

6 Plans

6.1	ITER Construction and Commissioning Plan	2
6.1.1	Introduction	2
6.1.2	Initial and Background Conditions	2
6.1.3	Overall and Summary Schedule	2
6.1.4	Construction and Early Procurements	7
6.1.4.1	Procurement Assumptions	7
6.1.4.2	Buildings and Licence to Construct	7
6.1.4.3	Procurement of Long Lead-Time Items	8
6.1.4.3.1	Magnets	8
6.1.4.3.2	Vacuum Vessel and Port Stub Extensions	11
6.1.5	Tokamak Assembly and Plant Installation	11
6.1.5.1	Tokamak Assembly	11
6.1.5.1.1	Tokamak Assembly Plan	11
6.1.5.1.2	Cryostat	11
6.1.5.1.3	Divertor and Blanket Modules	11
6.1.5.1.4	Divertor and Blanket Remote Handling Systems	11
6.1.5.2	Procurement and Installation of Major Sub-Systems	12
6.1.5.2.1	RF H&CD System	12
6.1.5.2.2	NB H&CD System	12
6.1.5.2.3	Cooling Water System	12
6.1.5.2.4	Tritium Plant	13
6.1.6	Commissioning Plan	13
6.1.6.1	Individual Sub-System Test	13
6.1.6.2	Integrated Commissioning up to the First Plasma Discharge	13
6.1.6.2.1	Preparation for Integrated Commissioning	13
6.1.6.2.2	Integrated Commissioning Procedure	14
6.1.6.3	Commissioning after First Plasma	15
6.2	ITER Operation Plan	15
6.2.1	Introduction	15
6.2.2	ITER Plant Operation and Constraints	15
6.2.2.1	General Considerations of ITER Operation	15
6.2.2.2	ITER Tritium Breeding Blanket and DEMO-Relevant Blanket Testing	16
6.2.3	Operation Plan	16
6.2.3.1	Summary of the First Decade of Operation	16
6.2.3.2	Pre-Conditioning Phase for First Plasma	17
6.2.3.3	Hydrogen Phase	17
6.2.3.4	Preparation Phase for DT Operation	20
6.2.3.5	Deuterium Phase	20
6.2.3.6	First Deuterium-Tritium Phase	20
6.2.3.7	Operation after the First 10 Years – Second DT Phase	21
6.2.4	Maintenance	21
6.2.5	Tritium Supply	22
6.3	Decommissioning Plan	22
6.3.1	Introduction and Summary	22
6.3.2	ITER Decommissioning Schedule	23
6.3.3	Overall Schedule	24

This chapter describes the ITER construction, commissioning, operation and decommissioning plan. The corresponding plan for human and financial resources is addressed in the next chapter.

6.1 ITER Construction and Commissioning Plan

6.1.1 Introduction

The planning schedule for supply, construction/assembly and commissioning set out below depends on a number of assumptions detailed in the following. As the design progresses decisions reached by the Parties may confirm or alter the assumptions that have led to the schedule's present status. The actual plan will depend on the licensing procedure, as well as the organization and arrangements that will be put in place for the procurement, construction and commissioning.

6.1.2 Initial and Background Conditions

The construction agreement is expected to be signed at the end of 2002 or the beginning of 2003 following formal negotiations. The ITER legal entity (ILE) will be established after ratification of the agreement within each Party. This organisation will start the formal regulatory procedure and procurement process for the long lead-time items. The regulatory approval process, however, will remain speculative until a site is formally selected. As the site proposals are received before or at a sufficiently early stage of negotiations, it will be possible to assess the time needed for licensing in the various possible host Parties and the effects on the overall schedule. Since the start of the actual construction on the site depends upon when the license to construct is issued by the regulatory authority, dates in the construction and commissioning plan are, therefore, measured in months from a start date ("T = 0") defined as the date at which the actual construction work of excavation for the tokamak buildings is started.

Furthermore, the following assumptions pertain at T = 0.

- Informal dialogue with regulatory authorities should be established and should orientate the technical preparation toward a license application with a view to solving the major technical issues prior to establishment of the ILE. Documents required for the formal regulatory process are assumed to be prepared before the ILE exists, so as to allow the ILE to begin the formal regulatory process immediately after its establishment.
- Procurement specification of equipment/material for the longest lead-time items and critical buildings are assumed to be finalized during the co-ordinated technical activities (CTA).
- Procurement sharing is assumed to be agreed among the Parties during the CTA so as to permit the placing of all contracts at the appropriate time. Particularly the longest lead-time items and the on-site fabrication buildings for magnets which are not related directly licensing issues are procured immediately after the establishment of the ILE and before T = 0.
- The construction site work starts immediately at T = 0. It is assumed that site preparation has been started sufficiently early by the host Party so as not to place constraints on the start of construction.

6.1.3 Overall and Summary Schedule

The overall schedule that leads up to the first hydrogen plasma operation is shown in Figure 6.1.3-1. It represents a reference scenario, which is a success-oriented schedule of

procurement, construction, assembly and commissioning of ITER, based on the assumptions. It is concluded that the construction period is eight years from the start of construction on site (T = 0) to the first hydrogen plasma operation. To meet this schedule, the procurement contracts for the longest lead-time items, particularly the superconducting strands and the TF coils have to be started about 15 months before T = 0. Assuming a reasonable duration for receiving bids, contracting and designing the manufacturing process, the bid cycle must be started 21 ~ 24 months before T = 0 under the ILE. If the license is obtained from the Host Country Regulators within a period of 2 years after the ILE is established (including the case where it will be available immediately after) the overall schedule will be unchanged, saying about ten years from the establishment of the ILE to the first plasma. On the contrary, if it takes longer to obtain the license, the schedule will slip in time by the equivalent amount.

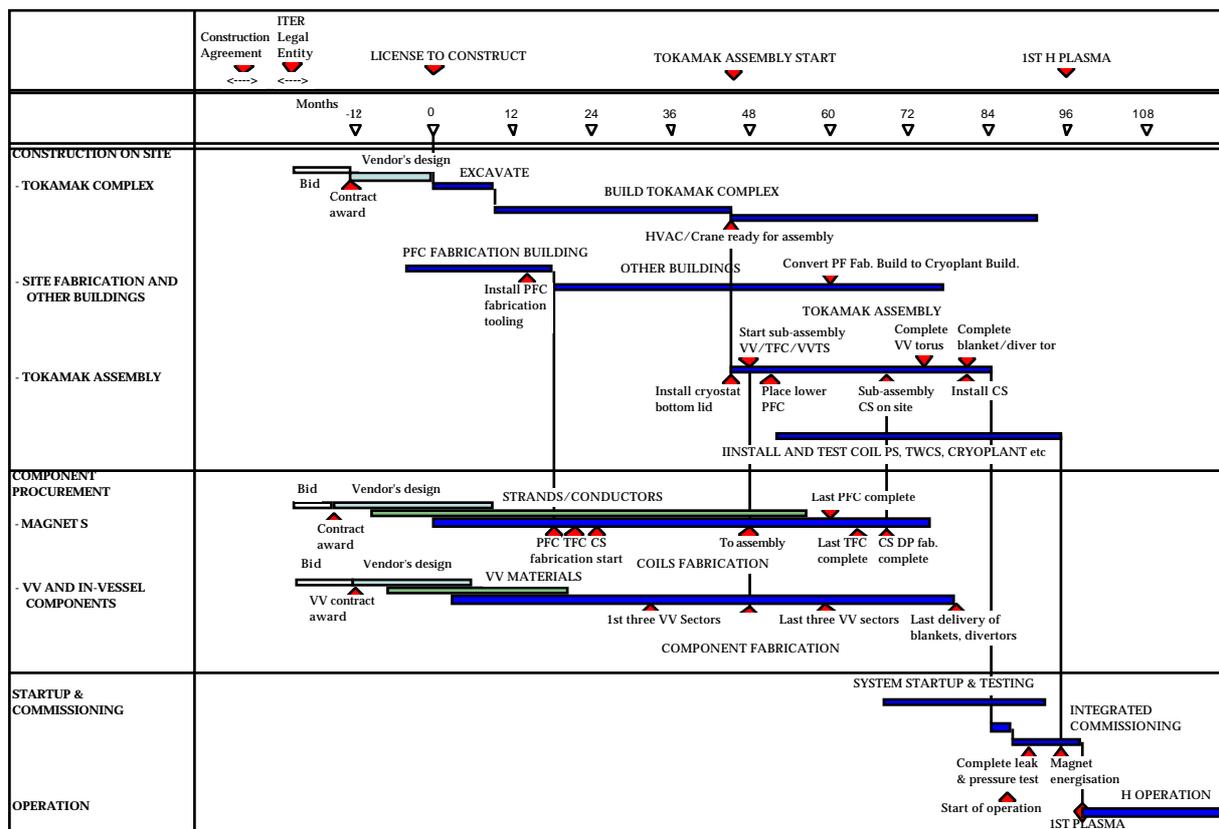


Figure 6.1.3-1 Overall Schedule up to First Plasma

The detailed construction schedule is developed to correspond to each procurement package specified for the cost estimate. The schedule for each package includes procurement specification preparation, bid process, vendor’s design (if appropriate), manufacturing (if appropriate), transport to site (if appropriate), installation and commissioning. The summary level of the construction schedule, which includes, in general, one line per procurement package, is shown in Figure 6.1.3-2.

