SAPIENZA
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Final Design of the Safety-relevant Chilled Water System (CHWS-1) of ITER Plant

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Abstract

The PhD activity, discussed in this document, was conducted between 2018 and 2021 in a collaboration between DIAEE of Sapienza University of Rome and the ITER Organization.

The purpose of this work is to develop the Final Design of the Safety-relevant Chilled Water System (CHWS-1) of ITER plant. In particular, the study will be oriented towards the thermal-hydraulic design in connection with its safety functional analysis.

Chilled Water System (CHWS-1) is an ITER safety cooling system comprised of two independent and segregated trains (CHWS-1A and CHWS-1B), which provide cooling water to components located in Tokamak and Hot Cell Complexes.

It is a Safety Important System which operation is needed for the proper functioning of Protection/Safety Important Activities (PIA) & Components (PIC/SIC).

The performed analyses have the object of determine, develop and validate the operating procedures and required I&C to be implemented in CHWS-1. These operations have been developed by combining the thermal-hydraulic modelling with the simulation of I&C during normal and abnormal scenarios (incident and accident events). Particular emphasis is given to CHWS-1 accident detection and mitigation system following the ITER SIC Requirements.

First part of the work consists in defining CHWS-1 all possible operating scenarios, perform sizing calculations of all the system components and execute relevant steady-state simulations. For this purpose, several CHWS-1 models were creating using the thermo-hydraulic software AFT Fathom9 based on the system stage approaches (First Plasma (FPO) and Post First Plasma (PFPO-I & PFPO-II) Operations).

Sensitivity analysis on critical aspects of the system was performed based on these Fathom Models.

All the safety functions assigned to CHWS-1 were identified along with their performance requirements. Functional Analysis was developed with a structured top-down approach, starting from the System Requirements deducing the Basic functions until components needed to fulfil the requirements.

All the Postulated Initiated Events (PIEs) are considered, in order to identify the required safety functions.

Each function was analysed to identify its importance to safety, equipment protection etc.

The actuators and the sequence of the actions to be performed, either automatically or manually, are described.

In order to verify the postulated accident management strategy and the defined CHWS-1 instrumentation and control (I&C), a simplified RELAP5-3D model of CHWS-1B was developed.

Based on the pre-determined relevant PIEs, three transient scenarios were analysed: LOCA Accident in the DTR, Pipe Leakage in the System, VV-PHTS HX Incident/Accident.

The simulation results are studied to analyse and verify the system behavior as well as eventually implement its design, studying the required actions to reach and maintain a safe state after the given events.

With respect to the events studied, the CHWS-1 Design & Operation was demonstrated, justified and validated in compliance with ITER SIC Requirements and CHWS-1 SIC Classification.

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Definitions

ACP	Activated Corrosion Product
AFT	Applied Flow Technology
BDBA	Beyond Design Basis Accidents
BEP	Best Efficiency Point
CBS	Control Breakdown Structure
CCF	Common Cause Failure
CCWS	Component Cooling Water System
CSS	Central Safety System
CHWS	Chilled Water System
CWT	Cooling Water Tank
DBA	Design Basis Accidents
DM	Demineralized Water
DTR	Drain Tank Room
DU	Dangerous Undetected
FAL	Final Actuation Logic
FCV	Flow Control Valve
FP	Fail in Position
HCC	Hard Core Components
HX	Heat Exchanger
HLA	High Level Alarm
HPA	High Pressure Alarm
I&C	Instrumentation and Control
IN-DA	Indian Domestic Agency
IS	Interface Sheet
LAC	Local Air Cooler
LFA	Low Flow Alarm
LLA	Low Level Alarm
LOOP	Loss of Off Site Power
LPA	Low Pressure Alarm
MCSF	Minimum Continuous Stable Flow
MWC	Meter Water Column
NPSH	Net Positive Suction Head
NPSHa	Net Positive Suction Head Available
NPSHr	Net Positive Suction Head Required
NSR	Non-Safety Related
P&ID	Process and Instrumentation Diagram
PBS	Plant Breakdown Structure
PFD	Process Flow Diagram
PFPO	Post Fusion Power Operation
PIA	Protection Important Activities
PIC	Protection Important Components

PIE	Postulated Initiating Events
PLOF	Pump On/Off Control
PLPR	Pump Electrical & Mechanical Control Function
POS	Plasma Operation State
PRV	Pressure Relief Valve
PST	Pool Scrubber Tank
PZLC	Pressurizer Level Control
PZPC	Pressurizer Pressure Control
PZR	Pressurizer
QC	Quality Class
NPSHa	Net Positive Suction Head-Available
NPSHr	Net Positive Suction Head-Required
SIC	Safety Important Class
SL	Surge Line
SRD	System Requirement Document
SR	Safety Relevant
SRD	System Requirement Document
SSC	System, Structure and Component
SQS	Department for Safety, Quality & Security
STM	Short Term Maintenance
TBM	Test Blanket Module
TBMS	Test Blanket Module System
TDJ	Time Dependent Junction
TDV	Time Dependent Volume
TCS	Test Condition State
TL	Tangent Line
V&V	Verification and Validation
VHLA	Very High Level Alarm
VLLA	Very Low Level Alarm
VST	Vapour Suppression Tank
VV-PHTS	Vacuum Vessel Primary Heat Transfer System
VVPSS	Vacuum Vessel Pressure Suppression System

1 Introduction

1.1 ITER Background

ITER is a large-scale project that aims to demonstrate the availability of exploiting magnetic confinement fusion for the production of energy.

The main goals of this project are to achieve enough fusion to produce 10 times as much thermal output power as thermal power absorbed by the plasma for short time periods; to demonstrate and test technologies that would be needed to operate a fusion power plant including cryogenics, heating, control, and diagnostics systems, including remote maintenance; to achieve and learn from a burning plasma; to test tritium breeding; and to demonstrate the safety of a fusion plant.
It will be an experimental machine, so its aim isn't the energy production, but it will open the way to the first commercial fusion power plant, DEMO, which operation is forecasted within 2050.

ITER is a complex project conceived in 1986. In 2006 the ITER Agreement was signed at Bruxelles by seven parties (European Union, United States, China, India, Japan, Russia and South Korea) and South France has been selected as the most suitable site for the construction of the facility.
Currently, 35 nations are collaborating to build the world's largest tokamak; a magnetic fusion device that has been designed to prove the feasibility to use fusion as a large-scale and carbon-free source of energy based on the same principle that provides power to our sun and stars.
The importance of this project is also linked to the fact that the fusion is considered the future of energy. (the importance of this project is linked to consider the fusion like the future of energy).
The next decades are crucially important to reduce greenhouse gas emissions. Many are the advantages that the fusion pursues:
Absence of CO_2 emissions. It doesn't emit harmful toxins like carbon dioxide CO_2 or other greenhouse gases into the atmosphere. Its major by-product is helium: an inert, non-toxic gas.
Sustainability. Fusion fuels are widely available and nearly inexhaustible. Deuterium can be distilled from all forms of water, while tritium will be produced during the fusion reaction as fusion neutrons interact with lithium. (Terrestrial reserves of lithium would permit the operation of fusion power plants for more than 1,000 years, while sea-based reserves of lithium would fulfil needs for millions of years.)
Abundant energy. Fusing atoms together in a controlled way releases nearly four million times more energy than a chemical reaction such as the burning of coal, oil or gas and four

times as much as nuclear fission reactions (at equal mass). Fusion has the potential to provide the kind of baseload energy needed to provide electricity to our cities and our industries.

No long-lived radioactive waste. Nuclear fusion reactors produce no high activity, long-lived nuclear waste. The activation of components in a fusion reactor is low enough for the materials to be recycled or reused within 100 years.

Limited risk of proliferation. Fusion doesn't employ fissile materials like uranium and plutonium (radioactive tritium is neither a fissile nor a fissionable material.) There are no enriched materials in a fusion reactor like ITER that could be exploited to make nuclear weapons.

No risk of meltdown. A core meltdown nuclear accident (e.g. Fukushima or Chernobyl) is not possible in a tokamak fusion device. It is difficult to reach and maintain the conditions necessary for fusion and if any disturbance occurs, the plasma cools within seconds and the reaction stops.

The quantity of fuel present in the vessel at any one time is enough for a few seconds only and there is no risk of a chain reaction.

Competitive cost. The power output of the kind of fusion reactor that is envisaged for the second half of this century will be similar to that of a fission reactor, (i.e., between 1 and 1.7 gigawatts). The average cost per kilowatt of electricity is also expected to be similar; it will be slightly more expensive at the beginning, when the technology is new, and less expensive as economies of scale bring the costs down.

The ideal future energy combination for the planet would be based on a variety of generation methods instead of a large reliance on one source. As a new source of carbon-free baseload electricity, producing no long-lived radioactive waste, fusion could make a positive contribution to the challenges of resource availability, reduced carbon emissions, and safety issues and fission waste disposal.

1.1.1 ITER Reactor

ITER is designed to confine deuterium-tritium plasma in which a significant α-particle population dominate the heating plasma operations to produce 500 MW of thermal output power for periods of 400 to 600 seconds, from an input power of 50 MW.

Its stated purpose is scientific research, and technology demonstration of a large fusion reactor, without electricity generation.

This experimental machine is based on the tokamak concept of magnetic confinement.

Tokamak is a chamber under high vacuum, where extremely hot plasma of hydrogen isotopes is controlled and stabilized by huge magnetic confinement. A great amount of the power released by the plasma is carried out by neutrons produced within the reaction and absorbed by the surrounding walls of the chamber.

The heat is then extracted by a cooling water circuit and released in the environment, but able in the future to supply the energy production of a plant.

Plasma current is induced by a transformer, with the central magnetic coil. The heating provided by the plasma (known as Ohmic heating) supplies up to a third of the 100 million degrees Celsius temperature required to make fusion occur. Additional plasma heating is provided by neutral beam injection. In this process, neutral hydrogen atoms are injected at high speed into the plasma, ionized and trapped by the magnetic field.

Plasma confinement is result of a controlled interaction of many complex systems, working to achieve the ideal condition for the reaction to occur.

The main systems involved in plasma confinement and heat removal are:

- Magnet System;
- Vacuum Vessel / Blanket / Divertor assembly;
- Cryostat and Thermal Shield System;
- Heating and Current Drive System;
- Cooling Water Systems.

1.2 Cooling Water System

Operation of ITER is strongly dependent on the excess heat removal from the in-vessel components and the vacuum vessel during all stages of Tokamak operations.

This aim will be accomplished by the Cooling Water System (CWS).

Cooling Water System (CWS) is designed to reject all the heat loads generated in the plasma, when it will be heated at 50 MW and the D-T fusion power heat will reach 500 MW with an amplification factor Q=10. The heat will be transmitted to the In-Vessel components through the Tokamak Cooling Water System (TCWS) to the intermediate closed loop Component Cooling Water System (CCWS) and then to the environment via the open Heat Rejection System (HRS).

In that condition, CWS shall remove a peak heat load of about 1150 MW.

In addition to main heat removal action, the CWS performs the following functions:

- Controlling water chemistry, to minimize corrosion in the systems cooled by CWS.
- Providing the capability to drain and dry the cooling loops, to facilitate maintenance of the components in the CWS and the systems served by it.
- Facilitating leak detection and leak localization, for CWS and client systems.
- Monitoring heat removed from the in-vessel components and vacuum vessel.

The relationship among the above stated subsystems is shown in Figure 1-1.

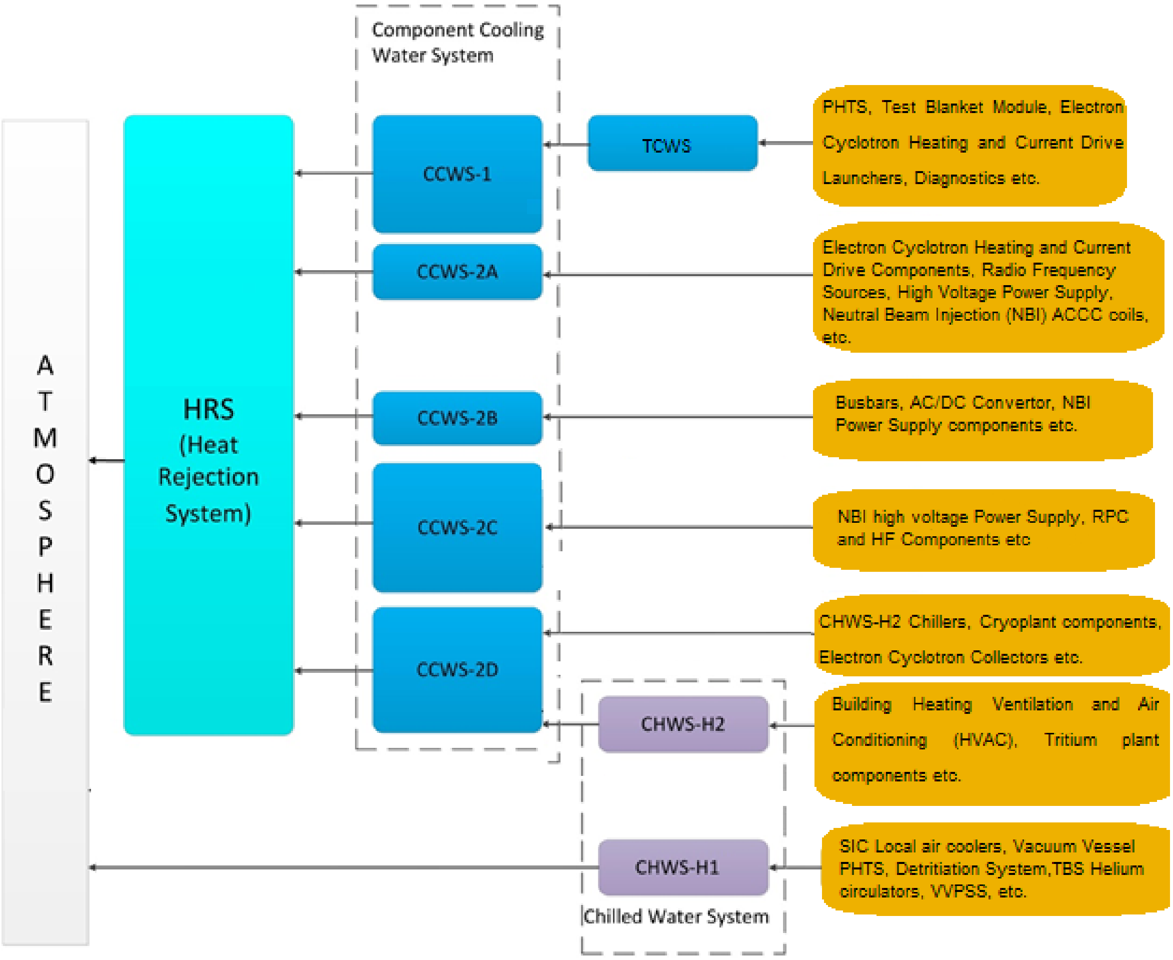


Figure 1-1: CWS Subsystems

This document scope is limited only to CHWS-1. It is a Safety Important System that supplies water to the components requiring a lower coolant temperature than CCWS.

CHWS-1 is divided in two subsystems, CHWS-1A and CHWS-1B, and provides 6°C cooling water to safety-relevant redundant components in Tokamak and Hot Cell Complexes of ITER.

The systems cooled by CHWS-1 are the Detritiation System (DS), Local Air Coolers (LACs), Vacuum Vessel Primary Heat Transfer System (VV-PHTS), Vacuum Vessel Pressure Suppression System (VVPSS), Test Blanket Module (TBM) Helium Coolant System and Hot Cell Furnaces.

1.3 Process Design Methodology

In order to develop a complete design of the CHWS-1 several steps have been followed, as shown in Figure 1-2:

- All the information related to the system requirements and the required conditions at the interface with the systems, served by CHWS-1, were collected.

  The layout of the CHWS-1 as well as the input data from the sizing calculations (pipes lengths, bends, elevations etc.) were extracted from Isometric Drawings obtained using a 3D CAD Model of the preliminary design of the system.

- CHWS-1A&B were modelled on AFT Fathom9. Using an iterating process (described in **§3**), system sizing calculations were performed; the operating parameters of CHWS-1A&B were obtained and used as an input to create Process Flow Diagrams (**§A1**).

- The CHWS-1 Fathom models and the output data of the system sizing calculations were used to identify the design condition of the system, in terms of pressure and temperature (**§A2** and **§A3**).

- Process and Instrumentation Diagrams (P&IDs) were created based on the previous sizing and design calculation. The process behind the creation of these documents is strongly linked to the next step, the analysis of the I&C requirements; for this reason several iteration were necessary in order to obtain a final version of the P&IDs.

- In order to achieve the requirements of CHWS-1, the system safety functions were defined and consequentially I&C functional requirements were elaborated to manage the desired operation (**§5**).

  Several incident/accident simulations were performed in order to analyses and verify the system behavior, the required actions to reach and maintain a safe state after the given events and, if necessary, required implementations in the I&C (**§6**).

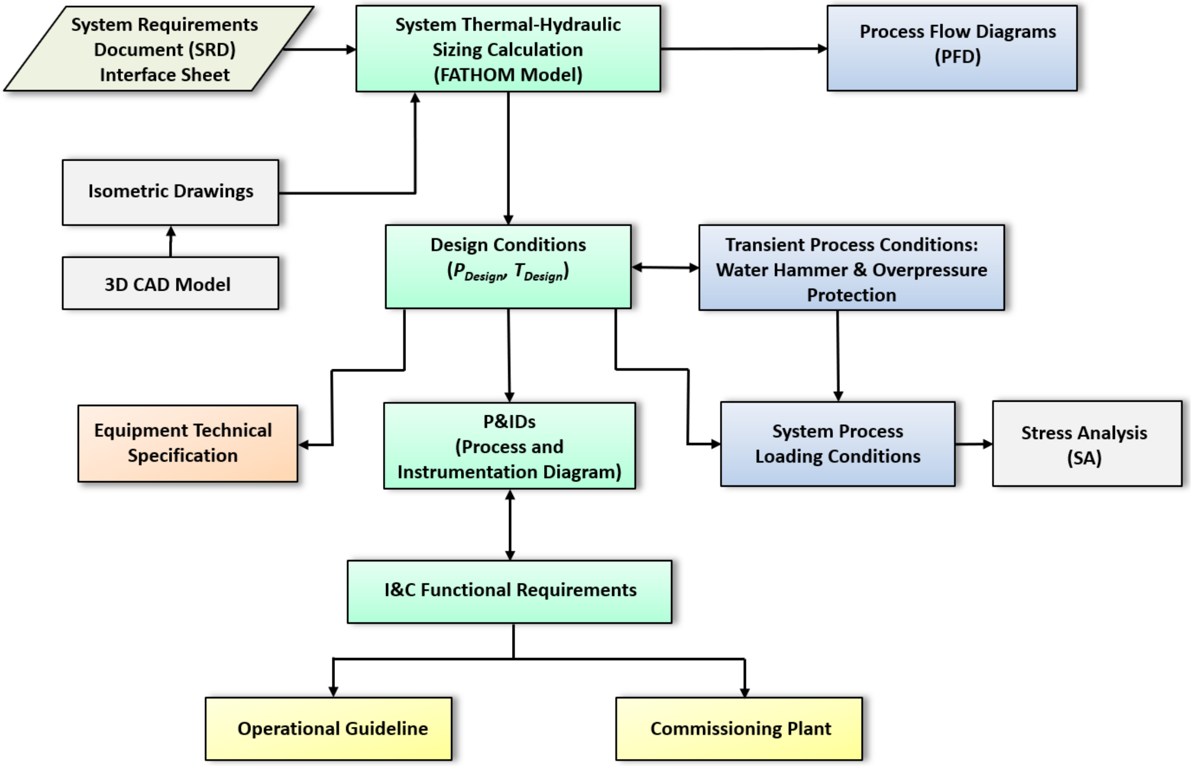


Figure 1-2: Process Design Methodology

1.4 Objectives of the Present Analysis

The objective of the present work is focused on the final design of the safety-relevant CHWS-1 of ITER plant. In particular, the work is oriented towards the thermal-hydraulic design in connection with its safety functional analysis.

All the required safety functions of the system have to be design, including all the situations normal, incidental and accidental ones to maintain the plant in a safe operation domain. They are based on the safety principle of defence in depth in order to prevent, detect and/or mitigate situations.

CHWS-1 is a Safety Important System which operation is needed for the proper functioning of Protection/Safety Important Activities (PIA) & Components (PIC/SIC).

Therefore, the CHWS-1 Safety Instrumentation and Control (I&C) plays an important role of its relevant design.

Main Object of this internship is to develop, analyse and determine the corresponding operating procedures and required I&C to be implemented in CHWS-1 by combining the thermal-hydraulic modelling with the simulation of I&C in some reference accidental scenarios. Particular emphasis shall be given to CHWS-1 accident detection and mitigation system following the ITER SIC Requirements.

Since ITER Plant is one of a kind nuclear fusion plant, the CHWS-1 SIC system design, its assessment and validation represent a challenge of great importance mainly due to the need of an innovative approach to the different safety requirements vs. the valid ones for nuclear fission plants.

1.5 Organization of the Work

The work is divided into the following main parts:
Preliminary sizing and modelling of the system using the thermal-hydraulic software AFT Fathom 9. The design of the system had some modification during the evolution of the project (First Plasma Design, Post First Plasma Operation (PFPO-I) and the final design). For this reason, several models have been developed. The system sizing parameters have been determined, including pipe and valve sizing as well as chillers and pumps requirements. Consequently, the system parameters (pressure, massflow, temperature, heatload) have been analysed during different operating modes (§3).
In **§4** is identified and provided a complete list of the functions assigned to CHWS-1 in order to describe their possible implementation in agreement with the standard ITER IO guidelines/rules.
The designed functions include CHWS-1 normal, incidental and accidental conditions.
Postulated accident management strategy is included while also defining CHWS-1 instrumentation and control (I&C), which play a relevant role in event detection and mitigation procedures.
Incidental and accidental events have been performed using the code RELAP5-3D. A simplified RELAP5-3D model of CHWS-1B was developed to simulate thermal hydraulic transient scenarios as well as to define and size system operation and control.

1.6 Computational Tools

Preliminary modelling of CHWS-1A and CHWS-1B were done using the thermal-hydraulic software AFT Fathom 9. It performs steady-state flowrate and heat transfer analyses of complex hydraulic systems. It was used in order to perform system sizing calculations and verify the CHWS-1 main parameters during different modes.

A model of CHWS-1B is built and analysed in RELAP5-3D version 4.4.2. The aims were: to verify the components design and to evaluate the system performances under steady-state and transient scenarios as well as to define system operation and control.

1.6.1 AFT Fathom9

AFT Fathom (referred to as Fathom in this document) is commercially available thermal-hydraulic software.
It performs steady-state flowrate and heat transfer analyses of complex hydraulic systems.
Fathom is one of the most used hydraulic software for calculating pressure drop and, in general, incompressible liquid behaviour inside a defined circuit.

Many components can be modelled with the software: piping, branches, tee junctions, valves (FCVs, isolation and check valves), filters, heat exchangers, pressurizers, pumps, etc.

It provides hundreds of standard loss models for pipe system components. Newton-Raphson method is used to solve the fundamental equations of pipe flow that govern mass and momentum balance. Solutions are obtained by iteration, and matrix methods optimized for speed are employed to obtain convergence.

1.6.2 RELAP5-3D Code

RELAP5-3D is a code series developed at Idaho National Laboratory (INL) for the analysis of transients and accidents in water–cooled nuclear plants and related systems.

RELAP5-3D can be used for the study of the behavior of a cooling system during steady-state conditions and to simulate a wide variety of thermal-hydraulic transient scenarios.

The code includes many generic component models from which general systems can be simulated (pumps, valves, pipes, heat structures, pressurizers, control system components, etc.).

The hydrodynamic model and the associated numerical scheme are based on the use of fluid control volumes and junctions to model the exact geometry of the system. The control volumes can be viewed as stream tubes having inlet and outlet junctions. Control volumes are connected in series, using junctions to represent a flow path.

Heat exchange is also modelled using a finite difference mesh to calculate temperatures and heat flux. The heat structure is thermally connected to the hydrodynamic volume through a heat flux that is calculated using heat transfer correlations. The heat structures are used to simulate pipe walls, heater elements and heat exchanger surfaces.

2 Overview Chiller Water System (CHWS-1)

CHWS-1 design considers two independent and segregated subsystems, CHWS-1A and CHWS-1B. Their primary function is to provide 6°C cooling water to safety-relevant redundant components in Tokamak and Hot Cell Complexes of ITER. Namely, it represents the secondary side of heat exchangers found in ITER Detritiation System (DS), Local Air Coolers (LACs), Vacuum Vessel Primary Heat Transfer System (VV-PHTS), Vacuum Vessel Pressure Suppression System (VVPSS), Test Blanket Module (TBM) Helium Coolant System and Hot Cell furnaces.

2.1 CHWS-1 Layout

Original CHWS-1 design consisted of two redundant chiller trains that served all the clients via a common piping distribution network installed across the Tokamak and Hot Cell Complexes.

Each train comprises three air cooled chillers, three chilled water circulating pumps and a pressurizer.

This configuration guaranteed exclusively the redundancy of chillers and pumps, but not of all the system.

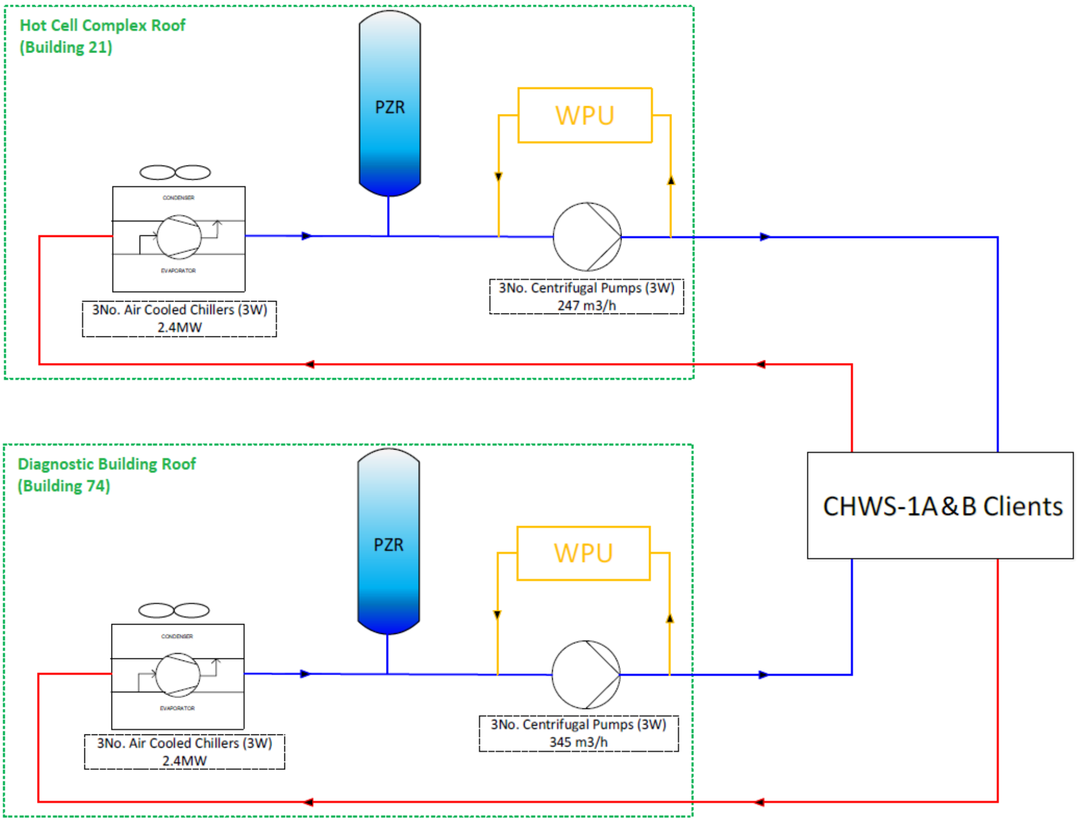


Figure 2-1: Old Design Configuration

As a result of a reviewing process, SQS (Department for Safety, Quality & Security) concluded that the system shall be able to tolerate a postulated line break and thus a common piping network would not suffice. In light of this, a new project was developed in November 2015 and it involves the redundancy of all the system, providing the alimentations of the clients not only with one loop but with two independent ones.

It’s been proposed to reconfigure CHWS-1 to be two independent systems serving SIC equipment assigned to safety trains A and B. A schematic representation of the current CHWS-1 design is shown in Figure 2-2.

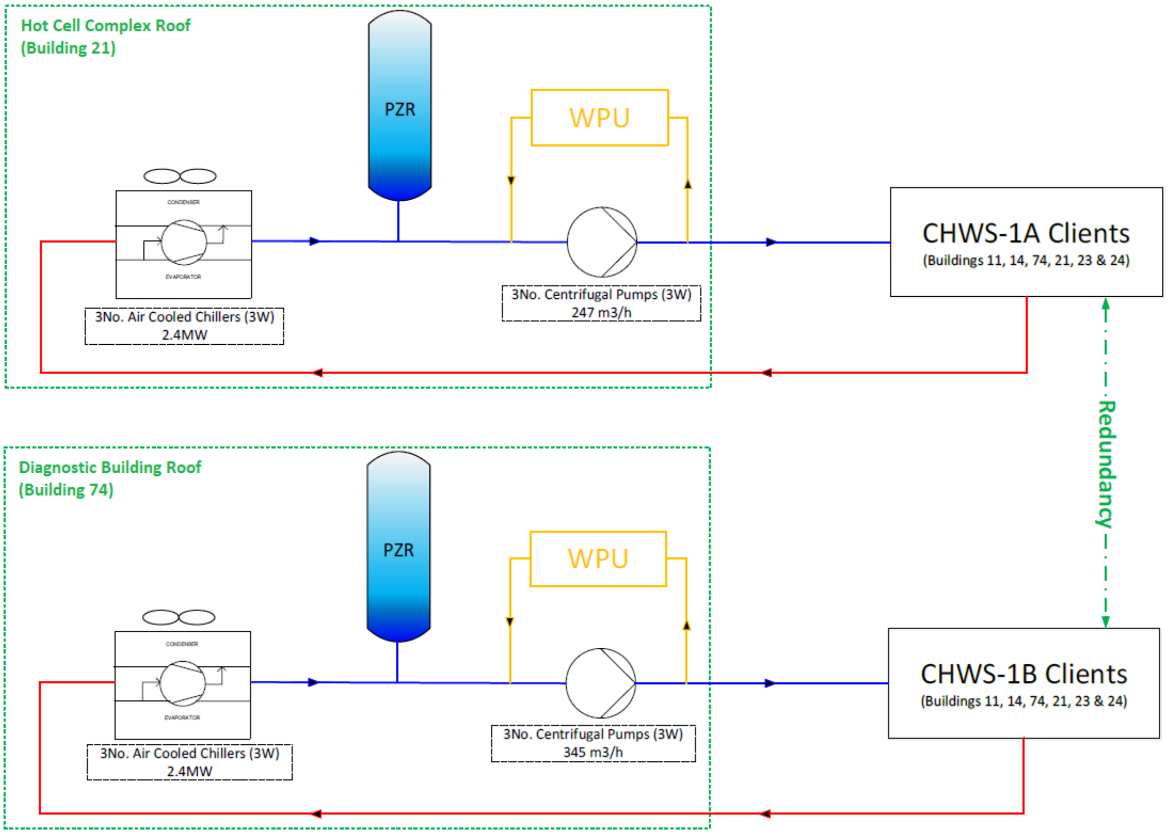


Figure 2-2: CHWS-1 New Design Configuration

Therefore, with this implementation, CHWS-1 new design considers two completely independent and segregated systems (train A & B) which are inherently compliant with the equipment redundancy assured by the clients.

Each train consists of three air cooled chillers, three horizontal centrifugal pumps, a pressurizer, chemical dosing system, strainers, valves, together with a dedicated piping distribution as well as instrumentation for monitoring and operational purposes.

The independence of these systems is also guaranteed by the physical separation of piping and equipment. CHWS-1B chillers, pumps and pressurizer will be located on the roof of Diagnostic Building (Building 74) while CHWS-1A chillers, pumps and pressurizer shall be located on the roof of the Hot Cell Complex (Building 21).

Their physical separation has the aim to minimize the effect of system shut down given any event. In addition, simultaneous failure of both trains is not envisaged. During the operating states both systems are capable to work in parallel, using two pumps (each train) in order to feed the clients with the required cooling water.

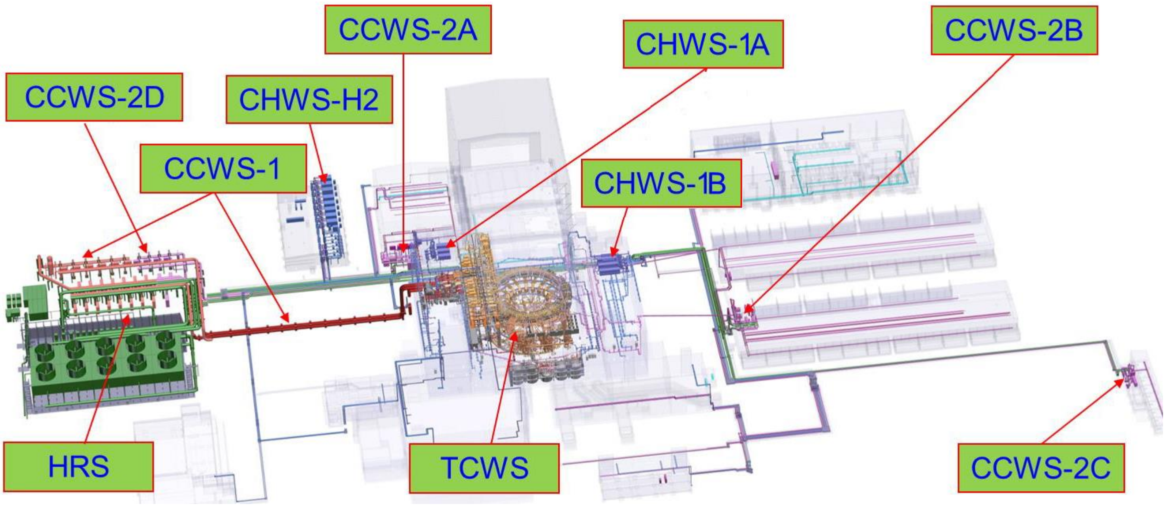


Figure 2-3: CWS Arrangement in on ITER site

The layout of the system and its operating requirement change during the first steps of the plant operation.

Three different stage approaches have been identified: First Plasma, Post First Plasma PFPO-I and Post First Plasma PFPO-II.

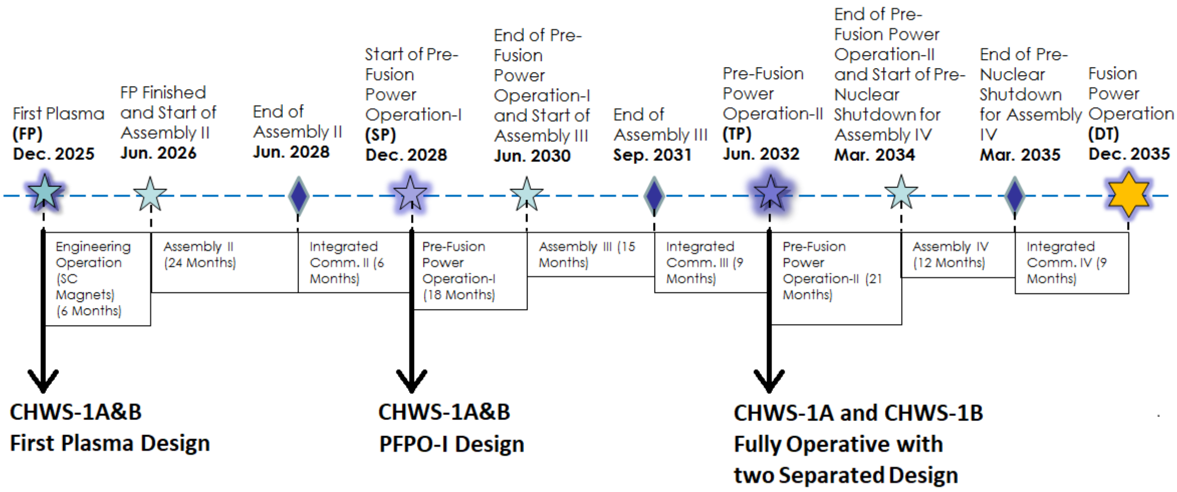


Figure 2-4: ITER Timeline

During First Plasma, CHWS-1B captive piping is connected to the cooling system CHWS-2 and, if necessary, supply chilled water to Local Air Coolers present in Tokamak Complex. CHWS-1 A&B SIC function and equipment are required later than First Plasma, but the relevant piping in Tokamak Complex shall be considered captive. No safety SIC cooling is requested but, if required, the SIC cubicles should be cooled by chilled water.

CHWS-1A&B pumps and chillers are not working during this operating state and they will be installed later in the system.

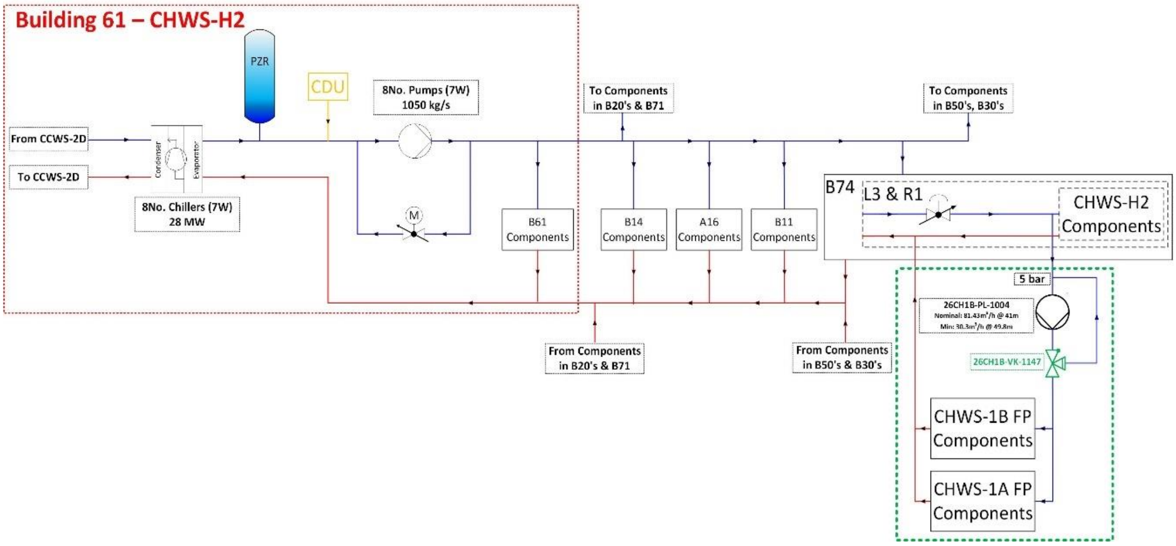
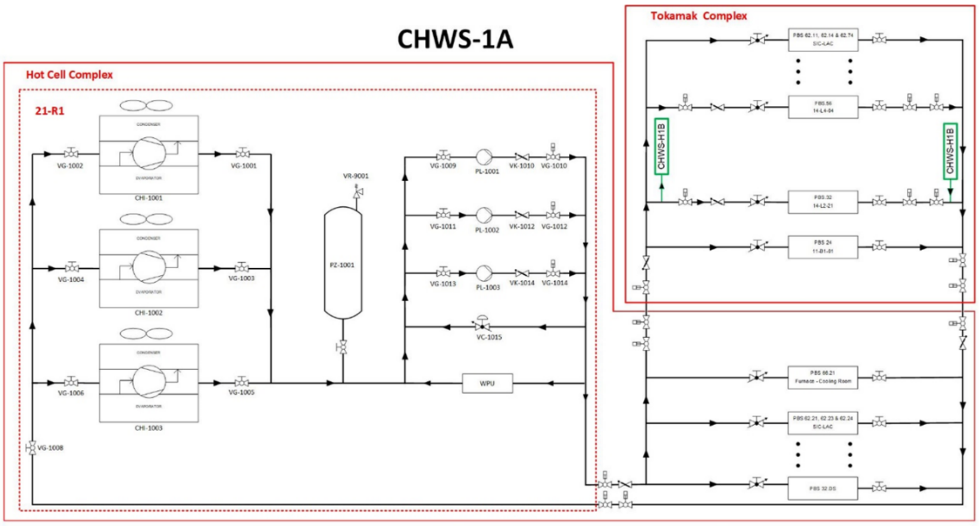


Figure 2-5: CHWS-1 and CHWS-H2 First Plasma Configuration



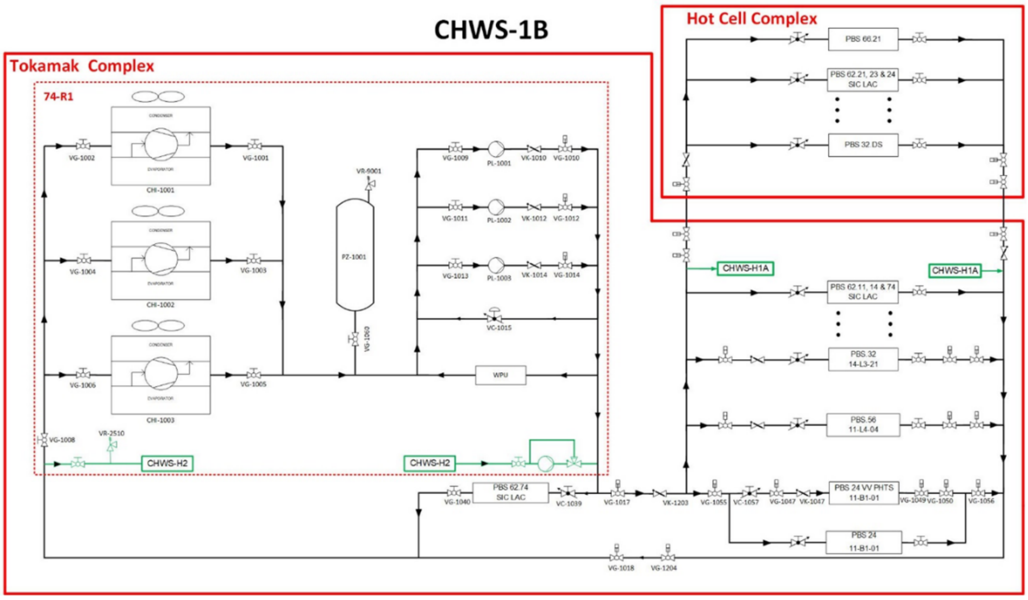


Figure 2-6 CHWS-1 Layout during First Plasma

After First Plasma Operations the connection between CHWS-1 and CHWS-2 will be removed while the connection between CHWS-1B and CHWS-1A is maintained for the Pre-Fusion Power Operation- PFPO-I.

During the PFPO-I the cooling operations are guaranteed by the CHWS-1B chillers; they cool down the water from 12°C to 6°C while one CHWS-1B pump provides the flow to the required components (1W + 2S configuration). The pump bypass line is used to accommodate the excess of flow.

After this operating mode, the temporary connection between CHWS-1A and 1B will be removed and the two systems will operate independently.

Furthermore, CHWS-1 has the following classification:
Safety Important Class (SIC) system with safety class SIC-2. It is a system used to prevent, detect or mitigate incidents and accidents.
Seismic Class 1 (SC-1). It has to be functional during and after a SL-2 earthquake and shall be able to be restarted immediately in consistent with power supply availability.
Quality Class 1 (QC-1). Class 1 is the most restricted class; quality Classes is a function of SSCs (System, Structure and Component) affecting quality, performance, cost or reliability of ITER facility and classified as Nuclear Safety Important (PIC/SIC), Safety Relevant (SR) and Non-Safety Related (NSR).

Table 2-1: CHWS-1 Stage Approach Configuration

	First Plasma	**Pre-Fusion Power Operation I**	**Pre-Fusion Power Operation II**	**Fusion Power Operation**
CHWS-1A	Temporary Connection between: - CHWS-1B and CHWS-H2 - CHWS-1A and CHWS-1B in order to serve Tokamak Complex LACs. No SIC requirement	Temporary Connection between CHWS-1A and CHWS-1B. No SIC requirement	Available	Available
CHWS-1B			Available	Available

2.2 CHWS-1 Requirements

CHWS-1 technical requirements have to be identified, mainly two classes of requirements are outlined: safety and operational.

- Safety requirements: in order to guarantee safety functions and design, the system has to be protected from, the effects of internal/external hazards. This is reflected in this set of requirements.

- Operational requirements collect all the needs that guarantee cooling water at 6ºC to all the required systems.

2.2.1 Operational Requirements

CHWS-1 shall provide cooling water at 6ºC to client systems, transfer heat directly from the systems to the atmosphere, through air-cooled chillers during normal and accidental conditions and guarantee the complete redundancy of these operations which is satisfied considering the equipment redundancy assured by the components fed by CHWS-1.

The system is sized for a temperature difference of 6° (6°C supply, 12°C return) while its operating pressure regime is 0.13 - 1.3 MPa.
With regards to cooling capacity, CHWS-1A and CHWS-1B can remove 1.81 MW and 2.39 MW, respectively, with a total flowrate of 72.25 kg/s and 95.44 kg/s.

CHWS-1 should supply chilled water to:

- Vacuum Vessel Pressure Suppression System (PBS 24 VS).
- Air Detritiation System (PBS 32.DS).
- Tokamak Complex LACs for cooling of SIC cubicles (PBS 62.11, PBS 62.14 and PBS 62.74).
- VV-PHTS (PBS 26.PH.VV) (only during loss of offsite power supply).
- Test Blanket Modules System (PBS 56).
- Hot Cell Complex LACs (PBS 62.21).
- Hot Cell Complex HE Furnace Cooling (PBS 66.21).

