

2.10 Assembly Equipment and Procedures

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2.10.1 Introduction

The assembly plan defines the sequences of operations developed to complete the assembly of the tokamak, which includes the cryostat and the sub-systems contained therein. The scope of the plan includes the on-site transport of the components, preparation (pre-assembly) of the components, sub-assembly of the integrated assembly units, and final assembly inside the tokamak pit.

The assembly plan will be the basis for establishing the scope of the detailed assembly procedures which will be used to assemble the tokamak in accordance with local regulations.

To complete the assembly operations will require both specially designed, purpose-built tools, and standard, commercially available equipment. To support the assembly process, a number of services; metrology, metallurgy, beryllium control, health physics and occupational safety, will be established, and provided at the site.

2.10.2 Basic Concept

The tokamak is assembled from 9 sectors, each with a toroidal angle of 40°, and comprising a sector of VV, two TF coils, the associated VV thermal shield (VVTS), and two VV gravity supports (VVGs), which provide both the vertical support and lateral stabilisation to the VV in the completed tokamak. The components are delivered to the site individually, and sub-assembled into sectors using purpose built jigs and fixtures in the assembly hall.

Prior to installing the sectors in the tokamak pit, the tokamak gravity supports (GS), lower cryostat sections, and the components which cannot be installed following final assembly of the sectors, principally the lower PF coils, lower correction coils (CCs), the lower CC feeders, and the lower pretensioning rings, are installed, or placed in the pit.

The sectors are transferred to the pit sequentially. The TF coils and VVTS sectors are connected in the same sequence, whereas the VV sectors are joined (welded) according to a plan which aims to minimise deformations, and the associated technical risk.

Following installation of the final sector, the TF coil pretensioning rings are installed, and the preload applied to each of the coils. A detailed dimensional survey at this stage provides the

geometrical estimate of the magnetic datums for the as-built TF magnet, and these are used as reference for all subsequent installation operations.

The VV is closed toroidally, with the welding of near-diametrically opposite joints. Clean conditions are then established inside the vessel, and the installation of the in-vessel systems is completed. The completion of the installation of the ex-vessel components proceeds in parallel.

2.10.3 Assembly Strategy

The assembly plan is aimed at achieving the technical requirements for the assembled sub-systems, within the desired assembly schedule. There are three main issues:

- the tight installation tolerances required for the major components of the tokamak, considering the large size and weight of the components - to achieve these, the assembly plan must follow sequences and processes which minimise both deviations and the residual stresses in the components, and which allow for the correction of any deviations as they occur, so that alignment errors do not accumulate;
- routing of components through the building complex to avoid potential conflicts between activities that are carried out in parallel - this must be carefully planned, and also includes the routing of systems which must be transferred via the assembly facilities, and be installed elsewhere in the building, such as in the galleries;
- use of appropriate clean conditions - to meet the vacuum requirements, the assembly of all of the tokamak components must be carried out under clean conditions, and the assembly of the components containing beryllium will require additional precautions.

2.10.3.1 Tolerance Requirements

With the alignment tolerances close to the limit of what is achievable, the accumulation of deviations must be strictly controlled. The assembly plan is therefore designed to correct alignment deviations at each step of the assembly sequence. This strategy relies on linking a sophisticated optical metrology system (OMS) to a CAD system, which can generate and analyse complex 3-D models in near-real time, and provide a complete, evolutionary database of the as-built (i.e. assembled) components and of the overall tokamak geometry.

With respect to the major components, it is essential that most geometrical interfaces have the provision for adjustment (generally shimming) included in their design.

The strategy for controlling the dimensions of the tokamak build is illustrated in Figure 2.10.3-1. Component installation will be preceded by a comprehensive survey of the tokamak pit, and a best-fitting process will then be used to define the "pit assembly datum" with respect to the as-built pit geometry. Prior to completion of the TF magnet, the large components will each be independently aligned with respect to these datums. In principle, the datums will be fixed for the duration of this part of the assembly, although, in practice, it may be advantageous to progressively modify the datums, and the assembly of the TF magnet would then proceed via a process of best-fitting (adjusting) of the datums to the as-built geometry of the TF magnet.

On completion of the assembly (and pre-tensioning) of the TF magnet, a comprehensive survey of the TF coils will be combined with manufacturing dimensional control data to provide a geometrical estimate of the magnetic axis of the machine; this is referred to by the

term "tokamak assembly datum" in Figure 2.10.3-1. Subsequent alignment operations, primarily on the components which are tightly toleranced, will be carried out relative to the tokamak assembly datum.

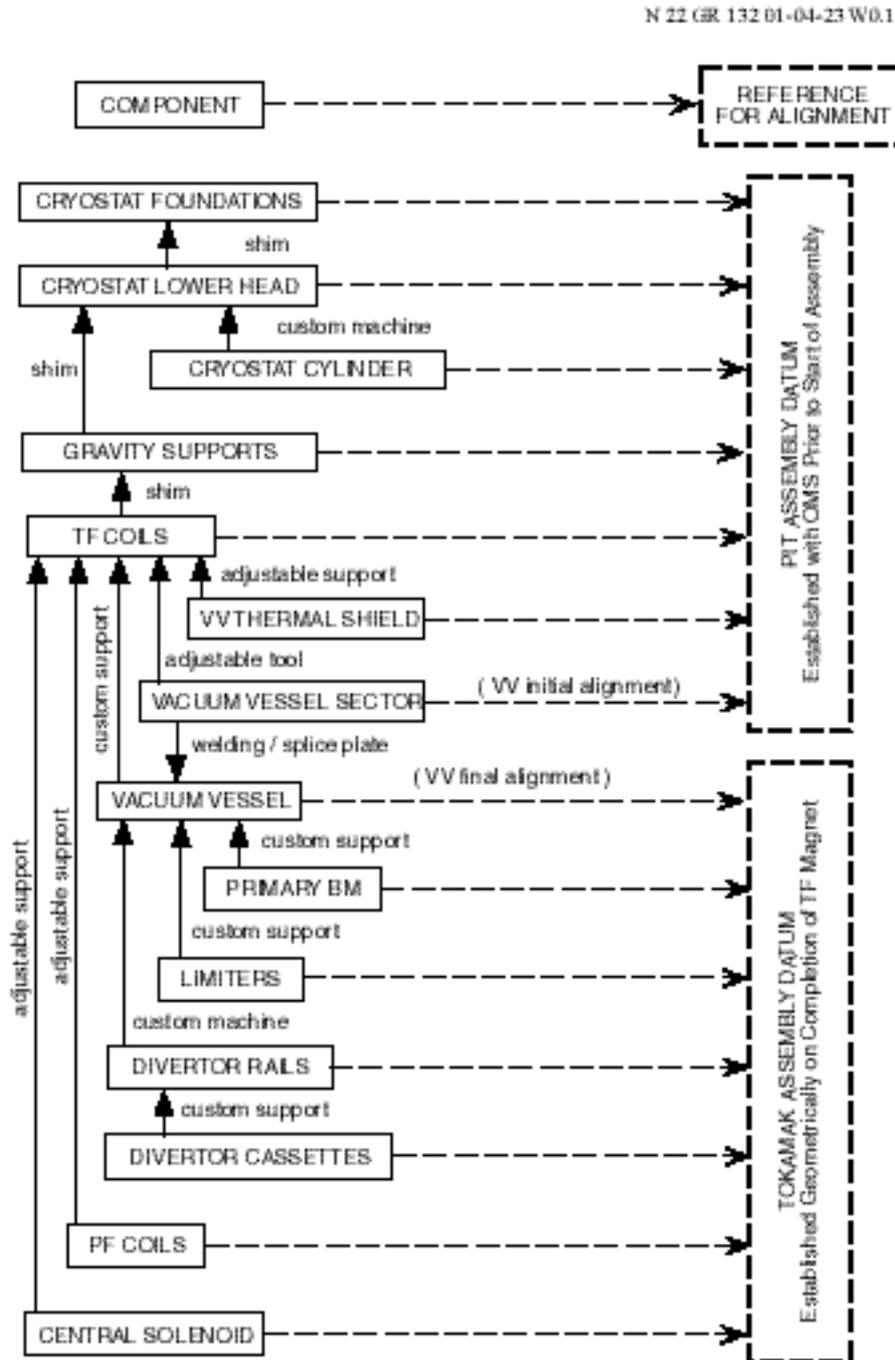


Figure 2.10.3-1 Tokamak Alignment Strategy

Figure 2.10.3-1 also identifies the proposed method of adjusting the component interfaces at each assembly step.

2.10.3.2 Building Utilisation

The assembly processes in the assembly hall of the laydown, assembly and RF heating building are aimed at obtaining the maximum utility from the available layout, which is constrained by crane coverage limitations for the heavy lifts.