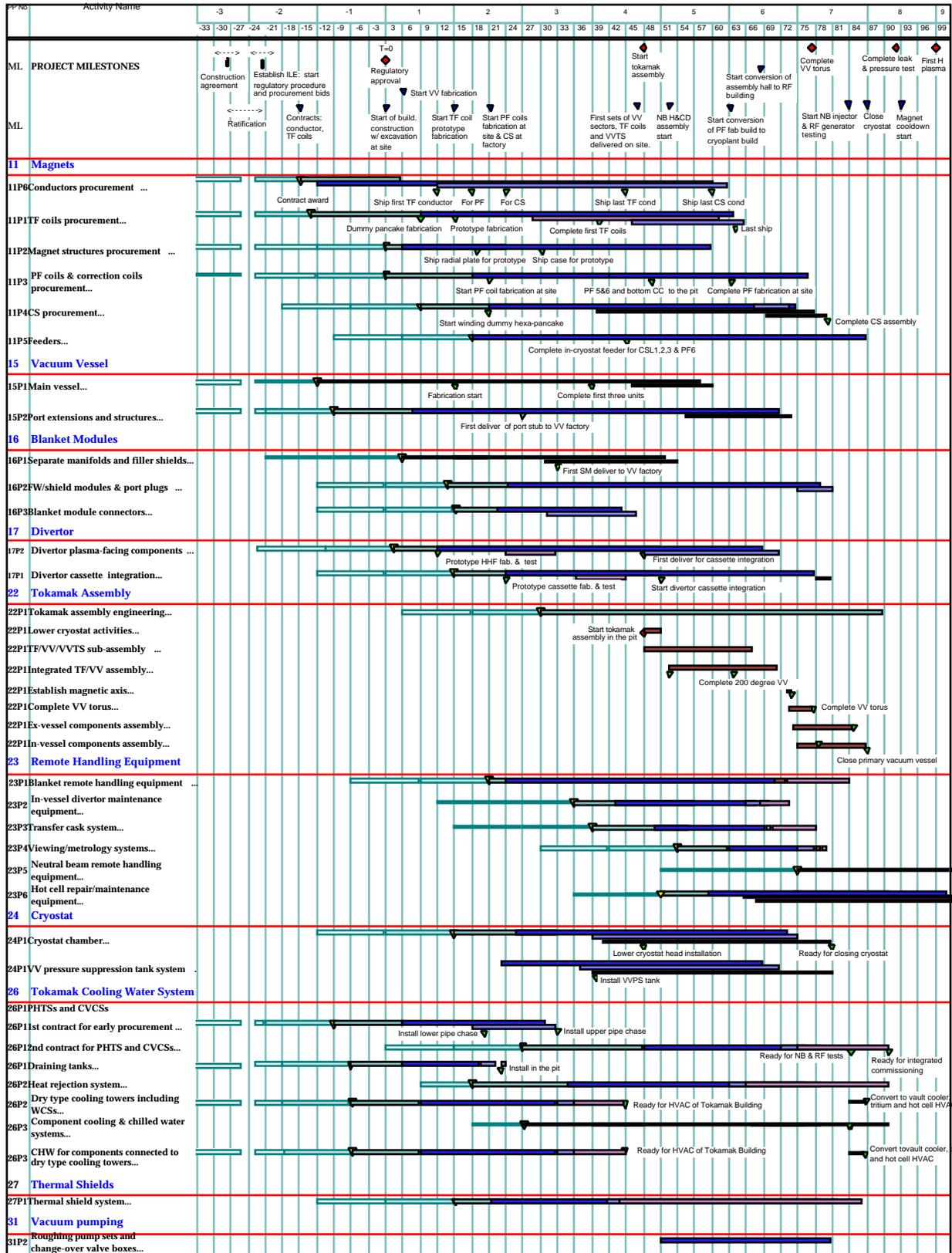


Figure 6.1.3-2

Summary Construction Schedule by Procurement Package

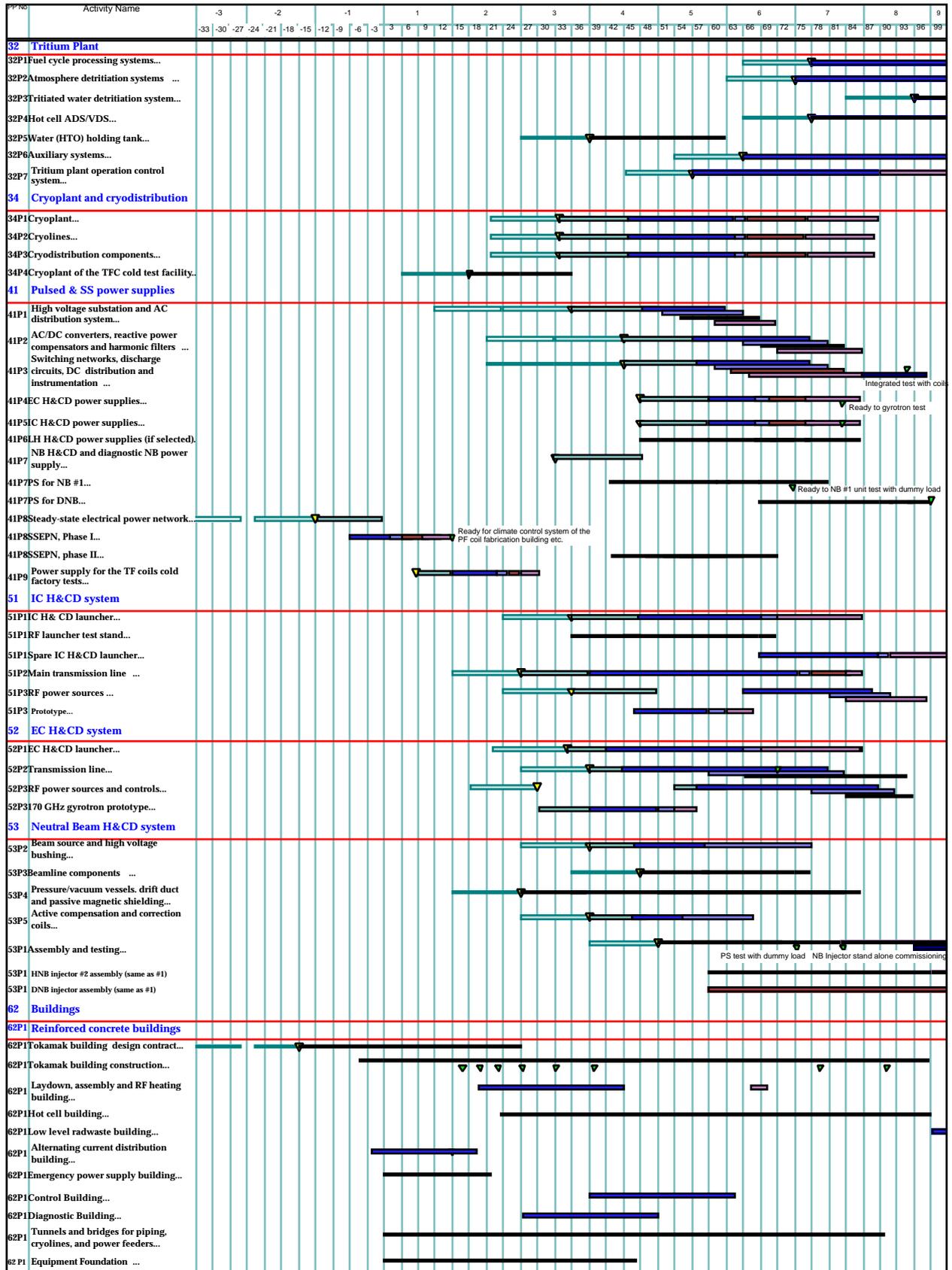


Figure 6.1.3-2 (cont.)

