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ESS requirements on neutron scattering instrument with respect to remote handling compatibility

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1. GENERAL REMARKS

The current ESS operational schedule for steady-state operation defines the long shutdown period, where maintenance in the bunker area is possible [1]. This period is the only realistic time where access to the bunker area is permitted for maintenance and repairs. To be able to quickly access components and systems in these areas the ESS has decided [2], in line with the ALARA principle [3], to implement basic remote handling compatibility requirements for all neutron scattering instruments. Remote handling allows the ESS to keep the dose on maintenance personnel to acceptable levels [4], whilst maintenance periods are being minimised.

1.1 Document objectives

This document provides design guidance to ensure remote handling compatibility of ESS neutron scattering instruments. It outlines the ESS-NSS Remote Handling (RH) strategy as well as defining the best practices relevant to remote handling. It is meant to be used in liaison with the system specific technical standards presented in section 3.10.

1.2 Document scope

This document provides information to engineers and managers involved in or affected by the instruments projects at the ESS. The document defines and describes:

- How to use the guideline document and technical standards.
- RH scope of, areas and conditions
- RH classification, handling and storage strategies
- RH assessment and evaluation in instrument projects
- RH best design practices in
    - Handling considerations
    - Grappling, manipulation and load transfer
    - Alignment
    - Identification and interfaces
    - Activation and decontamination
    - Viewing and visibility
    - Failure considerations
    - Standardisation
- The base set of ESS standard remote handling equipment

Although this document provides design guidance and best practice for the design of RH compatible components, individual technical groups shall be consulted at all stages of the design and procurement process to ensure best practice and compatibility.

1.3 Stakeholders

All personnel engaged in the successful design, construction and maintenance of the ESS neutron instruments.

Table 1 - Stakeholder table

Group ID	Stakeholder group	Individual ID	Stakeholder	Surrogate
SH-3	ESS governance	SH-3.1	ESS ERIC Council	ESS DG
SH-4	Regulators			ESS ESH&Q

SH-5	Operators	SH-5.2	Maintenance operators	Logistics staff Instrument technologies technical staff Survey and alignment staff Instrument project teams ESS core engineering team
SH-10	ESS developers			Instrument technologies technical staff Survey and alignment staff Instrument project teams NSS Core engineering team

1.4 Applicability

This document applies to the design of components and systems for neutron scattering instruments within all areas where remote handling is required. The affected areas are described in section 2.1 of this document.

1.5 Method of use

This document contains information for all stakeholders about the best practice related to designing and building components for remote handling compatibility for the neutron scattering instruments.

This document specifies the overall design best practices and requirements. The document serves as the parent document to a series of technical standard components and solutions. These standard components and solutions should be used in junction with this document, not independently. The available documents are listed in section 3.10 and are available for use on confluence.

Specific implementations of the remote handling guidelines are available for:

- Neutron choppers (CHIM concept) – ESS-0041170

2. ESS-NSS REMOTE HANDLING STRATEGY

The ESS remote handling strategy is aiming to combine general best practices with sensible standard components and concepts to minimise cost and effort during construction whilst enabling efficient maintenance and repair activities during operations. It is important to understand that even though neutron scattering instruments are highly individual and unique, many solutions and concepts can be reused. This will lower the long-term financial obligations of the ESS facility besides adhering to the ALARA principle.

Depending on the power ramp up of the facility, the exact time when activation levels prohibits personal access is uncertain. Systems at SNS have been running for more than ten years, and only recently have remote handling operations been of interest. As on SNS, it is imperative that systems are prepared and designed for remote handling from the start. Retrofitting systems with remote handling is both costly and inefficient [5]. Having systems prepared for remote handling does not put any constraints on the upgrade scope of the ESS machine.

2.1 RH operational areas

Remote handling compatibility is required for all components that fulfil any of the statements in section 2.4 and is installed on a neutron scattering instrument in either D01, D02, D03, E01 or E02.

2.2 Environmental conditions during RH operations

The radiological environmental conditions expected in the bunker area where remote handling is required is defined in ESS-0052649 [6].

Environmental conditions for the individual instruments are defined by the instrument teams on a case by case basis.

The instrument halls are classified as supervised areas [7]. The yearly annual dose allowed on radiation worker type staff is 2mSv per year [4].

The instrument halls can be sectioned into two areas with respect to crane coverage, the monolith area and the instrument halls. Both areas are served by cranes with different load capacity, mainly 20tonne and 5tonne options [8]. Due to crane agility limitations, all instrument remote handling operations are foreseen to be performed using the 5tonne hoist.

2.3 Modules

An instrument design shall be broken up into suitable sections called a remote handling module (from now on only called modules) during the detailed design phase of the project.

A module is defined, in the context of remote handling and instrument design, as a common maintenance unit or a collection of components/assemblies that are intended to be extracted with one operation.

Example 1: A chopper assembly mounted on its support is considered two modules. The chopper assembly is extracted and handled independent of the support structure. Any cables and other utilities attached to the chopper assembly is part of the same module.