A temporary area will be established outside the south end of the building complex (see Figure 2.10.3-2) in which to unpack and/or clean the large components before entry into the assembly hall. A similar, but smaller, area will be established in the hot cell building, to the north. The routing of the components into and through the building will conform to the following basic plan.

Initial assembly phase:

- the sub-assembly tooling and workstations for the VVTS, TF coils and VV will be cleaned, installed and tested in the assembly hall;
- the cryostat foundations, base sections and cylinder, and the lower, trapped PF coils, PF5 and PF6, will be cleaned, and then prepared in the laydown area prior to installation in the pit (this will require lifting these components over the sub-assembly tooling and workstations, with consequent limitations on the height of these lifts).

This strategy will allow the sub-assembly of the 40° assembly sectors, which affects the critical path of the assembly schedule, to begin in parallel with, or prior to, the installation of the lower cryostat components. In this way, the start of installation of the 40° assembly sectors in the pit may be advanced, and the assembly schedule minimised.

TF coil, VV, VV ports and in-vessel components:

- the VV sectors, VVTS sectors and TF coils will be cleaned in the south facility, and then prepared, sub-assembled and controlled in the assembly hall;
- the VV port sections, and the blanket modules, divertor cassettes and other in-vessel components will be unpacked and cleaned, prepared and controlled in the hot cell, located to the north of the tokamak hall; these components will then be routed to the VV via the tokamak hall lift and galleries.

The routing of the components through the building complex is also indicated in Figure 2.10.3-2.

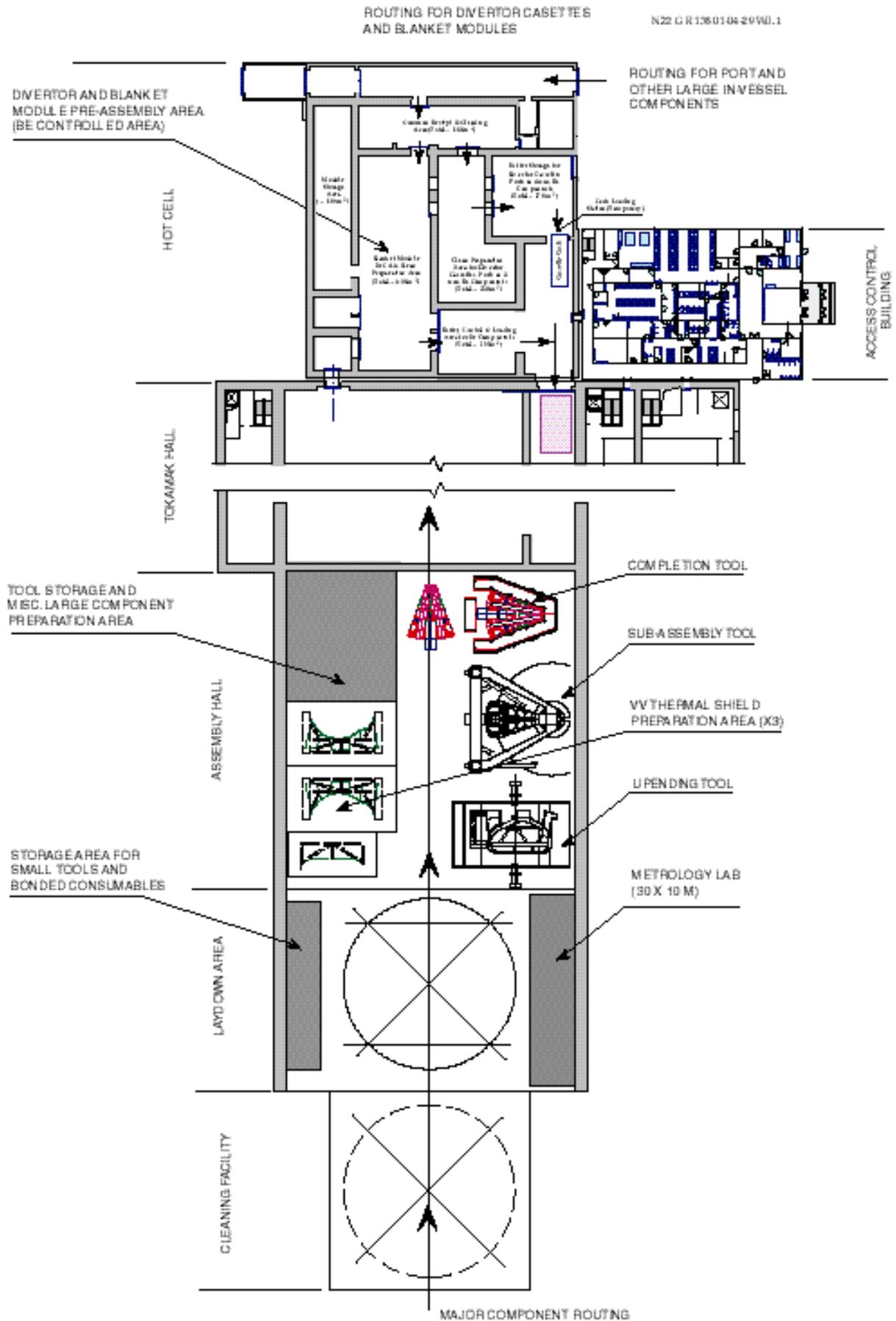


Figure 2.10.3-2 Utilisation of Tokamak Building during Initial Assembly

2.10.3.3 Clean Conditions and Be Control

The correct functioning of the in-vessel and in-cryostat components necessitates the achievement of a high level of cleanliness prior to operation. To ensure cleanliness of the in-cryostat components, for which a systematic, post-assembly cleaning is unfeasible, the building complex will be operated under conditions equivalent, or near to class 100,000 clean room conditions (target conditions); components will be cleaned prior to entry, personnel will be appropriately dressed, and “dirty” processes and tooling specifically excluded from the area.

To ensure compatibility with the achievement of ultra-high vacuum operating conditions, a higher standard of cleanliness will be required for the interior of the VV, and for the in-vessel components. The following strategy will permit the establishment and maintenance of clean conditions for the in-vessel assembly operations, whilst minimising the detrimental effect on the productivity of the workforce:

- the assembly of the VV will be carried out under the same conditions as for the cryostat and other in-cryostat components;
- following toroidal closure of the VV, and installation of the VVGS, an independent ventilation and access system will be installed in the galleries surrounding the bioshield, and connected to the VV via a number of its ports: the remaining ports will be sealed using temporary blanking plates;
- the interior of the VV will be cleaned to the required standards using techniques applicable for ultra-high vacuum components, e.g. scrubbing and pressure washing with approved detergents and solvents, rinsing with demineralised water and “warm” air drying, and clean conditions established;
- in-port and in-vessel assembly shall then be carried out under clean conditions.

Beryllium is a material which in dust form is classified as hazardous to health, and special precautions will be necessary when components containing Be and its compounds are being handled, prepared and assembled. The principle source of Be in ITER is the blanket modules, which are clad with a solid layer of metallic Be. For preparatory operations, a dedicated Be control area will be established in the hot cell building, see Figure 2.10.3-2, and, prior to installation of the first blanket module, similar controls will be applied to the VV. The two areas will be maintained under negative pressure via separate, local ventilation systems, which will exhaust via HEPA filters.

Access to the Be-controlled areas will be restricted to a specific group of registered workers, strictly regulated, and extensive routine monitoring for surface and airborne Be dust will be required. The Be components will be exposed only in these areas; for transit to, and between, the areas the components will be packaged in sealed containers (such as the gallery transport casks).

2.10.4 **Tokamak Assembly Plan**

2.10.4.1 Tokamak Boundaries

The tokamak assembly plan will require approximately 10^6 man hours to complete. The estimated duration for the activities is approximately 4 years.

The assembly plan covers the cryostat and the sub-systems contained therein. A limited number of components external to the cryostat are also included in the scope of the assembly plan; typically these are attached to the cryostat, and form the interface with the surrounding building/systems, e.g., gravity support pedestals and the penetrations for the magnet feeders. The following sub-systems are included in the scope of the assembly plan:

- Cryostat and penetrations;
- Bioshield lid;
- Magnet system, comprising;
 - Toroidal field coils and structures
 - Gravity supports
 - Poloidal field coils and supports
 - Central solenoid and supports
 - Correction coils and supports
 - In-cryostat feeders
- Vacuum vessel;
 - Vacuum vessel
 - Ports
 - VV gravity supports
- Thermal shields, comprising;
 - Vacuum vessel thermal shields
 - Cryostat thermal shields
 - Transition thermal shields
- In-vessel components, comprising;
 - Divertor
 - Blanket modules
- In-port components, comprising;
 - Cryopumps
 - Diagnostics
 - Test blanket modules
 - Additional heating systems.

and all associated in-cryostat pipework, instrumentation and cabling.

The overall dimensions and approximate mass of each of the major components in its assembly configuration is given in Table 2.10.4-1.

