management team through the Neutron Instruments Lead Engineer.

This phase should also include detailed planning for Phase 4 (Installation and Integration) of the instrument in the Neutron Instrument hall. If it is deemed by the NSS Project management to be schedule critical, the latter portion of this phase may also include site preparation of the civil works and physical infrastructure in the experiment halls and guide hall that supports the technical equipment (such as installation of anchoring plates and mechanical support structures, preparation of electrical and electronic distribution panels, and preparation of temporary shielding structures). The NSS Construction Engineer will coordinate this effort and, where appropriate, purchase the needed materials and labour for the Neutron Instrument teams.

This phase should also include refinement of the resource plan for Phase 4, and refinement of the plan for Phase 5 (Hot Commissioning).

- **Tollgate 4 – Installation Readiness Review**

Prior to commencement of installation a review will be conducted by the NSS Project management team. Installation can begin, if the completeness of the instrument has reached an acceptable level, i.e.,

- all major components delivered on site,
- site preparation has been completed,
- resources are available for performing the installation work (e.g. technical staff, essential infrastructure such as cranes and electrical services) and
- the instrument site has been cleared for safety and security.

3.3.2.3 Internally developed Instruments

Internally developed instruments shall follow the relevant ESS processes as applicable, while external (through in-kind and other partners) instrument teams can opt to develop in accordance to respective entities processes as long as the requested information with respect to context and format is provided to ESS as per this process.

Applicable processes for internally developed instruments for the Proposal and Planning stage are:

- ESS Process for Implementation, ESS-0015095
- ESS Process for Integration, ESS-0015102
- ESS Process for Verification, ESS-0015096
- ESS Process for Transition, ESS-0015097
- ESS Process for Operation, ESS-0015099
- ESS Process for Maintenance, ESS-0015100
- ESS Process for Procurement, ESS-0019735

Other relevant ESS wide processes shall be followed as applicable as well.

Accompanying procedures, guidelines and handbooks are to be adhered to as applicable.

3.3.3 Installation and Commissioning

3.3.3.1 PHASE 4 - Instrument Installation and Integration

- **On site construction**

Here the individual components (neutron transport system, beam shapers and choppers, sample stages, detector systems and shielding, including vacuum chambers, etc.) are installed and secured. Installation of the technical components into the physical infrastructure will be performed by the appropriate partners, vendors, and technical groups associated with the Neutron Instrument. The day-to-day work will be coordinated by the NSS Construction Engineer.

- **System Integration**

Here the individual components of the Neutron Instrument are connected and integrated into a working system. Integration includes mechanical, electrical, vacuum and communications systems. Also the Instrument's Personnel Safety Systems (PSS) are installed and integrated with the instrument and with the ESS central Instrument Control System (ICS).

- **Cold commissioning**

Cold commissioning will test and validate Neutron Instrument components and systems without spallation neutrons. The focus is on ensuring that all components and systems work, fixing bugs, and preparing for "hot" commissioning. By the end of this phase, the Neutron Instrument should be able to run as if doing an experiment and all systems engineering verification and testing possible without neutrons should be complete.

Results of cold commissioning tests are to be recorded and all systems documented in preparation for Tollgate 5 (the safety systems readiness review).

- **Tollgate 5 – Safety Systems Acceptance Review**

An internal review of testing procedures and safety systems, primarily the Personnel Safety System (PSS), will be performed prior to starting beam testing or hot commissioning of Neutron Instrument components tied to the PSS. All operational documents are reviewed and approved. The Neutron Instrument Commissioning Plan is presented and accepted. The Neutron Instrument Project is completed at the end of this review.

3.3.3.2 PHASE 5 -Neutron Instrument Hot Commissioning

Any integration testing requiring spallation neutrons is performed here. The Neutron Instrument team executes the Neutron Instrument Commissioning Plan and verifies the performance and capabilities of the Neutron Instrument, including test experiments and

demonstration experiments. Problems and issues found in this phase are fixed with operational funds. All documentation necessary for operation and maintenance is to be completed in this phase.

- **Safety systems commissioning**

Here all personnel safety systems (PSS) are confirmed to be operational and radiation dose levels are verified to comply with operational requirements. In the event that some radiation dose levels are found not to comply with operational requirements, steps to bring those components into compliance should take the highest priority. Critical radiological safety measurements are to be made in consultation with the Environment, Health and Safety Division and the ESS Neutron Optics and Shielding Group.

- **Critical performance verification**

Here the critical performance criteria are tested by measurement. A report is prepared evaluating the observed performance against design objectives and identifying any critical shortfalls for consideration of ESS management to address before moving into operations. Critical performance measurements are to be made in consultation with the ESS Neutron Optics and Shielding Group.