CHWS-1 also provides a secondary confinement function in the event of a TCWS heat exchange leak and meets the Safety-Important Component (SIC) requirements.
The system must maintain the coolant temperatures, pressures, flow rates and water chemistry to ensure that component temperatures and thermal margins are maintained during all the operations.
It has also to provide:
The capability to drain and refill CHWS components, for maintenance the capability to drain and refill client systems.
The sampling capability for the CHWS including periodic sampling for tritium and Activated Corrosion Products (ACPs).

2.2.2 Safety Requirement

ITER nuclear safety functions includes radioactive confinement and limitation of radiation exposure. ITER has also established a program for personnel protection against accidents anticipated during construction, operation and maintenance activities. The objective of safety classification is to ensure that the nuclear safety functions are well preserved along with a high level of worker safety is achieved.

CHWS-1 is Safety Important Class (SIC) system. SIC components are designed to withstand all loads and conditions resultant from any design basis situations (normal operations or incidental/accidental situations) during and after which the system shall continue accomplishing its functions.

Piping that penetrates a confinement barrier is designed to ensure that the confinement function is maintained during and after a design-basis event, including a seismic event.

CHWS-1 functions are guaranteed thanks to the redundancy of the two subsystems (CHWS-1A and CHWS-1B), hence it is classified as SIC-2 system.

CHWS-1 provides static and dynamic confinement. The dynamic confinement consists in supply chilled water to PIC components (Detritiation System (DS), Local Air Coolers (LAC), Vacuum Vessel Pressure Suppression System (VVPSS) and Test Blanket Module System (TBMS)). The components fed by CHWS-1A&B are redundant and, for this reason, the piping and equipment are classified SIC-2 when providing cooling capacity.

2.3 Operating Modes

2.3.1 Cooling Mode

Mode 1: Plasma Operating states

During Plasma Operating States (POS), cooling water total flow is 72.25 kg/s for CHWS-1A and 95.44 kg/s for CHWS-1B.

During POS, cooling water is not provided to the VV PHTS and the CHWS-1B isolation valves located in its line are close; the excess of water flows through the pumps bypass line in order to maintain the operating condition of the pumps.

The parameters listed in Table 2-2 represent the maximum values of heat load and flowrate available from CHWS-1.

The components cooled by the system are linked to both the trains in order to guarantee the redundancy of the CHWS-1.

During these operating states, the redundant components would decide which train use in order to work at the required conditions. Bearing this in mind, CHWS-1 total flowrates as well as each component flowrate correspond to their maximum values that can attain during all operating modes.

Cooling water, provided to each component, has a 6°C temperature. The maximum temperature increase allowed is 6°C, so the maximum outlet temperature from each cooled component is be 12°C.

Table 2-2 Thermal-Hydraulic parameters during POS

Operation Mode	Thermal-Hydraulic Parameters	CHWS-1A	CHWS-1B
POS	Power [MW]	1.81	1.793
	Flow Rate [kg/s]	72.25	95.45
	Maximum temperature increase trough each component [°C]	6	6
	Pressure drop through each component [MPa]	0.2 - 0.4	0.2 - 0.4

Mode 2: Test and Conditioning

CHWS-1 A&B systems are in continuous operation and chilled water requirement are 61 kg/sec.
The system operates the same way it operates in the POS condition. The flows is achieved with the help of control valves at the inlet line of each component, cooled by the CHWS-1.

Mode 3: STM/ LTM State:

CHWS-1 system is in continuous operation and chilled water requirement is 69 and 96 kg/s, respectively. The system operates the same way it operates in the POS condition. The flow is properly distributed with the help of manual control valves at the inlet line of each component, cooled by the CHWS-1.

Mode 4: Additional Case/State - Loss of offsite power supply

In case of loss of offsite power, CHWS-1B is requested to remove heat from VV PHTS heat exchanger.

It should be noted that during POS the flow is not provided to the VV PHTS and the CHWS-1B solation valves located in its line are close. Moreover, in case of LOOP from water baking operation, as long as VV PHTS primary pressure is above CHWS-1B pressure, the opening of the CHWS-1B isolation valves is not allowed.

Total flow is 95.44 kg/s and the heat load is 2.39MW.

CHWS-1A is not affected by VV-PHTS and therefore there are no variations with respect to its operating states during LOOP.

Table 2-3: Thermal-Hydraulic parameters during Loss of offsite power supply

Operation Mode	Thermal-Hydraulic Parameters	CHWS-1A	CHWS-1B
Loss of offsite power supply	Power [MW]	1.81	2.39
	Flow Rate [kg/s]	72.252	95.44
	Maximum temperature increase trough the component [°C]	6	6
	Pressure drop through the component [MPa]	0.2 - 0.4	0.2 - 0.4

2.3.2 Mode 5: Off Mode

In Off Mode there is no flowrate and no heat transfer, the system or components are in its de-energized state or under shutdown.

The system temperature reaches the room ambient temperature (minimum room temperature is 5 °C). This can occur when the system is starting after long shutdown, complete plant shut down for maintenance.

2.3.3 Mode 6: Maintenance Mode

Planned maintenance can be performed during ITER Machine States Long Term Maintenance (LTM).

During this mode, the system has been partially or fully drained and secured as required for maintenance. CHWS-1 is depressurized at ambient conditions.

The drained portions opened for maintenance are filled with air, while the ones closed are filled with nitrogen to prevent corrosion.

3 CHWS-1 Sizing Calculations and Steady-State Analyses

In order to determine system sizing parameters for the Chilled Water System (CHWS-1), including pipe and valve sizing as well as chillers and pump requirements, several models of the CHWS-1A and CHWS-1B have been created with the thermal-hydraulic software AFT Fathom 9.

3.1 Sizing Assumptions

In order to develop the CHWS-1 Fathom Model and to identify all the input data that have to be provided, several assumptions have been made.
Some of these assumptions are not verified, this is due to the fact that a part of the system design is still ongoing (Hot Cell Complex) and thus, only estimates can be done.

3.1.1 Unverified Assumptions

1) Pipe lengths, pipe routing and junction elevations in the Tokamak Complex were extracted from CHWS-1A&B isometrics while the data in the Hot Cell Complex were collected by-hand using the blueprint of the buildings. All these data are stored in a support Excel file. It includes straight piping, bends (45 and 90 degrees), reducers and expanders.
2) Valves data have been extracted from manufacturer (Neway) datasheet. For the valves that haven't been procured yet and for the pumps, preliminary datasheet has been used in this sizing calculation. It should be updated with the final manufacturer datasheet after selection of the pump and valve manufacturers.
3) CHWS-1A chiller, pumps and PZR are located in the Hot Cell Complex and the design of the system in that area is still ongoing; for this reason, the configuration of these components are assumed to be identical as in CHWS-1B. The same can be said with respect to the connecting pipes between these components.
4) At the time the CHWS-1 Fathom model was created, no isometrics or 3D models corresponding to the CHWS-1 pipe routing in the Hot Cell Complex existed. The data were collected according to the position of each component, cooled by the system, and the blueprint of the buildings.

   For preliminary calculations of Hot Cell Complex pipe lengths and added K factors, the following steps apply:

   - Using blueprints of the Hot Cell Complex, a hypothetical pipe routing is tracked.
   - In order to guarantee the physical separation of the CHWS-1A and CHWS-1B, the pipe routing of both trains is defined in parallel.
   - The lengths of the pipes considering the distance between two components or tee in x-y-z coordinates is measured as:

$$\mathrm{L}_{\mathrm{p}_1-\mathrm{p}_2} = \left|\mathrm{x}_{\mathrm{p}_2} - \mathrm{x}_{\mathrm{p}_1}\right| + \left|\mathrm{y}_{\mathrm{p}_2} - \mathrm{y}_{\mathrm{p}_1}\right| + \left|\mathrm{z}_{\mathrm{p}_2} - \mathrm{z}_{\mathrm{p}_1}\right|$$

   - A factor of 25% is added to consider bends or elbows that could be present in the pipe routing.

$$\mathrm{L}_{25\%} = 0.25 * \mathrm{L}_{\mathrm{p}_1-\mathrm{p}_2}$$

   - To account for the pressure loss due to fittings, an additional K factor is considered. For this case, a factor of 20% is considered.

$$K_{add} = 0.2 f \frac{L_{25\%}}{ID}$$

Where:

- f is the Pipe Friction Factor
- ID is the Inner Diameter

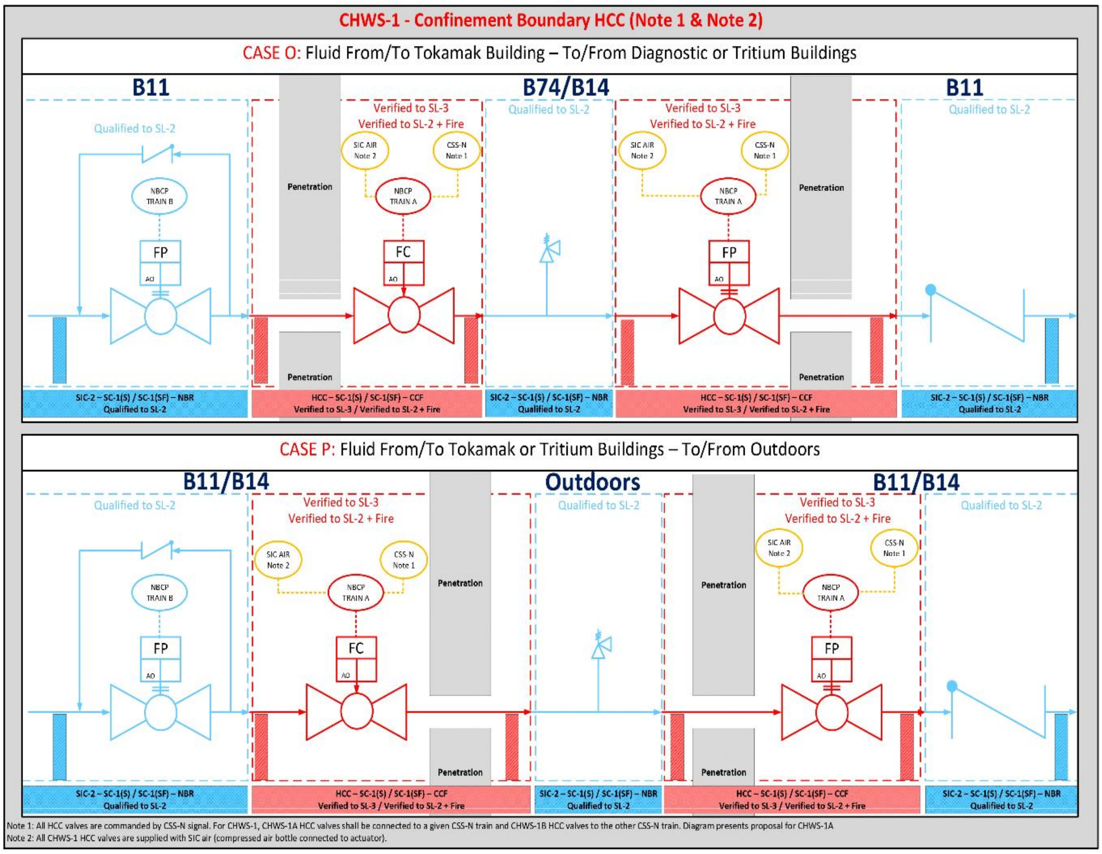
5) CHWS-1 provides chilled water to the secondary side of heat exchangers found in ITER Detritiation System (DS), Local Air Coolers (LACs), Vacuum Vessel Primary Heat Transfer System (VV-PHTS), Vacuum Vessel Pressure Suppression System (VVPSS), Test Blanket Module (TBM) Helium Coolant System and Hot Cell furnaces. The fathom model is properly modelled until the interface point of each system (till the valve located in the inlet and outlet line of the heat exchanger). The pipe segments that link the valves to the heat exchanger are considered to be frictionless and 1 m long. This simplification can be safely applied as long the information on the corresponding IS is respected.

3.1.2 Justified Assumptions and Modelling Simplifications

1) Pressure drop, between the interface points of cooled components, is assumed as 0.2 MPa for Vapour Suppression Tank System (PBS 24), Air Detritiation System (PBS 32) and LACs while TBM Helium Coolant Systems (PBS 56) have a maximum pressure drop of 0.4 MPa.
2) VV-PHTS pressure drop is assumed as 0.15 MPa. This value has been calculated importing in the Fathom Model the pipes length extracted from the isometrics. It’s been considered also the fittings and the valves shown in the VV-PHTS P&IDs and the heat exchanger pressure drop of 0.05 MPa (according to the data extracted the VV-PHTS sizing report). The result of this analysis provided a total pressure drop of 0.116 MPa; so in order to be conservative 0.15 MPa has been considered.
3) CHWS-B shall provide cooling water to VV-PHTS only in case of Loss of Outside Power (LOOP). During Plasma Operation (POS), the isolation valves located in the inlet and outlet line serving VV-PHTS are closed.
4) In the Fathom Model the pipes are considered perfectly insulated (Heat Transfer Model: Adiabatic).
5) Sampling system interaction is considered negligible and it is not modelled in the Fathom model.
6) The pipe material is Stainless Steel, ASTM A 312 TP 304L and A 358 GR 304L. The absolute roughness of the pipe is assumed to be 15μm.
7) Thermal expansion of the pipes is not considered. This is a conservative approach because pipe thermal expansion would reduce pressure losses.
8) For estimating water volumes of CHWS-1 (calculation needed for the PZR sizing requirement) the following considerations apply:
    - Volumes of straight piping, bends, tees, o-lets, and valves are summed and stored in a support Excel file.

- Each LAC water volume is assumed to correspond to an equivalent length of 30 m (10 m for supply pipe, 10 m for LAC, and 10 m for return pipe) at DN of the LAC; except for CHWS-1B LAC in 74-L3-11. This component is connected to 74-B2; for this reason, an equivalent length of 50 m was considered.
- The water volume of the other components has been collected from the corresponding interface sheet.
- Each Chiller has a water volume of 0.09 m3 (Data extracted from Carrier Catalogue).
- A 10% margin was added on the sum of all the water volumes for covering minor system components (pumps, valves and strainers).

9) Hard Core Components (HCCs) were located in the system (as shown in Figure 3-1 , in order to prevent cliff edge effects (dose to population above 10 mSv, contamination of the ground water or high radiation field which avoids long term human intervention on the site).



Note 1: All HCC valves are commanded by CSS-N signal. For CHWS-1, CHWS-1A HCC valves shall be connected to a given CSS-N train and CHWS-1B HCC valves to the other CSS-N train. Diagram presents proposal for CHWS-1A

Note 2: All CHWS-1 HCC valves are supplied with SIC air (compressed air bottle connected to actuator).

Figure 3-1: Confinement Boundary HCC

These HCC isolation valves have designed with the following actuator failure mode: Fail in Position on Active System & Fail Close on Passive System Failures (FP & FC).

The actuation of the valve is executed by a system divided in two parts acting on the same pneumatic actuator. Each system has a different failure mode:

- *Active system (connected to I&C system):* This system is based on the classical pneumatic circuit in order to operate a pneumatic actuator. It is based on pre-actuator (solenoid/piezo directional control valve), compressed air and electrical signals from control system. It has the tasks to open and close the valve following the associate signals from the control system.

  Any anomalies (absence of compressed air and/or absence of electrical signals) shall freeze the position of the valve. Active system failure mode is Fail in Position (FP).

- Passive system (independent to I&C system): It is based on pure passive components (no electrical signals) and it is not fed by compressed air.

  The only source of power, available for the passive system, is the pressure of the process fluid (water). The only task of the passive system is to drive the valve to the close position in case of valve upstream and/or downstream depressurization. This task shall be performed independently of the status/behaviour of the active system.

  In case of correct pressure, the passive system shall not interfere with the active system and the relative operation of the valve. Passive system failure mode is Fail Close (FC).

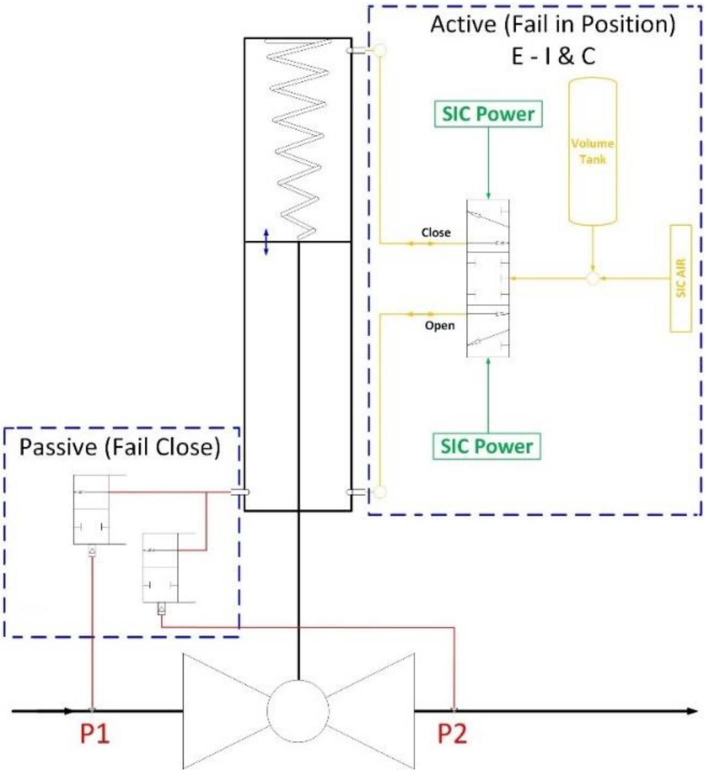


Figure 3-2: CHWS-1 Hard Core Component (HCC) Valve

3.2 CHWS-1 Fathom Model Input

In order to develop a proper CHWS-1 Model, each design component represented in Fathom (piping, tee junctions, bends, valves, etc.) has to be characterized by a set of input. These inputs have been selected, based on the assumptions (**§3.1**), and the operating requirements (**§2.2**).

To get acceptable convergence of the Fathom model, the following tolerance data was reduced:

- Relative temperature tolerance from 1E-3 (default value) to 1E-7.
- Relative flow rate tolerance from 1E-3 (default value) to 1E-7.
- Relative pressure tolerance from 1E-3 (default value) to 1E-7.

Moreover the Fathom Model designs of CHWS-1A and CHWS-1B are shown in the detailed system Process Flow Diagrams (PFDs) (**§A1**).

1.1.1 Piping

Relevant information obtained from the CHWS-1 isometrics (pipe length and routing inside the Tokamak Complex), were imported in AFT Fathom 9.

For the piping network inside the Hot Cell Complex the estimation of the length and the calculation of the additional K factor are made following the methodology described in the Assumption 4) (**§3.1**).

Pipe sizing was done by performing iterations in Fathom. The objective was to select the appropriate DN so that fluid velocity was kept in the range between 0.5 m/s – 4 m/s and FCVs throttling value was kept between 20% - 80%. The following steps apply:

1. The pipes were first sized with the DN provided by the preliminary IN DA design. Then, a first run was performed in Fathom to verify that all the components required flow was satisfied.
2. Flow velocity should not be higher than 4 m/s in order to avoid the worsening of corrosion and erosion effects and the generation of noise and pipe vibrations. In other words, the pipe diameter was increased when the velocity exceeded this value and it was decreased if in case of too low velocity.
3. A FCV is located on the line of each component served by CHWS-1. Following recommended best engineering practices; a FCV should throttle at no less than 20%, in order to properly operate, while avoiding cavitation risks. The output data of the second step was collected and the diameter of the lines, with FCV operating at less than 20%, was reduced while also monitoring the flow velocity. Cavitation analysis has been performed in order to verify the operating conditions.

The pipe material is Stainless Steel, ASTM A 312 TP 304L or A 358 GR 304L and the absolute Roughness of the pipe is set to15μm.

Exception is made for the pipes that, in the Fathom Model, link the valves to the heat exchanger of each component cooled by CHWS-1.

The considered interface points between CHWS-1 and these components are the valves located in the inlet and outlet line. The pipes are modelled with a fictitious length of 1 m and frictionless; while all the component required conditions are imposed and analysed in the heat exchanger modelled in Fathom.

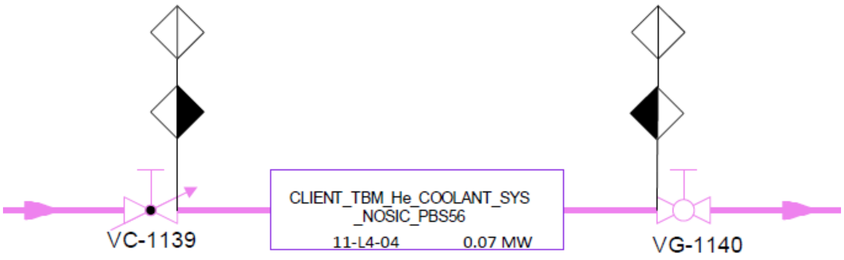
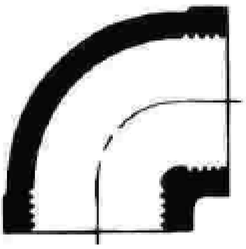


Figure 3-3: Interface points between CHWS-1 and a supplied system

An additional K factor is added in the piping input to take into account the bends and area changes (Reducers and Expanders).

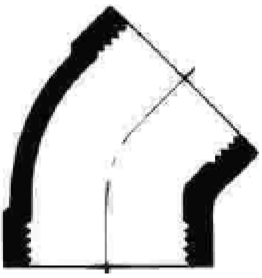
The bend number, bend radius and bend angle are extracted from the CHWS-1 isometrics. The corresponding friction form loss coefficient was calculated using the following formulas:

90° Bend



$$K_{90} = 14\, f_T$$

45° Bend



$$K_{45} = (n-1)\left(0.25\,\pi\, f_T \frac{r}{d} + 0.5\, K_{90}\right) + K_{90}$$

Where:

- – N is the number of bends
- – K is the resistance coefficient for on 90 bend

The area changes data (Elevation and angle (θ)) in the piping are also extracted from the isometrics and they are modelled in the Fathom with the “Conical Transition” set.

The reducers and expanders of CHWS-1 piping are based on ASME B16.9-2007. Their angles (θ) are calculated based on the length (L):

$$\theta = 2\ \mathrm{Arctan}\left[0.5\left(\frac{DN_{large} - DN_{small}}{L}\right)\right]$$

1.1.2 Tees

Tees' elevations are extracted the isometrics. All tees are modelled selecting "Detailed" as Loss Model, "Rounded" as Tee Type and with an angle of 90 degrees. These inputs make it possible to account for friction losses at the junction.

1.1.3 Isolation Valves

Isolation valves have modelled on Fathom with constant CV. The selected isolation valves are ball valves with ASME Class 300. The valves CVs are taken from Neway datasheet. Exception is made for isolation valves with DN200. These valves have not been procured yet and a preliminary datasheet has been used.
Part of these valves is HCCs located in the system, in order to prevent cliff edge effects.
The elevation of the valves is extracted from the isometrics.

Table 3-1: Isolation Valves CVs

DN	Type of Valve	ASME	CV	Reference
15	Ball	300	18	Neway Catalogue
25	Ball	300	56	Neway Catalogue
40	Ball	300	142	Neway Catalogue
50	Ball	300	240	Neway Catalogue
65	Ball	300	352	Neway Catalogue
80	Ball	300	560	Neway Catalogue
100	Ball	300	1069	Neway Catalogue
150	Ball	300	2507	Neway Catalogue
200	Ball	300	10780	Velan Catalogue

1.1.4 Check Valves

Check valves have modelled on Fathom with constant CV.
The valves CVs are taken from Neway Catalogue. The valves with DN 50, DN 65 and DN 200 have not been procured yet, for this reason preliminary CV values have been taken from VELAN Catalogue.
The check valves with DN < 50 are lift check valves (butt-welded) while for DN ≥ 50 axial valves (butt-welded) are selected; both with ASME Class 300.
The elevation of the valves is extracted from the isometrics.

Table 3-2: Check Valves CVs

DN	Type of Valve	ASME	CV	Reference
15	Lift Check	300	3.9	Neway Catalogue
25	Lift Check	300	11.84	Neway Catalogue
40	Lift Check	300	30	Neway Catalogue
50	Axial	300	95	Velan Catalogue
65	Axial	300	150	Velan Catalogue
80	Axial	300	243	Neway Catalogue
100	Axial	300	432	Neway Catalogue
150	Axial	300	1012	Neway Catalogue
200	Axial	300	1750	Velan Catalogue

3.2.1 Control Valves

Control valves are located at the inlet line of each component served by CHWS-1 and used to meet the flow requirement.
For the CHWS-1 flow control valves globe valves with ASME Class 300 have been selected. In Fathom, they are modelled as “Flow Control Valve Type” and their CV characteristic have been provided.

Characteristic curves were identified considering different valve plug shapes: Linear, S-shape, Quick and Equal %.

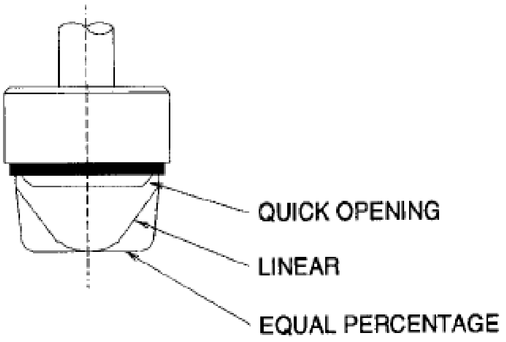


Figure 3-4: Ball valve plug types

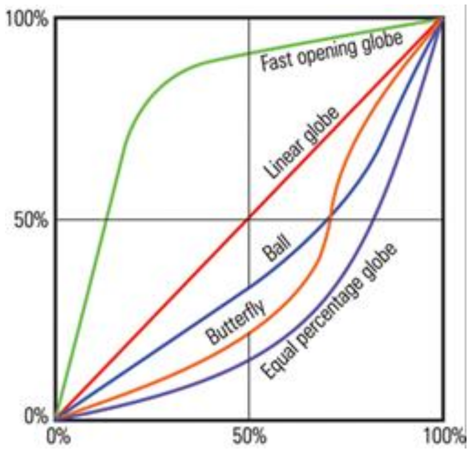


Figure 3-5: Common Inherent Characteristics Curves

For globe control valves, equal% and linear CVs characteristics are used in order to ensure control loop stability.

The CV data are extracted from Neway catalogue for valves with DN25, DN40, DN65 and DN100. The valves with DN 15, DN50, DN80 and DN100 have not been procured yet, so preliminary data are extracted from Ghibson catalogue.

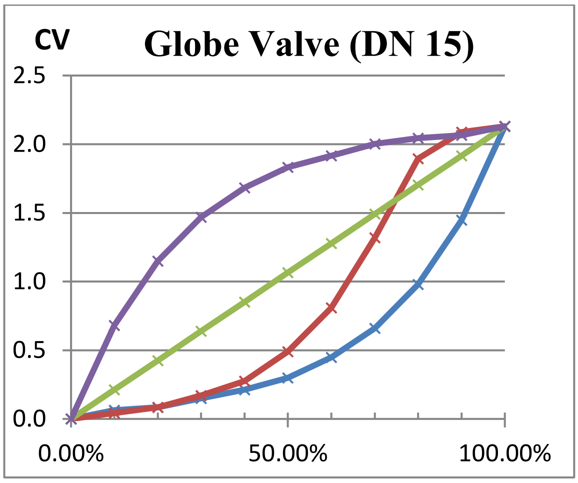


Figure 3-6: CV Curves of Globe Valve (DN15)

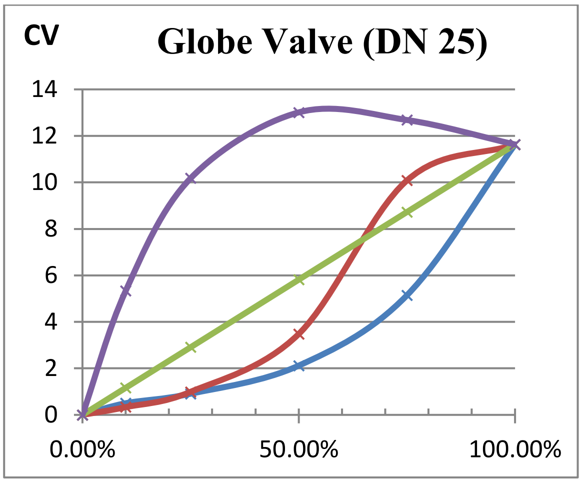


Figure 3-7: CV Curves of Globe Valve (DN25)

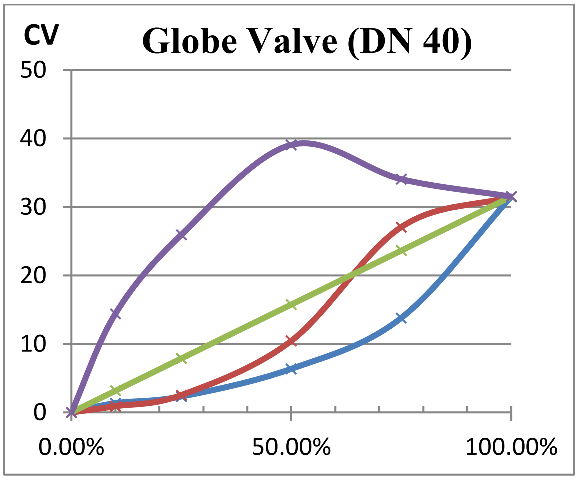


Figure 3-8: CV Curves of Globe Valve (DN40)

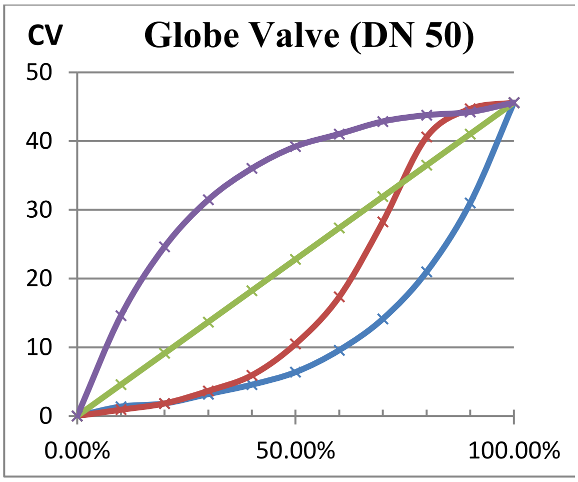


Figure 3-9: CV Curves of Globe Valve (DN50)

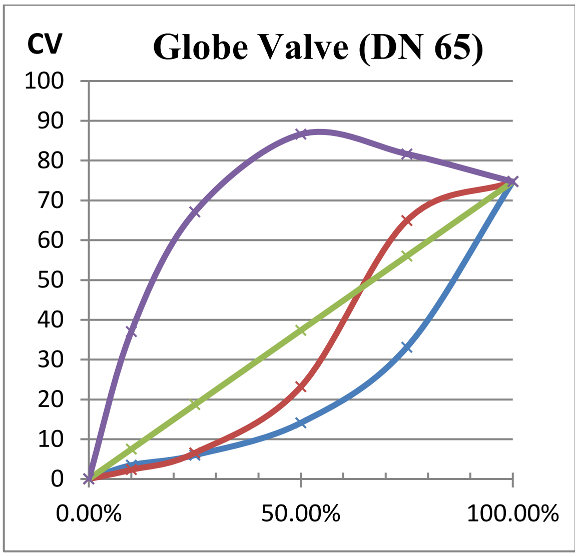


Figure 3-10: CV Curves of Globe Valve (DN65)

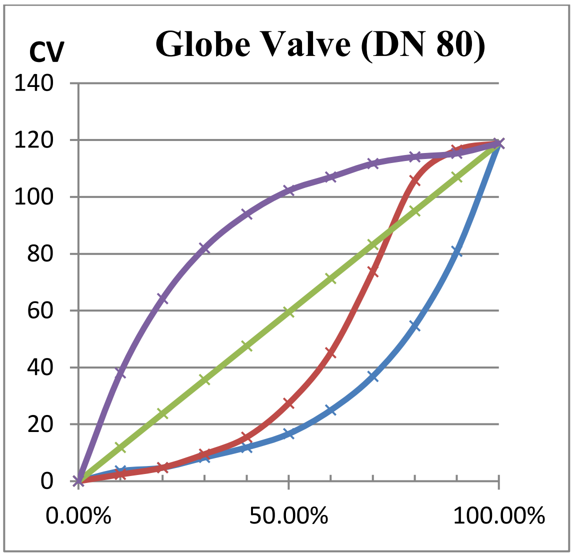


Figure 3-11: CV Curves of Globe Valve (DN80)

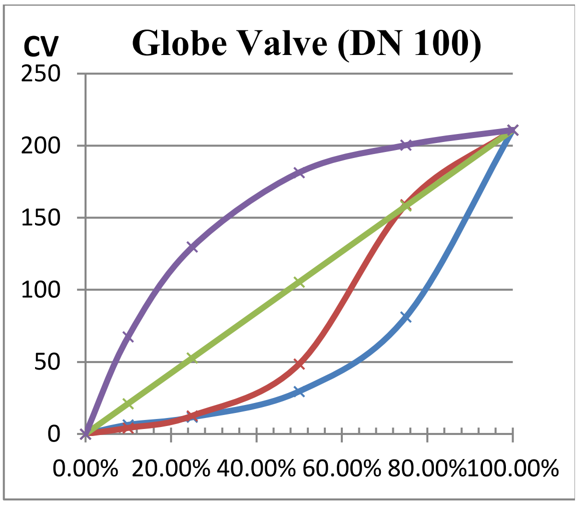


Figure 3-12: CV Curves of Globe Valve (DN100)

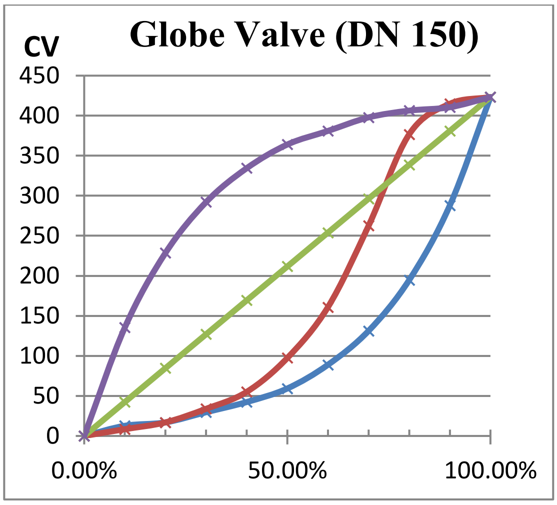


Figure 3-13: CV Curves of Globe Valve (DN150)

3.2.2 Heat Exchangers

In the Fathom model, the components cooled by the CHWS-1 are simply represented by a heat exchanger, which is integrated with a “Resistance Curve” as Loss Model. This curve is a quadratic-best-fit created by Fathom based on the input data of required flow and pressure drop.

In the heat exchanger a Thermal Model has to be specified. In order to impose the required heat load, the option “Specified Heat Rate In Contant” has been selected.

Table 3-3: CHWS-1A Summary of Heat Loads and Flows

PBS	Components		Heat load [kW]	Flow rate [kg/s]
PBS 24 VS	Vapour Suppression Tank System		160	6.4
PBS 32.DS	Air Detritiation System		605	24.095
PBS 56	TBM Helium Coolant Systems		110	4.4
PBS 62.11 PBS 62.14 PBS 62.74	Tokamak Complex LACs for cooling of SIC cubicles		285	11.426
PBS 62.21* PBS 62.23* PBS 62.24*	Hot Cell Complex LACs		557	22.248
PBS 66.21*	Furnace 1&2 Cooling Room 1	HE Furnace 1 Cooling	100	3.98
		HE Furnace 2 Cooling		
Total:			1817	72.549

Table 3-4 CHWS-1A Summary of Heat Loads and Flows

PBS	Components	Heat load [kW]	Flow rate [kg/s]
PBS 24 VS	Vapour Suppression Tank System	160	6.40
PBS 26.PH.VV	VV-PHTS (Loss of offsite power only)	600	23.90
PBS 32.DS	Air Detritiation System	605	24.10
PBS 56	TBM Helium Coolant Systems	70	2.8
PBS 62.11 PBS 62.14 PBS 62.74	Tokamak Complex LACs for cooling of SIC cubicles	279	11.19
PBS 62.21* PBS 62.23*	Hot Cell Complex LACs	579	23.07

PBS	Components		Heat load [kW]	Flow rate [kg/s]
PBS 66.21	Furnace 1&2 Cooling Room 2	HE Furnace 1 Cooling	100	3.98
		HE Furnace 2 Cooling		
	Total:		2393	95.44

Heat exchangers are also used for modelling the Chillers.
These heat exchangers are integrated with a “Resistance Curve” (taken from Carrier chiller datasheet) as Loss Model and “Controlled Downstream Temperature” as Thermal Model in order to impose an outlet temperature of 6°C.

3.2.3 Pumps

Each train has two operating pumps and one stand by pump working in parallel to circulate chilled water across the complete piping layout.

Steady-State Case 1 (**§3.3**) is used to size the pumps. In this analysed case, the pumps are modelled with fixed flow rate to determine the required head. Output data, obtained running Fathom, were used to select the preliminary manufacturer datasheet.

In Steady-State Case 2 (**§3.3**) the pumps curves, extracted from the Steady-State Case 1 scenario, are used.

During first plasma, a twin pump is located in the line that collects CHWS-H2 and CHWS-1. Steady-State Case 7 (**§3.3**) is used to size this pump and in Steady-State Case 7 the pump curves are used.

3.2.4 Pressurizer

3.2.4.1 Pressurizer Operating Pressure

In both CHWS-1 trains, a pressurizer is considered in order to provide system pressure and volume control.
The system is initially filled with make-up water from available source.
Pre-charge pressure is added above the static pressure available in the pressurizer. Nitrogen is used as pre-charge medium.
Minimum nitrogen pre-charge pressure required was worked out based on the maximum elevation of the components served by CHWS-1.
During normal operation pre-charge pressure is maintained at 0.22 MPa for both the systems.
All the input data are listed in Table 3-5

Table 3-5 PZR Pre-Charge Pressure

Parameter	General calculation	Units	CHWS-1A	CHWS-1B
Highest elevation of component, cooled by CHWS-1, h_{HC}	Extracted from Isometrics	m	33.58	36.02
PZR Water Level from ground, h_{PZR}	Extracted from Isometrics	m	22.00	18.00
Static difference, Δh_h	$\Delta h_h = h_{HC} - h_{PZR}$	m	11.58	18.02
Total Static head, Δh_{tot}	$\Delta h_{tot} = \Delta h_h + 2m$	m	13.58	20.02
Minimum Pre-charge Pressure	Δh_{tot} *0.0098	MPa	0.13	0.20
Normal Operation Pre-Charge Pressure		MPa	0.22	0.22

3.3 Steady-State Scenarios

The operating conditions of the Fathom Model have been collected considering different cases; they are listed in the paragraphs reported hereafter.

These scenarios have been analysed in order to size the pumps and the corresponding bypass line and to study how the system works during different operating states.

3.3.1 Case 1 and Case 2: CHWS-1 Pump Sizing

Case 1 is used to verify the CHWS-1 requirements and to provide the pump sizing requirements.

In this scenario CHWS-1A&B provide cooling water to all the components (included VV-PHTS), as shown in Table 3-6 and Table 3-7.

Table 3-6 CHWS-1A Summary of Heat Loads and Flows

PBS	Components	Heat load [MW]	Flow rate [kg/s]
PBS 24 VS	Vapour Suppression Tank System	0.16	6.4
PBS 32.DS	Air Detritiation System	0.605	24.095
PBS 56	TBM Helium Coolant Systems	0.11	4.4

PBS	Components		Heat load [MW]	Flow rate [kg/s]
PBS 62.11 PBS 62.14 PBS 62.74	Tokamak Complex LACs for cooling of SIC cubicles		0.285	11.426
PBS 62.21* PBS 62.23* PBS 62.24*	Hot Cell Complex LACs		0.557	22.248
PBS 66.21*	Furnace 1&2 Cooling Room 1	HE Furnace 1 Cooling	0.1	3.98
		HE Furnace 2 Cooling		
Total:			1.817	72.549

* Hot Cell Complex loads values are estimates since Hot Cell Complex design is ongoing

Table 3-7 CHWS-1B Summary of Heat Loads and Flows

PBS	Components		Heat load [MW]	Flow rate [kg/s]
PBS 24 VS	Vapour Suppression Tank System		0.16	6.4
PBS 26.PH.VV	VV-PHTS (Loss of offsite power only)		0.60	23.90
PBS 32.DS	Air Detritiation System		0.605	24.095
PBS 56	TBM Helium Coolant Systems		0.07	2.8
PBS 62.11 PBS 62.14 PBS 62.74	Tokamak Complex LACs for cooling of SIC cubicles		0.279	11.192
PBS 62.21* PBS 62.23*	Hot Cell Complex LACs		0.536	21.349
PBS 66.21	Furnace 1&2 Cooling Room 2	HE Furnace 1 Cooling	0.1	3.98
		HE Furnace 2 Cooling		
	Total:		2.350	93.716

The following specific settings were fixed on the Fathom Model:

- Two pumps are set with constant flow rate (while the third pump is in standby) at 36.13 kg/s for CHWS-1A and 47.72 kg/s for CHWS-1B.
- The cooling water is provided to all the components, listed in Table 3-6 and Table 3-7.
- Flow Control Valves, located on the inlet line of each component cooled by CHWS-1, were set for the required flow rate.

Using the pump fixed flow condition, one flow path in the piping layout needs to have a set pressure drop with FCV fully open (without control) in order to run Fathom properly. In general, this flow path corresponds to the one with most resistance; for both the systems, it is the one that feed TBS Helium circulators.
With the Fathom output data is possible to determinate pump minimum sizing requirements; FCVs open percent and the pressurizer set point.

In ***Case 2*** the pump curves, selected according to the Steady-State Case 1 output data.

The following specific settings were imposed in the Fathom Model:

- Two pump curves are used, one for CHWS-1A pumps and one for CHWS-1B.
- Fixed speed mode was selected.

3.3.2 Case 3: CHWS-1 Operating Condition with fixed Opening Setpoint of the FCVs

In this scenario, the output data of the CHWS-1 flow control valves, obtained running Case 2, are implemented in the Fathom Model.
The setting of the FCVs in the Model have been modified to make them work with fixed opening percentage and CV (obtained from Case 2).
This case has been used to double check the operating condition of the system and simulate the realistic behaviour of the FCVs. In fact, they are manual control valves; during the start-up of the system, they achieve a certain opening point and maintain it during the operating conditions.

3.3.3 Case 4: Bypass Valve setpoint during Cooling Mode

During CHWS-1B plasma operation, as described in **§2.3.1**, VV-PHTS is isolated from the system and the valves in its line are closed.
In order to maintain the operating condition of the pumps, the excess of water flows through the pumps bypass line.
This case is used to set the opening percentage of the bypass valve.

The following specific settings were fixed on the Fathom Model:

- Two CHWS-1B pumps are set with constant flow rate (while the third pump is in standby) at 47.72 kg/s.

- The isolation valves located in the VV-PHTS line are closed.
- The valve located in the pumps bypass line is set in order to guarantee a flowrate of 23.9 kg/s (value required from VV-PHTS in case of LOOP).

3.3.4 Case 5: Commissioning Operation

During commissioning operation all flow control valves, located at the inlet line of each cooled component, are fully closed.
Two of the three pumps are not running, they are isolated by closing the corresponding ball valves (located upstream and downstream each pump).
Cooling water, that passes through the operative pump, returns through the bypass line.
This case is also used to size the bypass line.

3.3.5 Case 6: Twin Pump Sizing (First Plasma Operation)

During First Plasma Operation, temporary piping connection between CHWS-H2 and CHWS-1 is located on the roof of the Diagnostic Building (B74-R1) while a connection between CHWS-1B and CHWS-1A is located on the Tritium Building (B14-L5) (as shown in Figure 2-6).
An in-line pump is placed in this connection in order to compensate the additional pressure losses in the First Plasma piping layout (**§4.1).**
After first plasma, this temporary connection will not be necessary anymore. Thus, CHWS-H2 and CHWS-1 will be disconnected and sealed.

CHWS-H2 must remove 0.388 MW and it must provide 15.972 kg/s to CHWS-1.
Heat load and flow requirements are to be met by CHWS-H2 chillers and pumps, respectively.
Thermal-hydraulic parameters required during First Plasma are listed in Table 3-8.

Table 3-8 Thermal-Hydraulic parameters during First Plasma

Description	Value	Units
Number of Connections:	1	
Flow rate	22.62	kg/s
Power	0.56	MW
Minimum P inlet at CHWS-H2 – CHWS-1 connection	0.7	MPa,g

Description	Value	Units
Required P Return at CHWS-H2 – CHWS-1connection	0.3	MPa,g
Maximum pressure drop	0.4	MPa,g

In this scenario, the cooling water is not be provided at the components served by CHWS-1. Only the Local Air Coolers (SIC LACs) located in the Tokamak Complex are fed during this operating mode, as listed in Table 3-9.