Summary Construction Schedule by Procurement Package

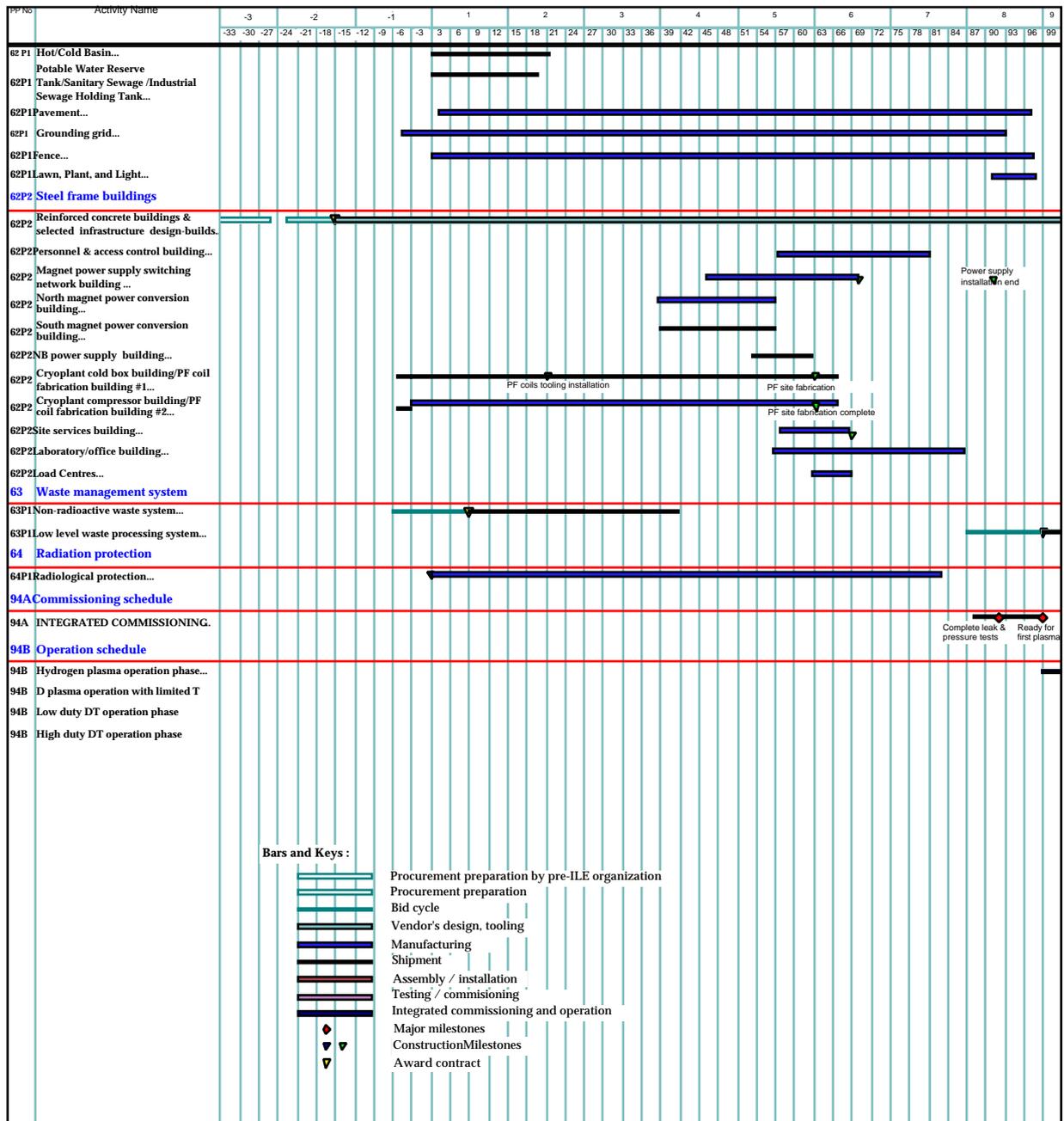


Figure 6.1.3-2 (cont.)

Summary Construction Schedule by Procurement Package

6.1.4 Construction and Early Procurements

6.1.4.1 Procurement Assumptions

The lead-times for the different components of ITER vary widely. Also some items – including the tokamak buildings with parts of water cooling pipes, parts of the cryostat, magnets, and vacuum vessel - are logically on the critical path irrespective of their time schedule, whereas others can be delayed until the date when they would lie on the critical path. In addition, cash flow may pose constraints which conflict with the need to make procurement at a date compatible with the smooth planning of implementation. For the purposes of evolving this schedule, procurement is assumed to occur such that systems/components are delivered just in time, i.e. at the latest time, on the critical path, for assembly and installation/construction, in accordance with the construction logic. In a second evolution of this plan, some items could be moved earlier in the schedule to gain some margins, which would remove those items from the critical path. If cash flow peaks caused by critical items are high, items which is not on the critical path are procured earlier than the just-in-time plan in order to avoid peaky cash flow.

Another important assumption is that the placing of purchase orders is allowed on the establishment of the ILE, in order to allow vendor's design and tooling preparation for the critical lead-time components and buildings. In reality, for non-safety-related items (e.g. magnets), manufacturing can even be started before the granting of a construction licence, provided it is clear one will eventually be granted. For safety-related items, however, construction can start only after the license to construct is issued, if necessary through a second contract. Documentation required for purchasing the various items will be completed in time for the scheduled procurement. The procurement bid process is assumed to take typically six to twelve months from the release of tender documents to industries to the awarding of contracts.

6.1.4.2 Buildings and Licence to Construct

In order to start excavation immediately at $T = 0$, the design of the complex must be complete by then. The contract for the vendor's preparation of the complex, thus, has to be awarded at least twelve to fifteen months before. Considering a period for procurement bid process, the tender documents have to be released by the ILE 21 to 24 months before $T = 0$. If the regulatory licensing procedure is required more than 21 to 24 months at the host country, the start of the Tokamak complex construction is delayed and licensing become critical path. If it takes less than two years, the critical path is not the license and construction of the buildings but the procurement of long lead-time items by the ILE.

Excavation is to be completed within 9 months. Installation of the large pipes of the primary heat transfer system that are installed in the tokamak building below grade will follow after basemat construction. Drain tanks are also installed to the bottom of the tokamak building around month 20. The major part of the tokamak building must be functional, including cranes and HVAC system, by the end of 45 months from $T = 0$ in order to allow the timely start of tokamak assembly. With these assumptions, the large pipe chase, drain tanks and heat rejection system for the HVAC is needed to start procurement before $T=0$.

Two cryoplant buildings are to be built and serve dual purposes, as the PF coils fabrication buildings in the early stage, and cryoplant cold box and compressor buildings later. To maximise the time available for PF coil manufacture and to allow the cryoplant to be used for NB injector stand-alone commissioning and magnet cooldown in time, the construction of these buildings is also started at $T = 0$, or sooner.

6.1.4.3 Procurement of Long Lead-Time Items

6.1.4.3.1 *Magnets*

Magnets are definitely on the critical path if license process does not require more than two years. It is essential to purchase an initial quantity of Nb_3Sn conductor to train the firms for the forthcoming series strand production, and to award the contract for the design of the TF coils manufacturing prior to $T = 0$, as soon as the ILE is established. This should be possible if (1) a sufficient number of contractors in the world have been qualified and trained, (2) the detailed specifications for manufacturing TF coils are fully available by the time of the signing of the construction agreement, and (3) procurement sharing is agreed among the Parties before the signing of the construction agreement. This allows the call for tender to be issued immediately after the establishment of the ILE.

A prototype TF coil is fabricated in order to establish technical basis for the manufacturing process. It will be a spare coil later. In order to meet the pre-assembly of TF coils and vacuum vessel sectors in the assembly hall, the first TF coil at least must be delivered by month 45, and the last one by month 62. Manufacturing time for one TF coil including a cold test of the winding pack is 17 months. Fabricating two TF coils simultaneously after one prototype, the manufacturing time for 19 coils takes 57 months, almost five years in total. Allowing a reasonable duration for establishing the manufacturing process, procuring materials and preparing toolings, the contracts should be awarded at least 12 to 15 months before $T = 0$.

Figure 6.1.4-1 shows the plan of the TF coils and VV sectors procurements linked to the tokamak assembly. The VV11-12 sector is delivered just in time for sub-assembly with the TF11 and TF12 even if the VV procurement started at $T = 0$. The delivery of the last two TF coils, TF17 and TF18 also just coincides with the last sub-assembly of the VV and TF coils with the VV thermal shield.

Most of the PF coils are too large to consider their transfer from the factory to the site (unless both factory and ITER site have deep water access). Thus, fabrication on site is planned. To save cost, the cryoplant buildings are used for fabrication. After the fabrication of all six PF coils, the buildings have to be converted to install cryoplant cold boxes and compressors. In order to meet the plan for the magnets cool-down test at month 91, the conversion of the buildings has to be started at month 61. The fabrication of all six PF coils is required 42 months. Thus, the fabrication of the PF coil at site must start at month 18. Another four to six months are needed for installation and commissioning of the PF coil winding tools. It is concluded that the construction of the PF coils fabrication buildings have to start four months before $T = 0$ at site. The lower PF coils, PF5 and PF6 are easily ready for placement at the bottom of the pit at the beginning of the tokamak assembly starting in month 46 and the other coils are stored until the time of installation.

