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Guideline

ITER Remote Maintenance Management System (IRMMS)

This document describes and defines the overall management methodology for preparation and implementation of ITER Remote Handling systems and activities. It is complementary to and should be viewed alongside the ITER Remote Handling Code of Practice [1].

Approval Process			
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ITER Remote Maintenance Management System (IRMMS)

Abstract

This document describes and defines the overall management methodology for preparation and implementation of ITER Remote Handling systems and activities. The IRMMS is intended to be used as a reference guide by all personnel who have an interface and influence in the successful outcome of the ITER maintenance activities. These stakeholders include not only the IO remote handling responsible engineers but also the personnel responsible for design, procurement, operation, and licensing of the ITER plant.

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Records of Revision

Rev. No.	Date	Pages	Description of changes
1.2	30-04-2008		IO takes over responsibility for document
1.3	08-08-2008	Throughout Throughout 9,12,26,46,47,49, 50,52,53,93 31 34,35 66,68,72,73 93	Scope is **remote** maintenance only Minor text corrections Update to operating parameters Caesium oven is intervention task Alignment with PR definitions Alignment with RH SRD's IVVS Plug replacement task added
1.4	20-10-2008	33,36,37 Annexe G	Plant Definition Form added
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1.6	23-02-2009	34 – 35 36 – 45 25,54	RH Classification flowchart and implications RH Procurement Specification Process added RH Operational Areas diagram updated

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1 Executive Summary

This document describes and defines the overall management methodology for preparation and implementation of ITER Remote Handling systems and activities. It is complementary to and should be viewed alongside the ITER Remote Handling Code of Practice [1].

Maintenance of ITER systems located within the ITER Tokamak Building will depend to a very significant extent on the ITER remote handling capability. Wherever possible manual maintenance methods will be used, however all of the in-vessel components must be handled and maintained using remote handling methods. With the exception of NB Cell which has a dedicated remote maintenance system all other remotely maintainable ITER plant items will be removed from the Tokamak Building and taken to the ITER Hot Cell for maintenance and repair. Additionally, in some areas of the Port Cells and Gallery it will be necessary to adopt a mixed approach involving both remote handling and manual operations.

The ITER Remote Maintenance Management System (IRMMS) is intended to be used as a reference guide by all personnel who have an interface and influence in the successful outcome of the ITER maintenance activities. These stakeholders include not only the IO remote handling responsible engineers but also the personnel responsible for design, procurement, operation, and licensing of the ITER plant.

The IRMMS describes the rationale and priorities for the management controls and explains in detail the overall life cycles for each of the three key elements which will have a major impact on the success of ITER remote maintenance:-

- The IO Plant remote handling compatibility
- The ITER Remote Handling equipment
- The ITER Remote Handling operations

The efficiency and safety of remote handling operations is directly related to the design and operation of the RH equipment but also most significantly on the compatibility of the items being handled. The remote handling compatibility of ITER plant is assured by the adoption of a systematic methodology as described in terms of overall ITER plant life cycle with the management and interface control points defined for all stages of plant, specification, design, manufacture and installation. Application of the methodology is supported by an approved set of standards which are specified and described within the complementary document; the IRHCOP.

To achieve safe and efficient remote operation of the handling equipment the ITER remote maintenance system (IRMS) must be specified, designed, procured and commissioned using a consistent and complete 'whole life' approach. The IRMMS describes the methodology to be adopted for implementation of the IRMS and provides a detailed life cycle for the equipment including the management and interface control points. The

IRMMS also provides general guidance and standards for specifying the appropriate requirements including the provision of key non-functional elements such as equipment failure modes and recovery after failure.

The speed, efficiency and flexibility of remote handling operations will directly and significantly impact on the overall ITER Tokamak Availability. The IRMMS provides a detailed description of the lifecycle for preparation and implementation of remote operations. The lifecycle identifies management control points, key activities and interfaces necessary to prepare and implement ITER remote operations.

2 Scope of the ITER Remote Maintenance Management System (IRMMS)

This document describes and defines the overall management methodology for preparation and implementation of ITER Remote Handling systems and activities. It is complementary to and should be viewed alongside the ITER Remote Handling Code of Practice [1].

The IRMMS provides information to those ITER Organisation staff involved or affected by the need for remote handling.

The IRMMS defines and describes:

- the boundaries and interfaces for the ITER remote handling team
- the role and impact on the project timeline of remote handling operations
- the overall strategy for remote handling of ITER
- the remote handling task areas and operating environment
- the project life cycle for remote handling compatible ITER plant
- the ITER maintenance system
- the approach to ITER remote handling operations

3 Glossary

AIV	Assembly Integration and Verification
ATS	Air Transfer System
CAD	Computer Aided Design
CMM	Cassette Multi-functional Mover
Component	Plant item installed on the Tokamak
CONNET	Control Network
CTM	Cassette Toroidal Mover
DAQNET	Data Acquisition Network
DCR	Design Change Request
FMECA	Failure Mode, Effects Criticality Analysis
FILENET	File transfer Network
FRACAS	Fault Reporting and Corrective Action System
HMI	Human-Machine Interface
HVAC	Heating, Ventilation and Air Conditioning
IMMP	ITER Maintenance Management Plan
IRMMS	ITER Remote Maintenance Management System
IRMS	ITER Remote Maintenance System
IO	ITER Organisation
IRHCOP	ITER Remote Handling Code of Practice
IVT	In-Vessel Transporter
IVVS	In-Vessel Viewing System
MAM	Multi-purpose Arm Manipulator
MTBM	Mean Time Between Maintenance/Modification
MDT	Mean Down Time
MPD	Multi-Purpose Deployer
NB	Neutral Beam
OSD	Operation Sequence Description
Plant	ITER plant item - Interchangeable with ITER Component
QA	Quality Assurance
RH	Remote Handling
RAMI	Reliability, Availability, Maintainability, Inspectability
RHCA	RH Compatibility Assessment
RPE	Respiratory Protection Equipment
RHOMS	Remote Handling Operations Management System
SOR	Statement of Readiness
SRD	System Requirements Document
tbc	To be confirmed
tbd	To be decided
VR	Virtual Reality
VV	Vacuum Vessel

4 Definitions

4.1 Remote Handling

"Remote handling is the synergistic combination of technology and engineering management systems to enable operators to safely, reliably and repeatedly perform manipulation of items without being in personal contact with those items." [2]

ITER presents a challenge for remote handling greater than anything seen anywhere in the world previously. As with ITER itself the remote handling challenge is complex and demanding of technological, managerial, programmatic and statutory aspects.

4.2 ITER RH Shutdown and RH Intervention

An ITER remote handling shutdown comprises the implementation of remote handling operations within the Tokamak environment following a suitable decay period and with the working environments conditioned to present minimum practical hostility to the remote handling equipment.

An ITER remote handling intervention comprises the implementation of remote handling operations after the minimum of decay period and with the Tokamak primary systems remaining active.

Table 4.2.1 summarises the distinction between shutdowns and interventions.

IO System	RH Shutdown	RH Intervention
TF & PF magnets	Deactivated, residual magnetic field < 1mT	Deactivated, residual magnetic field < 1mT
Vacuum systems	Systems are dormant and all working areas are at nominal atmospheric pressure (with small atmospheric depression for contamination control purposes).	Systems on and maintaining UHV conditions
RH operating area temperatures	Will be maintained near ambient (< 50°C)	Up to 120° C
RH operating area background radiation levels	Levels will vary according to area and decay period. 100- 500 Gy/hr	Levels will vary according to area. Up to 1500 (tbc) Gy/hr
Plant electrical power	Power to the Plant is isolated.	Electrical power is 'live'

Table 4.2.1 Conditions for ITER shutdowns and interventions

4.3 ITER Plant

All hardware items whether individual components, modules or major systems which are to be installed on the ITER machine.

5 ITER programme aspects

5.1 The need for maintenance and remote handling

Maintenance of ITER plant will be required under the scenarios shown in table 5.1.1.

Potential trigger event	Consequent actions	Maintenance scenario	Examples
Plant failure prevents continued ITER operation	Immediate repair or replacement required	Unscheduled shutdown	i. Large leak on the primary vacuum system ii. Mechanical failure of part of first wall
Plant fails or degrades but ITER continues to operate	Repair or replacement scheduled for next convenient opportunity	Scheduled shutdown	i. Partial loss of additional heating or diagnostic systems. ii. Limited damage to first wall components.
Plant degrades at a known rate and requires periodic replacement	Periodic replacement as preventative maintenance	Scheduled intervention or shutdown	i. Caesium ovens in NB system. ii. Blanket system.
Plant is designed to be changed for experimental purposes	Scheduled replacement	Scheduled shutdown	i. Test Blanket Modules

Table 5.1.1 ITER potential remote handling shutdowns and interventions

As far as is possible and practical maintenance of plant will be performed manually i.e. by suitably qualified and experience personnel working directly on the plant concerned. The plant and areas suitable for man access will be defined and controlled by ITER Health Physics and Safety Policies. In normal situations, exposure shall be as low as reasonably achievable and in any case < 10mSv/yr [4]. For the purposes of guidance and planning it has been assumed that the target dose for hands-on operations is less then 100μSv/hr.

In many areas of ITER it will be impossible or impractical to send personnel. Maintenance tasks in these areas will be conducted using remote handling methods.

In some areas the maintenance tasks may be performed using a mixed approach with manual support to remote handling methods e.g. inside the port cells.

5.2 Impact of RH on the ITER Scientific Programme

The success of the ITER scientific programme is inextricably linked to the ability of those responsible for remote handling operations to perform their work efficiently and in a timely way.

The Availability of ITER for operation is related to the frequency of maintenance or modification and the total down time to implement the maintenance or modifications:-

$$\text{ITER Availability for Operations} = \frac{\text{MTBM}}{\text{MTBM + MDT}}$$

Where: MTBM – Mean Time Between Maintenance/Modification
MDT – Mean Down Time for Maintenance/Modification

The ITER Scientific programme aims for Machine Inherent Availability (excludes operational problems/delays) of > 60% [3].

The MTBM is dependant on a combination of:-

- programmatic choice (how often to make modifications as part of the experimental programme)
- component reliability (period between component failures and between preventative maintenance activities e.g. refurbishments).

The MDT is dependant on a combination of:-

- time to implement the planned maintenance/modifications including all associated overheads
- time to implement the un-planned maintenance/modifications including associated overheads

The elements which affect MDT are shown diagrammatically in fig 5.2.1.

In practise the time taken for remote manipulation is the dominant element and is itself significantly influenced by:-

- the level of detail addressed in advanced preparation
- the suitability of the remote handling equipment
- the compatibility of the plant being handled
- the organisation and management of the remote handling operations

This IRMMS contains detailed information and guidance focussed on facilitating all IO stakeholders to contribute to the maximisation of ITER Availability for Operations.

Fig 5.2.1 Factors affecting ITER Mean Down Time

5.3 Stakeholders in ITER remote handling

The IO stakeholders responsible for a successful outcome to ITER remote handling are:-

- The IO RH team
    - The IO RH managers
    - The IO RH equipment design engineers
    - The IO RH equipment maintenance engineers
    - The IO RH systems engineers
    - The IO RH operations engineers
    - The IO RH VR engineers
    - The IO RH Operators
    - The IO RH maintenance technicians
- The IO project management
- The IO physicists
- The IO plant design engineers
- The IO plant procurement engineers
- The IO plant Assembly, Integration and Verification engineers
- The IO Quality Assurance team
- The personnel providing the above functions in the Domestic Agencies
- The IO Plant Operators

All of these participants have a stake in achieving:-

- Safe remote handling operation campaigns
- The required ITER Machine Inherent Availability of > 60% [3].

Within the context of IO technical management controls (§8) the stakeholders are subdivided as follows.

1) IO Plant Stakeholders:
    a. IO physicists related to specification and design of the plant.
    b. The IO plant design engineers
    c. The IO plant procurement engineers
    d. The IO plant Assembly, Integration and Verification engineers
    e. The IO Quality Assurance team
    f. The relevant personnel providing the above functions in the Domestic Agencies
    g. The IO Plant Operators

2) RH Equipment Stakeholders:
    a. The IO RH systems engineers
    b. The IO RH equipment design engineers
    c. The IO RH maintenance engineers
    d. The IO RH maintenance technicians

3) RH Operations Stakeholders:
    a. The IO RH operations engineers
    b. The IO RH VR engineers
    c. The IO RH operators

5.4 The ITER Organisation Remote Handling Team

5.4.1 *Overall team organisation*

The organisation and roles within the IO remote handling team will change in response to the needs of the overall project programme and will adopt a different structure for each of the two main phases, Design and Procurement and Operations, as shown in figures 5.4.1 and 5.4.2.

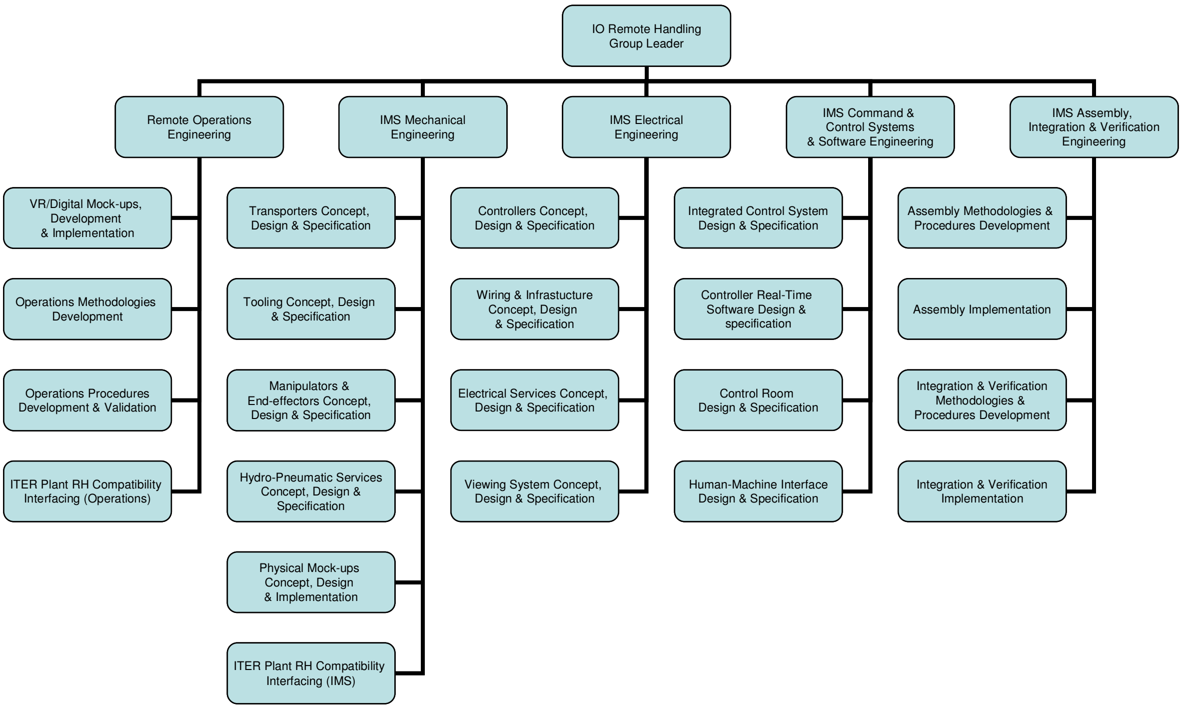

Figure 5.4.1 IO Remote Handling Group Organisation during the IO Design and Procurement Phase.

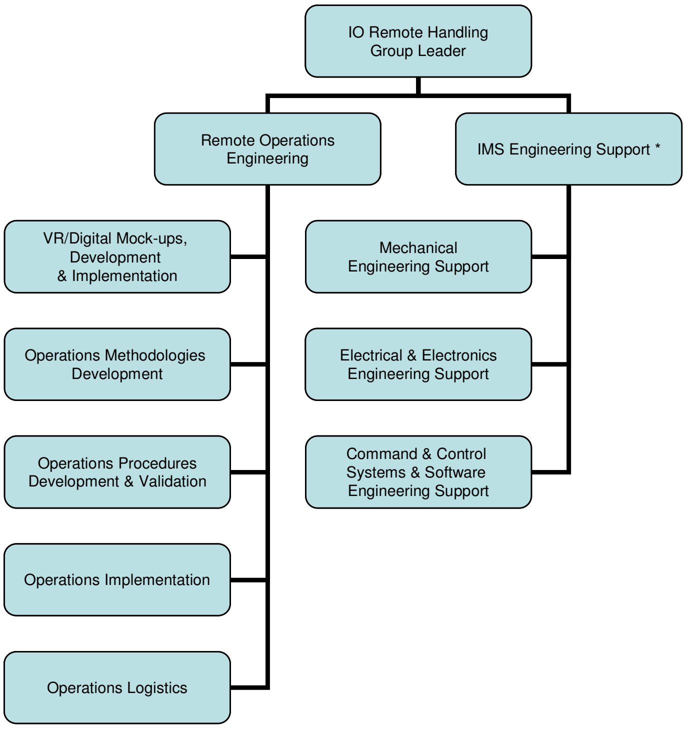

Figure 5.4.2 IO Remote Handling Group Organisation during the IO Operations Phase

5.4.2 RH team member roles during the ITER Design and Procurement phase

Table 5.4.1 defines the roles and qualifications required for RH team members during the IO design and procurement phase.

Position	Role	Qualifications / Experience
(a) Management		
Group Leader	Full responsibility for strategy, organisation, management and delivery of the IRMS, the first tranche of remote handling operations procedures and the IO Plant RH compatibility.	10 years experience in management of a complex engineering function. 10 years experience in the design and implementation of remote handling equipment and operations.
(b) Remote Operations Engineering		
Senior RH Operations Engineer	Full responsibility for conceptualisation, characterisation and development of remote operations methodologies.	5 years experience at Operations Engineer level. Successful completion of the ITER Senior Operations Engineer training course. Experience with working practises found in nuclear

Position	Role	Qualifications / Experience
		plant environment or a similarly regulated industry.
RH Operations Engineer	Deputy to the Senior Operations Engineer. Responsible for detailed creation and validation of the RH operations procedures.	Engineering qualification at Senior Technician level Or 2 years experience at Operator level. And Successful completion of the ITER Operations Engineer training course. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
VR/Digital Mock-up Engineer	Full responsibility for creation and maintenance of the RH Virtual mock-up.	Minimum of senior technician level engineering qualification. 5 years experience with creation and use of 3D CAD and 3D real time computer graphics.
RH Compatibility Engineer (Operations)	Responsible for the assessment and approval of ITER Plant concepts and designs in order to ensure full RH compatibility with remote operations methods and standards.	Same as required for the Senior RH Operations Engineer.
(c) Mechanical Engineering		
Senior Mechanical Engineer	Full responsibility for the concept design, development and specification of IRMS equipment mechanical sub-systems and physical mock-ups.	Professional (Graduate Level) mechanical engineer. 10 years experience in the design and development of electro-mechanical or electro-hydraulic equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
Mechanical Engineer (IRMS)	Working under the supervision of a senior mechanical engineer. Responsible for the concept design, development and specification of IRMS equipment mechanical sub-	Professional (Graduate Level) mechanical engineer. 2 years experience in the design and development of electro-mechanical or electro-hydraulic equipment. Experience with working

Position	Role	Qualifications / Experience
	systems.	practises found in nuclear plant environment or a similarly regulated industry.
Mechanical Engineer (Mock-ups)	Working under the supervision of a senior mechanical engineer. Responsible for the concept design, development and specification of the Test Stand and Hot Cell task mock-ups.	Professional (Graduate Level) mechanical engineer. 2 years experience in the design and development of electro-mechanical or electro-hydraulic equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
Mechanical Designer(IRMS)	Working under the supervision of a mechanical engineer. Responsible for the layout and creation of CATIA models and 2D drawings for concept design and specification of IRMS equipment mechanical sub-systems.	Engineering drawing office qualifications. 2 years experience in the use of CATIA for the design of electro-mechanical or electro-hydraulic equipment.
RH Compatibility Engineer (IRMS)	Responsible for the assessment and approval of ITER Plant concepts and designs in order to ensure full RH compatibility with IRMS capabilities and standards.	Professional (Graduate Level) mechanical engineer. 2 years experience in the design and development of electro-mechanical or electro-hydraulic remote handling equipment.
Senior Mechanical Technician	Full responsibility for organisation and management of technicians. Full responsibility for assembly, testing and workshop/laboratory activities in support of the IRMS procurement, AIV and mock-up activities.	Recognised workshop practise qualification and accredited technician apprenticeship. 10 years experience in a laboratory environment involved with maintenance and development of complex electro-mechanical or electro-hydraulic equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
Mechanical Technician	Responsible for mechanical equipment assembly, testing and workshop/laboratory	Recognised workshop practise qualification and accredited technician

Position	Role	Qualifications / Experience
	services in support of the IRMS procurement, AIV and mock-up activities.	apprenticeship. 2 years experience in a laboratory environment involved with maintenance and development of complex electro-mechanical or electro-hydraulic equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
(d) Electrical Engineering		
Senior Electronics Engineer	Full responsibility for the concept design, development and specification of IRMS equipment, test stand and mock-ups electronics sub-systems.	Professional (Graduate Level) electronics engineer. 10 years experience in the design and development of electronics systems for servo-controlled handling equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
Electronics Engineer	Working under the supervision of the senior electronics design engineer. Responsible for the concept design, development and specification of IRMS equipment, test stand and mock-ups electronics sub-systems.	Professional (Graduate Level) mechanical engineer. 2 years experience in the design and development of electronics systems for servo-controlled handling equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
Senior Electrical Engineer	Full responsibility for the concept design, development and specification of IRMS equipment, test stand and mock-ups wiring & infrastructure sub-systems.	Professional (Graduate Level) electrical engineer. 10 years experience in the design and development of electrical systems and services for mobile handling equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
Electrical	Working under the	Professional (Graduate Level)

Position	Role	Qualifications / Experience
Engineer	supervision of the senior electrical design engineer. Responsible for the concept design, development and specification of IRMS equipment, test stand and mock-ups electrical and infrastructure sub-systems.	electrical engineer. 2 years experience in the design and development of electrical systems and services for mobile handling equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
Viewing Engineer	Full responsibility for the concept design, development and specification of IRMS viewing and environment sensing sub-systems.	Professional (Graduate Level) electronics or electrical engineer. 5 years experience in the design and development of viewing systems for hostile environments.
Senior Electrical/ Electronics Technician	Full responsibility for organisation and management of electrical and electronics technicians. Full responsibility for electrical and electronic sub-systems assembly, testing and workshop/laboratory activities in support of the IRMS procurement, AIV and mock-up activities.	Recognised workshop practise qualification and accredited technician apprenticeship. 10 years experience in a laboratory environment involved with maintenance and development of complex electro-mechanical or electro-hydraulic equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
Electrical / Electronics Technician	Responsible for electrical and/or electronic systems assembly, testing and workshop/laboratory services in support of the IRMS procurement, AIV and mock-up activities.	Recognised workshop practise qualification and accredited technician apprenticeship. 2 years experience in a laboratory environment involved with maintenance and development of complex electro-mechanical or electro-hydraulic equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.