Example 2: A girder with several sets of components mounted on is considered as a single module as long as the extraction strategy is to remove the entire girder in one operation.

2.4 Classification

Every module installed on an ESS instrument shall be classified. The classification shall be done during phase two of the instrument projects and is part of the deliverable for TG3 (see section 2.7). The classes have been established by assessing the expected activation and with respect to the operating and maintenance schedule of components. The modules are evaluated with respect to the following criteria,

- Location
- Level of activation after 72 hours
- Expected service interval [9]
- Reliability

Three possible classifications for modules have been identified as described in the sections below.

2.4.1 Types of remote handling operations

The ESS-NSS remote handling strategy strives to reduce the amount of different types of RH operations performed at the ESS. This is done to reduce complexity and cost in both the design and construction of the instruments and the tooling required.

NSS remote handling strategy limits the types of operations to the following;

- Disconnection and extraction of module.
- Reinstallation and reconnection of module.
- Inspection of module and/or components.
- Realignment of module and/or components.

Any operations intended for remote handling beyond the listed operations shall require consultation and approval from the ESS.

The types of operations required to be remote handling compatible is dependent on the module's location, level of activation, expected service interval and reliability (see section 2.4.3, 2.4.42.4.5).

2.4.2 Remote handling areas

There are two main remote handling areas at ESS. They are mainly determined by the density of currently planned and expected future equipment [2]. Higher density of equipment leads to a more complex environment where personal access is more hazardous. Given the need to allow for as much personal access as possible within the bunker, the area requiring full remote handling compatibility has been minimised.

The two areas are defined as,

- Yellow area – Modules within or partially within the area between R6 and R11.5m.
- Blue area – Modules fully outside R11.5m and inside the bunker shielding.

2.4.3 Full remote handling compatibility (Full-RH)

Full-RH is the higher classification of remote handling compatibility. In this classification modules with maintenance requirements, difficult placement or other constraining features belong.

Modules shall be classified as Full-RH if **any** of the following criteria apply:

- Module is installed in the yellow area and
  - Any component in the module critical for the performance of the instrument has an expected maintenance interval of less than five years, or
  - Any component in the module critical for the performance of the instrument has an expected mean time to failure of less than ten years.
- Module is installed in the blue area and
  - Any component in the module critical for the performance of the instrument has an expected maintenance interval of less than five years, or
  - Any component in the module critical for the performance of the instrument has an expected mean time to failure of less than ten years or
  - Module contains a significant hazard to personnel during interventions, due to activation (>25μSv/h on contact after 72h of beam off after 100 days of full power exposure according to ESS-0001786) or
  - Module contains a significant hazard to personnel during intervention, due to unknown levels of activation.
- Module has to be removed to access another Full-RH module.

Typical modules classified as Full-RH:

- Chopper assemblies
- Collimator assemblies
- Shutters
- T0-Choppers

Full-RH modules shall be designed to use remote handling in the following operations;

- Disconnection and extraction of module.
- Reinstallation and reconnection of module.
- Inspection of module and/or components (when required).
- Realignment of module and/or components (when required).

2.4.4 Limited remote handling compatibility (Limited-RH)

Limited-RH is the lower classification of remote handling compatibility. Modules belong to this classification if they have little or low maintenance needs, simple placement and no other constraining features.

Modules shall be classified as Limited-RH if it is installed within the yellow area and is not classified as Full-RH

Typical modules classified as Limited-RH:

- Base plates
- Supports and alignment mounts

- Most neutron guides
- Service infrastructure

Limited RH modules shall be designed to use remote handling in the following operations;

- Disconnection and extraction of module.
- Inspection of module and/or components (when required).
- Realignment of module and/or components (when required).

2.4.5 Non-RH

Non-RH classification applies to all modules that does not fall into Full-RH or Limited-RH classification. These components and modules are not subject to the rules and recommendations in this document.

2.5 Handling strategy

ESS-NSS does not foresee any need to do remote handling maintenance, neither in-situ or in hot-cell type areas. All maintenance is foreseen to be carried out using traditional hands-on methods once a module has been extracted and its activation has reached acceptable levels [4]. The NSS remote handling strategy limits the remote handling operations to the activities specified in section 2.4.1.

All new-installation operations are considered to be carried out hands-on once sufficient time has passed to grant personal access to the area.

It is neither economic nor practical to develop and prepare a remote handling solution optimised for each possible task on the ESS beamlines. Beamline modules should be designed to use the common RH tooling (see section 4) and minimise the need for specialised RH tooling.

Some components/modules will be too active to directly work on after being extracted. These will be placed in specifically defined areas on the ESS site for temporary cooldown storage.

In many cases the cool down period will exceed the available time during a maintenance period. In these cases, the module and/or component will have to be replaced with a spare identical module/component and then reinstalled (called hot-swap). The extracted component/module will be stored until maintenance can be carried out.

If a component emits more than 3μSv/h [4] it should be placed in a protective casket. The casket shall be designed to reduce the radiation to levels below 3μSv/h.