- **Scientific Performance Demonstration**

Here standard 'benchmark' measurements are performed, results are processed and analysed and shown to satisfy expectations of scientific quality. Here also friendly user experiments are performed. Such experiments are performed with the key members of the scientific community who have been closely involved in the instrument construction project, who have expertise and willingness to participate in problem solving activities and in addition who have seminal measurements to make which will test the ability of the instrument to perform high quality measurements. In addition to measurements selected on the criteria above, some measurements should be included because of their potential to produce exciting scientific results that can be published in international journals, and/or that can be used to promote the instrument to the wider neutron user community.

Any modifications made to this instrument during the commissioning phase are to be documented (included production of as-built drawings) prior to tollgate 6 (the operations readiness review).

- **Tollgate 6 – Neutron Instrument Operations Readiness Review**

Changes and modifications made during the beam testing phase are reviewed. All operational documents (including technical reports and drawings, user manuals and safety procedures) are reviewed and approved. The Neutron Instrument Operation Plan is presented and accepted. The Neutron Instrument Project is completed at the end of this review.

3.3.3.3 Internally developed Instruments

Internally developed instruments shall follow the relevant ESS processes as applicable, while external (through in-kind and other partners) instrument teams can opt to develop in accordance to respective entities processes as long as the requested information with respect to context and format is provided to ESS as per this process.

Applicable processes for internally developed instruments for the Proposal and Planning stage are:

- ESS Process for Integration, ESS-0015102
- ESS Process for Verification, ESS-0015096
- ESS Process for Validation, ESS-0015098
- ESS Process for Operation, ESS-0015099
- ESS Process for Maintenance, ESS-0015100
- ESS Process for Procurement, ESS-0019735

Other relevant ESS wide processes shall be followed as applicable as well.

Accompanying procedures, guidelines and handbooks are to be adhered to as applicable.

3.4 Output

Upon successful completion of the Neutron Instrument commissioning stage, the Neutron Instrument enters User Operations, as per the operational doctrines of the ESS facility.

4. LIST OF ABBREVIATIONS

Abbreviation	Explanation of abbreviation
CAD	Computer Aided Design
CDR	Critical Design Review
CF	Conventional Facilities
ICS	Instrument Control Systems
IRR	Installation Readiness Review
N/A	Not Applicable
ORR	Operations Readiness Review
P&ID	Process and Instrument Diagram
PDR	Preliminary Design Review
SAC	Scientific Advisory Committee
SAR	Safety Systems Acceptance Review
STAP	Scientific and Technical Advisory Panel
STC	ESS Steering Committee
TPM	Technical Performance Measures

5. GLOSSARY

Term	Definition
Architectural Design	Architectural Design is the synthesized solution that satisfies system requirements.
Integration	Integration is the assembly of a system ensuring it is consistent with the architectural design.
Maintenance	The purpose of Maintenance is to sustain the capability of the system to provide a service.
Operation	Operation is the sustainment of the system in order to deliver its services.
Stakeholder Requirements Definition	Stakeholder Requirements Definition is activity to define the requirements for a system that can provide the services needed by users and other stakeholders in a defined environment.
TPM	N/A
Transition	Transition is done to establish a capability to provide services specified by stakeholder requirements in the operational environment.
Validation	Validation is intended to provide objective evidence that the services provided by a system when in use comply with stakeholders' requirements, achieving its intended use in its intended operational environment. In short it responds to the question – "did we build the right thing?"
Verification	Verification is intended to confirm that the specified requirements are fulfilled by the system. In short it responds to the question – "did we build the thing right?"

6. REFERENCES

[1] Policy for Building Neutron Instruments, *ESS-/STC/13/M1/012*

[2] Roles of STAPs to support instrument construction, *ESS-0032507*

[3] Procedure for the Selection of Neutron Instruments for ESS- TBD,

[4] Concept of Operations for the NMX Neutron Instrument, *February,* 2016, Concept of Operations for the ODIN Neutron Instrument, *February, 2016.*

[5] Neutron Cost Category Letter Appendix 1, December, 2015

[6] Instrument Construction Projects; Tollgate 2 Review and Decision, *ESS-0043330, November 2015*

Planned Documents related to this one;

- Neutron Instrument Project Planning Stage Description
- Neutron Instrument Work Package Baseline document descriptions
- Neutron Instrument Project Construction Stage Description (forthcoming)
- Neutron Instrument Project Tollgate 3 Review Description (forthcoming)
- Neutron Instrument Project Tollgate 4 Review Description (forthcoming)
- Neutron Instrument Project Tollgate 5 Review Description (forthcoming)
- ESS Operations Plan
- Reference document list (not the actual documents)

DOCUMENT REVISION HISTORY

Revision	Reason for and description of change	Author	Date
1-7	First issues	Rob Connatser, Oliver Kirstein	
8	Updates to the latter phases of the process to clarify it. Also it formally incorporates and reflect relevant Systems Engineering terminology.	Shane Kennedy	December 2015