Table 3-9 CHWS-1 Components fed during First Plasma Operation

Fathom Object - me/ID	Fathom Tag	Location	Train	Flow Rate (kg/s)	Heat load (kW)
J44	6274AC-ACR-5501&1750	74-L3-11& 74-B2-12	CHWS-1B	1.492	37.5
J48	6211AC-ACR-5751	11-L3-04SW	CHWS-1B	0.2	4.1
J52	6211AC-ACR-4751	11-L2-04SW	CHWS-1B	0.5	12
J68	6211AC-ACR-1502&1751	11-B2-04SE& 11-B2-05SE	CHWS-1B	0.7	18.5
J74	6211AC-ACR-4752	11-L2-05SE	CHWS-1B	0.9	21.6
J80	6214AC-ACR-1751&9251	14-B1-07A	CHWS-1B	1.5	37.5
J84	214AC-ACR-5752&5751	14-L3-05A	CHWS-1B	2.08	52.2
J95	6211AC-ACR-4751	11-R1-04B	CHWS-1B	0.2	5
J116	6274AC-ACR-4501	74-L2-32	CHWS-1A	0.64	16.1
J120	6274AC-ACR-3501	74-L1-25	CHWS-1A	0.4	9.6
J124	6211AC-ACR-3502	11-L1-05NW	CHWS-1A	0.7	17.6
J129	6274AC-ACR-1501	74-B1-29	CHWS-1A	0.64	16
J132	6211AC-ACR-1501	11-B2-05NW	CHWS-1A	0.423	10.6

Fathom Object - me/ID	Fathom Tag	Location	Train	Flow Rate (kg/s)	Heat load (kW)
J139	6211AC-ACR-8502	11-R1-04A	CHWS-1A	0.2	5
J147	6211AC-ACR-5502	11-L3-04NE	CHWS-1A	0.243	6.1
J150	6214AC-ACR-4501&9451	14-L2-05A	CHWS-1A	2.2	54.2
J158	6211AC-ACG-3503	11-L1-04NE	CHWS-1A	0.73	18.3
J162	6211AC-ACR-1752&1504	11-B2-04NE& 11-B2-05NE	CHWS-1A	0.3	7.6
J165	6211AC-ACR-7016&7017	11-L5-04S	CHWS-1B	1.7	42.7
J170	6214AC-ACR-3501&9351	14-L1-04	CHWS-1A	1.55	38.9
J371	6211AC-ACR-7018&7019	11-L5-04N	CHWS-1A	1.48	37.2
J826	6211AC-ACR-7014&7015	11-L5-05S	CHWS-1B	1.92	48.2
J832	6211AC-ACR-7012&7013	11-L5-05N	CHWS-1A	1.92	48.2

The other components are isolated, closing the valves located in their inlet and outlet lines.

The system layout in this Steady-State Case has been modify:

- CHWS-1 chillers and pumps have been isolated; they are not operative during the First Plasma Operation.
- The components that are not fed by CHWS-1 during First Plasma Operation been isolated (closing the valves located in their inlet and outlet line).
- Temporary connection between CHWS-1 and CHWS-H2 has implemented in the Fathom Model and a twin pump is located in the inlet line of the connection.
- Temporary connection between CHWS-1A and CHWS-1B has implemented in the Fathom Model.

This case is used to verify the CHWS-1 interface requirements and to provide the twin pump sizing requirement during the First Plasma Operation.

Using the pump fixed flow condition, one flow path in the piping layout needs to have a set pressure drop with FCV fully open (without control) in order to run Fathom properly.
With the Fathom output data is possible to determine pump minimum sizing requirements and verify that the FCVs open percentage are in the acceptable range of values (between 20%-80%).

3.3.6 Case 7: First Plasma Operation

This case is used to verify the operating condition of CHWS-1 during First Plasma.
The system layout during this a-lysis is the same described in the **§3.3.5**.

In this scenario the pump curves, selected according to the Steady-State Case 7 output data, are used as “Pump Model” of the twin pump in Fathom.

3.3.7 Case 8: Post First Plasma Operation (PFPO-I)

After First Plasma Operations the connection between CHWS-1 and CHWS-H2 will be removed while the connection between CHWS-1B and CHWS-1A (B14-L5) is maintained.

During this operating mode the cooling water is provided to the SIC LACs located in the Tokamak Complex. The components, listed in Table 3-9, are fed during this operating state.

CHWS-1B chillers cool down the water from 12°C to 6°C while one CHWS-1B pump guarantees the flow to the required components (1W + 2S configuration). The pump bypass line is used in order to guarantee the operating condition.

After this operating mode, the temporary connection between CHWS-1A and 1B will be removed and the two systems will operate independently.

This case is used to verify the operating condition of CHWS-1 during Post First Plasma (PFPO-I).

The following modifications have been applied to the system layout in this Steady-State Case:

- CHWS-1A chillers and pumps have been isolated; they are not operative during Post First Plasma Operation.
- The cooling water is provided to the same components fed during First Plasma. The components that are not fed by CHWS-1 during First Plasma Operation have been isolated (closing the valves located in their inlet and outlet line).
- Temporary connection from CHWS-1A and CHWS-1B is implemented in the Fathom Model.
- CHWS-1B chillers and pump operate to guarantee the cooling water in all the system.
- The pump bypass line is used to control the flow through the operating CHWS-1B pump and to guarantee the operating conditions.

4 Steady-State Conditions Results

The results, obtained running several operating modes in Fathom, were used to size the main CHWS-1 components (pumps, FCVs and pressurizer) and to verify the main parameters of the system (**§A1**).

The procedure shown in Figure 4-1 has been followed in order to obtain the final design of the system and verify system operating conditions during Steady-State Modes.

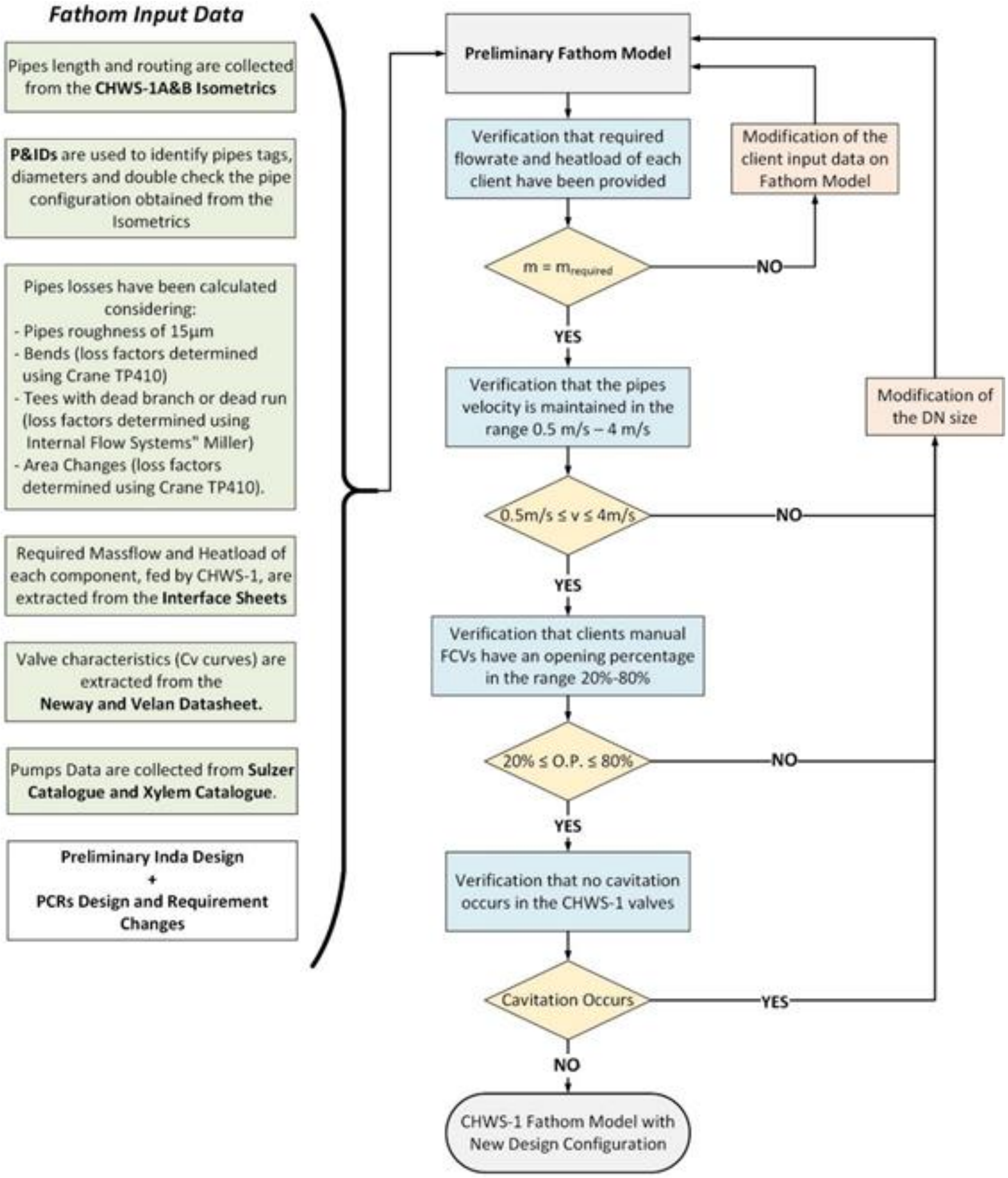


Figure 4-1: CHWS-1 Sizing Calculations- Flowchart

4.1 Sizing Requirements for CHWS-1 Pumps

In Steady-State Case 1, the pumps were modelled with a fixed flow and overall efficiency of 100%, in order to determine the required head.
The output data obtained are listed in Table 4-1.

Table 4-1 CHWS-1 Pump Sizing Calculation Results (Case 1)

Fathom Object Name/ID	P&ID Tag	Flow Rate [kg/s]	P_{In} [MPa]	P_{Out} [MPa]	dP [MPa]	dH [m]	dH + Margin [m]	Overall Power [kW]	$NPSH_A$ (m)
J25	26CH1B-PL-1003*	-	-	-	-	-	-	-	-
J29	26CH1B-PL-1002	47.905	0.19	1.01	0.82	84.09	92.50	26.33	19.07
J33	26CH1B-PL-1001	47.905	0.19	1.01	0.82	83.45	91.80	26.13	19.35
J222	26CH1A-PL-1003*	-	-	-	-	-	-	-	-
J226	26CH1A-PL-1002	36.415	0.18	0.96	0.78	79.23	87.15	17.82	18.76
J230	26CH1A-PL-1001	36.415	0.18	0.96	0.78	79.27	87.20	17.83	18.56

Despite the Hot Cell Complex layout is not fully developed, a 10% margin is added to the required head of the pumps by engineering judgment in order to cover possible Fathom uncertainties and to be conservative.

Pump degradation over the time should also be considered by the pump manufacturer, which finally results in having even more margin on the pump head: this type of margin is not considered in the Fathom calculations.

These sizing requirements were used to select the preliminary manufacturer datasheet (Figure 4-2 and Figure 4-3).
The selected pump curve is used as “Pump Model” in Steady-State Case 2.

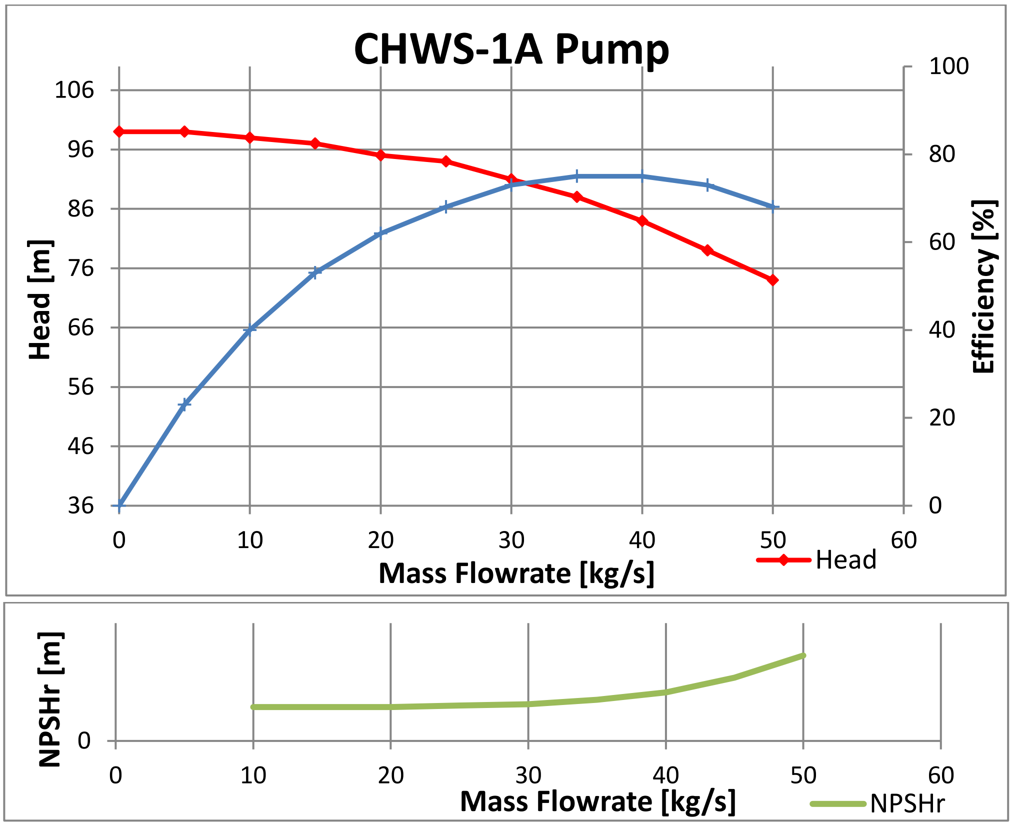


Figure 4-2: CHWS-1A Pump Curves

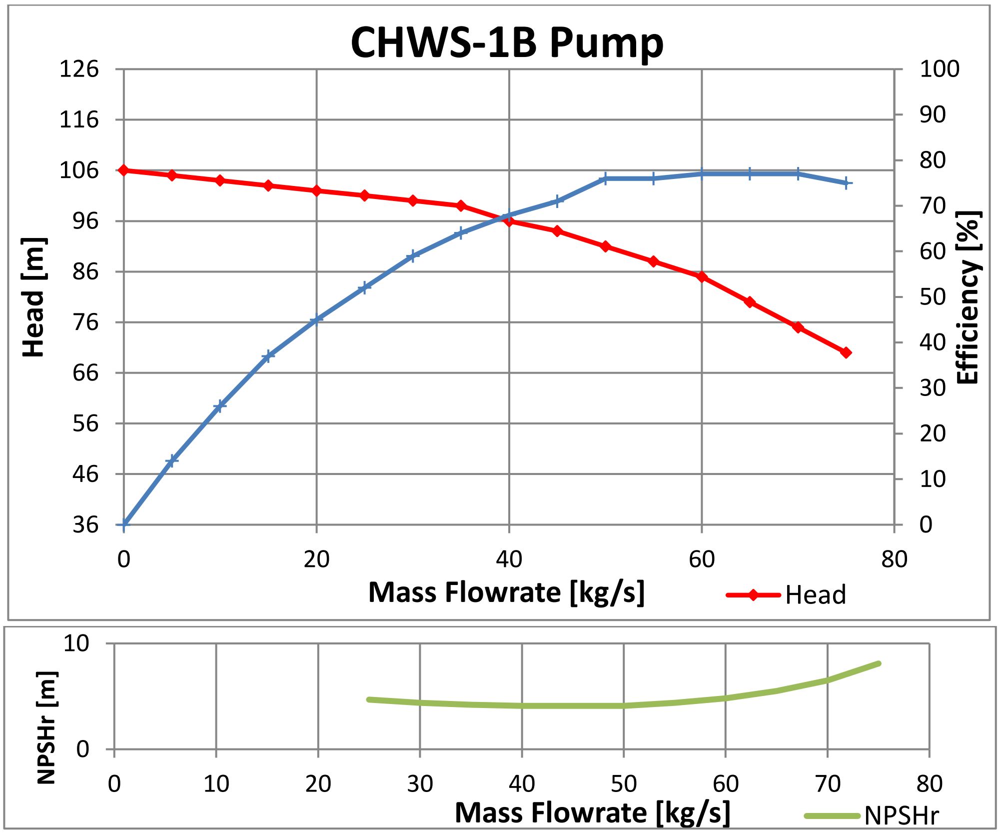


Figure 4-3: CHWS-1B Pump Curves

In Steady-State Case 7 a twin pump is used to maintain the required pressures in the IFPs between CHWS-1 and CHWS-H2 during first plasma.

The pump was selected in order to guarantee 0.7 MPa,g in the inlet IFP and 0.3 MPa,g in the outlet IFP.

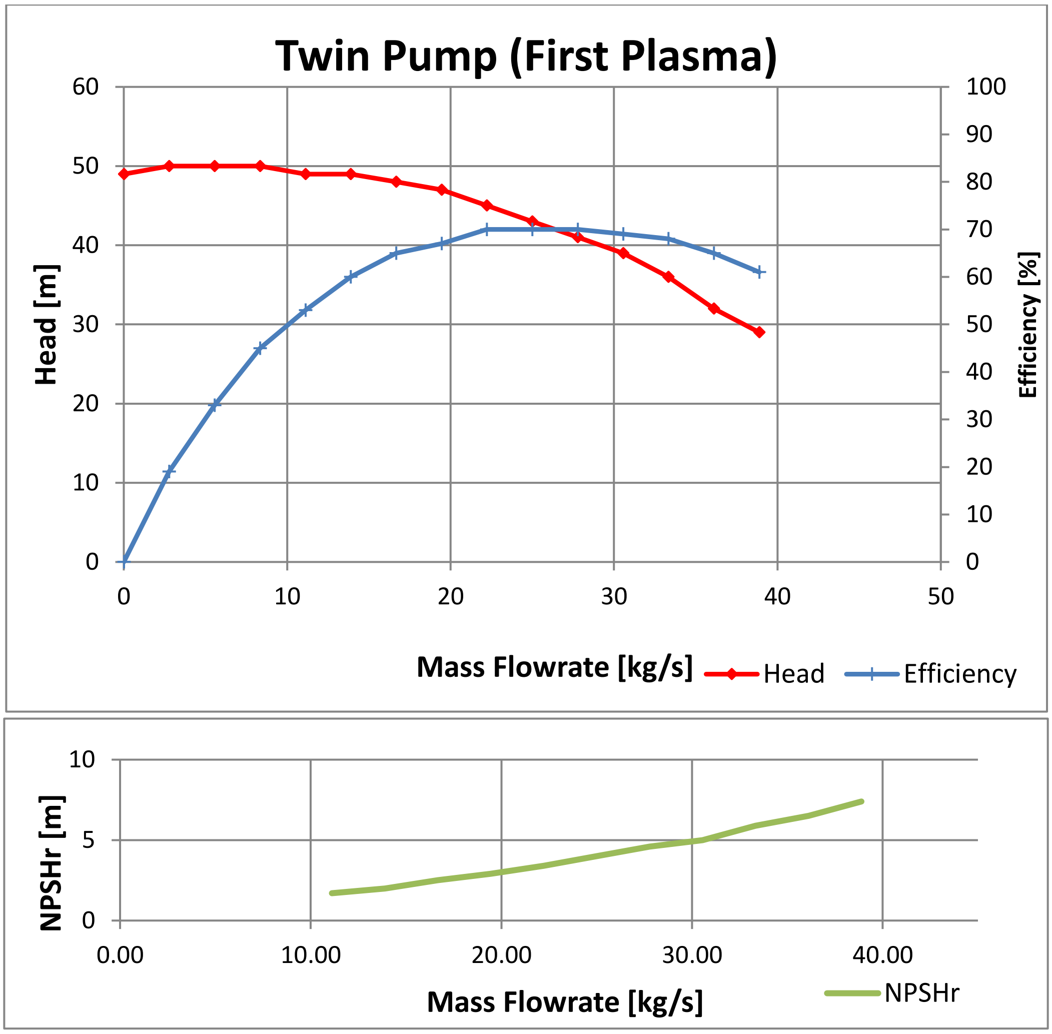


Figure 4-4: Twin Pump Curves (First Plasma)

4.2 Sizing Requirement for CHWS-1 Flow Control Valves

The conditions of FCVs, located in the line of each cooled component, during normal operations are extracted from the Fathom output.

They are manual flow control valves and their opening percentage is fixed in order to guarantee the required massflow to each component fed by CHWS-1.

Three set points need to be considered, the open percentage during first plasma operation, PFPO-I and PFPO-II.

4.3 Verification of Valve Cavitation

A final step in the FCVs selection consists in verifying that no cavitation occurs during all the system operating modes. Two methods have been used and all the CHWS-1 valves don't present cavitation issues.

In Figure 4-5 the procedure that has been followed.

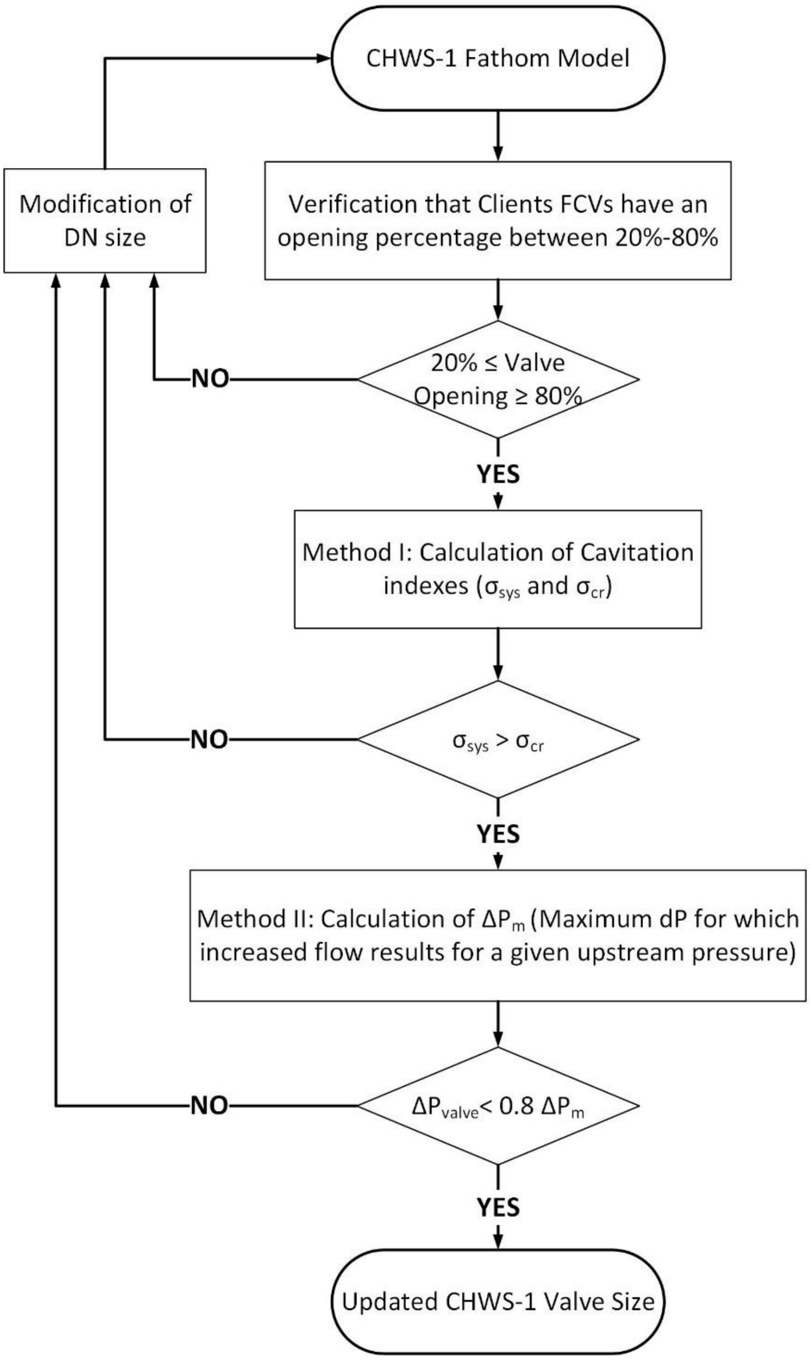


Figure 4-5: Verification of Valve Cavitation

4.3.1.1 First Cavitation Method

In order to verify if cavitation occurs in the CHWS-1 valves, cavitation indices have to be calculated.
In this analysis system cavitation index has been compared with cavitation indices obtained from experimental data for the considered valve.

System cavitation index is express as follows:

$$\sigma_{\mathrm{sys}} = \frac{P_d - P_v}{P_u - P_d}$$

- P_d = downstream pressure [bar,g]
- P_v =vapor pressure adjusted for temperature and atmospheric pressure (-1 bar,g for water at 12 °C), measured at sea level.
- P_u = upstream pressure [bar,g]

Cavitation indexes from experimental data are four: Incipient, Critical, Incipient Damage and Chocking. These data are typically reported for a given valve size and upstream test pressure.

Incipient cavitation is a conservative limit; it is used only when no disturbances can be tolerated and usually it’s too restrictive to be considered as design limit.

A globe valve with DN150 (P_{uo} = 60 psi and P_{vg0} = -12 psi) is used as test valve (Figure 4-6).

Critical and incipient damage limits have been considered.

$$\begin{cases} \sigma_{c,0} = 0.59 + 5.6C_d - 16C_d^2 + 90C_d^3 \\ \sigma_{id,0} = 0.48 - 6.1C_d + 53C_d^2 - 77C_d^3 \end{cases}$$

Where discharge coefficient, C_d, is calculated from equation:

$$C_d = \frac{v}{\sqrt{2g\Delta H + v^2}}$$

- ΔH = head throughout the valve (output data extracted from Fathom)
- v = fluid velocity in the pipe upstream the valve (output data extracted from Fathom)

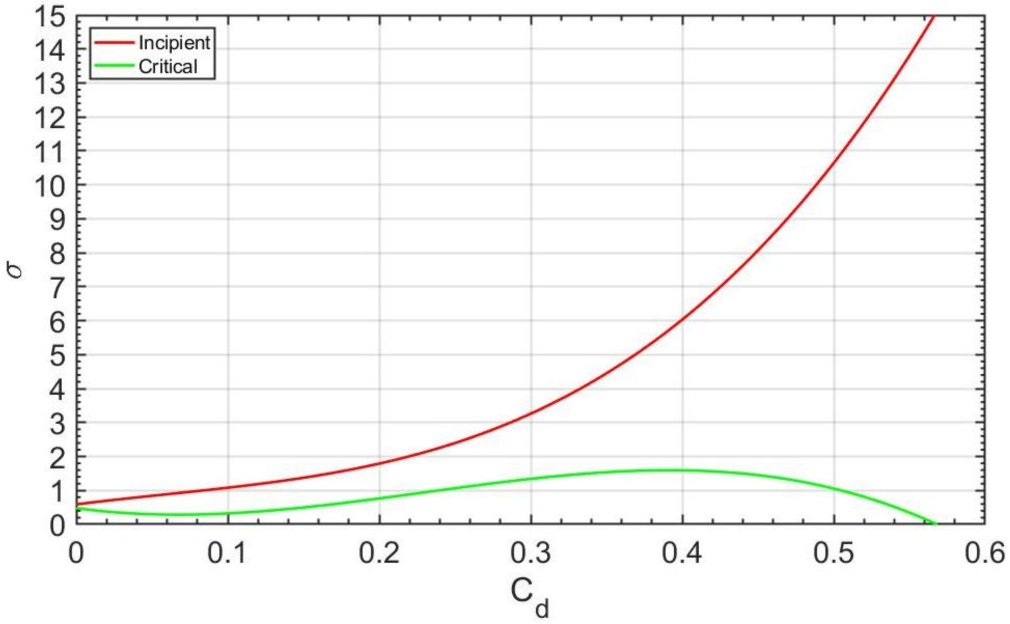


Figure 4-6 Critical and incipient damage for 6 in. globe valve

These indices are corrected for size and pressure scale effects by the following equations.

$$\begin{cases} \sigma_c = \text{PSE} \cdot \text{SSE} \ \cdot \sigma_{c,0} \\ \sigma_{id} = \text{PSE} \cdot \text{SSE} \ \cdot \sigma_{id,0} \end{cases}$$

Sizing scale effect (SSE) was calculated with the formula:

$$\text{SSE} = \left(\frac{D}{d}\right)^{Y}$$

- D = diameter of the system valves size [mm],
- d = diameter of the test valve [mm],
- Y = size scale exponent. $Y = (K_l)^{-0.25}$

  Where $K_l = 890 \frac{ID_v{}^4}{CV_v{}^2}$

Pressure scale effect (PSE) was calculated with the formula:

$$\text{PSE} = \left(\frac{P_u - P_{vg}}{P_{u0} - P_{vg0}}\right)^{X}$$

- P_u = CHWS-1 valve upstream pressure [bar]
- P_{vg} = vapor pressure adjusted for temperature and atmospheric pressure (−1 bar,g)
- P_{u0} = test valve upstream pressure (4.83 bar,g)

- P_{vg0} = vapor pressure from test (-0.83 bar,g)

Since $\sigma_{sys} > \sigma_c > \sigma_{id}$ cavitation doesn't occur.

4.3.2 Second Cavitation Method

The flow through the valves can be expressed as proportional to the square root of the pressure drop. This proportion is no more valid when the pressure drops below the vapor pressure.

When considering the valve susceptibility to cavitation, a characteristic of importance is the valve pressure recovery factor, F_L. It accounts for the influence of the valve geometry on its capacity at choked flow conditions.

Maximum pressure drop through the valve, for which increased flow resulting for a given upstream pressure, was calculated following the expression:

$$\Delta P_m = F_L^2(P_u - P_{vc})$$

- P_u = CHWS-1 valve upstream pressure [bar]
- F_L = valve pressure recovery factors (0.9 for single port globe valve)
- P_{vc} = Vena contracta pressure [bar].

Vena contracta pressure is not readily measurable, it can be expressed as:

$$P_{vc} = F_F P_V$$

- F_F = Fluid critical pressure ratio factor. $F_F = 0.96 - 0.28\sqrt{\frac{P_v}{P_c}}$
- Pv = Fluid vapor pressure (0.014 bar)
- Pc = Fluid critical pressure (220.5 bar) is referred to as the Choked Flow Equation. It has been used to determine allowable pressure drops for valves to avoid cavitation damage.

ΔP_m equation is referred to the choked flow conditions.
In order to set a first cut in evaluation criteria for valves used in throttled service, the following condition has been imposed:

$$\Delta p_{valve} < 0.8 * \Delta p_m$$

4.4 Pressurizer Sizing Requirement

CHWS-1 pressurizer is designed to perform the following functions:

- Pressurize the system in order to maintain the water in a subcooled liquid phase.
- Guarantee an expansion tank for fluid expansion and contraction associated with the temperature variations expected from off mode (environment temperature of 45°C) to cooling mode (minimum temperature of 6°C).
- Maintain sufficient NPSH available on the suction lines of the pumps.
- Provide overpressure protection for the system.

4.4.1 PZR Design Considerations

The following points should also be considered:

- PZR Aspect Ratio: The PZR inner volume is 1 m^3. In order to have the lowest PRZ weight for the given volume, the optimum L/D ratio has to be calculated (where L is the total length of the straight portion and D is the inner diameter).

  This parameter varies with pressure, allowable stress, corrosion allowance ad joint efficient.
  The optimum aspect ratio has been calculated according to Procedure 2-19, Method 2, from the Technical Guide "Pressure Vessel Design Manual" (Dennis MOSS) and ASME Boiler and Pressure Vessel Code Section II.

  L/D is related to a factor (F_2) that was calculated according to the formula:

$$F_2 = C * \left(\frac{S_{max} * E}{p_{design}} - 0.6 \right) = 7''$$

  - C is the corrosion allowance $C = 1.6$ mm .
  - S_{max} is the design stress intensity limit. $S = 126$ MPa.
  - E is the joint efficiency. $E = 1$.
  - p_{design} is the design pressure of the system. $p_{design} = 0.9$ MPa .

  The optimum L/D value is 2.7.

  New diameter and inner height of the PZR are:

$$\begin{cases} D = 0.75 \text{ m} \\ L = 2.014 \text{ m} \end{cases}$$

  This configuration guarantees a lowest PRZ weight.

- PZR Wall Thickness: Minimum required thickness is calculated according to ASME Boiler and Pressure Vessel Code Section II.

$$t_{PRZ}^{min} = \frac{D}{2}\left(\exp\left[\frac{p_{design}}{S_{max} * E}\right]\right)$$

- D is the inner diameter of the pressurizer. $D = 0.75$ m.
- P_{design} is the design pressure of the system. p_{PRZ} =1.67.
- S_{max} is the design stress intensity limit. $S = 126$ MPa (Below 100 °C).
- E is the weld joint efficiency of PZR. $E = 0.8$.

Table 4-2 PZR Aspect Ratio and Wall Thickness

Description	**Units**	**Value**
Design pressure	MPa	0.9
Weld joint efficiency (E)	-	0.80
Design stress intensity limit (S_{max})	MPa	126.00
Corrosion allowance (C)	mm	1.60
Corrosion allowance (C)	"	0.06
F2 Coefficient	"	7
V_{cyl}	"	30.58
Original L/D	-	2.15
Optimum aspect ratio	-	2.70
New Diameter	m	0.75
New Length	m	2.01
New L/D	-	2.68
Wall thickness (t_{PRZ})	mm	3.36
Wall thickness + 20% margin	mm	4.04

4.4.2 PZR Volume

PZR total volume consists of four volume allocations.

4.4.2.1 Minimum PZR Level

Last tap in the pressurizer is located at the bottom of the PZR vertical cylinder.
This volume should be always full of water during cooling mode in order to avoid formation of vortex and provide a sufficient NPSH at the pumps.

Maximum surge line flowrate of PZR during normal operation is equal to CHWS-1 maximum water contraction. Maximum contraction rate is obtained during the transition from off mode (45°C) to cooling mode (6°C) and is calculated as follows:

$$\begin{cases} Q = \rho_w V_{w,CHWS-1} c_p \dfrac{dT}{dt} \\ \Gamma = V_{w,CHWS-1} \dfrac{d\rho}{dt} \end{cases}$$

Minimum submergence for preventing formation of vortex in PZR during normal operation is preliminary calculated according to the following formula:

$$Sub = ID_{\text{surge line}} + \frac{\Gamma}{\left(1069 * D_{PZR}{}^{1.5}\right)}$$

Table 4-3: Minimum PZR Level Calculation

Description	**General calculation**	**Units**	**CHWS 1A**	**CHWS 1B**
Average Density, ρ_w	$\rho_w = \dfrac{\rho(45°C, p_{PZR}) + \rho(6°C, p_{PZR})}{2}$	kg/m^3	995.71	995.71
Maximum Chillers Heat Removal, Q		MW	1.8	2.46
Average specific heat capacity, $C_{p,w}$	$c_{p,w} = \dfrac{c_p(45°C, p_{PZR}) + c_p(6°C, p_{PZR})}{2}$	kJ/kgK	4.18	4.18
Maximum Contraction Flowrate, Γ	$\Gamma = \dfrac{Q}{\rho_w c_{p,w}} \dfrac{d\rho}{dT}$	l/s	0.03	0.04
Surge Line Inlet Diameter, ID		m	0.04	0.04

Description	General calculation	Units	CHWS 1A	CHWS 1B
Minimum Submergence for Preventing Vortex Formation	$\mathrm{Sub} = \mathrm{ID}_{\text{surge line}} + \frac{\Gamma}{1069 * \mathrm{D}_{\text{surge line}}{}^{1.5}}$	m	0.05	0.05
Height of the Lower Tap		m	0.19	0.19

PRZ Lower tap is above the minimum submergence limit, so there is no formation of vortex during normal operation.

4.4.2.2 Minimum Nitrogen Space

The highest tap of the PZR water level sensor was assumed at elevation 10% higher than the VHLA.
At the maximum PZR water level, the volume occupied by the nitrogen must be at least 10% of total PRZ volume.

Table 4-4: PZR Minimum Nitrogen Space Calculation

Description	General calculation	Units	Value
Upper Head Volume	$\mathrm{V}_{\mathrm{UH}} = (\pi/24) * \mathrm{D}_{\mathrm{PZR}}{}^{3}$	m^3	0.06
Height of the Higher Tap from TL	$\mathrm{L}_{\mathrm{HT}} = 1.1 * \mathrm{L}_{\mathrm{VHLA}}$	m	1.30
Volume Above Higher Tap	$\mathrm{V}_{\text{above VHLA}} = \mathrm{V}_{\mathrm{PRZ}} - \mathrm{V}_{\mathrm{HH}} - \frac{\pi \mathrm{D}_{\mathrm{PZR}}^{2}}{4} \mathrm{L}_{\mathrm{HT}}$	m	0.31
Required N_2 volume at the maximum PZR water level	$\mathrm{V}_{\mathrm{min},\mathrm{N}_2} = 0.1 * \mathrm{V}_{\mathrm{PZR}}$	m	0.10

In the current PZR design the required minimum nitrogen volume is respected.

4.4.2.3 Operating Margin

This volume corresponds to the PRZ operating margin. This margin must cover the PRZ level measurement uncertainly and is assumed as ±5% MR (2 σ , two-sided distribution, 95% confidence).
This margin as to be divided in 2 equal parts and added at the bottom of the minimum expected PRZ level and at the top of the maximum expected PRZ level.

Measuring error is calculated using the formula: $L_{E\text{-}PZR}$ = (1.645 / 2) x 5% MR x (2.014) = 0.083 m and total operating margin height is $L_{M\text{-}PZR}$ = 2* $L_{E\text{-}PZR}$= 0.166 m.
Total operating margin volume is $V_{M\text{-}PRZ}$ = 0.073 m^3.

4.4.2.4 Nominal Surge Space

This allocation represents the fluid volume due to the expansion and contraction during CHWS-1 normal operations. It is determined considering the maximum temperature variation of the water and the corresponding volume variations.

The size of the pressurizer is based on the variation of cooling water volume from ambient temperature (45 °C) to final operative temperature (6 °C).
As the heat load increases from 0% to 100%, the temperature at each fed component increases from initial temperature, 6 °C to the final temperature 12 °C based on the heat load which results in volume increasing of the cooling water; this expansion in volume is marginal and it is not considered for the pressurizer sizing.

A measurement uncertainty of ±2% MR (2 σ , two-sided distribution, 95% confidence) is considered, assuming conservatively a process temperature range of 50°C (L_{E-PRZ} =1.645 /2 x 2% MR x (50 °C)).

PZR design must thus account an error of 0.9 °C.

Two cases were analysed:

- PZR sizing case. In this case, the maximum variation of water volume in the PZR has been studied. The maximum water contraction in PZR is due to the variation of temperature from 45°C (maximum off mode temperature) to 6°C (minimum temperature during cooling mode).
- PZR variations during cooling mode. In this case the water volume variation is due to the temperature range from 6°C to 12°C (operating temperatures during cooling mode).

Table 4-5 PZR Surge Volume Calculation

Description	**General calculation**	**Units**	**CHWS-1A**	**CHWS-1B**
V_{wtr}: Water volume in the system		m^3	28.05	39.38
PZR Sizing Case				
T_{cold}: Min Temperature	6°C - 0.9 °C	°C	5.10	5.10
ρ_{cold}: Max Density	ρ (T_{cold} , p_{PZR})	kg/m^3	1000.00	1000.00
T_{hot}: Max Temperature	45°C + 0.9°C	°C	45.90	45.90
ρ_{hot}: Min Density	ρ (T_{hot} , p_{PZR})	kg/m^3	989.87	989.87
ΔM_{tot}: Surge Mass	Vwtr* (ρ_{hot} - ρc_{old})	kg	284.03	398.71
V_{surge}: Surge Volume (Between 5.1 and 45.9 °C)	ΔM_{tot} /ρ_{hot}	m^3	0.29	0.40
L_{surge}: Surge Height	4*V_{surge}/(π D_{PZR}^2)	m	0.65	0.91

Description	General calculation	Units	CHWS-1A	CHWS-1B
(Between 5.1 and 45.9 °C)				
Water Volume Variation in PZR during Cooling Mode				
T_{cold}: Min Temperature	6°C - 0.9 °C	°C	5.10	5.10
ρ_{cold}: Max Density	ρ (T_{cold} , p_{PZR})	kg/m^3	1000.00	1000.00
T_{hot}: Max Temperature	12°C + 0.9°C	°C	12.90	12.90
ρ_{hot}: Min Density	ρ (T_{hot} , p_{PZR})	kg/m^3	999.42	999.42
ΔM_{totC}: Surge Mass (Between 5.1 and 12.9 °C)	$(V_{wtr}/2)*(\rho_{hot} - \rho_{cold})$	kg	8.07	11.33
V_{surgeC}: Surge Volume (Between 5.1 and 12.9°C)	$\Delta M_{tot} / \rho_{hot}$	m^3	0.01	0.01
L_{surgeC}: Surge Height (Between 5.1 and 12.9°C)	$4*V_{surgeC}/(\pi D_{PZR}^2)$	m	0.02	0.03

4.4.3 PRV set point

Pressurizer is equipped with a safety relief valve.
The set pressure is determined so that the peak pressure in the lowest component, cooled by CHWS-1, doesn't exceed the system design pressure during normal operation of the pumps.

$$p_{\text{set point}} = P2 + \Delta p_h = 0.9$$

- P2 = 2.1 MPa is the design pressure (as explained in Appendix 0).
- Δp_h is the pressure due to height difference between the component, located in the lowest zone, and the pressurizer.

An allowable overpressure of 10% was considered.
Relieving pressure is the total of set pressure plus overpressure.

$$p_{\text{Relieving}} = p_{\text{set point}} + \text{Overpressure} = 1.1 * p_{\text{set point}} = 1 \text{ MPa}$$

In order to uniform the operating conditions of CHWS-1A and CHWS-1B, the more restrictive value of relieving pressure was considered for both the systems.

Table 4-6 PRV set point

Description	General calculation	Units	CHWS-1A	CHWS-1B
Max allowable pressure in zone, P2	Design pressure	MPa	2.10	2.10
Static pressure, Δp_h	Pressure due to height difference between the lowest component, served by CHWS-1, and PZR	MPa	0.31	0.27
Pump head during normal operation, Δp_{pump}		MPa	0.87	0.92
PRV set point	$p_{\text{set point}} = p_2 - \Delta p_h - \Delta p_{\text{pump}}$	MPa	0.9	0.9
Overpressure	10% margin	MPa	0.01	0.01
Relieving Pressure	$1.1 * p_{\text{set point}}$	MPa	1.00	1.00

4.5 Verification of Interface Requirements

All the interface requirements of the systems cooled by CHWS-1 have been compared with the results extracted by the Fathom outputs.
During CHWS-1 operating states:

- Heat load and flowrate required by all the cooled components are fulfilled.
- Temperature requirements are achieved. For each component, 6°C chiller water is provided and the maximum return temperature from the client system is 12°C.
- Pressure, measured by Fathom at the interface point, is below the maximum supply pressure indicate in the IS.

