Assembly Installation studies for the ITER cryoline system

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Abstract. The ITER cryoline (CL) system consists of a complex network of vacuum insulated multi and single process pipe (PP) lines distributed over three different areas at ITER site. The installation of these CLs in the Tokamak building is a very challenging and highly integrated task due to the presence of many equipment in their vicinity. Dedicated study has been performed to develop the realistic plan and to figure out constraints for complete realization of the CL network. This study includes the concept for assembly and installation of CLs within restricted premises of the Tokamak building, to fulfil the objective of generating technical inputs, defining the processes, construction sequence, tooling, resources and thorough understanding of one of the most challenging network of CLs in present time. The installation sequence for all the CLs inside Tokamak building has also been developed to respect the ITER Construction Master Schedule. The paper describes the ITER CL system, the assembly and installation plan developed considering the layout constraints and complexity arising from the integrated installation in the Tokamak building.

1. Introduction
The purpose of the ITER cryogenic system [1] is to provide the required operational conditions for the magnet system, vacuum system, thermal shield and small users like diagnostics. The CL system [2] is part of overall ITER cryogenic system which has three main subsystems; the cryoplants, the cryodistribution (CD) and the cryolines. The CL system consists of 37 types of vacuum jacketed transfer lines. The CLs form a structured network with a total length of about 5 km spread inside the Tokamak building, on a dedicated plant bridge and in cryoplant building/area. Figure 1 and 2 shows the three-dimensional (3D) schematic layout of the CLs and Warm Lines (WLs) in Cryoplant and Tokamak building respectively. The routing of the CLs is very complex with large number of bends at odd angles, branches and tight positional tolerances due to limited space availability, specifically inside the Tokamak building. The CLs demand very high availability and reliability which is ensured via extensive technical specifications along with stringent design, fabrication, inspection and quality control, safety and regulatory requirements in addition to very demanding loads specification [3]. Table 1 summarizes the brief technical specifications of the ITER CLs and WLs. The conceptual phase of the CLs has been completed and the detailed design is ongoing. The CLs are part of the in-kind supply from India. They are grouped in to two main groups for procurement, project execution and schedule control; X: complex cryolines (from 4 to 7 PP) and Y: relatively simpler cryolines (maximum 3 PP). Each group is further divided in five lots and each lot is composed of several lines.
Figure 1. Schematic layout of the CLs and WLs in Cryoplant building/plant bridge

Figure 2. Schematic layout of the CLs and WLs in Tokamak building

Table 1. Technical specification for ITER CLs and WLs

| Specification/description | ITER CLs                          | ITER WLs                          |
|--------------------------|-----------------------------------|-----------------------------------|
| No. of process pipes (PP)| 1 to 7                             | 1                                 |
| Length                   | ~ 5000 m                           | ~ 6000 m                          |
| No, type of lines        | 21 multi, 16 single process lines  | 55 single process lines           |
| Outer Vacuum Jacket (OVJ)| DN 100 to DN 1000                  | DN 50 to DN 1600                  |
| Element/Spool shape      | Straight, Tee, Elbow, Z            | Straight, Tee, Elbow, Z           |
| Temperature levels       | 4.5 K (3.8 K), 50 K, 80 K, 300 K   | 300 K, 423 K, 473 K               |
| Fluids                   | Helium (He), Nitrogen (N2)         | Helium, Nitrogen, He+N2+Oil       |
| Pressure of process fluid| Maximum 21 bar                     | Maximum 42 bar                    |
| Materials of PP/OVJ      | 1.4306,14435 (304L/316L)           | 304/304L (or eq. EN)              |
| Quality Classes (QC)     | QC 1, QC 2                         | QC 2, QC 3, QC 4                 |
| Seismic Classes (SC)     | SC1 (SF), SC1 (S), SC2, NSC        | SC2, NSC                          |
| Safety Classes           | SIC-II, SR, Non-SIC                | SR, Non-SIC                       |
2. Installation challenges
The installation of the CLs is extremely challenging and highly integrated task due to the tight positional tolerances, limited space availability and minimum repair capability once all the systems are in position, specifically inside the Tokamak building. It demands high level of co-ordination between various installation agencies, quality, safety officers and site construction in-charge. One more challenge is participation of more than one industrial partner for installation of the ITER CLs. There are overall 6 cryogenic contracts to manage during the installation phase. In Tokamak building many sub-systems will be installed, with many contractors, at the same time. The co-ordination, organization and intense collaboration among the various installation teams are of paramount importance for the successful integration at ITER site. Most of the CLs in Tokamak building are Quality Class One (QC 1) components which requires 100% volumetric inspection. Specific inspections and controls will be performed during the installation; this has to be considered in the plan. It is important to maintain the schedule window provided for various installation activities, without much interruption. In order to comply with the specified insulation vacuum pressure, strict cleaning activities and cleanliness control is required during installation. Environment free from dust, particles, metal chips and other debris, no carbon steel construction nearby (cutting, grinding) and stop of building construction activities nearby is foreseen to create vacuum class environment. The site constraints, limitations and dependencies needs to be considered to properly plan the installation.