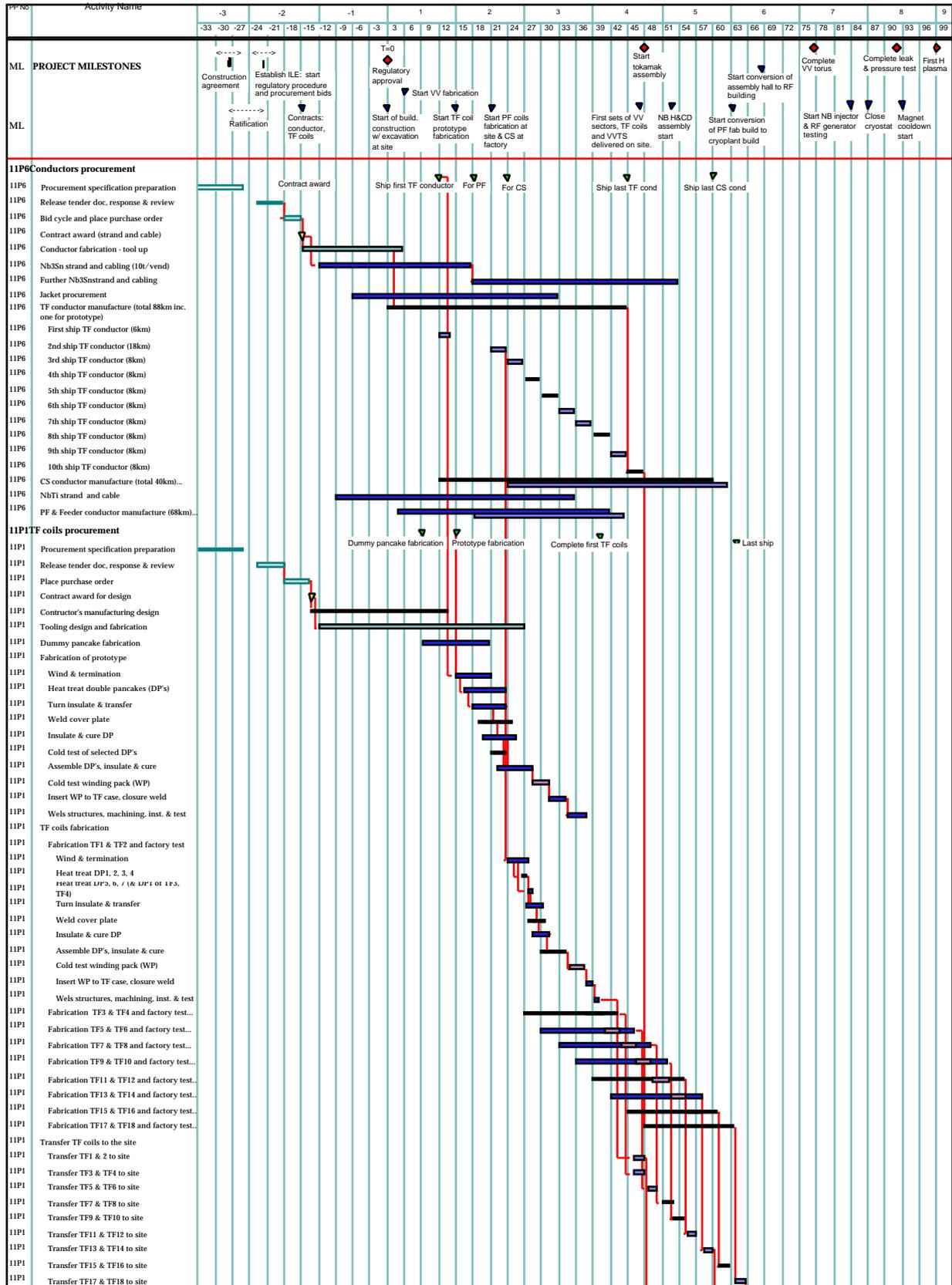


Figure 6.1.4-1

TF Coils and Vacuum Vessel Procurements to meet Assembly

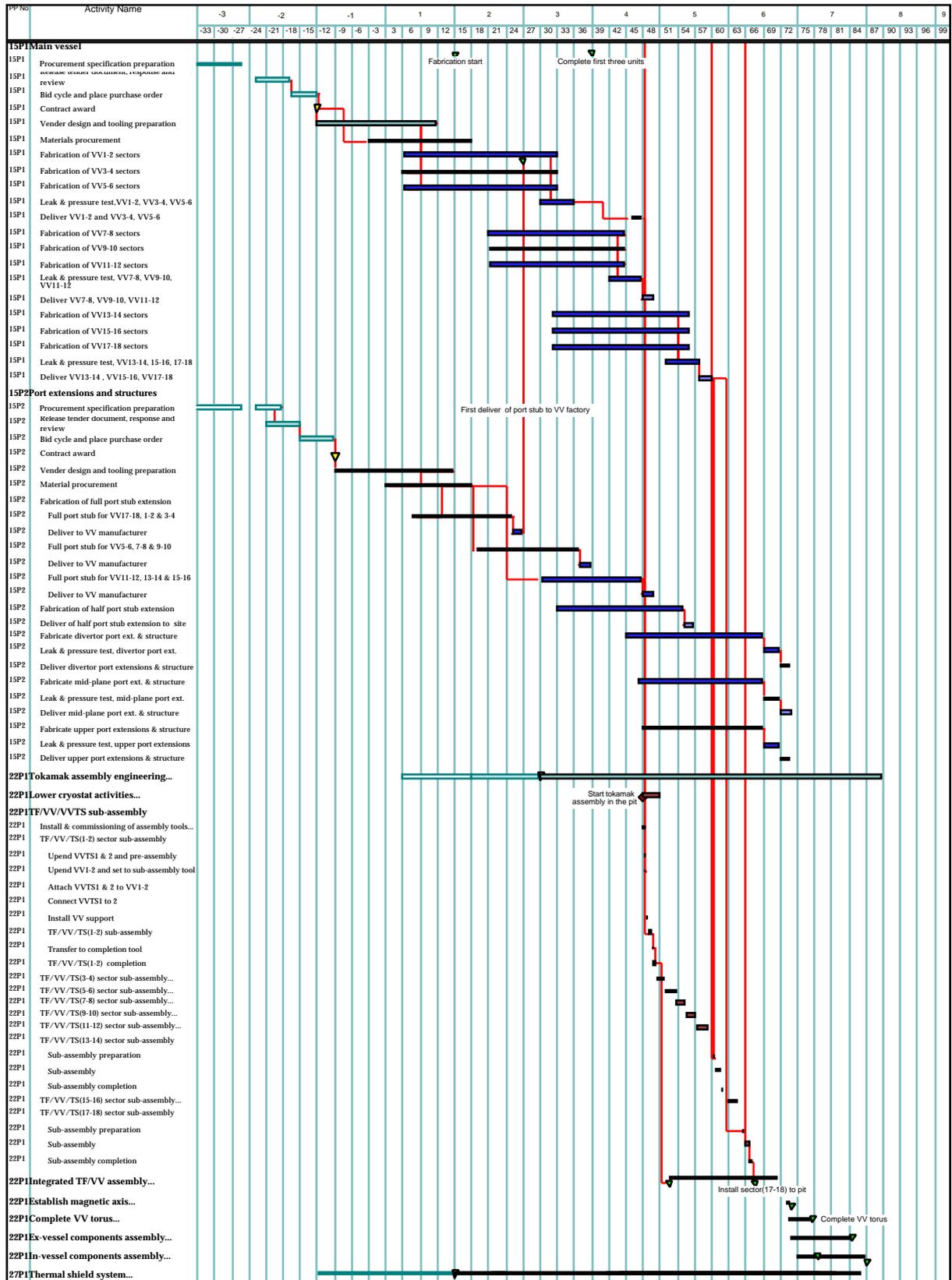


Figure 6.1.4-1 (cont.)

TF Coils and Vacuum Vessel Procurements to meet Assembly

6.1.4.3.2 *Vacuum Vessel and Port Stub Extensions*

Nine (40°) sectors are shipped to the construction site and pre-assembled with the TF coils and vacuum vessel thermal shield (VVTS) in the assembly hall before being installed in the pit. Three VV sectors are simultaneously at different stages of manufacture. The manufacturing time for one sector including the welding of a port stub extension at the factory is 27 months. Another 3 months are taken into account for shipping and inspection for acceptance at the site. The manufacturing time for the 9 sectors is 54 months in total. The last sector should be accepted on site at month 62. Allowing a reasonable duration for establishing the manufacturing process and materials procurement, the contracts must be awarded 12 months before $T = 0$ although the fabrication of the VV sector is started after regulatory approval.

6.1.5 **Tokamak Assembly and Plant Installation**

6.1.5.1 Tokamak Assembly

6.1.5.1.1 *Tokamak Assembly Plan*

The tokamak assembly logic and procedure are described in detail in 2.10. The assembly procedure is grouped in five activities, lower cryostat assembly, TF/VV/VVTS (machine 40° sector) sub-assembly in the assembly hall, integrated TF/VV/VVTS assembly in the pit, in-vessel component assembly after completion of the torus and establishment of the magnetic axis, and ex-vessel component assembly. It takes two and a half years to complete the assembly of the vacuum vessel torus with TF coils and VV thermal shields. About a year is needed to assemble the in-vessel components and ex-vessel components simultaneously after completion of the torus and establishment of the magnetic axis.

6.1.5.1.2 *Cryostat*

The tokamak assembly starts with the installation of the ring pedestal support column and the bottom lid of the cryostat, placed on the basemat of the pit at month 45. The lower cryostat cylinder is then installed. For manufacturing of the bottom lid 12 months are needed at the factory and a further 6 months for construction work on the site before installation. Early procurement is required, namely within nine to twelve months after $T = 0$. The upper cylinder and top lid of the cryostat will be fabricated to match the tokamak assembly process. The completion of the cryostat with the installation of the top lid is at month 84.

6.1.5.1.3 *Divertor and Blanket Modules*

In-vessel components such as the divertor cassettes and shield blanket modules are installed after the completion of the vacuum vessel torus. The procurement of those components is not critical and it is sufficient to award the contracts between month 3 and month 12.

6.1.5.1.4 *Divertor and Blanket Remote Handling Systems*

The full operation of the remote handling system will be required just before D and DT plasma operation. However, the handling equipment without full remote capability will be used for the initial assembly of the divertor cassettes and shield blanket modules. This

equipment should be available before the installation of the divertor cassettes and shield blanket modules.

6.1.5.2 Procurement and Installation of Major Sub-Systems

The installation and assembly of all sub-systems and most of their functional acceptance tests should be completed before the integrated systems commissioning preceding the first plasma. Relevant parts of the CODAC system, to allow individual sub-system testing, must also be ready by then.

6.1.5.2.1 *RF H&CD System*

A prototype of 170 MHz gyrotron is to be fabricated and tested before manufacturing 24 gyrotron units. A prototype RF power source for the IC H&CD system is also expected to be developed before manufacturing 8 units. Performance testing of those prototype power generators has to be started at month 60 or earlier. It is assumed that those tests are performed at off-site facilities. The RF launchers of both IC and EC systems need to have performance tests before installation in the VV ports. A common RF test stand is provided for these performance tests, on site.

RF power sources and power supplies are installed in the laydown, assembly and RF heating building after the sub-assembly of the VV, TF coils and VV thermal shields are completed at month 66. The RF power supplies are installed and tested first. Performance and acceptance tests of the gyrotron and IC power sources are started at month 81.