Position	Role	Qualifications / Experience
(e) Command & Control Systems and Software Engineering		
Senior Control Systems & Software Engineer	Full responsibility for the concept design and specification of the overall IRMS Integrated Control System. Full responsibility for the concept design and specification of the IRMS equipment control system software. Full responsibility for the specification of IRMS equipment control system behaviour. Full responsibility for the concept design and specification of IRMS Human Machine Interfaces.	Professional (Graduate Level) control systems engineer. 10 years experience in the design and optimisation of electro-mechanical or electro-hydraulic servo-control systems and their associated software and HMI's.
Control Systems Engineer	Working under the supervision of the senior control systems and software engineer. Responsible for the concept design, development and specification of IRMS equipment servo-control systems.	Professional (Graduate Level) control systems engineer. 2 years experience in the design and optimisation of electro-mechanical or electro-hydraulic servo-control systems.
Real time Software Engineer	Working under the supervision of the senior control systems and software engineer. Responsible for the concept design and specification of IRMS equipment real time software systems.	Professional (Graduate Level) software engineer. 2 years experience in the design and optimisation of real time control software for electro-mechanical or electro-hydraulic systems.
HMI software engineer	Working under the supervision of the senior control systems and software engineer. Responsible for the concept design and specification of IRMS equipment HMI software systems.	Professional (Graduate Level) software engineer. 2 years experience in the design and optimisation of HMI's and GUI's for electro-mechanical or electro-hydraulic systems.
(f) Assembly, Integration and Verification (AIV) Engineering		
Senior AIV Engineer	Full responsibility for the derivation and	Professional (Graduate Level) engineer.

Position	Role	Qualifications / Experience
	implementation of an AIV programme for all IRMS sub-systems.	10 years experience in the implementation of AIV for complex electro-mechanical or electro-hydraulic systems. Experience with working practises found in nuclear plant environment or a similarly regulated industry.
AIV Engineer	Working under the supervision of the senior AIV Engineer. Responsibility for the derivation and implementation of AIV processes and procedures and for all IRMS sub-systems.	Professional (Graduate Level) engineer. 2 years experience in the implementation of AIV for complex electro-mechanical or electro-hydraulic systems. Experience with working practises found in nuclear plant environment or a similarly regulated industry.

Table 5.4.1 RH team roles required for the IO Design and Procurement phase

5.4.3 RH team member roles during the ITER Operations phase

Shutdowns and interventions taking place during the IO operations phase will require the command and control of remote operations in up to eight areas contemporaneously:-

- In-Vessel & port cells for Divertor Handling
- In-Vessel & port cells for Blanket Handling
- Port cells for Plug Handling
- Gallery & Lift for cask command & control
- Hot Cell main refurbishment area
- Hot Cell plug refurbishment area
- Test Stand
- NB Cell

During the IO operations phase there will be also be the requirement for command and control of the IVVS inside the torus albeit not in parallel with the above.

The total number of staff required to support the above remote operations will depend on the number of remote handling control rooms which can be managed in parallel and the operations shift working requirements.

Operations in any one of the above areas will be implemented by a team of staff comprising those managing and performing the operations together with those directly supporting the operations logistics and the IRMS equipment. A remote handling operations team for a single shift normal days scenario will comprise the staff as defined in table 5.4.2.

Position	No. per Shift Team	Role	Qualifications
Senior Operations Engineer	1	Full responsibility for safe and efficient implementation of the planned remote operations. Full responsibility to implement contingency plans in the event of an unexpected occurrence.	5 years experience at Operations Engineer level. Successful completion of the ITER Senior Operations Engineer training course.
Operations Engineer	1	Deputy to the Senior Operations Engineer. Responsible for detailed organisation and management of the RH operations procedures. Responsible to ensure short and medium term future logistical arrangements are in place.	Engineering qualification at Senior Technician level Or 5 years experience at Operator level. And Successful completion of the ITER Operations Engineer training course.
VR/Digital Mock-up Engineer	1	Full responsibility for creation and maintenance of the RH Virtual mock-up.	Minimum of senior technician level engineering qualification. 5 years experience with creation and use of 3D CAD and 3D real time computer graphics.
RH Operator	3 min. (Depends on shutdown activities)	Responsible for safe and efficient operation of designated RH equipment.	Engineering qualification at engineer level. Successful completion of Operator training course for the designated RH equipment.
RH Operations Support Engineer	1	Responsible for organisation of technicians and staff from other departments to ensure timely supply of components and IRMS equipment in compliance with the remote	Engineering qualification at engineer level.

		operations logistics.	
RH Equipment Support Engineer (Mechanical)	1	Responsible for first line response in the event of a mechanical fault on any IRMS system.	Engineering qualification at engineer level. Successful completion of RH equipment support engineer course.
RH Equipment Support Engineer (Electrical & Wiring infrastructure)	1	Responsible for first line response in the event of an electrical or wiring infrastructure fault on any IRMS system.	Engineering qualification at engineer level. Successful completion of RH equipment support engineer course.
RH Equipment Support Engineer (Controls, HMI & Software)	1	Responsible for first line response in the event of a control system, HMI or software fault on any IRMS system.	Engineering qualification at engineer level. Successful completion of RH equipment support engineer course.
RH Equipment Specialist Support Engineer	1 per type of IRMS sub-system	Responsible for analysis and rectification of mechanical /electrical/electronic/software sub-system faults in designated IRMS equipment. Responsible for definition of the preventative maintenance activities on the designated system.	Professional (Graduate Level) engineer. 5 years experience in the design and development of IRMS type equipment. Experience with working practises found in nuclear plant environment or a similarly regulated industry.

Table 5.4.2 ITER RH operations team structure and roles

The total number of staff needed to implement and support a remote operations campaign will be a multiple of the above to suit the requirements for parallel operation and/or multiple shift operations.

Additionally, for any given shift pattern provision must be made for the possibility of personnel sickness and leave.

Other IO staff will indirectly support the remote handling operations including those involved with Health Physics, Waste Management, Tritium processing, HVAC, power and services and manual operations. These perform many other additional functions and are not listed here.

6 ITER Remote Handling (RH) baseline strategy

6.1 RH operational areas

Remote handling operations will be required in the areas as shown in fig 6.1.1

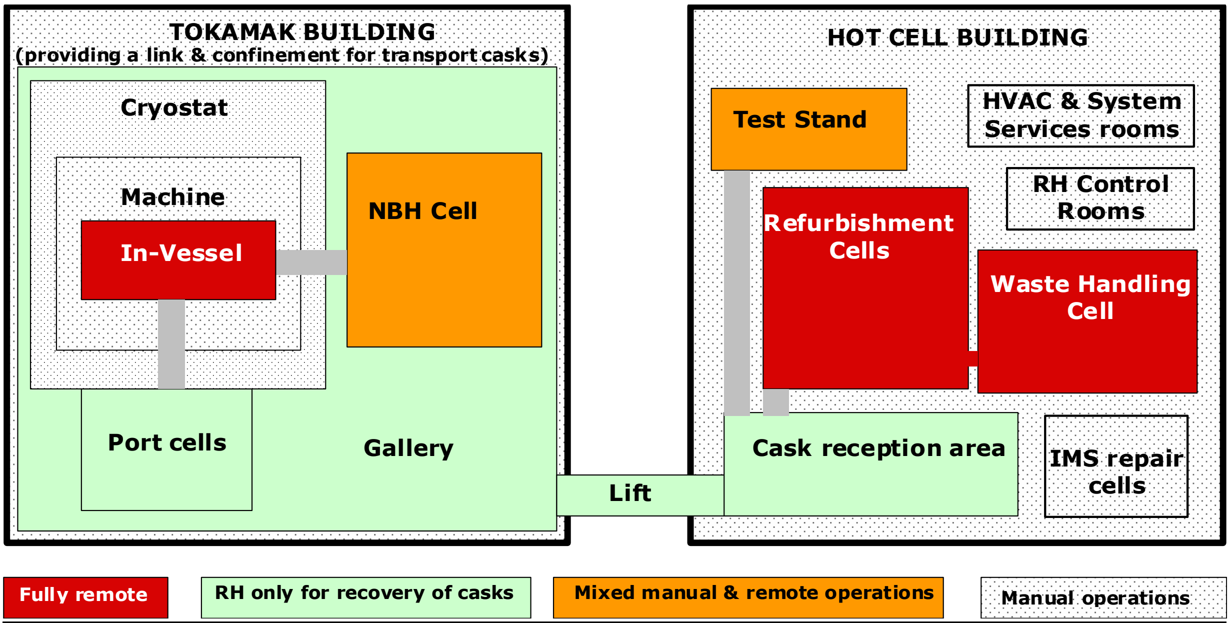

Fig 6.1.1 Remote Handling Operational Areas

6.2 Environmental conditions during RH operations

The environmental conditions expected inside to persist in the areas during remote handling operations are shown in table 6.2.1.

Area	Dose rate		Vacuum		Temp.		Tritium	Beryllium	Magnetic field	
	Peak	Bckgnd	On	Off	On	Off			On	Off
	Gy/hr	Gy/hr	Pa	Bar	C	C	Bq/m³	µgm/m³	Tesla	Tesla
In-Vessel	tbd	< 500	10^{-3}	~1	120	<50	tbd	tbd	4-8	0.001
NB Cell	0.1	< 0.01	n/a	~1	n/a	<50	tbd	tbd	~0.1	0
Port Cells	tbd	tbd	n/a	~1	n/a	<50	tbd	tbd	tbd	0
Hot Cell	tbd	tbd	n/a	~1	n/a	<50	tbd	tbd	n/a	0
Lift & Gallery	tbd	tbd	n/a	~1	n/a	<25	tbd	tbd	tbd	0

Table 6.2.1 Environmental conditions inside remote handling operations areas

6.3 ITER Experimental Programme and RH Shutdowns

6.3.1 General requirements

The ITER Machine Operation Plan [3] defines the maximum frequency and duration of scheduled shutdowns in support of the ITER experimental programme [4]. The plan drives the scale and overall planning for the IRMS and its operation.

In addition to the activities defined in and from [3] the remote handling systems are required to be prepared to conduct unscheduled shutdowns resulting from unexpected plant failure.

6.3.2 Remote handling scheduled shutdown – general operating scenario

The general structure of a remote handling shutdown is shown in figure 6.3.2:-

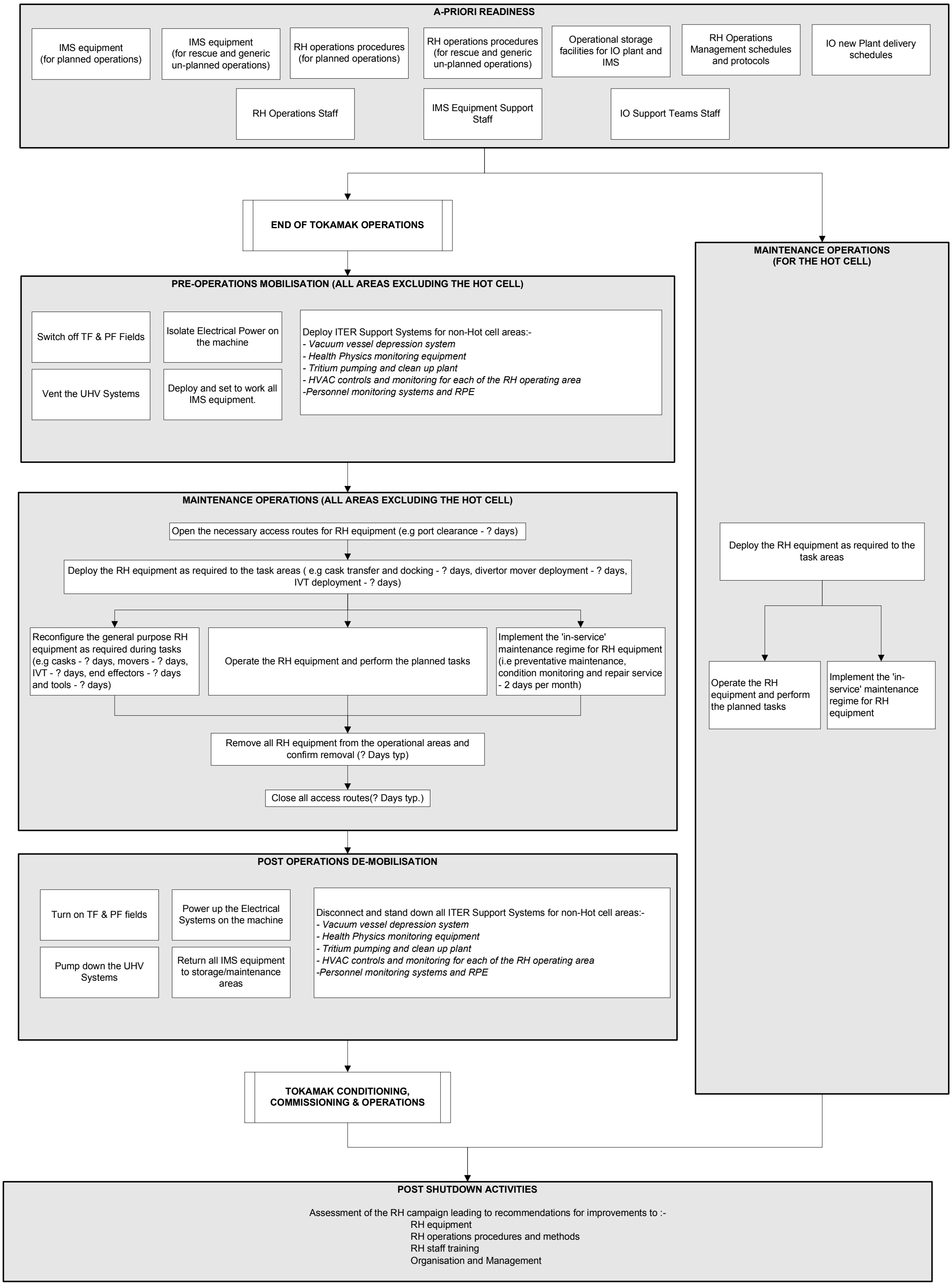

Figure 6.3.2 ITER remote handling shutdown operations scenario

6.3.3 Remote handling scheduled intervention

The general structure of a remote handling intervention is shown in figure 6.3.3:-

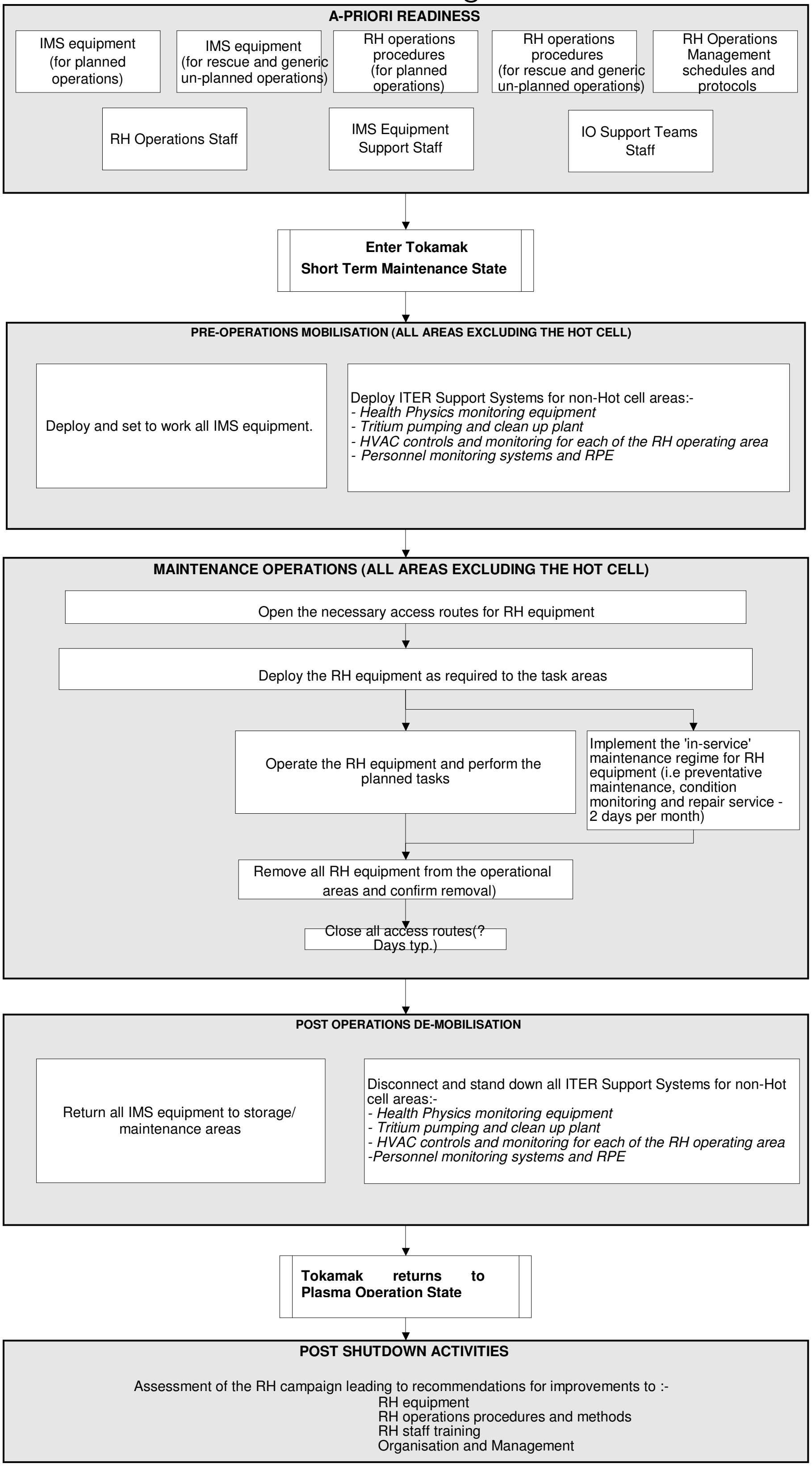

Figure 6.3.3 ITER remote handling intervention operations scenario

As presently envisaged:-

- Interventions in-vessel are limited to visual inspection using the IVVS, all other activities require a shutdown to be implemented.
- Interventions in the NB Cell are limited to visual inspection and caesium oven replacement using the NB maintenance system, all other activities require a shutdown to be implemented.

6.3.4 Unplanned remote handling operations

6.3.4.1 Unplanned tasks occurring during scheduled shutdowns

The prototypical nature of the ITER machine and its RH systems will certainly result in the occurrence of a number of unplanned events during an otherwise scheduled shutdown.
The unplanned events will have a variety of potential causes including:-

- In-situ ITER plant unable to be removed due to damage
- Unexpected debris found within the Tokamak
- Unexpected Tokamak deformations
- New ITER plant unable to be installed as designed
- RH equipment failure
- RH equipment incompatible with new or in-situ plant
- Project demands for new tasks not previously identified

The response to any of the above occurring during a scheduled shutdown will be an ad-hoc implementation of some or all of the following:-

- Analysis of the event which will invariably include remote inspection and manipulation.
- Development of a solution to the event which may include targeted tests using spare or mock-up components and RH equipment.
- Rehearsal and qualification of the solution to the event including validation using the hardware and Virtual Reality mock-ups.
- Rectification of the unplanned event.

The delay resulting from such an occurrence will depend directly on the event itself, the level of preparedness for such an event and the flexibility of the remote handling equipment and team.

6.3.4.2 Unscheduled shutdowns

In the event of a failure of ITER plant the project management will invoke a protocol to assess the situation and decide if an unscheduled shutdown is required. The protocol will involve a discussion and appraisal by the remote handling team with the aim to assess the level of preparedness for performing the required tasks.

If it is decided to conduct an unscheduled shutdown then the overall logistics and operating scenario will be the same as described in §6.3.2.

As a matter of good working practise the IRMS care and maintenance programme activities which occur in the periods between scheduled shutdowns will be managed to ensure that any of the IRMS equipment designed for shutdown activities can be made ready for deployment and use within a maximum period of 3 months from the date of the request.
Furthermore, all necessary RH operations related activities (see figure 6.3.2) will also be maintained on a maximum 1 month state of readiness.
Factors which affect the amount of time necessary to prepare the facilities for use in an unplanned shutdown include:-

- Availability of spares
- Modularity of the RH equipment
- IRMS modification/upgrade programme
- IRMS equipment preventative maintenance schedule
- RH staff training
- RH Operations procedures
- IRMS and RH operations support facilities
- RH operations utilities

The baseline remote handling equipment designed to perform an RH shutdown is described in §10.

6.3.4.3 Unscheduled interventions

In the event of a failure of ITER plant the project management will invoke a protocol to assess the situation and decide if an unscheduled intervention is required. The protocol will involve a discussion and appraisal by the remote handling team with the aim to assess the level of preparedness for performing the required tasks.

As a matter of good working practise the IRMS care and maintenance programme activities which occur in the periods between planned shutdowns will be managed to ensure that any of the IRMS equipment designed for intervention activities can be made ready for deployment and use within a maximum period from the date of the request.

- IVVS: 12 hours
- Caesium oven: 2 weeks

The baseline remote handling equipment designed to perform an RH intervention is described in §10.

6.4 Overall approach to ensure successful RH for ITER

It is neither economic nor practical to develop and prepare a remote handling capability optimised for all possible tasks on ITER. Accordingly the approach adopted for preparation of ITER remote handling is structured as follows:-

- A-priori classification of all ITER plant to identify their future potential need for remote handling – RH Classifications (see §7)

- The design of ITER plant in a modular form to facilitate removal and replacement of Line Replaceable Units from the Tokamak Building. Remote maintenance of individual components is designed to be performed primarily within the ITER Hot Cell – RH Compatibility of ITER Plant

- Incorporation of features into ITER components based on their remote handling classification and post manufacture verification of the features – RH Compatibility of ITER Plant

- Preparation of equipment for remote handling of ITER plant according to their remote handling classification – ITER Maintenance System

- Preparation of remote handling operations methods and personnel according to their remote handling classification – RH Operations

7 RH Classifications

7.1 Classification Definitions

All ITER plant will be classified according to their remote handling requirements by the following classification scheme. Plant that obstructs access for remote maintenance shall be given at least the same classification as the plant to which the access is blocked, if they require remote handling. Once the classification has been determined, the type of remote handling equipment required, the guidelines for plant design, and the program to assure remote handling compatibility can be established. Classification is based on the need for scheduled or unscheduled maintenance or modification, and the likelihood of maintenance as determined by the plant designers, and on the impact of the maintenance procedure on ITER operations and availability.
It is assumed throughout that, although they may impact upon the machine operations, component failures do not actually prevent machine operations. Operations would therefore continue, albeit at a reduced level, until the next scheduled shutdown, at which point the component maintenance can be carried out. Failures that prevent machine operations, and therefore require immediate unscheduled shutdowns, would have a FMECA rating of level 4 (Critical), or greater, and the occurrence rate for an event of this severity level should be less than 1 in 2000 years according to the ITER RAMI plan (ITER_D_2F4UBJ).

RH Class 1

RH Class 1 components require scheduled maintenance or replacement several times during the life of the machine. Components with a failure probability greater than 1 in 20 (based on RAMI analysis) years should be RH Class 1 for scheduled preventative maintenance. The plant designs and the associated remote handling equipment and service procedures, are optimised to ensure task completion within a minimum time. Class 1 tasks shall not require opening of the cryostat. The feasibility of Class 1 maintenance tasks shall be verified through the use of mock-ups as part of the component's design process. Full demonstration is required for Class 1 RH plant prior to their use (i.e. prior to first assembly). Plant items with RH Class 1 must be specified adopting the IO QA standard design and operation safety margins. RH equipment should be designed and procured before machine first assembly.

RH Class 2

RH Class 2 components do not require scheduled remote maintenance but are likely to require unscheduled maintenance. Components which have a failure probability less than 1 in 20 years but greater than 1 in 200 years (based on RAMI analysis) should be RH Class 2. **These components are designed for full remote repair or replacement, but minimisation of repair and replacement time is subordinate to consideration for machine availability, component design, such as nuclear performance and operational reliability.** Class 2 tasks shall not require opening of the cryostat. The feasibility of Class 2 maintenance tasks shall be verified and may involve the use of mock-ups as part of the component's design process. Full demonstration is required for Class 2 RH plant prior to their use (i.e. prior to first assembly). Plant items with RH Class 2 must be specified with nuclear industry standard design and operation safety margins. RH equipment should be designed and procured before machine first assembly.

