

ITER-Cryostat & Vacuum Vessel Pressure Suppression System (VVPSS)

(WBS 2.4):

Main Function of the ITER Cryostat:

- Cryostat volume will be evacuated and maintained at $\leq 1 \times 10^{-6}$ mbar pressure to provide vacuum environment to avoid excessive thermal loads applied to the components operated at cryogenic temperature, such as super conducting magnet system, by gas conduction and convection;
- Cryostat forms a physical envelop surrounding the vacuum vessel, which automatically enhances confinement functions and can be a part of the secondary confinement barrier
- Cryostat allows passive removal of decay heat of vacuum vessel and in-vessel components by gas conduction and convection;
- Cryostat has penetrations for:
 - Equipment connecting elements of systems outside the cryostat to the corresponding elements inside the cryostat (magnet feeders, water cooling pipes, instrumentation feed through, CV pumping systems);
 - Access to VV ports;
 - Access for maintenance equipment into the cryostat;
 - Access to the CS coil for possible direct removal
- Cryostat transfers all the loads, which derive from the tokamak basic machine and the cryostat itself during the normal and off-normal operational regimes and at specified accidental conditions, to the floor of the tokamak pit through its support structures.
- Cryostat includes overpressure protection for itself.

Cryostat configuration:

ITER Cryostat is a fully welded cylindrical vacuum/pressure chamber with top domed shape lid and bottom flat head. The material of construction of cryostat would be stainless steel 304L grade. The overall dimensions of the cryostat is ~29 meter (Diameter) x 28 meter (Height) with a shell thickness ~50/60 millimeter. The ASME Section VIII Division 2 shall be used for design, construction and testing of the cryostat. The expected dimensional accuracy like out of roundness shall be better than $\sim 0.001D$ and offset in field joint between sections shall be $\sim 4-8$ mm.

The main sections of the cryostat as shown in Fig.1 are:

- (A) **Upper Head:** The upper head is a semi tori-spherical dome shaped with ~ 29 m diameter x ~ 3.5 m height with a shell thickness $\sim 50/60$ mm with stiffening ribs. Upper head has provision for the man access as well as removable cover in case of major maintenance.
- (B) **Main cylindrical section:** This is made of two parts of almost equal weight for assembly reasons and its diameter is ~ 29 m and height is 19.56 m. Top end of cylindrical section will be welded with upper head and bottom end will be welded with lower head at site. Typical thickness of these two cylindrical sections would be $\sim 50/60$ mm and is stiffened for external pressure by equally spaced, circumferential and vertical stiffening rings and ribs. The minimum required thickness and distance between stiffening rings have been defined for external pressure in accordance with ASME code section VIII, division 2, article D-3. Because of its minimum intrusion into the inner space of the cryostat, T-section reinforcement profiles with adequate strength margin have been selected.