CHWS-1 (PBS26) and VVPSS (PBS 24.VP) Interface Requirements

Table 4-7 Thermal-hydraulic parameters for CHWS-1 – VVPSS updated interface requirements

Loop Serving Component →	**CHWS-1A**	**CHWS-1B**
Parameter ↓ **Location→**	**11-B2-01**	**11-B2-01**
Heat to be removed by CHW [max, MW]	0.16	0.16
Supply pressure (Fathom output data) [MPa,g]	0.78	0.79

Loop Serving Component →	**CHWS-1A**	**CHWS-1B**
Parameter ↓ Location→	**11-B2-01**	**11-B2-01**
Supply pressure (from IS) [max, MPa,g]	(0. 9)	(0. 9)
Inlet temperature [°C]	6	6
Outlet temperature [°C]	12	12
Pressure drop within client system [max nominal flow, MPa]	(0.2)	(0.2)
Required flow rate [nominal, kg/s]	6.4	6.4

CHWS-1 (PBS26) and Tritium Plant (PBS32) Interface Requirements

Table 4-8 Thermal-hydraulic parameters for CHWS-1 – PBS 32 updated interface requirements

Loop Serving Component →	**CHWS-1A**		**CHWS-1B**	
Parameter ↓ Location →	**14-L2-21**	**21-L3-11**	**14-L3-21**	**21-L3-14**
Heat to be removed by CHW [max, MW]	0.39	0.215	0.39	0.215
CHW supply pressure (Fathom output data) [MPa,g]	0.67	0.49	0.50	0.50
CHW supply pressure (from IS) [max, MPa,g]	(0.7) *	(0.55) *	(0.5) *	(0.5) *
CHW inlet temperature [°C]	6	6	6	6
CHW outlet temperature [°C]	12	12	12	12
Pressure drop within client system [max nominal flow, MPa]	(0.2)	(0.2)	(0.2)	(0.2)
Required CHW flow rate [nominal, kg/s]	15.54	8.56	15.54	8.56
Total Headload [MW]	0.605		0.605	
Total Flow Rate [nominal, kg/s]	24.1		24.1	

CHWS-1 (PBS26) and TBMS (PBS56) Interface Requirements

Table 4-9 Thermal-hydraulic parameters for CHWS-1 – TBMS updated interface requirements

Loop Serving Component →	**CHWS-1A**	**CHWS-1B**
Parameter ↓ Location →	**14-L4-20**	**11-L4-04**
Heat to be removed by CHW [max, MW]	0.11	0.070
CHW supply pressure (Fathom output data) [MPa,g]	0.64	0.66
CHW supply pressure (from IS) [max, MPa,g]	(0. 8)	(0. 8)
CHW inlet temperature [°C]	6	6
CHW outlet temperature [°C]	12	12
Pressure drop within client system [max nominal flow, MPa]	(0. 4)	(0. 4)
Required CHW flow rate [nominal, kg/s]	4.38	2.79

CHWS-1 (PBS26) and VV-PHTS (PBS26. PH) Interface Requirements

Table 4-10 Thermal-hydraulic parameters for CHWS-1 – VV-PHTS updated interface requirements

Loop Serving Component →	**CHWS-1B**
Parameter ↓ Location →	**11-B1**
Heat to be removed by CHW [max, MW]	0.6
CHW supply pressure (Fathom output data) [MPa,g]	0.80
CHW supply pressure (from IS) [max, MPa,g]	(0.8)
CWS inlet temperature [°C]	6
CWS outlet temperature [°C]	12
Pressure drop within client system [MPa]	(0. 4)
Required CHW flow rate [nominal, kg/s]	23.9

CHWS-1 (PBS26) and Tokamak Complex LACs (62.11, 62.14, 62.74)

Table 4-11 Thermal-hydraulic parameters for CHWS-1 – 62.11/14/74 LACs updated interface

Location	**Train**	**Heat load [kW]**	**P_{inlet} (Fathom) [MPa,g]**	**P_{inlet} (IS data) [MPa,g]**	**Inlet Temperature [°C]**	**Outlet Temperature [°C]**	**dP [MPa]**	**Flow rate [kg/s]**
74-L2-32	CHWS-1A	16.1	0.63	(1.0)	6	12	(0.2)	0.64
74-L1-25	CHWS-1A	9.6	0.67	(1.0)	6	12	(0.2)	0.40
11-L1-05NW	CHWS-1A	17.6	0.69	(1.0)	6	12	(0.2)	0.70
74-B1-29	CHWS-1A	16.0	0.77	(1.0)	6	12	(0.2)	0.64
11-B2-05NW	CHWS-1A	10.6	0.77	(1.0)	6	12	(0.2)	0.42
11-R1-04A	CHWS-1A	5.0	0.64	(1.0)	6	12	(0.2)	0.20
11-L3-04NE	CHWS-1A	6.1	0.88	(1.0)	6	12	(0.2)	0.24
14-L2-05A	CHWS-1A	54.2	0.60	(1.0)	6	12	(0.2)	2.20
11-L1-04NE	CHWS-1A	18.3	0.66	(1.0)	6	12	(0.2)	0.73
11-B2-04NE& 11-B2-05NE	CHWS-1A	7.6	0.72	(1.0)	6	12	(0.2)	0.300
14-L1-04	CHWS-1A	38.9	0.67	(1.0)	6	12	(0.2)	1.550
11-L5-04N	CHWS-1A	37.2	0.61	(1.0)	6	12	(0.2)	1.480
11-L5-05N	CHWS-1A	48.2	0.61	(1.0)	6	12	(0.2)	1.92
74-L3-11& 74-B2-12	CHWS-1B	37.5	0.43	(1.0)	6	12	(0.2)	1.492
11-L3-04SW	CHWS-1B	4.1	0.95	(1.0)	6	12	(0.2)	0.2
11-L2-04SW	CHWS-1B	12.0	0.99	(1.0)	6	12	(0.2)	0.500
11-B2-04SE& 11-B2-05SE	CHWS-1B	18.5	0.61	(1.0)	6	12	(0.2)	0.700
11-L2-05SE	CHWS-1B	21.6	1.00	(1.0)	6	12	(0.2)	0.900

Location	Train	Heat load [kW]	P_{inlet} (Fathom) [MPa,g]	P_{inlet} (IS data) [MPa,g]	Inlet Temperature [°C]	Outlet Temperature [°C]	dP [MPa]	Flow rate [kg/s]
14-B1-07A	CHWS-1B	37.5	0.64	(1.0)	6	12	(0.2)	1.500
14-L3-05A	CHWS-1B	52.2	0.83	(1.0)	6	12	(0.2)	2.080
11-R1-04B	CHWS-1B	5.0	0.57	(1.0)	6	12	(0.2)	0.200
11-L5-04S	CHWS-1B	42.7	0.77	(1.0)	6	12	(0.2)	1.700
11-L5-05S	CHWS-1B	48.2	0.78	(1.0)	6	12	(0.2)	1.920

CHWS-1 (PBS26) and Hot Cell Complex LACs (62.21, 62.23, 62.24, 66.21)

Table 4-12 Thermal-hydraulic parameters for CHWS-1 – PBS 62.21/23/24 LACs updated interface

Location	Train	Heat load [kW]	P_{inlet} (Fathom) [MPa,g]	P_{inlet} (IS data) [MPa,g]	Inlet Temperature [°C]	Outlet Temperature [°C]	dP [MPa]	Flow rate [kg/s]
21-L3-09	CHWS-1A	26.50	0.51	(1.0)	6	12	(0. 2)	1.06
21-L3-08	CHWS-1A	24.50	0.52	(1.0)	6	12	(0. 2)	0.98
21-B2-03	CHWS-1A	1.70	0.84	(1.0)	6	12	(0. 2)	0.07
21-B2-20	CHWS-1A	2.69	0.75	(1.0)	6	12	(0. 2)	0.11
21-L1-14	CHWS-1A	16.06	0.59	(1.0)	6	12	(0. 2)	0.64
21-L1-10	CHWS-1A	4.76	0.63	(1.0)	6	12	(0. 2)	0.19
21-L1-12	CHWS-1A	3.74	0.60	(1.0)	6	12	(0. 2)	0.15
23-L1-23	CHWS-1A	10.42	0.59	(1.0)	6	12	(0. 2)	0.415
23-L1-22	CHWS-1A	13.79	0.59	(1.0)	6	12	(0. 2)	0.55
23-L1-21	CHWS-1A	7.05	0.59	(1.0)	6	12	(0. 2)	0.28
21-B1-20	CHWS-1A	2.69	0.70	(1.0)	6	12	(0. 2)	0.11
21-B1-17	CHWS-1A	41.27	0.78	(1.0)	6	12	(0. 2)	1.64

Location	**Train**	**Heat load [kW]**	**P_{inlet} (Fathom) [MPa,g]**	**P_{inlet} (IS data) [MPa,g]**	**Inlet Temperature [°C]**	**Outlet Temperature [°C]**	**dP [MPa]**	**Flow rate [kg/s]**
21-B1-14	CHWS-1A	40.86	0.79	(1.0)	6	12	(0. 2)	1.63
21-B2-17	CHWS-1A	41.27	0.82	(1.0)	6	12	(0. 2)	1.64
21-B2-14	CHWS-1A	40.86	0.84	(1.0)	6	12	(0. 2)	1.63
21-B2-06	CHWS-1A	1.80	0.84	(1.0)	6	12	(0. 2)	0.072
21-B2-30	CHWS-1A	2.17	0.75	(1.0)	6	12	(0. 2)	0.09
21-B2-29	CHWS-1A	0.90	0.76	(1.0)	6	12	(0. 2)	0.04
21-B2-15	CHWS-1A	58.13	0.79	(1.0)	6	12	(0. 2)	2.32
21-B2-32	CHWS-1A	36.64	0.78	(1.0)	6	12	(0. 2)	0.27
21-B2-27	CHWS-1A	10.01	0.78	(1.0)	6	12	(0. 2)	0.4
21-B2-21	CHWS-1A	100.00	0.81	(1.0)	6	12	(0. 2)	3.983
21-L3-11	CHWS-1A	215.00	0.49	(1.0)	6	12	(0. 2)	2.55
24-L2M-02	CHWS-1A	83.75	0.58	(1.0)	6	12	(0. 2)	3.34
21-L1-18	CHWS-1A	2.18	0.62	(1.0)	6	12	(0. 2)	0.087
21-L1-29A	CHWS-1A	2.36	0.61	(1.0)	6	12	(0. 2)	0.094
21-L1-17	CHWS-1A	5.68	0.59	(1.0)	6	12	(0. 2)	0.23
21-L3-13	CHWS-1A	32.30	0.45	(1.0)	6	12	(0. 2)	1.29
21-B2-19	CHWS-1A	1.70	0.74	(1.0)	6	12	(0. 2)	0.07
21-L3-14	CHWS-1B	72.91	0.52	(1.0)	6	12	(0. 2)	2.9
24-L3M-01	CHWS-1B	108.57	0.48	(1.0)	6	12	(0. 2)	4.32
21-L2-10	CHWS-1B	40.14	0.57	(1.0)	6	12	(0. 2)	1.6
21-L2-09	CHWS-1B	52.68	0.56	(1.0)	6	12	(0. 2)	2.1
21-L2-13	CHWS-1B	43.20	0.59	(1.0)	6	12	(0. 2)	1.72
21-B1-18	CHWS-1B	14.20	0.78	(1.0)	6	12	(0. 2)	0.57

Location	Train	Heat load [kW]	P_{inlet} (Fathom) [MPa,g]	P_{inlet} (IS data) [MPa,g]	Inlet Temperature [°C]	Outlet Temperature [°C]	dP [MPa]	Flow rate [kg/s]
21-L1-19	CHWS-1B	2.17	0.61	(1.0)	6	12	(0. 2)	0.09
21-L1-29B	CHWS-1B	2.36	0.62	(1.0)	6	12	(0. 2)	0.094
21-L1-12	CHWS-1B	3.74	0.60	(1.0)	6	12	(0. 2)	0.15
21-L1-10	CHWS-1B	4.76	0.63	(1.0)	6	12	(0. 2)	0.19
21-L1-14	CHWS-1B	16.06	0.59	(1.0)	6	12	(0. 2)	0.64
21-L1-17	CHWS-1B	5.68	0.59	(1.0)	6	12	(0. 2)	0.23
21-B1-37	CHWS-1B	73.53	0.73	(1.0)	6	12	(0. 2)	2.93
21-B1-14	CHWS-1B	40.86	0.79	(1.0)	6	12	(0. 2)	1.63
21-B1-17	CHWS-1B	41.27	0.78	(1.0)	6	12	(0. 2)	1.64
21-B2-30	CHWS-1B	2.17	0.75	(1.0)	6	12	(0. 2)	0.09
21-B1-07	CHWS-1B	1.32	0.74	(1.0)	6	12	(0. 2)	0.053
21-B2-14	CHWS-1B	40.86	0.84	(1.0)	6	12	(0. 2)	1.63
21-B2-06	CHWS-1B	1.80	0.84	(1.0)	6	12	(0. 2)	0.072
21-B2-18	CHWS-1B	100.00	0.73	(1.0)	6	12	(0. 2)	3.98
23-L2-09	CHWS-1B	10.63	0.59	(1.0)	6	12	(0. 2)	0.42

5 CHWS-1 Functional Analysis and I&C Requirements

The objective of this chapter is to design all the required functions, including all the situations normal, incidental and accidental ones to maintain the plant in a safe operation domain.
These analyses are based on the safety principle of defence in depth in order to prevent, detect and/or mitigate situations.

5.1 CHWS-1 Safety I&C Philosophy

The safety I&C philosophy, applied to CHWS-1, is based on the definition of the I&C safety functions.

These functions are to control, operate and/or monitor a defined part of the process to prevent a Design Basis Events and Beyond Design Basis Accidents (DBE/BDBA) from leading to unacceptable consequences, or to mitigate its consequences.
The implementations of the safety functions are performed by the I&C safety system.

5.2 Safety I&C Design

The protection system (safety I&C system) detects deviation from acceptable plant conditions and initiates actions to prevent an unsafe or potentially unsafe condition of the plant. Therefore, the protection system is required to:

- *Detect* that a process variable has reached the set point.
- *Initiate*, in correct sequence, the emergency operating procedures (EOPs) required by the corresponding safety function.
- *Display* the process variable value to the operator for use in taking manual protective action. For automatic actions, the safety system should allow for the acknowledgement of an alarm. Before the acknowledgment of an alarm, it should not be possible for the operator to activate an actuator that is receiving a safety order. After acknowledgement, it is possible to change the state of actuators submitted to the safety order.

  As an example, if the operator wants to open an isolation valve that has been closed by the safety system, after acknowledging the alarm they should be capable of doing it. Hence, the operator should have the possibility to inhibit the criteria that trig the closure of the valve.

The I&C safety system must be designed for high functional reliability and periodic testability.

The architecture of the I&C safety system of CHWS-1 implements the principles of redundancy and independency.

Redundancy implies that the function of a failing sensor/channel of the I&C system is taken over by a backup sensor/channel of the same construction to cope with the single failure criterion.

The independency prevents:

- propagation of failures between redundant parts within I&C system.
- common cause failures due to common internal system hazards (e.g. loss of one electrical power train).

Therefore, redundancy and independence into the protection system shall be sufficient to assure that:

- no single failure and CCF results in loss of the safety protection functions,

- removal from service of any component or channel does not result in loss of the required minimum redundancy.

The I&C safety system consists of sensors, a logic subsystem and final elements.

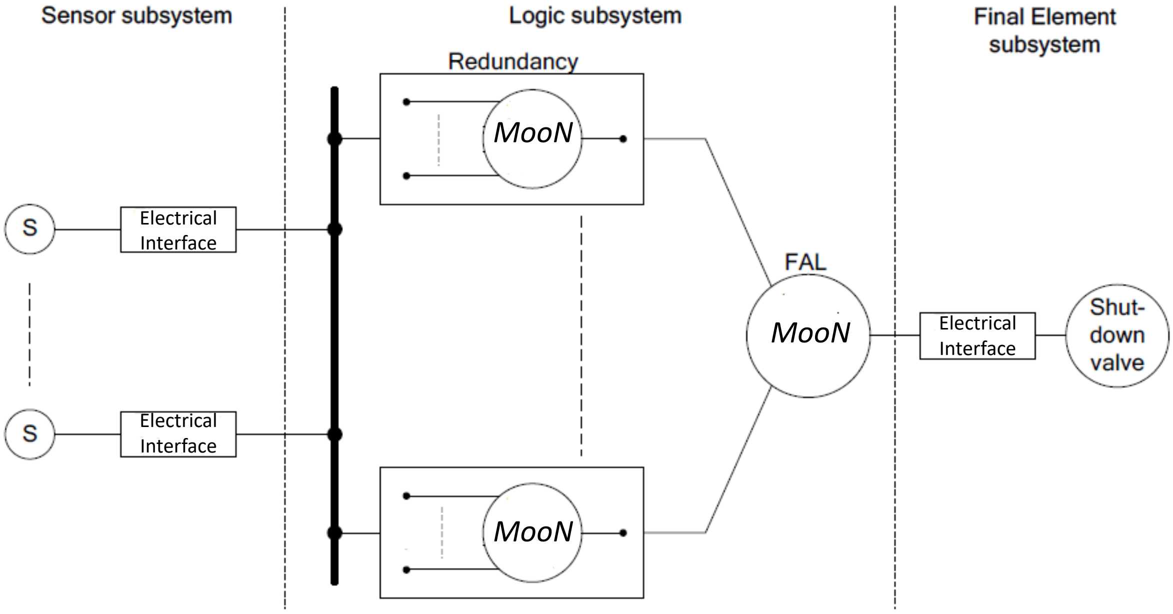


Figure 5-1: I&C Safety System architecture

Redundancies of the logic subsystem: these features are characterized by N channels which are redundant, identical and independent.

Safety Actuation Device (SAD) is the final element that comprises all the components and wiring/tubing processing the final signal(s) from the logic subsystem, including the final actuating components.

Final Actuating Components includes a logic combination of relays/contactors and electromechanical device and are called Final Actuation Logic (FAL).
The FAL (Final Actuation Logic) is the piece of equipment where the four redundant channels converge, performing MooN logic over the trip signals for commanding the safety actuation devices (valves, solenoids, etc.).
It is integrated in a metallic cabinet divided into four main enclosures, one for each instrumented redundancy.
There is a fifth enclosure used for test procedures and check-backs replication.
There are fireproof insulation walls between enclosures which ensure channel independency.

The FAL performs the main duties:

- Automatic initiation of safety actions (automatic trip).
- Manual initiation of safety action (manual trip).
- Termination of safety action (reset).

- Maintenance bypass of instrumentation channel.
- Inhibition of redundancy of safety actuation system.
- Safety actuation devices testing through the command of the safety bypass devices.

5.3 Safety I&C Classification

The classification of the I&C of safety functions is based on the classification strategy presented in the international standard IEC 61226, which is adopted in the ITER plant.
This standard establishes the criteria and methods that have to be used to assign the I&C safety functions to one of three categories A, B and C.

The classification of the safety functions depends on their contribution to the prevention and mitigation of postulated initiating events (PIEs), and to develop requirements that are consistent with the importance to safety of each of these categories.

- *Category A* denotes the functions that play a principal role in the achievement or maintenance of plant safety to prevent DBE from leading to unacceptable consequences. This role is essential at the beginning of the transient when no alternative actions can be taken, even if hidden faults can be detected. These functions play a principal role in the achievement or maintenance of the non-hazardous stable state.
- *Category B* denotes functions that play a complementary role to the category A functions in the achievement or maintenance of plant safety, especially the functions required to operate after the non-hazardous stable state has been achieved, to prevent DBE from leading to unacceptable consequences, or mitigate the consequences of DBE. The operation of a category B function may avoid the need to initiate a category A function.
- *Category C* denotes functions that play an auxiliary or indirect role in the achievement or maintenance of NPP safety. Category C includes functions that have some safety significance, but are not category A or B.

The general procedure followed to assign a specific category A, B or C to the I&C safety function is based on qualitative criteria reported in Table 5-1.

Table 5-1: Classification Criteria for the I&C Safety Category

SSC Safety Class	I&C Safety Category	Classification Criteria
SIC-2	A	Functions required to reach the non-hazardous stable state, to prevent a DBE from leading to unacceptable consequences, or to mitigate its consequences.

SSC Safety Class	I&C Safety Category	Classification Criteria
		Functions, whose failure or spurious actuation would lead to unacceptable consequences, and for which no other category A function exists that prevents the unacceptable consequences.
		Functions required to provide information and control capabilities that allow specified manual actions necessary to reach the non-hazardous stable state.
SIC-2	B	Functions required after the non-hazardous stable state of a DBE has been reached, to prevent it from leading to unacceptable consequences, or to mitigate the consequences.
		Functions required to provide information or control capabilities. They allow specified manual actions necessary after the non-hazardous stable state has been reached to prevent a DBE from leading to unacceptable consequences or mitigate the consequences.
		Functions, the failure of which, would require the operation of a Cat. A function to prevent an accident during normal operation.
		System process control functions operating so that main process variables are maintained within the limits assumed in the safety analysis, when these control functions are the only means of control of these variables.
		Functions used to prevent or mitigate a radioactive release outside of the limits and conditions of normal operation as defined in the safety analysis.
		Functions that provide continuous or intermittent tests or monitoring of functions in Cat. A to indicate their continued availability for operation and alert control room staff to their failures, when no alternative means (e.g. periodic tests) are provided to verify their availability.
SIC-2	C	System process control functions operating so that the main process variables are maintained within the limits assumed in the safety analysis and not covered by the Cat. B functions.
		Functions that provide continuous or intermittent tests or monitoring of functions in Cat. A and B to indicate their continued availability for operation and alert control room staff to their failures.
		Functions necessary to reach the safety probabilistic goals including those to reduce the expected frequency of a DBE
		Functions to monitor and take mitigating action following natural events (e.g. seismic, disturbance, extreme wind);

The process of identification and classification of the CHWS-1 functions is based on continue iteration throughout the design phase (**§3**) and subsequently during the transients analyses performed with RELAP5 (**§6**).

The method followed for the classification is shown in Figure 5-2

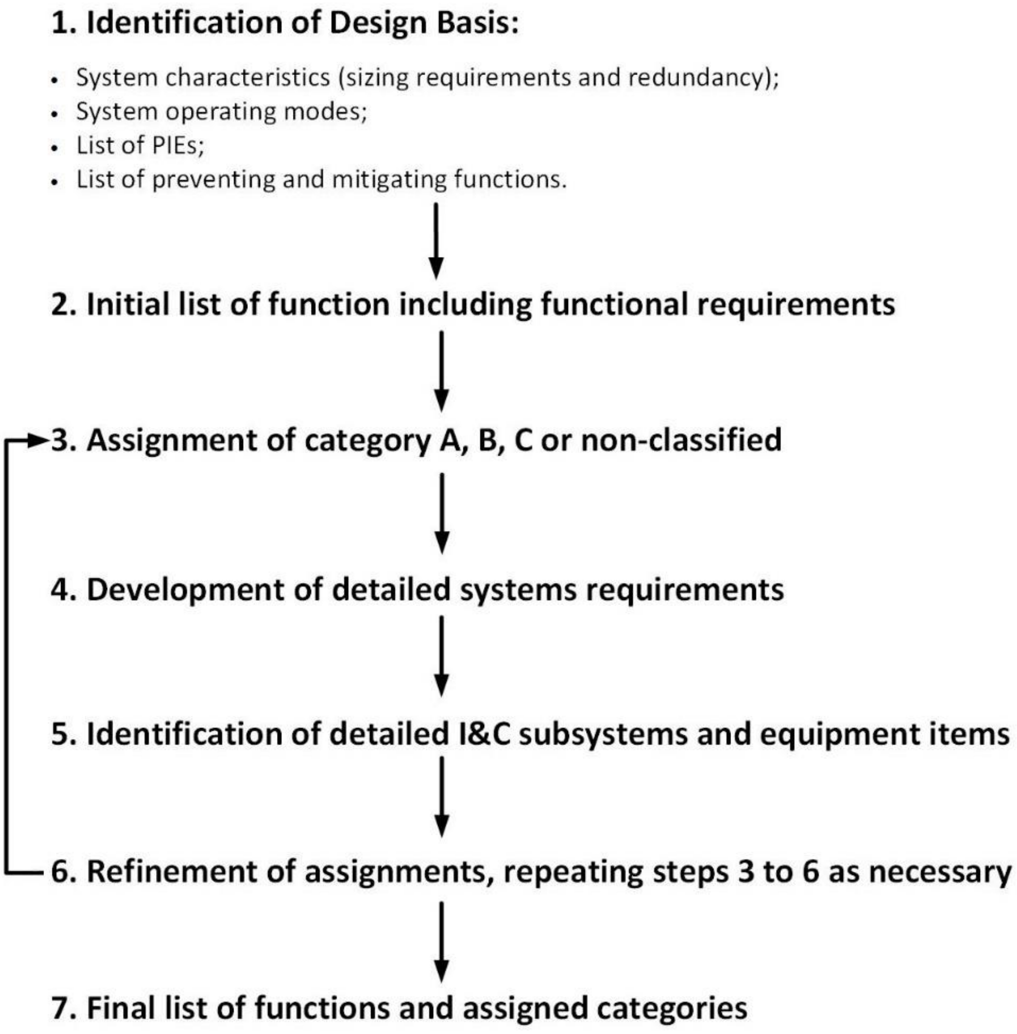


Figure 5-2: Method of functions classification

5.3.1 Redundancy and voting system

In order to implement a I&C safety function, the number of required sensors (identical or different) need to be identified based on the redundancy principle.

Namely the required number of instruments, higher than the necessary number, shall provide protection against single failures and shall prevent a random failure in one sensor from disabling the desired function.
Therefore, several similar instrument channels are used to measure the same physical variable and a voting logic (*MooN*) is applied to the redundant signals to identify and discard an erroneous channel.

The number of sensors per function is determined by comparing the reliability of the Logic Subsystem, for different logic structures *MooN* (M out of N majority logic), with the reliability of the Final Element (which is the Safety Actuation Device) in order to observe how they all contribute to the overall system reliability.

As the most common redundancy schemes used in I&C safety systems are the *2oo3* and *2oo4* structures, these configurations are the ones chosen for the analysis.

The analysis is performed considering worst-case scenario: the occurrence of an undetected failure in one channel of the *2oo3* and *2oo4* configuration.
All the elements are assumed to be non-repairable.

The reliability function of the *Voting Logic + Final Element*, which constitutes the protection system (PS) is given by the following equation:

$$\mathrm{R_{PS-MooN}} = \underbrace{\left[\sum_{\mathrm{x=M}}^{\mathrm{N}} \binom{\mathrm{N}}{\mathrm{M}} \mathrm{R_{ch}^{x}}(1-\mathrm{R_{ch}})^{\mathrm{N-x}}\right]}_{\mathrm{R_{VL-MooN}}} \cdot \mathrm{R_{FE}}$$

Where:

- $\binom{\mathrm{N}}{\mathrm{M}} = \frac{\mathrm{N!}}{\mathrm{(N-x)!x!}}$;
- $\mathrm{R_{ch}}$: Reliability of channel;
- $\mathrm{R_{FE}}$: Reliability of Final Element;
- $\mathrm{R_{VL-MooN}}$: Reliability of Voting Logic;

The reliability of the protection system $R_{PS-MooN}$ has two factors: The Reliability of Voting Logic $R_{VL-MooN}$ and the Reliability of Final Element R_{FE}.

Both configurations, *2oo3* and *2oo4,* show a reliability that is higher than the Final Element one.

The *2oo4* logic exhibit a higher reliability than the Final Element even when one of its channels is in failed state. This is not the case of the *2oo3* structure, since the *2oo2* configuration (which correspond to a *2oo3* with one failed channel) has lower reliability than the Final Element.

It can be generalized that any *2ooN* logic structure with N > 3 exhibits higher reliability than the final element even when one of is channels is in failed state.

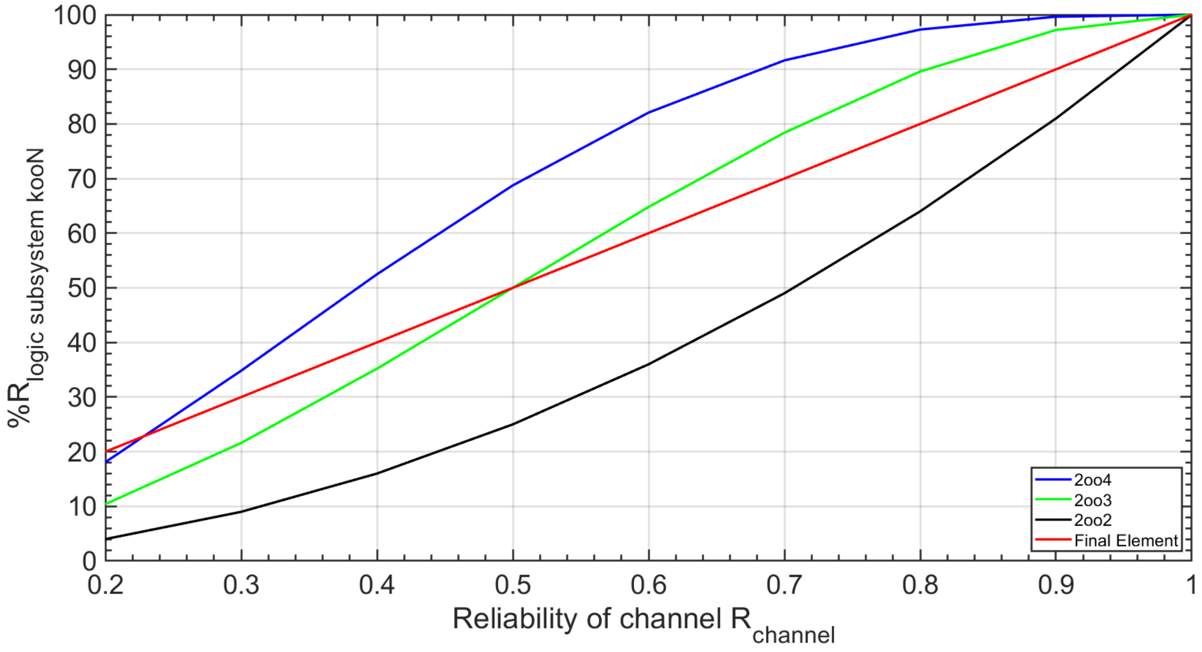


Figure 5-3: Reliability of the Voting Logic

In the case of the *2oo3* structure, the reliability is seriously affected when one channel is down due to a dangerous undetected (DU) failure. This is depicted in the black curve of Figure 5-3.

It is worth mentioning that most safety systems with a *2oo4* structure often give another important functionality, which is the ability to put one of the channels in what is called *maintenance mode*. This is done if a problem is detected in a channel.
The maintenance mode is an additional function that allows the *2oo4* structure to behave as a *2oo3* structure, leaving apart the channel with a detected failure.

The 2oo4 structure consists of four elements connected in parallel with a majority voting arrangement for the output signals so that the output state is not changed if only one channel gives a different result, which disagrees with the other three channels.

For the SIC-2B functions of the CHWS-1 usually is used this type of logic.

Figure 5-4 shown for example the logic 2oo4 applied for the pressure control in the drain tank room (explained in **§5.5.7**). It is highlighted the fact that the sensors must be located on two different electric trains (e.g. train A&B).

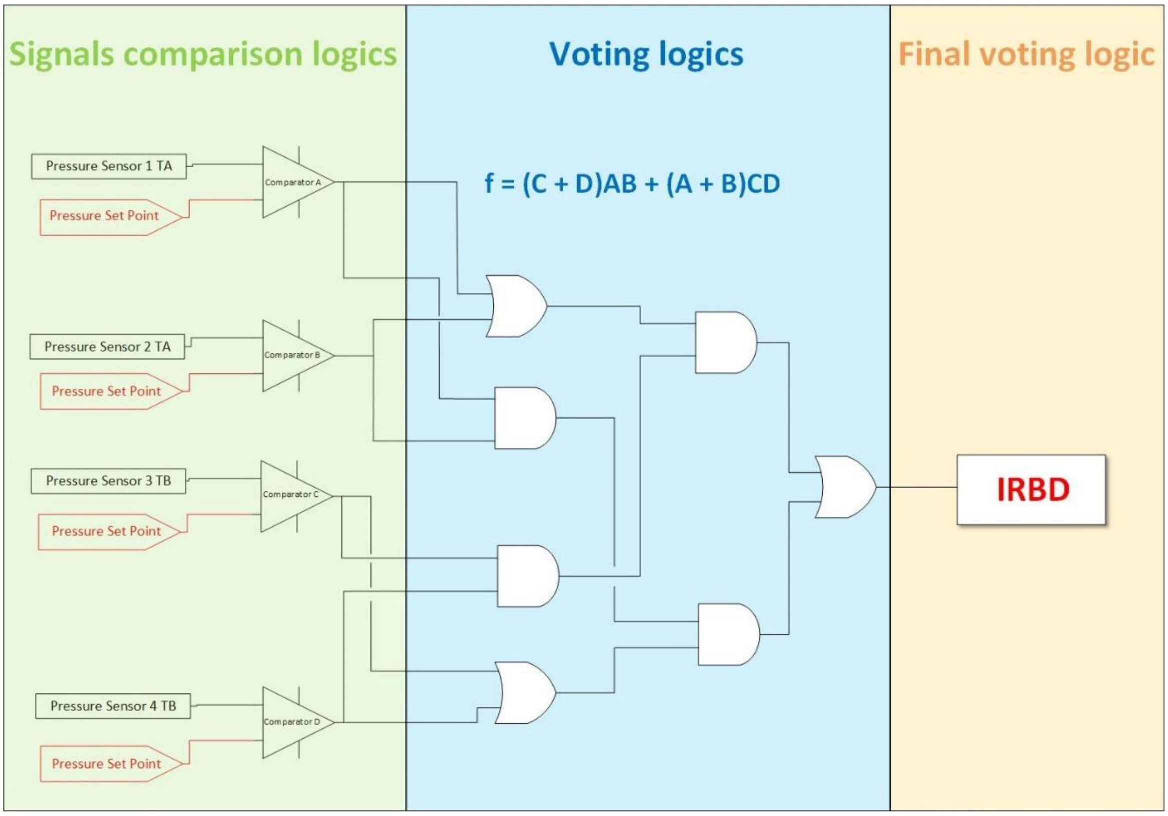


Figure 5-4: Voting Logic 2oo4

Table 5-2: Truth table of the 2oo4 voting logic

D	C	B	A	Z
			0	0
			1	0
		1	0	0
		1	1	0
	1	0	0	0
	1	0	1	0
	1	1	0	0
	1	1	1	1
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	1
1	1	0	0	0
1	1	0	1	1
1	1	1	0	1
1	1	1	1	1

Table 5-3: Karnaugh map of the 2oo4 voting logic

	AB				
		00	01	11	10
	00	0	0	0	0
CD	01	0	0	1	0
	11	0	1	1	1
	10	0	0	1	0

5.4 Control Breakdown Structure

The process requirements need to be transformed to the control requirements in order to achieve the control of the processes.

The control requirements are hierarchically structured in different levels of functions with increasing detail according to particular requirement.

Figure 5-5 shows the hierarchy of the defined control functions.

The sub-system function for CHWS-1 can be further broken down into level 4 functions. The following points drive the control breakdown structure of the CHWS-1.

- *CBS Level 1*: defines the control group in which has been grouped the Plant System I&C, namely CWS.
- *CBS Level 2*: defines the cooling function responsibility. This classification is termed as SCSU.
- *CBS Level 3*: is almost similar to PBS, i.e. the sub-system level (Combination of PBS L2 and PBS L3).
- *CBS Level 4*: is CHWS-1 process specific requirements.

The level 4 functions, to achieve the CHWS-1 requirements, are given in Table 5-4 and shown in Figure 5-5

Table 5-4: Level 4 functions for CHWS-1

Functional Requirement	Function ID	Category
Supply cooling water at 6°C temperature to several components for heat removal	HREM	Safety
Maintain positive pressure in the system	PRZ	Safety/Non-Safety
Generate differential pressure to recirculate cooling water through the components fed by CHWS-1	PMPG	Safety
Distribute cooling water to the required components at desired flow and pressure for heat removal	WD	Non-Safety
Maintain water chemistry by chemical dosing	WCC	Non-Safety
Guarantee the monitoring of the system safety operating parameters	SOPM	Safety

Functional Requirement	Function ID	Category
Guarantee the prompt detection and intervention of the system in case of a pipe break in wherever zone of the system.	LDI	Safety
Guarantee the prompt detection and intervention of the system in case of a pipe break in the drain tank room.	LDID	Safety

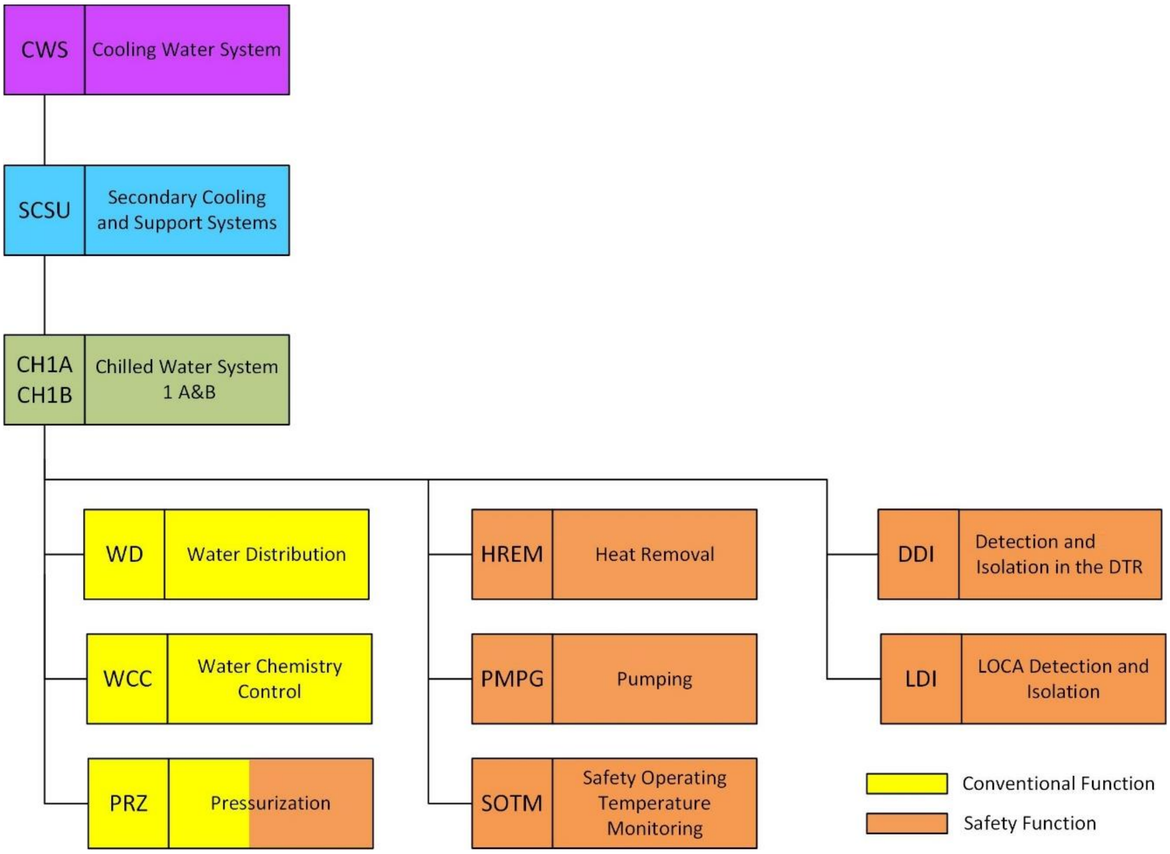


Figure 5-5: Control Breakdown System for CHWS-1

5.5 Description of Applicable I&C Functions during Cooling Mode

Following sections describe the functional analysis for Level 4 functions of CHWS-1 (Figure 5-5) and thereby to bring out I&C requirements of the function.

5.5.1 Heat Removal

Three chillers are used to remove heat in CHWS-1A and CHWS-1B, respectively.

The required supply temperature of 6 ºC is ensured by the internal process of chiller.

To support HREM function, following I&C functions are required:

- To facilitate remote operation of chiller, manual control facility must be provided to start or stop the chiller.
- The maximum operating temperature for the chillers is an outstanding point and it will be updated subsequently according to the supplier data. When the temperature in the chillers exceed the operating limit the shutdown of the chillers is commanded and consequently the trip of the pumps is commanded.

Functional Description

Applicable Modes: POS, TCS, STM/LTM, LOOP.
Safety Importance Classification: SIC-2B.
Category: Automatic.

5.5.2 Pressurization

Pressurizer, located on the suction line of the pumps, is used to pressurize the system and avoid the ingress of air.

PZR takes care of pressure variation occurred due to expansion and contraction of water dew to thermal variations.
It uses nitrogen as a blanket gas; the intake and exhaust of nitrogen need to be controlled to maintain desired pressure in the pressurizer.

PZR also provides facility to add water in the system during initial filling and to make-up for any losses occurred due to leak or pipe break.

To avoid the nitrogen entering in the loop, it is necessary to maintain the water level in the pressurizer up to predefined level. Hence, this level needs to be controlled using make-up and drain arrangement.
Falling water level in the pressurizer is an indication of loss of water inventory due to leak and the makeup line is required to intervene. Similarly, if the level in the pressurizer increases above certain value it indicates leak from the client systems to CHWS-1.

5.5.2.1 Pressure Control

The pressurizer, in both CHWS-1 subsystems, is filled with DM water and charged with nitrogen.
The pressurizer pre-charge pressure is 0.22 MPa for an associated level of 0.58 m (measured from the lower TL of the Pressurizer).
The pre-charge pressure has been selected to guarantee the required pressure at the interface points with the components cooled by CHWS-1. The pressure at the IS points can be regulated indirectly (without a pressure reducer device) controlling the pressure of the pressurizer.
Pressure control function, process monitoring and diagnostic functions are associated to PZPC (Pressurizer Pressure Control).

According to the results obtained running AFT Fathom, an operating margin of ±0.03 MPa has been considered and the following alarms are set in the pressurizer: High-Pressure Alarm (HPA) and Low-Pressure Alarm. (LPA).

In the case of PZR pressure reaching LPA, the valve in the nitrogen supply line opens. While in case of HPA the nitrogen vent line opens.

If the pressure reaches HPA, safety pressure relief valve (PRV) opens automatically, releasing excess pressure into the atmosphere.

Table 5-5: Pressure Alarms in the PZR

$P_{pre\text{-}charge}$ during normal operation	0.22 MPa
HPA	0. 25 MPa
LPA	0.19 MPa

Functional Classification

Safety Importance Classification: NO-SIC.
Category: Automatic.

5.5.2.2 Narrow Level Control

The PRZ level is controlled by the make-up DM water line and by the drain line both activated by the opening/closing of a control valve. Both these valves are commanded by the level measurement of the water inside the pressurizer.

Level control function, process monitoring and diagnostic functions are associated to PZLC. Two level warning are set in the pressurizer: High-Level Alarm (HLA) and Low-Level Alarm. (LLA).

In the case of level reaching LLA, the valve in the DM make-up line opens. While in case of HLA the drain line opens.

Furthermore, a warning to the operator is sent when the level reaches on of these limits.

In case of Loss of Offside Power an additional function is added.
If the level of water in the PZR increases until HLA, when CHWS-1 is operating in LOOP, one of the main causes could be a leakage from the VV-PHTS.

VV-PHTS is the only component that could operate at a higher pressure than CHWS-1. This happens only during VV-PHTS water baking mode and, as explained in **§2.3.1**, in that case the isolation valves that separate the two systems are closed.

Nevertheless, if the HLA is triggered during LOOP operation, a signal is sent to close the isolation valves in VV-PHTS line in order to avoid any potential risk of contamination.

Table 5-6: Narrow Level Control in the PZR

Level during normal operation	0.55-0.58 m
HLA	0.7 m
LLA	0.4 m

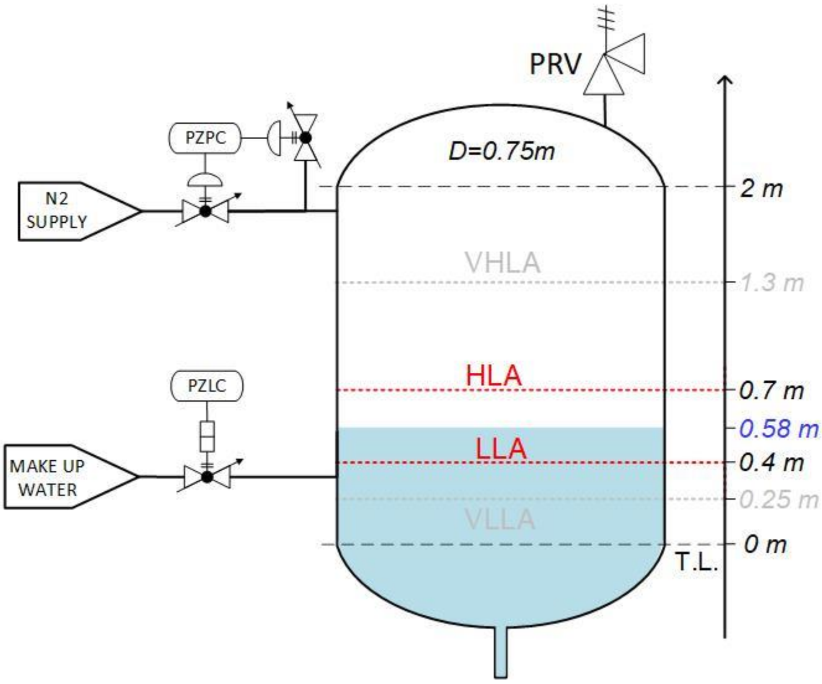


Figure 5-6: Level Control in the PZR

Functional Classification

Safety Importance Classification: SIC-2C.
Logic 1oo2
Category: Automatic.

5.5.3 Pumping

Horizontal Centrifugal Pumps are used to achieve required pressure to recirculate water. In order to improve availability of the function a 2 working + 1 standby pumps are installed. The suction pressure required for pumps is ensured by the pressurizer.

5.5.3.1 Pump On/Off Control

The pump start-up procedure is greatly influenced by the performance characteristics of the pump in question, that is, by the shape of its power-capacity curve. CHWS-1A&B pumps operates with low specific speed N_s (= 2960 rpm < 5000 rpm) and are characterized by power-capacity curve which rise from the shutoff condition to the normal operating capacity condition. Therefore, these pumps shall be started against a closed discharge in order to reduce the starting load on the driver. Although the current taken during start-up of motor is more than normal, by having closed the discharge valve of centrifugal pump it is possible avoid extra load act on the pump. The reverse procedure is applied to shut down.

Pump On/Off Control Function (PLOF) provides control to operate the pump allowing either the start-up or the shout-down.

- The start-up/shout-down action is followed by actuating the discharge valve to open or to close depending on whether the pumps are either started or stopped.

In addition to the control, the following functions are associated to PLOF.

- Process monitoring during start-up is required to monitor:
  - $NPSH_a$ by measuring the pump suction pressure P_{in}. $NPSH_a$ must be greater than or equal to the $NPSH_r$ to prevent cavitation. Low $NPSH_a$ is caused by a partially closed suction valves. Therefore, monitoring the position of the suction valve by limit switches prevents low suction pressure. An alarm is generated in case of the suction valve is not completely open.
  - Verify the pressure and level in the pressurizer to avoid potential nitrogen entrainment in case the level is too low.
- Equipment Monitoring during start-up is required to monitor:
  - Pump discharge valve position. The valve shall be closed.
  - Pump suction valve position. The valve shall be in open position.

Functional Classification

Safety Importance Classification: SIC-2C.
Category: Automatic.

5.5.3.2 Pump Electrical & Mechanical Control

Water pumps represent the majority of CMW components requiring investment protection. Therefore, to prevent any mechanical failure and hence the investment loss, the motor monitoring system shall continuously monitor the critical process parameters of the motor & pump assembly.

Pump Electrical & Mechanical Control Function (PLPR) protects the pumps against fault conditions (diagnostic and protection interlock functions).

Each of the pumps requires to be protected against the following fault conditions:

- Overcurrent, ground, and any other electrical faults are handled directly by the electrical power system. They usually result in tripping the switchgear of the pump.
- Overheating of the motor windings is measured by embedded sensors. 1 dual temperature sensor should be installed per winding (typically for an asynchronous

induction motor there are 3 windings, i.e. 3 temperature sensors). These sensors are wired to LV switchgear and PCS for continuous monitoring. An alarm is generated for each of these temperature sensors if it is above a certain limit. In case of motor winding temperature is very high, pump trip is generated.