RH Class 3

RH Class 3 components are not expected to require remote maintenance during the lifetime of ITER, but whose failure would impact ITER operation. These components are expected to last the lifetime of ITER, and major maintenance or upgrading is not anticipated. Components which have a failure probability less than 1 in 200 years but greater than 1 in 2000 years (based on RAMI analysis) should be RH Class 3. Although these components **must be designed to make disassembly and repair/replacement feasible by remote handling means,** their design emphasises the reliability and performance optimisation. Maintainability must be verified by detailed RH assessment. All plant items in RH Class 3 with the potential to stop Tokamak operations must be specified with above normal nuclear standard design and operation safety margins.
RH equipment should be designed but not procured before the nuclear phase.

Non-RH classified

Those components that do not require remote maintenance or replacement; this would include components that:

- are non-essential to ITER operation; or
- are considered expendable in the event of failure; or
- can be maintained hands-on after a reasonable delay; or
- have negligible risk of failure.

Those plant items having 'negligible risk of failure' must be specified with the highest practicable design and operation safety margins.

7.2 Classification Process Flowchart

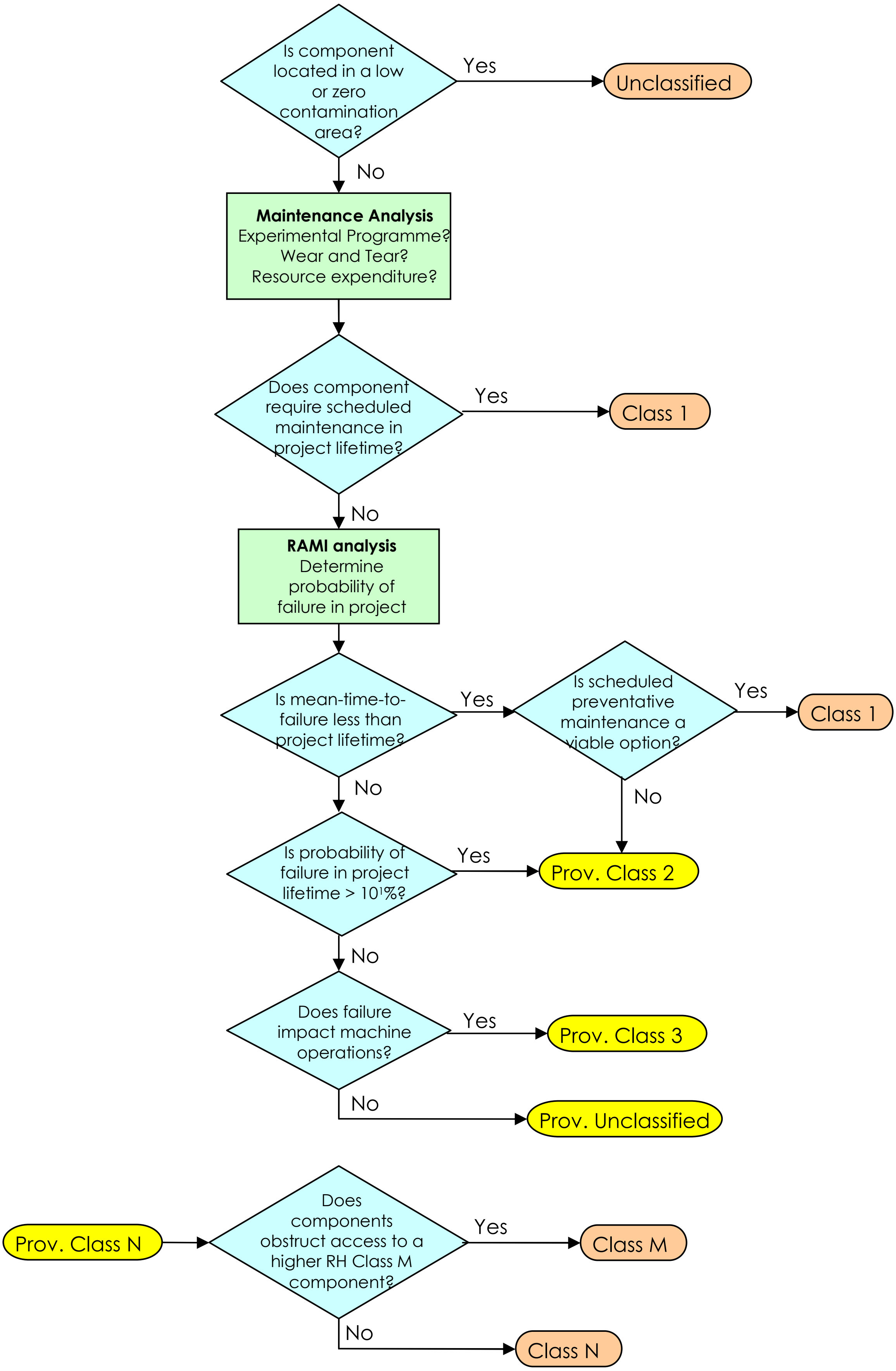

Fig.7.2.1 RH Classification Process Flowchart

Note [1]: This trigger level should be set by the project management.

7.3 Classification Implications

RH Classification				Statement is True
1	2	3	Non-Class	
O	O	O		Requires remote maintenance on failure
O	O	O		Failure would impact ITER operations
O				Requires scheduled RH maintenance (due to experimental programme, known wear-and-tear rate, or resource usage)
O				Failure probability is greater than 1 in 20 years and preventative maintenance is a viable option
O				Cannot be handled hands-on and blocks access to RH Class 1 component
	O			Failure probability is greater than 1 in 200 years[1]
	O			Cannot be handled hands-on and blocks access to RH Class 2 component
		O		Failure probability is greater than 1 in 2000 years[1]
			O	Failure probability is less then 1 in 2000 years[1] or Component can be maintained hands-on after a reasonable delay (100 days) [1] or Component is non-essential to ITER operations or can be considered expendable in the event of failure
O				Component design and RH operations optimised for minimum maintenance time
	O			Design for remote repair or replacement, but minimisation of repair or replacement time is subordinate to consideration for component design such as performance and reliability
		O		Design so that remote disassembly and repair/replacement is feasible, but design emphasises the reliability and performance optimisation.
O	O	O		Remote handling concept design shall be developed before nuclear phase
O	O			Remote handling equipment and tools shall be part of baseline and shall be procured prior to first installation of in-vessel components
O	O			Maintenance does not require opening of cryostat
Fully	Novel Aspects			Maintainability design shall be proven with mock-ups
O	O			Full demo required before first installation of in-vessel components
O				Components designed to IO QA standards and operations safety margins
	O			Components specified with nuclear industry standard design and operation safety margins
		O		Components specified with above normal nuclear standard design and operations safety margins

Table 7.3.1 RH Classification Implications

[1] These figures need to be confirmed by project management.

8 RH Management System Instruments

8.1 RH Procurement Specification Process

8.1.1 Introduction

The RH systems are procured on the basis of detailed design/functional specifications. A process is defined here to ensure that all the necessary considerations are applied to the creation of the procurement specifications.
The process defined here conforms to the overall ITER quality assurance plan (18) and the project design review procedures (19)

8.1.2 Overview

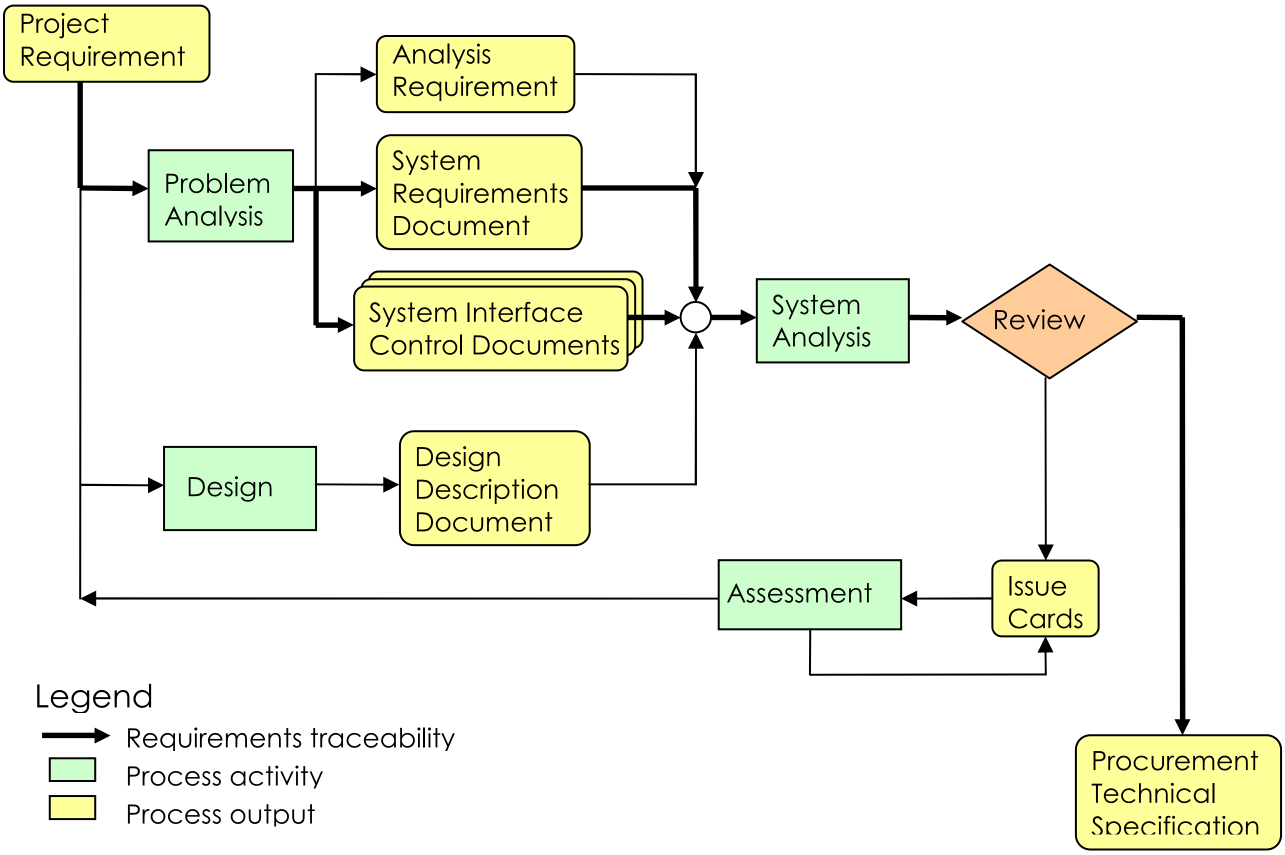

Fig. 8.1.1 Specification Process in ITER RH

The detailed design specifications need to provide the engineering design which will be detailed and manufactured in the procurement. The design will be the IO responsibility, and so must be demonstrated to a satisfactory level prior to the procurement. Due to the novel aspects of the ITER remote handling tasks, the functional specification procurements also need to provide a design that has been demonstrated to an acceptable level. This concept design shall prove the feasibility of the functional requirements, although it may not have the robustness that will be required of the production model.
The process loop shown in figure 8.1.1 may be repeated as often as necessary to arrive at a satisfactory specification. The path involving the design process will only be followed after some iterations have produced a relatively stable set

of requirements and is only strictly necessary for functional specification procurements if the problem does not already have an acceptable reference solution in the wider community.

Depending on the procurement specification type, 4 or 5 iterations through this process must be followed to satisfy ITER QA requirements:-

1. Analysis requirements review
2. System requirements document review
3. System interface review
4. Conceptual design review
5. Preliminary design review (detailed design specifications only)

8.1.3 Formal Reviews

8.1.3.1 Analysis requirements review

A RH sub-system analysis requirements document shall be reviewed via IDM.

The reviewers shall include representatives from the QA, Safety, and Remote Handling sections in order to confirm the sub-system classifications and to ratify the analyses processes defined in the analysis requirements document.

The document approver is the RH section group leader.

8.1.3.2 System requirements document review

The system requirements documents (SRD) are subject to formal review.

The system requirements document review shall follow the ITER SRD Review procedure (ITER_D_3EKEUJ).

8.1.3.3 System interface review

The system interface control documents (S-ICD) are subject to formal review.

The system interface review shall follow the ITER Interdisciplinary Technical Review procedure (ITER_D_27SZAL).

8.1.3.4 Conceptual design review

The concept designs are subject to formal review.

The concept design review shall follow the procedure for concept design review as described in the ITER Design Review document (ITER_D_2832CF).

8.1.3.5 Preliminary design review

Detailed design procurements require an additional iteration through the specification process culminating in the preliminary design review.

The preliminary design review shall follow the procedure for preliminary design review as described in the ITER Design Review document (ITER_D_2832CF).

8.1.4 Problem Analysis Process

8.1.4.1 Purpose

The problem analysis process develops the system functional and interface requirements.

8.1.4.2 Procedure

The project requirements are analysed by a suitably qualified and experienced remote handling engineer and the RH sub-system requirements are developed.

System Analysis Requirements
The RH sub-system classifications and the appropriate analysis requirements are assessed. A template (ITER_D_2M2JLC) is provided for the report document.

System Requirements Document
The procedure for developing SRD's is described the document:- Preparation, Review and Approval of SRDs (ITER_D_25DSU2).
Some guidance for writing good requirements is given at:-
https://user.iter.org/?uid=2FBNAY&action=get_document
https://user.iter.org/?uid=2EWMNX&action=get_document

System Interface Control Documents
The procedure and template for the system interface control documents is given at:-
https://user.iter.org/?uid=28VNJG&action=get_document

8.1.4.3 Input

- Project requirements.

8.1.4.4 Output

- Analysis requirements check list.
- System requirements document.
- System interface control documents.

8.1.4.5 Reviews

- Analysis requirements review
- System requirements document review
- System interface review

8.1.5 Design Process

8.1.5.1 Purpose

The purpose is to demonstrate the feasibility of the RH sub-system requirements specification and to provide a reference solution.

8.1.5.2 Procedure

The system requirements are analysed by suitably qualified and experienced remote handling engineers and an initial sub-system concept design is developed.
The design is refined iteratively based on the results of the system analysis processes.

8.1.5.3 Input

The system requirements document:- SRD-23-XX
The system interface control documents:- SRD-23-XX-XX

8.1.5.4 Output

The system design description document:- DDD-23-XX.

8.1.5.5 Review

- Conceptual design review.
- Preliminary design review (detailed design procurements only)

8.1.6 System Analysis Process

System analysis involves many activities as shown figure 8.1.2. Not all of these activities will be applicable to all of the RH systems:-

- Safety analysis is only applicable to safety important components (SIC),
- Independent Verification is only applicable to quality Class 1 systems,
- An RH study is only required if the system is RH Class 1 or 2.
- Physical mock-ups shall only be produced for systems that perform RH Class 1 operations or for RH Class 2 operations that have novel aspects to them.

The system analysis requirements document shall specify the analysis activities required for each particular RH system and shall provide an outline definition of the activity for the particular RH system.

- Purpose
- Procedure
- Input
- Output
- Review

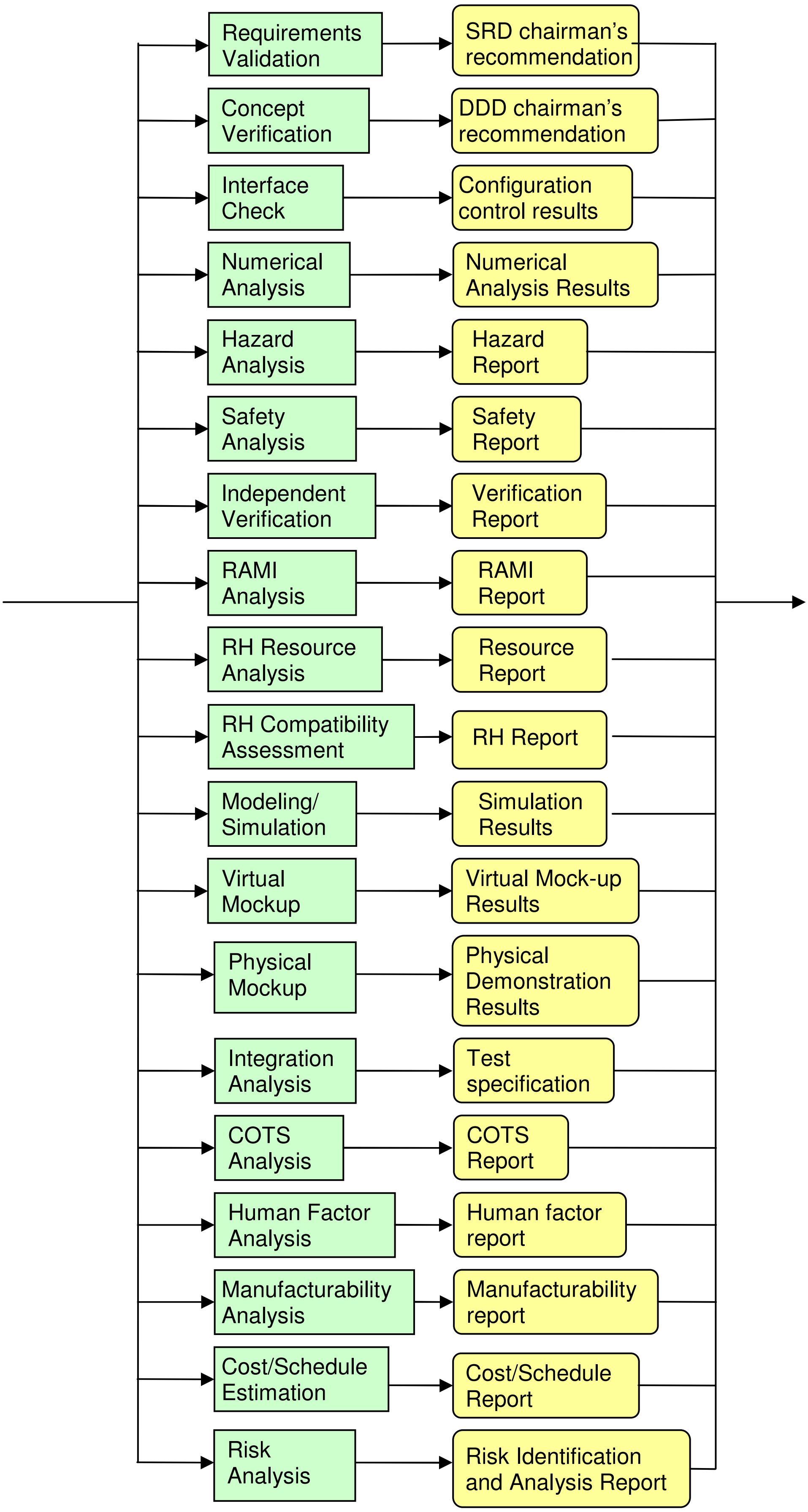

Fig.8.1.2 System Analysis Process

8.1.6.1 Requirements Validation Process

The requirements documents shall be validated to ensure that they contain a complete set of "good" requirements. The characteristics of "good" requirements are:-

- Correctness
- Necessity
- Clarity
- Focus
- Feasibility
- Verifiability

The procedure for the requirements validation process is covered by the ITER document:- Preparation, Review and Approval of SRDs (ITER_D_25DSU2).

8.1.6.2 Concept Verification Process

The concept design shall be verified against the system requirements, although some non-functional requirements may not be achieved or verifiable at the concept stage.

The verification process described here concerns the analysis of the design description document. Virtual reality and physical mock-up validation exercises are described elsewhere.

The concept verification reviews whether the design features should satisfy the functional requirements. This process should demonstrate how the system design optimally satisfies the requirements and design constraints.

The procedure for the DDD approval process shall be covered by an ITER procedure TBD.

8.1.6.3 Interface Verification Process

For mechanical systems a configuration model shall be developed for interference checking, assembly, and maintenance. This model shall be developed in detail where it interfaces with other systems.

Other types of systems may use other modeling tools for verification or rely on inspection of the specification.

The procedures followed for this process shall be provided by the supplier and approved by the IO.

The interface verification report is required for the review of the S-ICD documents at the **system interface review**.

8.1.6.4 Numerical Analysis Process

Numerical analysis studies will normally be required for mechanical systems. This analysis may take the form of finite element studies to establish that adequate safety margins exist for the envisaged loading conditions (nominal operations and design basis events).

Numerical analysis may also be required to confirm some design reference input data (such as radiation levels etc.).

The procedures followed for this process shall be provided by the supplier and approved by the IO.

The numerical analysis report is required for the **concept design review**.

8.1.6.5 Hazard Analysis Process

All the RH sub-systems shall undergo a hazard and operability (HAZOP) analysis after a relatively stable concept design has been produced.
The hazard analysis shall identify potential risks introduced by the sub-system operation from both a safety and an investment point of view. The design should be revised to eliminate unacceptable risks. The remaining unavoidable risks shall be protected against using the interlock and safety protection mechanisms.
The hazard analysis may form part of the safety analysis if one is required.
The issues discovered in the HAZOP analysis shall be tracked within a suitable database.
The procedures followed for this process shall be provided by the supplier and approved by the IO.
The hazard analysis report is required for the **concept design review**.

8.1.6.6 Safety Analysis Process

A safety analysis shall be applied to all safety important components (SIC) in the RH System.
The RH system must first be investigated to establish which are the safety important components. In general, any component that performs a safety function or whose failure would directly impair the performance of a safety function will be classified as being SIC.
The safety analysis should clearly define all the system nominal operating states, investigate the hazards that might affect the nominal operations, and describe the resulting conditions.
The safety analysis can result in design changes to meet and surpass safety regulatory requirements at the following levels:-

1. Improve robustness of system to deviations from nominal operations in the event of hazards,
2. Add specific protection systems to control deviations from nominal operations so as to avoid anticipated operational occurrences from escalating to incident or accident conditions,
3. Add specific safety systems to limit releases and move towards a safe state in the case of accidents within the design basis.

The RH safety case will need to be demonstrated as part of the ITER licensing process.
A procedure for the RH safety analysis process is provided in IDM (ITER_D_2DSLJB).
The safety analysis report is required for the **concept design review**.

8.1.6.7 Independent Verification Process

Independent verification is required for all Quality Class 1 systems.
RH systems are qualified as quality class 1 if they fulfil one of the following criteria (3):-

- Safety important component,

- Potential for severe health impact on worker or public,
- Potential for high cost impact to project (> 3 weeks loss of machine availability)

The independent verification process requires the verification of the requirements specifications through a review by persons independent of and unaffected by the system under consideration. This process shall verify that reference design data in the specification has been produced by verified and traceable processes, includes margins appropriate for safety components, and that ITER quality class 1 design and manufacturing requirements are adequately covered by the technical specifications.

8.1.6.8 RAMI Analysis Process

All the RH sub-systems shall undergo a RAMI analysis after a relatively stable concept design has been produced.
The RAMI analysis investigates the ability of the system to develop the required availability based on achieving adequate levels of reliability and maintainability.
The RAMI analysis will include a detailed functional breakdown of the system and a failure mode analysis in order to determine the weak areas of the design from a reliability point of view.
The recovery from failure, taking into account both rescue and maintenance, shall also be developed in this analysis, giving rise to requirements for spares and rescue/maintenance equipment.
The issues discovered in the RAMI analysis shall be tracked within the RAMI tools database.
The procedures followed for this process shall be provided by the supplier and approved by the IO.
The RAMI analysis report is required for the **preliminary design review**.

8.1.6.9 Resource Analysis Process

All RH sub-systems shall undergo a resource analysis study.
The RH sub-systems operate within an overall RH System. The resource utilization when performing particular RH operations must be studied to confirm that they are consistent with RH System safety and availability levels during the performance of the overall ITER maintenance tasks within the allowed shutdown periods.
The results of the resource analysis will be maintained within a specific software tool configured to track the RH resource usage during the planned shutdown scenarios.
The procedures followed for this process are TBD.
The resource analysis report is required for the **concept design review**.