Table 2.10.4-1 List of Major Tokamak Components

Component	Qty	Overall Dims (m)	Mass (tonne)
Cryostat Base Section	1	Ø 28.6 x 6.0	1187
Cryostat Lower Cylinder	1	Ø 28.6 x 10.2	730
Cryostat Upper Cylinder	1	Ø 28.6 x 8.8	680
Cryostat Lid	1	Ø 28.6 x 4.2	700
Bioshield Lid	1	Ø 12.0 x 2	500
Bioshield Lid	4	21.2 x 10.8 x 2	750
Gravity Support Pedestal	18	Ø 1.35 x 4.32	13.5
VV Sector (with some separate manifolds and fixtures)	9	14.0 x 8.0 x 8.0	700
VV Gravity Supports	18	1.9 x 1.4 x 0.5	5.3
TF Coil	18	16.6 x 9.0 x 2.7	325
Gravity Support	18	2.6 x 2.3 x 1.4	25.6
PF1 incl. Clamps	1	Ø 9.4 x 1.1	218
PF2 incl. Clamps	1	Ø 17.8 x 0.7	271
PF3 incl. Clamps	1	Ø 25.1 x 1.3	627
PF4 incl. Clamps	1	Ø 25.0 x 1.3	600
PF5 incl. Clamps	1	Ø 18.1 x 1.1	404
PF6 incl. Clamps	1	Ø 10.7 x 1.1	453
Central Solenoid	1	Ø 4.2 x 17.8	1117
Upper Correction Coil	6	7.0 x 4.2 x 0.2	14.7
Side Correction Coil	6	7.9 x 7.2 x 0.8	27.3
Lower Correction Coil	6	7.0 x 4.2 x 0.8	20.2
Divertor Cassette	54	3.4 x 2.1 x 0.8	12
Blanket Module (max)	421	(1.3-2.0) x (0.9-1.2) x 0.45	4.5
Inboard Cooling Manifold	9	6.9 x 3.2 x 1.0	2
Outboard Cooling Manifold	9	8.0 x 2.4 x 1.8	3

2.10.4.2 Scope of the Operations

The tokamak assembly plan includes all the operations required to progress the components from their point of reception, storage or manufacture on the ITER site, to their final installed position in the tokamak device. The following, generic sequence describes the scope of the operations for a typical component:

Initial Status of the Components

With the exception of the large components to be fabricated on site, i.e. the cryostat sections, and the PF2, PF3, PF4 and PF5 coils, each component to be assembled will be located in one of the paved, on-site storage areas.

The component will be contained in a “transport package” designed to support the component during shipping and handling, and to provide environmental protection and maintain cleanliness during transport and on-site storage.

Generic Operations

In general, each component will then go through the following process:

- i. the package containing the component will be rigged and positioned on a suitable transporter, and transferred to the appropriate cleaning facility, see Figure 2.10.3-2;
- ii. the component will be rigged and removed from its packaging; the packaging, and the external transporter will be removed from the cleaning facility, and the component placed on an internal, standardised air pallet; the temporary cranes and rigging will be removed from the cleaning facility;
- iii. the component will be unpacked, visually inspected, and cleaned as necessary;
- iv. the component will be transferred into the laydown area, pre-assembly inspections performed, and the component prepared for subsequent assembly;
- v. the component may be transferred to the designated sub-assembly area, and the sub-assembly operations completed;
- vi. the component will be transferred to the pit, either as an individual component or as a part of a sub-assembled unit, and assembled into the tokamak;

2.10.4.3 Outline Assembly Procedure

An outline procedure has been developed for the assembly of the tokamak as the basis for the elaboration of the detailed assembly sequences, conceptual design of the associated assembly tools, the evaluation of the assembly schedule, manpower and tooling requirements, and of the associated cost.

A high level summary is provided by the logic diagrams shown in Figures 2.10.4-2 to 2.10.4-6. The overall procedure is divided into the following six main sub-sections, see Figure 2.10.4-1:

2.2.A.1 Lower Cryostat Activities: (Figure 2.10.4-2) the sub-section includes the assembly procedures for the bottom of the cryostat, the gravity supports, and the lower PF coils; this section covers activities from the initial assembly in this area up to the placement of the first 40° assembly sector;

2.2.A.2 40° Sector Sub-Assembly: (Figure 2.10.4-3) includes installation of the VVTS workstations, the upending tool, the sector sub-assembly jig, and the sector completion tool, in addition to the procedures necessary to sub-assemble each of the nine sectors; each sector includes a pair of TF coils, a 40° segment of the VV and three VVTS parts, an inboard 40° sector and two outboard, opposite hand 20° sectors;

- 2.2.A.3 40° Sector Assembly: (Figure 2.10.4-4) covers the sequencing of the sector assembly in the cryostat;
- 2.2.A.4 Establish Tokamak Axis: (Figure 2.10.4-5) this section includes the pretensioning of the TF magnet, and the survey procedures by which the tokamak assembly datum is geometrically established, see also Figure 2.10.3-1;
- 2.2.A.5 Ex-Vessel Activities: (Figure 2.10.4-6) includes the welding of the final VV field joints (toroidal closure), and all of the assembly procedures for the components and systems external to the VV and ports, from the establishment of the magnetic datum to the preparation for commissioning; these activities, occur largely in parallel with the in-vessel assembly procedure;
- 2.2.A.6 In-Vessel Activities: (Figure 2.10.4-6) includes all of the assembly procedures specific to the VV and port internals, up to the preparation for commissioning.

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STARTING CONDITIONS:

TOKAMAK BUILDING COMPLEX COMPLETE
HVAC OPERATIONAL & ENVIRONMENT STABILISED
ESSENTIAL SITE FACILITIES AVAILABLE

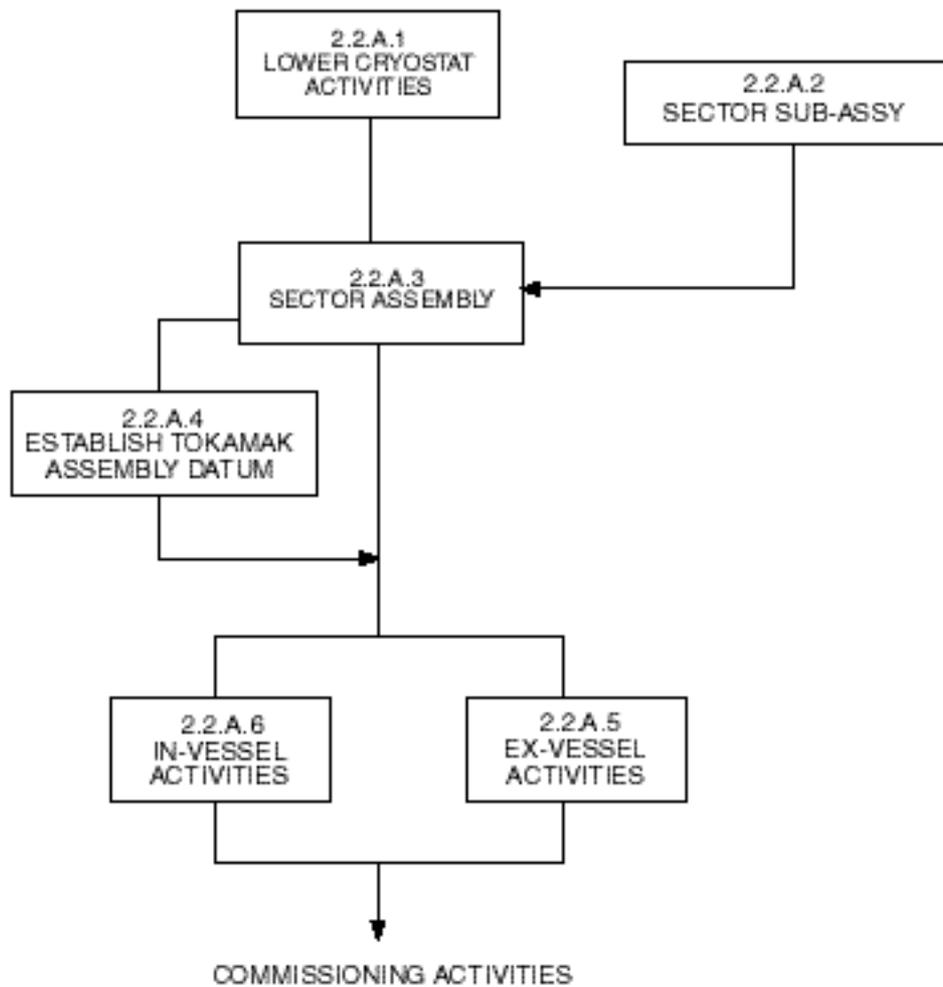


Figure 2.10.4-1 Overall Assembly Sequence – Top Level

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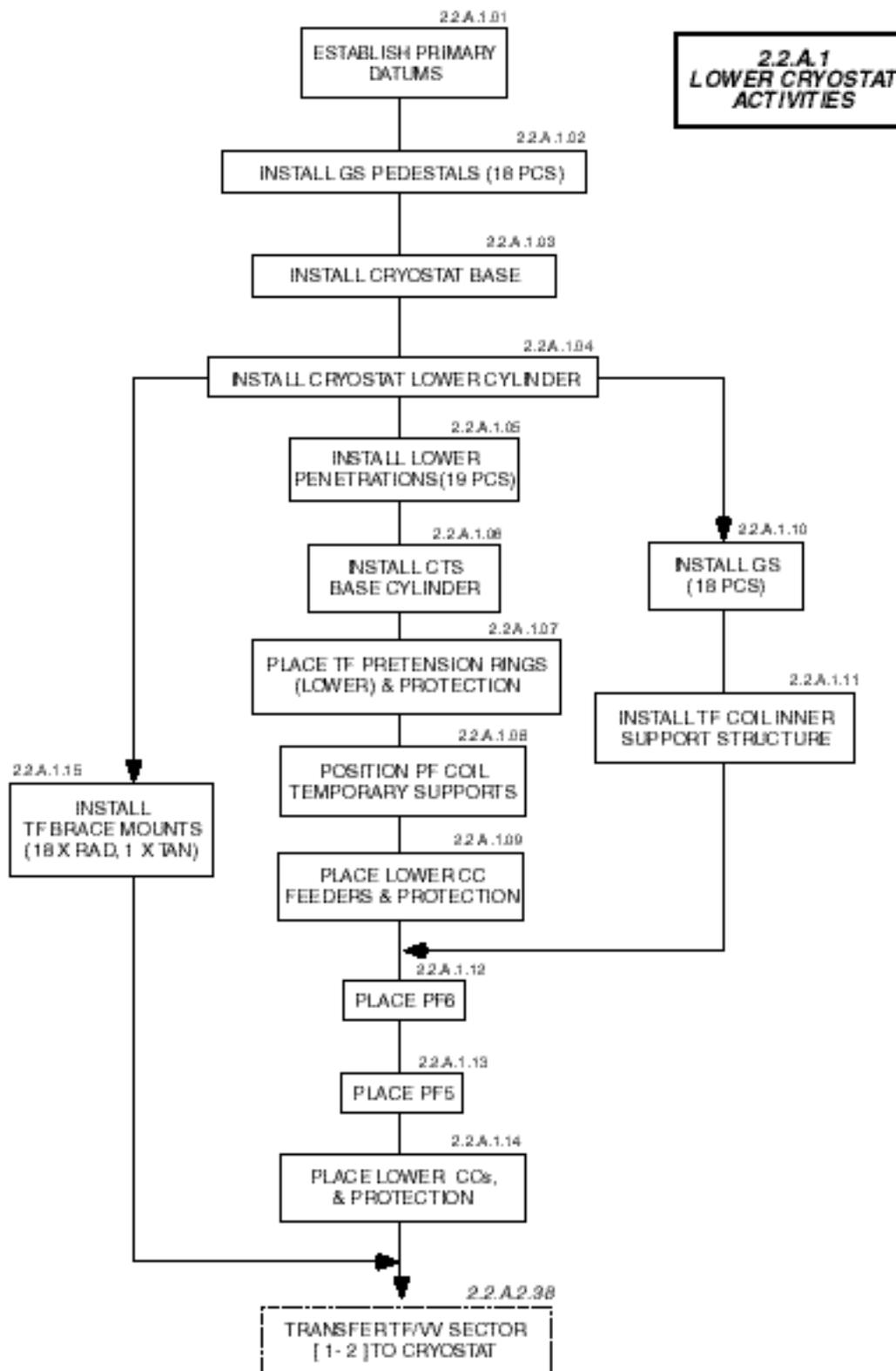


Figure 2.10.4-2 Assembly Sequence – Lower Cryostat Activities

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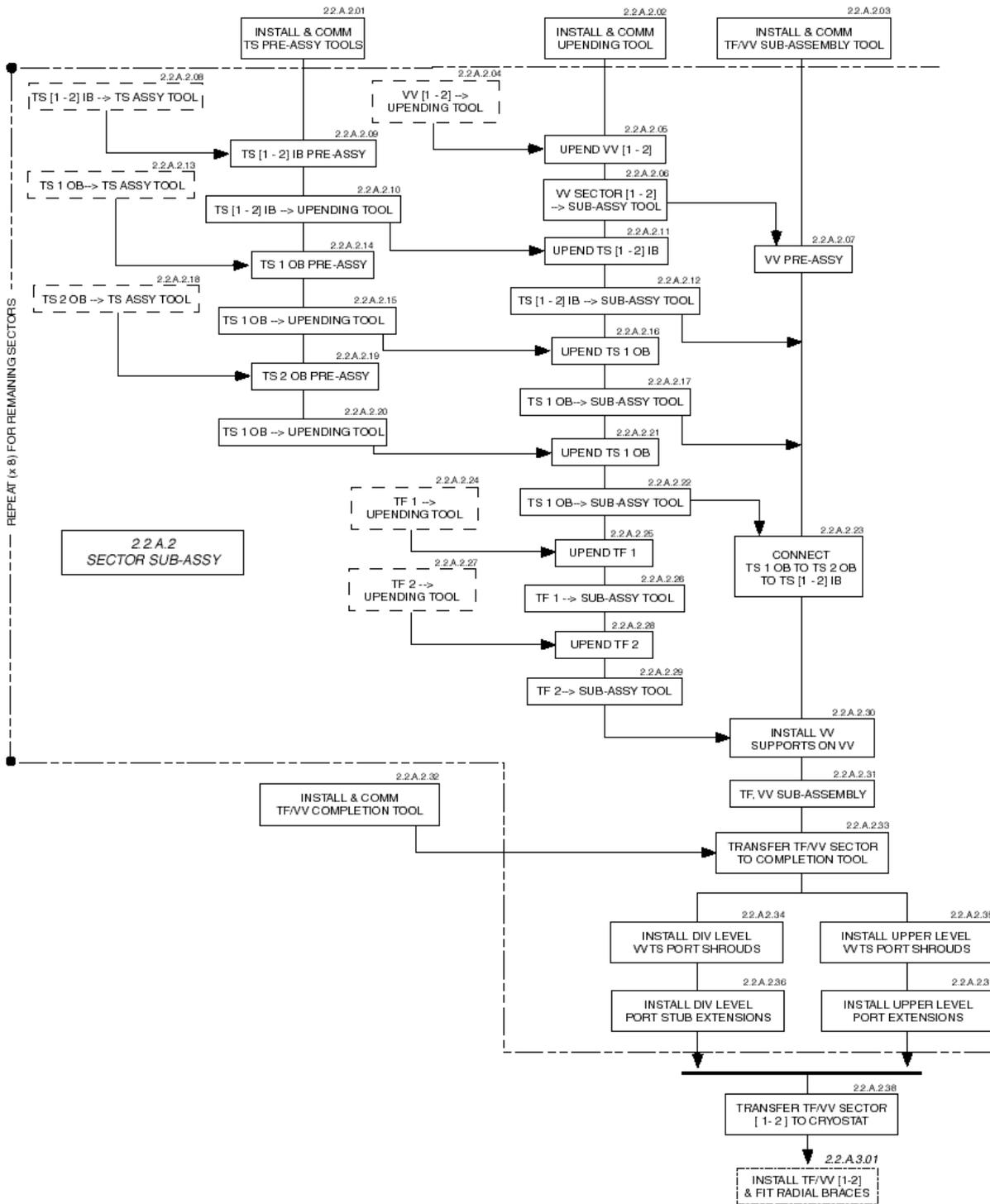