- Overheating of the motor (respectively pump) drive end/non-drive end bearings is measured by embedded sensors. One temperature sensor should be installed per bearing. These sensors are wired to LV switchgear and PCS for continuous monitoring. An alarm is generated for each of these temperature sensors if it is above a certain limit. In case of motor bearing temperature is very high, pump trip is generated.
- Vibration of the motor (respectively pump) is measured by vibration sensors attached to the drive end/non-drive end bearings. One vibration sensor should be installed per bearing. Vibration sensors are hardwired to PBS-26 PCS for continuous monitoring. An alarm is generated for each of these vibration sensors if it is above a certain limit.
- Reverse rotation switch is selected to check the rotation of motor & pump assembly during starting when the system is either in commissioning or maintenance activity. This monitoring activity is done to ensure that in case of wiring of the motor in reverse direction (assuming incorrect connections of the electrical phase) the cooling pump is tripped. Reverse rotation switch is hardwired to PBS-26 PCS for monitoring during starting.
- ∆P pressure instrumentation has been implemented per pump to monitor and survey pump degradation during its operating life.
- The suction line from the pump to system (return line) must be opened. Running the pump with an isolated suction line may result in damaging the pump. This may also damage its suction line if a steam pocket is formed and then collapsed, which could cause a significant water hammer.
- Mechanical seal injection is monitored by pressure sensor located on the injection line. A warning is generated in case that the pressure drops below a certain limit (not applicable to canned motor pump) and if the pressure drop below a lower value, the pump is stopped and an alarm is generated.

Functional Classification

Safety Importance Classification: SIC-2C.
Category: Automatic.

5.5.3.3 Pump Inlet Pressure

Two pressure sensors are located at the inlet of each pump in order to avoid low pressure issues that could cause the cavitation.

If the measured pressure reaches the LPA (0.07 MPa) the trip of the pump, located in the line of the triggering instrumentation, is commanded.

Functional Classification

Safety Importance Classification: SIC-2B.
Logic 1oo2
Category: Automatic.

5.5.3.4 Pump Bypass Line

The total flowrate of the system is measured by two sensors located in the main outlet line of the pumps.
The flow instrumentation commands the opening/closing of the FCV located in the pumps bypass line.

If one or more components, cooled by CHWS-1, are isolated during the system operations the bypass line intervenes to balance the flow and to maintain the required flow through the pumps.

For example, during cooling operating mode, CHWS-1B doesn’t need to provide water to VV-PHTS and the isolation valves located in its line are closed. The system needs to provide decay heat removal operations to this component only during Plasma Operation in case of Loss of off-site power (LOOP).

The flowrate target is 95.44 kg/s during cooling mode and LOOP conditions.

The difference between measured flowrate and the target is converted with a PID controller into a signal from -100% to 100% (PID controller output).

During cooling mode when the PID controller output is 0% the opening percentage of the bypass valve is maintained at 40%. While during LOOP when the PID controller output is 0% the bypass line is fully close.

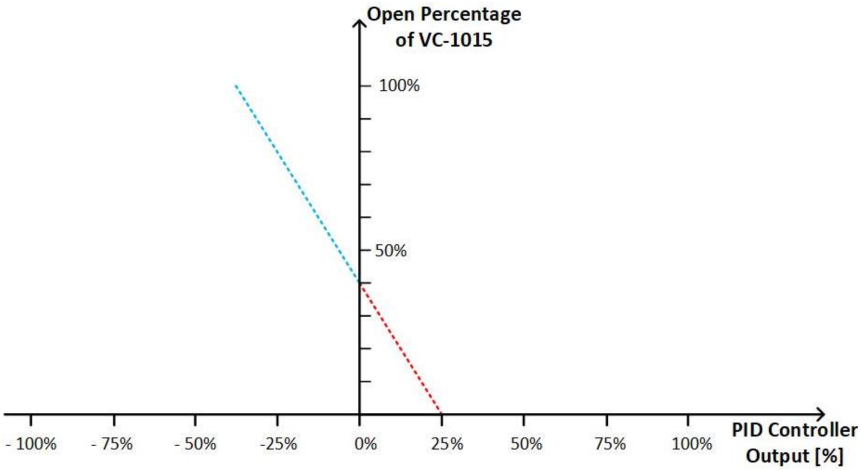


Figure 5-7 Flow Control through the Pumps Bypass Line (Cooling Mode)

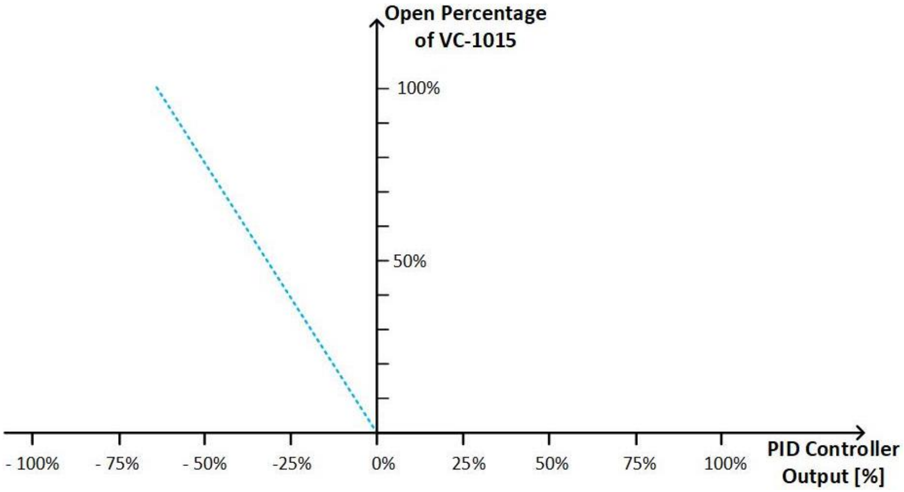


Figure 5-8 Flow Control through the Pumps Bypass Line (LOOP)

If the measured flow reaches the LFA (Low Flow Alarm), a warning is sent to the operator. The LFA is 47.5 kg/s (2*$MCSF_{pump}$).

Functional Classification

Safety Importance Classification: SIC-2C.
Logic 1oo2
Category: Automatic.

5.5.4 Water chemistry control (WCC)

In order to measure pH and Conductivity of the water, appropriate sensors are installed on the chilled water return header. All the piping in CHWS-1 system is stainless steel and water polishing unit is provided to both CHWS-1 systems.

Functional Classification

Safety Importance Classification: NO SIC.

5.5.5 Water Distribution

In CHWS-1, chilled water is distributed to various components using complex piping networks. These pipes are sized to carry specified flow to each component that must be cooled.

However, it is very difficult to achieve desired flow distribution across such a large network only by sizing of pipe. Hence, a manual control valves are provided upstream /downstream of each component, cooled by CHWS-1, to produce additional pressure drop and guarantee the required flow.

This control valve, together with an isolation valve located on the other end of the component, is used to isolate the line from the loop.

Functional Classification

Safety Importance Classification: NO SIC.

5.5.6 Safety Operating Parameter Monitoring – SOPM

5.5.6.1 Temperature Monitoring

In order to monitor the chiller water temperature several instrumentations have been located in through the system:

- In the chillers' inlet and outlet lines in order to guarantee the temperature operating range (6-12°C).
- In the outlet line of each component cooled by the system in order to verify that the temperature doesn't exceed 12°C.

Two warning of high temperature have been set: HTA and VHTA.

The HTA is set at 45°C (10% less than CHWS-1 design temperature) while the VHTA is 50°C (CHWS-1 design temperature).

If the temperature reaches HTA a first warning is sent to the operator while at VHTA the manual shut down of the system must be commanded.

Functional Classification

Safety Importance Classification: SIC-2C.
Category: Manual.

5.5.6.2 Pressure Monitoring

Pressure instrumentations are located through the system in order to monitor the operating conditions.

Two warning of high pressure have been set: HPA and VHPA.

The HPA is set at 10% less than design pressure while the VHPA is at the design pressure (data related the design values are shown in **§A2** and **§A3**).

Functional Classification

Safety Importance Classification: NO-SIC.
Category: Manual.

5.5.7 Detection and Isolation in the DTR

Tokamak Complex Drain Tank Room (DTR) represents critical zone for CHWS-1 because both the trains are placed there and in addition, a cooling pipe defined as high-energy line is in their vicinity. For this reason, it is important to be able to quickly detect and intervene in case of LOCA in this zone.

An automatic accident detection is required.

Pressure sensors are located in the inlet line that provides cooling water to two components in the DTR (VV-PHTS and VVPSS).

This instrumentation presents two set-point: HPA and LPA.
In both cases a signal is sent to command the closure of the isolation valves in the DTR to separate the affected zone.

Table 5-7: Pressure set-points -Instrumentation in DTR

$P_{pre\text{-}charge}$ during normal operation	1 MPa
LPA	0.6 MPa
HPA	1.5 MPa

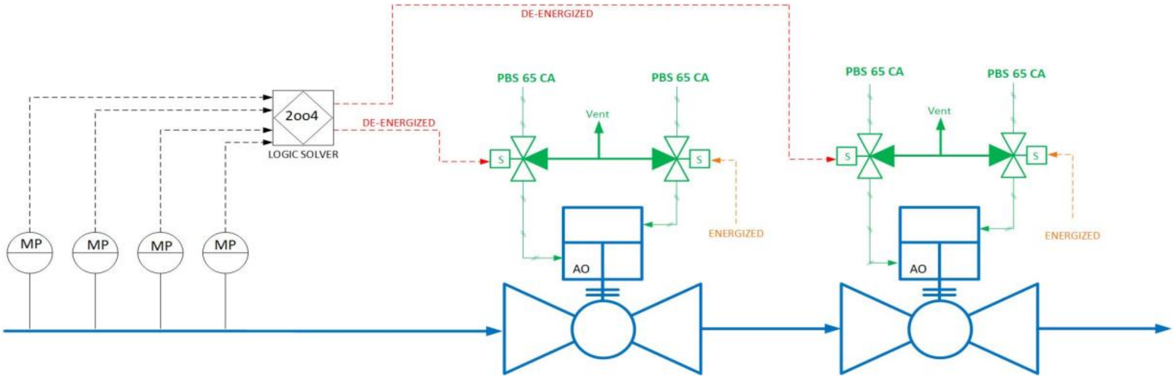


Figure 5-9: Pressure instrumentation in the DTR

Functional Classification

Safety Importance Classification: SIC-2B
Logic 2oo4
Category: Automatic

Performance Classification

The isolation valves have been considered with a maximum opening/closing time of 10 seconds, in order to guarantee a prompt intervention in case of accident but avoiding water hammer issues.

5.5.8 LOCA Detection and Isolation

CHWS-1 supplies cooling water to SIC components in Tokamak and Hot Cell Complex.

CHWS-1 piping may consider breaking during design basis events, creating a path across the confinement boundary. To avoid this to happen, isolation valves are provided.
These SIC building boundaries are governed by LDI (LOCA Detection and Isolation) function and it is required to meet the same level of confinement when a pipe penetrates this boundary.

The isolation valve arrangement at the SIC building boundary need to be closed when the initiating event occurs.

In case of a pipe break inside the CHWS-1, the signals that can be implemented to detect a LOCA are the following:

- Very Low-Level Alarm (VLLA) in the PZR;
- Low Pressure Alarm (LPA) measured at the inlet line of the pumps.

In order to intervene and stop the water realising from the system, the closure of all the PIC valves have to be commanded. For this reason, a SIC wide level control has been implemented in the system.

Four level sensors have been implemented in the pressurizer and two alarms are set: VLLA and VHLA. In both cases when the alarm is triggered the closure of the PIC valves is commanded.

Table 5-8: Narrow Level Control in the PZR

Level during normal operation	0.55-0.58 m
HLA	1.3 m
LLA	0.25 m

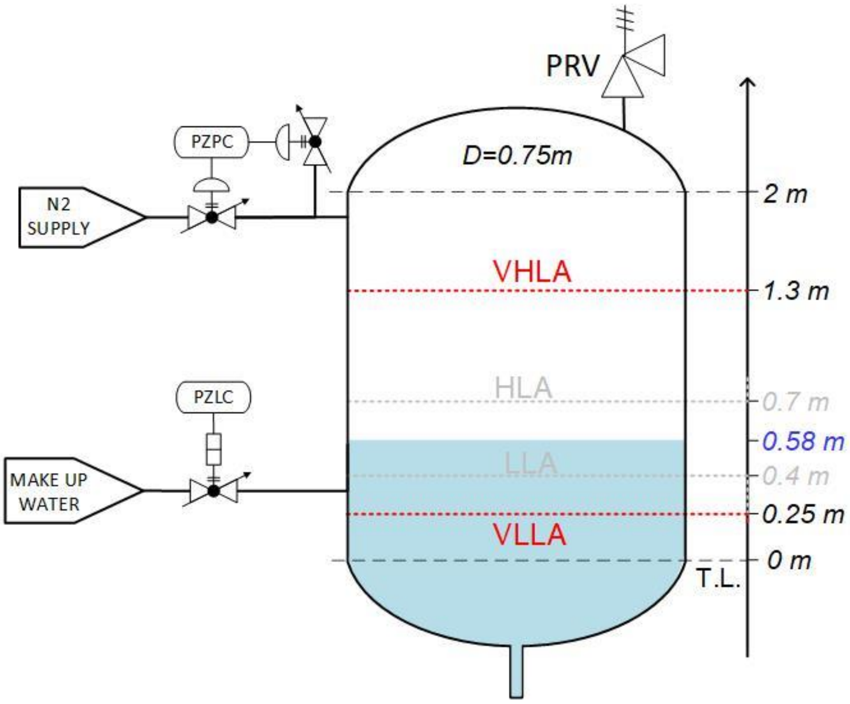


Figure 5-10: PZR Wide Level Control

In case of a large leakage in the system the level in the pressurizer decreases reaching the LLA.

The DM make-up line intervenes but the level continues decrease until the VLLA; at this point a signal is sent to command the closure of the PICs valves in the system.

In the meantime, due to the break in the system, the pressure instrumentation located at the inlet of the pumps intervene (due to the LPA) commanding the trip of the pumps.

Functional Classification

Safety Importance Classification: SIC-2B
Logic 2oo4
Category: Automatic

Performance Classification

The PIC valves have been considered with a maximum opening/closing time of 10 seconds to guarantee a prompt intervention in case of accident but avoid water hammer issues.

5.6 Transition between mode

5.6.1 From Maintenance Mode to Off Mode

When transitioning from maintenance mode to off mode, the operator fills/refills CHWS-1. Filling/refilling operation is entirely performed manually.

When transitioning from off mode to maintenance mode, the operator partially or fully drains CHWS-1. Draining operation is entirely performed manually by the lines located through the system.
Water level cannot be directly monitored but it can be indirectly estimated based on the drained inventory.

5.6.2 From Cooling Mode (POS/TCS/LTM/STM) to LOOP

This transition could happen only in the CHWS-1B (as explained in **§2.3.1**).

When transitioning from Cooling Mode (POS/TCS/LTM/STM) to LOOP Mode, the opening of the isolation valves located in the VV-PHTS line is commanded.
Consequently, the valve located in the pumps bypass line automatically closes.

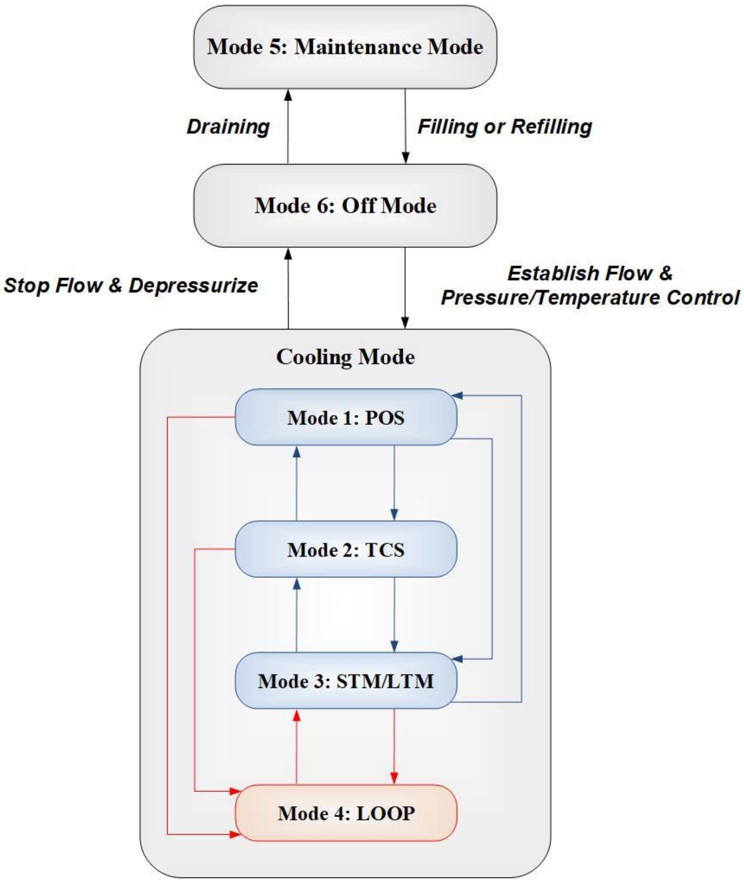


Figure 5-11: Transitions between Operating Modes

6 Incident/Accident Transient Analyses

6.1 Overall approach and PIEs

The analyses of postulated incidents and accidents are based on event scenarios that have been specified based on a systematic selection process, shown in Figure 6-1. It shows the two lines of event's identification:

- deterministic considerations leading to a list of reference events;
- complementary systematic approach starting with FMEA studies, leading to a comprehensive list of PIEs.

Each PIE is assessed to ensure that it is covered by one of the reference events analyses, if not a new event is defined.

Finally, the outcome of the reference events analyses is checked against the safety criteria to ensure compliance.

Basic accident initiating events are identified through comprehensive bottom-up component level analyses using systematic methods such as Failure Modes and Effects Analysis (FMEA).
These are to be supplemented by a top-down plant-level analysis using a Master Logic Diagram (MLD), as a check on the completeness of the FMEA results.

Accident initiators identified by the FMEA are grouped into families, each of which is termed a Postulated Initiating Event (PIE). The criterion for grouping is that basic initiators that have a similar impact on the system are put in the same PIE. The basic initiating events or causes of each PIE are documented because they may be useful for determining the frequency category of the PIE which is the sum of all the frequencies of the basic initiators included.
From the initiators grouped within each PIE, the one judged to have the greatest potential to result in hazardous consequences is chosen as the representative event for the PIE.

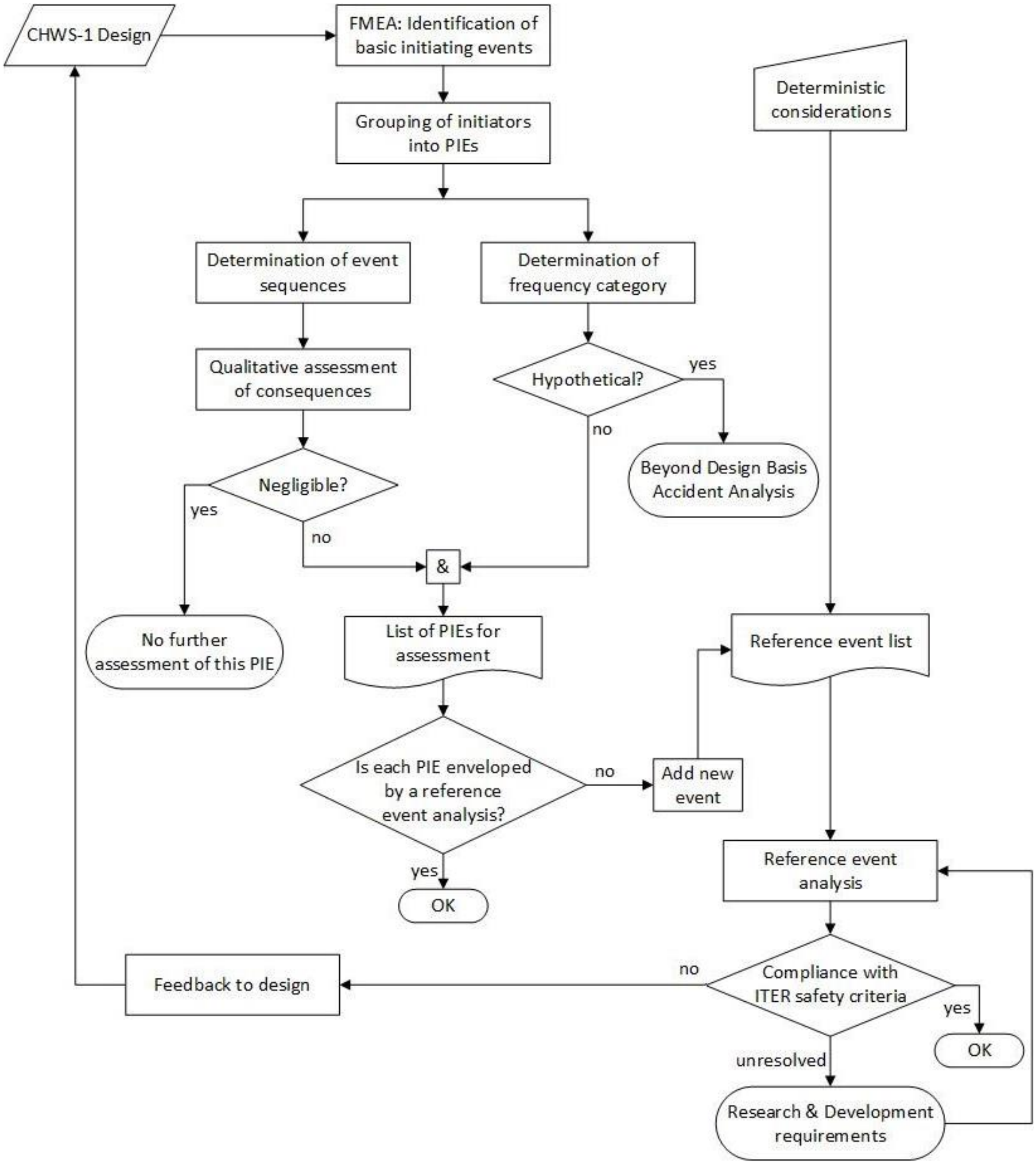


Figure 6-1: Overall Analysis Process

Each PIE is classified into one of the five frequency categories listed in Table 6-1. The frequency evaluation is shown in the records of the FMEA. These frequencies may be used as guidance when categorising an event sequence as normal, incident, accident or hypothetical.

A correspondence, based only on the initiator frequency, is also given in Table 5.4-1; other factors about the sequence, such as aggravating failures, may need to be taken into account for the event categorisation.

Table 6-1: Frequency categories for PIEs

Frequency Category	Frequency/yr	Corresponding Event Categorisation	Postulated Initiating Event
I	> 1	Normal	Operation in the normal power range. Normal system shutdown (Off Mode). Maintenance Mode (STM & LTM).
II	10^{-2}-1	incident	Overpressure due to the failure (“stuck-open”) of the DW make-up valve. Overpressure due to the failure (“stuck-open”) of the nitrogen supply valve. Pump trip (water hammer transient). Seismic Event. Pipe leakage in the system.
III	10^{-4}-10^{-2}	accident	Pipe break in the system.
IV	10^{-6}-10^{-4}		Fire Exposure
V	$< 10^{-6}$	hypothetical	VV-PHTS Decay Heat Exchanger Leak (during Baking Mode).

A qualitative assessment of the PIE is made to assess its potential importance and the need for further analysis. For some PIEs, further analysis is unnecessary, for one of these reasons:

- The inventory at stake, there is no risk to violate the project release guidelines for ITER conditions, even if the source term is not mitigated, then no further analysis is required.
- There is no credible accident sequence initiated by the PIE which could lead to significant consequences unless there is some aggravating failure that puts the sequence into the hypothetical category in which case the event may be analyzed as a Beyond Design Basis event.

The main events that are analysed in this document are the following:

- LOCA accident due to the pipe break in the Drain Tank Room (DTR).
- LOCA accident due Pipe break located in other zones of the system.
- Pipe leakage/small break in the system.
- VV-PHTS Decay Heat Exchanger Leak (during VV-PHTS Baking Mode Operation).

The evolution of these events was studied in the CHWS-1B because the configuration of this subsystem is already defined and frozen while a big part of the CHWS-1A design is still ongoing (because located in the Hot Cell Complex) (see **§3.1**).

6.2 CHWS-1B RELAP5-3D MODEL

In order to analyse the transient incidental/accidental scenarios, a full model of the CHWS-1B has been prepared. Its layout is shown in Figure 6-2.

The plasma operation of the system during steady-state conditions have been performed and the simulation outcomes were compared with design values (obtained from **§3**)in order to assess the appropriateness of the thermal-hydraulic model prepared.
Then, this steady-state calculation was used as initial condition to simulate the incidental and accidental scenarios.

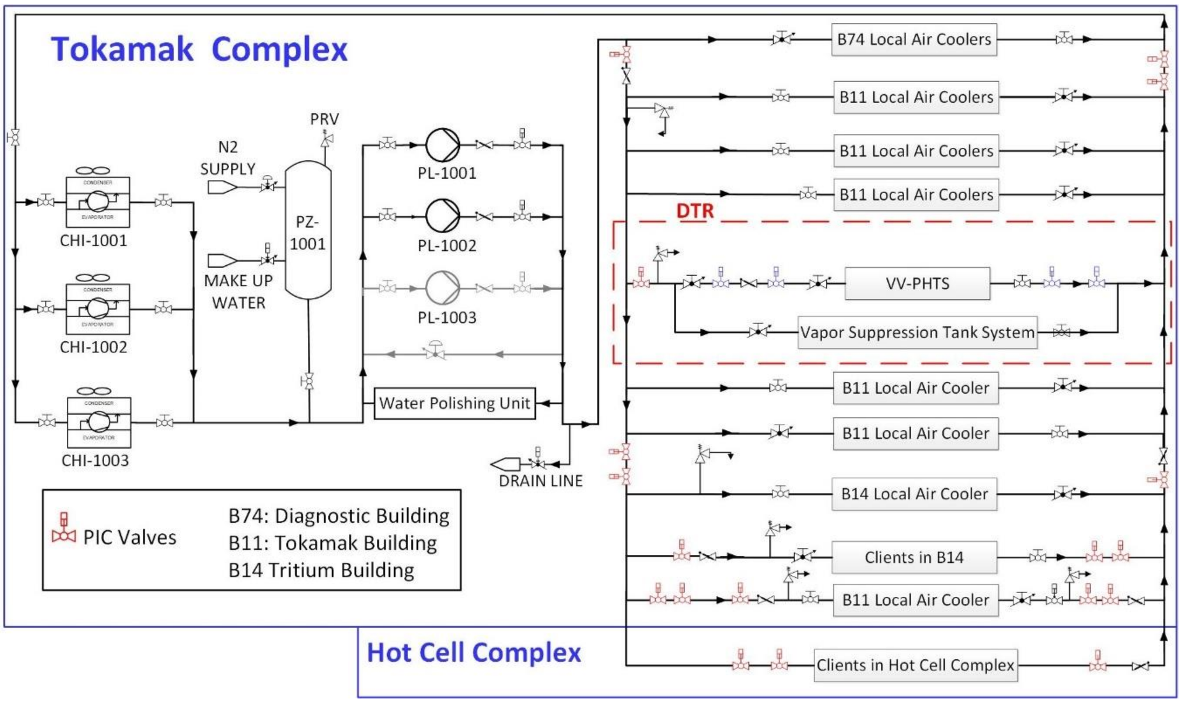


Figure 6-2: CHWS-1B Layout (RELAP5 Analysis)

To develop the CHWS-1B model, the following assumptions were considered:

- During the system nodalization, the sizing data as well as the elevations of all the pipelines and equipment components was maintained (based on **§3**). The ratio between the length of two adjacent control volumes was kept below 1.25.
- The model includes two operating pumps modelled as "Bingham Pump" and implemented with a logic trip based on the indication described in **§5.5.2**. The presence of the stand-by pump is excluded from this analysis.

- Pump by-pass line has been modelled to maintain the proper flow to each component served by CHWS-1B. Online flow meter is provided in the pump common discharge header and it is used to regulate the FCV located in the bypass line (based on **§5.5.2**). Associated logic has been implemented in the motor valve.
- Three air-cooled chillers have been modelled following a simplified approach: Their geometry has been selected in order to keep the total CHWS-1B water inventory. Heat structures have been implemented with a constant power boundary commanded by a trip logic to keep the water temperature at 6°C. A second trip has been set in order to interrupt chiller operation if the pump trip is commanded.
- A gas-PZR (N2) has been modelled as a vertical cylinder. Pressure and water level are maintained by a demineralized water (DM) make-up line, N2 supply line and a pressure relief valve.

  The N2 supply and DM make-up lines are both modelled with a time-dependent volume (TDV) and a motor valve. Corresponding valve trip logic is set according to **§5.5.2**.
- Each component fed by the system in the Tokamak Complex has been modelled individually, except for three interfaces in the Tritium Building (B14), which are located considerably far away from the Reference Events location. For this reason, they have been collapsed into one equivalent component.
- As Hot Cell Complex building design is in the conceptual phase, its contribution to the overall CHWS-1 has been included as a lump component, following a conservative approach.
- Each component cooled by CHWS-1B, except VV-PHTS, has been modelled with a pipe segment and a heat structure. The geometry has been defined to respect the water inventory for each unit, while its associated heat structure has been set with a constant power condition. The heat transfer of these components is not stopped during all the simulation. This represents a conservative approach for the analysis of the transient since, in real conditions, heat transfer is reduced as chilled water flow is interrupted.
- The primary side of the VV-PHTS Heat Exchanger is modelled in two different ways based on the analyzed scenario:
  - During CHWS-1 normal operation and when the incident scenario of the heat-exchanger leakage is performed, the HX primary side is modelled with a pipe segment connected upstream to a time dependent volume (TDV) and a time-dependent junction (TDJ) while it is connected downstream to a second TDV.
  - For the tubes rupture accidental events (**§6.4**), the primary side is modelled with two parallel pipes instead of one. One pipe segment is sized in order to represent the HX tubes that remain intact during the event (P-5 in Figure 6-3), while the other line (P-6 and P-8 in Figure 6-3) is sized according to the number of broken

tubes and consequently connected to the primary side in order to simulate the guillotine breaks (V-13 and V-14 in Figure 6-3)

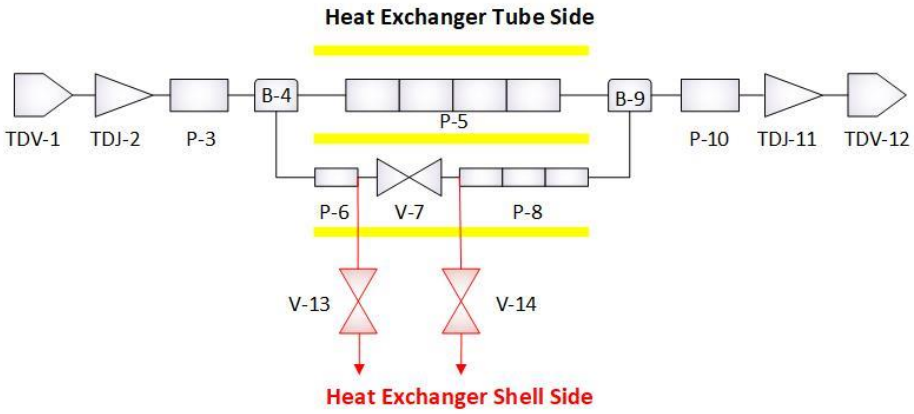


Figure 6-3: VV-PHTS Primary Side (during accidental scenarios)

While the secondary side of the HX is modelled as a single pipe segment connected to the CHWS-1 piping.

- CHWS-1 Protection Important Components (PICs) Valves are included in the model (marked in red in Figure 6-2).
- PIC valves and DTR isolation valves (marked in blue in Figure 6-2) have been modelled as motor valves with a closure time of 10 s. These assumptions have been taken in order to intervene promptly during accident cases, avoid pump cavitation, loss of cooling power efficiency and draining issue but also in order to avoid potential water hammer effects. The open/closure trip of these valves has been fixed according to **§5.5.7** and **§5.5.8**).
- Several pressure relief valves have been located throughout the system. These valves are modelled as servo valves and they intervene in case of over pressurization events in order to not exceed the design pressure in the system (2.1 MPa).
- Throughout this study, I&C response time of 5 seconds has been considered and implemented for all the CHWS-1B instrumentation taking into account Table 6-2.

Table 6-2: I&C response time

Sensor response time	1.5 s	Typical value, EPR^{TM} feedback
Response time for I&C acquisition card	0.27 s	HIMA 62100
Response time for duplication of analog signal from Central Safety System (CSS)	2 s	I&C card is MACX MCR-SL-RP-SSI-2I and its response time is ≤ 1.3 ms. The preliminary transmission time from CSS to system I&C is 2 s.

Processing time for PLC S7-4000	0.7 s	

6.3 LOCA Accident in the DTR

After having defined the system design and modelled CHWS-1B system on RELAP5, thermal transient simulations during LOCA event in the Tokamak Complex Drain Tank Room (DTR) has performed.

DTR represents critical zone for CHWS-1 because both the trains are placed there and in addition, a cooling pipe defined as high-energy line is located in their vicinity.

This study aims to investigate a postulated CHWS-1B pipe break in DTR, in order to analyse the event evolution and define required measures to isolate the affected CHWS-1B zone. In addition, it is also put forward the possibility to timely re-start the affected train and thus guarantee full safety cooling to CHWS-1 components outside DTR.

The results obtained from this numerical simulation allow to assess the capability of the system to respond to adverse conditions, verify the required time of intervention and evaluate the event mitigation.

Several pipe break scenarios have been performed, ranging from small to very large breaks (10% pipe area break to double-ended guillotine break).

The accumulated water leaked through the break is shown in Figure 6-4. The total inventory of the system corresponds to 40000 kg.

The simulation has been run for 1000 seconds to study the response of the system. This running time has been chosen so that the complete transient is captured.
During the first 100 seconds, a transient simulation has been performed to simulate the start-up of the system. Then, the system reaches and operates in steady-state conditions for 100 seconds.

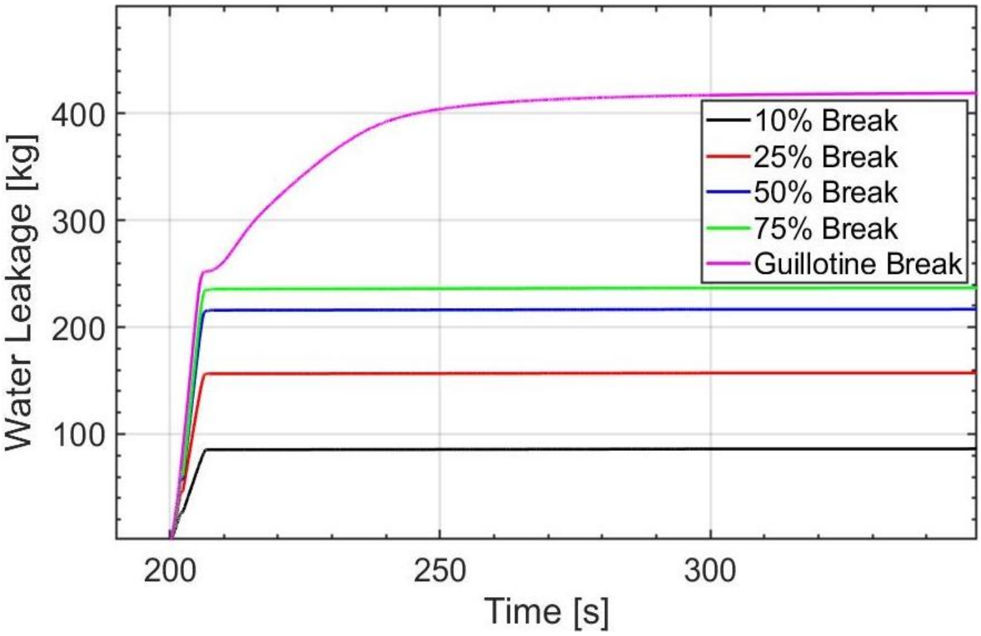


Figure 6-4: Amount of water through the pipe break (LOCA Accident in DTR)

At 200 seconds, the pipe break happens. For all the cases shown, few seconds after the pipe break, the pressure transmitter located in the DTR inlet line already records the anomaly; the measured pressure reaches the pressure setpoint and the signal to close the isolation valves in the DTR is sent (Figure 6-5).

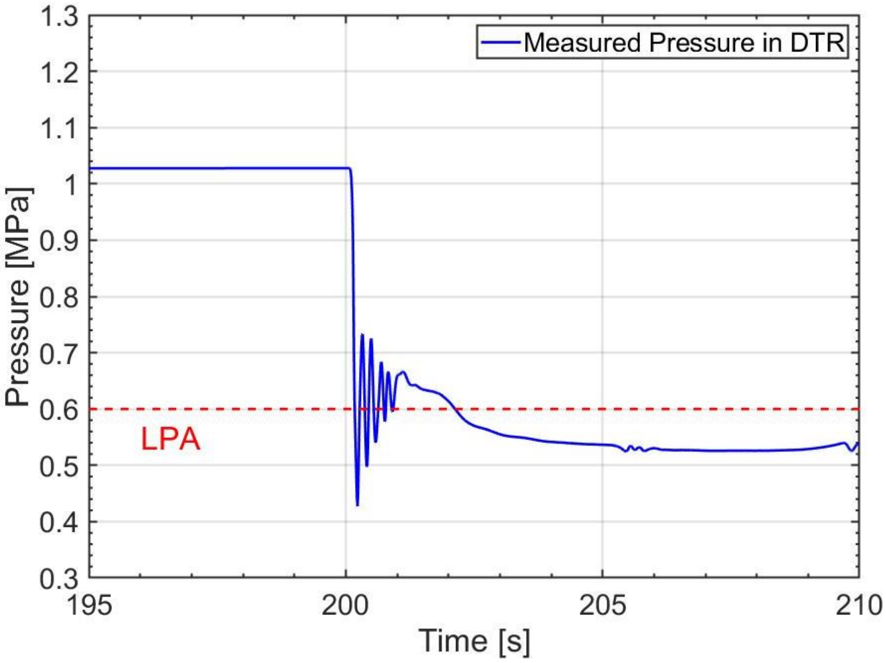


Figure 6-5: Measured pressure In the DTR (LOCA Accident in the DTR)

Meantime, also the pressure at the inlet of the pump quickly reaches the LPA (Figure 6-7) and in order to avoid cavitation their trip is commanded.

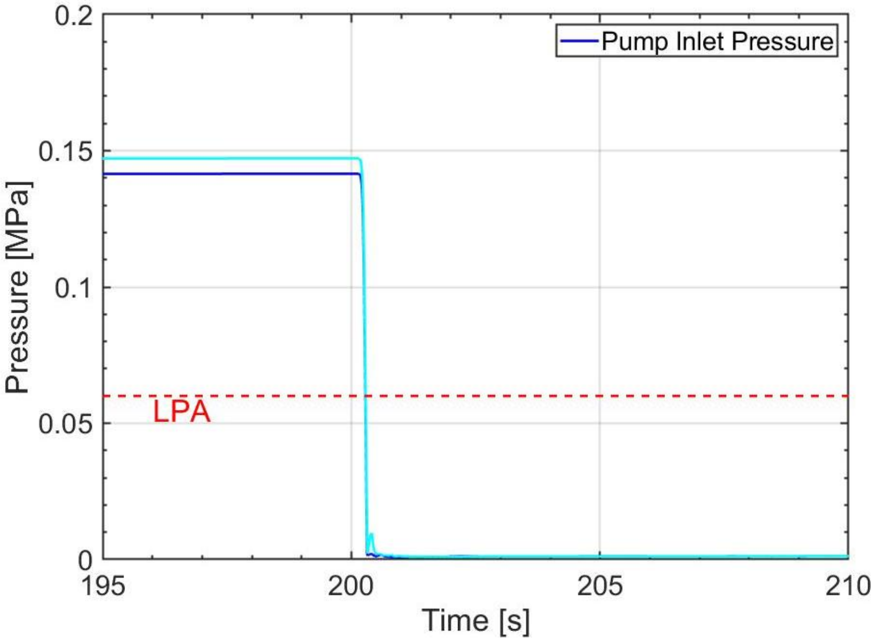


Figure 6-6: Pumps inlet pressure (LOCA Accident in the DTR)

In the PZR, the level of water decreases and reaches the LLA, and thus the make-up valve is commanded to open in order to provide demineralized water.

Figure 6-7 shows the trend of the water level in the PZR during a guillotine break and the state of the valves that determine the isolation and refilling of the system. This trend is maintained, also during the other accident scenarios. The intervention times remain unchanged while the PZR level variation is less accentuated according to the size of the break
After 290 s the curves stabilize and remain constant.

Although the line in the DTR is isolated in less than 20 seconds, the flow rate of water lost by CHWS-1B, during the guillotine break accident, continues to slowly increase up to approximately 100 seconds from the event start (as shown in Figure 6-4). This happens because the water inside the isolated section of the CHWS-1 piping, located in the DTR, flows through the pipe break even after the closure of the isolation valves.

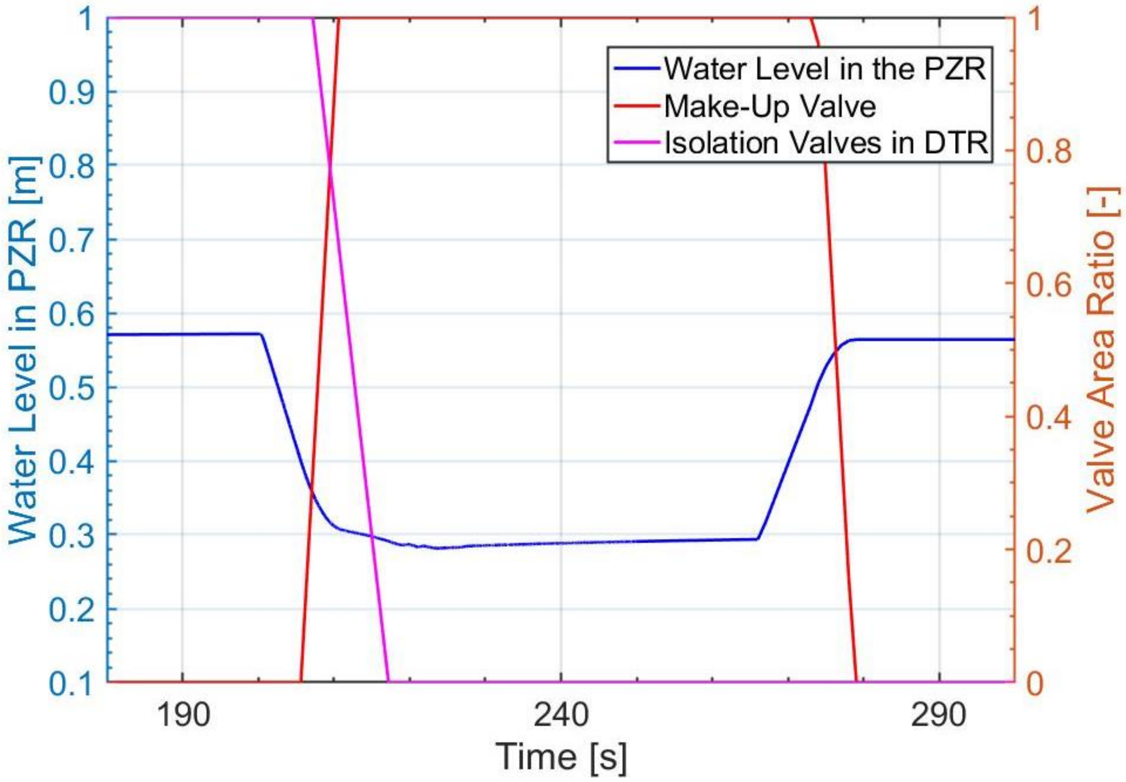


Figure 6-7: Level of water in the PZR (LOCA Accident in DTR)

After the stop of the system, the pressure and the temperature in the system increase due to the power provided by the heat exchangers at the system interfaces.
During these simulations, the components fed by the CHWS-1B have constant power so, even after the closure of the valves, the temperature and pressure increases more than in real conditions. Nevertheless, after a consistent amount of time from the start of the accident (800 seconds), the pressure conditions in the system are still under control.
Meanwhile, CHWS-1 cooling operation are still provided by the CHWS-1A.

When the accident is completely mitigated, the static pressure in the CHWS-1B needs to be restored and the system could be gradually restarted and returned to normal operating conditions, keeping the DTR isolated.

6.4 Pipe Leakage and Break in the System

The system behavior in case of a pipe rupture have been studied. Several simulations have been performed considering different location (with different elevations) for the pipe break. In order to analyse events difficult to detect, two consideration have been followed:

- the rupture has been considered far from the Drain Tank Room so the involved instrumentation and the evolution of the events are different from the scenario described in **§6.3**.

- the affected zone is located far from the HCC valves, in order to not activate the passive confinement function described in **§3.1.1.6.3**

In case of rupture of a pipe with DN ≥ 40 the event has been classified as an accident (Cat III) while in case of DN < 40 the leakage of water is considered an incident (Cat II).
For the incidental scenario the leakage can be detected from the narrow level control in the pressurizer (**§5.5.2**).

The level in the PZR decreases until reaching the LLA then a warning is sent to the operator while the DM make- up line starts injecting water until the level reaches the normal operating point; Figure 6-8 shows one of the scenarios analyzed.