2.6 The need for and meaning of RH compatibility

It is well established RH-industry practice that the handling of modules using remote manipulation devices is made easier, faster and safer by the detailed consideration and accommodation of the module's handling needs from the earliest stage of its development cycle [5].

It has been demonstrated from past experience that the feasibility of handling modules not previously designed for RH compatibility varies from being impossible to being possible but at significant cost in time, money and risk. In the cases at JET (Joint European Torus) where remote handling was performed on previously non-RH compatible modules the time taken to perform the tasks was found to be of the order of 3 – 5 times longer than similar tasks involving modules which had been designed with RH compatibility [5]. There is a similar increase in the amount of preparation time required and, of particular relevance to ESS-NSS where manual access to the active areas for recovery or maintenance is severely restricted or impossible, a significant increase in the level of risk to the whole project.

The primary elements to ensure RH compatibility of beamline modules are as follows:

- Follow ESS RH best practices (as shown later).
- Use RH approved standard components and sizes (connectors, fluid couplings, pipe sizes etc.).
- Use RH approved standard features for self-alignment, lifting, grappling features and visual cues.
- Use of RH approved techniques for captive parts and fasteners.
- Clearances around module to for the installation path and in-situ positioning taking account the RH equipment.
- Provision for a means of protecting sensitive and delicate items during RH operations. This consideration includes the module being handled and the module in-situ.
- Adopt verification tests to incorporate test of RH compatibility.

2.7 The assessment of remote handling compatibility during instrument projects

The instrument projects are required to present the following during the TG3 review:

- Module definition and classification.
- RH consideration for handling, alignment and fastening.
- Failure analysis of modules.
- Case and reason when ESS best practices are not followed.
- Case and reason when ESS standard RH equipment is not used.
- Needs for specialised tooling outside of ESS standards.

The remote handling interfaces and designs will be included in the change control process [10]. The instruments projects shall communicate changes to TG3 scope as early as possible to allow for tools and equipment adaptation.

3. INSTRUMENT MODULE DESIGN BEST PRACTICES

In all areas modules shall be designed so that good RH best practise is applied e.g. maximise modularity, make sure that all fasteners, connectors, cables etc. are captive to the main module during handling, avoid double (or multiple) handling of module items and introduce self-alignment wherever possible.

A detailed set of guidelines for best practise is provided in the following sections and these principles will be applied during the assessment for RH compatibility of instrument modules.

3.1 Handling considerations

The general approach for ESS-NSS remote maintenance is that modules will be remotely detached/attached and transferred between its in-situ location and a dedicated repair/maintenance/storage facility within the ESS premises.

As far as is practicable, modules shall be designed to ensure that no complex or dexterous remote handling activities are required inside active areas. Remote handling in active areas shall be limited to the tasks specified in section 2.4.1.

Modules shall be designed to avoid the need for double (or multiple) simultaneous handling of items. The process of transferring a module from one piece RH equipment or crane to another, either directly or indirectly by means of an intermediary jig/support, has both the potential for the introduction of new failure scenarios and also will certainly significantly slow down the overall remote operation.

Modules shall be designed to be operated with the ESS overhead crane. The maximum capacity of the remote handling suitable bunker crane is 5000kg.

The maintenance areas will not be operated through remote handling, and direct maintenance operations are foreseen to take place once components have cooled down sufficiently as described in section 2.5.

3.2 Safe grappling of module during operations

Provision is needed for simple and safe engagement and disengagement with the modules. The design of attachment/grappling features is a deeply integrated activity module design.

Module design shall ensure that when the lifting equipment (mainly the overhead crane) is engaged with the module it is impossible to be ambiguous about its integrity and equally when the RH lifting equipment is disengaged. The preferred approach is to use a visible single point lifting interfaces per module. More details about the preferred designs can be found in section 3.10. Single point lifting systems requires adequate guidance of the module to ensure alignment and avoid damage to the module or its surrounding. More information on RH alignment is described in section 3.4.

Modules must be designed so that there are no loose items during handling. In principle this means that all bolts, nuts, washers, connectors and cables etc. disconnected for handling must be made captive to the main module.

Connecting cables and utilities (see 3.5.3) shall be disconnected and fixed before RH operations.

Information about the instrument hall hook (5 and 30 tonnes) dimensions will be added in this section in a later release of this document, once it is available.

3.3 Safe load transfer of module during handling

The transfer of load between the modules in-situ supports and the RH equipment can present significant difficulties and risks. The relative mechanical stiffness of the module itself, its supports and the RH equipment requires a controlled and gradual hand-over of the item whilst also taking the module's alignment and attachment requirements into account.

The preferred method is for a vertical load transfer during installation and extraction with simple lifting from above. The use of a crane for vertical lifting from above will provide compliance in 5 degrees of freedom (DoF) which also has the added benefit of aiding self-alignment of a module during its installation and extraction. [REFERENCE TO GERMAN LIFTING STANDARD]

Engagement and load transfer in any direction other than vertical from above will inevitably involve more complex handling and manipulation and thus more complex RH equipment. Any load transfers not directly vertical shall be discussed with and approved by the ESS.