Figure 2.10.4-3 Assembly Sequence – Sector Sub-Assembly

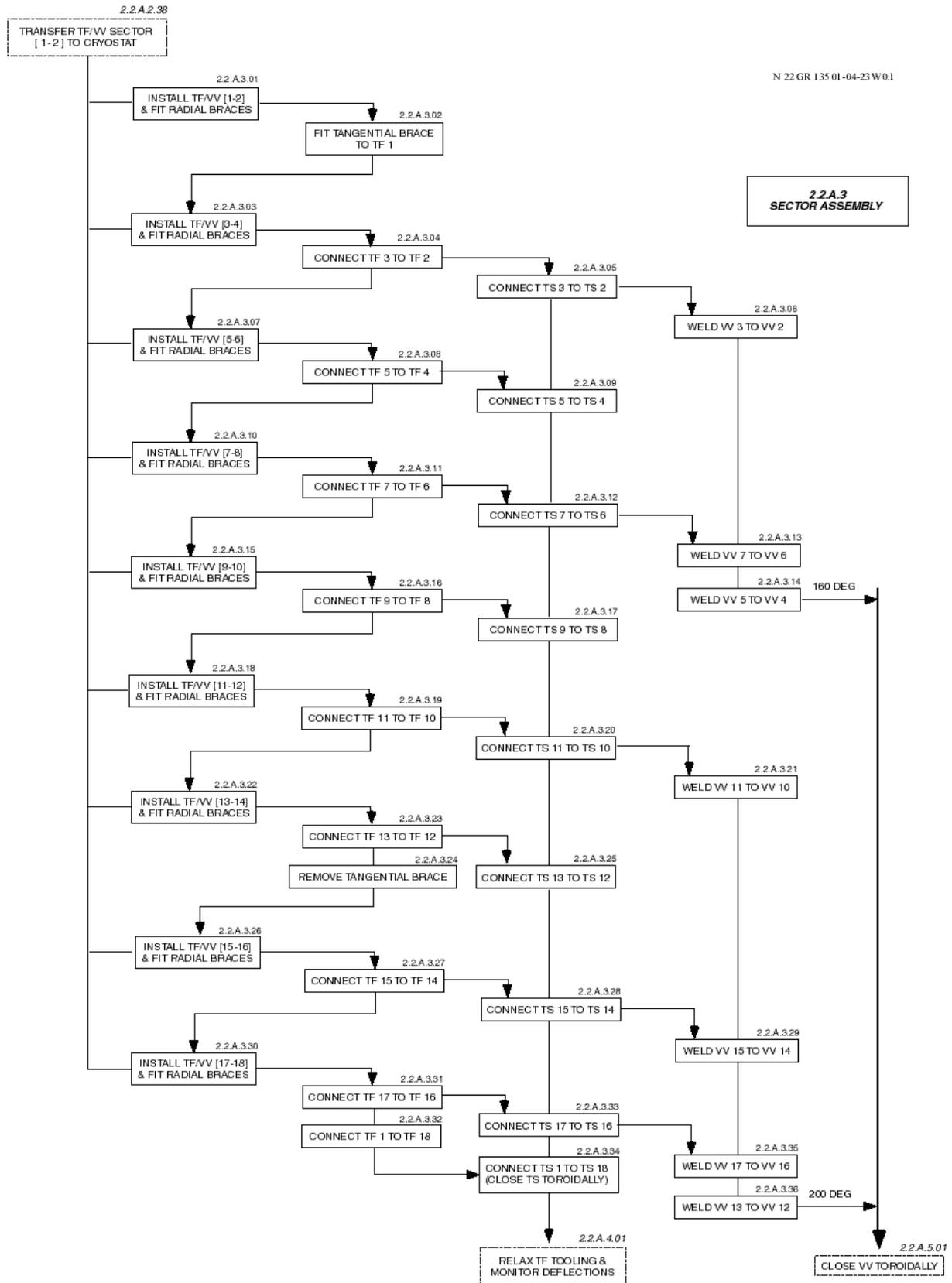


Figure 2.10.4-4 Assembly Sequence – Sector Assembly

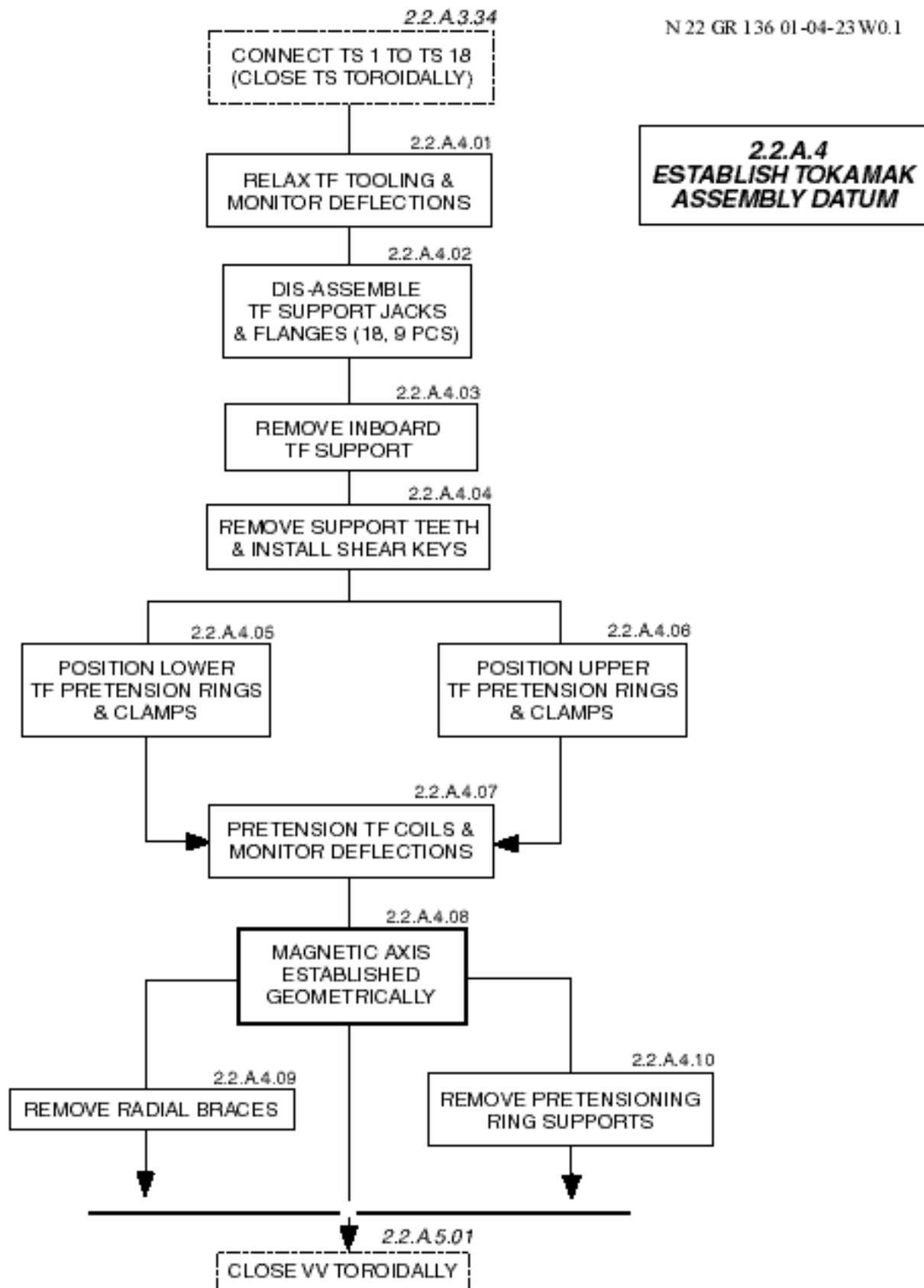


Figure 2.10.4-5 Assembly Sequence – Establish Assembly Datums

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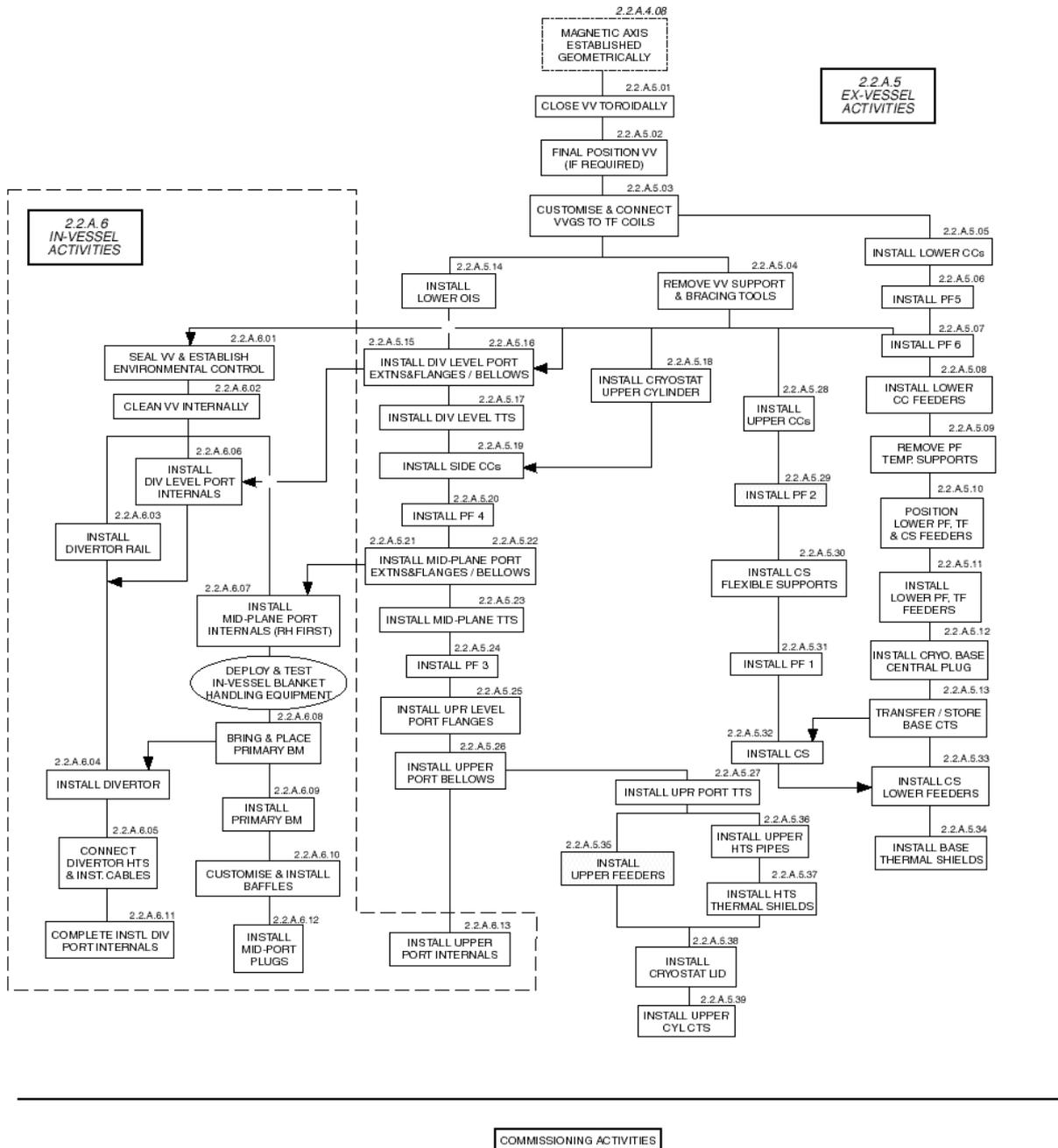