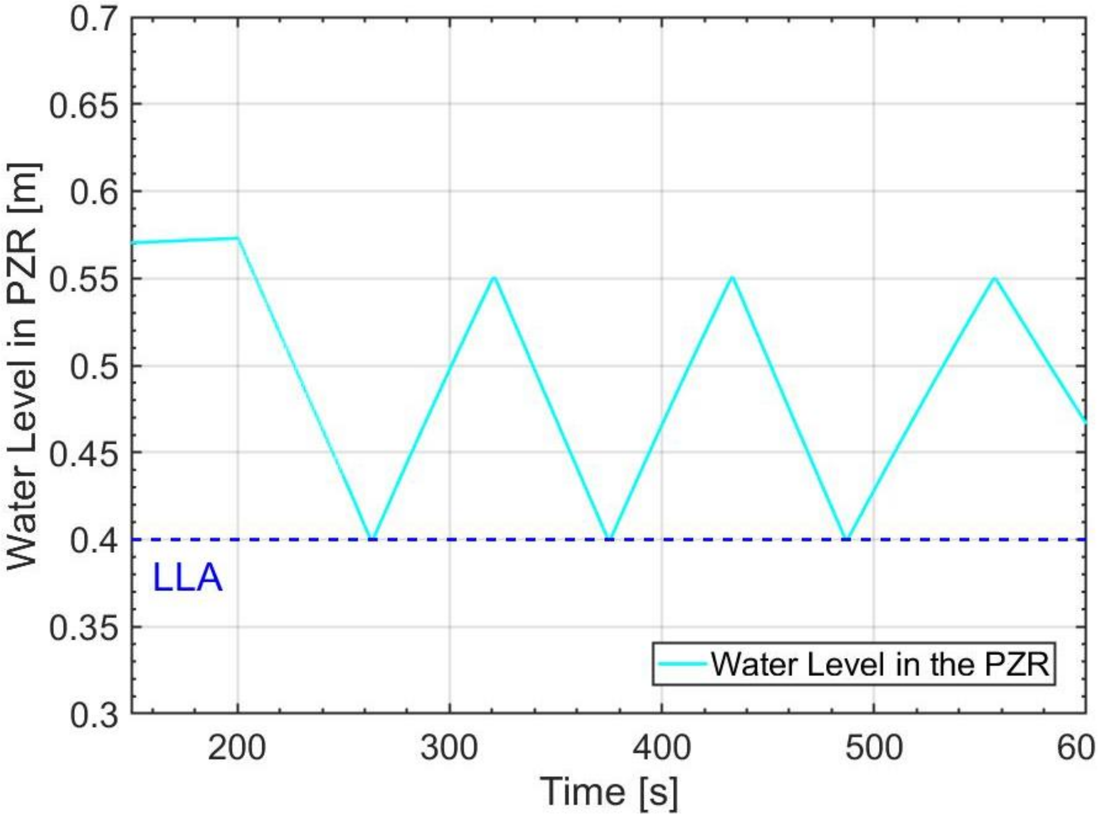


Figure 6-8: Level of water in the PZR (Small Pipe Break)

After receiving the warning, due to low level in the PZR, the operator can indagate the source of the leak in the system using two main instruments:

- Pressure instrumentation located through the system (**§5.5.6**).
- Flooding instruments located in the rooms where the components, cooled by the system, are located.

The affected zone shall be isolated, to protect the cooling function of the system, using an adequate system as isolation valves.

In case of an accident event, caused by the guillotine break of a large pipe (DN ≥ 40), a partial draining of the loop could be leaded.

In these analysed scenarios the level in the pressurizer continues to decrease after reaching the LLA because the make-up line cannot balance the water loss.
When the level reaches the VLLA a signal is sent to close the PICs valve.

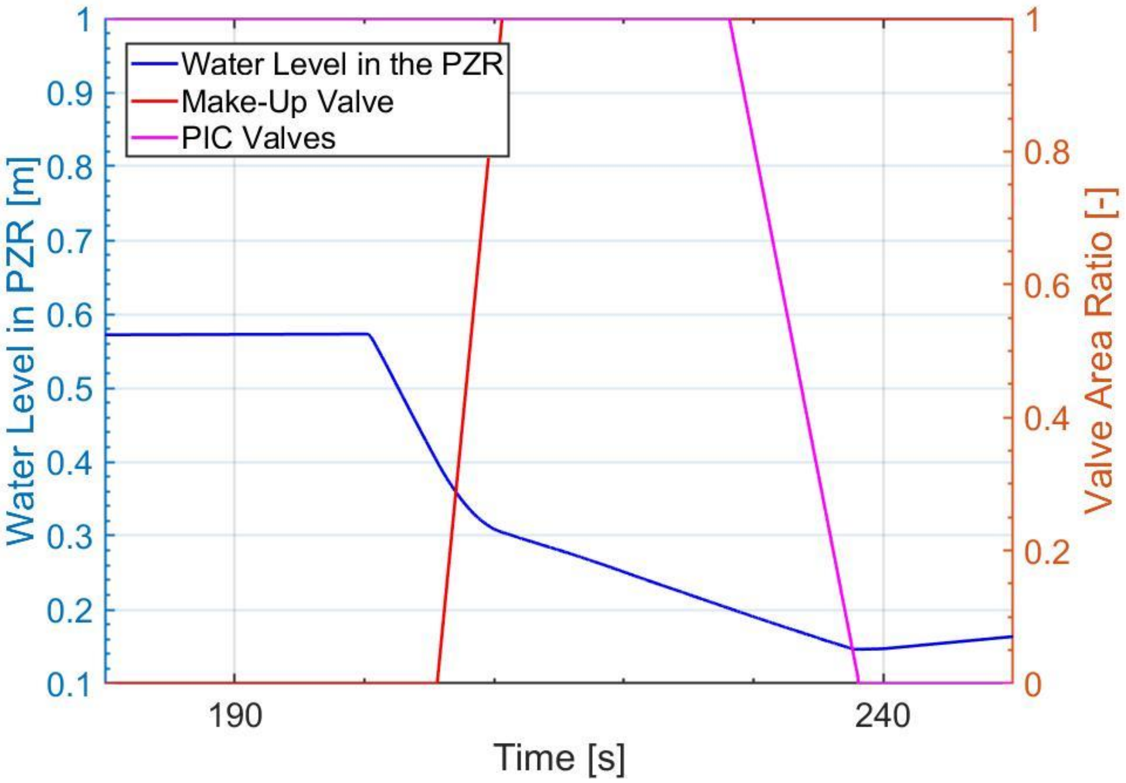


Figure 6-9: Level of water in the PZR (Big Pipe Break)

Meanwhile the instrumentation at the inlet of the pumps detects a drop of pressure and command the trip of the pumps.

After the shutdown of the CHWS-1B, it will be possible to identify and isolate the affected zone in order to restart the system; for the meantime the cooling operations are guaranteed by the CHWS-1A.

6.5 VV-PHTS Decay Heat Exchanger Leak (during VV-PHTS Baking Mode Operation)

This analysis is related to the study of postulated events (incident and accident) that could cause tritium contamination of CHWS-1.

The analysed cases are used in order to test the safety function of the system, verifying its capability of accident mitigation and confinement barrier, so that no environmental contamination could occur as a consequence of these scenarios.
Tritium contamination of CHWS-1 water may occur only via components, served by the system, by means of leakage through the corresponding heat exchangers.

It is assumed that a leak to CHWS-1 system can occur when VV-PHTS Decay HX primary side operating pressure is higher than the one measured on its secondary side (CHWS-1 side).
VV-PHTS is the only component, served by CHWS-1, that operates at higher pressure.
The analysis considers as Reference Event a water leakage from the VV-PHTS (primary side) to the CHWS-1B (secondary side).

This event could happen exclusively during water baking thermal hydraulic conditions on VV-PHTS side because it is the only operating mode in which the pressure in the heat exchanger primary side is higher than secondary side.

When VV-PHTS operates in water baking mode, the HX primary side is isolated from the rest of VV-PHTS system. In the secondary side, the chilled water is deviated through a bypass line that is used when Class IV power is available.

The aim is to analyse the system behavior if it is requested to provide decay heat removal operation during water baking mode. Consequently, in case of necessity, there could be the possibility to accelerate the reduction of temperature in the VV-PHTS due to the intervention of CHWS-1B.

In water baking operation, the heat exchanger pressure is 2 MPa on the primary side and 0.8 MPa on the secondary side.

The maximum tritium concentration in VV-PHTS cooling water is 0.21 mg/m^3 (76 GBq/m^3), including measurement uncertainties. While the maximum activity concentration due to ACPs is 66.5 MBq/ m^3.

Table 6-3: Operating Conditions of VV-PHTS Decay Heat Exchanger

	Primary Side		Secondary Side	
Temperature [°C]	195	176	6	12
Pressure [MPa]	2	1.98	0.8	0.75
Mass flow [kg/s]	23.9		20	

The following scenarios have been studied:

- Incident event: heat exchanger leakage.
- Accident event: heat exchanger tube rupture.
- Accident event: multiple heat exchanger tubes rupture.

The aim of incident analysis is to calculate the maximum allowed leakage through the decay heat exchanger, verify that no significant radiation deposit in the system results from the event and no serious consequential failures are expected.

While the accident scenarios, due to heat exchanger tubes rupture, are studied in order to analyse the system behavior and estimate the impact of the event in term of contamination.

6.5.1 Tritium and Activated Corrosion Product (ACP) Limitations

A drain line is provided in the CHWS-1 system to command, by operator action, the discharge of contaminated water. The drain line is further connected to the plant waste disposal system.

ITER suspicious effluents are sent to ITER Radwaste Treatment & Storage System and, afterwards, to the CEA/Cadarache Centre facilities for processing before release into the environment.

The maximum allowed level of activity contamination must be 74 MBq/m^3 for tritium releases and 74 kBq/m^3 for ACPs, according to ITER and CEA limitations. In order to guarantee CHWS-1B capability of quickly draining and refilling water, this limitation cannot be exceeded.

6.5.2 Analysis of the VV-PHTS HX Incident/Accident events

After having defined the CHWS-1B design, steady-state and transient analysis have been performed in incidental and accidental conditions.

All the analysed events consist in a water leakage from the VV-PHTS (primary side) to the CHWS-1B (secondary side).

During all the RELAP5 cases, in the first 100 seconds, a transient simulation has been performed in order to reproduce the start-up of the system. Then, the system reaches and operates in steady-state conditions for 100 seconds.
At 200 seconds from the start of the simulation, the incident/accident happens.
The results obtained from these numerical simulations allow to assess the capability of the system to respond to adverse conditions, verify the required time of intervention and evaluate the event mitigation.

6.5.2.1 Heat Exchanger Leakage

The incident case due to a small leakage has been analysed.
The cause of this leakage might be a small crack in the heat exchanger tubes and it represents, in practical terms, a difficult scenario to detect.

The size of this postulated small crack is defined so that the maximum leak rate in the heat exchanger does not cause CHWS-1B to exceed the contamination limit of 74 MBq/m^3 (see **§6.5.1**) and guarantee the CHWS-1 operation for 32 hours. The 32 hours value was selected as representative of a long duration loss of off-site power.

Indeed, the leakage rate was calculated considering the maximum contaminated activity in VV-PHTS water (76 GBq/ m^3) and the total CHWS-1B water inventory of 57 m^3:

$$Q_{\text{leakage,MAX}} = \frac{(74\ \text{MBq/m}^3)\ \cdot\ 57\ \text{m}^3}{32\text{h}\ \cdot\ (76010\ \text{MBq/m}^3)} = 1.66\ \text{E}^{-03} = 1.66\ \text{l/h}$$

The RELAP5 simulation was performed for over 32 h in order to test the safety of the system and verify how it intervenes in order to not exceed the contamination level in the water.

It is crucial to be able to promptly discover the incident and isolate the affected zone; in order to mitigate the water contamination due to this event, the two CHWS-1B valves located on inlet and outlet lines of the VV-PHTS decay heat exchanger need to be closed. These valves are provided with fail in position type actuator.

The level of water in the PZR gradually increases until it reaches the HLA. At this point, a signal commands the closure of the isolation valves in the DTR (Figure 6-10).

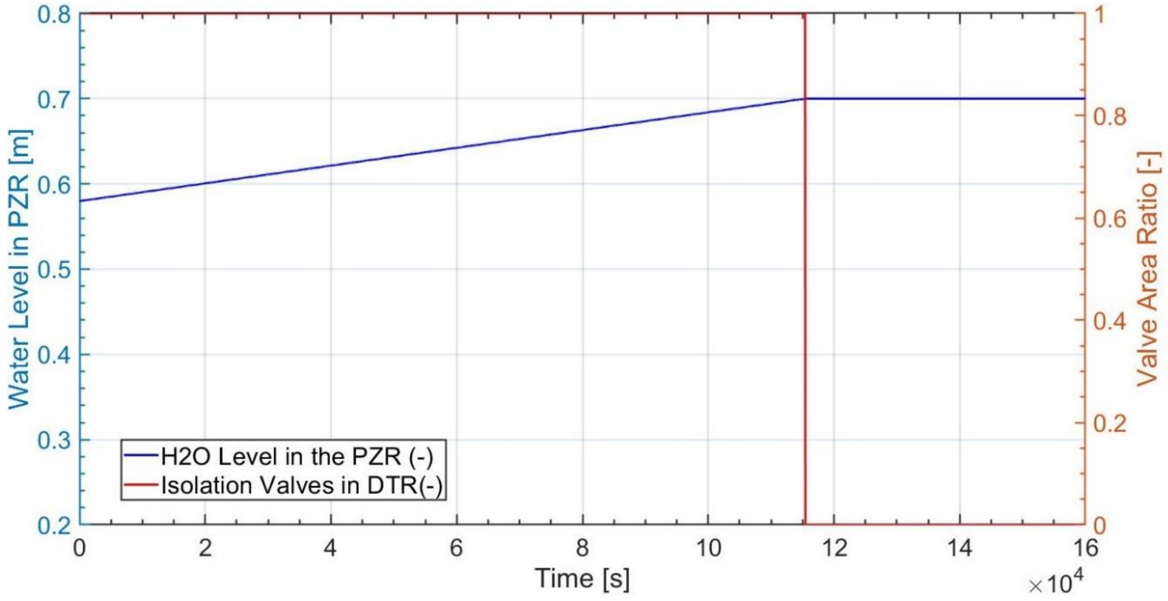


Figure 6-10: Level of water in the PZR vs time (incident analysis)

According to **§6.2**, the VV-PHTS is isolated 15 seconds after HLA is triggered (5 s have been considered for the I&C response time and further 10 s for the closure of the valves).

After the isolation of the affected CHWS-1B lines, the instrumentation located in the discharge line of the pumps detects a flow variation and commands the opening of the valve in the bypass line; in this way, the system can continue its operation, guaranteeing the required mass flow to the remain components fed by CHWS-1B.

In Figure 6-11, the trend of the mass flow through the bypass line has been shown.

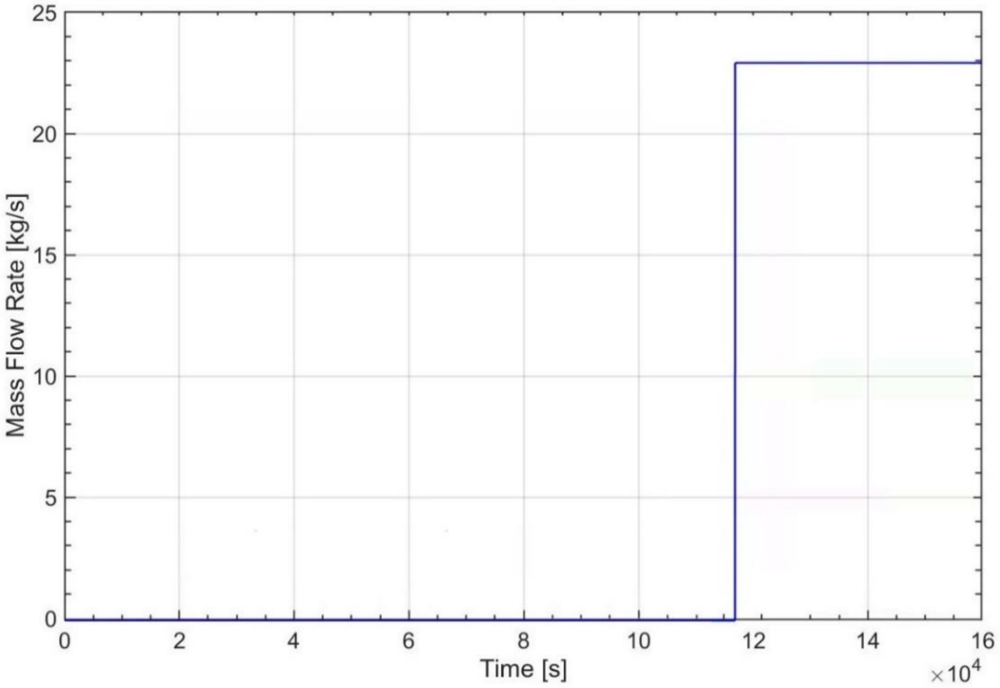


Figure 6-11: Mass flow through the pumps bypass line (incident analysis)

The total amount of water that flows from VV-PHTS into CHWS-1 during the RELAP5 simulation is 46.17 kg (Figure 6-12). In order to be conservative, this water has been considered with the maximum tritium concentration of 76 GBq/ m^3 and maximum ACPs concentration of 66.5 MBq/ m^3.

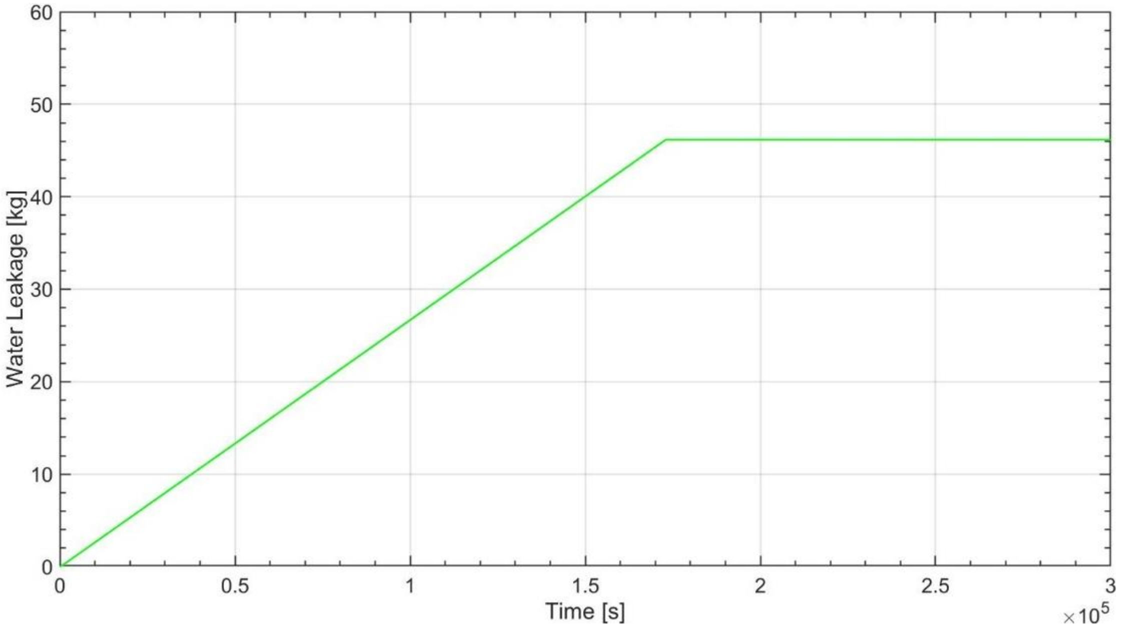


Figure 6-12: Amount of water leaked from VV-PHTS to CHWS-1(incident analysis)

The leak flow into the secondary loop is an input parameter to calculate the level of contamination in the system due to this event. It is assumed that tritium and ACPs, leaked into the HX secondary side, are confined within the secondary loop, which is considered to be intact.
Activation products and tritium are not released into the atmosphere.

The total inventory of the CHWS-1B corresponds to 57 m^3 and, consequently, the level of contamination due to this event has been calculated and shown in Table 6-4.

$$C_{T,CHWS-1B} = \frac{C_{T,VV-PHTS} \cdot \rho \cdot Q_{leak}}{Q_{tot,CHWS-1B}} = \frac{76\ \mathrm{GBq/m^3} \cdot 46.17\ \mathrm{kg}}{57\mathrm{m^3} \cdot 10^3 \mathrm{kg/m^3}} = 61.6\ \ \mathrm{MBq/m^3}$$

$$C_{ACPs,CHWS-1B} = \frac{C_{ACPs,VV-PHTS} \cdot \rho \cdot Q_{leak}}{Q_{tot,CHWS-1B}} = \frac{66.5\ \mathrm{MBq/m^3} \cdot 46.17\ \mathrm{kg}}{57\mathrm{m^3} \cdot 10^3 \mathrm{kg/m^3}} = 53.9 \cdot 10^{-3}\ \ \mathrm{MBq/m^3}$$

Where:
$C_{T,CHWS-1B}$ and $C_{ACPs,CHWS-1B}$ are, respectively, the tritium and ACP activity concentrations in the system after the incidental event.

$C_{T,VV-PHTS}$ and $C_{ACPs,CHWS-1B}$, respectively, the maximum tritium and ACP activity concentrations in VV-PHTS.

Q_{leak} is the total amount of water that flows from VV-PHTS into CHWS-1.

$Q_{tot,CHES-1B}$ is the total inventory of CHWS-1B.

Table 6-4: Contamination due to leakage of VV-PHTS heat exchanger

	CHWS-1B Contamination Level	Contamination Limitation
Tritium Concentration [MBq/m^3]	61.6	74
ACPs Concentration [MBq/m^3]	53.9 ·10^{-3}	74 ·10^{-3}

Both tritium and ACPs concentrations result below the limitations.

Moreover, a sampling connection is provided in the CHWS-1B system and periodic sampling may be taken for water quality analysis.
At this point, the drain line may be opened in order to discharge the contaminated water. While the PZR make-up line may refill the system with clean demineralized water.

6.5.2.2 Heat Exchanger Tubes Break

HE tubes ruptures have been analysed as accidental cases in order to investigate the system behavior and to guarantee a proper detection and mitigation of these events.

The VV-PHTS decay heat exchanger is a “Shell and Tube, 1 shell pass and 2 tube passes” and the guillotine break of a tube has been performed.

Afterwards, the simultaneous failure of 5 tubes (10% of the HX total tubes) has been studied to test the robustness of the analysis with respect to multiple failures.

The transient analysis has been performed starting from steady-state and it lasted 1200 seconds in order to be able to analyse the event fully.
All the events cause a rapid increase of CHWS-1B pressure in the DTR that is detected by the instrumentation located in that zone (see **§5.5.7**).
Consequently, the closure of the PIC valves in the DTR and the trip of the pumps are commanded and in 15 seconds (5 seconds is due to the I&C timing and 10 seconds is the valves closure time), the system stops operating.

Figure 6-13 shows water level trend in the PZR during a guillotine break and the state of the valves that determine the isolation of the system.

In Figure 6-14, it is shown the amount of contaminated water that flows in CHWS-1B during the accident scenarios.

No action from the primary side has been considered.

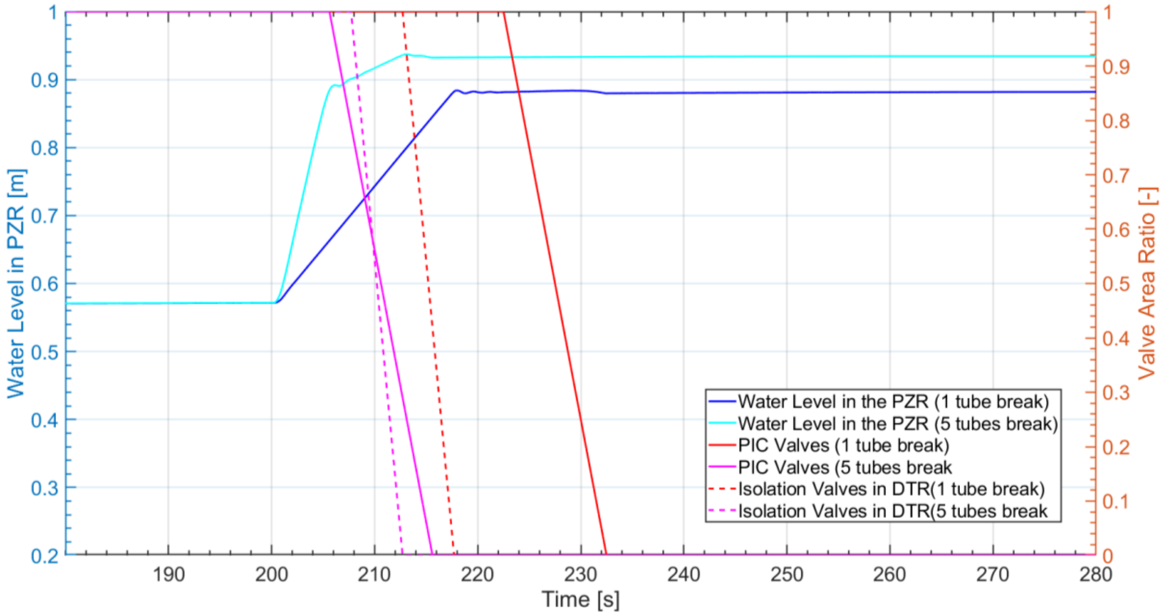


Figure 6-13: Level of water in the PZR and PIC valves state vs time

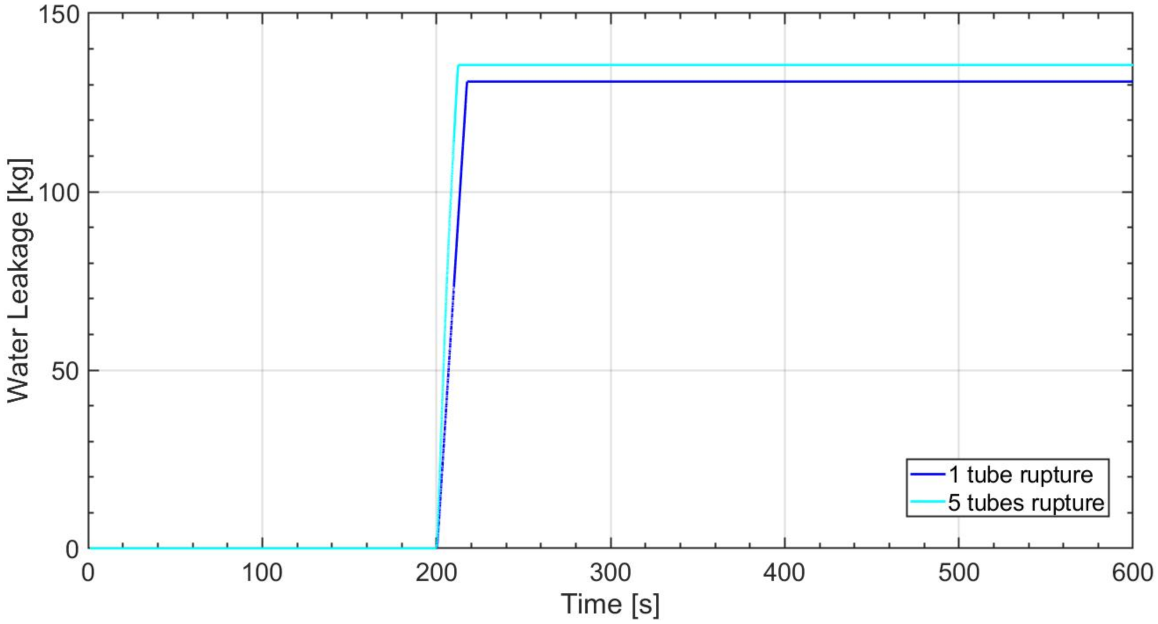


Figure 6-14: Amount of water through VV-PHTS heat exchanger

The high pressure setpoint of the I&C and the closure time of the valves have also been selected to avoid a peak of pressure during the accident could exceed the CHWS-1B design pressure, eventually jeopardising the system.

These accidents cause the over pressurization of the system. The radioactive contamination exceeds the limitations provided in **§6.5.1**.

$$C_{T,CHWS-1B} = \frac{C_{T,VV-PHTS} \cdot \rho \cdot Q_{5-\text{tube break}}}{Q_{tot,CHWS-1B}} = \frac{76\ \text{GBq/m}^3 \cdot 135.5\ \text{kg}}{57\text{m}^3 \cdot 10^3 \text{kg/m}^3} = 180.6\ \text{MBq/m}^3$$

$$C_{ACPs,CHWS-1B} = \frac{C_{ACPs,VV-PHTS} \cdot \rho \cdot Q_{leak}}{Q_{tot,CHWS-1B}} = \frac{66.5\ \text{MBq/m}^3 \cdot 135.5\ \text{kg}}{57\text{m}^3 \cdot 10^3 \text{kg/m}^3} = 15.8 \cdot 10^{-2}\ \text{MBq/m}^3$$

Where:

$C_{T,CHWS-1B}$ and $C_{ACPs,CHWS-1B}$ are, respectively, the tritium and ACP activity concentrations in the system after the accidental event.

$C_{T,VV-PHTS}$ and $C_{ACPs,CHWS-1B}$, respectively, the maximum tritium and ACP activity concentrations in VV-PHTS.

$Q_{5\text{-tube break}}$ is the total amount of water that flows from VV-PHTS into CHWS-1.

$Q_{tot,CHES-1B}$ is the total inventory of CHWS-1B.

Table 6-5: Contamination due to VV-PHTS Heat Exchanger Tubes Rupture

	CHWS-1B Contamination Level (1-tube break)	CHWS-1B Contamination Level (5-tube break)	Contamination Limitation
Tritium Concentration [MBq/m^3]	174.48	180.67	74
ACPs Concentration [MBq/m^3]	$15.26 \cdot 10^{-2}$	$15.81 \cdot 10^{-2}$	$74 \cdot 10^{-3}$

The system cannot continue to guarantee its function of water regulation by refilling and draining lines. CHWS-1B shutdown is executed.

After the closure of the PIC valves, the pressure and the temperature in the system increase due to the power provided by the heat exchangers at the system interfaces.

As mentioned in **§6.2**, in order to be conservative, the components fed by the CHWS-1B have been modelled with constant power. For this reason, after the closure of the PIC valves, temperature and pressure in the system will increase more than in real conditions.

Pressure relief valves (shown in Figure 6-2 and described in 6.2) intervene in order to counteract the pressure increase and not exceed the system design pressure.
Nevertheless, after 15 min, the pressure conditions in the system are still under control (Figure 6-15).

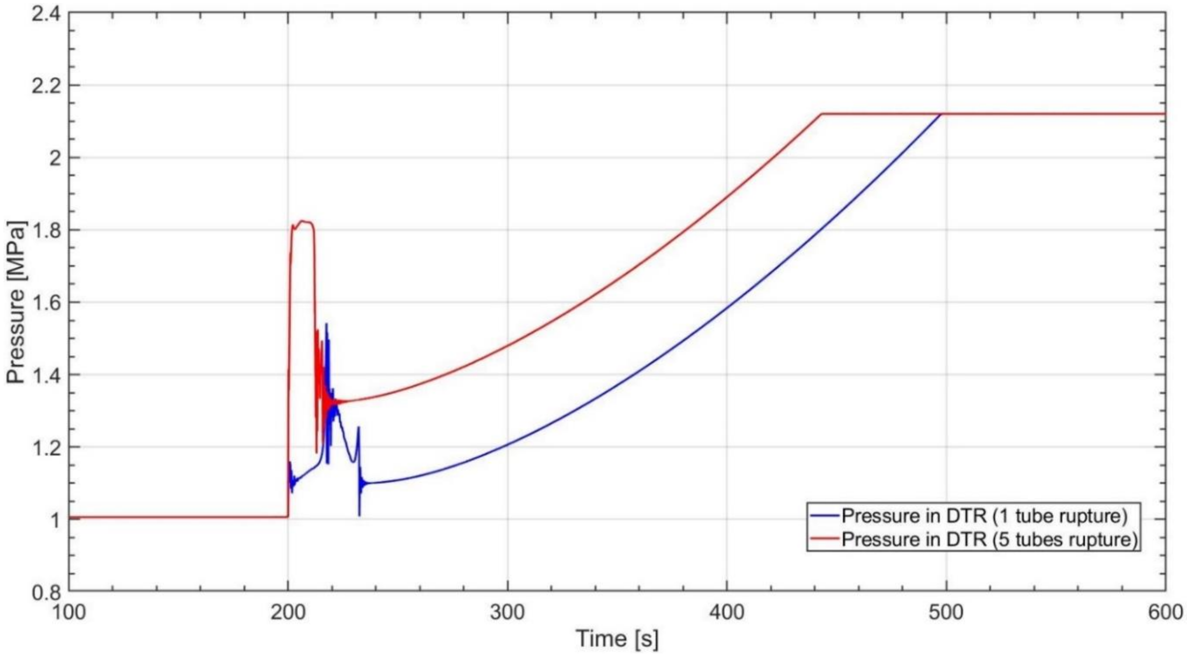


Figure 6-15: Measured pressure in the DTR inlet line

Meanwhile, CHWS-1 cooling operation is still provided by the CHWS-1A.

After the complete mitigation of the accident, the CHWS-1B system could be gradually restarted and returned to normal operating conditions, keeping the damaged zone (DTR) isolated.

The simulation outcome shows that the system is able to detect and mitigate the incident/accident efficiently.
The considered events have been studied exclusively for academic purposes, because classified as Cat V and beyond the design basis of ITER (**§6.1**). Nevertheless, the analysis is useful if VV-PHTS temperature reduction is increased by CHWS-1B early intervention.

The results show that for incidental and accidental events including water contamination as well as pressure and temperature transients, there is no risk of system failure and environmental hazard.

During the analysed incident, the heat exchanger leakage is promptly detected and the affected line isolated. The level of tritium is maintained below the required limitation of 74 MBq/m^3 while the system can quickly drain the contaminated water.

More severe leakages, due to a single or multiple tube rupture in the heat exchanger, cause an over pressurization of the system and the contaminated water in CHWS-1B rapidly exceeds the tritium limitations. The accident management strategy guarantees the efficient shutdown of the CHWS-1B without affecting the integrity of the system; it can assure the possibility to restart the system afterwards. Meanwhile, the cooling operation of the system is accomplished by CHWS-1A.

This activity highlights that the system is able to mitigate all analysed incidental/accidental scenarios effectively. Nevertheless, the shutdown of the system must be executed in order to avoid exposing other components, served by CHWS-1B, to contamination risk.

As the current CHWS-1B design eliminates the chance of these events to ever occur, this study provides supporting evidence that it is a valid operating choice. Meanwhile, this investigation provides supporting evidence if CHWS-1 were to provide cooling capacity during VV baking mode.

7 Conclusions and future perspectives

This PhD activity, conducted with a collaboration between DIAEE of Sapienza University of Rome and the ITER Organization, consists into the develop of the final design of the safety-relevant CHWS-1 of ITER plant.

The operating procedures to be implemented in CHWS-1 have been analysed, developed and validated in order to guarantee the ITER SIC requirements and classification.

The document describes all the steps that have been followed in order to complete the design of the system. The complete sizing of all the CHWS-1 components have been procured and sensitivity analyses have been performed in order to guarantee the required conditions during all the system operating mode. A complete functional analysis has been carried out and the required I&C have been implemented in CHWS-1 by combining the thermal-hydraulic modelling with the simulation of I&C in several reference accidental scenarios.

The complete design is then demonstrated and validated performing several RELAP5-3D simulations that highlighted the CHWS-1 ability to guarantee cooling operation during all the normal and abnormal events.

Particular emphasis is given to CHWS-1 accident detection and mitigation system following the ITER SIC Requirements.

During the first part of the work a preliminary design of the CHWS-1 was developed and a thermal-hydraulic model was created using AFT Fathom9.
A list all possible operating scenarios were identified and relevant steady-state simulations were executed: First Plasma, Post First Plasma Operation (PFPO-I), Plasma Operation (PFPO-II).
The selection and sizing of CHWS-1 components was completed with several iterations and performing the different operating mode of the system. The operating parameters of the system, during normal operation, was studied in order to verify that CHWS-1 requirements were fulfilled.

The system is designed to perform certain safety functions to support the overall plant operation. For this reason, after realizing the sizing of the CHWS-1, it was important to analyse the system in the functional perspective to verify its completeness.

The objectives of the safety functions are to design all the functions required, including all the situations normal, incidental and accidental ones to maintain the plant in a safe operation domain. They are based on the safety principle of defence in depth in order to prevent, detect and/or mitigate situations.
The main function of the system is then divided into several small functions doing specific task to support the main function. These safety functions are analysed to identify its importance to safety, equipment protection etc., the dependencies & interfaces (physical & functional), reliability & availability requirements etc.

Each function was classified based on the standard IEC 61226 adapted to the ITER plant as follows:

- Category A: Function whose failure could lead directly to an incident or accident, causing significant risk of exposure or contamination.
- Category B: Function whose operation or presence is necessary to limit the consequences of an incident or accident that could result in significant risk of external or internal exposure.
- Category C: Function whose operation or presence is necessary to ensure the availability of important elements for protection (PIC), safety classified (SIC) including:
  - by providing auxiliary required by the PIC/SIC.
  - detecting internal and external hazards that can damage the PIC/SIC.
  - ensuring the protection of PIC/SIC.

The main functions of the CHWS-1 are:

- Pressurization
- Pumping
- Heat Removal
- Water Distribution
- Water Chemistry Control
- Safety Operating Parameters Monitoring
- LOCA Detection and Isolation in the DTR
- LOCA Detection and Isolation

I&C requirements were established for each function and automatic or manual actions were identified in order to reach and maintain a safety state after an incident or an accident.

All the Postulated Initiated Events are considered.

The categorisation of these event, as either an incident or an accident, was done mainly according to its likelihood.

Accident scenarios put specific requirements on the design to ensure that they do not propagate to the stage of jeopardising the functionality of the system. These requirements may include quantitative values for a design limit or set-points for some safety operation such as opening of relief valves or closure of isolation valves.

Postulated events that are extremely unlikely to occur, for example because they involve two completely independent aggravating failures each of low likelihood, are in ITER called hypothetical events They are also known as Beyond Design Base Accidents (BDBA), to indicate that they have not been specifically taken into account in the design. Nevertheless, analysis of postulated BDBA events is performed, to show the robustness of the design and demonstrate an ultimate safety margin.

In order to analyse the system behaviour in case of incidental/accidental scenarios a preliminary model of CHWS-1B was prepared using the code RELAP5-3D.

Three scenarios have been described in this document: LOCA Accident in the DTR, Pipe Leakage in the System, VV-PHTS HX Incident/Accident.
A sensitivity analysis was carried out and the different cases were evaluated on the basis of main parameters (mass flow, pressure, temperature).

These simulations were performed in order to analyses and verify the system behavior, the required actions to reach and maintain a safe state after the given events and, if necessary, required implementations in the I&C (**§6**).

DTR represents critical zone for CHWS-1 because both the trains are placed there and in addition, a cooling pipe defined as high-energy line is located in their vicinity.
For this reason, numerous I&C were implemented in this zone and several pipe break scenarios were analysed.
Other pipe leakage scenarios were also performed in different zones of the system in order to analyse the system capability to promptly intervene.

During all the transient cases, the accident management strategy guarantees efficient detection and mitigation.
In fact, after the isolation and the shutdown of the system, it is possible to maintain a stable condition for a consistent amount of time without affecting the integrity of the system.

In order to test the safety function of the system postulated events (incident and accident) that could cause tritium contamination of CHWS-1 were studied.
Three scenarios have been studied: an incident event (heat exchanger pipe leakage) and two accident events (heat exchanger tube break and multiple tubes break.
These are considered BDBA events but, as explained before, they were used to verify the system capability of accident mitigation and confinement barrier, so that no environmental contamination could occur as a consequence of these scenarios.
During the analysed scenarios, the simulation outcome shows that the system is able to detect and mitigate the incident/accident efficiently.
Despite the considered events have been studied exclusively for academic purposes, the analysis is useful if VV-PHTS temperature reduction is increased by CHWS-1B early intervention. This study may also be used to optimize CHWS-1 design and operating modes.
The results show that for incidental and accidental events including water contamination as well as pressure and temperature transients, there is no risk of system failure and environmental hazard.
During the analysed incident, the heat exchanger leakage is promptly detected and the affected line isolated. The level of tritium is maintained below the required limitation of 74 MBq/m^3 while the system can quickly drain the contaminated water.
More severe leakages, due to a single or multiple tube rupture in the heat exchanger, cause an over pressurization of the system and the contaminated water in CHWS-1B rapidly exceeds the tritium limitations. The accident management strategy guarantees the efficient shutdown of the CHWS-1B without affecting the integrity of the system; it can assure the

possibility to restart the system afterwards. Meanwhile, the cooling operation of the system is accomplished by CHWS-1A.

As the current CHWS-1B design eliminates the chance of these events to ever occur, this study provides supporting evidence that it is a valid operating choice. Meanwhile, this investigation provides supporting evidence if CHWS-1 were to provide cooling capacity during VV baking mode.

In conclusion, the performed activities highlight that the system is able to mitigate all analysed incidental/accidental scenarios effectively, demonstrating, justifying and validating CHWS-1 Design & Operation in compliance with ITER SIC Requirements and SIC Classification.

The CHWS-1 still have ongoing aspects in term of design. The layout of the system inside the Hot Cell Complex is not finalized and further modifications could be implemented.

The components that must be cooled by CHWS-1 in this area have been decided, as well as the rooms where they will be placed, but no isometrics are still available and complete pipe routing through the buildings is still hypothetic.

More information will be available with the progress of the Hot Cell Complex project and its construction. When it will reach a more mature state, the CHWS-1 design procedure described in this document could be implemented.

Isometrics and 3D Models regarding the system layout in the Hot Cell Complex will be produced and used as input to update the Fathom models.

The operating condition will be verified without the assumptions that were used in this document to compensate the ongoing state of the design.

Consequently, the functional analysis and the I&C requirements could be tested and validated again.

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A1. Process Flow Diagrams

The following sections present the corresponding PFDs following the operating modes described in **§2.3** and listed in Table A1- 1.

Table A1- 1: PFDs Operating Modes

CHWS-1 First Plasma Operation	No safety SIC cooling is requested. SIC LACs in the Tokamak Complex are the only components that should be cooled by chilled water. CHWS-1A piping distribution in Tokamak Complex is connected to CHWS-1B in one location. Then, CHWS-1B shares a pipe connection with CHWS-H2 so that cooling capacity is provided by CHWS-H2.
Post-First Plasma Operation I (PFPO-I)	SIC LACs in the Tokamak Complex are the only components that should be cooled by chilled water. CHWS-1A piping distribution in Tokamak Complex is connected to CHWS-1B in one location and cooling capacity is provided by CHWS-1B pumps, pressurizer and chillers.
CHWS-1A PFPO-II & DT Operation	All the components, cooled by CHWS-1A, are in operation and CHWS-1A pumps, pressurizer and chillers provide cooling capacity. First Plasma connection with CHWS-1B is removed/isolated.
CHWS-1B PFPO-II & DT Operation (VV-PHTS isolated)	All the components, cooled by CHWS-1B, are in operation except for VV-PHTS which does not require cooling actions. Its interface is isolated during this operating mode and the excess flow is accommodated in the pumps by-pass line. First Plasma connections with CHWS-H2 and CHWS-1A are removed/isolated.
CHWS-1B PFPO-II & DT Operation (LOOP)	This mode of operation is triggered with Loss of Off-Site Power. VV-PHTS requires cooling action, thus all the components, cooled by CHWS-1B, are in operation. CHWS-1B pumps, pressurizer and chillers provide cooling capacity.

These PFDs show the system layout and the main operational parameters, such as flowrate, velocity, pressure, temperature and elevation. The following should be noted:

- Flowrate: reading is shown in *kg/s* for all relevant location along the system, as indicated by the diamond-shape icon in the PFDs
- Velocity: reading is shown in *m/s* for all relevant location along the system, as indicated by the diamond-shape icon in the PFDs. With regards to pipes, corresponding velocity is read from pipe connected upstream to it.
- Pressure: reading is shown in *MPa* (absolute) for all relevant location along the system, as indicated by the diamond-shape icon in the PFDs. With regards to valves, upstream and downstream readings are provided, whereas only upstream pressure readings are provided for pipes.

- Temperature: reading is shown in ℃ for all relevant location along the system, as indicated by the diamond-shape icon in the PFDs.
- Heat load: reading is shown in *kW*, only for the first diamond-shape icon located downstream each component served by the system as indicated in the PFDs.
- Elevation: reading is shown in *m* for all relevant valves along the system, as indicated by the diamond-shape icon in the PFDs.