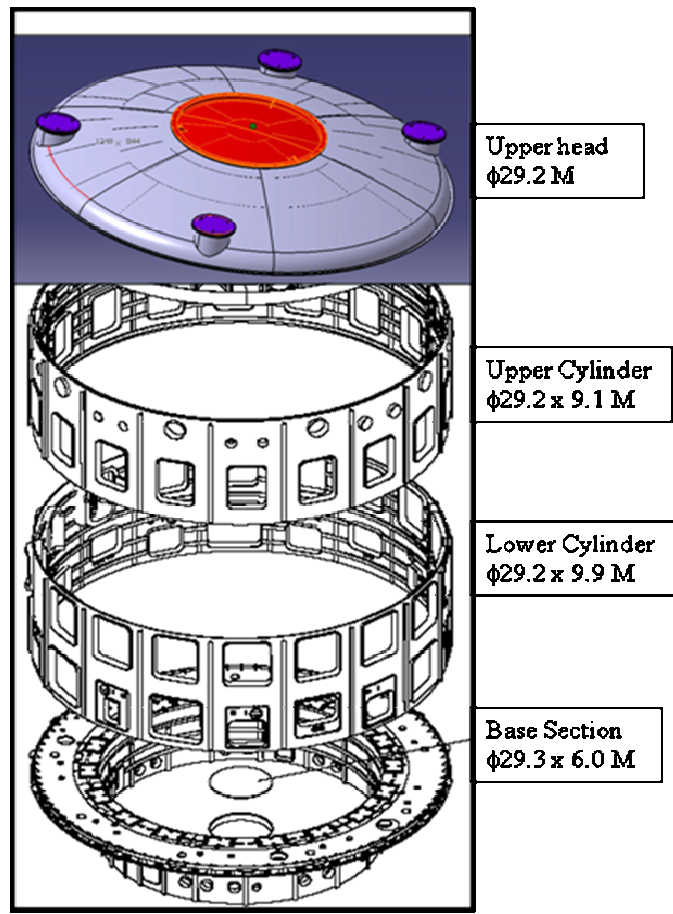


Fig.1 Cryostat Sections

- (C) **Lower head:** This consists of horizontal annular ring, reduced diameter (18 m) cylindrical section and bottom plate. Outer diameter of horizontal ring is ~29 m same as main cylindrical section and inner diameter is 18 m. Horizontal ring at inner bore is connection with the gravity support of ITER and at its outer circumference it is firmly connected with the bio-shield at a position where an external floor slab provides additional lateral stiffness.
- (D) **Penetrations:** There are large numbers of penetrations at different locations on Cryostat walls for (i) access to vacuum vessel port, (ii) water coolant pipes, (iii) cold helium gas for thermal shields, (iv) cryo-fluid (liquid helium) and (v) current feed lines to magnets. Also, there are ports in lower cylinder for horizontal entry and on upper head for vertical entry to carry out manned (or remote) repair and inspection. In the very unlikely case that large components located inside the cryostat need to be replaced. Diameter of circular penetrations varies from 0.1 m diameter to 1.4 m and dimensions of rectangular penetrations varies from 2.1 m \times 1.3 m to 3.8 m \times 2.8 m. In all there are about 400 different types of penetrations on Cryostat and most of them are connected to different components / subsystems at ITER site.
- (E) **Cryostat Ducts and Bellows:** Large ducts (~3m height x ~2m width) interconnect the VV ports with corresponding aligned penetrations in the cryostat vessel. Bellows are integrated in the duct to compensate for differential movements. These bellows have a rectangular shape and are made

of stainless steel 304L grade. Bellows as shown in Fig.2 will provide flexibility during vessel baking and cryostat cooling and other loading events like seismic etc.