Figure 2.10.4-6 Assembly Sequence – Ex-Vessel & In-Vessel Assembly

2.10.5 Assembly Tools

To complete the assembly operations described in the assembly plan will require a comprehensive package of tools; this will include both purpose-built jigs, fixtures and handling tools, and standard, commercially available equipment. A list of the major tools is provided in Table 2.10.5-1.

2.10.5.1 General Design Principles

Although the assembly tools comprise a diverse range of equipment, with highly different functions, requirements and capacities, a number of common design principles/philosophies have been universally applied to their design:

Accuracy

The positioning tolerances for the major components are typically in the low mm range. The accuracy of the positioning features of the tools have to be compatible with this requirement.

Capacity

Prior to the availability of final design data, the design of the major tools is presently based on 110% of the current component weights, to accommodate possible future design changes and to provide an allowance for any small ancillary tooling, work platforms, etc., which may be attached to the components.

Currently an absolute limit of 1,500 t is imposed on the weight of any single lift, plus rigging, by the capacity of the dual crane lifting system. The limit for single crane lifts is 750 t. To increase operational flexibility, where possible, the combined weight of tooling plus component should not exceed the capacity of the single crane.

Handling

All component parts of the tools, e.g. component support members, access platforms etc., shall be provided with handling features to interface with standard lifting eyes or shackles, to facilitate their lifting with standard equipment.

Materials

Special consideration has to be given to the selection of the materials to be used in the construction of the tools. The most severe requirements are applied to the tools which will be used inside the vacuum vessel, where conditions of cleanliness suitable for ultra high vacuum operation must be established and maintained.

Multi-functionality

The design of single tools with the capability of performing multiple operations, or the use of common elements in different tools, is a potential reducer of the overall cost of the assembly, and this shall be considered in the design of each tool.

Table 2.10.5-1 List of Major Tokamak Assembly Tools

WBS Identifier	Tool	Comments
2.2.B.01	Assembly Control Tools	
2.2.B.01.01	Metrology laboratory	
2.2.B.01.02	Metallurgy laboratory	
2.2.B.01.03	Beryllium analysis laboratory	
2.2.B.01.04	Health physics laboratory	
2.2.B.01.05	Machine shop	
2.2.B.02	Assembly Support Tools	
2.2.B.02.01	Cleaning facilities	
2.2.B.02.02	Cryostat access equipment	
2.2.B.02.03	VV access & control system	
2.2.B.02.04	Be enclosure and environmental control	Blanket Module preparation area
2.2.B.02.05	Clean preparation area	Divertor Cassette preparation area
2.2.B.03	Sector Sub-Assembly Tools	
2.2.B.03.01	Upending Tool	Multiple purpose
2.2.B.03.02	TFC, VV and VVTS Handling Tools	1 each: TF coil horizontal lifting tool; VV sector horizontal lifting tool; TF coil vertical lifting tool; VV sector vertical lifting tool
2.2.B.03.03	Sector sub-assembly tool	
2.2.B.03.04	Sector lifting tool	
2.2.B.03.05	Sector completion tool	Alternatively, 2 nd sub-assembly tool (2.2.B.03.03)
2.2.B.04	TFC, VV and VVTS assy tools	
2.2.B.04.01	TF gravity support assy tools	
2.2.B.04.02	TF coil inner support	
2.2.B.04.03	TF coil bracing tools	
2.2.B.04.04	Guides and positioning jacks for TF coil placement	
2.2.B.04.05	TFC assembly tools	
2.2.B.04.06	VVTS assembly tools	
2.2.B.04.07	VV welding tools	
2.2.B.04.08	VV gravity support survey tool	
2.2.B.04.09	TF coil pretensioning ring installation tools:	
2.2.B.05	Cryostat assembly tools	
2.2.B.05.01	Cryostat survey tools	
2.2.B.05.02	Cryostat installation tools	
2.2.B.05.03	Cryostat welding tools:	

WBS Identifier	Tool	Comments
2.2.B.06	Cryostat thermal shield assembly tools	TBD
2.2.B.07	PF coil assembly tools	
2.2.B.07.01	PF coil handling tools	
2.2.B.07.02	PF coil survey tools	
2.2.B.07.03	PF coil installation tools	
2.2.B.08	Port & piping assembly tools	
2.2.B.08.01	Port handling tools	sets. 1 x upper, 2 x mid-plane & 2 divertor
2.2.B.08.02	Port welding tools:	
2.2.B.08.03	Port bellows installation tools	sets, 1 x upper, 1 x mid-plane, 1 x divertor
2.2.B.08.04	Port pipework installation tools	sets, handling tools (orbital / bore welding tools incl. in standard tools
2.2.B.09	CS assembly tools	
2.2.B.09.01	CS assembly tool	support & access facility installed in assembly hall
2.2.B.09.02	CS lifting tool	incl. interface for independent support from upper TF coil
2.2.B.09.03	CS installation tools	
2.2.B.10	Correction coil & feeder assembly tools	
2.2.B.10.01	Correction coil assembly tools	
2.2.B.10.02	Feeder positioning tools	
2.2.B.11	In-vessel assembly tools	
2.2.B.11.01	Vessel washing equipment	sets
2.2.B.11.02	In-vessel staging	modular on per VV sector basis
2.2.B.11.03	In-vessel component installation tools	
2.2.B.12	Common handling tools	
2.2.B.12.01	Integrated heavy transporter system	Heavy roller system Air bearing system Self-propelled modular transporter system Boom gantry system Gallery transporter system Standardised air pallet system
2.2.B.12.02	Common heavy lifting tools	Dual hoist lifting beam Universal lifting beam
2.2.B.12.03	Standard handling tools:	Temporary crane Flat bed truck Fork lift truck

WBS Identifier	Tool	Comments
2.2.B.13	Standard tools	Welding tools (manual, orbital & bore welders), pipe cutting tools, jacks, assembly hall machining facilities (bed plate & tools), fastening tools (torque wrenches, stud pretensioners, etc.), standard handling tools, hydraulic pressure testing equipment, temporary clean room

Safety/Personnel Access

The design and operation of the machine assembly tools shall conform to good industrial safety practices. In particular, the following specific issues shall be addressed by the design:

- the installation of the components will require personnel to work at significant heights (25 – 30 m) above the effective floor level, i.e. the cryostat base; personnel access to the sectors shall, preferably, be provided via specifically designed platforms, or temporary staging; the use of scaffolding, which could be erected in such a way as to interfere with the safe operation of the tools, is discouraged;
- with a combined mass of ~ 1,400 t, the 40° assembly sectors and their associated lifting equipment, are substantial loads, which require accurate alignment; the design of the tools must allow personnel access to check alignment and/or level during lifting and placement, whilst ensuring that the operations do not necessitate personnel moving or working below the suspended load.

2.10.5.2 Tool Description

Assembly Control and Support (2.2.B.01, 2.2.B.02)

These groups of “tools” include the facilities necessary to control the quality of the work (metrology and metallurgy), and to ensure that the project’s statutory obligations in terms of worker safety (beryllium control, health physics, and occupational safety). It may be cost-effective to sub-contract some of the required services to outside suppliers. This will be investigated following site selection, when the local engineering infrastructure is known.