In all cases, it is recommended that load transfer is in effect over a significant length of straight motion rather than over a short length or in a complex trajectory.

All specialised lifting rigs and remote handling equipment should be avoided. A list of available ESS standard equipment is available in section 4.

Considerations shall be made to placement of module once it is extracted. This can include, but is not limited, to special storage racks and frames and protective covers.

3.4 Safe alignment of module

During RH operations, it is important to ensure that module self-engages and aligns during installation and extraction.

The RH equipment (i.e. overhead cranes in this case) shall not be relied upon to be 'accurate' in its movements and positioning. It can be assumed that the RH equipment will be able to move smoothly and slowly, however it will not be able to move accurately to a given co-ordinate in an absolute reference system.

Modules shall be designed to be self-aligning during installation and extraction. Alignment shall be gradual and phased so that one degree of freedom is constrained at a time. More information on gradual alignment can be found in 3.4.2.

The design of a location device shall take into account the realistic capture range of the mating features and fasteners.

The alignment shall not be over-constrained and shall be toleranced to accommodate in-service distortions as well as manufacturing variations. Modules shall be designed to prevent wedging and jamming of parts. More information on wedging and jamming can be found in 3.4.1.

Consideration should be given to what RH equipment and tooling will be used to perform the task, when designing the module alignment system.

The orientation of the module shall be considered, i.e. installation on the ceiling or on a vertical wall is complicated by the gravity vector. Supporting indicators such as built-in spirit levels should be used to aid module orientation where possible and applicable.

Unambiguous sensors/indicators should be used where practicable to show that module items are fully engaged (e.g. lining up features on mating items).

Locations devices shall be designed such that it is impossible to mate modules incorrectly (e.g. asymmetric dowel pins prevent the wrong orientation). Visual cues should also be used where practicable to assist correct assembly.

Careful consideration should be given to choosing the correct datum and then tolerancing all module items accordingly with respect to that datum.

3.4.1 Jamming and Wedging

From the outset jamming and wedging conditions must be understood so it can be avoided in the design of alignment features for modules.

Jamming occurs when an external force causes two plant items to lock-up during assembly (see Figure 1). When the external force is removed, these forces disappear and the two items are no longer jammed. A jamming condition can be recovered by removing the external force, however, the design of RH locating devices shall minimise the possibility of jamming.

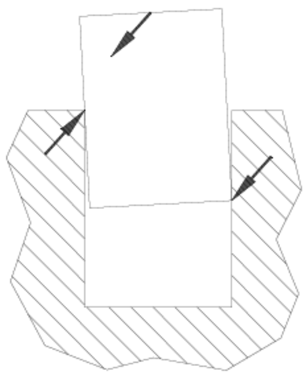


Figure 1 – Jamming

Wedging occurs when forces between the two assembled parts are internally balanced – i.e. with no externally applied force (see Figure 2). When this occurs an additional force (whose magnitude is difficult to accurately quantify) is required to deform the items in order to release them. A wedging condition is difficult to recover, therefore, the design of locating devices shall eliminate the possibility of wedging.

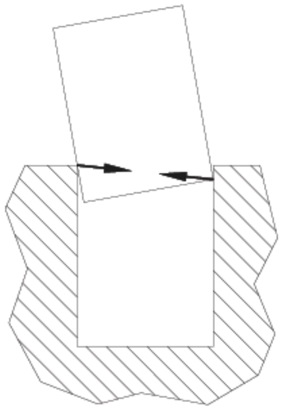


Figure 2 - Wedging

3.4.2 Kinematic constraint

A free body that is to be located by means of RH has a total of six degrees of freedom (DoF), three translations and three rotations (Figure 3). The purpose of locating devices is to progressively reduce the number of degrees of freedoms of the handled module to ensure that the mating process is carried out in a controlled manner without damage.

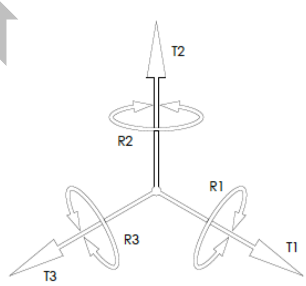


Figure 3 - Six degrees of freedom

An example of an RH compatible assembly using the kinematically constrained staged approach is given in Table 2 and Figure 4. At each stage of location, the number of DoFs has been reduced until the plant item is fully installed (DoF = 0). This general principle of staged kinematic constraint should be applied when developing a RH location device.

For each application, the method of kinematic constraint should be clearly defined. The number of steps required is dependent upon the complexity and required accuracy of the location device.

Location features shall be oriented vertically to avoid placing dowels in shear.