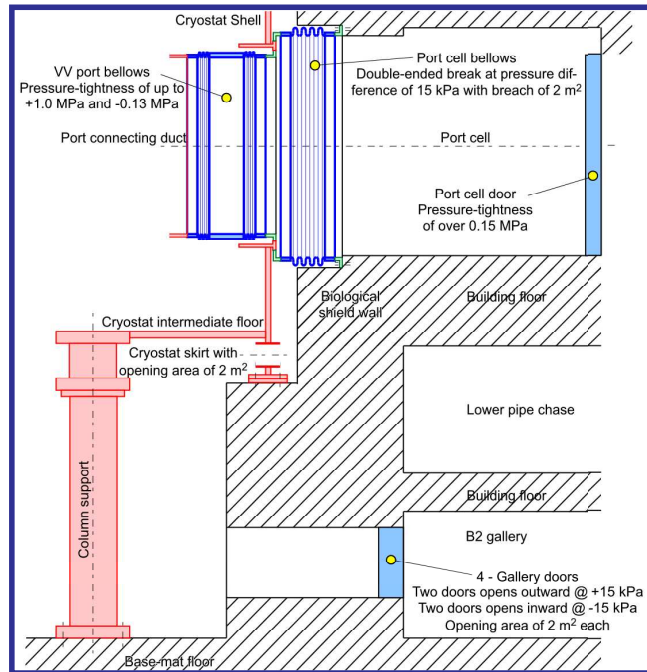


Fig.2 Cryostat port duct & port cell Bellows assembly

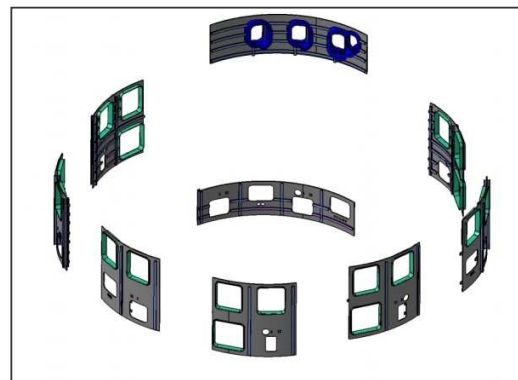
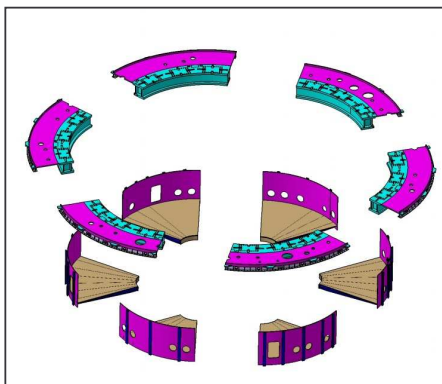
(F) Gravity support: Gravity support for ITER consists of eighteen columns having flexibility in radial direction and no flexibility in vertical as well as toroidal direction. These supports will be bolted with ring pedestal of Cryostat.

Cryostat Loads:

The main design loads considered are external pressure of 0.1 MPa, for normal operation under vacuum, and 0.2 MPa absolute internal pressures, for the conditions assuming the loss of helium and water from coolant lines routed through the cryostat. The load combination with seismic loads and the pressure loads is taken into account for the structural design.

Cryostat Fabrication and Assembly:

Pre-fabricated components (e.g. shown in Fig.3) of Cryostat will be delivered to ITER site and will be pre-assembled (e.g. shown in Fig.4) and tested in site fabrication area of ITER. These pre-assembled modules will be moved to ITER final assembly area. All these components will be thoroughly cleaned before their pre-assembly. Large amount of welding will be required to join these components at site in the ITER assembly hall (e.g. shown in Fig.5).