8.1.6.10 RH Compatibility Assessment Process

All RH sub-systems that require remote maintenance (RH Class 1) or rescue on failure (RH Class 2) shall have a study performed to verify that adequate provisions and handling features have been included in the concept design.

The result of the study shall be a report on the compatibility with the RH baseline system.
A procedure for the RH compatibility assessment is provided in IDM (ITER_D_2DSYAB)
The RH compatibility assessment is required for the **concept design review**.

8.1.6.11 Modeling/Simulation Process

Modeling is the representation of an entity for purposes of presenting, studying, and analyzing its characteristics. SysML is a modeling language which may be used for modeling complex systems in order to help verify that they meet their requirements. This tool may be useful for the analysis of RH control systems.
Offline simulations are used to establish that performance requirements are being met by the design. This type of analysis will often take place using commercial tools such as Matlab™.
The procedures followed for this process shall be provided by the supplier and approved by the IO.
The modeling/simulation report is required for the **concept design review**.

8.1.6.12 Virtual Mockup Process

A virtual mock-up analysis shall be performed for all RH mechanical systems.
A virtual mock-up is a model of the RH sub-system and the operating environment within a virtual reality tool. It can be used to validate the equipment kinematics, operation sequences, and collision free trajectories.
All the RH sub-system concepts shall be analysed using a virtual mock-up. The models, operation sequences, and analysis results shall be stored for continual reference in the VR system database.
The procedures followed for this process shall be provided by the supplier and approved by the IO.
The virtual mock-up report is required for the **concept design review**.

8.1.6.13 Physical Mockup Process

All RH systems required for RH Class 1 operations shall have their concept design demonstrated with full scale physical mock-ups.
All RH systems required for RH Class 2 operations which have novel aspects must also have their concept design demonstrated with full scale physical mock-ups.
The physical mock-ups must be able to demonstrate the system functionality and will therefore require significant test facilities to represent the operating environment.
The results of the mock-ups are used to refine the concept design until the feasibility of the functional requirements is demonstrated.
The procedures followed for this process shall be provided by the supplier and approved by the IO.
The physical mock-up report is required for the **concept design review**.

8.1.6.14 Integration Analysis Process

An acceptance test specification is required for the procurement specification.
The ITER facilities and integration requirements shall be analysed in order to produce an acceptance test specification which can be used to verify that the sub-system meets the requirements.
The test specification report is required for the **concept design review**.

8.1.6.15 COTS and Standardization Analysis Process

Commercial, Off-The-Shelf components should be used where possible. The use of standard parts from a master list should be encouraged.
The COTS and Standardization report is required for the **preliminary design review**.

8.1.6.16 Human Factor Analysis Process

Human factors need to be considered for operability and maintainability.
The human factor report is required for the **preliminary design review**.

8.1.6.17 Manufacturability Process

A manufacturability study must be provided to establish that the design is manufacturable. Evidence from the manufacture of R&D prototypes may be acceptable.
The manufacturability report is required for the **preliminary design review**.

8.1.6.18 Cost/Schedule Estimation Process

A cost and scheduling estimation exercise shall be carried out on each RH sub-system.
The cost and schedule report is required for the **concept design review**.

8.1.6.19 Risk Analysis Process

A risk analysis shall be performed on each RH sub-system.
The procedure and report format are described in the ITER Risk Identification and Analysis Template (ITER_D_2DLTYX).
The risk identification and analysis report is required for the **concept design review**.

8.2 RH Management Control Instruments

The activities required for successful preparation and implementation of ITER remote handling involve the management and control of interfaces between all of the stakeholders identified in section 5.3.

Table 8.1 defines the Management Control Instruments used for this purpose.

Function	Management Instrument	Reference
IO shutdown or intervention request for RH tasks	Shutdown / Intervention Plan	IO QA manual [12]
Definition of plant RH requirements	Plant Definition Form (PDF)	Annexe G
Definition of RH Task requirements	Task Definition Form (TDF)	Annexe A
Changes to ITER plant design	Design Change Request (DCR)	IO QA manual [12]
Changes to IRMS Equipment design	Design Change Request (DCR)	IO QA manual [12]
Assessment and approval of IO Plant compatibility for RH	RH Compatibility Assessment (RHCA)	Annexe B
Approval of IO Plant concept design and associated System Requirements Document (SRD)	System Interface Control Document	Ref. [17]
Approval of RH equipment concept design and associated SRD.	tbd	tbd
Approval of RH operations concept design.	Operations Sequence Description (OSD)	Annexe D
Approval of IO Plant 'As-Built'	RH Compatibility Assessment (RHCA)	Annexe B
Approval of RH equipment 'As-Built'	tbd	tbd
Approval of IRMS RH Equipment as ready to use for RH operations (Shutdown or mock-up operations)	IRMS Statement of readiness (SOR)	Annexe C
Approval of RH Operations Methodology for an RH Task	tbd	tbd
Definition of RH task operations methodology	Operations Sequence Description (OSD)	Annexe D
Approval of RH Operations detailed operating instructions documentation	RH Operations Documentation release form	Annexe E
Definition of additions to RH Virtual Simulation	VR Simulation Requirements Specification	tbd
Definition of requirements for a physical RH mock-up	Technical Specification	tbd

Table 8.1 Management Control Instruments for RH Life Cycle activities

9 RH Compatibility of ITER plant

9.1 The need for and meaning of RH compatibility

It is well established RH industry practice [5][6][7] that the handling of plant using remote manipulation devices is made easier, faster and safer by the detailed consideration and accommodation of the plant's handling needs from the earliest stage of its development cycle.

Experience from JET [5] has demonstrated that the feasibility of handling of plant not previously designed for RH compatibility varies from being impossible to being possible but at significant cost in time, money and risk. RH was first conducted inside the JET torus in 1998 after 15 years of Tokamak operation and development. Various plant items inside the JET torus had been considered to never require RH and so were not designed for RH compatibility. However, the JET programme demands changed over time and some of these non-RH plant were required to be remotely handled. In the cases where this was impossible, due mainly to access and mass limitations, the tasks were performed manually in a strictly controlled regime of personnel controlled access to the torus (this will not be possible in ITER). In the cases where the tasks were possible to be done remotely a programme of work including design and development of new RH equipment and operations was implemented. In these latter cases the time taken to perform the tasks was found to be of the order of 3 – 5 times longer [5] than similar tasks involving plant which had been designed with RH compatibility.

ITER presents the most demanding challenge to RH ever. After the machine enters its active phase it will be impossible to make changes to, inspections or cleaning of any of the plant in the active areas other than by RH means. It is essential therefore that all plant with RH classifications 1, 2 and 3 are designed and built with RH compatibility.

The primary elements to ensure RH compatibility of ITER plant are as follows:-

- At the design stage:
    - Use of only IO authorised standard sizes e.g. pipe sizes etc
    - Use of only IO RH authorised standard sub-components e.g. electrical connectors, fluid couplings, flanges, fixings etc
    - Inclusion of IO RH authorised standard features e.g. for self-alignment, lifting attachment, gripping/grappling features, visual cues etc
    - Use of only IO RH authorised processes e.g. welding, cutting etc
    - Use of IO RH authorised techniques e.g. elimination of all non-captive parts, use of removable/replaceable threaded inserts, inclusion of mechanical compliance on pipework to facilitate alignment.

  - Provision of clearances around plant to facilitate access (deployment and use) e.g. for RH manipulators, RH tools, RH lifting etc
  - Provision of suitable clearances and materials to facilitate viewing and sensing by the RH equipment

- At the manufacturing and build stage:

  - Adoption of IO RH authorised quality requirements e.g. dimensional tolerances on bolt threads, surface finish and dimensional tolerances of mating parts etc
  - Qualification tests of plant for IO RH authorisation as ready for RH

All of the IO RH standards are defined in and readily available from the IRHCOP [1].

9.2 Life Cycle for Remote Handling Compatible Plant

The successful implementation of RH for ITER involves all stakeholders to be engaged in a rigorous process of interdependent activities described herein as the RH Life Cycle.

The activities, processes and management controls involved in the RH Life Cycle are shown in fig 9.2.1.

It is essential that all new plant destined for installation on ITER and which may ultimately require remote handling be developed should be life cycle compatible.

The life cycle shown has been developed from and is consistent with practical experience gained at the JET project over the past 10 years.

The main features to note are:-

- Plant concept design to be developed in parallel with RH equipment concept design and development of operational methodologies.

- The Plant and RH Equipment procurement activities must not be initiated until both the Plant and related RH Equipment concept design phases are concluded.

- The conclusion of Plant and related RH Equipment concept phases requires the approval by all stakeholders of both the concepts and the System Requirements Documents.

- All new, or modified, plant which may be handled remotely must be tested and approved in its 'As-Built' state by the RH stakeholders.

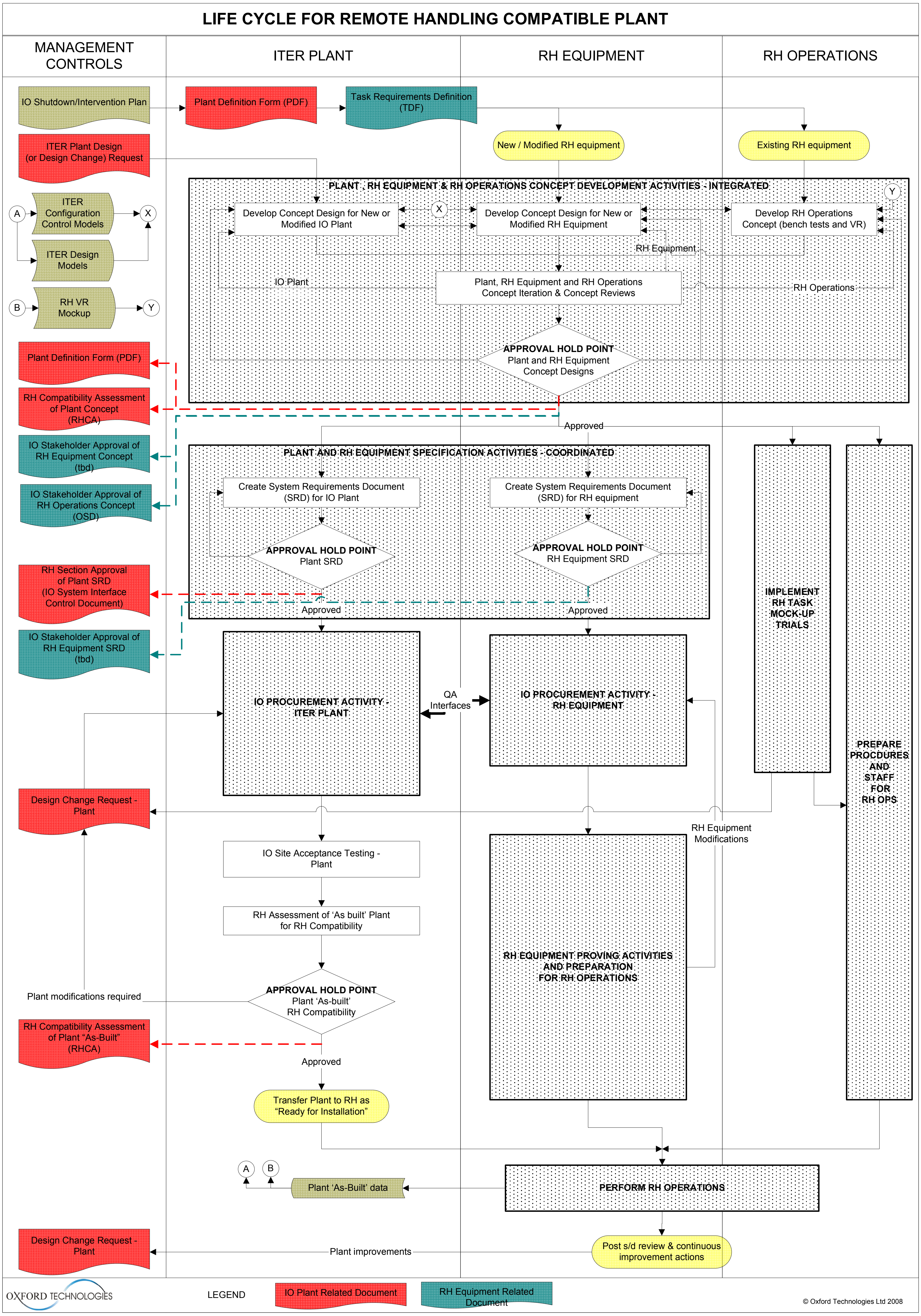

Fig. 9.2.1 Life-Cycle for Remote Handling Compatibility

The management and process controls required to achieve RH compatibility of ITER plant are described in table 9.2.1.

Life Cycle Activity	Processes	Management Controls	Responsibilities	
			Author	Approval
ITER Plant Concept Design	The plant concept design must be developed in parallel with that of the RH equipment concept and RH operations methodologies. Approval of the Plant concept design.	Plant Definition Form RH Compatibility Assessment Form (RHCA)	IO Plant RO RH Section	RH Section RH Section
RH Equipment Concept Design	RH equipment concepts developed in parallel with that of the Plant. Approval of the RH equipment concept design	tbd	RH Section	IO Plant RO
RH Operations Concept	RH operations methodologies developed in parallel with that of the Plant. Approval of the RH Operations Methodology.	Operations Sequence Description (OSD)	RH Section	IO Plant RO
ITER Plant Specification (for procurement)	Design and Specification activities. Must not commence until the concept phase of both Plant and RH equipment are concluded.	IO Plant Requirements Specification. (SRD)	IO Plant RO	RH Section
RH Equipment Specification (for procurement)	Design and Specification activities. Must not commence until the concept phase of both Plant and RH	RH Equipment Requirements Specification. (SRD)	RH Section	IO Plant RO

	equipment are concluded.			
ITER Plant procurement.	Detailed interfacing between IO Plant and RH Equipment procurement activities – design and manufacture concessions.	QA interface controls. Design Change Requests	tbd IO Procure ment RO	tbd RH Section
	Assessment and approval of the 'As-Built' plant for compatibility with RH requirements.	RH Compatibility Assessment Form (RHCA)	RH Section	RH Section
RH Equipment procurement.	Approval of the 'As-Built' RH Equipment for compatibility with the IO Plant requirements.	tbd	RH Section	IO Plant RO
All phases of the IO Plant life cycle	Creation and maintenance of an 'as built' 3-D configuration control model of the ITER machine and the RH equipment.	The IO configuration control model.	IO Design Office	IO Design Office

Table 9.2.1 Division of Responsibilities during IO Plant Life Cycle

9.3 Pre-defined standards for compatibility

The ITER RH Code of Practice [1] contains details of all the IO RH authorised standards, including:-

(a) RH principles for design of ITER Components, including:-

- Remote grappling/holding of the plant.
- How to ensure safe and secure grapple before release of the plant from its in-situ location.

- Identification of the plant before removal and identification of the location for the new plant before installation.
- Method for safe and smooth transfer of weight of the plant item from its in-situ position onto the RH equipment during removal from in-situ.
- Method for safe and smooth alignment of plant into the correct position during installation.
- Method for safe and smooth release of load from the RH equipment during installation of the plant.
- How to ensure good viewing/sensing of the plant item condition before removal
- How to ensure appropriate viewing during grappling before removal and during installation taking account of camera positioning, lighting sources and shadows.
- The proposed use by the plant responsible engineer of any non-standard RH elements including:-
    - alignment features
    - viewing cues
    - lifting/grappling points
    - electrical connectors
    - flanged couplings
    - fluid couplings
    - bolts and nuts
    - welded joints
    - RH tool built-in alignment and attachment features
    - RH tool clearance requirements – to be considered during both the grappling and the manoeuvring/operating phases

(b) Standard Plant items:

- Electrical connectors
- Welded joints
- Pipe joints
- Fluid couplings
- Cryogenic compatible couplings
- Lifting and handling features
- Location devices
- Fasteners

(c) Standard RH Equipment:

- Divertor Handling
- Blanket Handling
- Hot Cell equipment
- Plug Handling
- Torus Housekeeping and Unplanned Interventions
- Lifting and Cranes
- Manipulators
- Manipulator Deployed Tooling
- Support equipment
- Viewing & lighting systems

(d) Remote Handling Operations standards:

- General guidance
- Operations Planning & Preparation
- Staffing and Organisation
- Preparation for Operations
- Virtual Mock-ups
- Physical Mock-ups
- Derivation of Cycle Times
- Training Operators
- Preparing remote handling procedures
- Flexibility of Format to Deal with Unrehearsed Tasks
- Remote Operations Control Room
- Tool and Component Tracking Systems

(e) Principles for RH Equipment

- Design Specification
- Tolerance to environment conditions
- Services
- Operation & MMI's
- Electric Equipment
- Hydraulic Equipment
- Manipulator grasping points
- Materials
- Lubrication
- Maintenance
- Failure modes
- Reliability and Rescue from failure
- Qualifying equipment for RH operations

All standards contained within the IRHCOP are proven and authorised for use by the IO, its partners and sub-contractors.
Proposals to include new standards or to modify existing standards must be made to the IO RH section leader.
Authorisation for additions to the IRHCOP is made by the IO section leader and only after full assessment and review by the IO RH stakeholders which may include testing and/or expert assessment.

10 ITER Remote Maintenance System (IRMS)

10.1 RH Operating Regime

Fig 10.1.1 shows the areas serviced by the IRMS.

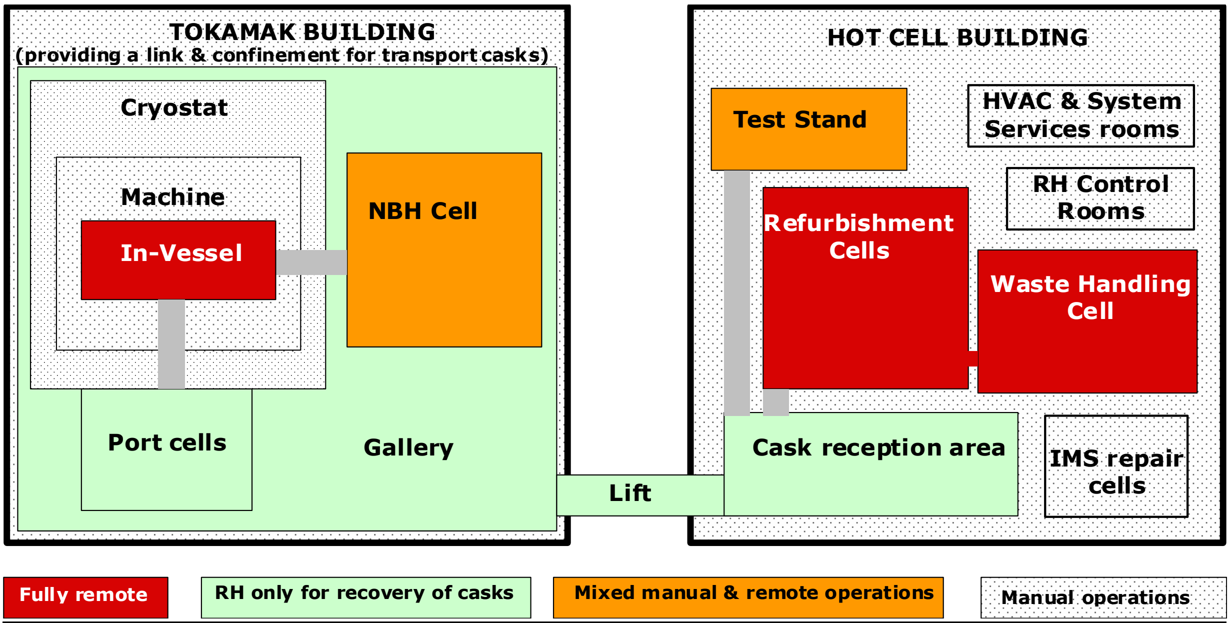

Fig 10.1.1 ITER areas serviced by the ITER Maintenance System

The IRMS is required to provide full remote handling capability (including rescue) inside:-

- In-Vessel
- Hot Cell
- NB Cell

The IRMS is required to provide remote handling suitable for combined use with local manual support inside:-

- NB Cell
- Hot Cell (part)
- Port Cells
- Test Stand Area

The IRMS is required to provide full remote handling capability for rescue of casks inside:-

- Lift
- Gallery
- Hot-Cell

The IRMS is required to provide full capability for its own maintenance inside:-

- Hot Cell
- NB Cell
- Test Stand Area

10.2 Baseline IRMS for all areas except the ITER Hot Cell Building

10.2.1 Overview

The IRMS remote handling equipment comprises:-

- In-Vessel handling equipment
  - Divertor Remote Handling System
  - Blanket Remote Handling System
  - In-Vessel Viewing System
- Port Plug Handling Systems
- Transfer Cask System
- Neutral Beam Remote Maintenance System
- Remote Handling Control System
  - RH Control Room MMI equipment
  - RH Control System hardware
  - RH Control System software

10.2.2 Divertor remote handling equipment

10.2.2.1 Basic Functions and Configuration

The divertor remote handling system shall provide the following overall functions:

- Insertion / extraction of divertor cassettes and their transport to/from a transfer cask docked at divertor level RH ports
- Insertion / extraction of divertor level diagnostic assemblies and their transport to/from a transfer cask docked at divertor level RH ports
- Removal / replacement of the divertor level RH port primary closure plate (PCP)
- Dust removal in and around the divertor region during the cassette removal process

The divertor handling system is deployed through the lower VV ports n. 2, 8, 14.

The divertor RH system consists of:-

- Cassette multi-functional mover (CMM)
  The CMM implements the radial transport of components along the inclined RH ports in a cantilevered configuration. It includes a common tractor and a set of changeable end-effectors designed to accommodate the various component requirements. End-effector changeover is an automatic operation performed in the hot cell.
- Cassette toroidal mover (CTM)
  The CTM implements the toroidal transport of cassettes from the RH port location to their final assembly location inside the vacuum vessel. It is introduced into the vacuum vessel using the CMM end-effector for standard cassette handling.
- Manipulator arm (MAM)

Both the CMM and CTM shall be equipped with an on-board dexterous manipulator arm for tools handling and general purpose manipulation.

- Control system
  Control of the divertor remote handling equipment is implemented both locally using local programmable handheld controllers (commissioning and first training) and remotely from the remote handling control-room.
- Tooling system
  Each of the CTM and CMM MAM's will utilise RH tooling, tools services, viewing and local tools storage.

