

8.7 In-Cryostat Repair

8.7.1 Function, Basic Configuration and System Boundaries

The functional requirements for in-cryostat repair are to inspect and repair machine components located between the inside of the cryostat wall and the outside of the vacuum vessel.

These maintenance operations shall include the following:

- Magnet (power and helium) termination joints and module bypass joints
- Inspection and bolt tensioning of the intercoil structures
- Vacuum and cryogenic leak checking
- Inspection of instruments and sensors
- Inspection of electrical and thermal shorts
- Inspection of thermal shield

Other, extremely less likely repair operations include:

- Central solenoid disassembly/re-assembly
- Poloidal field coil disassembly/re-assembly
- Toroidal field coil and vacuum vessel sector disassembly/re-assembly

8.7.2 Requirements

8.7.2.1 Environmental Conditions for In-Cryostat Repair

Typical conditions during in-cryostat repair are:

- atmosphere: air;
- pressure: 1 bar absolute;
- temperature: ambient;
- radiation: see Table 8.7-1
- contamination:
 - None during maintenance
 - Tritium, activated dust and beryllium during machine disassembly.
- magnetic field: zero.

Table 8.7-1 Dose Rates during Remote In-Cryostat Maintenance

No.	Building	Location	Main operation items	Dose rate (10 ⁶ s after shutdown)
a	In-cryostat	Inboard upper in-cryostat	PF-1 repair, break boxes repair	40 μ Sv/hr
b	In-cryostat	Outboard upper in-cryostat	PF-2 repair, break boxes repair	100 μ Sv/hr
c	In-cryostat	Outboard mid-plane in-cryostat	PF-3 repair, bypass joint repair	(1) IC H&CD port 70-280 μ Sv/hr (side),
d	In-cryostat	Outboard mid-plane in-cryostat	PF-4 repair, bypass joint repair	70-150 μ Sv/hr (upper) 100 μ Sv/hr (behind),
e	In-cryostat	Outboard lower in-cryostat	PF-5 repair, break boxes repair, TF break boxes repair	120- 350 μ Sv/hr (behind VV primary closure plate),
f	Tokamak Pit / Gallery	Inside of bioshield plug in upper port	Diagnostic maintenance Upper port assembly maintenance	70-150 μ Sv/hr (lower) (2) Maintenance port
g	Tokamak Pit / Gallery	Inside of bioshield plug in equatorial port	Blanket module repair EC H&CD, IC H&CD maintenance Equatorial port assembly maintenance	100- 400 μ Sv/hr (upper) (3) NB H&CD port : TBD (4) Cryopump port
h	Tokamak Pit / Gallery	Inside of bioshield plug in divertor port	Divertor cassette repair Cryopump valve repair Divertor port assembly maintenance	2000 μ Sv/hr (upper) (5) Upper port :TBD
i	In-cryostat	Inboard lower in-cryostat	PF-6 repair, break boxes repair	40 μ Sv/hr
j	In-cryostat	Solenoid bore	CS repair, break boxes repair	4 μ Sv/hr
k	Crane Hall	Upper bioshield lid (floor in tokamak building)	CS,TF coils/VV disassembly and re- assembly	0.5 μ Sv/hr (During operation, no hole case)

8.7.2.2 Repair

To develop the in-cryostat repair strategy, a number of postulated RH class 3 repair tasks have been selected as possible in-cryostat repair activities.

- PF, TF and CS magnet (power and cryogenic) terminal joint repair
- PF coil magnet module bypass operations
- The toroidal field (TF) coils repair or replacement
- Central solenoid (CS) module coils repair or replacement
- Poloidal field (PF) coils repair or replacement
- Vacuum vessel repair or replacement

8.7.2.3 Shielding

1) During Cryostat Repair

The fundamental repair strategy assumes that sufficient shielding will be provided to allow hands-on access as the primary method of repair.

The following guidelines shall be followed when formulating a strategy for in-cryostat repair operations:

- hands-on repair is the reference scenario, with remote repair as a back-up should detailed activation calculation results turn out to preclude hands-on repair, or shielding cannot be designed to be as efficient as required;
- permanent walkways should be available inside the cryostat for hands-on operations. These include fixed walkways, lifting points and other features to simplify and reduce the duration of in-cryostat operations;
- back-up provisions for in-cryostat remote operations should be provided and where practicable, the special features introduced for hands-on operations should be used.