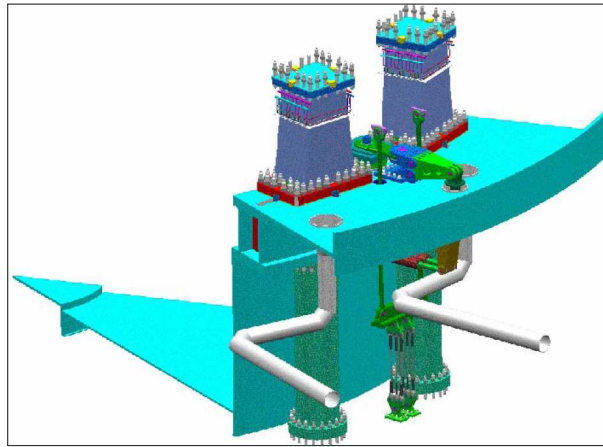


Fig.3 Cryostat Pre-fabricated components

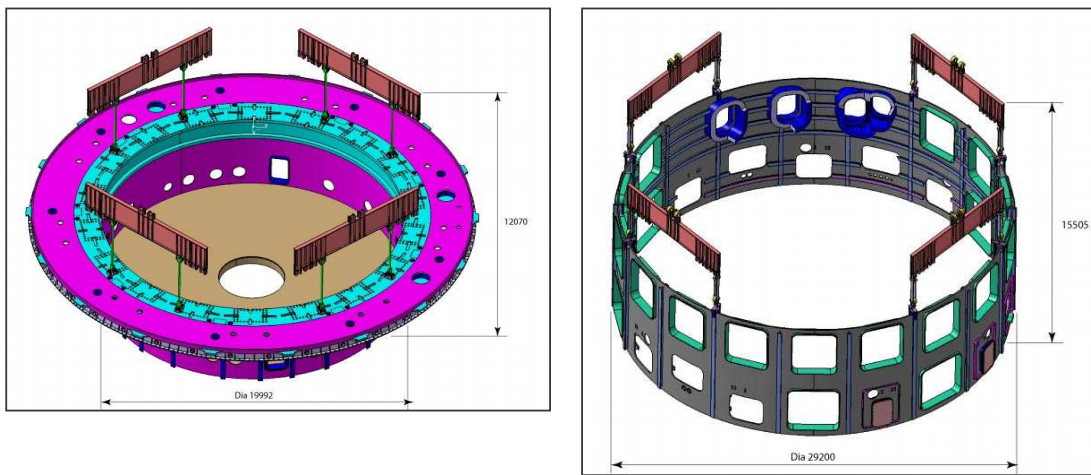


Fig.4 Cryostat Sections Pre-assembled at ITER site

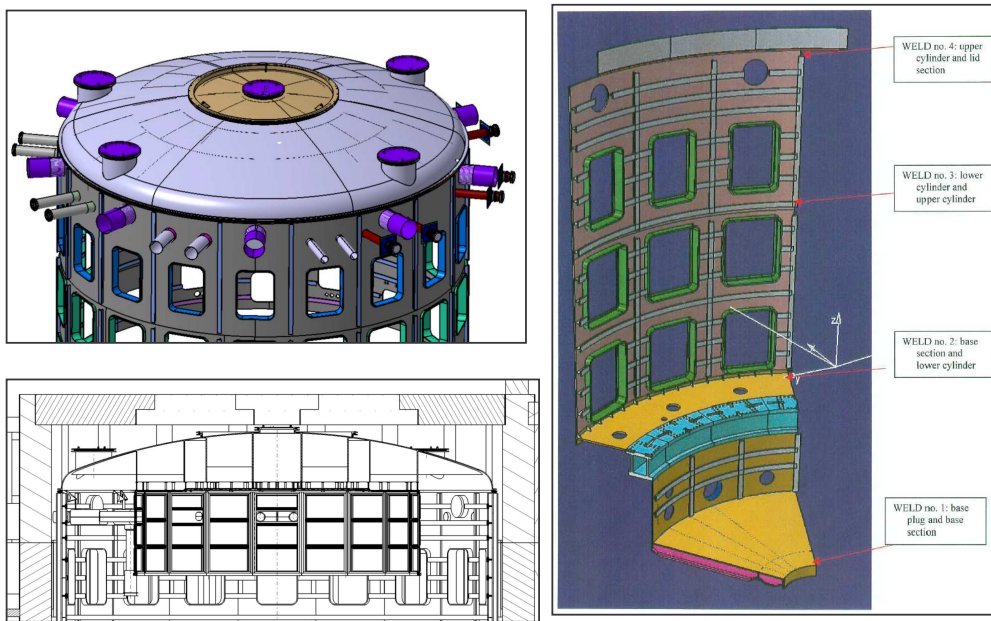


Fig.5 Cryostat Sections Assembly in ITER hall

Cryostat testing:

During assembly the cryostat shall be subjected to an extensive programmed of vacuum and pressure tests to confirm achievement of the design requirements, and to satisfy the construction code requirements (statutory requirements). Local testing of individual assembly field joints and individual components, and integrated global testing of the complete cryostat and VV systems will be required. Cryostat field joint shall be tested by MSLD (Mass spectrometer Leak Detection) method using Helium gas in sniffer mode and allowable leak rate shall be 1×10^{-7} mbar-ltr/sec. Integrated pressure test for the Cryostat also shall be performed by pressurizing the cryostat to ~ 0.23 MPa using GN₂.