6.1.5.2.2 *NB H&CD System*

The vessel of the NB injector system is a part of the primary vacuum boundary. It is assumed that the final connection to the primary vacuum is made after a stand-alone commissioning test of the NB injector at month 90.

The NB injectors require about six months for stand-alone commissioning before integrated commissioning. Another six months are required for a power supply test with dummy load before the stand-alone commissioning. The construction schedule of the NB power supplies therefore allows them to be ready at month 72.

6.1.5.2.3 *Cooling Water System*

The tokamak cooling water system is procured and installed in order to meet the first hydraulic test of the VV and in-vessel components at month 91 during integrated commissioning. The construction schedule of the components and chilled water cooling systems is therefore linked to the plan to begin NB injector stand-alone commissioning at month 75. However, It is sufficient to start procurement of the tokamak and component water cooling systems from month 15 to month 24, except for embedded pipework in or between buildings.

The lower pipe chase of the primary heat transfer loops and drain tanks are placed on the basement level of the pit during the construction of the tokamak building and in the surrounding service tunnels. Thus these components have to be procured early as discussed at 6.1.4.2.

The HVAC systems of the tokamak buildings must be ready before the start of tokamak assembly in month 46. It is not necessary to construct the full heat rejection system with wet cooling towers by then just for the ventilation of the building. Instead, the chilled water system can be used for the HVAC system of the building during tokamak assembly etc. The chilled water system must be procured 6 months before $T = 0$ - the cooling tower it needs initially, before the full heat rejection system is ready, could serve as the safety-related HVAC system.

6.1.5.2.4 *Tritium Plant*

Most of the tritium plant facilities are not needed before the start of D and DT operation. The procurement activities are introduced later phase of the construction and installation and commissioning tests are performed through hydrogen plasma operation phase.

6.1.6 **Commissioning Plan**

6.1.6.1 Individual Sub-System Test

Testing of each individual plant subsystem has to start immediately when permitted by their delivery and by the corresponding assembly work. Individual plant subsystem tests will be done by simulating interfaces with other systems or by using dummy loads or bypasses. Links with the CODAC supervisory control system are compulsory at this time. Each individual subsystem must be ready before the next phase of integrated testing with other subsystems. Subsystems, not needed in an early phase will be commissioned in parallel with operation.

The following system tests will be carried out:

- magnet power supply with dummy load (one by one);
- cryoplant and cryodistribution with bypasses (one by one);
- tokamak cooling water system with bypasses;
- vacuum roughing pumps by closing gate valve to the main chamber;
- additional heating, current drive and diagnostics;
- gas fuelling without tritium.

A more complex example is that of the remote handling (RH) equipment. Many RH tools, especially transporters, will be tested on mock-ups during the construction phase. Some complete RH techniques will be used as part of the initial installation either because it is more efficient or for demonstration purposes. Therefore, the major RH equipment will be installed and commissioned before first plasma.

6.1.6.2 Integrated Commissioning up to the First Plasma Discharge

6.1.6.2.1 *Preparation for Integrated Commissioning*

The integrated commissioning is a start of machine operation performed by the operation staffs. There will be the need for adequate testing of controls and interfaces between subsystems. CODAC is designed to permit testing of the complete system in the absence of one or more of the sub-subsystems. Subsystem controllers are designed to provide simulated data for equipment status, alarm monitoring and responses to command. (In reality, it is too

complicated to provide perfectly simulated data and responses in many systems. However, at a minimum, simplified data and responses will be provided.)

At the conclusion of this phase the whole CODAC system is ready.

6.1.6.2.2 *Integrated Commissioning Procedure*

All systems are tested to the extent possible without plasma. This includes the following major items.

(1) Vacuum leak and pressure test

The pumpdown of the cryostat and vacuum vessel for leak tests starts at month 86 with the following test sequence:

- (i) all components will be individually tested at operating pressure (with helium);
- (ii) a global leak test will be conducted with all components pressurized to operating pressure;
- (iii) pressure testing of the vacuum vessel and cryostat will be made, if required;
- (iv) a final global leak test will be conducted with all components pressurized to operating pressure, and VV and cryostat under vacuum.

(2) Hydraulic test and baking

(3) Magnet cooldown

After completion of a global leak test of the cryostat, the cooldown of the magnets can be started at month 91. It takes 40 days to cool down all TF coils, CS, PF and correction coils. Information for optimization of the cooldown procedure is obtained during this testing period.

(4) TF coil energisation

Main testing activities are (1) the energisation of all superconducting coils, (2) operation of fast discharge units and power supply units with coils and (3) AC loss measurements of each coil. These are scheduled to take about four months for the first coil energisation test. Error field measurement and checks of accuracy of alignment of the first wall to the toroidal magnetic field are also performed during this phase.

(5) Pulsing without plasma

Wall conditioning including baking and glow discharge cleaning starts at month 94 and the commissioning of pulsed operation without plasma, including calibration of magnetics, is continued until the first plasma discharge at the end of month 96.

At the end of this phase the following will be achieved:

- readiness of operation of the tokamak machine (e.g., vacuum, baking, sufficiently high toroidal magnetic field (4 T) to match ECH&CD for start-up and discharge cleaning, and more than 50% of coil currents in all PF coils);
- readiness of all subsystems, including the additional heating and current drive system, start-up diagnostics set, and fuelling (except the tritium system), which are needed for H plasma operation. Initial test blanket modules (or blanking plugs) have been installed and commissioned. Some subsystems may be completed later.

6.1.6.3 Commissioning after First Plasma

After the first plasma there will be further integrated commissioning over about four years leading to full operation in DT. The first 2.5 years of operation without DT is defined as a "pre-nuclear commissioning phase" and "nuclear commissioning" (about one year) will be done by using DD discharges with limited amounts of tritium. These commissioning activities are treated as part of the operation plan set out in the next section.

6.2 **ITER Operation Plan**

6.2.1 **Introduction**

Operation is divided into 4 phases: hydrogen phase, deuterium phase with limited tritium use, and two deuterium-tritium plasma phases. As a plasma experimental facility, the operation starts from the first plasma with hydrogen. However, as a nuclear fusion experimental facility, the hydrogen phase is defined as a "pre-nuclear commissioning phase", and the ITER machine will be fully commissioned and operated with the full plasma current and the full heating power with H plasma discharges. Then, after nuclear commissioning by using D plasma discharges with a limited amount of tritium, the full deuterium-tritium operation starts to develop high-Q inductive and fully non-inductive operation and highly reliable operation. Operational modes will be continuously improved and the more reliable operation will be used for the breeding blanket tests. In this section, the operation plan of these phases is summarized.

6.2.2 **ITER Plant Operation and Constraints**

6.2.2.1 General Considerations of ITER Operation

The following principles and assumptions are adopted for ITER operation.

- (1) It is essential that all the individual sub-systems be separately tested to the greatest extent possible before being linked to ITER to minimize the time devoted to integrated commissioning and troubleshooting at the full plant level.

The operation schedule should be as time efficient as possible. Commissioning should proceed as rapidly as possible, but with adequate time devoted to identifying and fixing machine problems. Before starting D operation with a limited use of tritium, all pre-nuclear commissioning should be completed with/without hydrogen plasma with the full engineering parameters except those relating only to DT operation.

- (2) ITER operation will have to be efficient in order to make optimum use of the machine. Methods foreseen for ensuring this include:

- participation of remote experimental sites;
- continuous operation, i.e. 3 shifts - 24 hours/day;
- long operation phases with a relatively long break, e.g. 10 days continuous operation and 1 week break;
- a few months break per year for maintenance, further installation and commissioning.

Very careful planning is essential for ITER operation. The permissible parameters and conditions will have to be authorized in advance and the operation must be within the envelope of the approved conditions. In order to assess the planned operation, a comprehensive simulation code, including both engineering and physics, is essential. It will have to be developed during the construction phase, tested during the commissioning phase and improved during operation. This code will be essential also during operation for real-time or almost real-time analyses and display to understand plasma and machine behaviour and to optimize operation conditions.

6.2.2.2 ITER Tritium Breeding Blanket and DEMO-Relevant Blanket Testing

One of the objectives of ITER is to demonstrate fusion technologies in an integrated system by performing integrated testing of nuclear components required to utilize fusion energy. In the detailed technical objectives, it is stated that "ITER should test design concepts of tritium breeding blankets relevant to a reactor. The tests foreseen on modules include the demonstration of a breeding capability that would lead to tritium self-sufficiency in a reactor, the extraction of high-grade heat, and electricity generation."