A1.1. PFD- First Plasma Operation

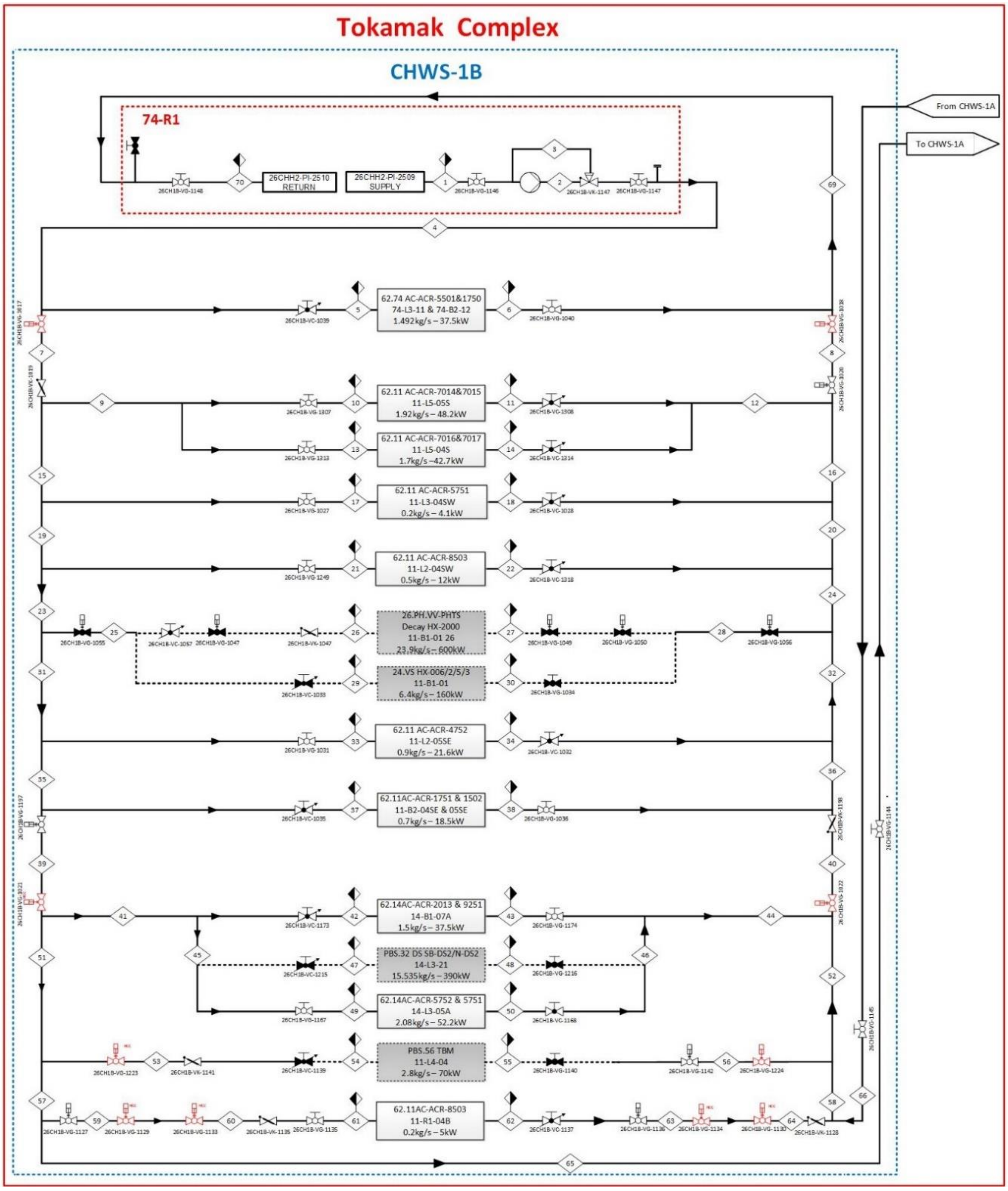

Figure A1- 1: CHWS-1 First Plasma Operation (CHWS-1B)

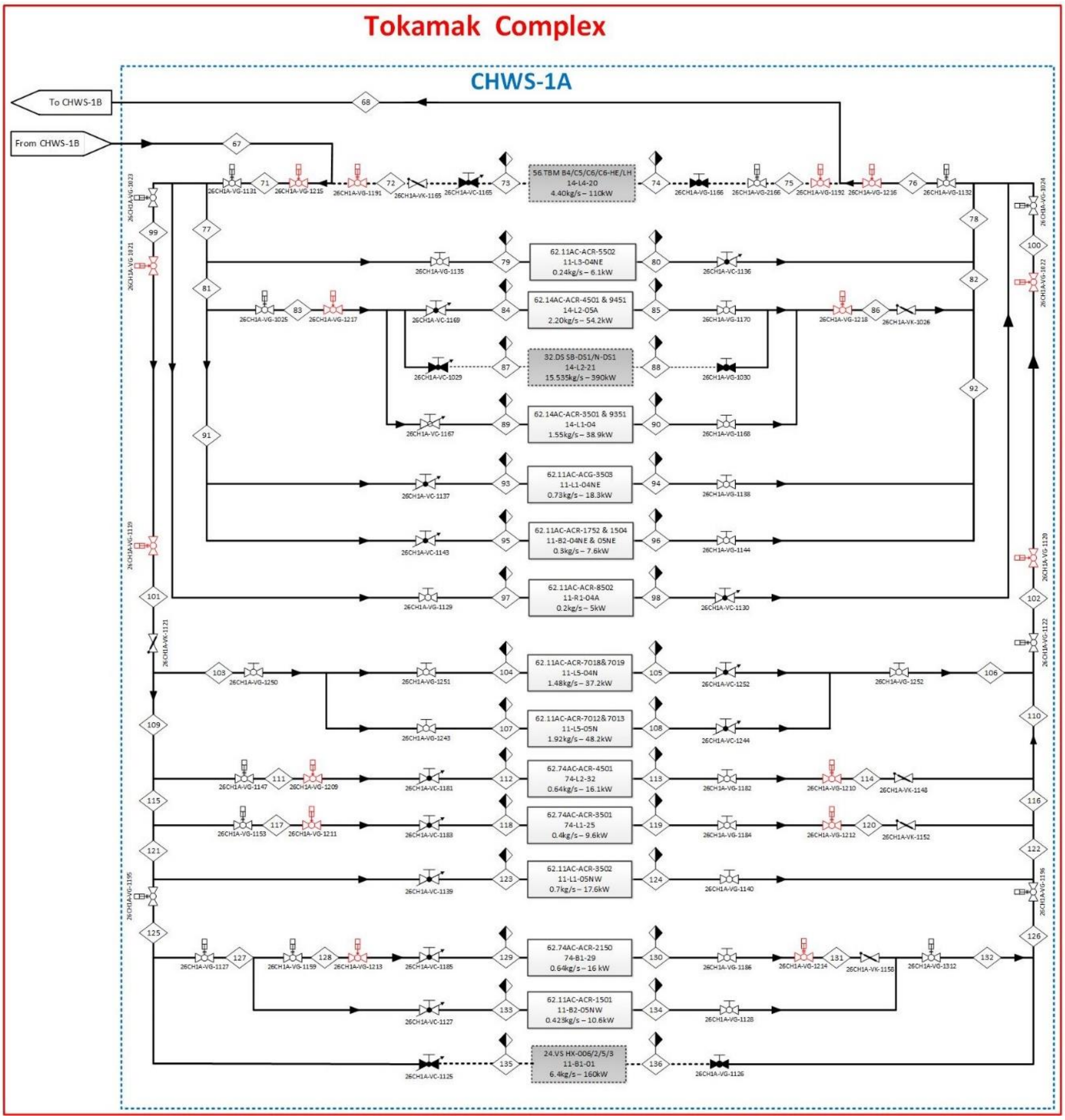

Figure A1- 2: CHWS-1 First Plasma Operation (CHWS-1A)

Table A1- 2: CHWS-1 Operating Conditions during First Plasma

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
2	26CH1B-VK-1147	1.21	1.19	6	22.62	4.74	-	16.72
3	26CH1B-PI-1152	1.21	-	6	0.00	0.00	-	-
4	26CH1B-PI-1016	1.16	-	6	22.62	0.70	-	-

PFD REF.	**P&ID Tag**	**P_{in} (MPa)**	**P_{out} (MPa)**	**Temperature (°C)**	**Flow rate (kg/s)**	**Velocity (m/s)**	**Heat load (kW)**	**Elevation (m)**
5	26CH1B-VC-1039	1.17	0.73	6	1.49	1.14	-	14.29
6	26CH1B-VG-1040	0.53	0.53	12	1.49	1.14	37.50	14.29
7	26CH1B-VG-1017	1.11	1.11	6	21.13	0.65	-	22.79
8	26CH1B-VG-1018	0.42	0.42	12	21.13	0.65	-	22.79
9	26CH1B-PI-1313	1.12	-	6	3.62	2.76	-	-
10	26CH1B-VG-1307	1.04	1.04	6	1.92	1.46	-	27.65
11	26CH1B-VC-1308	0.84	0.40	12	1.92	1.46	48.20	27.65
12	26CH1B-PI-1314	0.40	-	12	3.62	2.76	-	-
13	26CH1B-VG-1313	1.03	1.03	6	1.70	1.29	-	27.65
14	26CH1B-VC-1314	0.83	0.41	12	1.70	1.29	42.70	27.65
15	26CH1B-PI-1213	1.13	-	6	17.51	0.54	-	-
16	26CH1B-PI-1214	0.53	-	12	17.51	0.54	-	-
17	26CH1B-VG-1027	1.22	1.22	6	0.20	1.02	-	11.68
18	26CH1B-VC-1028	1.02	0.53	11	0.20	1.02	4.10	11.58
19	26CH1B-PI-1325	1.22	-	6	17.31	0.54	-	-
20	26CH1B-PI-1326	0.57	-	12	17.31	0.54	-	-
21	26CH1B-VG-1249	1.26	1.26	6	0.50	0.90	-	7.70
22	26CH1B-VC-1318	1.06	0.57	12	0.50	0.90	12.00	7.70
23	26CH1B-PI-1325	1.26	-	6	16.81	0.52	-	-
24	26CH1B-PI-1326	0.60	-	12	16.81	0.52	-	-
25	26CH1B-PI-1329	1.37	-	6	0.00	0.00	-	-
26	26CH1B-VK-1047	N/A	N/A	-	0.00	0.00	-	-5.88
27	26CH1B-VG-1049	N/A	N/A	-	0.00	0.00	-	-5.11
28	26CH1B-PI-1056	0.67	-	12	0.00	0.00	-	-
29	26CH1B-VC-1033	1.40	N/A	-	0.00	0.00	-	-6.23
30	26CH1B-VG-1034	N/A	0.70	12	0.00	0.00	-	-6.23
31	26CH1B-PI-1197	1.29	-	6	16.81	0.52	-	-
32	26CH1B-PI-1198	0.57	-	12	16.81	0.52	-	-

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
33	26CH1B-VG-1031	1.27	1.27	6	0.90	1.61	-	6.10
34	26CH1B-VC-1032	1.07	0.59	12	0.90	1.61	21.60	6.10
35	26CH1B-PI-7037	1.26	-	6	15.91	0.49	-	-
36	26CH1B-PI-1198	0.57	-	12	15.91	0.49	-	-
37	26CH1B-VC-1035	1.38	0.90	6	0.70	0.53	-	-5.10
38	26CH1B-VG-1036	0.70	0.70	12	0.70	0.53	18.50	-5.08
39	26CH1B-PI-1021	1.26	-	6	15.21	0.47	-	-
40	26CH1B-PI-1022	0.57	-	12	15.21	0.47	-	-
41	26CH1B-PI-1175	1.25	-	6	3.58	0.44	-	-
42	26CH1B-VC-1173	1.35	0.90	6	1.50	1.14	-	-3.83
43	26CH1B-VG-1174	0.70	0.70	12	1.50	1.14	37.50	-3.83
44	26CH1B-PI-1176	0.57	-	12	3.58	0.44	-	-
45	26CH1B-PI-1191	1.23	-	6	2.08	0.25	-	-
46	26CH1B-PI-1192	0.51	-	12	2.08	0.25	-	-
47	26CH1B-VC-1215	1.22	N/A	-	0.00	0.00	-	11.95
48	26CH1B-VG-1216	N/A	0.53	12	0.00	0.00	-	11.95
49	26CH1B-VG-1167	1.14	1.14	6	2.08	1.58	-	16.19
50	26CH1B-VC-1168	0.94	0.51	12	2.08	1.58	52.20	16.19
51	26CH1B-PI-1189	1.23	-	6	11.63	0.62	-	-
52	26CH1B-PI-1190	0.48	-	12	11.63	0.62	-	-
53	26CH1B-PI-1223	1.15	-	6	0.00	0.00	-	-
54	26CH1B-VC-1139	1.15	N/A	-	0.00	0.00	-	18.58
55	26CH1B-VG-1140	N/A	0.46	12	0.00	0.00	-	18.98
56	26CH1B-VG-1224	0.46	0.46	12	0.00	0.00	-	18.98
57	26CH1B-PI-1265	1.09	-	6	11.63	0.62	-	-
58	26CH1B-PI-1266	0.40	-	12	11.63	0.62	-	-
59	26CH1B-VG-1129	1.01	1.01	6	0.20	1.02	-	32.48
60	26CH1B-VG-1133	0.91	0.91	6	0.20	1.02	-	34.67

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
61	26CH1B-VG-1135	0.86	0.86	6	0.20	1.02	-	36.02
62	26CH1B-VC-1137	0.66	0.40	12	0.20	1.02	5.00	36.02
63	26CH1B-VG-1134	0.38	0.38	12	0.20	1.02	-	34.97
64	26CH1B-VG-1130	0.34	0.34	12	0.20	1.02	-	32.48
65	26CH1B-PI-1303	1.04	-	6	11.43	3.70	-	-
66	26CH1B-PI-1304	0.44	-	12	11.43	3.70	-	-
67	26CH1B-PI-1234	1.09	-	6	11.43	3.70	-	-
68	26CH1B-PI-1233	0.50	-	12	11.43	3.70	-	-
69	26CH1B-PI-1008	0.41	-	12	22.62	0.70	-	-
70	26CH1B-VG-1148	0.40	0.40	12	22.62	4.74	-	17.43
71	26CH1A-VG-1215	1.04	1.04	6	11.43	3.70	-	21.40
72	26CH1A-VG-1191	1.06	N/A	-	0.00	0.00	-	23.90
73	26CH1A-VC-1165	N/A	N/A	-	0.00	0.00	-	23.90
74	26CH1A-VG-1166	N/A	N/A	-	0.00	0.00	0.00	23.90
75	26CH1A-VG-1192	N/A	0.51	12	0.00	0.00	-	21.40
76	26CH1A-VG-1216	0.54	0.54	12	11.43	3.70	-	21.40
77	26CH1A-PI-1199	1.06	-	6	5.02	0.61	-	-
78	26CH1A-PI-1200	0.68	-	12	5.02	0.61	-	-
79	26CH1A-VG-1135	1.11	1.11	6	0.24	1.24	-	11.75
80	26CH1A-VC-1136	0.91	0.68	12	0.24	1.24	6.10	11.75
81	26CH1A-PI-1201	1.14	-	6	4.78	0.58	-	-
82	26CH1A-PI-1202	0.72	-	12	4.78	0.58	-	-
83	26CH1A-VG-1217	1.15	1.15	6	3.75	0.46	-	7.66
84	26CH1A-VC-1169	1.12	0.91	6	2.20	1.67	-	9.82
85	26CH1A-VG-1170	0.71	0.71	12	2.20	1.68	54.20	9.82
86	26CH1A-VG-1218	0.72	0.72	12	3.75	0.46	-	7.66
87	26CH1A-VC-1029	1.17	N/A	-	0.00	0.00	-	5.54
88	26CH1A-VG-1030	N/A	0.75	12	0.00	0.00	0.00	5.14

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
89	26CH1A-VC-1167	1.19	0.97	6	1.55	1.18	-	2.86
90	26CH1A-VG-1168	0.77	0.77	12	1.55	1.18	38.90	2.86
91	26CH1A-PI-1141	1.18	-	6	1.03	0.78	-	-
92	26CH1A-PI-1142	0.79	-	12	1.03	0.78	-	-
93	26CH1A-VC-1137	1.22	1.00	6	0.73	1.31	-	0.61
94	26CH1A-VG-1138	0.79	0.79	12	0.73	1.31	18.30	0.93
95	26CH1A-VC-1143	1.27	1.05	6	0.30	0.54	-	-5.21
96	26CH1A-VG-1144	0.85	0.85	12	0.30	0.54	7.60	-5.25
97	26CH1A-VG-1129	0.88	0.88	6	0.20	1.02	-	33.58
98	26CH1A-VC-1130	0.68	0.48	12	0.20	1.02	5.00	33.18
99	26CH1A-VG-1021	1.03	1.03	6	6.20	0.76	-	22.68
100	26CH1A-VG-1022	0.54	0.54	12	6.20	0.76	-	22.68
101	26CH1A-VG-1119	0.99	0.99	6	6.20	1.30	-	24.50
102	26CH1A-VG-1120	0.54	0.54	12	6.20	1.30	-	23.66
103	26CH1A-PI-1251	0.99	-	6	3.40	2.59	-	-
104	26CH1A-VG-1251	0.89	0.89	6	1.48	1.13	-	27.65
105	26CH1A-VC-1252	0.69	0.58	12	1.48	1.13	37.20	27.65
106	26CH1A-PI-1252	0.57	-	12	3.40	2.59	-	-
107	26CH1A-VG-1243	0.89	0.89	6	1.92	1.46	-	27.65
108	26CH1A-VC-1244	0.69	0.57	12	1.92	1.46	48.20	27.65
109	26CH1A-PI-1187	1.00	-	6	2.80	0.59	-	-
110	26CH1A-PI-1188	0.67	-	11.948	2.80	0.59	-	-
111	26CH1A-VG-1209	1.14	1.14	6	0.64	1.15	-	8.18
112	26CH1A-VC-1181	1.13	0.92	6	0.64	1.15	-	8.18
113	26CH1A-VG-1182	0.72	0.72	12	0.64	1.15	16.10	8.48
114	26CH1A-VG-1210	0.72	0.72	12	0.64	1.15	-	8.18
115	26CH1A-PI-1221	1.15	-	6	2.16	0.45	-	-
116	26CH1A-PI-1222	0.74	-	12	2.16	0.45	-	-

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
117	26CH1A-VG-1211	1.20	1.20	6	0.40	0.72	-	2.39
118	26CH1A-VC-1183	1.19	0.96	6	0.40	0.72	-	2.77
119	26CH1A-VG-1184	0.76	0.76	12	0.40	0.72	9.60	3.02
120	26CH1A-VG-1212	0.76	0.76	12	0.40	0.72	-	2.77
121	26CH1A-PI-1195	1.20	-	6	1.76	0.37	-	-
122	26CH1A-PI-1196	0.77	-	12	1.76	0.37	-	-
123	26CH1A-VC-1139	1.22	0.98	6	0.70	1.26	-	0.74
124	26CH1A-VG-1140	0.78	0.78	12	0.70	1.26	17.60	0.74
125	26CH1A-PI-1123	1.25	-	6	1.06	0.22	-	-
126	26CH1A-PI-1124	0.81	-	12	1.06	0.22	-	-
127	26CH1A-PI-1127	1.27	-	6	1.06	1.91	-	-
128	26CH1A-VG-1213	1.22	1.22	6	0.64	1.15	-	-2.40
129	26CH1A-VC-1185	1.22	1.05	6	0.64	1.15	-	-2.66
130	26CH1A-VG-1186	0.85	0.84	12	0.64	1.15	16.40	-2.33
131	26CH1A-VG-1214	0.84	0.84	12	0.64	1.15	-	-2.40
132	26CH1A-PI-1220	0.82	-	12	1.06	1.91	-	-
133	26CH1A-VC-1127	1.27	1.05	6	0.42	0.76	-	-5.50
134	26CH1A-VG-1128	0.86	0.86	12	0.42	0.76	10.60	-6.56
135	26CH1A-VC-1125	1.30	N/A	-	0.00	0.00	-	-7.56
136	26CH1A-VG-1126	N/A	0.84	12	0.00	0.00	-	-6.53

A1.2. PFD – CHWS-Post First Plasma Operation (PFPO-I)

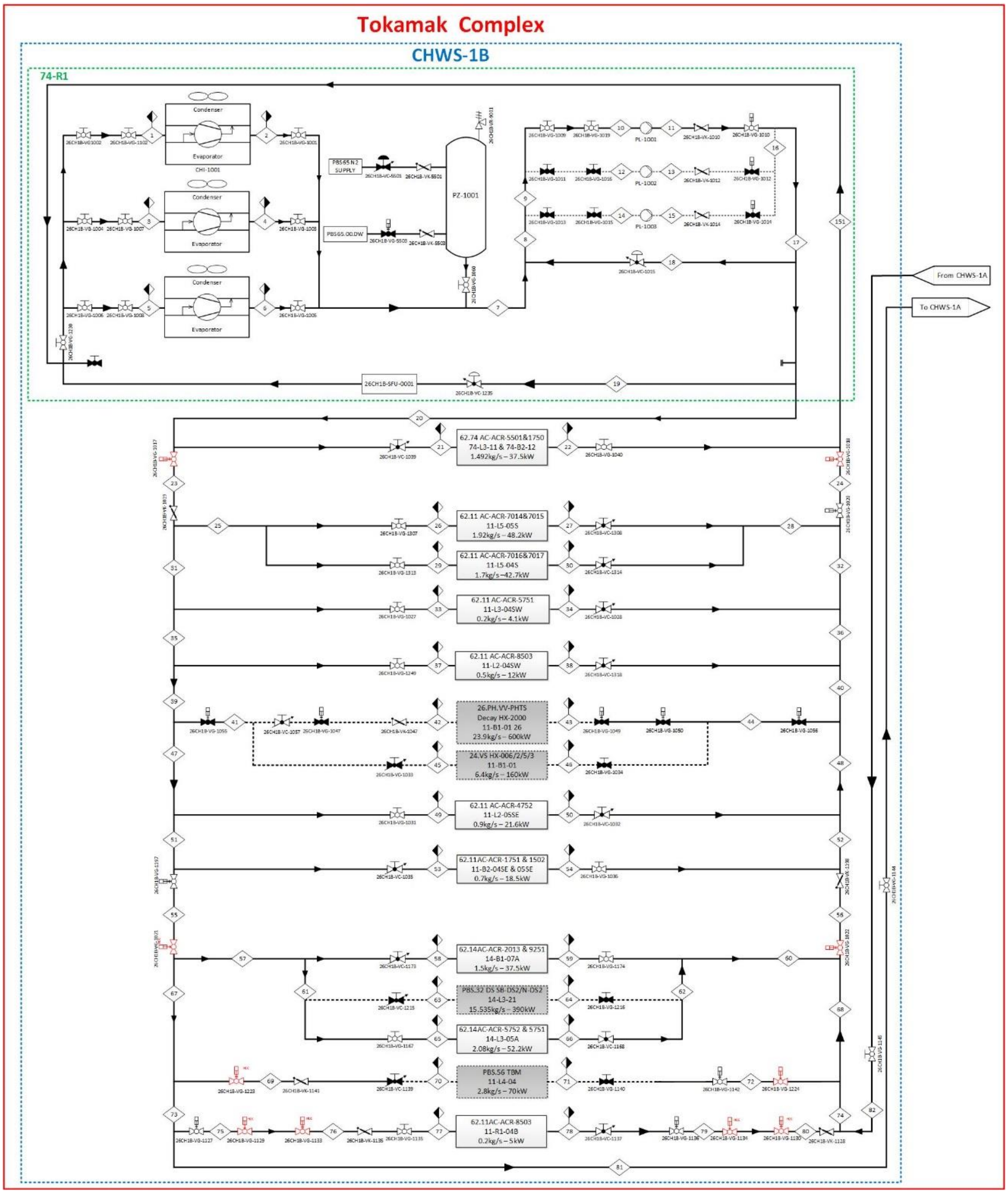

Figure A1- 3 Post First Plasma Operation-PFPO-I (CHWS-1B)

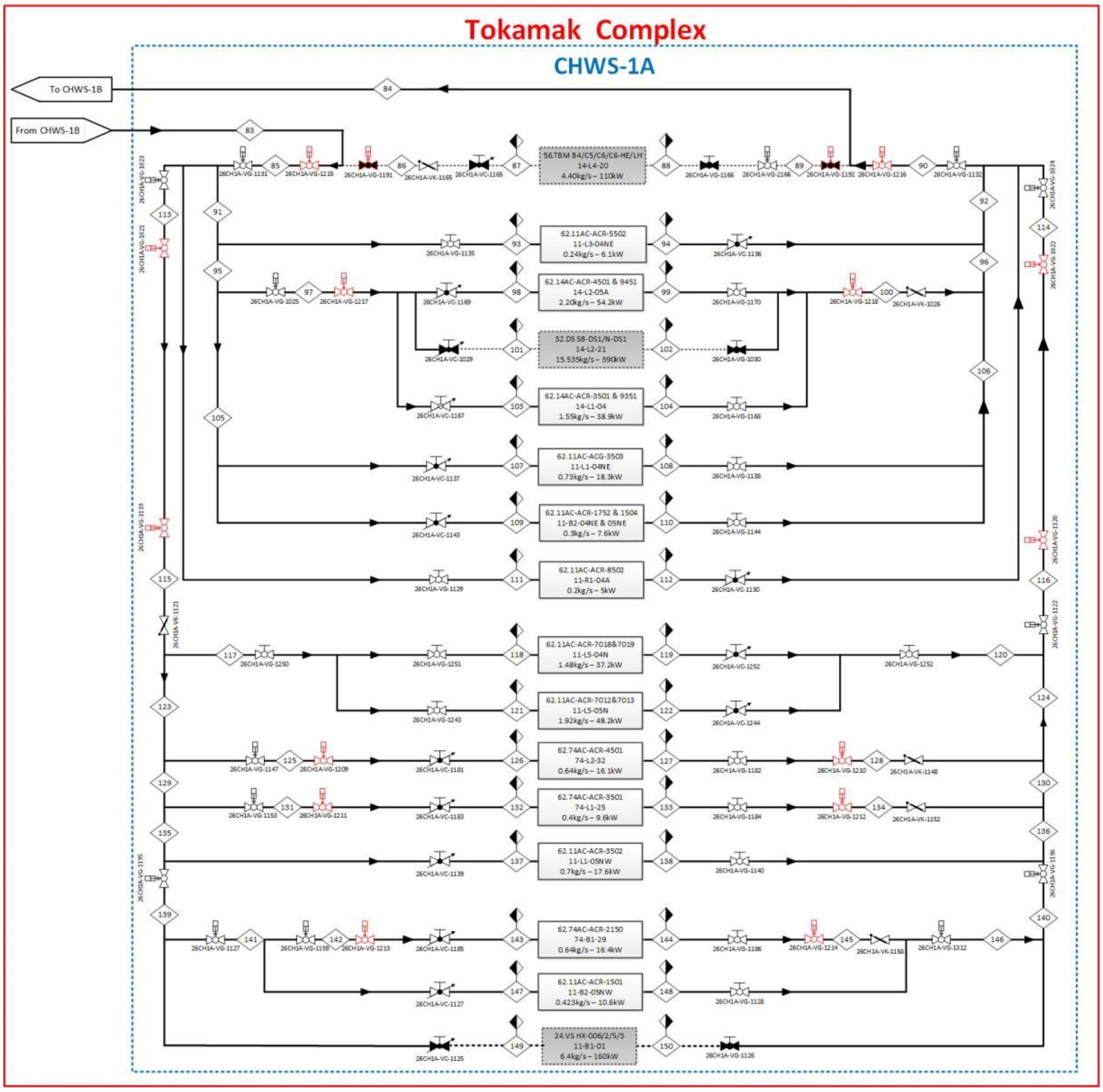

Figure A1- 4: Post First Plasma Operation-PFPO-I (CHWS-1A)

Table A1- 3: CHWS-1 Operating Conditions during Post First Plasma (PFPO-I)

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
1	26CH1B-PI-1002	0.23	-	12	7.47	0.40	-	-
2	26CH1B-PI-1001	0.23	-	6	7.47	0.40	-	-
3	26CH1B-PI-1004	0.23	-	12	7.43	0.40	-	-
4	26CH1B-PI-1003	0.23	-	6	7.43	0.40	-	-
5	26CH1B-PI-1006	0.23	-	12	7.72	0.41	-	-
6	26CH1B-PI-1005	0.23	-	6	7.72	0.41	-	-

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
7	26CH1B-PI-1007	0.21	-	6	22.62	0.70	-	-
8	26CH1B-PI-1007	0.21	-	6	44.90	1.39	-	-
9	26CH1B-PI-1007	0.21	-	6	44.90	1.39	-	-
10	26CH1B-PI-1009	0.18	-	6	44.90	2.41	-	-
11	26CH1B-PI-1010	1.12	-	6	44.90	2.41	-	-
12	26CH1B-PI-1011	-	-	-	0.00	0.00	-	-
13	26CH1B-PI-1012	-	-	-	0.00	0.00	-	-
14	26CH1B-PI-1013	-	-	-	0.00	0.00	-	-
15	26CH1B-PI-1014	-	-	-	0.00	0.00	-	-
16	26CH1B-PI-1229	1.10	-	6	0.00	0.00	-	-
17	26CH1B-PI-1229	1.10	-	6	44.90	1.39	-	-
18	26CH1B-PI-1015	1.10	0.61	6	22.28	1.20	-	18.35
19	WPU	-						
20	26CH1B-PI-1016	1.10	-	6	22.62	0.70	-	-
21	26CH1B-VC-1039	1.11	0.48	6	1.49	1.14	-	14.29
22	26CH1B-VG-1040	0.28	0.28	12	1.49	1.14	37.50	14.29
23	26CH1B-VG-1017	1.06	1.06	6	21.13	0.65	-	22.79
24	26CH1B-VG-1018	0.17	0.17	12	21.13	0.65	-	22.79
25	26CH1B-PI-1313	1.07	-	6	3.62	2.76	-	-
26	26CH1B-VG-1307	0.98	0.98	6	1.92	1.46	-	27.65
27	26CH1B-VC-1308	0.78	0.15	12	1.92	1.46	48.20	27.65
28	26CH1B-PI-1314	0.15	-	12	3.62	2.76	-	-
29	26CH1B-VG-1313	0.97	0.97	6	1.70	1.29	-	27.65
30	26CH1B-VC-1314	0.77	0.16	12	1.70	1.29	42.70	27.65
31	26CH1B-PI-1213	1.07	-	6	17.51	0.54	-	-
32	26CH1B-PI-1214	0.28	-	12	17.51	0.54	-	-
33	26CH1B-VG-1027	1.16	1.16	6	0.20	1.02	-	11.68
34	26CH1B-VC-1028	0.96	0.28	11	0.20	1.02	4.10	11.58

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
35	26CH1B-PI-1325	1.17	-	6	17.31	0.54	-	-
36	26CH1B-PI-1326	0.32	-	12	17.31	0.54	-	-
37	26CH1B-VG-1249	1.20	1.20	6	0.50	0.90	-	7.70
38	26CH1B-VC-1318	1.00	0.32	12	0.50	0.90	12.00	7.70
39	26CH1B-PI-1325	1.21	-	6	16.81	0.52	-	-
40	26CH1B-PI-1326	0.35	-	12	16.81	0.52	-	-
41	26CH1B-PI-1329	1.31	-	6	0.00	0.00	-	-
42	26CH1B-VK-1047	N/A	-	-	0.00	0.00	-	-5.88
43	26CH1B-VG-1049	N/A	-	-	0.00	0.00	0.00	-5.11
44	26CH1B-PI-1056	0.43	-	12	0.00	0.00	-	-
45	26CH1B-VC-1033	1.34	-	-	0.00	0.00	-	-6.23
46	26CH1B-VG-1034	0.17	0.46	12	0.00	0.00	0.00	22.78
47	26CH1B-PI-1197	1.24	-	6	16.81	0.52	-	-
48	26CH1B-PI-1198	0.32	-	12	16.81	0.52	-	-
49	26CH1B-VG-1031	1.21	1.21	6	0.90	1.61	-	6.10
50	26CH1B-VC-1032	1.01	0.34	12	0.90	1.61	21.60	6.10
51	26CH1B-PI-7037	1.21	-	6	15.91	0.49	-	-
52	26CH1B-PI-1198	0.32	-	12	15.91	0.49	-	-
53	26CH1B-VC-1035	1.33	0.65	6	0.70	0.53	-	-5.10
54	26CH1B-VG-1036	0.45	0.41	12	0.70	0.53	18.50	-5.08
55	26CH1B-PI-1021	1.20	-	6	15.21	0.47	-	-
56	26CH1B-PI-1022	0.32	-	12	15.21	0.47	-	-
57	26CH1B-PI-1175	1.19	-	6	3.58	0.44	-	-
58	26CH1B-VC-1173	1.30	0.65	6	1.50	1.14	-	-3.83
59	26CH1B-VG-1174	0.45	0.45	12	1.50	1.14	37.50	-3.83
60	26CH1B-PI-1176	0.32	-	12	3.58	0.44	-	-
61	26CH1B-PI-1191	1.17	-	6	2.08	0.25	-	-
62	26CH1B-PI-1192	0.26	-	112	2.08	0.25	-	-

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
63	26CH1B-VC-1215	1.16	-	-	0.00	0.00	-	11.95
64	26CH1B-VG-1216	N/A	0.28	12	0.00	0.00	0.00	11.95
65	26CH1B-VG-1167	1.09	1.09	6	2.08	1.58	-	16.19
66	26CH1B-VC-1168	0.89	0.26	12	2.08	1.58	52.20	16.19
67	26CH1B-PI-1189	1.18	-	6	11.63	0.62	-	-
68	26CH1B-PI-1190	0.23	-	12	11.63	0.62	-	-
69	26CH1B-PI-1223	1.09	-	6	0.00	0.00	-	-
70	26CH1B-VC-1139	1.10	-	-	0.00	0.00	-	18.58
71	26CH1B-VG-1140	N/A	0.21	12	0.00	0.00	0.00	18.98
72	26CH1B-VG-1224	0.09	0.09	12	0.20	1.02	-	31.48
73	26CH1B-PI-1265	1.04	-	6	11.63	0.62	-	-
74	26CH1B-PI-1266	0.10	-	12	11.63	0.62	-	-
75	26CH1B-VG-1129	0.95	0.95	6	0.20	1.02	-	32.48
76	26CH1B-VG-1133	0.86	-	6	0.20	1.02	-	34.67
77	26CH1B-VG-1135	0.81	0.81	6	0.20	1.02	-	36.02
78	26CH1B-VC-1137	0.61	0.15	12	0.20	1.02	5.00	36.02
79	26CH1B-VG-1134	0.13	0.13	12	0.20	1.02	-	34.97
80	26CH1B-VG-1130	0.09	0.09	12	0.20	1.02	-	32.48
81	26CH1B-PI-1303	0.98	-	6	11.43	3.70	-	-
82	26CH1B-PI-1304	0.20	-	12	11.43	3.70	-	-
83	26CH1B-PI-1234	1.03	-	6	11.43	3.70	-	-
84	26CH1B-PI-1233	0.25	-	12	11.43	3.70	-	-
85	26CH1A-VG-1215	0.99	0.98	6	11.43	3.70	-	21.40
86	26CH1A-VG-1191	1.00	-	-	0.00	0.00	-	23.90
87	26CH1A-VC-1165	N/A	-	-	0.00	0.00	-	23.90
88	26CH1A-VG-1166	N/A	-	-	0.00	0.00	0.00	23.90
89	26CH1A-VG-1192	N/A	-	-	0.00	0.00	-	23.90
90	26CH1A-VG-1216	0.29	0.30	12	11.43	3.70	-	21.40

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
91	26CH1A-PI-1199	1.00	-	6	5.02	0.61	-	-
92	26CH1A-PI-1200	0.43	-	12	5.02	0.61	-	-
93	26CH1A-VG-1135	1.05	1.05	6	0.24	1.24	-	11.75
94	26CH1A-VC-1136	0.85	0.43	12	0.24	1.24	6.10	11.75
95	26CH1A-PI-1201	1.08	-	6	4.78	0.58	-	-
96	26CH1A-PI-1202	0.47	-	12	4.78	0.58	-	-
97	26CH1A-VG-1217	1.10	1.10	6	3.75	0.46	-	7.66
98	26CH1A-VC-1169	1.07	0.66	6	2.20	1.67	-	9.82
99	26CH1A-VG-1170	0.46	0.46	12	2.20	1.68	54.20	9.82
100	26CH1A-VG-1218	0.47	0.47	12	3.75	0.46	-	7.66
101	26CH1A-VC-1029	1.12	-	-	0.00	0.00	-	5.54
102	26CH1A-VG-1030	N/A	0.50	12	0.00	0.00	0.00	5.14
103	26CH1A-VC-1167	1.14	0.72	6	1.55	1.18	-	2.86
104	26CH1A-VG-1168	0.52	0.52	12	1.55	1.18	38.90	2.86
105	26CH1A-PI-1141	1.13	-	6	1.03	0.78	-	-
106	26CH1A-PI-1142	0.54	-	12	1.03	0.78	-	-
107	26CH1A-VC-1137	1.16	0.75	6	0.73	1.31	-	0.61
108	26CH1A-VG-1138	0.54	0.54	12	0.73	1.31	18.30	0.93
109	26CH1A-VC-1143	1.22	0.80	6	0.30	0.54	-	-5.21
110	26CH1A-VG-1144	0.60	0.60	12	0.30	0.54	7.60	-5.25
111	26CH1A-VG-1129	0.82	0.82	6	0.20	1.02	-	33.58
112	26CH1A-VC-1130	0.63	0.23	12	0.20	1.02	5.00	33.18
113	26CH1A-VG-1021	0.97	0.97	6	6.20	0.76	-	22.68
114	26CH1A-VG-1022	0.29	0.29	12	6.20	0.76	-	22.68
115	26CH1A-VG-1119	0.94	0.94	6	6.20	1.30	-	24.50
116	26CH1A-VG-1120	0.29	0.29	12	6.20	1.30	-	23.66
117	26CH1A-PI-1251	0.94	-	6	3.40	2.59	-	-
118	26CH1A-VG-1251	0.83	0.83	6	1.48	1.13	-	27.65

PFD REF.	**P&ID Tag**	**P_{in} (MPa)**	**P_{out} (MPa)**	**Temperature (°C)**	**Flow rate (kg/s)**	**Velocity (m/s)**	**Heat load (kW)**	**Elevation (m)**
119	26CH1A-VC-1252	0.63	0.33	12	1.48	1.13	37.20	27.65
120	26CH1A-PI-1252	0.32	-	12	3.40	2.59	-	-
121	26CH1A-VG-1243	0.83	0.83	6	1.92	1.46	-	27.65
122	26CH1A-VC-1244	0.63	0.32	12	1.92	1.46	48.20	27.65
123	26CH1A-PI-1187	0.94	-	6	2.80	0.59	-	-
124	26CH1A-PI-1188	0.42	-	12	2.80	0.59	-	-
125	26CH1A-VG-1209	1.08	1.08	6	0.64	1.15	-	8.18
126	26CH1A-VC-1181	1.08	0.67	6	0.64	1.15	-	8.18
127	26CH1A-VG-1182	0.47	0.47	12	0.64	1.15	16.10	8.48
128	26CH1A-VG-1210	0.47	0.47	12	0.64	1.15	-	8.18
129	26CH1A-PI-1221	1.09	-	6	2.16	0.45	-	-
130	26CH1A-PI-1222	0.49	-	12	2.16	0.45	-	-
131	26CH1A-VG-1211	1.14	1.14	6	0.40	0.72	-	2.39
132	26CH1A-VC-1183	1.14	0.71	6	0.40	0.72	-	2.77
133	26CH1A-VG-1184	0.51	0.51	12	0.40	0.72	9.60	3.02
134	26CH1A-VG-1212	0.51	0.51	12	0.40	0.72	-	2.77
135	26CH1A-PI-1195	1.15	-	6	1.76	0.37	-	-
136	26CH1A-PI-1196	0.52	-	12	1.76	0.37	-	-
137	26CH1A-VC-1139	1.16	0.73	6	0.70	1.26	-	0.74
138	26CH1A-VG-1140	0.53	0.53	12	0.70	1.26	17.60	0.74
139	26CH1A-PI-1123	1.19	-	6	1.06	0.22	-	-
140	26CH1A-PI-1124	0.56	-	12	1.06	0.22	-	-
141	26CH1A-PI-1127	1.21	-	6	1.06	1.91	-	-
142	26CH1A-VG-1213	1.17	1.17	6	0.64	1.15	-	-2.4
143	26CH1A-VC-1185	1.16	0.80	6	0.64	1.15	-	-2.66
144	26CH1A-VG-1186	0.60	0.60	12	0.64	1.15	16.00	-2.33
145	26CH1A-VG-1214	0.59	0.59	12	0.64	1.15	-	-2.40
146	26CH1A-PI-1220	0.57	-	12	1.06	1.91	-	-

PFD REF.	**P&ID Tag**	**P_{in} (MPa)**	**P_{out} (MPa)**	**Temperature (°C)**	**Flow rate (kg/s)**	**Velocity (m/s)**	**Heat load (kW)**	**Elevation (m)**
147	26CH1A-VC-1127	1.22	0.80	6	0.42	0.76	-	-5.50
148	26CH1A-VG-1128	0.61	0.61	12	0.42	0.76	10.60	-6.56
149	26CH1A-VC-1125	1.25	-	-	0.00	0.00	-	-7.56
150	26CH1A-VG-1126	N/A	0.59	12	0.00	0.00	0.00	-6.53
151	26CH1B-PI-1008	0.16	-	12	22.62	0.70	-	-

A1.3. PFD – CHWS-1A Cooling Operation during Post First Plasma Operation (PFPO-II)

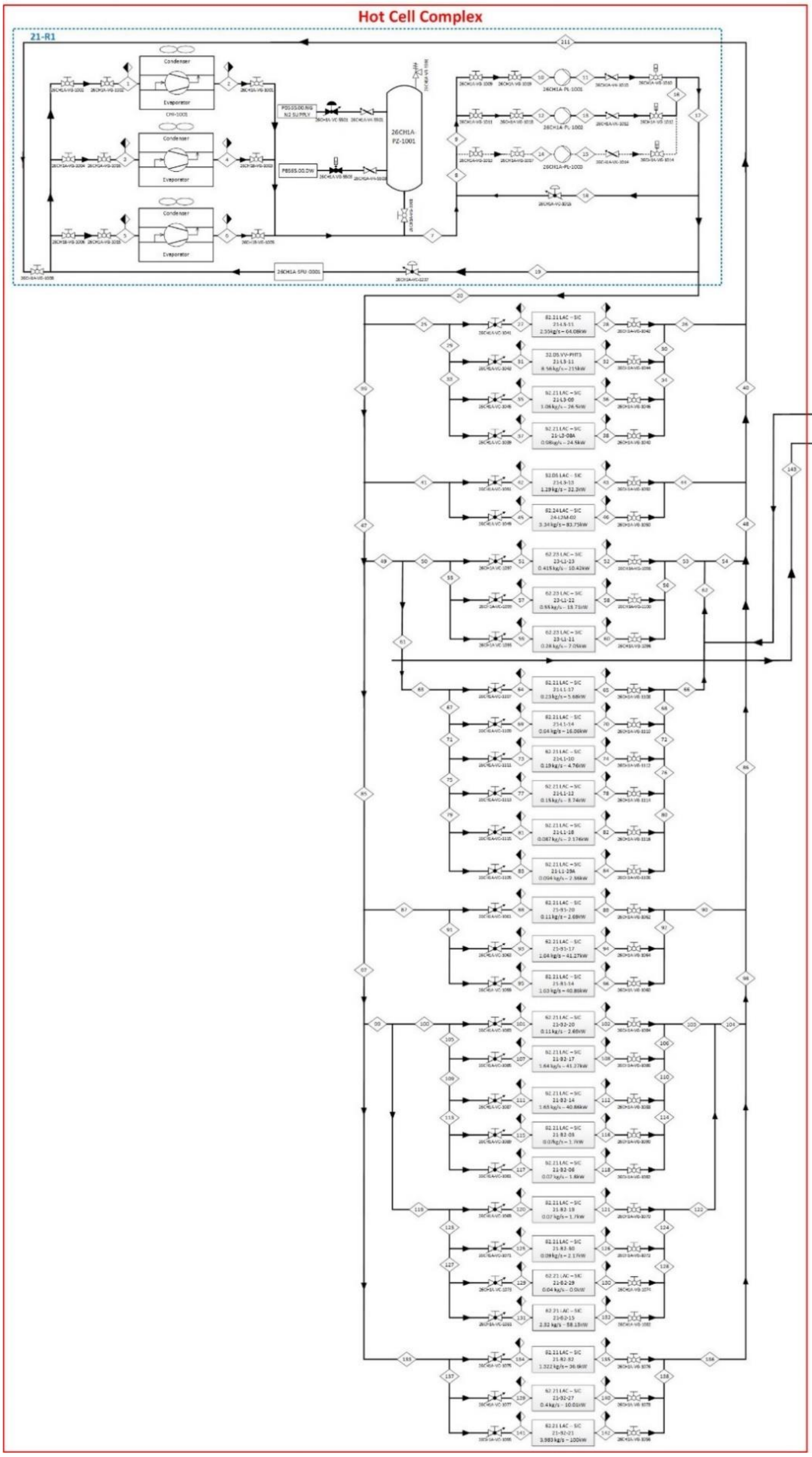

Figure A1- 5: CHWS-1A Operating Condition (PFPO-II) (Hot Cell Complex)