Table 2 - Staged kinematic constraint

Step	**DoF's**	**Type**
1. Module held in free space	6	3 Translation 3 Rotation
2. Module located on dowel ball-end	4	1 Translation 3 Rotation
3. Module located on single long ball-ended dowel pin	2	1 Translation 1 Rotation
4. Module item located on second short dowel pin	1	1 Translation 0 Rotation

5. Module fully in contact with mating face	0	0 Translation 0 Rotation

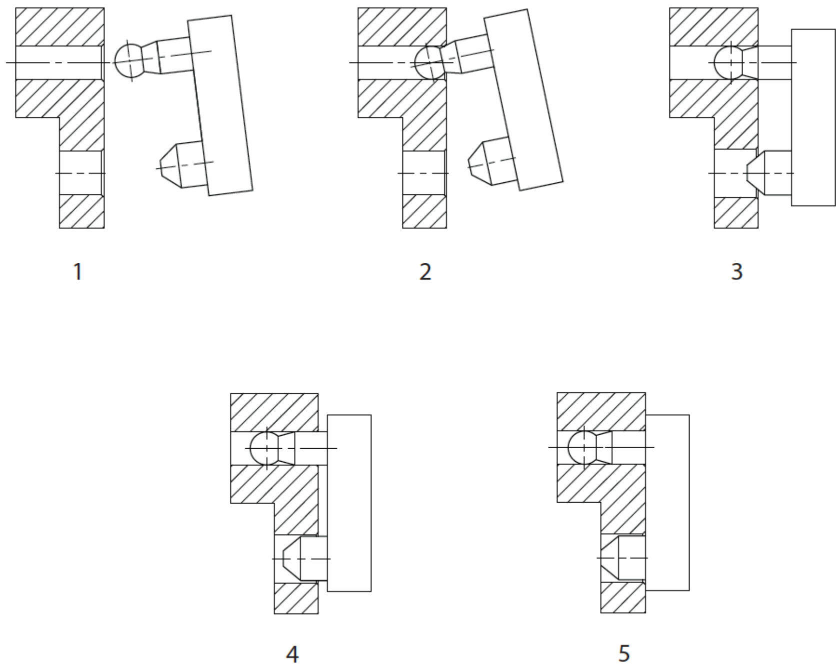


Figure 4 - Kinematic constraint stages

3.4.3 Edge guides

Edge guides are a simple method of providing module location. In a single plane three points of contact are used to define the correct position and two perpendicular forces are required to fully constrain the item.

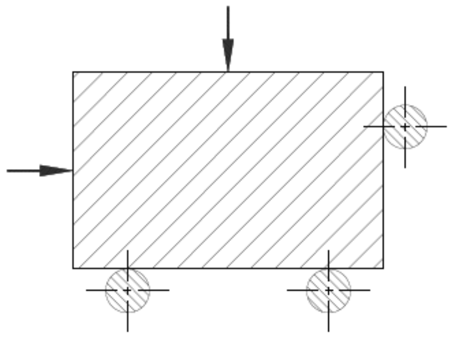


Figure 5 - Three-point edge location principle

The plane of location can be either vertical or horizontal. When the plane is vertical, careful consideration must be made to the applied forces (both static weight and dynamic loads) on the supports.

Edge guides are particularly appropriate where a clear view of the installation process is required as the supports are external to the located plant item.

Edge guides are not preferred within the ESS common shielding bunker since all remote handling operations are foreseen to be vertical using crane based solutions (i.e. it is difficult to add a second load).

3.4.4 Guide pins

This sections describes the use of guide pins/rods in juncture of handling misalignment. Guide pins/rods can be replaced by rollers or equivalent if it better suits the specific design. The rollers shall follow the same design considerations as guide pins.

Guide pins or rods should be used where a large misalignment needs to be reduced. This type of pin should be used to provide coarse initial location as the first stage in reducing the DoF's of a located module. The guide pin is used to reduce the initial misalignment to bring the dowel pins within their capture range which themselves provide accurate final location (Figure 6).

Guide pins can be mounted on either the module or the mating structure depending upon the specific requirements of the design. The length of the guide pin is determined by nature of the interface (i.e. not damaging surrounding equipment) and the available visibility during assembly – a longer guide pin is required where visual access is poor. Typically, the guide pins are long enough to clear the components from the surrounding sensitive equipment and/or allow for easy engagement during installation. Neighbouring instruments and infrastructure should be considered as well as instrument internal equipment.

If more than one guide pin is used, to further constrain the DoF, they should be of different lengths to gradually reduce the DoF. Pins should be sufficiently tapered to aid installation without becoming a personal hazard.