ITER has assigned 3 equatorial ports for testing tritium breeding blankets. At present, six tritium-breeding reactor-relevant blanket concepts are planned in the Parties' programme which is intended to achieve the following main objectives:

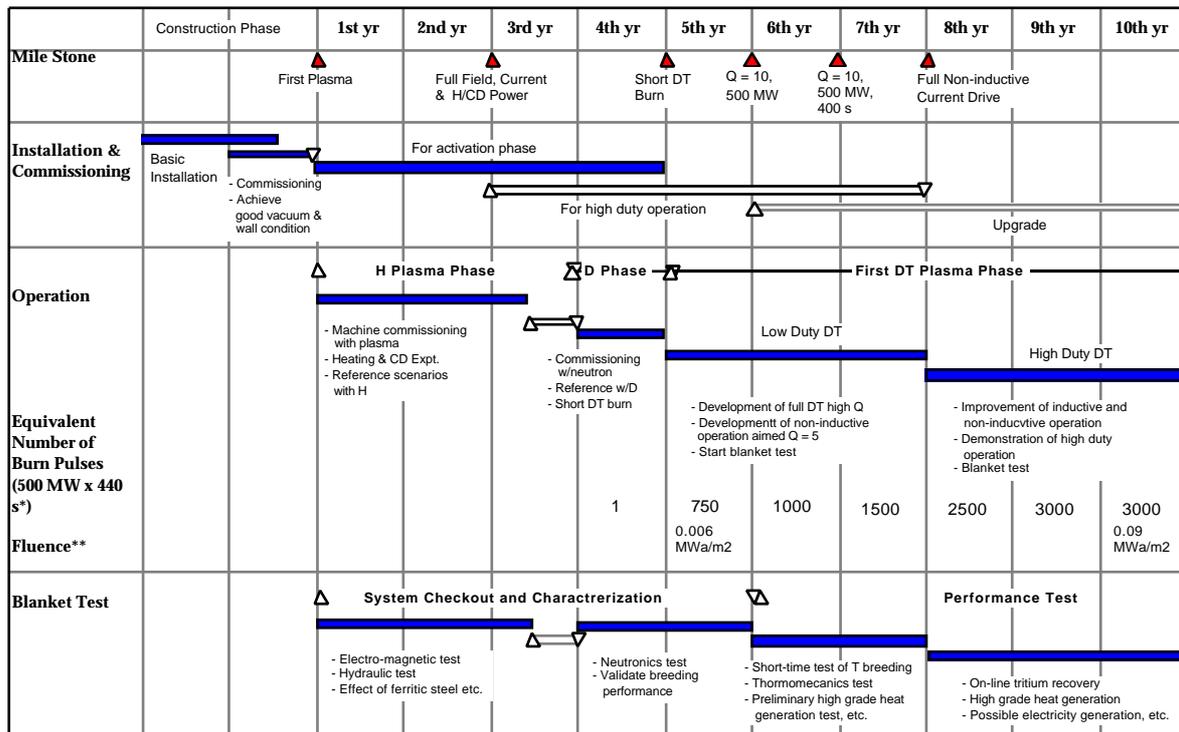
- 1) demonstrate tritium breeding performance and verify the on-line tritium recovery and control systems;
- 2) demonstrate high-grade heat extraction suitable for electricity generation;
- 3) validate and calibrate the design tools and the database used in the blanket design process including neutronics, electromagnetics, heat transfer, and hydraulics;
- 4) demonstrate the integral performance of the blanket systems under different loading conditions;
- 5) observe early irradiation effects on the performance of the blanket modules.

The test program requires installing the test blanket modules early in ITER operation, before the DT operation. The first 10 years testing schedule is shown in Figure 6.2.3-1 featuring the main test items. This test plan will be integrated with the different phases of the physics programme, with emphasis on test campaigns of a few days of repetitive pulses, dedicated to functional blanket tests mostly during the 8th –10th year of operation and beyond.

6.2.3 **Operation Plan**

6.2.3.1 Summary of the First Decade of Operation

The operation phase of ITER begins with a year of integrated commissioning of sub-systems, followed by the first period of machine exploitation, lasting roughly a decade. The plan is shown in Figure 6.2.3-1. About 2.5 years of initial operation in hydrogen, and a 1 year DD phase with limited use of T will be followed by operation with full DT. Various operational modes are envisaged, including initial ohmic and auxiliary heated pulses in H, 400 s high Q pulses, and longer pulses with non-inductive current drive. Although the main emphasis will initially be on studies of the reference scenarios, blanket module testing will also be carried out whenever significant neutron fluxes become available. The operating plan allows for maintenance, further installation and commissioning.



* The burn time of 440 s includes 400 s flat top and equivalent time which additional flux is counted during ramp-up and ramp-down.
 ** Average Fluence at First Wall (Neutron wall load is 0.56 MW/m² in average and 0.77MW/m² at outboard midplane.)

Figure 6.2.3-1 Initial Operation Plan

6.2.3.2 Pre-Conditioning Phase for First Plasma

After about one year of integrated commissioning including vacuum pumping of a few months and discharge cleaning of a few weeks, all of the ITER plant except some subsystems such as the tritium plant, hot cells and radioactive material storage will have been completed and be ready to operate with hydrogen plasmas with conservative coil currents (50%) and low heating power per system available (~ 10 MW) with a short pulse, and with the necessary diagnostics for hydrogen plasmas (see Table 2.6-1).

6.2.3.3 Hydrogen Phase

In this phase, lasting 2.5 years, no fusion reactions occur, and the ITER in-vessel components are not activated and not contaminated by tritium. However, ITER will be commissioned with tokamak discharges with the same electromagnetic characteristics as for D and DT operation.

In this H phase, a reference operational scenario is developed, i.e. plasma current initiation, current ramp-up, formation of divertor configuration, further current ramp-up, plasma density build up and ramp-down. By the end of the H phase, the nominal plasma current will have been achieved at the maximum toroidal magnetic field of 5.3 T at the plasma centre and about 70 MW of external heating power with a flat top duration of about one hundred seconds. The heat flux to the limiter and the peak heat flux to the divertor target will be in the

same range of average values as for the reference operation during the DT-phase. Therefore control of both the main plasma and the divertor plasma can be studied with a detached or partially detached plasma and compared with numerical predictions.

Adequacy of heating power for the L-H transition, P_{L-H} should be confirmed as soon as possible. However, the L to H-mode transition may not be obtained in H plasma operation unless working with a low toroidal magnetic field, low density plasma, and high heating power. In order to use the RF H&CD system applicable for the second harmonic radio frequency, about 50% of the toroidal field would be needed. Due to the high divertor heat load and the high neutral beam shine-through with low density plasma, the operation space will be limited. Nevertheless, extrapolation to full power operation with DT plasma should be possible.

If the energy confinement of hydrogen plasma is as good as predicted by the scaling¹ of IPB98(y,1), the following operation would be possible at about 50% of the maximum toroidal field.

- Operation at high enough normalised beta ($\beta_N \approx 2$) near the Greenwald density limit to test the stability and confinement property for the full DT operation. In this operation, the fusion figure of merit defined by $n T$ will be at least one order of magnitude larger than the values achieved in present day tokamaks with $T_i \sim T_e$ conditions.
- Discharges with similar dimensionless parameter values to the reference DT discharges with the full additional heating power. Under this condition, stabilisation of neoclassical tearing modes and profile controllability can also be studied.
- Various schemes of non-inductive operations at plasma densities compatible with the divertor, with the full current drive heating power. Advanced scenarios will be tested.

However, many tokamak experiments have poorer confinement characteristics of H plasmas than D plasmas, except in JET. Even in JET, H plasmas have lower confinement than D plasmas unless the heating power is much higher than P_{L-H} (more than 30%). Therefore, it is not clear whether these operations are possible or not. If not, only limited studies will be done for the preparation of DT operation. For steady-state operation, only a preliminary experiment will be performed with a small bootstrap current due to the low power achieved in these H plasmas. Only fundamental tests of non-inductive current drive will be carried out.

Concerning transient phenomena, electromagnetic loads due to disruptions or vertical displacement events, and heat loads due to runaway electrons, have the same characteristics as in the DT phase. The confined plasma thermal energy of H plasma is much less than that of a full DT plasma. Thus, the very short pulsed thermal load due to the thermal quench preceding the current quench during disruption is much less than that of a full DT plasma. Therefore, three effects, i.e., the effect of this thermal quench (mainly evaporation of the surface of the divertor target), the effect of neutrons, and the effect of alpha particle plasma heating and material bombardment, can not be tested in this H-phase, but almost all other transient plasma effects can be investigated. This reduces uncertainty significantly and allows optimization of plasma control to prevent and/or mitigate severe disruptions and vertical displacement events (VDEs) in later phases.

¹ ITER Physics Basis, Nucl. Fus. 39, 2137 (1999)

Therefore, in conclusion, the H phase of operation is a useful and necessary step in the preparation for DT operation. Nevertheless, its duration will in fact be a reflection of how good is the confinement with hydrogen. In the case of good results, this phase will probably be extended a further year to explore further confinement studies.

The major steps of hydrogen operation are as follows:

First year

- >10 MA, >100 s (flat top), > 4 T
- Commissioning of divertor, NB (H injection), RF, diagnostics

Remarks

- (a) The most efficient combination of cleaning methods of the first wall and the divertor with EC/IC H&CD will be developed during this period. Good wall conditions will be achieved in the first few months.
- (b) With relatively undemanding plasma operation, e.g. $q_{95} \geq 4$, all plasma control systems, pumping/fuelling systems, the initial set of diagnostics and most of NB/RF heating systems will be tested. On-line analysis and display of results are essential.
- (c) In order to have careful and useful operation, pulse repetition time will be relatively long, typically one hour except for standard pulses for wall-conditioning shots or machine test shots.
- (d) In parallel with plasma discharges, commissioning of the magnet system including AC loss measurements and increase of coil currents will continue.
- (e) Heat load to the limiter is the same as in full DT operations.
- (f) A major aim will be to reduce uncertainties of plasma transient and divertor operation.

Second year

- 15 MA, 100 s, 5.3 T, NB/RF ~70 MW/ 50 s
 - Reference plasma current wave forms with full heating and current drive
 - Medium density ($> (0.7 \times 10^{20} \text{ m}^{-3})$) and clean plasma ($Z_{\text{eff}} \sim 2$) with a detached/partially detached divertor
- Test the mitigation of VDEs and disruptions
- Start of remote experimental sites if required

Remarks

- (a) Demonstrate the full engineering performance of ITER except systems relating to tritium.
- (b) Focuses on reference scenarios at full current.
- (c) Tests the heating power necessary for the L-H transition.
- (d) Electromagnetic loads due to VDEs and disruptions are almost the same as in full DT operations.
- (e) Peak heat flux on the divertor target is almost the same as in full DT operation.