3. Installation plan
The installation of CLs will start in cryoplant buildings before moving to “B2” level of Tokamak building to “L3” level through two dedicated shafts. Within the Tokamak building the CLs are present at six different levels: L3, L2, L1, B1- B1 port cells, B2M and B2 level. Area by Area installation has been envisaged in each level. Within given area, the activities are divided in to different construction work packages (CWP); each CWP includes installation of one or more lines. Modular approach has been planned for the assembly of the CLs. Each CL will be divided into number of spools/elements for ease of manufacturing, assembly, transport, handling and installation at site. Logistics constraint (container size), building constraints (space availability to enter and move in different levels of Tokamak building including trajectory), less number of site welds, less number of variety (for repeatability in production) and adjustment for last connection with equipment are the major factors considered for the segmentation of the CLs. The maximum length of the spool has been kept about 10 meter. Sequential deliveries have been planned as per installation schedule. Figure 3 shows the major activities to be carried out during the installation phase leading to the final acceptance of the CLs.

3.1. Configuration on arrival at site
Each pre-fabricated and factory accepted spool with rugged packing mechanism will be transported to the ITER site. The maximum and the average weight of the spool will be about 10 tons and about 5 tons respectively. The process pipes and outer jacket will be pressurized during transportation with dry air or nitrogen at about 1.1 bar(a). The pre-fabricated external supports (as much as possible) will also be delivered along with the spools. The process pipes will be delivered with extra length for pipe adjustment during installation. Each spool of the CLs will be delivered with end caps at the extremities and will be identified with appropriate permanent labels containing the unique equipment number as per ITER numbering system. Table 2 summarizes the tentative number of spools per installation area. It is estimated that about 870 spools for the CLs and 1200 spools for WLs will arrive at site in about 300 containers. On arrival spools will be stored at pre-designated storage area and incoming inspection
will be carried out along with documentary evidence as part of the quality assurance. ITER incoming inspections will ensure any visible damage, control of pressure and accelerations during the transport. The activities like unloading the container, approach to storage area and loading from storage for final delivery to site have been planned to suit the site constraints.

![Diagram of site activities]

**Figure 3.** Major site activities during the installation of the CLs

**Table 2.** Summary of the spools for all ITER CLs and WLs

| Building/Area      | Area/level in building | CLs | WLs | Total |
|--------------------|------------------------|-----|-----|-------|
| Tokamak Building   | L3                     | 190 | 280 | 470   |
|                    | NW Shaft (L2, L1, B1)  | 25  | 0   | 25    |
|                    | SW Shaft (L2, L1, B1)  | 15  | 10  | 35    |
|                    | B1 Gallery-B1 port cells | 35 | 0   | 35    |
|                    | B2 / B2M               | 190 | 170 | 360   |
| Plant Bridge       | --                     | 70  | 120 | 190   |
| Cryoplant building | 51 (Compressor building)| 85 | 380 | 465   |
|                    | 52 (Cryoplant building)| 65  | 70  | 135   |
|                    | Area 53                 | 195 | 170 | 365   |
| **Total**          |                        | 870 | 1200| 2070  |

**3.2. Transportation from storage area to installation site**

The trajectory of spools from storage till the final installation location has been studied. The spools will be brought to B2 level of Tokamak building via B2 level of adjacent Tritium Building (B14) via opening 5.3 m height x 7 m length. There will be a temporary platform placed in seismic pit on the east side of Tritium Building to facilitate the entry of equipment. The platform will be 12 m long, 9 m wide and 3.3 m high from the ground. The spools will be brought to the platform using the mobile crane. The spools to B2M will follow the same trajectory till B2 and then will be lifted from B2 and brought to B2M via access opening 3.1 m height x 5.6 m length. The spools will be brought from B2
to B1 via cargo lift (11 m length x 6.9 m width) inside the Tokamak building. For the L3 level, the spools will be brought directly to L3 via adjacent assembly hall. The L1-L3 level will be reached via dedicated ceiling opening between L3 and L4 level. The spools will be lowered from L3 level in to two shafts -NW and SW (Refer Figure 2). The study performed based on current design shows that it is possible for ~10 m spool to rotate, enter through the opening and manoeuvre in B11 galleries to reach the final installation location of the spool in all levels of B11.