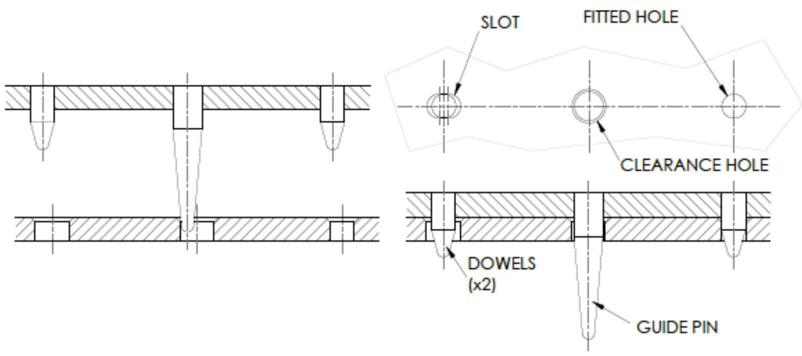


Figure 6 - Guide pin

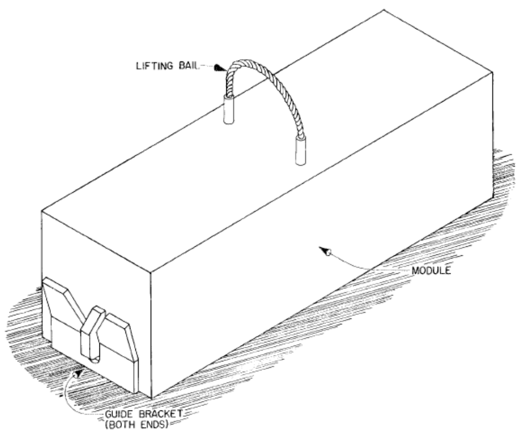


Figure 7 - Guide bracket example

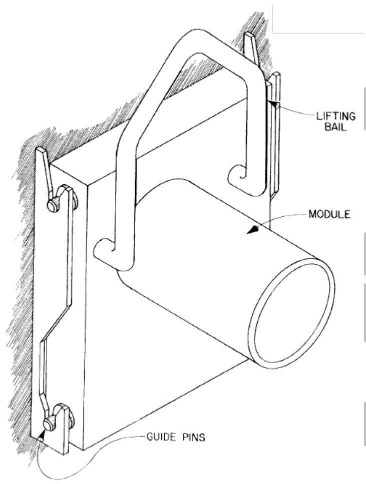


Figure 8 - Vertical hanger bracket example

3.4.5 Dowelling arrangement

Dowels provide an accurate method of final location for two mating items. A minimum of two dowels and one contact surface is required to fully constrain a module.

The proportions of the dowel (length and diameter) must be sized appropriately with respect to the method of manipulation used and the anticipated loads that could be applied during assembly.

Dowels should also be used to protect against side loads on mechanical fasteners during installation and in-operation. Thread damage and seizure may result from this type of loading and this risk should be minimised during design.

A limitation of this method of location is that the dowel(s), contained within the body of the module, are usually obscured during engagement. This method, therefore, relies upon good kinematic constraint and good visibility.

The generic parallel dowel pins are generally used in pairs to fully constrain two mating surfaces. One dowel located in a fitted hole eliminates two translational DoF's and the second dowel in a short slot eliminates a rotational DoF about the fitted hole (see Figure 9).

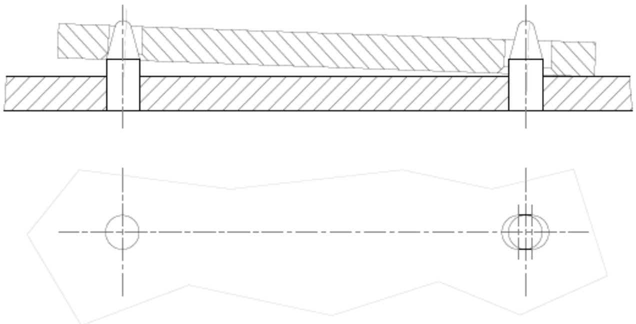


Figure 9 - Parallel dowel pin

Dowels should be as short as possible to provide adequate location and strength whilst minimising the risk of jamming. In addition, the profile of the nose of the dowel should be such that it increases the capture range and also avoids jamming.

Cylindrical dowel pins should be spaced apart as far as possible in order to minimise jamming of the pins when angular misalignment occurs during assembly.

3.4.6 Tracker points

Modules requiring survey and alignment during installation or operations shall contain survey point interfaces according to ESS-0011484.

3.5 Module interfaces

Interfaces between two modules and between a module and the surrounding shall be clear and unambiguous.

As far as possible, modules should be independent of other modules, requiring little or no interaction between each other.

3.5.1 Bolted interfaces

Bolting operations will be performed using a standard suite of remote handling tools and it is essential therefore to comply with the standard types and sizes (see section 3.10).

The number and types of bolts shall be minimised to reduce the number and types of RH operations. As a general principle fewer larger bolts is preferred over many small bolts.

Fasteners should be of the standard captive "Pop-up" design (see section 3.10) to minimise risk of damage during installation and extraction. Bolt captivation shall allow the bolts to be fully unscrewed whilst the plant remains in its installed position.

3.5.2 Welded interfaces

Welding shall be avoided for all mechanical connections and couplings between modules.

If no other alternative is possible, solutions should be discussed and approved by the ESS.

3.5.3 Electrical and fluid interfaces

Electrical and fluid ("utility") interfaces for one module with respect to the surrounding shall be concentrated at one point with relatively easy access for connecting and disconnecting.

3.5.3.1 Routing

The cables and utilities shall be routed to avoid access limitations to remote handling interfaces.

Utilities and cables shall be routed so any disconnection needed for maintenance extraction is placed within 200mm of the bottom of the bunker roof shielding.