10.2.2.2 Functional, Performance and Operational limits

- Environmental Conditions during divertor handling
  - Atmosphere: dry air
  - Pressure: ~ 1 bar
  - Temperature: < 50°C
  - Humidity: ~ 0 %
  - Gamma radiation dose rates: (10^6 seconds after plasma operations)
    - In-Vessel: 100 Gy/hr in divertor region.
    - Cassette contact: ~ 75 Gy/h (TBC)
    - Inside the remote handling port: tbd Gy/hr
    - Between the port plug flange (in place) and the cryostat: <100µSv/hr
  - Contamination: tritium, activated dust (C, Be and W)
  - Magnetic field: < 1mT

- Load and Task characteristics :-
  - Standard cassette handling:
    - Weight: ~ 9 t
    - Dimensions: 3.3m (L) x 0.8m (W) x 2.5m (H)
    - Related RH operations: locking-unlocking of the cassette supports, cassette handling and positioning, pipe cutting, welding and inspection
  - Central (or diagnostic) cassette handling:
    - Weight: ~ 11t (tbd - detailed design ongoing)
    - Dimensions: 3.3m (L) x 0.8m (W) x 2.5m (H) (tbd)
    - Related RH operations: locking-unlocking of the supports, cassette handling and positioning, pipe cutting, welding and inspection
  - Second cassette handling:
    - Weight: ~ 9.5 t (tbd - detailed design of instrumentation ongoing)
    - Dimensions: 3.3m (L) x 0.8m (W) x 2.5m (H)
    - Related RH operations: locking-unlocking of the supports, cassette handling and positioning, pipe cutting, welding and inspection, connection / disconnection of electrical connector

- Diagnostic rack handling:
  - Weight: tbd - detailed design ongoing
  - Dimensions: tbd - detailed design ongoing
  - Related RH operations: locking-unlocking of the supports, connections, handling and positioning
- Primary closure plate handling:
  - Weight: ~ 3 t
  - Dimensions: 1.4m (H) x 2.3m (W) x 0.3m (T)
  - Related RH operations: flange bolting-unbolting, lip seal cutting, welding, inspection and plate handling and positioning, pipe cutting, welding and inspection (tbd – PCP bolting & sealing arrangement under review)
- Cassette toroidal mover handling:
  - Weight: ~ 4 t
  - Dimensions: 3.3m (L) x 0.8m (W) x 2.5m (H) (note: L = 4.7m including onboard umbilical assembly)
  - Related RH operations: handling and positioning, umbilical installation and connection

- Speed of Operations: (excluding machine de-energize, venting and pump down, re-energize times):
  - replacement of the entire divertor < 6 months
  - Replacement of one cassette < 8 weeks (varies depending on location of faulty cassette).

- Operational Life:
  - 25 years:- assembly, three full divertor exchanges over the lifetime of ITER, decommissioning

10.2.3 Blanket Handling Equipment

10.2.3.1 Basic Functions and Configuration

- The blanket handling system shall provide the following overall functions:
  - Blanket module and/or First Wall removal from and replacement to the VV wall
  - Blanket module and/or First Wall transportation into and out of the VV
  - Bolting for fixing modules by flexible supports
  - Cooling pipe connection cutting, welding and weld inspection
  - Blanket module earthing device disconnection and re-connection
  - Insertion of NB duct liner maintenance tool s

The blanket handling system is deployed through the equatorial VV ports no. 3, 8, 12, 17.

- The blanket RH system consists of:-

- In-vessel transporter (IVT)

The in-vessel transporter (IVT) will provide the functions of transporting and handling blanket modules and tools inside the VV. The IVT is composed of the following elements;

    - Vehicle manipulator
        - The vehicle manipulator consists of a vehicle travelling along the rail, incorporating a telescopic manipulator capable of accessing all in-vessel areas except the divertor area.
    - Blanket handling gripper
        - A blanket handling gripper, mounted on the end of the telescopic manipulator and providing the functions of gripping a blanket module and temporarily bolting it to the VV wall using the earth strap fixations.
    - Articulated rail
        - Two semi-circular rails, deployable from two RH ports, forming a continuous 360° toroidal rail when both are installed.
    - Rail support device
        - Rail support by dedicated supports located in RH ports, which assist in the deployment of the final rail elements.
    - Rail deploying equipment
        - Rail installation by dedicated vehicle manipulator that is inserted into the vessel where it assembles and deploys the rails.
    - Umbilical and cable handling equipment
        - To handle the long complex umbilical during 180° vehicle and manipulator travel.
- Blanket transporter
    - The blanket transporter is used to deliver blanket modules and tools to the IVT with access through the remote handling port located at the equatorial level.
- Pipe Tool System
    - The blanket pipe tool system provides a set of tools to enable the cutting, welding and inspection of the blanket module water cooling pipes.
- Bolting tools
    - For handling the flexible support bolts for securing blanket modules and likewise the earth strap fixing bolts.
    - These tools access blanket modules from the plasma side of the modules.
- In-cask storage rack
    - To reduce the docking and transportation duration to and from the Tokamak building, an in-cask storage rack provides storage for three modules inside the RH cask.
- Rescue tools

        - Allows the vehicle manipulator mechanism to be actuated from outside the VV in the event of a vehicle manipulator locomotion malfunction.
    - Control system.
        - Controls all RH devices in such a way that four vehicle manipulators, together with all associated blanket RH handling can operate simultaneously at all four designated VV ports. Control is implemented using local programmable handheld control panels (commissioning and first training) or remotely from the control-room (normal RH configuration).

10.2.3.2 Functional, Performance and Operational limits

- Environmental conditions during blanket handling
    - Atmosphere: dry air
    - Pressure: ~ 1 bar
    - Temperature: < 50°C
    - Humidity: ~ 0 %
    - Gamma radiation dose rates: (10^6 seconds after plasma operations)
        - In-Vessel: Max 500 Gy/hr
        - Inside the remote handling port: tbd Gy/hr
        - Module contact: ~75 Sv/hr
        - Between the port plug flange (in place) and the cryostat: <100µSv/hr
    - Contamination: tritium, activated dust (C, Be and W)
    - Magnetic field: < 1mT
- Load and Task characteristics :-
    - Blanket handling:
        - 440 Modules of 30 types
        - Max. Module weight: 4.5 t
        - Module tbd weight: tbd
        - Dimensions: tbd
        - Related RH operations: tbd
- Speed of Operations:
    - Replacement of all modules < 2 years.
    - Replacement of one module < 8 weeks.
- Operational Life:
    - 25 years (ITER assembly, 1 full blanket exchange, and de-commissioning)

10.2.4 *In-Vessel Viewing System*

10.2.4.1 Basic Functions and Configuration

- The IVVS shall provide the following overall functions:
    - Viewing and Inspection of the first wall
    - Dimensional measurement of the first wall components

- The IVVS system consists of:-
  - 6 IVVS units located at lower positions 03, 05, 09, 11, 15 and 17. Note: A single ITER IVVS unit comprises a viewing/metrology probe mounted on a deployment arm inserted into the ITER plasma chamber between the divertor outer target and the lower outer blanket modules.

NB. When not in operation each IVVS unit is housed within a cylindrical storage plug mounted on the lower port Primary Closure Plate. This storage plug also accommodates the Glow Discharge System (GDS) probe and its deployment system.
Deployment of the IVVS requires prior withdrawal of GDS since both systems share same vacuum vessel penetration.

10.2.4.2 Functional, Performance and Operational limits

- Environmental conditions during IVVS operation:

(a) Vessel Short Term Maintenance State (STM) (RH intervention)
  - Atmosphere: Vacuum @ 10^{-3} Pa
  - Temperature:120°C (240°C for baking)
  - Gamma radiation dose rates (12 hours after plasma operations): 1500 (TBC) Gy/hr.
  - Contamination: tritium, activated dust (C, Be and W)
  - Magnetic field: < 0.1 Tesla

(b) Vessel Long Term Maintenance State (LTM) (RH Shutdown)
  - Atmosphere: dry air
  - Pressure: ~ 1 bar
  - Temperature: < 50°C
  - Humidity: ~ 0 %
  - Gamma radiation dose rates: (10^6 seconds after plasma operations)
    - In-Vessel: Max 100- Gy/hr in divertor region.
  - Contamination: tritium, activated dust (C, Be and W)
  - Magnetic field: < 1mT
- Task characteristics :-
  - Access through 200mm diameter ports in vacuum vessel and 150mm x 150mm penetration at first wall
  - Viewing resolution: < 1mm
  - Dimensional measurement accuracy: (+/-) 0.5mm at reference distance of 5m
- Speed of Operations:
  - Visual Inspection of one ITER sector: < 2 hrs
  - Dimensional survey of one ITER sector: < 8 hrs
- Operational Life:
  - tbd

10.2.5 *In-Vessel Multi-Purpose Deployer System*

10.2.5.1 Basic Functions and Configuration

- The MPD shall provide the following overall functions (tbc):
  - In-VV water leak localization
  - In-VV viewing (close up)
  - Dust measurement (partial cleaning)
  - Support to baseline in-VV RH operations

- The MPD system consists of:
  - tbd

10.2.5.2 Functional, Performance and Operational limits

- Environmental conditions during MPD operation:
  - Atmosphere: dry air
  - Pressure: ~ 1 bar
  - Temperature: < 50°C
  - Humidity: ~ 0 %
  - Gamma radiation dose rates: (10^6 seconds after plasma operations)
    - In-Vessel: Max 500 Gy/hr
    - Inside the remote handling port: tbd Gy/hr
    - Component contact: ~75 Sv/hr
    - Between the port plug flange (in place) and the cryostat: <100µSv/hr
  - Contamination: tritium, activated dust (C, Be and W)
  - Magnetic field: zero
- Load and Task characteristics :-
  - Handling of housekeeping tools:
    - Max. tool weight: tbd
    - Max. tool dimensions: tbd
  - Handling of in-vessel components:
    - Max. component weight: tbd
    - Max. component dimensions: tbd
- Speed of Operations:
  - Deployment of MPD from in-cask to in-vessel: <tbd
  - Remote exchange of MPD tooling and/or end-effector: < tbd
  - Full in-vessel detailed inspection: < tbd
  - Full divertor cleaning: <tbd
  - Deployment and use of leak detection equipment: < tbd
- Operational Life:
  - tbd

10.2.6 Port Plug handling systems

10.2.6.1 Basic Functions and Configuration

Port plug handling operations are required at numerous locations around the ITER tokamak. They are defined as the RH equipment (tractors, tooling etc) necessary to install / extract port plugs, excluding the transfer cask system (see section 10.2.7) within which they are housed.

Port plug handling systems are required to handle the following port-mounted systems:

- o Upper port plugs (diagnostic, heating)
- o Equatorial port plugs (Test blankets, diagnostic, heating)
- o IVVS plugs (at divertor level)
- o Cryopumps and cryopump valves (at divertor level)

10.2.6.2 Functional, Performance and Operational limits

- Environmental conditions during port plug handling
  - o Gas: dry air
  - o Pressure: ~ 1 bar
  - o Temperature: < 50°C
  - o Humidity: ~ 0 %
  - o Gamma radiation dose rates: (10^6 seconds after plasma operation): tbd
  - o Contamination: tritium, activated dust (C, Be and W)
  - o Magnetic field: <1mT
- Speed of Operations:
  - o Removal of a port plug and replacement with a new/refurbished plug shall require less than 1 month RH intervention.
- Operational Life:
  - o tbd

10.2.7 Cask Transfer System

10.2.7.1 Basic Functions and Configuration

Remotely operated transfer casks constitute the principal means of transferring in-vessel and in-port components to and from the hot cell.

The cask transfer system equipment has the following functions and basic configuration:

- The transfer cask system shall provide the following overall functions:
  - o Docking and sealing of the casks to the machine at the flanges of the divertor, equatorial and upper ports.
  - o Docking of the casks at the hot cell using an emulation of the appropriate VV port.

- Supporting the various items of in-cask equipment (e.g. IVT, CMM, port plug tractors)
- A transfer cask system consists of:-
  - Cask envelope

  The cask envelope provides the sealed volume for contamination control during the component transfer and houses the in-cask equipment. The front section of the envelope contains a double door system which interfaces with the VV port flange. A second double door system is located at the back of the envelope to facilitate in-cask rescue operations.
  - Pallet

  The cask pallet is connected to the cask envelope and provides the interface with the air transfer system (ATS) and the building floor. The pallet contains four independent jacking legs which allows for orientation of the cask double door flange to match the VV flange. A sliding mechanism at the pallet-envelope interface allows the envelope to slide forward, thus bridging the gap between building and Tokamak (necessary to accommodate the cryostat bellows gap). The pallet supports a large multi-connector which supplied the necessary services for the envelope, pallet and in-cask equipment once the cask is set in position in front of the port at the VV port flange or hot cell.
  - Air Transfer System (ATS)

  The ATS is a self-contained transport unit which sits below the main cask envelope/pallet. It supports the weight of the cask on a virtually frictionless air film which acts as a compact, high load capacity, flexible interface between the cask and the building floor. Air to the bearings is supplied by a set of compressors on-board the ATS and multi-directional cask motion and steering is achieved by a double set of pivoting drive wheels powered by electric motors. All powered systems on board the ATS are fed by a set of on-board batteries. Communications between ATS and RH control room are achieved via a wireless connection.

10.2.7.2 Functional, Performance and Operational limits

- Environmental conditions within the cask envelope during operations:
  - Gas: air
  - Pressure: ~ 1 bar (min 0.95 bar - max 1.05 bar)
  - Temperature: < 50°C (tbd)
  - Humidity: ~ 0 % (tbd)
  - Gamma radiation dose rates: 120Gy/hr with 2 blanket modules
  - Contamination: tritium, activated dust (C, Be and W)
  - Magnetic field: <1mT
- Environmental conditions around the cask envelope during operations:
  - Gas: air
  - Pressure: ~ 1 bar
  - Temperature: < 25°C (tbd)
  - Humidity: tbd
  - Gamma radiation dose rates: tbd

    - Contamination: None
    - Magnetic field: <1mT
- Load and Task characteristics :-
    - The transfer cask system:
        - Transports contaminated/activated in-vessel components and remote handling equipment between the VV ports and the hot cell.
        - Is able to remotely connect to the VV port or hot cell ports via a double-seal door system.
        - Is capable of handling the maximum combined load of its self weight, the in-vessel components weight and of the on-board remote handling equipment :
        - Has on-board remote handling tools and devices to perform all the activities inside the cask required for loading and unloading the payload.
        - Is air-tight to prevent the spread of in-vessel contamination to the building environment with integral facilities to ensure pressure equalisation prior to opening the cask door.
- Sizes:-
    - The range of casks planned for use at ITER is shown in table 10.2.1.

Location	**Upper ports**	**Equatorial ports**			**Divertor ports**	
Cask type	Upper port plug	Eq. port plug	IVT main	IVT inter-mediate	Divertor	Cryo-pump IVVS
Length (mm)	8500			5540	8500	tbd
Envelope width (mm)	2050	2620			2220	tbd
Pallet width (mm)	2620					
Nominal height (mm)	3680					tbd
ATS dimensions L(mm) x W(mm)	8500 x 2400			5540 x 2400	8500 x 2400	tbd
Expected max payload (t)	20	45	9 (2 BMs)	4.5 (1 BM)	12	1

Table 10.2.1 – Casks and dimensions

- Operating speed :
    - Variable drive speed under all load and locomotion conditions:- 1km/hr
    - Minimum smooth speed: tbd
- Operational Life:
    - tbd

10.2.8 Neutral Beam Remote Maintenance System

10.2.8.1 Basic Functions and Configuration

- The NB RH system shall provide the following overall functions:
    - Removal and replacement of the caesium oven fuelling system
    - Removal and replacement of the beam source
    - Removal and replacement of the beam line components

  - Removal and replacement of the NB gate valve and duct bellows (tbc)
- The NB RH system consists of:-
  - Monorail crane system
  - Beam line remote handling mast transporter and manipulator system
  - Beam source remote handling floor mounted transporter and manipulator system
  - RH Tooling System for manipulators
  - Support vehicle

10.2.8.2 Functional, Performance and Operational limits

- Environmental conditions during NB Cell remote handling:-
  - Atmosphere: Air
  - Pressure: ~ 1 bar
  - Temperature: Ambient
  - Humidity: ~ 0 %
  - Gamma radiation dose rates:
    - Around ion source: < 0.4 mGy/hr
    - Outside the ion source vacuum boundary: < 0.01Gy/hr
    - Outside the beam line: < 0.01 Gy/hr
    - Outside the magnetic shield: < 10^{-4} Gy/hr
    - Around the fast shutter:< 0.1 Gy/hr
  - Contamination: tritium, activated dust (C, Be and W)
  - Magnetic field: ~ 0.1 Tesla
- Load and Task characteristics :-
  - NB Injector assembly weight – 26 t
  - Passive Magnetic Shield large end plate weight – 6 t
  - Beam Source Vessel end plate weight – 7.5 t
  - Electrostatic shield weight – tbd
  - Fast Shutter weight – tbd
  - Gate valve weight - tbd
- Operating speed :
  - Time required for removal and replacement of the caesium oven fuelling system – 7 days
  - Time required for removal and replacement of the beam source - tbd
  - Time required for removal l and replacement of the beam line components - tbd
  - Time required for removal and replacement of the NB gate valve and duct bellows - tbd
- Operational Life:
  - tbd

10.2.9 Remote Handling Control System

10.2.9.1 Basic Functions and Configuration

- The IO RH Control System shall provide the following overall functions. Command, Control and Monitoring of the following IRMS equipment:
    - Divertor Remote Handling System
    - Blanket Remote Handling System
    - Port Plug Handling System
    - Neutral Beam Remote Handling System
    - In-Vessel Viewing System
    - Cask Transfer System
    - Hot Cell Repair/Maintenance System
    - Hot Cell Processing
    - Remote handling Test Stand
- The IO RH Control System shall provide the following functions:-
    - Command & control of the remote handling equipment,
    - Selection and control of remote viewing,
    - Monitoring of the RH equipment operations in the remote environment,
    - Monitoring of the diagnostic status of RH equipment,
    - Control and recording of the remote handling operations,
    - Remote operation simulation capabilities for procedure planning,
    - Integration with the CODAC system (including Central Interlock System and Plant safety System).
- The RH control system is implemented with the following sub-systems:-
    - Control System Supervisor & Plant System Host
    - Plant Interlock System
    - Plant Safety System
    - Viewing System
    - Equipment Controllers
    - Command and Control System
    - Remote Diagnostics System
    - Virtual Reality System
    - Operations Management System
    - Equipment Management System
    - Data Acquisition Network (DAQNET)
    - Real time Control Network (CONNET)
    - File Transfer Network (FILENET)
    - Safety Network/Emergency Stop System
- The IO RH Control System has the basic configuration shown in figure 10.2.1

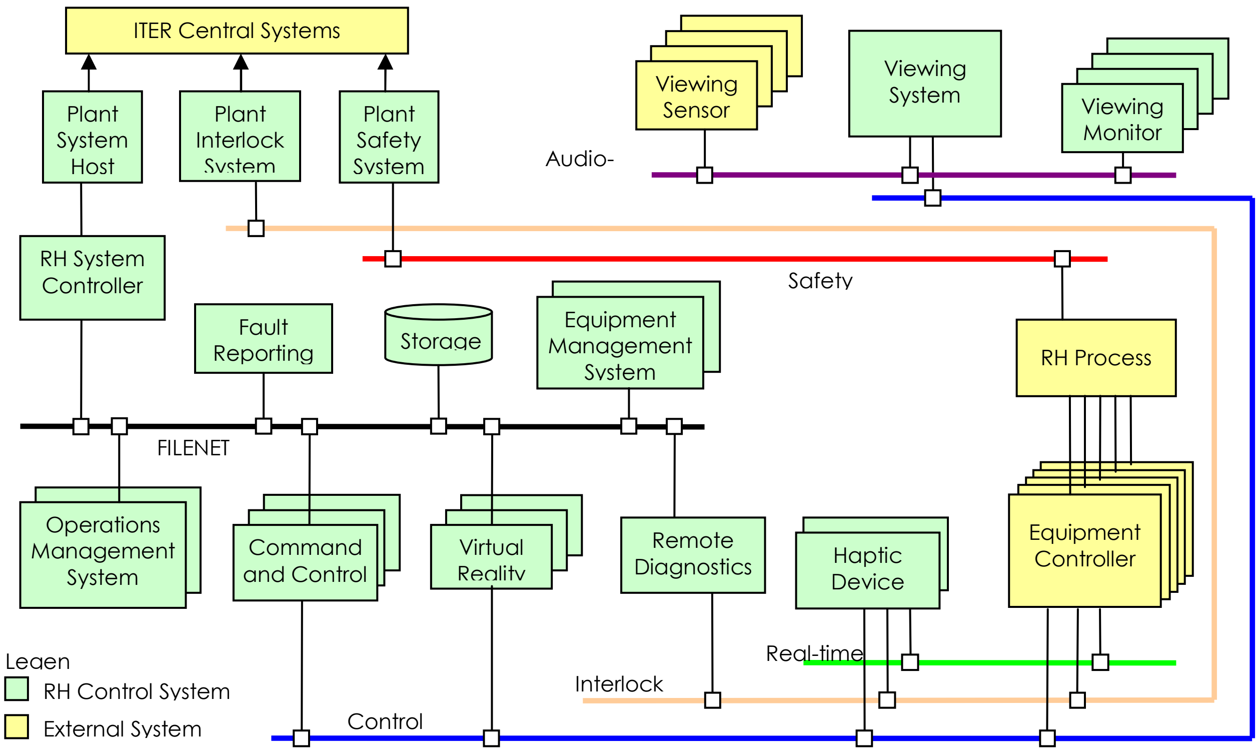

Figure 10.2.1 RH Control System Basic Configuration

10.2.9.2 RH Control System Functional, Performance and Operational Limits

10.2.9.2.1 The IRMS equipment controller sub-system

The IRMS equipment controller sub-system comprises a number of individual so-called 'local' controllers providing real time control of individual IRMS equipment.

The local controllers will interface directly to the IRMS equipment and the other sub-systems on the CONNET and the hard wired 'Safety' network.

The local controllers will provide all performance, function and signal conditioning features as required by each piece of IRMS equipment.

10.2.9.2.2 The Viewing sub-system

The Viewing sub-system provides the processing of viewing sensor signals (generally cameras) and their interconnection to any monitor in the control room. It is commanded and controlled via the Command and Control Sub-System.

10.2.9.2.3 The Command and Control sub-system

The Command and Control sub-system provides the interface between the operators and the equipment controllers. This system provides the following features:-

- Connection of the Human-Machine Interfaces (HMI) to any of the IRMS equipment

- Uniform Operator Interface, to avoid misinterpretations, to maximise operator flexibility, and to focus operator training on tasks rather than GUI's
- Frequent equipment status updates: 4 Hz minimum
- Clear presentation of important information
- Logging of messages
- Ergonomic layout of the Human-Machine Interface (HMI) elements
- Connectivity to virtual reality sub-system for on-line and off-line visualisation
- Connectivity to operations procedure sub-system
- Accurate off-line simulation of equipment behaviour

10.2.9.2.4 RH Control Room Sub-system

The number and size of control rooms to satisfy the overall IO RH requirements is based on the maximum number of contemporaneous operations.

The remote handling operational areas which require near full time command and control are:-

- Test Stand
- Hot Cell

The remote handling operational areas which require intermittent command and control are:-

- In-Vessel
- NB Cell

A minimum of two dedicated RH control rooms would seem to be required:-

- In-Vessel & Test Stand Operations (250m^2)
- NB Cell & Hot-Cell Operations (250m^2)

Each RH control room provides the following functionality:-

- Standardised Human-Machine Interfaces (HMI's)
- Standardised hardware and software
- Standardised methods for verbal and documentary communications between all RH operations stakeholders

Each RH control room will provide the same basic configuration:-

- Layout based on ergonomic principles taking account of operations personnel communications and decision making hierarchy, sensor feedback viewing and assimilation, HMI input devices space requirements and operator comfort.
- The control room HMI hardware provides a standard look and feel by standardisation of:-
    - Personal Computers
    - Control input devices (joysticks, haptic arms)
    - TV monitors
    - Audio/Video links to support teams and operators located outside the control room

10.2.9.2.5 The Virtual Reality Sub-system

The Virtual Reality Sub-system provides 3-D visualisation of the ITER digital mockup with the following characteristics:-

For operations:-

- Monitoring of RH equipment (including tools) in remote environment,
- Monitoring of the state of the remote environment,
- Monitoring of RH operations (e.g. manipulator picking up a tool),
- Provide early warning of potential collisions,
- Provide look-ahead visualisation of RH operations.

For planning:-

- Monitoring of simulated RH equipment in remote environment,
- Monitoring of simulated RH operations,
- Collision detection.

For virtual trials:-

- Driving of simulated equipment using input devices,
- Reflection of contact forces back to operator through haptic devices (~100Hz),
- Simulation of physical behaviours and interactions between items.