3.3. Installation sequence

Upon the satisfactory precondition verification, datum set out and survey of embedded plates, the CLs will be the first equipment to be installed in the galleries and other system follows the installation. The lines will be supported by external supports; individual or shared and part of the support will be installed before the lines. The installation sequence is consolidated based on the sub-system commissioning and the access to the specific area. The layout of CLs and project execution is such that multiple contractors for CLs will be installing the lines at the same time. The integration among the different contractors will have to be done in order to plan the day to day activities. The preferred installation sequence among the CLs in given area is planned with the following general principle;

- From farthest point from the entrance for spools to nearest point
- From top (close to ceiling) to bottom (floor)
- From inner wall (centre of Tokamak) to outer wall (external wall of tokamak building)
- From bigger line to smaller line

As an example [Refer Figure 4], B2 level is divided in 4 main areas (quadrant); A, B, C and D. The spools will be brought to the B2 level via opening E and will follow the ‘material movement’ path to reach the farthest point SW corner. The installation will commence from SW corner via two dedicated path indicated as ‘installation progress’ to complete it near point E. As shown in section S-S, the sequence of installation among the CLs will be as per the principle mentioned above. First the CL designated as 342CTS will be installed followed by 342CPL, 342SQL and the group of four WLs.

Few exceptions will have to be treated at each level as specific constraint where certain part CLs will be installed after other systems and such flexibility needs to be kept during the installation. The site to suit interconnections are planned to have freedom in the last connection with the equipment.

Figure 4. Area division of B2 level in Tokamak building and example of sequence
3.4. Joining of two cryoline spools

The CLs will be assembled by joining two spools by a junction/interconnection. The junction will be standardized to introduce simplicity in design and join variety of combinations of spools. These junctions can be with or without expansion joints. The length of the junction will depend on the DN size of the OVJ (vary from 500 mm to 1000 mm). Both ends of the junction will be designed for successive welding and cutting to facilitate the repair or maintenance of bellows (if required). The outer ring on the OVJ will be designed to meet this requirement. Figure 5 shows how two spools will be joined together on site. The misalignment during installation will be taken care by dedicated adapter piece to be fabricated with actual site measurements.

![Diagram of Joining of two cryoline spools on site](image)

**Figure 5.** Joining of two cryoline spools on site

4. Site work statistics

There are multiple welds in one junction of the CL due to multi process pipe construction. Although, the total length of the CL system is about 5 km, the total enveloped length of the pipes (all internal PP) and outer jacket comes out to be about 18.5 km. The welds performed during installation in the process pipes will be 100% butt-welds with full penetration. Fillet-welds are not accepted in the process pipes. The OVJ interconnections between two spools will be performed by means of fillet welds. The permanent joining of supports and other assemblies to the process pipes and OVJ will also be by fillet welds. It has been estimated that there will be about 7000 welds (process pipes and OVJ together) and about 1300 welds for the CLs and WLs respectively. In addition, about 3000 welds are expected for pre-fabricated external supports. Table 3 summarizes estimated onsite weld length. It has been observed that the weld length is more or less equal for PPs, OVJs and line supports. As described in Table 1, the lines have different quality class and therefore have different inspection/testing requirements. Visual test (VT) is 100%, therefore, entire weld length will undergo VT.

| Building/Area          | CLs + supports | WLs + supports | Total  |
|------------------------|----------------|----------------|--------|
| Tokamak Building       | 3800           | 200            | 4000   |
| Plant Bridge           | 700            | 100            | 800    |
| Cryoplant building/area| 3700           | 500            | 4200   |
| **Total**              | **8200**       | **800**        | **9000** |
Table 4 summarizes the test length for which the Radiography Test (RT) and Leak Test (LT) will have to be performed on site. In addition, thermal shock on sample welds will also be performed.