ITER-India's Scope of Work:

The major scope of the procurement package is engineering design, manufacturing Design, fabrication, inspection, testing, packing, dispatch, of cryostat, VVPSS & Bellow assemblies at ITER site. It also includes fabrication, inspection, testing of cryostat, bellow assemblies at ITER site and assembly & installation of cryostat, VVPSS and bellow assemblies in ITER tokamak hall. The demonstration of final pressure and leak testing of Cryostat, VVPSS & Bellow assemblies is part of the ITER-India scope.

Cryostat Design & Analysis Activities:

The Cryostat baseline design documents have been studied and critical design issues are understood. Design and analysis work is initiated to optimize cryostat shell thickness and the design change in the top lid structure. The structural analysis of Cryostat & VVPSS tank has been performed using ANSYS FEA software under the different loading conditions and combination like external pressure, gravity load and seismic loads as shown in Fig.6. The preliminary analysis result shows the possible reduction of cryostat wall thickness from the reference design wall thickness with a revised loading condition.

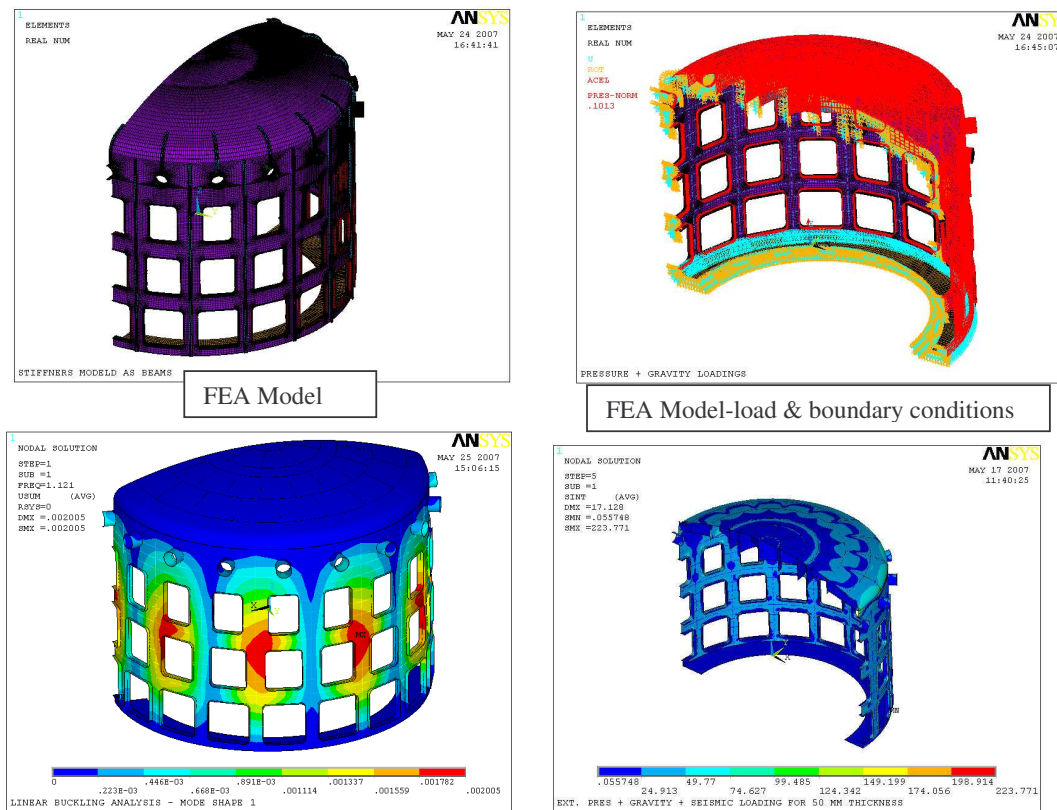


Fig.6 Cryostat Structural Design & Analysis preliminary results

Main Function of the ITER Vacuum Vessel Pressure Suppression System (VVPSS):