Third year, first period

- Full non-inductive current drive
- Test of stabilization of neoclassical tearing and resistive wall modes, if present

Remarks

- (a) If confinement of H plasma is sufficiently good, plasma operation simulating DT plasmas will be possible at about 50% of the maximum toroidal field.

Third year, second period

This period is reserved for the maintenance of plasma-facing components with possible personnel access, and further installation/commissioning. Removal of hydrogen or replacement of hydrogen by deuterium will also be started by using baking, glow discharges and rf discharge cleaning during commissioning.

6.2.3.4 Preparation Phase for DT Operation

In parallel with the H phase, commissioning of the remote maintenance system, tritium system and other additional systems is to be completed. The final test of safety function such as interlock systems is also carried out. By the end of the phase, ITER is ready to go to the deuterium plasma phase, which in its later stages involves limited tritium use.

6.2.3.5 Deuterium Phase

By using limited amounts of tritium in a deuterium plasma, the integrated ITER system is commissioned, especially with regard to shielding performance, including:

- "nuclear commissioning" of the machine with D(T) plasma, including the check and calibration of nuclear diagnostics, shielding tests and radiation monitoring;
- plasma physics experiments with minority T plasma.

Characteristics of deuterium plasma behavior are expected to be very similar to that of deuterium tritium plasma even if the alpha heating power is much less than the external heating power. Therefore, the reference plasma operational scenario including L to H mode transition, very short burn, demonstration of ELMy H mode for a long period and plasma termination, may be confirmed in this phase. The tritium balance is studied. In this period, no vacuum vent is planned. The major steps are as follows:

DD Experiment with limited T (fourth year)

- Replacement of H by D, clean D plasma
- Reference plasma (full current, heating power, density, detached/partially detached divertor, ELMy H mode)
- Finalize nuclear commissioning with a limited T including confirmation of neutron shield
- Obtain full operating license if required

6.2.3.6 First Deuterium-Tritium Phase

Development of a reference DT scenario will be intensively carried out by optimising and increasing tritium fuelling, the fusion power and burn pulse length. The reference operation with fusion power of ~ 0.5 GW and flat-top duration of ~ 400 s is planned to be achieved within the first two years of this phase. In this process, the key physics issues will be

investigated, and development of a reliable reference operation without severe disruptions and vertical displacement events will be finalized. It is an important issue to develop a long burn operation scenario fitting to high fluence engineering tests and compatible with an appropriate long life time of the high heat flux components. In parallel, additional scenarios will be studied for future operation.

After developing a reliable operation scenario, series of experiments including repeated operation for a few days are planned mainly as an engineering test including tests for the breeding blanket modules.

The major steps are as follows:

DT-1 Experiment (5th - 6th year)

- Burn control with $P_{\text{fus}} = 0.5\text{GW}$ and $t_{\text{burn}} = 400\text{ s}$
- Study of non-inductive operation
- Test of advanced modes
- Beta limit investigation

DT-2 Experiment (7 th year)

- 0.5 GW, 400 s, reliable operation
- Full non-inductive operation with a few hundred MW.
- Fusion power and pulse length increase with advanced modes

DT-3 Experiment (8 th - 10th year)

- High repetition of the reference scenario
 - Development of improved modes
 - Reactor plasma basis
- Achievement of a fluence by the end of the phase of about 0.1 MWa/m^2 on the first wall at the outboard equator.

6.2.3.7 Operation after the First 10 Years – Second DT Phase

A detailed operational plan has not been developed because it will depend on the plasma performance and operating experience obtained during the first ten years. However, it is foreseen that there will be more emphasis on optimization of performance and reliable operation to produce high neutron fluxes and fluences, particularly for blanket testing, using the most promising operational modes developed during the first ten years. Conditions for DEMO operation will be defined, and as much understanding as possible of such operation and hardware performance will be obtained. The total average neutron fluence at the first wall will reach 0.3 MWa/m^2 (0.43 MWa/m^2 at the outboard mid-plane)

6.2.4 **Maintenance**

In the hydrogen plasma phase, 2-3 months will be needed for maintenance and small additional installation and commissioning every half a year. After the H phase, half a year is reserved for maintenance, installation and commissioning. After starting DD operation,

maintenance will be remote. A few months regular maintenance will probably be needed every year.

6.2.5 Tritium Supply

The ITER plant must be operated, taking into account the available tritium externally supplied. A reasonable estimate of the available tritium from Canada, for example, is as follows:

22 kg by 2009 in storage,
1.5 kg/year from 2009.

The net tritium consumption is 0.4 g/plasma pulse at 500 MW burn with a flat top of 400 s. During the first 10 years of ITER operation, the total burn duration at 500 MW is planned to be about 0.15 years. The total consumption during the first 10 years is 4.7 kg. The typical tritium receipt, consumption, and site inventory during the first ten years are given in Table 6.2.5-1. During ITER operation, all tritium will be supplied by external sources.

Table 6.2.5-1 Receipt, Consumption and Site Inventory of Tritium

Year	Receipt (kg)	Consumed (kg)	Site Inventory (kg)
1	0.0	0.0	0.0
2	0.0	0.0	0.0
3	0.1	0.0	0.1
4	0.8	< 0.01	~ 0.9
5	0.8	0.3	~ 1.4
6	0.8	0.4	~ 1.8
7	0.8	0.6	~ 2.0
8	1.0	1.0	~ 2.0
9	1.2	1.2	~ 2.0
10	1.2	1.2	~ 2.0

For commissioning the tritium plant, several tens of grams of tritium will be needed. This will be carried out in parallel with hydrogen plasma operation. A small amount of tritium (< 0.01 g) will be burned during the deuterium plasma operation.

The maximum total tritium transportation per year will be about 1.2 kg/year in the first 10 years. Assuming a 50 g transport tritium container, there will be two shipments every month.

The total net tritium consumption over the plant life will be 16 kg with 500 MW x 0.55 year burn which gives 0.43 MWa/m² at the outboard equator or an average fluence of 0.3 MWa/m² on the first wall. This is well within the available Canadian reserves.

6.3 Decommissioning Plan

6.3.1 Introduction and Summary

It is assumed that the ITER organization at the end of operation will be responsible for starting the machine decommissioning through a de-activation period after which the facility

will be handed over to a new organization inside the ITER host country. It is therefore necessary to provide a feasible and flexible plan for the decommissioning of the ITER machine and associated activated/contaminated components. The plan is based on a rationale of resources and equipment usage optimization, and takes into account the statutory occupational radiological exposure (ORE) limits. The plan provides a framework to help the organisation to decide when and how to implement the ITER facility dismantling, depending on priorities applicable at the time. Flexibility is provided by the use of two separate phases. Each phase duration and activity can be modified (to a certain extent) to accommodate the organisational requirements and constraints.

The proposed decommissioning plan takes into account the impact of essential drivers such as the availability of equipment, facilities, staff, etc., and basic constraints like activation decay time. The proposed plan:

- a) allows the maximisation of the use of existing facilities and equipment while taking advantage of the experience and knowledge of the site personnel and equipment availability at the end of ITER operation;
- b) reduces capital investment required for new equipment and facilities procurement required in the later stages of the decommissioning;
- c) allows the choice between two decommissioning strategies by offering the following options for dismantling of most ex-vessel components:
 - option 1 = early dismantling most ex-vessel components during the de-activation phase;
 - option 2 = postponement of the expenditure required for the dismantling of ex-vessel components until after the decay period.

During the first phase, the machine will be de-activated and cleaned by removing tritium from the in-vessel components and any removable dust. Also, any liquid used in the ITER machine systems will be removed (no component cooling will be further required) and processed to remove activation products prior to their disposal. De-activation will include the removal and safe disposal of all the in-vessel components and, as an option, the ex-vessel components. The main vacuum vessel may be prepared for dismantling by cutting the inner vessel wall. The ITER de-activation will also provide corrosion protection, for components which are vulnerable to corrosion during the storage and dismantling period, if such corrosion would lead to a spread of contamination, or present unacceptable hazards to the public or workers. These activities will be carried out by the ITER organization using the remote handling facilities and staff existing at the end of the project. At the end of phase 1, the ITER facility will be handed over to the organization inside the host country that will be responsible for the subsequent phase of decommissioning after a dormant period for radioactive decay.

The plan does not include the dismantling of the buildings and of the non-activated/contaminated components (except, when applicable, for the ex-vessel components), or the removal of wastes from decommissioning. Outside of the pit, the re-use or scrap value of components is higher than the cost of their dismantling.

6.3.2 ITER Decommissioning Schedule

The proposed decommissioning scenario is broken down into its two main phases as shown in Table 6.3.2-1.

Table 6.3.2-1 Summary of the ITER Decommissioning Plan

PHASE	ACTIVITY	DESCRIPTION	DURATION
1	De-activation	a) Removal of mobilizable* tritium and dust from the machine using available techniques and equipment. Removal and de-activation of coolants. b) Classification and packaging of active, contaminated and toxic material. c) Removal of all the in-vessel components. OPTION 1: removal of ex-vessel components (if not done in phase 2).	~ 5 years
	The ITER facility is handed over to a new organization within the host country, responsible for the completion of the decommissioning		
Radioactivity decay period		a) The vacuum vessel radioactivity is left to decay to a level which allows the extraction of vessel sectors into the tokamak building (during phase 2) for size reduction and removal. b) No site activities are required except security and monitoring.	
PHASE	ACTIVITY	DESCRIPTION	DURATION
2	Final Dismantling and Disposal	a) Removal of vacuum vessel sectors and their size reduction by remote/semi-remote operations. OPTION 2: removal of ex-vessel components (if not done in phase 1) b) Classification and packaging of active, contaminated and toxic material	~ 6 years

* Mobilizable tritium is the tritium removable by the methods envisaged in Phase 1

6.3.3 Overall Schedule

The estimated decommissioning schedule is summarized in Figures 6.3.3-1, 6.3.3-2 and 6.3.3-3.