Also included is an on-site workshop (it may also be possible to contract-out this service), and the specialised access and control equipment required for the VV, cryostat and for the preparation of the beryllium containing components.

Sector Sub-Assembly (2.2.B.03)

The sub-assembly of the 40° assembly sectors is carried out in the assembly hall, with the components in their final, vertical orientation, see Figure 2.10.5-1. This option is preferred over “horizontal” sub-assembly because: for vertical sub-assembly the footprint of the tooling is smaller, and the reduction in the required floor space yields a corresponding reduction in building cost; vertical sub-assembly is less sensitive to component delivery scheduling; the capacity and cost of the upending tool is lower for vertical sub-assembly, without a corresponding increase in the other tooling.

The tooling comprises: an upending tool, which rotates the components to the vertical orientation; a sub-assembly tool, see Fig. 2.10.5-2, which supports the VV, and, via a rotary motion about the “machine axis”, incorporates first the VVTS, and then the TF coils; a completion tool, to which the sector is transferred for the installation of the VVTS port shrouds and VV port stub extensions. To maintain the desired schedule, and minimise overall cost, the completion tool, envisioned originally as a cost effective solution for the sub-assembly operations not requiring the specific functionality of the sub-assembly tool, may be replaced by a second sub-assembly tool.

The sub-assembly tools also include a number of handling tools for lifting the major components in both horizontal and vertical orientations.

Sector Assembly (2.2.B.04)

The principal sector assembly tools comprise an integrated system of supports and braces. These are used to position and align the components, and to stabilise them against lateral loads, such as seismic loads. The layout of the tools is shown in Figure 2.10.5-3.

The most substantial of the assembly tools is the inboard support for the TF coils. This tool, located inboard of the centre of gravity of the sectors, supports approximately 30% of their weight (~ 3,300 t) prior to toroidal completion of the TF magnet. For each TF coil, a radial slot in the support provides the means of registering the coil toroidally, and a system of lateral wedges provides the capability to adjust the toroidal position of the coils. A hydraulic jack installed in the base of each of the slots provides the capability to adjust the height at which each sector is supported independently, and, following completion of the assembly of the TF magnet, to unload the tool for disassembly and removal. A mechanical lock on each jack avoids the need to maintain hydraulic pressure throughout the assembly process, and the jacks are only pressurised to effect adjustment and/or unloading of the system.

During the initial stages of assembly, the coils are also restrained radially via a rigid connection to the support. As more sectors are installed, and connected, the GS of the TF coils become more effective at immobilising the sectors radially and, progressively, this function is shared between the tool and the GS.

The assembly tooling also includes the VV support tools, contained in 2.2.B.03, and a series of upper braces which connect: the outboard regions of the TF coils to the bioshield (radial braces); the top of the first coil to the bioshield (tangential brace); and provide temporary connection between the top of the TF coils of neighbouring sectors prior to connection of the respective intercoil structures (TF-TF braces).

Cryostat and Cryostat Thermal Shield Assembly (2.2.B.05, 2.2.B.06)

The cryostat assembly tools include the installation tools: purpose built fabrication/transport frames, for transporting the large sections from their sub-assembly area to the assembly hall; adapters that interface with the 4 universal lifting beams (2.2.B.12), for lifting the sections into the pit with the overhead cranes; and the support and guides which align the field joints as the sections are installed.

Specialised survey tools will be required to control the interfaces between the cryostat base and support pedestals, and also the interfaces between the cryostat base and the bioshield. The welding tools comprise the clamps which hold the field joints in alignment during the welding operations, the NG-TIG welding machines on which the welding process is based, and a purpose built track to support and guide the welding machines.

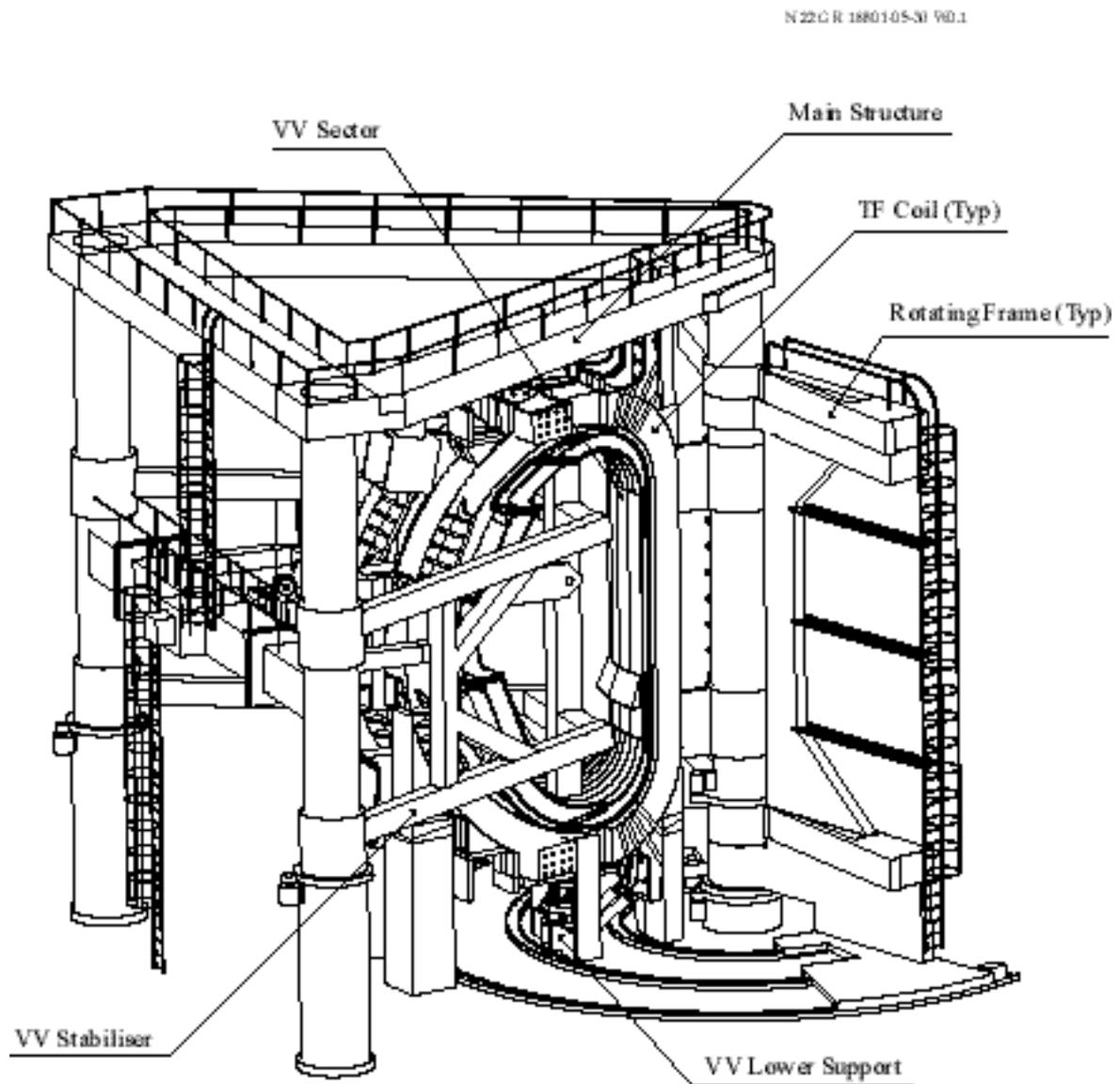


Figure 2.10.5-2 Sector Sub-Assembly Tool (2.2.B.03.03)