10.2.9.2.6 The Operations Management Sub-System

The Operations Management Sub-System is a database system for creating and re-playing procedures. It provides the following features:-

- Recording of operation sequences during planning phase,
- Replay of operation sequences during operations phase,
- Procedure steps are written in an unambiguous natural language,
- Equipment/tools/component locations are tracked throughout the procedures,
- Loops and branching is supported,
- Re-use of task sequences is supported,
- A flowchart shows an overview of the task,
- Flexibility to suspend tasks, and switch to other tasks,
- Capability to add notes (e.g. problems) while performing operations,
- Operation steps are ticked-off, time-stamped, and logged for audit purposes,
- Data is stored in an efficient manner and backed-up regularly,
- Automatic generation of reports,
- Generate lists of equipment/tools required for tasks,
- Communicate with Command and Control system.

10.2.9.2.7 The Equipment Management Sub-System

The Equipment Management Sub-System is a database system for tracking the location of IRMS equipment. It provides the following features:-

- Storage location of each IRMS equipment
- Radiological history of each IRMS equipment

- Maintenance record of each IRMS equipment
- IRMS equipment maintenance schedule
- IRMS equipment spare parts inventory and locations
- IRMS equipment reliability history

10.2.9.2.8 The Remote Diagnostics System

The Remote Diagnostics System provides facilities for collection, recording, and analysis of IRMS sub-system data (sensor signals, actuator signals etc) with the following features:-

- Continuous collection and archiving of data at low sample rate (~4Hz),
- Provide simple overview of the current system wellbeing,
- Capability to select individual sub-systems for higher rate sampling (~20Hz),
- Ability to select signals and time periods and display data in graphs,
- Ability to analyse signals using typical analysis tools (filters etc.),
- Ability to program rules for detecting abnormal behaviour.

10.3 <u>Baseline IRMS for the ITER Hot Cell Building</u>

10.3.1 <u>Overview</u>

The IRMS remote handling facilities in the Hot Cell Building comprises:-

- Hot Cell Refurbishment Facility
- Remote Handling Test Stand Facility

10.3.2 <u>Hot Cell Refurbishment Facility</u>

10.3.2.1 Basic Functions and Configuration

The Hot cell refurbishment remote handling facility has the following functions and basic configuration:

- The Hot cell refurbishment remote handling facility has the following functions:-
    - Refurbishment of Divertor Cassettes
    - Refurbishment of Diagnostic Plugs
    - Refurbishment of Heating Plugs
    - Refurbishment of Blanket Modules
    - Refurbishment of Test Blanket Plugs
    - Repair/Maintenance of In-Cask equipment

- The Hot cell refurbishment remote handling facility consists of:-

- Main refurbishment cell with:-
  - Craneage
  - Hot Cell Mast Transporters
  - Mast mounted Dexterous Manipulators
  - RH tools storage and deployment facilities
  - RH tools and service pack deployment facilities
  - General RH viewing systems
  - RH Inspection and measurement systems
  - Blanket and Divertor test facilities
  - Divertor and Blanket storage facilities
  - New component transfer and handling facilities
  - Crane decontamination, maintenance and repair facilities
- Plug refurbishment cell with:-
  - Craneage
  - Hot Cell Mast Transporters
  - Mast mounted Dexterous Manipulators
  - RH tools storage and deployment facilities
  - RH tools and service pack deployment facilities
  - General RH viewing systems
  - RH Inspection and measurement systems
  - Plug and NB test facilities
  - Plug and NB storage facilities
  - Crane decontamination, maintenance and repair facilities

10.3.2.2 Functional, Performance and Operational limits

- Environmental conditions for remote operations inside the main and plug refurbishment cells:-
  - Gas: Air
  - Pressure: ~ 1 bar
  - Temperature: 30-40 C
  - Humidity: ~ 0 % (tbd)
  - Gamma radiation dose rates:
    - Background of 10Gy/hr
    - Max. contact of 400Gy/hr
  - Contamination: tritium, activated dust (C, Be and W)
  - Magnetic field: zero
- Loads and Task characteristics :-
  - 65 tonnes max. load
- Operating speeds :
  - n/a
- Operational Life:
  - 30 yrs

10.3.3 Remote Handling Test Stand Facility

10.3.3.1 Basic Functions and Configuration

The RH test stand facility has the following functions and basic configuration:

- The RH test stand facility provides the following overall functions:
    - Testing and maintenance of IRMS remote handling equipment
    - Cask storage (part)
    - Maintenance training and rescue simulation
- The RH test stand facility consists of:-
    - 80° sectors of ITER vacuum vessel
    - Two IVT ports and port ducts
    - Equatorial plug port and port duct
    - Upper plug port and port duct
    - Divertor port and port duct
    - IVVS/Cryopump port duct
    - NB task mock-up
    - Cask maintenance area

10.3.3.2 Functional, Performance and Operational limits

- Environmental conditions during RH test stand operation
    - Atmosphere: Air
    - Pressure: ~ 1 bar
    - Temperature: ~ 25 C
    - Humidity: ~ 0 % (tbd)
    - Gamma radiation dose rates: None (tbc)
    - Contamination:
        - inside the stand - activated dust, beryllium; tritium - minimal
        - outside the stand – none; tritium - minimal
    - Magnetic field: zero
- Load and Task characteristics :-
    - As per main systems described herein.
- Operating speed :
    - As per main systems described herein.
- Operational Life:
    - As per main systems described herein.

10.4 RH Equipment life cycle

10.4.1 Overview

The life cycle for development, deployment and maintenance of the IRMS equipment is shown in fig.10.4.1.

A large proportion of the IRMS equipment will be bespoke and prototypical in their nature.

It will be vital for the success of ITER that all of the IRMS and particularly the bespoke equipment will be subject to a rigorous and reliable design, development and qualification process.

The generic life cycle steps for new and modified equipment will be:-

- Specification of Requirements (5%)
- Concept design & review (5%)
- Engineering design & review (15%)
- Procurement (45%)
- System Assembly, Integration, Verification & Commissioning (10%)
- Proving trials (20%)
- Statement of Readiness

The % figures indicate the proportion of total life cycle time that will be typically required for each stage [8].

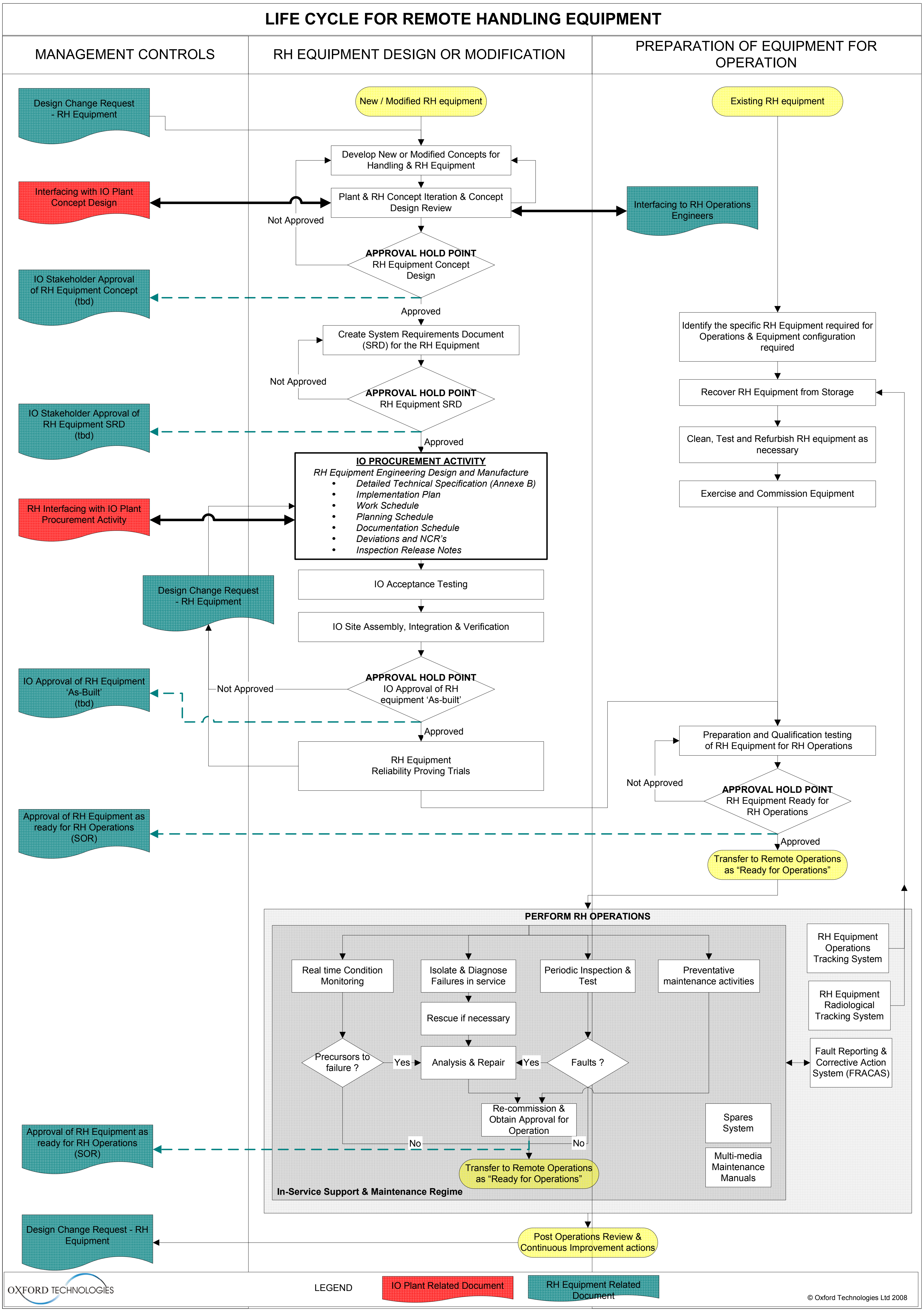

Fig 10.4.1 RH Equipment Life Cycle

The management and process controls required to successfully implement the RH Equipment life cycle are described in table 10.4.1.

Life Cycle Activity	Processes	Management Controls	Responsibilities	
			Author	Approval
RH Equipment Concept Design	RH equipment concepts developed in parallel with that of the Plant. Approval of the RH equipment concept design	tbd	RH Section	IO Plant RO
RH Equipment Specification (for procurement)	Design and Specification activities. Must not commence until the concept phase of both Plant and RH equipment are concluded.	RH Equipment Requirements Specification. (SRD)	RH Section	IO Plant RO
RH Equipment procurement.	Approval of the 'As-Built' RH Equipment for compatibility with the IO Plant requirements.	tbd	RH Section	IO Plant RO
RH Equipment preparation for Operations	Approval of the RH equipment as ready for operations.	Statement of Readiness (SOR)	RH IRMS RO	RH Section

Table 10.4.1 Division of Responsibilities for activities during the RH Equipment Life Cycle

10.4.2 Specification of IRMS Equipment Requirements

Fundamental to the success of these activities is the systematic derivation and control of the requirements and interfaces at every level from system architecture down to individual components.

The detailed content of requirements documents will vary according to the complexity of the IRMS equipment but each document must be written in accordance with the ITER Systems Requirement Document (SRD) [9].

A general content guideline for RH System requirement documents is given below:-

10.4.2.1 Functions, Basic Configuration and System Boundaries

- Overall system architecture
    - System layout
    - Sub-system configurations
    - Sub-system interfaces

- Equipment functional modes, including:-
    - Inactive commissioning mode:-
        - For system commissioning with the equipment in non-active areas
    - Active commissioning mode:-
        - For system re-commissioning with the equipment in fully remote areas e.g. to check and calibrate the system with respect to the operational environment after first deployment or failure.
    - Active motion mode, which may have sub-modes, e.g.:-
        - Single joint/axis motion
        - Resolved motion
        - Complex motion
            - and their sub-sub-modes, e.g.:-
                - Creep motion
                - Full speed motion
                - Open loop control motion
    - Ready state
        - Functionality when equipment is stationary and ready to move
    - Safe state
        - Functionality when equipment is stationary and all power to the field is switched off
    - Fail state
        - Equipment should always be required to fail ‘safe’ i.e. any failure will result in the equipment stopping within a specified time/distance and thereon remaining locked in position.
        - Equipment must be able to be interrogated for fault location and isolation
    - Rescue mode
        - Operational or sub-operational mode used when equipment has failed and needs to be rescued from the active area to a maintenance area
    - Manager mode

        - Facilities for a designated 'system manager' to interrogate and to change key parameters within the equipment control system
        - Backup and restore facilities
    - Simulation mode
        - Equipment control system configuration which allows operators to command and control a simulation of the equipment

- Equipment operational environment conditions, including:-
    - Temperature
    - Radiation
    - Magnetic field
    - Atmosphere (air, gas, water, vacuum , humidity)
    - Radiological contamination
    - Particulate contamination
    - Seismic events
    - Electromagnetic interference

- Interfaces to ITER component
    - Mechanical interfaces, including:-
        - Lifting and handling points (locations, dimensions, surface finishes and tolerances)
        - Lifting and handling constraints (identification of delicate or vulnerable parts, edges and surfaces etc)
    - Electrical interfaces, including:-
        - Electrical potential of the component being handled
        - Electrical connectors to be handled
    - Fluid interfaces, including:-
        - Quantity and type of fluid held within the component being handled
        - Fluid connectors to be handled
    - Thermal interfaces, including:-
        - Temperature of the component being handled
        - Heat sink or source requirements of the handling equipment

- Interfaces to ITER buildings and infrastructure, including characteristics of:-
    - Electrical power supply available
    - Communication network / infrastructure available
    - Gas/Air services available
    - Fluid services available
    - Mechanical interfaces between equipment and buildings
    - HVAC interfaces

10.4.2.2 Design Requirements

- General

- All IRMS equipment must be specified to satisfy the following general design requirements:-
  - IRMS Equipment must not contain any materials which are known to be incompatible with the working environment. In particular inside the ITER torus and related vacuum systems.

  - All IRMS equipment must be designed to be modular for ease of assembly, fault location and repair. Modules should take the form of Line-Replaceable-Units with simple interfaces to facilitate their removal and replacement

  - Al IRMS equipment should include provisions to ease fault location including:-
    - Built-In-Test
    - Control sensor connection points
    - Diagnostic sensors
    - Cabling/connector specific fault isolation facilities

  - All IRMS equipment must have design features to enable rescue after (any single point) failure

  - All IRMS manipulation equipment must be designed to accommodate extensions and adaptations for new tasks over the medium to long term

  - All IRMS equipment must be designed to detect and extinguish on-board fires

  - All IRMS equipment must be manufactured and assembled to ITER QA standards and relevant statutory lifting/robotic safety standards

  - All IRMS equipment must be designed to ensure 'safe' conditions after any failure (for a manipulation system this shall be fail to a stopped condition, for RH tooling this shall mean fail to stopped condition and with all appropriate power and services switched off, for viewing and similar sensing equipment this shall mean fail to a stopped condition but with camera/sensor signals remaining available if possible)

  - All IRMS equipment must be designed to ensure remote rescue after failure. The rescue after failure might be achieved using only on-board facilities (e.g. by means of including redundant actuator systems which can provide actuation sufficient for rescue) or rescue by means of including decoupling features and access points to allow other IRMS equipment to effect the rescue.

- Whenever possible IRMS equipment actuation systems should be electrically based. Hydraulic power systems should only be used on IRMS equipment when there is no practical electrical alternative.

- All IRMS equipment must be designed so ensure that no common mode failures can occur. Particular care must be taken to separate and protect key power and signal lines from each other and from any possible contamination by hydraulic fluid after failure.

- All IRMS equipment require the incorporation of facilities to enable remote monitoring of the condition of the equipment and to provide advanced warning of impending failure.

- All IRMS equipment must have provision for control of contamination by means of (in order of preference):-
    - Design features to prevent ingress of contamination to the inside of the equipment
    - Design construction to facilitate post operation decontamination from particulate by :-
        - Swabbing
        - Disassembly and aggressive cleaning of component parts
    - Design of features to install a protective, removable, layer of working area compatible flexible material

- Design requirements for Manipulation equipment
    - Manipulation and Lifting requirements
        - Lifting capacity (define the weights and centres of gravity of all items to be manipulated over the full dimensional operating volume)
        - Maximum static and dynamic loads and moments
        - Maximum acceptable forces which are allowed to be imposed on the ITER components being manipulated and the adjacent components in the working environment.
        - Maximum and minimum forces required to be imposed by the manipulation equipment as part of the task function
        - The required limits for mechanical stiffness/compliance
    - Motion requirements
        - Operational volume
        - Range of movements required

  - Number of degrees of freedom required
  - Dimensions of kinematic links
  - Position reference frame
  - Interlocks required
- Dimensional requirements
  - Minimum & maximum dimensions when operating and when folded/stored
  - Self weight requirement
  - Maximum transmission distances required between manipulation hardware, its control system unit and the HMI
- Operational performance

  Note: In the following if both types of motion mode are required then it is only necessary to specify the most stringent performance requirement)
  - For joint control modes, the individual axis/joint:-
    - joint static absolute position accuracy
    - joint static position repeatability
    - joint minimum speed
    - joint maximum speed
    - joint speed accuracy
    - joint position tracking error (with stated input command)
    - joint position control loop bandwidth
    - joint velocity control loop bandwidth
    - joint stopping distance under controlled stop command
    - joint stopping distance under safety mode stop command
  - For resolved motion modes, the Point of Reference (POR):-
    - POR static absolute position accuracy
    - POR static position repeatability
    - POR minimum speed
    - POR maximum speed
    - POR speed accuracy
    - POR position tracking error (with stated input command)
    - POR position control loop bandwidth
    - POR velocity control loop bandwidth
    - POR stopping distance under controlled stop command
    - POR stopping distance under safety mode stop command

- Design requirements for IRMS tooling equipment and associated services
  - Operational performance, depends on tooling function e.g.:-
    - Welding tools

        - Welding current and voltages (maximum, minimum)
        - Following accuracy for position and speed of the weld head
        - Feed speed range and accuracy of wire feed unit
        - Accuracy and bandwidth required for Automatic Voltage Control on weld head
    - Cutting tools
        - Cutting head speed (max, min and accuracy)
        - Cutting head force (max, min and accuracy)
        - Cutting head feed rate control (max, min and accuracy)
        - Need for swarf/dross control
    - Handling/manipulation/cleaning tools
        - Lifting capacity
        - Plant interface / grappling method
        - Maximum acceptable forces which are allowed to be imposed on the ITER components being manipulated and the adjacent components in the working environment.
        - Max and min speed for moving parts
  - Dimensional requirements
    - Minimum & maximum dimensions when operating and when stored
    - Self weight requirement

- Design requirements for IRMS Viewing equipment and associated services
  - Operational performance
    - Camera motion range required
    - Camera motion min and max speeds
    - Zoom lens motion range and speeds
    - Camera image characteristics (colour, resolution, light sensitivity, optical quality)
    - Camera view depth of field required
    - Lighting intensity and diffusivity
    - Lighting spectrum
  - Dimensional requirements
    - Minimum & maximum dimensions when operating and when stored
    - Self weight requirement

10.4.2.3 Safety Requirements

- IRMS equipment with SIC classification shall be designed with the required levels of reliability and redundancy that ensure IO compliance with the French nuclear licensing regulations.

- All IRMS equipment shall be designed such that the operation, inadvertent actuation, failure or damage shall not prevent Safety Important Components (SIC) from performing their safety functions when required.

- During the detail design phase, HAZOP (Hazard and operability) studies shall be undertaken and Safety Integrity Levels (SIL) established in accordance with IEC 61508 to ensure compliance with investment protection and safety requirements.

- All IRMS equipment shall fail safe on loss of power.

- All IRMS equipment must have an hierarchical safety system:-
  - Hard wired Emergency Stop Sub-system
  - Interface with ITER infrastructure high level emergency stop systems
  - Control sub-system hardware watchdog timer
  - Control sub-system software monitoring and protection against uncommanded motions and gross errors
  - HMI facilities for software driven halt command resulting in immediate application of brakes or equivalent
  - HMI facilities for software driven soft stop resulting in controlled deceleration and stopping

- All IRMS equipment must have provision for on-board fire detection and extinguishing

- All IRMS manipulation equipment must have provision for the prediction and warning of impending collisions with the working environment

- All IRMS equipment operating in areas accessible to personnel must have interlocked access controls to the areas.

- All IRMS equipment must have provision for a mobile (flying lead) emergency stop button in order to facilitate mixed manual and IRMS equipment operations in the same area for commissioning and maintenance.

- All IRMS equipment utilising hydraulic power must use intrinsically safe (non-flammable) fluid

- All electrical cabling used within all IRMS equipment must use fire retardant insulation material producing low smoke zero halogen.

10.4.2.4 Operation and Maintenance

- Human-Machine-Interface requirements

  - IRMS equipment must be commanded and controlled using an HMI user interface consistent with the equipment in the ITER RH control room (ref. §10.2.9) and the IRMS HMI standard style [10]

- Availability requirements
  - All IRMS equipment must be designed for lifetime continuous operation of over tbd hours.
  - All IRMS equipment which is intended to be deployed into the active areas must be designed to achieve an MTBF of more than tbd hours.
    - The design must be of a conservative nature:-
      - making as much use as possible of COTS equipment with proven pedigree for reliability
      - using high margins of safety for mechanical and electrical stresses
    - Verification of the design against this requirement will be made by analytical assessment and post delivery proving trials. The analytical assessment will comprise a full FMEA and a quantitative analysis of reliability based on commercially available empirical data.
  - All IRMS equipment which is not intended to be deployed into the active areas must be designed to achieve an MTBF of more than tbd hours.
  - All IRMS equipment must be designed for ease of maintenance and support in operations, i.e.:-
    - ease of fault finding (using Built In Test, sensor monitoring points and integrated diagnostic sensors)
    - Line Replaceable Unit construction to ease repair. Designed to facilitate removal and replacement by personnel in pressurised suits
    - Rationalisation of sub-system elements and working practices where possible, see the IRHCOP [1]
      - Mechanical sub-systems
      - Wiring sub-systems
      - Control system hardware
      - Control system software
  - All IRMS equipment must be delivered with a recommended spare parts list identifying those parts with lead times longer than 24 hours and with a credible possibility of failure within the lifetime of the equipment.

10.4.2.5 Quality requirements

- Control of equipment readiness for operations SOR system
- Continuous improvement
  - Post s/d reviews (ref. §10.4)
  - FRACAS (ref. §10.4.6)

10.4.2.6 Applicable Codes and Standards

- General
  - Legal & Statutory obligations
    - EC Machinery Directives
    - ITER Safety group (tbd)
  - French NII (tbd)
  - Compliance with ITER safety case (tbd)
  - IAEA and Host regulations
    - Radiological hazards
    - Beryllium
    - Waste management group
- Mechanical IRMS Equipment
  - ISO 10218, 1992 manipulating industrial robots (tbd)
  - ANSI/RIA R15.06-1992 Industrial robots and robot systems (tbd)
  - ISO/French Hydraulics standard and quality (tbd)
- IRMS Electrical & Electronic Equipment
  - ISO/French Wiring standard and quality (tbd)
  - IEC 204-1, 1992: Electrical equipment of industrial machines
  - ANSI/NFPA 79: Electrical standard for industrial machinery
- IRMS Software
  - tbd

10.4.3 Design and Manufacture

The general technical requirements associated with detail design and manufacture of IRMS systems must include reference to the relevant sections of:-

- ITER Drawing Office standard practices [11]
- ITER QA department manual [12]
- ITER vacuum design handbook [13]

Additionally the IRMS technical requirements must address the pertinent elements from the following lists:-

- For IRMS mechanical and electro-mechanical systems
  - Performance analysis requirements
  - Acceptance testing requirements including any special test equipment
  - Stress analysis requirements
  - Welding requirements
  - Machining requirements
  - Materials constraints
  - Radiation tolerance requirements
  - Assembly requirements
  - Documentation for maintenance and operation
- For IRMS electrical and electronic systems
  - Electro-Magnetic Compatibility requirements

  - Radiation tolerance requirements
  - Wiring constraints
  - Wiring drawings requirements
  - Electronic component stress requirements
  - PCB and sub-assembly mounting requirements
  - Performance analysis requirements
  - Signal conditioning requirements
  - Acceptance testing requirements including any special test equipment
  - Documentation for maintenance and operation

10.4.4 Assembly, Integration and Verification

A key part of the overall process is the Assembly, Integration and Verification phase at which point all of the sub-systems are assembled together and made to work by a process of systematic integration and test.
After assembly, the system must be verified to be compliant with respect to the final version of the requirements specification.
Successful completion of the AIV phase marks the end of the product creation stage and will realise a functional system qualified against its requirements – however, it does not qualify the system as proven for use in fully remote conditions.