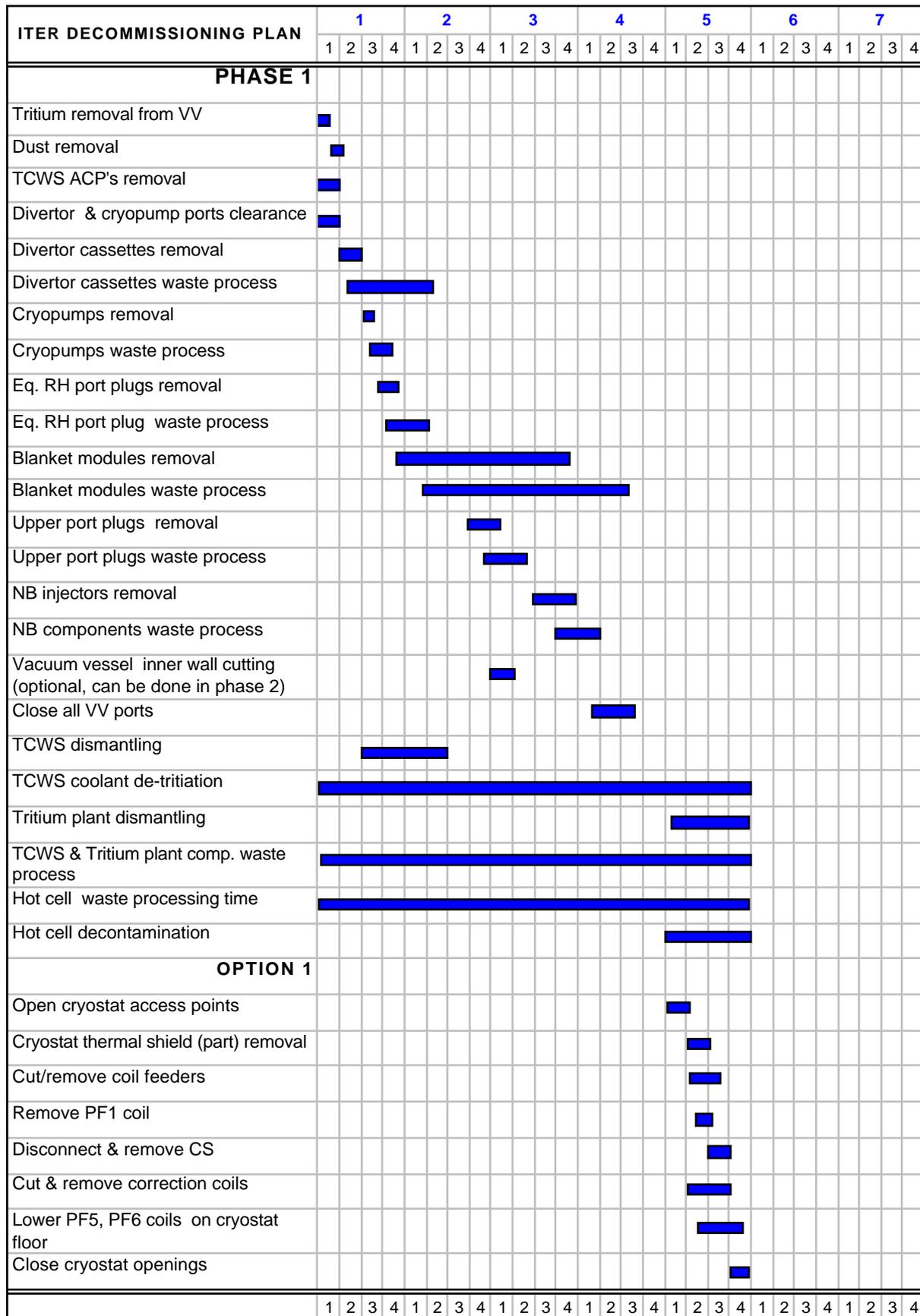


Figure 6.3.3-1

Decommissioning Schedule Phase 1

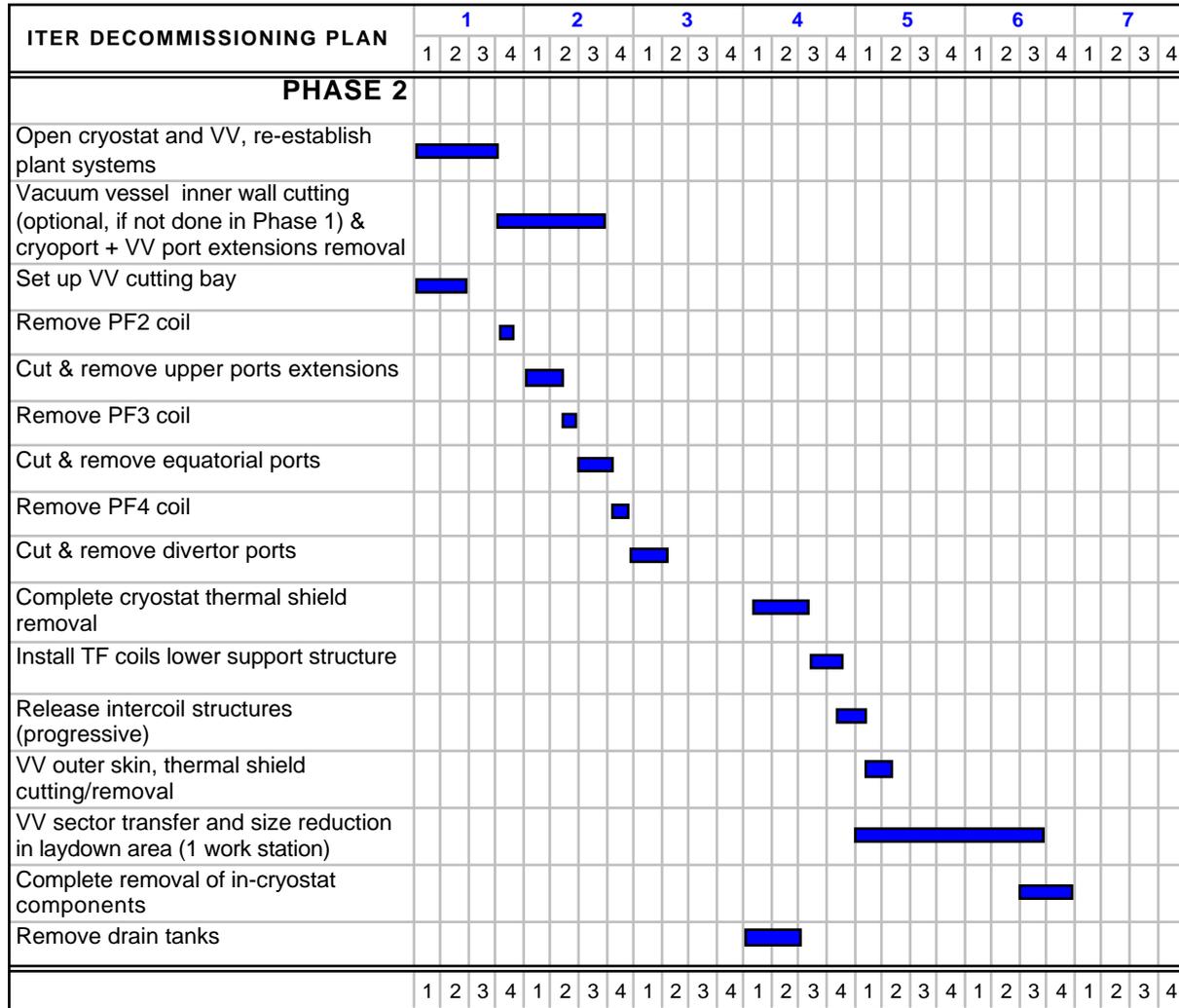


Figure 6.3.3-2 Decommissioning Schedule Phase 2

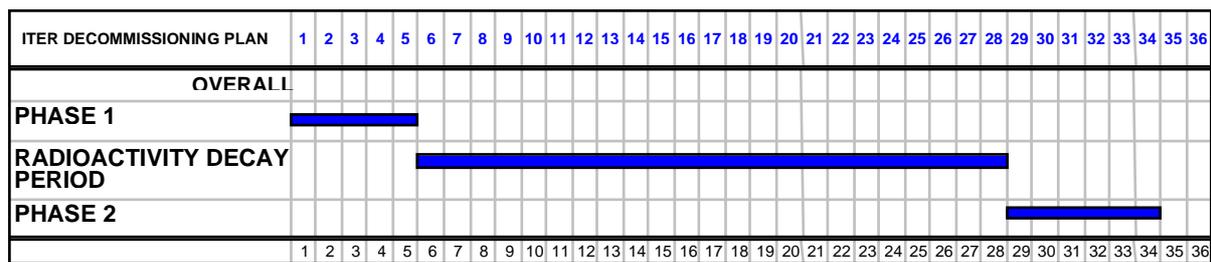


Figure 6.3.3-3 Decommissioning Schedule Overall