Utilities should be routed upwards using a self-supporting section of pipe, called a snorkel, attached to the module. The snorkel should end with a flexible section and connected to the fixed installation. This will minimise the length of radiation and wear sensitive flexible sections. A simplified example is shown in Figure 10.

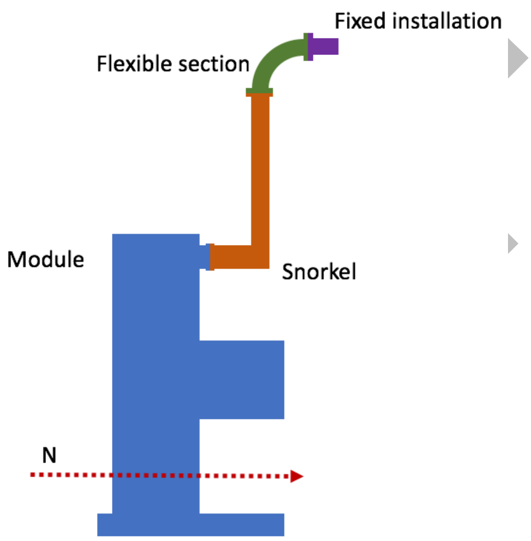


Figure 10 - Example of utilities routing (vacuum snorkel on chopper)

3.5.3.2 *Bundling*

The cables and utilities shall be collected in appropriate bundles. This is to avoid damage and unnecessary wear during handing. It also simplifies the interface during remote handling activities by clearly separating bundles to different extraction modules. Larger collected connectors are preferred over multiple smaller connectors, as shown in Figure 11.

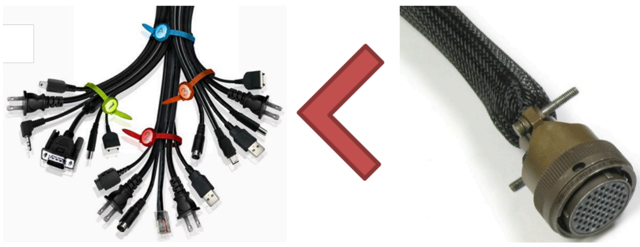
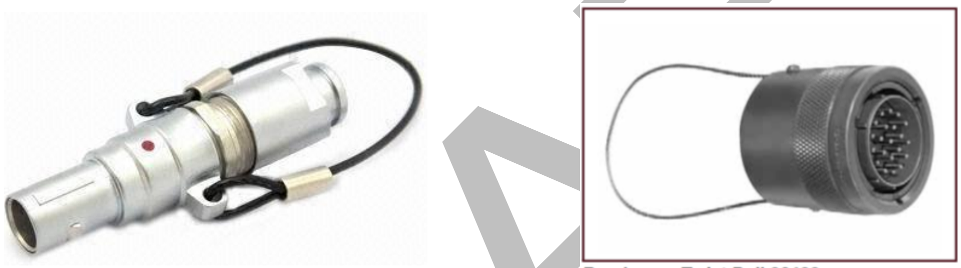


Figure 11 - Connector types

3.5.3.3 *Connectors*

Connectors shall be suitable for remote handling procedures to minimise exposure to radiation during connection/disconnection. Different connector series are available on the market for different levels of integration and remote handling capability, as shown in Figure 12 and Figure 13. Push-pull type connectors with lanyard pulls are preferred, but also "breakaway" plugs in bayonet type connector series are acceptable alternatives.

Figure 12 – Full remote handling connectors (RH-I)



Breakaway Twist Pull 26482

Figure 13 – Connectors for remote disconnection (RH-II)

Exposure time during connection, position of the connection point and radiation level at the time of connection have to be taken into account when selecting connector types.

A fully integrated, fully remote handling version with connector for electrical signals, fluids and gases is shown in Figure 14.

Figure 14 – Fully integrated connector platform

More information on standard cables and connectors can be found in section 3.10.

3.6 Identification of module and its location

Provision shall be made to ensure that all modules and the related installation locations are easy to identify from the working platform or by using the camera system available.

Both ends of cables and utilities connections to the module shall be clearly marked with its title, function and location.

Two to three independent inspection features should be included to ensure correct module assembly where applicable. These inspection features should provide unambiguous indication of alignment.

3.7 Minimising activation of installed modules

Minimising activation of installed components reduces the required cooldown period for both personal access to the bunker area and for the hands-on maintenance on extracted components.

Selection of the correct materials is crucial for minimising the activation. Instruments shall comply to the instruction and materials list found in section 3.10. Any exceptions shall be reviewed and approved by ESS.

3.8 Minimising contamination

Equipment removed from the bunker shall be decontaminated if required. If cooldown period is not available, or sufficient, most equipment can be decontaminated to reduce the gamma radiation at the surface to acceptable levels prior to performing maintenance. The following considerations are important:

1. If possible choose construction materials that minimise the need for decontamination.
2. If (1) is not possible choose construction materials which resist degradation by the decontamination fluids.
3. If equipment is not to be reused, it may be constructed of lower grade materials not resistant to the decontamination fluids.
4. Consider the decontamination procedures so the design of the equipment can reflect the following features:
    - No blind holes unless provided with drain ports.
    - Specify continuous welds to fill cracks and crevices.
    - Use smooth or polished metal surfaces.
    - Avoid porous materials, if possible.
    - Eliminate joints that may trap material, where possible.