10.4.5 Qualification of the IRMS for Operations

All IRMS equipment which is intended to be deployed to the ITER RH active areas must be subject to a period of proving trials. The proving trials can take the form of mock-up operations activities or stand-alone test operations. The proving trials must address the following aspects:-

- Reliability
- Failure mode behaviour
- Feasibility of rescue after failure
- Ease of fault location and maintainability
- Ease of use

The proving trials will occupy almost 20% of the total life cycle time and will invariably result in identification of design changes – both urgent and longer term.

At the successful end of the proving trials the IRMS equipment will be considered as qualified for remote operation use and a Statement of Readiness form must be raised and approved.

10.4.6 Support of IRMS equipment during remote operations

The IRMS equipment in operational service will be supported by a team of maintenance engineers supported by specialists with detailed knowledge of each equipment and sub-system.
The support activities required during equipment operation includes:-

- Preventative Maintenance
  - Periodic replacement of consumables & short life parts
  - On-line condition monitoring
  - Periodic visual inspection
  - Periodic functional and performance testing

- Response to failures in service
  - First line call-out procedures
  - Fault isolation and diagnosis methodologies
  - Rescue procedures and activities

- Fault Reporting and Corrective Action System

- Tracking of IRMS equipment location and radiological status

- Control and management of spares and maintenance/service manuals

Preventative Maintenance activities will be implemented by trained staff using proven and approved maintenance procedures. The maintenance procedures will be developed and written taking account of the fact that much of the preventative work will be conducted by personnel in RPE clothing. A key part of the Preventative Maintenance activities is a formal Condition Monitoring regime combining both periodic inspection and test with on-line computer based monitoring of the IRMS sensors with a view to automatically identifying abnormal behaviour and pre-cursors to failure. The cost measured in lost operations time of failures which require the IRMS equipment to be rescued from their working environment followed and fault isolation/repair can be very significant (i.e. weeks) and the value of preventative maintenance in the IO RH operations environment is a vital activity.

In the case of failure the following formal escalation approach will be adopted:-

1. RH Operations Engineer will implement the relevant instructions for first actions in the event of a specified type of fault. The first action guidance notes are prepared a-priori by the IRMS Equipment responsible engineers and provide simple actions which may rectify the fault &/or will reveal more information about the fault.
2. If necessary the RH Operations Engineer will then call the first line IRMS support engineer for advice and action.
3. If necessary the IRMS support engineer will attend and take responsibility for the IRMS equipment from the RH Operations Engineer. The support

engineer will address the fault and if possible affect a repair with the IRMS equipment in-situ.

4. If unable to affect a repair in situ the IRMS support engineer will call the relevant IRMS specialist engineer for advice and action.
5. The specialist engineer will then implement the appropriate repair activities.
6. If it considered necessary to rescue the IRMS equipment from in-situ back to a convenient maintenance area then the specialist engineer will call the overall operations manager for advice and action.
7. If it is required to rescue the failed IRMS equipment and transfer it to a maintenance area then the relevant rescue scenario operation will be implemented.

After repair at stage 1 of the above process the RH operations engineer will be authorised by the IRMS equipment support engineer to implement simple re-commissioning actions and thence continue with operations.
After repair at any point other than stage 1 the IRMS support engineer will implement a formal re-commissioning activity and raise a Statement of Readiness for approval by the appropriate IRMS engineers and managers.

A key tool for continuous improvement of all the IRMS equipment is the formal Fault Reporting and Corrective Action System (FRACAS) – see Annexe F. All IRMS equipment faults and bugs, of any significance regardless of whether the fault stops operations, will be reported by the RH operations team. The FRACAS reports will be reviewed by the IRMS equipment support engineers and appropriate actions taken.

The location and the radiological status of all IRMS equipment must be tracked at all times. The location information is important for all stakeholders engaged in the remote operations and the maintenance and storage of IRMS equipment. The radiological information is important to both the IRMS equipment support team regarding the equipment life and also for the IO waste management team who will need the Tritium, Beryllium and activated particulate exposure history.

The management and control of IRMS equipment spares and the maintenance/service manuals are a key element in both the preventative maintenance and repair after failure activities.

11 Remote Handling Operations

11.1 Overall organisation and management of remote operations

All IO stakeholders require that the ITER remote operations be performed with maximum effectiveness and efficiency in order to minimise maintenance time and maximise Tokamak Availability.

Experience from other relevant facilities [14] demonstrates that successful remote operations are dependant upon detailed and comprehensive advanced preparations coupled with careful organisation and management during implementation.

ITER remote operations will be at least an order of magnitude larger and more complex than any remote operations previously undertaken anywhere in the world and consequently a detailed and thorough preparation is an imperative.

The IO remote operations whole life cycle is shown in figure 11.1.1

Experience has shown that the relationship between the time required to perform a known number of remote operations tasks inside the JET torus and the time required to prepare for these tasks is typically a ratio of 3:1 [14], i.e. tasks requiring a 6 month remote operations campaign will take typically 18 months of preparation in advance.

ITER remote operations will be required in a number of areas contemporaneously and this will place significant demands on IO resource organisation and remote operations management. Accordingly the life cycle shown in figure 11.1.1 will need to be applied to the RH activities for each area individually and where there are common elements will need careful integration between the areas.

ITER decommissioning will be achieved using an extension of some or all of the operational phase IRMS based on a schedule and with a budget to be decided in the future. The ITER decommissioning phase will have no impact on the operational phase RH effort and is not considered herein.

ITER remote operations will be subject to French licensing regulations. The IO RH stakeholders are obliged to ensure that licensing, safety case and other statutory regulations in the following areas are addressed appropriately:-

- Hot Cell and Tokamak Building layout
- Lift and Gallery layout
- Handling, packing and transport of radioactive and toxic waste

- Remote operations potential impact on radiological and contamination release in both normal and rescue scenarios
- Personnel safety for remote operators and support staff
- Personnel safety during mixed manual and remote operations.

ITER remote operations will inevitably be required to respond to circumstances and perform tasks unforeseen at the outset of shutdown or intervention planning. The ITER remote operations capability must be able to respond and react efficiently when new demands are made in both the short, medium and long term. This will be achieved by adopting the following approach:-

- RH stakeholders are directly engaged within the management and organisation of shutdown planning from the earliest stage.
- Preparation of operations methodologies and task procedures are made in a systematic working environment with appropriate interface review and control points.
- RH task procedures will be created at two levels of detail; a high level (Operations Sequence Description) to ensure IO stakeholder approval and engagement in advance of the more detailed task procedures to be used for operations.
- All RH task procedures will be constructed and stored within the ITER RH Human Machine Interface hardware and software system to provide enhanced facilities for common language, re-usability, audit checking and consistency allowing efficient staff training.
- All RH task procedures will be hierarchical to facilitate the creation and use of very short term task schedules. The task schedules will define task logistics and requirements on a daily or hourly basis and be simply input to the overall RH task procedures.
- All RH task procedures will include flow controls to facilitate decision points within tasks.
- All RH task methods and detailed procedures will be validated using a Virtual Reality Simulation. The same VR simulation will be used during remote operations.
- All new, and some repeated, RH task methods will be checked and validated using physical mock-ups and real IRMS equipment.
- All RH operations staff will be trained for inter-changeable operation of any IRMS equipment.
- RH operations staff training will be formalised, requiring an initial qualification by written and practical testing followed by ongoing periodic refresher courses and re-assessments.
- RH operations staff will be selected from the multi-skilled team of technicians maintaining, commissioning and developing IRMS equipment.
- Management of remote operations during shutdowns, the transfer of information between the RH operations teams, within the RH stakeholders, within the IO stakeholders and to the wider community will be systematically controlled.
- A system of continuous improvement for equipment, operations and organisation/management will be implemented. During all remote

operations (mock-up or real) all faults and issues for improvement will be recorded and acted on according to urgency.

- At the end of each ITER shutdown the RH stakeholders will conduct systematic reviews of equipment, organisation, personnel and management and make recommendations for continuous improvement.

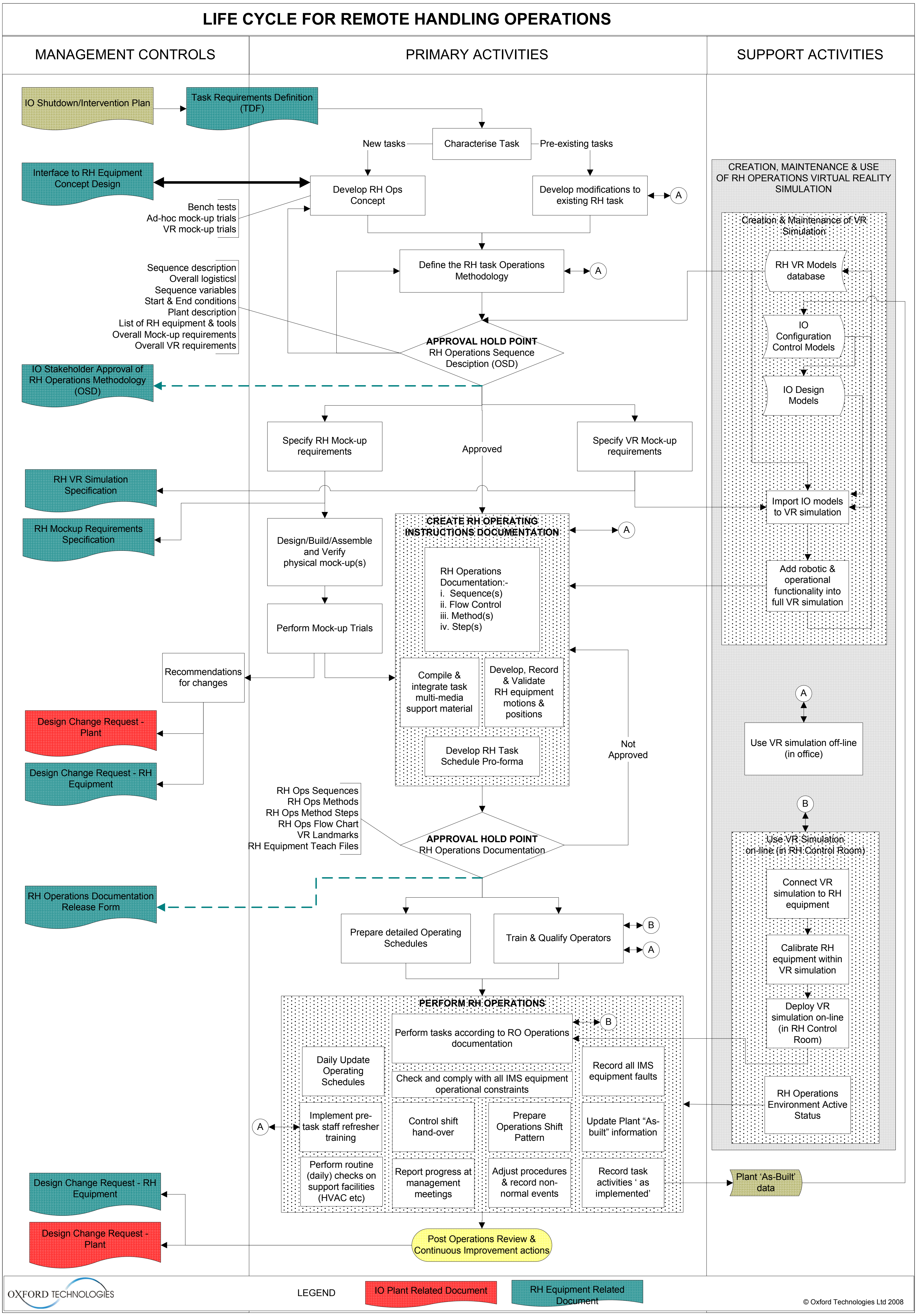

Figure 11.1.1 ITER Remote Operations whole life cycle.

The management and process controls required to successfully implement the RH Operations life cycle are described in table 11.1.1.

Life Cycle Activity	Processes	Management Controls	Responsibilities	
			Author	Approval
RH Operations concept development	RH operations methodologies developed in parallel with that of the Plant.	Operations Sequence Description (OSD)	RH Section	IO Plant RO & RH Section
RH Operations proving trials	Implementation of physical mock-up trials	Mock-up Requirements Specification (tbd)	RH Section	RH Section
	Recommendations for changes to IO Plant design	Design Change Request (DCR)	RH Section	IO Plant RO
	Recommendations for changes to RH Equipment design	Design Change Request (DCR)	RH Section	RH Section
	Implementation of Virtual Reality (VR) Mock-up trials	VR Requirements Specification (tbd)	RH Section	RH Section
RH Operations Procedure Development	Review and approval of all detailed operations documentation	RH Operations Documentation Release Form	RH Section	RH Section
Post shutdown review	Recommendations for changes to IO Plant design	Design Change Request (DCR)	RH Section	IO Plant RO
	Recommendations for changes to RH Equipment design	Design Change Request (DCR)	RH Section	RH Section

Table 11.1.1 Division of Responsibilities for activities during the RH Operations Life Cycle

11.2 Preparation of remote operations

The RH operations preparation phase comprises the following steps:-

- Planning and definition of an ITER shutdown leading to RH task requirements
- Characterisation of the RH tasks in terms of their novelty and challenge to RH operations capabilities
- Development of a manipulation/handling methodology
- Negotiating and obtaining agreement from all stakeholders of the overall handling methodology
- Development and validation of the necessary RH operations detailed procedure(s)
- Training and qualification of RH operations staff

In general ITER remote operations will be performed within a pre-planned campaign environment with the ITER machine in shutdown configuration (see section 4.2). On some occasions there will be a requirement to perform remote operations with the ITER machine in Intervention configuration (see section 4.2). In either case the IO management will provide the initial input request for RH activities in the form of a shutdown or intervention plan with high level activity headings and overall durations. The planning will be developed in consultation with the IO RH section management and the agreed baseline plan will be used as input for all RH preparations and subsequent operations.

The preparations make extensive use of both physical and virtual mock-up facilities. In general all RH tasks will be developed and validated using the ITER RH virtual mock-up. The IO full scale physical mock-up (the Test Stand) will be used to develop and validate those tasks which involve physical uncertainties (e.g friction, structural compliances, thermal processes etc) which are not able to be reliably simulated with the virtual mock-up.

VR mock-ups are a subset of the RH VR Simulation. The VR Simulation is used extensively during preparation and operation phases to provide an accurate representation of the ITER plant at different stages of build. The construction and configuration control of the ITER RH VR Simulation is managed by dedicated members of the RH Team.

11.2.1 Task characterisation and overall methodology

The first stages of preparation will be implemented by an appointed Senior RH Operations Engineer. The use of a Senior Engineer in the early stages will ensure that past experience and consistency of approach is adopted across all tasks.

Where practical and cost effective the appointed RH Engineer will call for and make use of bench tests or ad-hoc physical mock-up trials. The aim of these tests is to provide practical information about the feasibility of performing new or otherwise uncertain handling operations.

In characterisation and preparation of an RH task methodology the RH engineer will assess the following (minimum) aspects:-

1) Remote grappling/holding of the plant.
2) How to ensure safe and secure grapple before release of the plant from its in-situ location.
3) Identification of the plant before removal and identification of the location for the new plant before installation.
4) Method for safe and smooth transfer of weight of the plant item from its in-situ position onto the RH equipment during removal from in-situ.
5) Method for safe and smooth alignment of plant into the correct position during installation.
6) Method for safe and smooth release of load from the RH equipment during installation of the plant.
7) How to ensure good viewing/sensing of the plant item condition before removal.
8) How to ensure appropriate viewing during grappling before removal and during installation taking account of camera positioning, lighting sources and shadows.
9) Check space and clearance for deployment and attachment of remote handling transporters, end-effectors, tools and viewing equipment.
10) The proposed use by the plant responsible engineer of any non-standard RH elements including:-
    a) alignment features
    b) viewing cues
    c) lifting/grappling points
    d) electrical connectors
    e) flanged couplings
    f) fluid couplings
    g) bolts and nuts
    h) welded joints
    i) RH tool built-in alignment and attachment features
    j) RH tool clearance requirements – to be considered during both the grappling and the manoeuvring/operating phases

11) Check space and clearance for manoeuvring of plant with the RH tooling attached.
12) Knowledge about the plant centre of gravity and its effect on the remote handling tooling and methodology.
13) Potential problems with jamming and crabbing of plant item during installation and removal from in-situ.
14) The consistency of the plant design with an efficient remote operations process, taking account of:-
    a) Overall tooling required
    b) Task Logistics
    c) Number of “handling” activities required to be performed in parallel
    d) Amount of double handling to complete the task
    e) Tooling services logistics
    f) Level of task difficulty and the novelty of the task measured with respect to the demand on the operator training programme

15) The demands imposed by the plant design on the remote handling equipment positional accuracy.
16) The potential physical condition of the plant – it will always be assumed that the plant needs to be handled even if it or its neighbours are damaged from:-
    a) Re-solidified molten metal obstructing access to plant, to its fixation device and to the plant alignment features.
    b) Broken or bent elements obstructing access or grappling of the plant.
17) Compliance of the plant with the stated IRMS equipment load capabilities:-
    a) under static conditions
    b) taking account of potential strain energy in the plant in-situ
    c) under dynamic (manoeuvring) conditions.
18) Check that provision is made in the plant design for potential seized bolts/nuts.
19) Check that provision is made in the plant design for recovery from cross threading and seizure of bolts/nuts during installation.
20) Check that remote handling lighting and built-in visual cues will not be obstructed during the remote operation.
21) Ensure that the plant design is consistent with all of the relevant remote handling failure from recovery procedures and preparations.
22) Check that the plant does not have the potential to cause damage to the remote handling equipment, resulting from unexpected levels of:
    a) Temperature
    b) Radiation
    c) Electrical potential
    d) Trapped volumes of water or other fluids which may become released during handling.
23) Examine the provisions made in the plant design to prevent or at least minimise the potential for galling and cold welding during Tokamak operation.
24) Ensure that appropriate provision is made to prevent plant fixations to become loose during Tokamak operation.
25) Consider the methods that can be used to diagnose and locate faults or problems during execution of the remote handling tasks.
26) For plant that requires cutting activities:-
    a) The provision and methodology for strain relief during cutting
    b) The provision and methodology for swarf/dross removal
27) For plant that requires welding activities:-
    a) The provision for remote cleaning of the welded joint
    b) The provision for remote alignment and support during weld of the seam/joint
    c) The provision for weld purge gas supply and measurement
    d) The provision for shroud gas supply and measurement
    e) The provision for NDT during and after welding, including possibly:-
        i) Visual inspection
        ii) Ultrasonic inspection

iii) Radiographic
iv) Helium spray/sniffing

It is important that before any work is started on the detailed RH operations procedures there is consensus between all stakeholders on how the remote operations are to be performed, i.e. between those responsible for RH operations, RH equipment to be used, the plant to be handled and others such as those responsible for waste, safety, quality and licensing. This is achieved by discussion and negotiation between the IO stakeholders and the Senior RH Operations Engineer concluding with approval at review of the Operations Sequence Description (OSD).

The OSD, Annexe D, contains a definition of how the task will be performed remotely, the sequence of steps, the IRMS equipment required, the start and end states, the support facilities required during preparation and operations phases and the overall task logistics.

11.2.2 Detailed RH operations documentation

After approval of the remote operations methodology the appointed RH Operations Engineer will proceed to develop the RH task in full detail and record the outcome in comprehensive procedures and documentation for use during the shutdown or intervention.

The physical and VR mock-ups will be used to provide input and to validate the procedure during development and during this phase there will invariably be some recommendations for design changes of plant or IRMS equipment – these are fed back into the IO management system by means of the Design Change Request procedure [15].

The ITER RH operations procedure documents and hierarchy are shown in figure 11.2.1. These procedures and associated support information will be input to the ITER RH Operations Management System (RHOMS). The support information includes:-

- IRMS Equipment teach files
- Virtual Reality simulation landmarks
- Images
- Movies
- IRMS and Plant data files
- IRMS and Plant design files
- Mock-up records

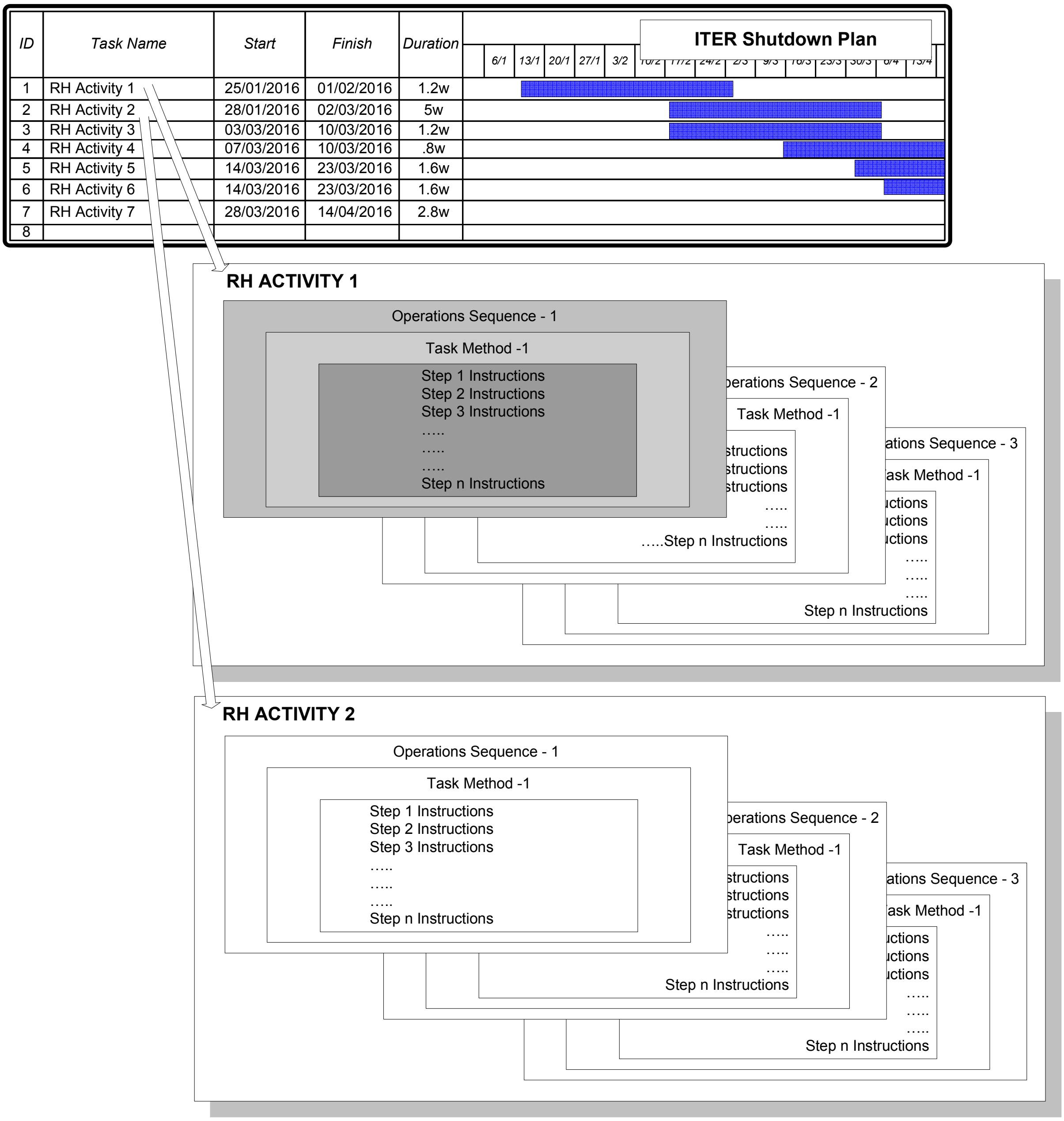

Figure.11.2.1 RH Operations procedures documentation hierarchy

11.2.3 Task and Staff preparations

The operations preparations phase is completed by training of the RH operating staff (see 11.4) and preparation of the detailed content of all RH operations schedules.