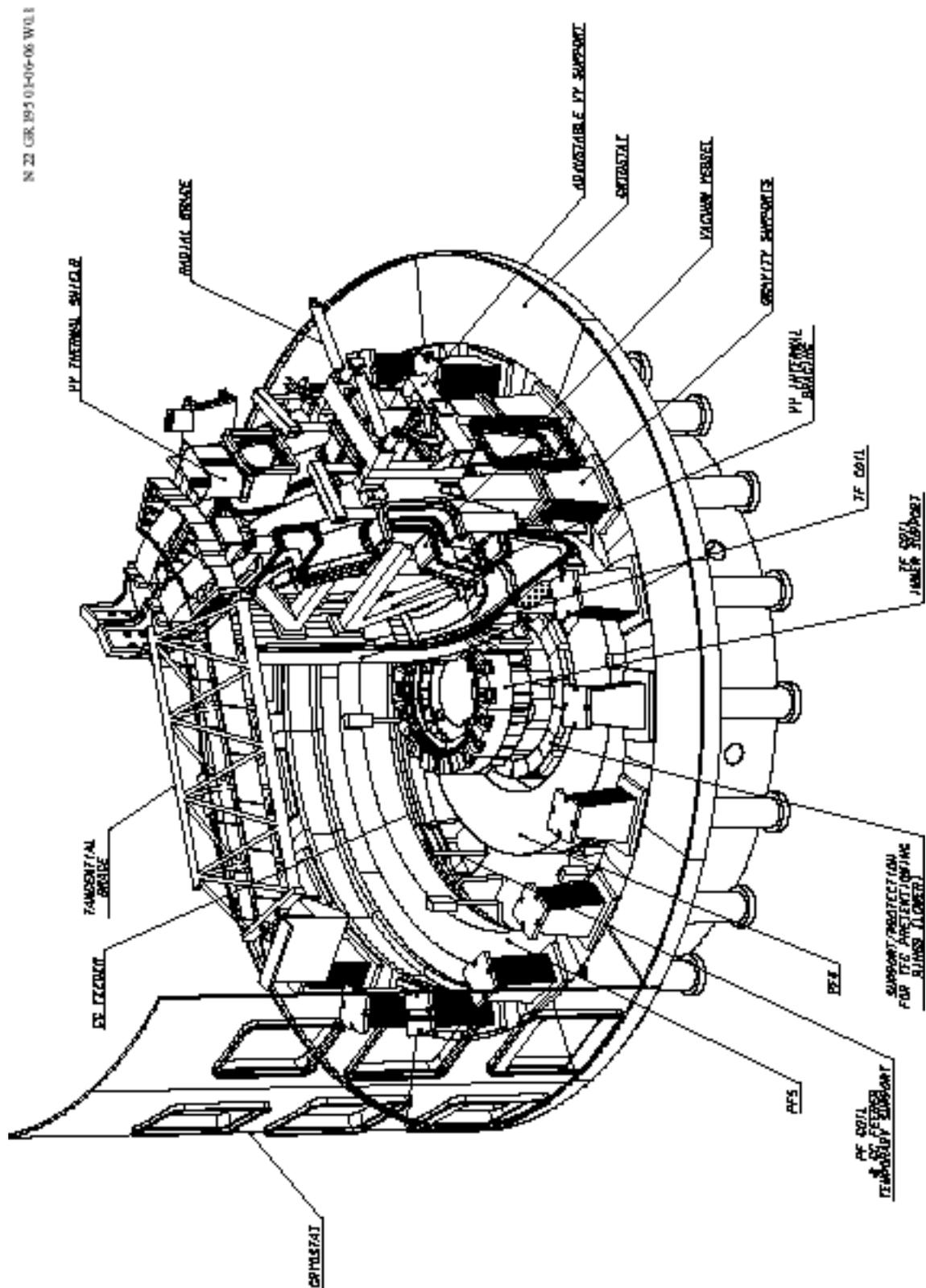


Figure 2.10.5-3 Layout of Assembly Support and Bracing Tools (2.2.B.04)

PF Coil Assembly (2.2.B.07)

This group of tools includes, for each coil: a transportation frame, to support and protect the coil during on-site transit; purpose-built survey tools; lifting adapters to interface with the universal lifting beams (2.2.B.12); and installation tools, mainly temporary, as well as adjustable supports.

In addition, for the two lower trapped coils (PF5 and PF6), an array of support frames are provided to support the coils from the cryostat base, at the minimum height consistent with providing the required “ground” clearance for the coil feeders, for the duration of the sector assembly stage; and a distributed jacking system, to raise the lower coils to their final, installed elevation.

Port and Piping Assembly (2.2.B.08)

The port assembly tools comprise: the handling and positioning equipment necessary to introduce the port through the bioshield and align it with the port stub/stub extension, a machine tool to correct the perimeter of the port stub to provide the correct welding fit-up for port installation (the port handling and positioning equipment will be used to introduce, support and align the machine tool), survey tools for the field joint splice plates, welding clamps; welding rail and NG TIG welding tools, and installation tools for handling and positioning the splice plates.

The piping assembly tools consist of handling fixtures, and standard orbital welding tools.

Central Solenoid Assembly (2.2.B.09)

The principal assembly tool for the CS is a lifting tool with the capability of adjusting the vertical alignment of the coil with high precision. The tools must also interface with the upper region of the TFCs, to provide the required support to the CS during installation, without unnecessarily occupying the overhead cranes, which are heavily utilised for assembly. Survey tools will be required to determine the custom dimensions for the CS flexible supports.

In addition, a support and positioning fixture will be required to facilitate installation of the lower centring device.

Correction Coil and Feeder Assembly (2.2.B.10)

This group of tools comprise, for each design of CC; a handling strongback, to stiffen and protect the coil during handling; survey tools for the CC supports; and welding fixtures to position and support the coil clamps during installation.

In-Vessel Assembly (2.2.B.11)

For the two major in-vessel systems, the blanket and divertor, the approach will be to use the remote handling tools to transport and manipulate the components inside the vessel, possibly operated in a hands-on mode. Also, variants of the remote welding tools, adapted for hands-on operation, may be used if commercially proven alternatives cannot be found for the specialised weld geometries which exist, for example, between the blanket modules and their

co-axial feed pipes. Elsewhere, commercially available equipment will be used for the installation of the in-vessel components.

Common Handling (2.2.B.12)

The common handling tools include the lifting tools required to interface the overhead cranes with various, purpose-built component lifting tools. Presently these comprise: the dual hoist beam - a device with a single, centrally located, slewing attachment with 750 t capacity. This lifting beam, which will be attached to the two hoists of a single crane beam, will be used for lifts in the 375 t to 750 t range, thereby freeing the second overhead crane for increased operational flexibility; a set of 4 universal lifting beams, spreader beams that will be connected to each of the four 375 t crane hooks via a central attachment, and to the component via an attachment at each of their extremities, to provide a low mass, toroidally distributed 8 point lift for the large diameter components, such as the cryostat sections and the PF coils.

The other major handling tool is an integrated system of heavy, surface-based transporters based on a diverse range of technologies. Generally, the large components will be moved between the on-site fabrication/storage areas and the cleaning facility via a customised arrangement of self-propelled modular transporters. These are self-levelling, multi-wheeled, flat bed devices, with the capability of operating in the confined spaces of the compact ITER site, and, if required, on unpaved surfaces. It is anticipated that the self-propelled modular transporters will also be required for delivery operations, leading to heavy utilisation of the units.

Specifically for the cryostat sections, which will be fabricated in an area aligned with the centreline of the building, rail-mounted, heavy roller units will provide an inexpensive and robust solution for transport to the cleaning facility, without imposing unnecessary burdens on the heavily utilised self-propelled modular transporters.

The systems for moving the components inside the clean areas will utilise air pad technology. The purpose-built transport frames for the larger, heavy components, such as the PF coils and cryostat sections will integrate provision for handling with air pads once the cleaning operations have been completed. For the other movements inside the assembly hall and galleries, a standardised range of air pallets will be used.

For loading and unloading components between the various transport systems, where overhead crane capacity is not available, a boom-gantry system is proposed.

In addition, a number of conservatively sized portable cranes, flat bed trucks and fork lift trucks will be required.

Standard Tools (2.2.B.13)

This group includes the standard, commercially available tools required to complete the assembly operations, which are not covered elsewhere in the tooling list. One major item is the assembly hall bedplate and machining centre, which, given the prohibitive cost and logistical difficulties associated with the return of even one of the large components to the supplier for modification or rework, will provide a cost effective, on-site machining capability for the largest of the components.

2.10.6 Assessment and Future Work

The strategies required to assemble the tokamak have been developed, and an overall assembly plan established. The reference assembly plan has been assessed, and the major, critical tools conceptualised, within the scope of design tasks to the Home Teams, and no lack-of-feasibility issues have been identified. The principal aims of the activities foreseen for the period prior to construction are the widening of the scope of the design and planning base to cover all of the tokamak systems and tools, and their elaboration to a greater level of detail than was previously warranted. More specifically:

- for the assembly plan, there remains an uncertainty concerning the dimensional control of the major components in the pit; the assembly plan depends on the assumption that survey techniques and procedures can be developed that will allow the metrology system to function at the limit of its capability under the non-ideal geometrical constraints which exist in the VV and pit, and this remains to be confirmed via a testing program;
- the effort in terms of man hours and schedule for the assembly have been evaluated, but there is room for further optimisation, by means of the development of a resource-loaded schedule - such work would also confirm and optimise the building utilisation;
- although the details of many of the critical assembly procedures have been developed, the scope of this work needs to cover all the major procedures envisaged; the fully detailed procedures for all assembly sequences can be finalised only after the design of the components is fully frozen, and the applicable regulations are known, following site selection;
- the conceptual design of the major tools is well advanced; the scope of the design activities now needs to be extended to include the minor tools; the design of all the tools must be reviewed following site selection, when the applicable codes and standards will be defined, and may be incorporated into the design of the tools.