3.9 Viewing/Visibility

The visibility of RH operations is a crucial consideration. If the task area cannot be seen from the work platform or through the camera system, it will be impossible to perform the remote handling operation. When required, the ESS-NSS will incorporate cameras and associated lighting systems to improve visibility. However, instrument teams should strive for designs requiring no additional viewing aids.

It is essential for all remote handling compatible modules that there is as much provision as possible of visual cues. The implementation of visual cues depends significantly on the application. The following guidelines should be followed:

- Provide high contrast or colour difference between two mating modules.
- Provide physical features that clearly align when correctly assembled.
- Avoid highly reflective surfaces where possible.
- All module items, particularly connectors, wiring and other multiple items shall be clearly marked and identified (see section 3.6).
- All module items which require inspection in service should, wherever possible, incorporate inspection access facilities such as guide tubes for deployment of viewing probes in difficult areas
- All plant items which require metrology inspection or alignment must incorporate suitable attachment points for targets and datum references (see section 3.4.6).

3.9.1 Failure and damage considerations

It is important to the success of any neutron scattering instrument that any credible module failure or damage scenario must not result in an irrecoverable situation. Proper failure analysis can improve the reliability and availability of instruments while failure recovery analysis will ensure maintainability and an overall reduction of personnel dose exposure.

All modules shall be assessed for the probability and modes of failure.

The following shall be provided for all modules:

- Perform malfunction/failure analysis of equipment operations to assure that failure modes do not lead to more failures etc.
- A method to effectively detect failures and identify the specific malfunctions or failures if critical for the performance of the instrument.
- Methods to recover from and repair all foreseen failures.
- Methods to stop flows or bypass process materials and to drain components prior to removal.
- Assure that the design and associated maintenance time periods meet module availability requirements.
- Recommend in-service preventive maintenance inspections and operations, and methods for accomplishing them.

An important element of this consideration is that the designated remote handling mechanical interfaces between the module and RH equipment shall not be damaged by any module failure or damage scenario.

3.10 Standardisation

Standard equipment selection reduces overall design and construction costs of a module, reduces spare parts inventories, reduced the cost for maintenance tooling and minimises operator training time for maintenance. General standardization guidelines for equipment designers include the following:

- Commercially purchased components, modified if necessary, are preferred to specially designed and fabricated components.
- The number of different types of commercially purchased components should be limited.
- Utilize standard design solutions, as described in the detailed documents, wherever possible in preference to creating new design solutions.

The ESS has developed, evaluated and approved a range of module sub-components for remote handling compatibility. There are approved and endorsed technical solutions in the following fields:

- Location and alignment devices
- Fasteners and mechanical load transferring components
- Lifting and handling features
- Electrical connectors
- Fluid couplings
- Construction materials use at ESS instruments

Additional areas of standardisation may be developed with time, as well as solutions for specific technical challenges.

Information on the available standards, drawings, models and specifications are available at the remote handling Confluence webpage [11].

In case instrument teams would like to use components or systems not listed in the documents above, the instrument team shall provide a justification to ESS.

4. STANDARD ESS RH TOOLING

A set of standard RH tooling and equipment will reduce the construction cost of instruments due to fewer specialised solutions and less development time. It will also reduce operational costs by reducing the spare part inventory and reduced time for maintenance training.

The standard set of remote handling tooling and equipment is provided by the ESS.

Any specialised operations where the standard tools are not sufficient shall be part of the individual instrument project.

4.1 Lifting equipment

Details of the standardised ESS RH lifting equipment will be added in a later release of this document.

4.2 Work platform

Details of the standardised ESS RH work platform will be added in a later release of this document.

4.3 Bolt handling system

Details of the standardised ESS RH bolt handling system will be added in a later release of this document.

4.4 Positioning assistance equipment

Details of the standardised ESS RH positioning assistance equipment lifting equipment will be added in a later release of this document.

4.5 Grappling equipment

Details of the standardised ESS RH grappling equipment will be added in a later release of this document.

4.6 Lighting system

Details of the standardised ESS RH lighting system will be added in a later release of this document.

4.7 Vision system

Details of the standardised ESS RH vision system will be added in a later release of this document.

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6. LIST OF ABBREVIATIONS

Abbreviation	Explanation of abbreviation
ESS	European Spallation Source
NSS	Neutron Scattering Systems
ALARA	As Low As Reasonably Achievable
RH	Remote Handling
CHIM	Chopper Integration Module
SNS	Spallation Neutron Source
JET	Joint European Torus
TG	Toll Gate
DoF	Degrees of Freedom

DOCUMENT REVISION HISTORY

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0.1	Draft release	2017-02-24