11.3 Implementation of remote operations

11.3.1 General

ITER remote operations will be performed in a number of areas simultaneously. Of particular note is the need to perform operations in the Tokamak Building and the Hot Cell Building in parallel.

Furthermore, there may be the requirement to implement parallel operations in different areas within the Tokamak Building (e.g. NB Cell, Lower, Equatorial and Upper port plug cells). Similarly it may be necessary to perform RH operations with two or more cells within the Hot Cell Building.
The number, design and features of ITER RH control rooms is yet to be decided and implemented.

In the remaining paragraphs of this section the implementation of RH operations will be described in terms of activities to be performed in a single operations area.

11.3.2 Shutdown and Intervention operations activities

All RH operations will be conducted under the IO Safe System of Working rules and regulations.

ITER remote operations will be conducted by multiple teams of operators and engineers organised and managed to ensure round the clock operations.
Each team will comprise:-

- IRMS equipment operators
- RH Operations Engineers
- RH Operations Support Engineers

The IRMS equipment operators will be taken from the a-priori qualified operators of specific IRMS equipment (see §11.4) who will have been additionally trained for unusual or difficult planned shutdown tasks.

The daily RH operations schedule will define and dictate the specific activities and plant to be handled. The RHOMS instructions and the associated schedule will be managed and implemented by the RH operations team senior operations engineer.

The ITER RH control room (§10.2.9.2.4) will facilitate verbal and visual communications flow between the team members.

It is expected that extensive use will be made of the Virtual Reality simulation to display in real-time the positions and configuration of IRMS equipment and the working environment.

As the activities proceed the RH operations team will be required to perform a number of functions in addition to the specific RH operation activities:-

- Implement pre-task staff refresher training immediately in advance of remote implementation
- Perform checks on the functioning of key facilities supporting the remote operations:
    - contamination control ventilation depression systems
    - tritium and radiological monitoring systems
    - tritium pumping and clean up plant
    - electrical power supplies
    - gas and air services to IRMS
- Maintain a detailed, time-stamped, record of all RH operations activities 'as implemented'.
- Maintain a detailed, time-stamped, record of Plant configuration and component location during handling operations. Including items designated as radiological waste.
- Provide formal feedback to IO stakeholders of Plant 'as-built' configuration which is found to be inconsistent with the IO Configuration Control Models.
- Ensure effective information transfer between RH operations teams scheduled on different working shifts.
- Ensure effective information transfer to IO shutdown management.
- Make adjustments as required to operations procedures/instructions and record the changes for post-shutdown analysis.
- Report and record all IRMS equipment faults and non-normal events.
- Ensure that all IRMS equipment operational constraints are recognised and complied with.

11.3.3 Remote operations on mock-ups

Remote operations performed on the ITER full scale mock-up facility will also be conducted under the IO Safe System of Working rules and regulations.

Many of the elements required for full remote operations and described in §11.3.2 will not apply during mock-up operations. However, the following are required to be implemented during mock-up operations:-

- All operators must be fully qualified for the IRMS equipment being used
- Report and record all IRMS equipment faults and non-normal events
- Make adjustments as required to operations procedures/instructions and record the changes.

11.4 Staff Training

ITER remote operations will be performed on a shift pattern basis by teams of trained and qualified RH staff (ref §5.4.3).

Remote operations at ITER will be unique and specialised. It will not be possible to recruit staff with a-priori appropriate experience and qualifications. Accordingly all staff to be engaged on ITER remote operations will require dedicated training.

As a matter of principle the RH operators will be trained to become specialists in the operation of specific sets of IRMS equipment and therein to perform the most common or generic type of tasks using the equipment. However, some RH tasks may be of a novel nature or requiring an unusually demanding skill level. These tasks will require specialised training immediately before an operational campaign.

It is planned to make use of many of the engineers and technicians engaged in the IO RH team during the design, procurement and first assembly phases. This will have the benefit of maintaining a continuity of personnel and working culture and also most significantly will result in the operation of IRMS equipment by personnel who have a detailed and deep understanding of the equipment.

12 Baseline Remote Handling Tasks

12.1 IO Interventions

ITER RH interventions affect two areas only, In-Vessel and the NB Cell.

12.1.1 In-Vessel

During an In-vessel intervention:-

- The IVVS will be used to provide a visual inspection of the first wall

No other activities are envisaged

12.1.2 NB Cell

During an NB Cell intervention:-

- The NB maintenance system will be used to provide a visual inspection of the cell and the plant.
- The NB maintenance system will be used to replace the caesium ovens.

No other activities are envisaged

12.2 IO Shutdowns - Divertor Cassette Tasks

Plant	Task	Purpose	Task Location	RH Class
Standard Cassette	Removal & Reinstallation	Preventative maintenance	In-Vessel	1
Central (diagnostic) Cassette	Removal & Reinstallation	Preventative maintenance	In-Vessel	1
Second (Instrumented) Cassette	Removal & Reinstallation	Preventative maintenance	In-Vessel	1
Diagnostic Rack	Removal & Reinstallation	Preventative maintenance	In-Vessel	1
All cassettes	Cleaning of Divertor before removal	Housekeeping	In-Vessel	1
All cassettes	Replace PFC's on Divertor cassette	Preventative maintenance	Hot Cell	1
Central (diagnostic) Cassette	Replace diagnostics	Preventative maintenance	Hot Cell	1
Second (Instrumented) Cassette	Replace diagnostics	Preventative maintenance	Hot Cell	1

Central (diagnostic) Cassette	Functional test of diagnostics	Preventative maintenance	Hot Cell	1
Second (Instrumented) Cassette	Functional test of diagnostics	Preventative maintenance	Hot Cell	1
Diagnostic Racks	Test and repair diagnostics on diagnostic racks	Preventative maintenance	Hot Cell	1
Diagnostic Racks	Test and repair diagnostics on diagnostic racks	Preventative maintenance	Hot Cell	1
All cassettes	Cleaning of Divertor Cassettes	Housekeeping	Hot Cell	1
All cassettes	Replace Divertor Cassette to vessel attachments	tbd	Hot Cell	1

12.3 IO Shutdowns - Blanket Modules tasks

Plant	Task	Purpose	Task Location	RH Class
Blanket Module	Removal and replacement of Blanket Module	Preventative maintenance	In-Vessel	2
Blanket Module	Replace FW panels on Blanket Module	Preventative maintenance	Hot Cell	2
Blanket Module	Cleaning of Blanket Modules in the Dust Cleaning Facility	Housekeeping	Hot Cell	2

12.4 IO Shutdowns – NB Maintenance tasks

Plant	Task	Purpose	Task Location	RH Class
NB Caesium Oven(s)	Remove the spent caesium ovens from the ion source and replacement with a new / fully charged unit.	Preventative maintenance	NB Cell	1
NB Injector assembly	Remove the NB Injector assembly from the BSV (for inspection / cleaning) and replacement with a new / reconditioned unit.	Preventative maintenance	NB Cell	2
NB Beam Line Components	Fast Shutter	Repair after failure	NB Cell	2
NB Beam Line Components	Duct Liner beam facing panels	Repair after failure	tbd	2
NB Beam Line Components	Neutralizer	Repair after failure	NB Cell	2

NB Beam Line Components	Residual Ion Dump	Repair after failure	NB Cell	2
NB Beam Line Components	Calorimeter	Repair after failure	NB Cell	2
NB Beam Line Components	Gate Valve & Duct Bellows	Repair after failure	NB Cell	3
NB Beam Line Components	Duct Liner	Repair after failure	NB Cell	3

12.5 IO Shutdowns - Equatorial port plugs tasks

Plant	Task	Purpose	Task Location	RH Class
TBM Plug	Refurbishment	Upgrade	Hot Cell	1
Diagnostic Plugs	Refurbishment	Preventative Maintenance	Hot Cell	1/2
Limiter Plugs	Replace PFW	Preventative Maintenance	Hot Cell	1
ICH Plugs	Refurbishment	Preventative Maintenance	Hot Cell	2

12.6 IO Shutdowns - Upper port plugs tasks

Plant	Task	Purpose	Task Location	RH Class
ECH plug	Removal and replacement of ECE plug	Repair after failure	Upper Port	2
ECH plug	Cleaning of In-Vessel Mirrors	General housekeeping	Hot Cell	2
Diagnostic plugs	Removal and replacement	Repair after failure	Hot Cell	2
Upper plugs	Cleaning of plug	Housekeeping	Hot Cell	tbd

12.7 IO Shutdowns - Port Cell plant tasks

Plant	Task	Purpose	Task Location	RH Class
Primary Closure Plate	Removal & Reinstallation	To gain access to the Divertor.	Port Cell	1
Primary Closure plate	Replace lip seal on VV primary closure plate	Replacement of a	Hot Cell	tbd

		consumable		
Cryopump valve	Replacement	Repair after failure	Port Cell	2
IVVS	Replacement	Replace after failure	Port Cell	2

12.8 IO Shutdowns - Unplanned maintenance tasks

Plant	Task	Purpose	Task Location	RH Class
All in-vessel components	Recovery of debris	Unscheduled maintenance	In-Vessel	tbd
All in-vessel components	Vacuum leak detection	Unscheduled maintenance	In-Vessel	tbd
All in-vessel components	Water leak detection	Unscheduled maintenance	In-Vessel	tbd
All in-vessel components	Water leak mopping	Unscheduled maintenance	In-Vessel	tbd
All in-vessel components	Vacuum weld repair	Unscheduled maintenance	In-Vessel	tbd
All in-vessel components	Visual inspection of first wall	Unscheduled maintenance	In-Vessel	tbd
All in-vessel components	Dust measurement and/or removal	Scheduled & Unscheduled maintenance	In-Vessel	tbd

12.9 IO Shutdowns - Housekeeping tasks

Plant	Task	Purpose	Task Location	RH Class
All plant and IRMS in the Hot Cell	Disposal of Radwaste	General housekeeping	Hot Cell	tbd
All plant and IRMS in the Hot Cell	Maintain Hot Cell infrastructure	General housekeeping	Hot Cell	tbd
All plant and IRMS in the Hot Cell	Maintenance of TBM Auxiliary Equipment Unit	General housekeeping	Hot Cell	tbd
All plant and IRMS in the Hot Cell	Preparation of TBM Auxiliary Equipment Unit	General housekeeping	Hot Cell	tbd
All plant and IRMS in the Hot Cell	Preparation of transfer casks (end-effector change)	General housekeeping	Hot Cell	tbd

All plant and IRMS in the Hot Cell	Maintenance of transfer casks	General housekeeping	Hot Cell	tbd

12.10 IO Shutdowns - IRMS Equipment maintenance tasks

Plant	Task	Purpose	Task Location	RH Class
IRMS Hot-Cell equipment	Repair of Hot Cell RH equipment	Repair after failure	Hot Cell	tbd
IRMS In-Vessel equipment	Repair of In-Vessel RH equipment	Repair after failure	Hot Cell	tbd
IRMS In-Vessel equipment	Cleaning	House-keeping	Hot Cell	tbd
IRMS transport casks	Cleaning	House-keeping	Hot Cell	tbd
IRMS transport casks	Preparation for In-Vessel operations	House-keeping	Hot Cell	tbd

12.11 IO Shutdowns - IRMS Equipment rescue tasks

Plant	Task	Purpose	Task Location	RH Class
CMM	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	In-Vessel	2
CTM	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	In-Vessel	2
CTM & CMM MAM	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	In-Vessel	2
CTM & CMM MAM RH Tooling	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	In-Vessel	2
IVT Manipulator	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	In-Vessel	2
IVT Manipulator tooling system	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	In-Vessel	2
IVT Blanket Handling	Rescue of failed IRMS unit	Transfer failed IRMS unit to	In-Vessel	2

Gripper		Hot Cell		
IVT Articulated Rail & Support	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	In-Vessel	2
IVT Rail deployment manipulator	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	In-Vessel	2
IVT umbilical handling system	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	In-Vessel	2
Port plug tractor	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	Port Cells Gallery Lift Hot Cell Receipt	2
Port plug RH tooling system	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	Port Cells Gallery Lift Hot Cell Receipt	2
Upper port plug cask system	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	Port Cells Gallery Lift Hot Cell Receipt	2
Equatorial port plug cask system	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	Port Cells Gallery Lift Hot Cell Receipt	2
Divertor port plug cask system	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	Port Cells Gallery Lift Hot Cell Receipt	2
In-cask RH tooling system(s)	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell	Port Cells	2
NB Monorail Crane	Rescue of failed IRMS unit	Transfer failed IRMS unit to tbd	NB Cell	2
NB Mast Transporter	Rescue of failed IRMS unit	Transfer failed IRMS unit to tbd	NB Cell	2

NB Mast Manipulator	Rescue of failed IRMS unit	Transfer failed IRMS unit to tbd	NB Cell	2
NB Floor Mounted Transporter	Rescue of failed IRMS unit	Transfer failed IRMS unit to tbd	NB Cell	2
NB Floor Mounted Transporter Manipulator	Rescue of failed IRMS unit	Transfer failed IRMS unit to tbd	NB Cell	2
NB Manipulator(s) RH tooling system(s)	Rescue of failed IRMS unit	Transfer failed IRMS unit to tbd	NB Cell	2
Hot Cell Craneage	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell crane repair area	Hot Cell	2
Hot Cell Mast Transporters	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell Mast repair area	Hot Cell	2
Hot Cell Mast Manipulators	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell Manipulator repair area	Hot Cell	2
Hot Cell Manipulator RH tooling system(s)	Rescue of failed IRMS unit	Transfer failed IRMS unit to Hot Cell RH tools repair area	Hot Cell	2

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Form # - ITER_D_2L9KGL

Annexe A - ITER Remote Handling Task Definition Form

Purpose

The RH Task Definition Form (TDF) is the device by which an RH task is characterised and summarised in general terms.

Implementation

The RH Task Definition Form (TDF) is created at an early stage of the, ITER plant, IRMS and RH operations development life cycles in order to scope the RH task constraints, requirements and overall boundaries.

REMOTE HANDLING TASK DEFINITION FORM

Task Description	

Task Objective
•
Target Plant
•
Start Point
•
End Point
•
Assumptions
•
Main Issues
•

Remote Handling Sequence

•

Remote Handling Tools	
Tooling Function	**Characteristics**

Outstanding Issues			
Issue of concern	**Name**	**Date issue raised**	**Date issue resolved**

Sources of Data
Level of confidence in the source data

Revision History:			
Issue	**Author**	**Date**	**Comments**

Form # - ITER_D_2LT2NA

Annexe B - ITER Remote Handling Compatibility Assessment form

Purpose

The RH Compatibility Assessment (RHCA) form is the device by which the IO RH section authorise the approval and/or comments regarding the compatibility of an ITER plant for remote handling.

Implementation

The RHCA is formally employed in two stages:-

1) Assessment of Plant concept design
2) Assessment of Plant after manufacture – 'As-built'

Form # - ITER_D_2LT2NA

ITER REMOTE HANDLING COMPATIBILITY ASSESSMENT FORM

Additional documents, sketches and other information can be added at the end of this form

Plant Item:		**New Plant or Mod?**	
RH Assessor:			

1. Description of Plant (to be filled in by the component's designer)			
2. General Assembly (to be filled in by the component's designer)			
CATIA Model ref.		Issue date	
Document ref.		Issue date	

3. Physical Properties (to be filled in by the component's designer)	
Mass [kg]:	•
Outside dimensions [m]:	•
Material(s):	•
Other properties:	•

4. Condition	
Remote Handling Class:	•
Contact dose rate during RH:	•
Temperature during RH:	•
Maintenance / Replacement Schedule:	•
Transfer Cask interface:	•
Other considerations:	•

5. Plant Interfaces (to be filled in by the component's designer)	
Mating / Associated	•

Components:	
Positional Accuracy required[mm]:	•
Services:	•

6. Remote Handling features	
Fixings:	•
Self alignment features:	•
Handling points:	•
RH standard connectors:	•
RH standard welded joints:	•
RH standard pipe joints:	•
Delicate surfaces/elements:	•
Other considerations:	•

7. Remote Maintenance Requirements (to be filled in by the component's designer)	
Task	Comments / Notes

8. Sources of Data / References:

9. Level of confidence in the source data:

10. Overall Assessment:
Is Plant RH compatible ?

Form # - ITER_D_2LT2NA

Recommendations:

11. Revision History:					
Issue	Author		Date	Review Stage (Concept or 'As Built')	Comments
	Name	Sig			

12. Approval History:				
Issue	Approved by		Date	Comments
	Name	Sig		

13. Any additional information and references
•

Annexe C - IRMS Statement of Readiness Form

Purpose

The RH Statement of Readiness (SOR) form is the device by which the IO RH section qualify and approve each part of the IRMS for use in remote operations.
Remote operations can take place either under mock-up or fully remote scenarios and only the IRMS elements that have a-prior qualification as recorded by an approved SOR can be used for operation.

Implementation

An SOR is raised and implemented in accordance with remote operations planning requirements.
SOR's will be raised for individual pieces of equipment and for complete systems and also for suites of equipment e.g. blanket handling tool suite.

The organisation and management of the SOR system requirements is not the subject of this document.

An SOR must contain information and notifications regarding the following elements:-

- ID no for the IRMS equipment/sub-system/system/suite
  - Allocated by the RH Section
- Name of the IRMS equipment/sub-system/system/suite
  - Allocated by the RH Section
- Responsible Officer for the SOR
- Authorisation signature
- SOR authorisation validity date range
  - Practical limits for operational use before re-qualification is necessary (defined for each equipment by the RH Section)
- IRMS equipment/sub-system/system/suite test document references
  - References to tests implemented to qualify and prove IRMS functionality, performance, safety and failure behaviour.
- Declared operational constraints for the IRMS equipment/sub-system/system/suite
  - Statement by SOR responsible officer of all equipment limits and constraints to be observed by the RH operators during the stated validity period.

Form # - ITER_D_2MV64A

IRMS STATEMENT OF READINESS (SOR)

IRMS Identifier:				Equipment: Sub-system: System: Suite:	☐ ☐ ☐ ☐
SOR Id:					
Valid from:					
Valid to:					
IRMS Test Records:					
IRMS Operational Constraints:					
SOR Prepared by:		Signature:		Date:	
SOR Authorised by:		Signature:		Date:	

Annexe D - ITER Remote Handling Operations Sequence Description

Purpose

The RH OSD is the device by which an RH operation is described in general terms.
It is written in a form suitable for dissemination and assessment by all stakeholders in the RH task concerned.

Implementation

The RH OSD is written, reviewed and approved at an early stage of operations documentation development. It is finalised and approved before any detailed operations instructions are developed.

Form # - ITER_D_2LEMDX

OPERATIONS SEQUENCE DESCRIPTION

Task Identifier	

Description
Task Objective
Plant
•
Assumptions
Start Conditions
•
End Condition
•
Remote Operations Sequence
•
Required IRMS systems
•
Logistics & Flow Chart Reference
•
Sequence Variables
•
Teach files
•
Physical Mockup Requirements

Virtual Reality Mockup Requirements
Reference Drawings & Documentation
•
Task Hints & Tips

Form # - ITER_D_2LQ6V5

Annexe E - RH Operations Instructions Documentation Release Form

Purpose

The RH Operating Instructions Document Release Form is the device by which all ITER RH operations instructions, schedules and associated documentation are approved for use.

Implementation:-

The RH Operating Instructions Documentation is authorised for use after presentation and peer review at a formal RH operations review meeting.

Form # - ITER_D_2LQ6V5

ITER RH OPERATIONS INSTRUCTIONS DOCUMENTATION RELEASE FORM

Task	
Operations RO:	
OSD reference no:	

ODS Element	Date	Author
Sequences		
Flow Chart		
Task Schedule pro-forma		
Boom teach files		
Sketch/Image files		
VR Landmarks		

Prepared by:		Signature:		Date:	
Authorised by:		Signature:		Date:	

Annexe F - ITER Remote Handling Fault Reporting and Corrective Action System (FRACAS)

Purpose

The RH Fault Reporting and Corrective Action System (FRACAS) is the device by which all IRMS faults and non-normal behaviour is recorded, reviewed and acted upon.
The ITER RH FRACAS is a key element of the RH Section emphasis on continuous improvement.

Implementation

The ITER RH FRACAS is a SQL database application implemented on a PC platform in the following steps:-

1. In response to the occurrence of a fault or non-normal event; the observer uses the FRACAS Fault Entry form to record the details of the fault/event. (NB: In the event that the fault requires immediate attention then the processes for diagnosis and repair are instigated – these are not part of this document)
2. The FRACAS manager analyses and categorises all reported faults on a weekly basis and tables them for discussion with the IRMS responsible engineers.
3. The outcome from discussions and actions implemented with respect to each fault are recorded on the FRACAS Fault Review form.
4. When all actions related to the reported fault have been completed or transferred to a different system then the FRACAS report is closed and archived.

Form # - ITER_D_2N4RBA

ITER RH FRACAS
FAULT REPORTING FORM

IRMS Equipment identifier:	
Description of the fault:	
Task being performed when fault occurred:	
Fault codes / Error messages reported by the IRMS:	
Name of the Operator and Operations RO:	
Actions taken at time of the event:	
Date and time of event: (automatically generated)	
FRACAS ID: (automatically generated)	

Form # - ITER_D_2N4RBA

ITER RH FRACAS
FAULT REVIEW FORM

IRMS Equipment identifier:		
FRACAS ID:		
Date and time of event:		
IRMS Equipment RO:		
Review action on:		
Actions taken at time of event:		
Review outcome:	Short Term Actions:	
	Long Term Actions:	
Next planned review date:		
Date Fault Report is closed:		

Form # - ITER_D_2N6ZG3

Annexe G - ITER Plant Definition Form

Purpose

The ITER Plant Definition Form (PDF) is the device by which ITER Plant responsible officers define an ITER component that is to be RH compatibility.

Implementation

The RH Plant Definition Form (PDF) is created at an early stage of the ITER plant life cycles. It is used by the ITER PBS responsible officers to declare a component that requires RH maintenance and to provide the summary data required by the RH Section to evaluate the component for compatibility with the baseline RH equipment and operations.

REMOTE HANDLING PLANT DATA SHEET 1 - DESCRIPTION

Description:
General Assembly:

Form # - ITER_D_2N6ZG3

REMOTE HANDLING PLANT DATA SHEET 2 - PROPERTIES

Physical Properties:	
Mass [tons]	
Size [m]:	
Material(s)	
Other properties	
Condition:	
Contact Radiation dose rate	
Temperature during handling	
Maintenance Schedule	
Transfer Cask interface	
Other considerations	
Remote Handling features:	
Fixings	
Self alignment features	
Handling points	
Delicate surfaces/elements	
Other considerations	
Remote Maintenance requirements:	

Task	**Comments/Notes**