Table 4. Summary of estimated test length (meter)

| Building/Area          | CLs PP | WLs | Total |
|------------------------|--------|-----|-------|
| Tokamak Building       | 1400   | 150 | 1600  |
| Plant Bridge           | 300    | 50  | 375   |
| Cryo plant building    | 900    | 150 | 1150  |
| **Total**              | 2600   | 350 | **3125** |

5. Tools and resources

Several teams working in parallel at different locations inside the Tokomak building for installation and in temporary workshop for the pre-installation activity has been planned. Each team will involve various disciplines required for the installation of the CLs as per the foreseen site activities. The standard tools for which the movement and the foot prints have been verified for utilization in Tokamak building are summarized in Table 5. The required team structure and necessary standard as well as special designed tools needed for installation of the CLs will be further detailed by the contractors based on their study and site execution plan to suit the site requirements and constraints.

Table 5. Resources and tools for installation

| Type of resources in typical team | Tools |
|----------------------------------|-------|
| Welder - stainless steel         | • Welding machines (manual, orbital) |
| Welder - carbon steel            | • Fork Lift (manual, electric) |
| Rigger, Fitter, Helper           | • Scissor lift table (electric, hydraulic) |
|                                  | • Elevating work platforms |
|                                  | • Portable small crane (‘A’ type, jib) |
|                                  | • Mini spider crane |
| Technician – MLI, NDT – RT, LT, VT, testing, survey | • Hand tools - drills, grinders, wrenches |
| Material handling operators      | • Chain hoist, Wire rope hoist (manual, electric), Scaffoldings |
| Engineer - Technical, Quality, Safety | • Survey related tools and instruments |
| Site in charge                   | • Tools for - thermal shock, radiography, helium leak test |

6. Installation schedule

The installation schedule has been developed based on the top down approach to meet the milestones defined in ITER Construction Master Schedule (CMS). The logic follows delivery schedule, interface availability and sub-system requirements. The installation of the CLs starts once the building(s) is ready to receive the equipment. Reasonable duration for each activity during the installation with the foreseen resources has been estimated and the detailed schedule for one of the CLs is developed. This input has been used mainly to assign the duration required for the installation of certain length of CL with certain number of interconnections to develop the detailed installation schedule for all the CLs. The detailed sequence among the lines (CLs and WLs in each area), the co-activities and the logic for testing of each CL are also part of it. The schedule assumes availability of installation window without any major interruptions, site authorizations are given in reasonable time and 10% rework. It does not consider a complete failure of the lines during the testing phase that follows the site installation. It has been estimated that with one shift with one team, about 26 months and 30 months are needed for lines installation in B2 and L3 level respectively, which are the densest galleries for the CLs. Multiple teams will work in parallel in different areas to meet overall allocated time for a given gallery and if required second shift installations can also be foreseen. The site work will comply with the French legislation and ITER Organization (IO-CT) safety rules concerning occupational health, safety and environmental protection. The contractor will also comply with the Cryogenic Safety Handbook. The first batch of the lines will be delivered in 2016. The on-site installation activities will be performed...
through 2017 to 2021. The performance measurement of the cryopump loop CLs will be carried out
during 2022 in order to be ready for the cryogenic sub-systems commissioning.

7. Risk
Detailed risk analysis [4] for the CL system has been performed and the identified risks along with the
mitigation plan have been included in the project risk register. The risks have been grouped in low,
medium, high based on the likelihood of occurrence and the impact factors. Following are some of the
major risks identified during the installation phase;

- Non-availability or delayed availability of storage area / pre-assembly area at ITER site
- Non-availability of allotted timeslot for material movement/installation of due to co-activity
- Non-availability of allotted timeslot for radiography
- Slow installation at start due to learning curve and site adaptation
- Failure of welding during testing (non-destructive test or pressure test)
- Under estimation and mis-calculation of installation process and duration due to complicacies
- Civil work tolerance and equipment position tolerance more than considered in the design
- Priority change due to the project decisions

8. Conclusion
The conceptual assembly and installation plan respecting the ITER CMS has been developed with
spool movements, construction sequence, tooling and resources. Modular approach has been foreseen
for the installation of the CLs with sequential deliveries and continuous supply chain management to
minimize on site inventory. The site to suit interconnection with equipment is planned and will be
manufactured after dimension and equipment position tolerance check. Parallel installation activities
have been planned and the schedule assumes multiple teams working on sites at different installation
areas. The skilled teams from industries will execute the work as per work instructions, strict
inspection-control and supervision of technical teams from IO-CT and ITER-India. Considering huge
number of interfaces of CLs, complex routing in restricted premises of Tokamak building, the overall
success for installation depends upon efficient co-ordination among all the concerned actors on site.
Further detailed plan for the installation of the CLs will be worked out with industrial partners.

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Disclaimer
The views and opinions expressed herein do not necessarily reflect those of the ITER Organization.

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