The Vacuum Vessel Pressure Suppression System (VVPSS) as shown in Fig: 7 is for overpressure protection to limit the maximum pressure in the Vacuum Vessel (VV) to 0.2 MPa during in-vessel coolant leak events. This also functions to maintain the VV long-term pressure below atmospheric pressure during air or incondensable gases ingress. This is a safety function as a large internal pressure could lead to a breach of the primary radioactivity confinement barrier.

Typical Design Parameters for VVPSS

	Parameter
Overall Diameter	6m
Length	46m
Structural Material ⁽¹⁾	ASME SA-516 Gr.55
Operating Pressure	Vacuum (< 4.2 kPa)
Design Pressure	0.2 MPa
Typical shell thickness	30 mm
Initial max Water temperature	30 C
Initial water mass	~675 t
Tank volume	~1200 m ³

VVPSS Operation:

During an in-vessel coolant leak the VVPSS acts in concert with the safety drainage system. Steam produced in the VV flows to the suppression tank where it is condensed. The safety drainage system is brought into play automatically by the opening of the valves, which are part of the cooling water system. The drain valves timely opened after the break prevent additional steam generation and long term VV pressurization due to heat accumulation from the in-vessel components.

Vacuum Vessel Pressure Suppression System (VVPSS):

ITER VVPSS consists of (i) Pressure suppression tank, (ii) Distributor, (iii) Relief pipes, (iv) Rupture disc, (v) Bleed line, (vi) Guard vacuum system and (vii) Support structure. VVPSS consists of a large linear tank (as shown in Fig.8) of 46 m length and a circular cross section of 6 m diameter, containing 1200 m³ room temperature water to condense the steam resulting from the most adverse in-vessel coolant leak. The VVPSS tank is designed for 0.2 MPa and constructed in ferrite steel. The tank is connected to the vacuum vessel through three main relief pipes, each pipe incorporating double rupture disc assemblies. Rupture disc acts as vacuum boundary between the vacuum vessel and the room temperature suppression water during normal operation. Total relief pipe area requirement is 1.0 m², in order to maintain vacuum vessel pressure below 0.2 MPa during failure mode. In the design, this flow area is provided by two of the relief pipes, the third being redundant. The VVPSS also includes a bypass system for the rupture discs and other instrumentations. During an in-vessel coolant leak the VVPSS acts in concert with the vacuum vessel drainage system, which facilitates timely drainage of water from the vacuum vessel to limit the amount of steam that the suppression tank has to condense. The vacuum vessel drainage system is brought into play

automatically by the opening of rupture discs in the VV drainage lines, for a large coolant leak, and by opening of drainage valves for a small one. These drainage rupture discs and valves are part of the VVPSS. The VVPSS is connected to the radioactive gaseous processing system, the low level waste processing system, the liquid and gas distribution system and the leak detection system.