2) During Disassembly/Re-assembly of In-Cryostat Components

In case of VV/TF coils disassembly/reassembly, the VV/TF coils should be locally shielded for moving to the top of the bioshield and be accommodated in a shielded cask to reduce skyshine dose.

8.7.2.4 Dimensions and Weight of In-Cryostat Components

Table 8.7-2 provides typical dimensions and weights of major in-cryostat components that may have to be handled during major disassembly/re-assembly operations.

Table 8.7-2 Typical Dimensions and Weight of Major Ex-Vessel Components

Component	Quantity	Unit Weight (tonne, each)	Max. Width (m)	Max. Height (m)	Weight (tonne)
Central solenoid/winding pack	6	107	4.2	18.8	642
Poloidal field coils		214			214
PF-1	1		9.5	2.4	
PF-2	1	259	18.5	1.9	259
PF-3	1	945	25.5	1.2	945
PF-4	1	913	26.0	1.2	913
PF-5	1	390	18.2	2.4	390
PF-6	1	435	10.8	2.4	435
VV supports (V)	18	17	~ 1.2	~ 2.0	306
CS support	1	399	ϕ 5.33	~ 5.4	399
Toroidal field coils	18	274	11.97	14.5	4,932
Outer intercoil structure connectors	18	13	ϕ 0.14	~ 1.0	234
Gravity supports	18	24	2.5	5.5	432
Feeders (PF)	433 m	0.24 t/m	-	-	104
Feeders (TF)	86 m	0.24 t/m	-	-	21
Cryostat lid	1	665	28.5	3.7	655
Vacuum vessel sectors	18	361	4.1	11.3	6,500

8.7.2.5 Reliability

All in-cryostat components shall be conservatively designed and have factors of reliability to render failure extremely unlikely.

8.7.2.6 Durability

All in-cryostat components shall be designed to last the life of the machine and should not require maintenance.

8.7.2.7 Access

Access is required to the following components:

- Magnet (power and helium) termination joints and module bypass joints.
- Access to the PF1 and 2 coils from the upper central cryostat roof.
- Access to the PF3 and 4 coils for joint bypass operations from within the equatorial horizontal port ducts.
- PF5 and 6 coils from below at the divertor port level.

- TF coils 1 through 18 from below.
- CS modules 1 through 3 to be accessed from above
- CS modules 4 through 6 from below (TBD).

8.7.2.8 Space

In-Cryostat Repair

A minimum radial clearance of approximately 1 m is required to allow worker access to create a PF magnet module bypass.

Disassembly/Reassembly of In-Cryostat Components

Disassembly/reassembly of in-cryostat components is a basic requirement that impacts machine layout and building design. Table 8.7-2 shows the typical dimensions and weight of in-cryostat components that may have to be maneuvered in the tokamak crane hall, the assembly hall, or laydown area during machine disassembly/reassembly.

8.7.2.9 Occupational Radiation Exposure Limits

Table 8.7-3 shows the radiation exposure limits during in-cryostat maintenance. In-cryostat maintenance must comply with the ALARA principles (see the PSR and the PDS).

Table 8.7-3 Radiation Exposure Limits for Hands-On Maintenance

< 750 μSv/h	Maximum dose rate for access zone C
< 0.5 mSv/shift	Project guideline for individual dose per shift
< 30 person-mSv	Initial limit on collective dose for planned maintenance task (e.g. 15 persons @ 2 mSv or 30 persons @ 1 mSv)
< 20 mSv/a	Regulatory limit for total individual dose

8.7.3 Codes and Standards

- Control system standards:
 - IEC 204-1, 1992: Electrical equipment of industrial machines, or
 - ANSI/NFPA 79: Electrical standard for industrial machinery
- Machinery (Robot) safety standard:
 - ISO 10218, 1992 Manipulating industrial robots. Safety, or
 - ANSI/RIA R15.06-1992 Industrial robots and robot systems. Safety requirements
- Welding and inspection: generic at the time of procurement
- Materials: generic at the time of procurement
- Standard Control system items: generic at the time of procurement