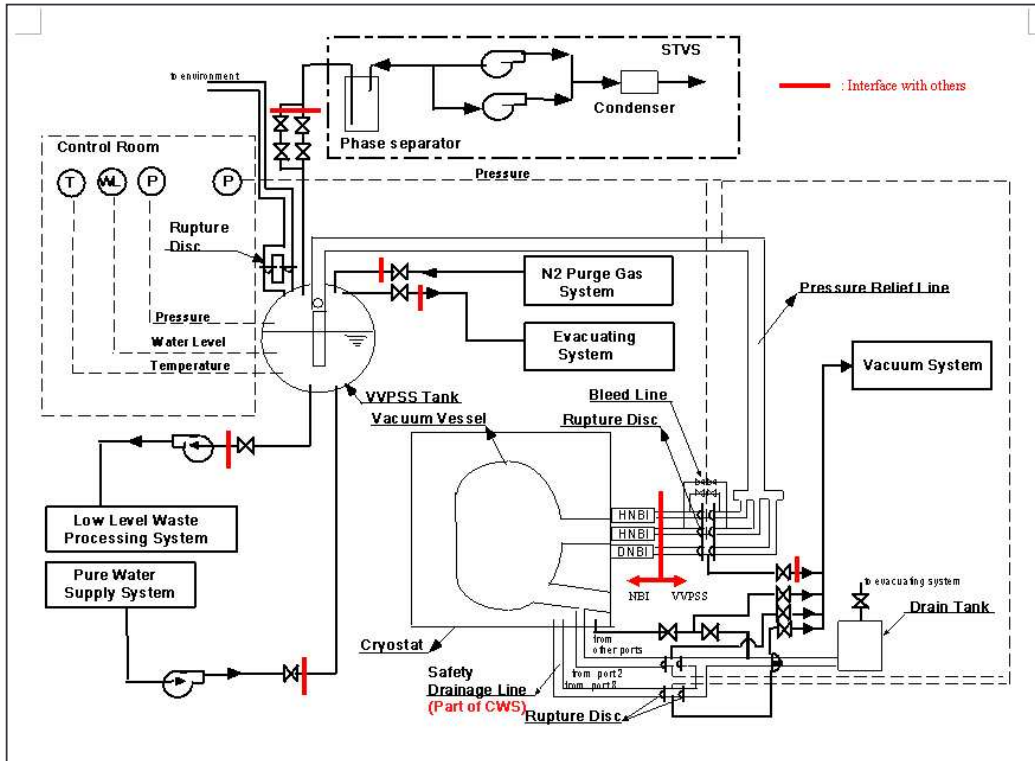


Fig. 7 VVPSS SCHEMATIC (Boundary of IN-PT procurement limits)

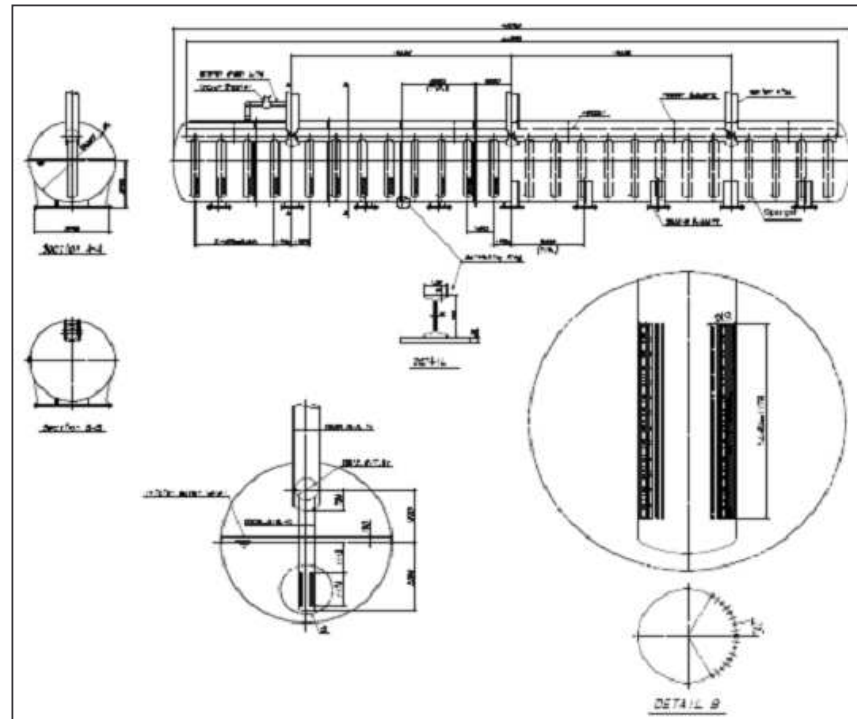


Fig: 8 VVPSS TANK