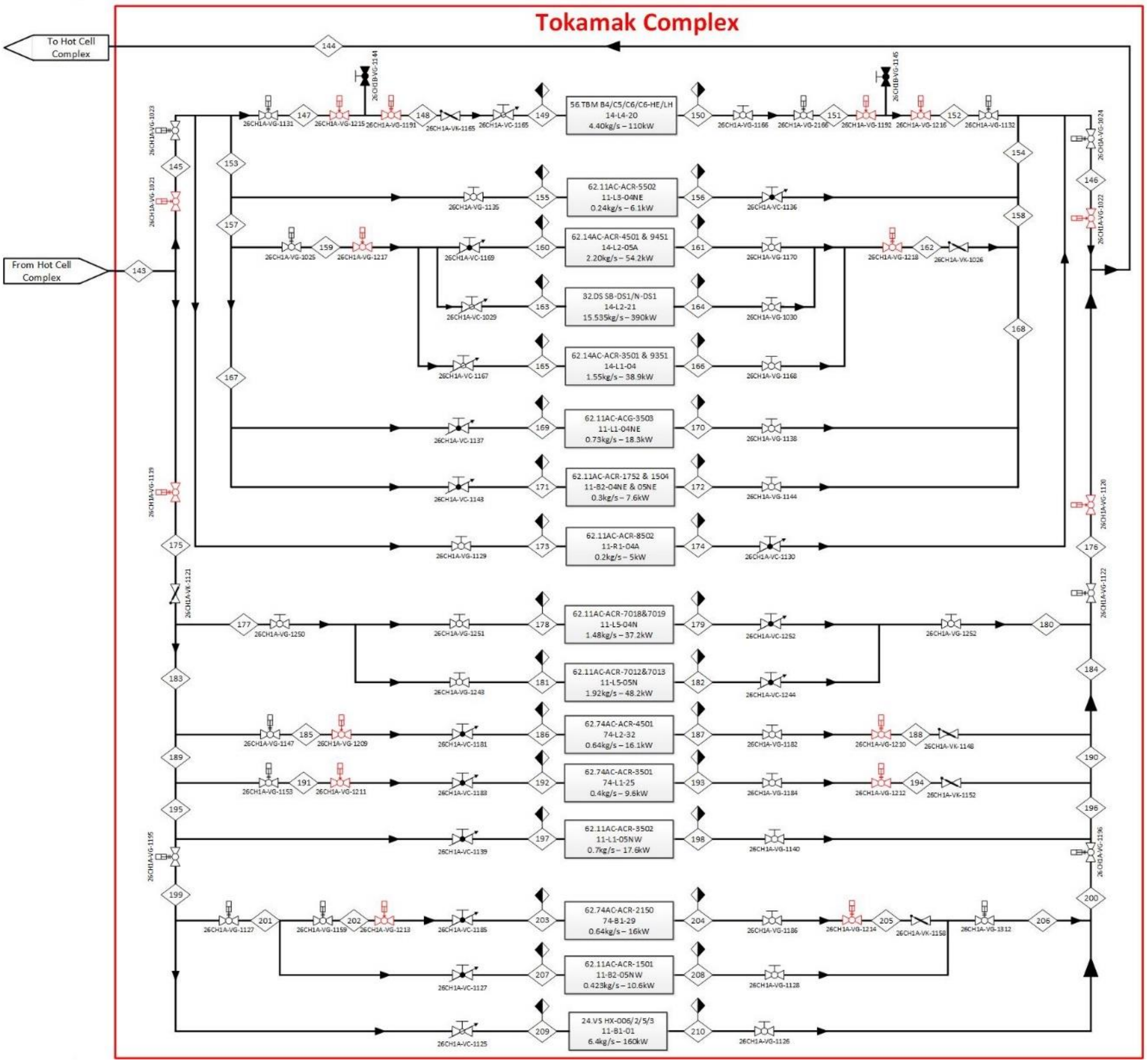

Figure A1- 6: CHWS-1A Operating Condition (PFPO-II) (Tokamak Complex)

Table A1- 4: CHWS-1A Operating Conditions (PFPO-II)

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
1	26CH1A-PI-1002	0.24	-	12	24.48	1.31	-	-
2	26CH1A-PI-1001	0.23	-	6	24.48	1.31	-	-
3	26CH1A-PI-1004	0.24	-	12	24.27	1.30	-	-
4	26CH1A-PI-1003	0.23	-	6	24.27	1.30	-	-
5	26CH1A-PI-1006	0.24	-	12	24.55	1.32	-	-
6	26CH1A-PI-1005	0.23	-	6	24.55	1.32	-	-

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
7	26CH1A-PI-1015	0.21	-	6	73.30	2.27	-	-
8	26CH1A-PI-1007	0.20	-	6	73.30	2.27	-	-
9	26CH1A-PI-1007	0.20	-	6	73.30	2.27	-	-
10	26CH1A-PI-1009	0.17	-	6	39.04	2.09	-	-
11	26CH1A-PI-1010	1.01	-	6	39.04	2.09	-	-
12	26CH1A-PI-1011	0.14	-	6	34.26	1.84	-	-
13	26CH1A-PI-1012	1.01	-	6	34.26	1.84	-	-
14	26CH1A-PI-1013	-	-	-	0.00	0.00	-	-
15	26CH1A-PI-1014	-	-	-	0.00	0.00	-	-
16	26CH1A-PI-1016	0.99	-	6	34.26	1.06	-	-
17	26CH1A-PI-1016	0.22	-	12	24.55	1.32	-	-
18	26CH1A-VC-1015	0.99	0.21	6	0.00	0.00	-	21.97
19	WPU	#N/D						
20	26CH1A-PI-1016	0.98	-	6	73.30	2.27	-	-
25	26CH1A-PI-1035	1.03	-	6	13.15	2.76	-	-
26	26CH1A-PI-1036	0.38	-	12	13.15	2.76	-	-
27	26CH1A-VC-1041	0.94	0.59	6	2.55	1.94	-	15.63
28	26CH1A-VG-1042	0.39	0.39	12	2.55	1.94	64.08	15.63
29	26CH1A-PI-1035	0.94	-	6	10.60	2.22	-	-
30	26CH1A-PI-1036	0.38	-	12	10.60	2.22	-	-
31	26CH1A-VC-1043	0.94	0.59	6	8.56	1.79	-	15.63
32	26CH1A-VG-1044	0.39	0.39	12	8.56	1.80	215.00	15.63
33	26CH1A-PI-1035	0.94	-	6	2.04	1.55	-	-

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
34	26CH1A-PI-1036	0.40	-	12	2.04	1.55	-	-
35	26CH1A-VC-1045	0.92	0.61	6	1.06	1.90	-	15.63
36	26CH1A-VG-1046	0.41	0.41	12	1.06	1.90	26.50	15.63
37	26CH1A-VC-1039	0.91	0.62	6	0.98	1.76	-	15.63
38	26CH1A-VG-1040	0.42	0.42	12	0.98	1.76	24.50	15.63
39	26CH1A-PI-1017	1.04	-	6	60.15	3.23	-	-
40	26CH1A-PI-1018	0.35	-	12	60.15	3.23	-	-
41	26CH1A-PI-1047	1.07	-	6	4.63	2.14	-	-
42	26CH1A-VC-1091	0.96	0.55	6	1.29	2.31	-	15.63
43	26CH1A-VG-1092	0.35	0.35	12	1.29	2.31	32.30	15.63
44	26CH1A-PI-1048	0.35	-	12	4.63	2.14	-	-
45	26CH1A-VC-1049	0.91	0.68	6	3.34	2.54	-	11.52
46	26CH1A-VG-1050	0.48	0.48	12	3.34	2.54	83.75	11.52
47	26CH1A-PI-1239	1.07	-	6	55.52	2.98	-	-
48	26CH1A-PI-1240	0.45	-	12	55.52	2.98	-	-
49	26CH1A-PI-1239	1.16	-	6	40.40	2.17	-	-
50	26CH1A-PI-1093	1.16	-	6	1.25	0.95	-	-
51	26CH1A-VC-1097	1.13	0.69	6	0.42	0.74	-	1.67
52	26CH1A-VG-1098	0.49	0.49	12	0.42	0.74	10.42	1.67
53	26CH1A-PI-1094	0.48	-	12	1.25	0.95	-	-
54	26CH1A-PI-1240	0.46	-	12	40.40	2.17	-	-
55	26CH1A-PI-1093	1.13	-	6	0.83	0.63	-	-
56	26CH1A-PI-1094	0.49	-	12	0.83	0.63	-	-

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
57	26CH1A-VC-1099	1.13	0.69	6	0.55	0.99	-	1.67
58	26CH1A-VG-1100	0.49	0.49	12	0.55	0.99	13.79	1.67
59	26CH1A-VC-1095	1.13	0.69	6	0.28	0.50	-	1.67
60	26CH1A-VG-1096	0.49	0.49	12	0.28	0.50	7.05	1.67
61	26CH1A-PI-1239	1.16	-	6	39.15	2.10	-	-
62	26CH1A-PI-1240	0.48	-	12	39.15	2.10	-	-
63	26CH1A-PI-1101	1.14	-	6	1.39	1.06	-	-
64	26CH1A-VC-1107	1.13	0.69	6	0.23	1.17	-	1.67
65	26CH1A-VG-1108	0.49	0.49	12	0.23	1.17	5.68	1.67
66	26CH1A-PI-1102	0.49	-	12	1.39	1.06	-	-
67	26CH1A-PI-1101	1.13	-	6	1.16	0.88	-	-
68	26CH1A-PI-1102	0.49	-	12	1.16	0.88	-	-
69	26CH1A-VC-1109	1.12	0.69	6	0.64	1.15	-	1.67
70	26CH1A-VG-1110	0.49	0.49	12	0.64	1.15	16.06	1.67
71	26CH1A-PI-1103	1.13	-	6	0.52	0.93	-	-
72	26CH1A-PI-1104	0.49	-	12	0.52	0.93	-	-
73	26CH1A-VC-1111	1.09	0.73	6	0.19	0.97	-	1.67
74	26CH1A-VC-1112	0.53	0.53	12	0.19	0.97	4.76	1.67
75	26CH1A-PI-1103	1.12	-	6	0.33	0.59	-	-
76	26CH1A-PI-1104	0.50	-	12	0.33	0.59	-	-
77	26CH1A-VC-1113	1.12	0.70	6	0.15	0.77	-	1.67
78	26CH1A-VG-1114	0.50	0.50	12	0.15	0.77	3.74	1.67
79	26CH1A-PI-1105	1.12	-	6	0.18	0.92	-	-

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
80	26CH1A-PI-1106	0.51	-	12	0.18	0.92	-	-
81	26CH1A-VC-1115	1.11	0.72	6	0.09	0.44	-	1.67
82	26CH1A-VG-1116	0.52	0.52	12	0.09	0.44	2.18	1.67
83	26CH1A-VC-1105	1.10	0.71	6	0.09	0.48	-	1.67
84	26CH1A-VG-1106	0.51	0.51	12	0.09	0.48	2.36	1.67
85	26CH1A-PI-1051	1.16	-	6	15.13	1.84	-	-
86	26CH1A-PI-1052	0.54	-	12	15.13	1.84	-	-
87	26CH1A-PI-1057	1.24	-	6	3.38	2.57	-	-
88	26CH1A-VC-1061	1.19	0.80	6	0.11	0.56	-	-6.76
89	26CH1A-VG-1062	0.60	0.60	12	0.11	0.56	2.69	-6.76
90	26CH1A-PI-1058	0.59	-	12	3.38	2.57	-	-
91	26CH1A-PI-1057	1.18	-	6	3.27	2.49	-	-
92	26CH1A-PI-1058	0.68	-	12	3.27	2.49	-	-
93	26CH1A-VC-1063	1.10	0.88	6	1.64	1.25	41.27	-6.76
94	26CH1A-VG-1064	0.68	0.68	12	1.64	1.25	-	-6.76
95	26CH1A-VC-1059	1.09	0.89	6	1.63	1.24	-	-6.76
96	26CH1A-VG-1060	0.69	0.69	12	1.63	1.24	40.86	-6.76
97	26CH1A-PI-1053	1.24	-	6	11.75	2.46	-	-
98	26CH1A-PI-1054	0.59	-	12	11.75	2.46	-	-
99	26CH1A-PI-1065	1.25	-	6	6.04	2.79	-	-
100	26CH1A-PI-1079	1.22	-	6	2.52	1.92	-	-
101	26CH1A-VC-1083	1.20	0.85	6	0.11	0.56	-	-10.46
102	26CH1A-VG-1084	0.65	0.65	12	0.11	0.56	2.69	-10.46

PFD REF.	**P&ID Tag**	**P_{in} (MPa)**	**P_{out} (MPa)**	**Temperature (°C)**	**Flow rate (kg/s)**	**Velocity (m/s)**	**Heat load (kW)**	**Elevation (m)**
103	26CH1A-PI-1080	0.65	-	12	3.52	2.68	-	-
104	26CH1A-PI-1066	0.63	-	12	6.04	2.79	-	-
105	26CH1A-PI-1079	1.20	-	6	3.41	2.60	-	-
106	26CH1A-PI-1080	0.70	-	12	3.41	2.60	-	-
107	26CH1A-VC-1085	1.13	0.92	6	1.64	2.94	-	-10.46
108	26CH1A-VG-1086	0.72	0.72	12	1.64	2.94	41.27	-10.46
109	26CH1A-PI-1079	1.15	-	6	1.77	1.35	-	-
110	26CH1A-PI-1080	0.72	-	12	1.77	1.35	-	-
111	26CH1A-VC-1087	1.10	0.95	6	1.63	2.92	-	-10.46
112	26CH1A-VG-1088	0.75	0.74	12	1.63	2.92	40.86	-10.46
113	26CH1A-PI-1081	1.13	-	6	0.14	0.72	-	-
114	26CH1A-PI-1082	0.74	-	12	0.14	0.72	-	-
115	26CH1A-VC-1089	1.11	0.94	6	0.07	0.36	-	-10.46
116	26CH1A-VG-1090	0.74	0.74	12	0.07	0.36	1.70	-10.46
117	26CH1A-VC-1081	1.11	0.94	6	0.07	0.37	-	-10.46
118	26CH1A-VG-1082	0.74	0.74	12	0.07	0.37	1.80	-10.46
119	26CH1A-PI-1067	1.22	-	6	2.52	1.92	-	-
120	26CH1A-VC-1069	1.21	0.84	6	0.07	0.36	-	-10.46
121	26CH1A-VG-1070	0.64	0.64	12	0.07	0.36	1.70	-10.46
122	26CH1A-PI-1068	0.64	-	12	2.52	1.92	-	-
123	26CH1A-PI-1067	1.21	-	6	2.45	1.87	-	-
124	26CH1A-PI-1068	0.65	-	12	2.45	1.87	-	-
125	26CH1A-VC-1071	1.20	0.86	6	0.09	0.46	-	-10.46

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
126	26CH1A-VG-1072	0.66	0.66	12	0.09	0.46	2.17	-10.46
127	26CH1A-PI-1067	1.20	-	6	2.36	1.80	-	-
128	26CH1A-PI-1068	0.66	-	12	2.36	1.80	-	-
129	26CH1A-VC-1073	1.19	0.86	6	0.04	0.20	-	-10.46
130	26CH1A-VG-1074	0.66	0.66	12	0.04	0.20	0.90	-10.46
131	26CH1A-VC-1067	1.17	0.89	6	2.32	1.77	-	-10.46
132	26CH1A-VG-1068	0.69	0.69	12	2.32	1.77	58.13	-10.46
133	26CH1A-PI-1055	1.26	-	6	5.71	2.63	-	-
134	26CH1A-VC-1075	1.17	0.88	6	1.32	2.37	-	-10.46
135	26CH1A-VG-1076	0.68	0.68	12	1.32	2.37	36.60	-10.46
136	26CH1A-PI-1056	0.66	-	12	5.71	2.64	-	-
137	26CH1A-PI-1055	1.19	-	6	4.38	2.02	-	-
138	26CH1A-PI-1056	0.68	-	12	4.38	2.03	-	-
139	26CH1A-VC-1077	1.18	0.88	6	0.40	0.72	-	-10.46
140	26CH1A-VG-1078	0.68	0.68	12	0.40	0.72	10.01	-10.46
141	26CH1A-VC-1055	1.15	0.91	6	3.98	1.84	-	-10.46
142	26CH1A-VG-1056	0.71	0.71	12	3.98	1.84	100.00	-10.46
143	26CH1A-PI-1239	1.12	-	6	37.76	2.03	-	-
144	26CH1A-PI-1240	0.50	-	12	37.76	2.03	-	-
145	26CH1A-VG-1021	0.90	0.90	6	25.16	3.06	-	22.68
146	26CH1A-VG-1022	0.30	0.30	12	25.16	3.06	-	22.68
147	26CH1A-VG-1215	0.89	0.88	6	4.40	1.42	-	21.40
148	26CH1A-VG-1191	0.85	0.85	6	4.40	2.03	-	23.90

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
149	26CH1A-VC-1165	0.83	0.74	6	4.40	2.03	-	23.90
150	26CH1A-VG-1166	0.34	0.34	12	4.40	2.03	110.00	23.90
151	26CH1A-VG-1192	0.34	0.34	12	4.40	2.03	-	21.40
152	26CH1A-VG-1216	0.34	0.34	12	4.40	1.42	-	21.40
153	26CH1A-PI-1199	0.93	-	6	20.56	2.50	-	-
154	26CH1A-PI-1200	0.44	-	12	20.56	2.50	-	-
155	26CH1A-VG-1135	0.98	0.98	6	0.24	1.24	-	11.75
156	26CH1A-VC-1136	0.78	0.45	12	0.24	1.24	6.10	11.75
157	26CH1A-PI-1201	1.01	-	6	20.32	2.47	-	-
158	26CH1A-PI-1202	0.49	-	12	20.32	2.47	-	-
159	26CH1A-VG-1217	1.01	1.01	6	19.29	2.35	-	7.66
160	26CH1A-VC-1169	0.96	0.71	6	2.20	1.67	-	9.82
161	26CH1A-VG-1170	0.51	0.50	12	2.20	1.68	54.20	9.82
162	26CH1A-VG-1218	0.50	0.50	12	19.29	2.35	-	7.66
163	26CH1A-VC-1029	0.99	0.77	6	15.54	3.26	-	5.54
164	26CH1A-VG-1030	0.57	0.57	12	15.54	3.26	390.00	5.14
165	26CH1A-VC-1167	1.04	0.77	6	1.55	1.18	-	2.86
166	26CH1A-VG-1168	0.57	0.57	12	1.55	1.18	38.90	2.86
167	26CH1A-PI-1141	1.05	-	6	1.03	0.78	-	-
168	26CH1A-PI-1142	0.56	-	12	1.03	0.78	-	-
169	26CH1A-VC-1137	1.08	0.77	6	0.73	1.31	-	0.61
170	26CH1A-VG-1138	0.56	0.56	12	0.73	1.31	18.30	0.93
171	26CH1A-VC-1143	1.14	0.82	6	0.30	0.54	-	-5.21

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
172	26CH1A-VG-1144	0.62	0.62	12	0.30	0.54	7.60	-5.25
173	26CH1A-VG-1129	0.74	0.74	6	0.20	1.02	-	33.58
174	26CH1A-VC-1130	0.55	0.25	12	0.20	1.02	5.00	33.18
175	26CH1A-VG-1119	0.82	0.82	6	12.60	2.64	-	24.50
176	26CH1A-VG-1120	0.34	0.34	12	12.60	2.64	-	23.66
177	26CH1A-PI-1251	0.82	-	6	3.40	2.59	-	-
178	26CH1A-VG-1251	0.71	0.71	6	1.48	1.13	-	27.65
179	26CH1A-VC-1252	0.51	0.38	12	1.48	1.13	37.20	27.65
180	26CH1A-PI-1252	0.37	-	12	3.40	2.59	-	-
181	26CH1A-VG-1243	0.71	0.71	6	1.92	1.46	-	27.65
182	26CH1A-VC-1244	0.51	0.38	12	1.92	1.46	48.20	27.65
183	26CH1A-PI-1187	0.82	-	6	9.20	1.93	-	-
184	26CH1A-PI-1188	0.48	-	12	9.20	1.93	-	-
185	26CH1A-VG-1209	0.95	0.95	6	0.64	1.15	-	8.18
186	26CH1A-VC-1181	0.94	0.73	6	0.64	1.15	-	8.18
187	26CH1A-VG-1182	0.53	0.53	12	0.64	1.15	16.10	8.48
188	26CH1A-VG-1210	0.53	0.53	12	0.64	1.15	-	8.18
189	26CH1A-PI-1221	0.96	-	6	8.56	1.80	-	-
190	26CH1A-PI-1222	0.56	-	12	8.56	1.80	-	-
191	26CH1A-VG-1211	1.01	1.01	6	0.40	0.72	-	2.39
192	26CH1A-VC-1183	1.00	0.78	6	0.40	0.72	-	2.77
193	26CH1A-VG-1184	0.57	0.57	12	0.40	0.72	9.60	3.02
194	26CH1A-VG-1212	0.58	0.58	12	0.40	0.72	-	2.77

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
195	26CH1A-PI-1195	1.01	-	6	8.16	1.71	-	-
196	26CH1A-PI-1196	0.59	-	12	8.16	1.71	-	-
197	26CH1A-VC-1139	1.03	0.79	6	0.70	1.26	-	0.74
198	26CH1A-VG-1140	0.59	0.59	12	0.70	1.26	17.60	0.74
199	26CH1A-PI-1123	1.05	-	6	7.46	1.56	-	-
200	26CH1A-PI-1124	0.63	-	12	7.46	1.57	-	-
201	26CH1A-PI-1127	1.07	-	6	1.06	1.91	-	-
202	26CH1A-VG-1213	1.03	1.04	6	0.64	1.15	-	-2.40
203	26CH1A-VC-1185	1.02	0.87	6	0.64	1.15	-	-2.66
204	26CH1A-VG-1186	0.66	0.66	12	0.64	1.15	16.00	-2.33
205	26CH1A-VG-1214	0.66	0.66	12	0.64	1.15	-	-2.40
206	26CH1A-PI-1220	0.64	-	12	1.06	1.91	-	-
207	26CH1A-VC-1127	1.08	0.87	6	0.42	0.76	-	-5.50
208	26CH1A-VG-1128	0.68	0.68	12	0.42	0.76	10.60	-6.56
209	26CH1A-VC-1125	1.09	0.89	6	6.40	2.07	-	-7.56
210	26CH1A-VG-1126	0.68	0.68	12	6.40	2.07	160.00	-6.53
211	26CH1A-PI-1008	0.29	-	12	73.30	2.27	-	-
212	26CH1B-PI-1234	0.88	-	6	0.00	0.00	-	-
213	26CH1B-PI-1233	0.34	-	12	0.00	0.00	-	-

A1.4. PFD – CHWS-1B Cooling Operation during Post First Plasma Operation (PFPO-II)

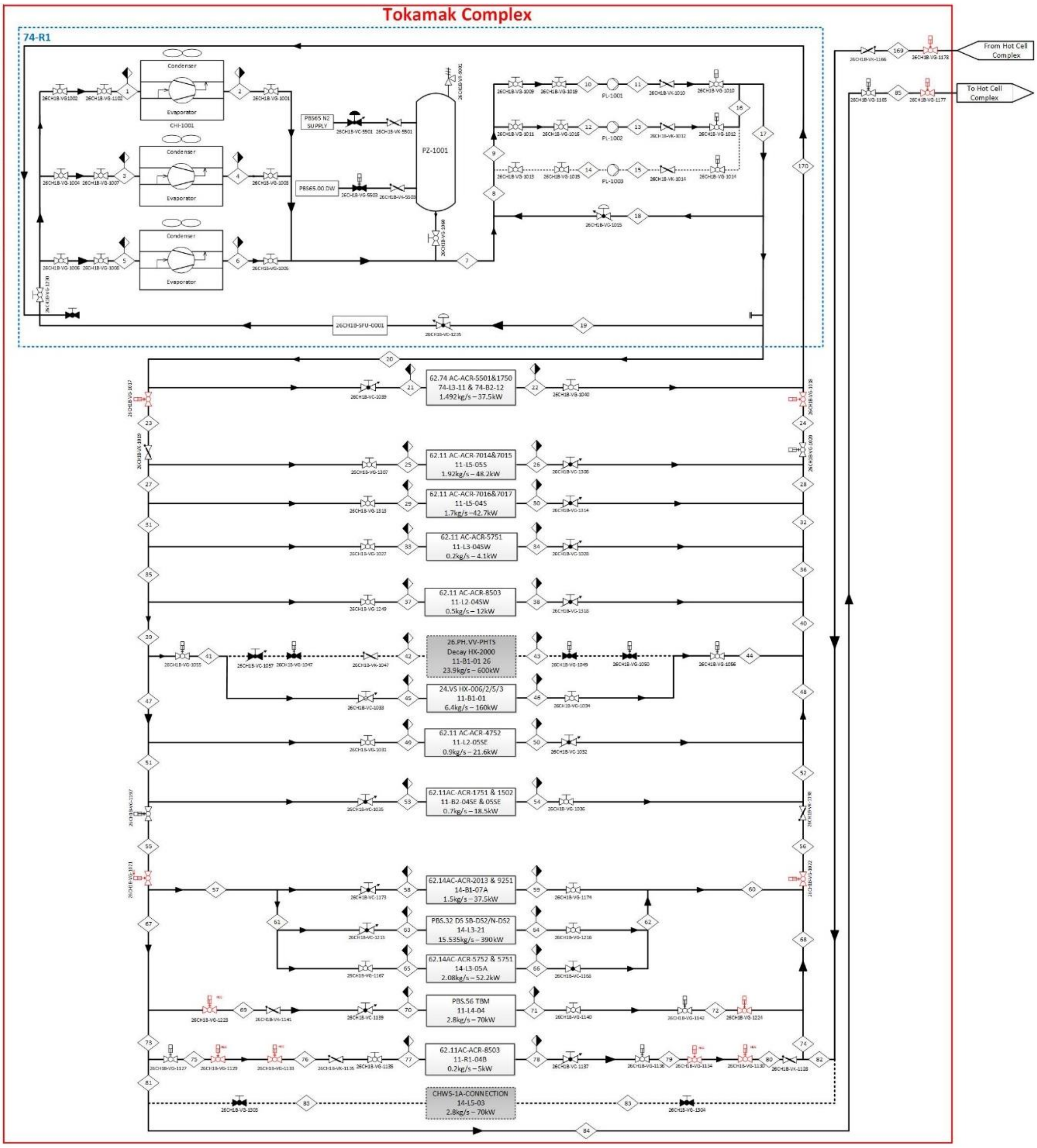

Figure A1- 7: CHWS-1B Operating Condition (PFPO-II) (Tokamak Complex)

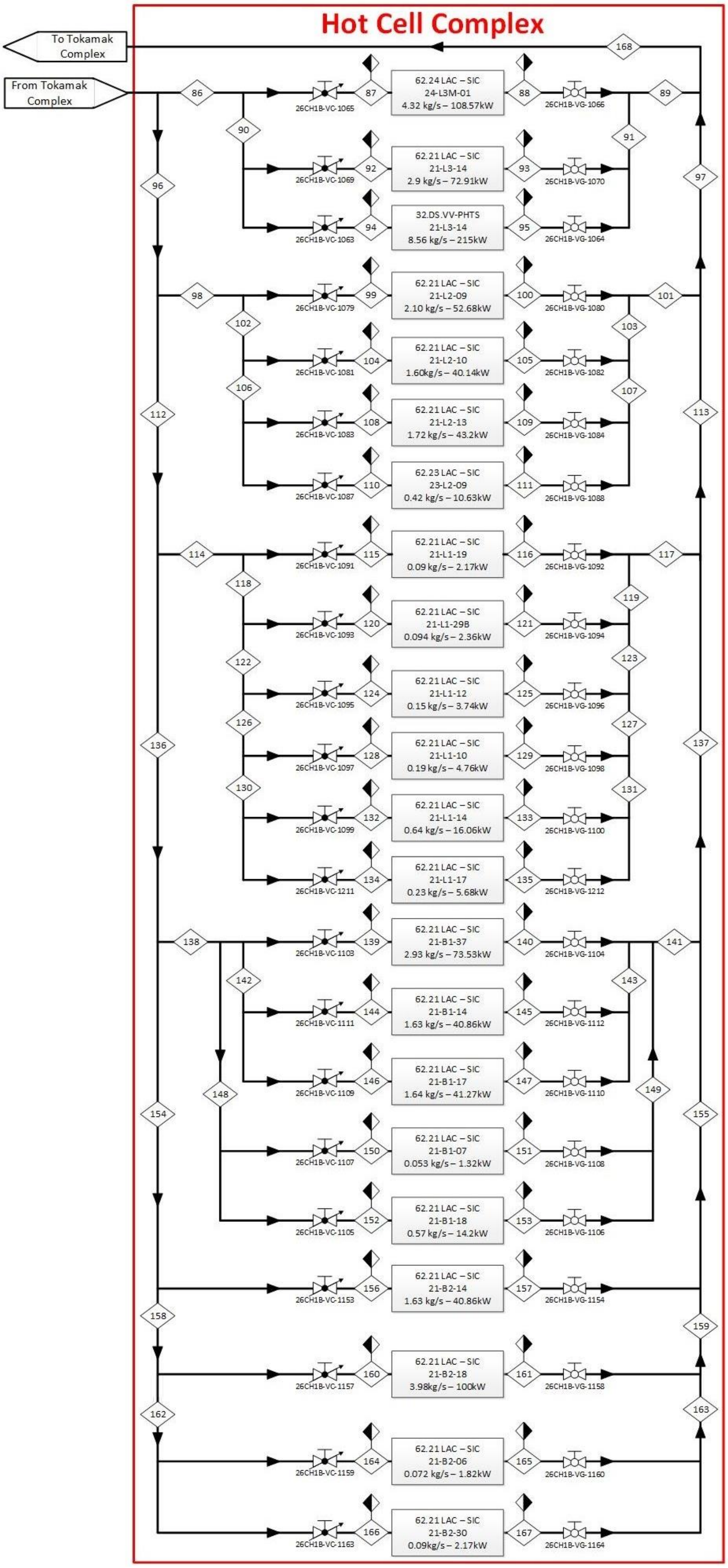

Figure A1- 8: CHWS-1B Operating Condition (PFPO-II) (Hot Cell Complex)

Table A1- 5: CHWS-1B Operating Condition (PFPO-II)

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
1	26CH1B-PI-1002	0.24	-	12	24.54	1.32	-	-
2	26CH1B-PI-1001	0.23	-	6	24.54	1.32	-	-
3	26CH1B-PI-1004	0.24	-	12	23.02	1.24	-	-
4	26CH1B-PI-1003	0.23	-	6	23.02	1.23	-	-
5	26CH1B-PI-1006	0.24	-	12	23.98	1.29	-	-
6	26CH1B-PI-1005	0.23	-	6	23.98	1.29	-	-
7	26CH1B-PI-1007	0.21	-	6	71.54	2.22	-	-
8	26CH1B-PI-1007	0.20	-	6	95.44	2.96	-	-
9	26CH1B-PI-1007	0.20	-	6	95.44	2.96	-	-
10	26CH1B-PI-1009	0.17	-	6	49.84	2.67	-	-
11	26CH1B-PI-1010	1.06	-	6	49.84	2.67	-	-
12	26CH1B-PI-1011	0.14	-	6	45.60	2.45	-	-
13	26CH1B-PI-1012	1.07	-	6	45.60	2.45	-	-
14	26CH1B-PI-1013	-	-	-	0.00	0.00	-	-
15	26CH1B-PI-1014	-	-	-	0.00	0.00	-	-
16	26CH1B-PI-1229	1.04	-	6	45.60	1.41	-	-
17	26CH1B-PI-1229	1.04	-	6	95.44	2.96	-	-
18	26CH1B-PI-1015	1.04	0.67	6	23.90	1.28	-	18.35
19	WPU	-						
20	26CH1B-PI-1016	1.04	-	6	71.54	2.22	-	-
21	26CH1B-VC-1039	1.04	0.51	6	1.49	1.14	-	14.29
22	26CH1B-VG-1040	0.31	0.31	12	1.49	1.14	37.50	14.29
23	26CH1B-VG-1017	0.98	0.98	6	70.04	2.17	-	22.79
24	26CH1B-VG-1018	0.19	0.19	12	70.04	2.17	-	22.79
25	26CH1B-PI-1313	0.99	-	6	3.62	2.76	-	-
26	26CH1B-VG-1307	0.90	0.90	6	1.92	1.46	-	27.65

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
27	26CH1B-VC-1308	0.70	0.18	12	1.92	1.46	48.20	27.65
28	26CH1B-PI-1314	0.18	-	12	3.62	2.76	-	-
29	26CH1B-VG-1313	0.89	0.89	6	1.70	1.29	-	27.65
30	26CH1B-VC-1314	0.69	0.19	12	1.70	1.29	42.70	27.65
31	26CH1B-PI-1213	0.99	-	6	66.42	2.06	-	-
32	26CH1B-PI-1214	0.31	-	12	66.42	2.06	-	-
33	26CH1B-VG-1027	1.08	1.08	6	0.20	1.02	-	11.68
34	26CH1B-VC-1028	0.88	0.31	11	0.20	1.02	4.10	11.58
35	26CH1B-PI-1325	1.08	-	6	66.22	2.05	-	-
36	26CH1B-PI-1326	0.35	-	12	66.22	2.05	-	-
37	26CH1B-VG-1249	1.12	1.12	6	0.50	0.90	-	7.70
38	26CH1B-VC-1318	0.92	0.35	12	0.50	0.90	12.00	7.70
39	26CH1B-PI-1325	1.12	-	6	65.72	2.04	-	-
40	26CH1B-PI-1326	0.37	-	12	65.72	2.04	-	-
41	26CH1B-PI-1329	1.22	-	6	6.40	0.78	-	-
42	26CH1B-VK-1047	N/A	-	-	0.00	0.00	-	-5.88
43	26CH1B-VG-1049	N/A	-	-	0.00	0.00	0.00	-5.11
44	26CH1B-PI-1056	0.46	-	12	6.40	0.78	-	-
45	26CH1B-VC-1033	1.24	0.71	6	6.40	2.07	-	-6.23
46	26CH1B-VG-1034	0.50	0.50	12	6.40	2.07	160.00	-6.23
47	26CH1B-PI-1197	1.15	-	6	59.32	1.84	-	-
48	26CH1B-PI-1198	0.36	-	12	59.32	1.84	-	-
49	26CH1B-VG-1031	1.12	1.12	6	0.90	1.61	-	6.10
50	26CH1B-VC-1032	0.92	0.38	12	0.90	1.61	21.60	6.10
51	26CH1B-PI-7037	1.11	-	6	58.42	1.81	-	-
52	26CH1B-PI-1198	0.36	-	12	58.42	1.81	-	-
53	26CH1B-VC-1035	1.23	0.69	6	0.70	0.53	-	-5.10
54	26CH1B-VG-1036	0.49	0.45	12	0.70	0.53	18.50	-5.08

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
55	26CH1B-PI-1021	1.10	-	6	57.72	1.79	-	-
56	26CH1B-PI-1022	0.36	-	12	57.72	1.79	-	-
57	26CH1B-PI-1175	1.08	-	6	19.12	2.33	-	-
58	26CH1B-VC-1173	1.17	0.71	6	1.50	1.14	-	-3.83
59	26CH1B-VG-1174	0.51	0.51	12	1.50	1.14	37.50	-3.83
60	26CH1B-PI-1176	0.39	-	12	19.12	2.33	-	-
61	26CH1B-PI-1191	1.04	-	6	17.62	2.14	-	-
62	26CH1B-PI-1192	0.33	-	12	17.62	2.15	-	-
63	26CH1B-VC-1215	1.00	0.57	6	15.54	3.26	-	11.95
64	26CH1B-VG-1216	0.37	0.37	12	15.54	3.26	-	11.95
65	26CH1B-VG-1167	0.96	0.96	6	2.08	1.58	-	16.19
66	26CH1B-VC-1168	0.76	0.34	12	2.08	1.58	52.20	16.19
67	26CH1B-PI-1189	1.07	-	6	38.61	2.07	-	-
68	26CH1B-PI-1190	0.28	-	12	38.61	2.07	-	-
69	26CH1B-PI-1223	0.97	-	6	2.80	2.13	-	-
70	26CH1B-VC-1139	0.90	0.73	6	2.80	2.13	-	18.58
71	26CH1B-VG-1140	0.33	0.32	12	2.80	2.13	70.00	18.98
72	26CH1B-VG-1224	0.15	0.14	12	0.20	1.02	-	31.48
73	26CH1B-PI-1265	0.93	-	6	35.81	1.92	-	-
74	26CH1B-PI-1266	0.16	-	12	35.81	1.92	-	-
75	26CH1B-VG-1129	0.84	0.84	6	0.20	1.02	-	32.48
76	26CH1B-VG-1133	0.74	-	6	0.20	1.02	-	-
77	26CH1B-VG-1135	0.70	0.70	6	0.20	1.02	-	36.02
78	26CH1B-VC-1137	0.50	0.21	12	0.20	1.02	5.00	36.02
79	26CH1B-VG-1134	0.19	0.19	12	0.20	1.02	-	34.97
80	26CH1B-VG-1130	0.14	0.14	12	0.20	1.02	-	32.48
81	26CH1B-PI-1165	0.87	-	6	35.61	1.91	-	-
82	26CH1B-PI-1166	0.18	-	12	35.61	1.91	-	-

PFD REF.	**P&ID Tag**	**P_{in} (MPa)**	**P_{out} (MPa)**	**Temperature (°C)**	**Flow rate (kg/s)**	**Velocity (m/s)**	**Heat load (kW)**	**Elevation (m)**
83	26CH1B-PI-1303	0.86	-	6	0.00	0.00	-	-
84	26CH1B-PI-1165	0.86	-	6	35.61	1.91	-	-
85	26CH1B-VG-1177	0.90	0.90	6	35.61	1.91	-	24.58
86	26CH1B-PI-1061	0.98	-	6	15.78	1.92	-	-
87	26CH1B-VC-1065	0.93	0.55	6	4.32	2.00	-	17.50
88	26CH1B-VG-1066	0.35	0.35	12	4.32	2.00	108.57	17.50
89	26CH1B-PI-1062	0.35	-	12	15.78	1.92	-	-
90	26CH1B-PI-1063	0.96	-	6	11.46	2.40	-	-
91	26CH1B-PI-1064	0.38	-	12	11.46	2.40	-	-
92	26CH1B-VC-1069	0.93	0.59	6	2.90	2.21	-	15.63
93	26CH1B-VG-1070	0.39	0.39	12	2.90	2.21	72.91	15.63
94	26CH1B-VC-1063	0.93	0.59	6	8.56	1.79	-	15.63
95	26CH1B-VG-1064	0.39	0.39	12	8.56	1.80	215.00	15.63
96	26CH1B-PI-1075	0.99	-	6	19.83	2.41	-	-
97	26CH1B-PI-1076	0.41	-	12	19.83	2.42	-	-
98	26CH1B-PI-1071	1.06	-	6	5.84	1.22	-	-
99	26CH1B-VC-1079	1.04	0.63	6	2.10	1.60	-	7.87
100	26CH1B-VG-1080	0.43	0.43	12	2.10	1.60	52.68	7.87
101	26CH1B-PI-1072	0.43	-	12	5.84	1.22	-	-
102	26CH1B-PI-1073	1.04	-	6	3.74	1.73	-	-
103	26CH1B-PI-1074	0.44	-	12	3.74	1.73	-	-
104	26CH1B-VC-1081	0.97	0.64	6	1.60	2.87	-	7.87
105	26CH1B-VG-1082	0.44	0.45	12	1.60	1.22	40.14	7.87
106	26CH1B-PI-1085	1.03	-	6	2.14	1.63	-	-
107	26CH1B-PI-1086	0.46	-	12	2.14	1.63	-	-
108	26CH1B-VC-1083	1.00	0.66	6	1.72	1.31	-	7.87
109	26CH1B-VG-1084	0.46	0.46	12	1.72	1.31	43.20	7.87
110	26CH1B-VC-1087	1.00	0.67	6	0.42	0.75	-	7.87

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
111	26CH1B-VG-1088	0.47	0.47	12	0.42	0.75	10.63	7.87
112	26CH1B-PI-1075	1.06	-	6	13.99	1.70	-	-
113	26CH1B-PI-1076	0.48	-	12	13.99	1.70	-	-
114	26CH1B-PI-1089	1.12	-	6	1.39	1.06	-	-
115	26CH1B-VC-1091	1.11	0.68	6	0.09	0.46	-	1.67
116	26CH1B-VG-1092	0.48	0.48	12	0.09	0.46	2.17	1.67
117	26CH1B-PI-1090	0.48	-	12	1.39	1.06	-	-
118	26CH1B-PI-1089	1.11	-	6	1.30	0.99	-	-
119	26CH1B-PI-1090	0.49	-	12	1.30	0.99	-	-
120	26CH1B-VC-1093	1.10	0.69	6	0.09	0.48	-	1.67
121	26CH1B-VG-1094	0.49	0.49	12	0.09	0.48	2.36	1.67
122	26CH1B-PI-1089	1.10	-	6	1.21	0.92	-	-
123	26CH1B-PI-1090	0.50	-	12	1.21	0.92	-	-
124	26CH1B-VC-1095	1.09	0.71	6	0.15	0.77	-	1.67
125	26CH1B-VG-1096	0.51	0.51	12	0.15	0.77	3.74	1.67
126	26CH1B-PI-1089	1.09	-	6	1.06	0.81	-	-
127	26CH1B-PI-1090	0.51	-	12	1.06	0.81	-	-
128	26CH1B-VC-1097	1.08	0.71	6	0.19	0.97	-	1.67
129	26CH1B-VG-1098	0.51	0.51	12	0.19	0.97	4.76	1.67
130	26CH1B-PI-1089	1.09	-	6	0.87	0.66	-	-
131	26CH1B-PI-1090	0.51	-	12	0.87	0.66	-	-
132	26CH1B-VC-1099	1.07	0.72	6	0.64	1.15	-	1.67
133	26CH1B-VG-1100	0.52	0.52	12	0.64	1.15	16.06	1.67
134	26CH1B-VC-1211	1.08	0.72	6	0.23	0.41	-	1.67
135	26CH1B-VG-1212	0.52	0.52	12	0.23	0.41	5.68	1.67
136	26CH1B-PI-1075	1.12	-	6	12.60	1.53	-	-
137	26CH1B-PI-1076	0.56	-	12	12.60	1.53	-	-
138	26CH1B-PI-1101	1.20	-	6	6.82	1.43	-	-

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
139	26CH1B-VC-1103	1.15	0.81	6	2.93	2.23	-	-6.76
140	26CH1B-VG-1104	0.61	0.61	12	2.93	2.23	73.53	-6.76
141	26CH1B-PI-1102	0.56	-	12	6.82	1.43	-	-
142	26CH1B-PI-1109	1.19	-	6	3.27	2.49	-	-
143	26CH1B-PI-1110	0.64	-	12	3.27	2.49	-	-
144	26CH1B-VC-1111	1.11	0.85	6	1.63	1.24	-	-6.76
145	26CH1B-VG-1112	0.65	0.65	12	1.63	1.24	40.86	-6.76
146	26CH1B-VC-1109	1.11	0.85	6	1.64	1.25	-	-6.76
147	26CH1B-VG-1110	0.65	0.65	12	1.64	1.25	41.27	-6.76
148	26CH1B-PI-1105	1.19	-	6	0.62	1.12	-	-
149	26CH1B-PI-1106	0.61	-	12	0.62	1.12	-	-
150	26CH1B-VC-1107	1.14	0.81	6	0.05	0.27	-	-6.76
151	26CH1B-VG-1108	0.61	0.61	12	0.05	0.27	1.32	-6.76
152	26CH1B-VC-1105	1.11	0.85	6	0.57	1.02	-	-6.76
153	26CH1B-VC-1106	0.65	0.65	12	0.57	1.02	14.20	-6.76
154	26CH1B-PI-1113	1.20	-	6	5.77	1.21	-	-
155	26CH1B-PI-1114	0.60	-	12	5.77	1.21	-	-
156	26CH1B-VC-1153	1.11	0.92	6	1.63	2.92	-	-10.46
157	26CH1B-VG-1154	0.72	0.72	12	1.63	2.92	40.86	-10.46
158	26CH1B-PI-1113	1.23	-	6	4.14	0.87	-	-
159	26CH1B-PI-1114	0.61	-	12	4.14	0.87	-	-
160	26CH1B-VC-1157	1.20	0.81	6	3.98	1.84	-	-10.46
161	26CH1B-VG-1158	0.61	0.61	12	3.98	1.84	100.00	-10.46
162	26CH1B-PI-1115	1.23	-	6	0.16	0.12	-	-
163	26CH1B-PI-1116	0.61	-	12	0.16	0.12	-	-
164	26CH1B-VC-1159	1.23	0.81	6	0.07	0.37	-	-10.46
165	26CH1B-VG-1160	0.61	0.61	12	0.07	0.37	1.82	-10.46
166	26CH1B-VC-1163	1.21	0.82	6	0.09	0.46	-	-10.46

PFD REF.	P&ID Tag	P_{in} (MPa)	P_{out} (MPa)	Temperature (°C)	Flow rate (kg/s)	Velocity (m/s)	Heat load (kW)	Elevation (m)
167	26CH1B-VC-1164	0.62	0.62	12	0.09	0.46	2.17	-10.46
168	26CH1B-PI-1062	0.33	-	12	35.61	1.91	-	-
169	26CH1B-VG-1178	0.24	0.24	12	35.61	1.91	-	24.12
170	26CH1B-PI-1008	0.18	-	12	71.54	2.22	-	-

A2. Design Pressure Calculation

In determining the design pressure, the following methodology has been applied:

- CHWS-1 sub-systems A&B are divided into pressure zones based on the peak pressures seen by the piping and equipment for their most-limiting operating modes (**§2.3**).
- Single failure affecting any of the CHWS-1A&B components (e.g. spurious opening of an isolation valve normally closed) must not result either in consequent pipe break or equipment damage. This is considered when defining the boundaries between the pressure zones.
- A minimum of 10% margin is then applied to the peak pressures in order to determine the design pressures for these different pressure zones.

The design pressures are rounded up with a precision of 0.1 MPa.

The highest pressures in the CHWS-1A&B pressurizers are reached during Plasma Operating State (POS); the nominal pressure in the is 0.22 MPa (**§3.2.4**) in order to guarantee a supply pressure to the cooled components above 0.4MPa.

Due to water level fluctuation, pressure variation are expected to not exceed 0.25 MPa (= 0.22 MPa + 0.03 MPa) as mentioned in **§5.5.2**.

A2.1. CHWS-1A Design Pressure

CHWS-1A is divided into 2 pressure zones which are numbered P1 and P2. They are shown in Figure A2- 1.

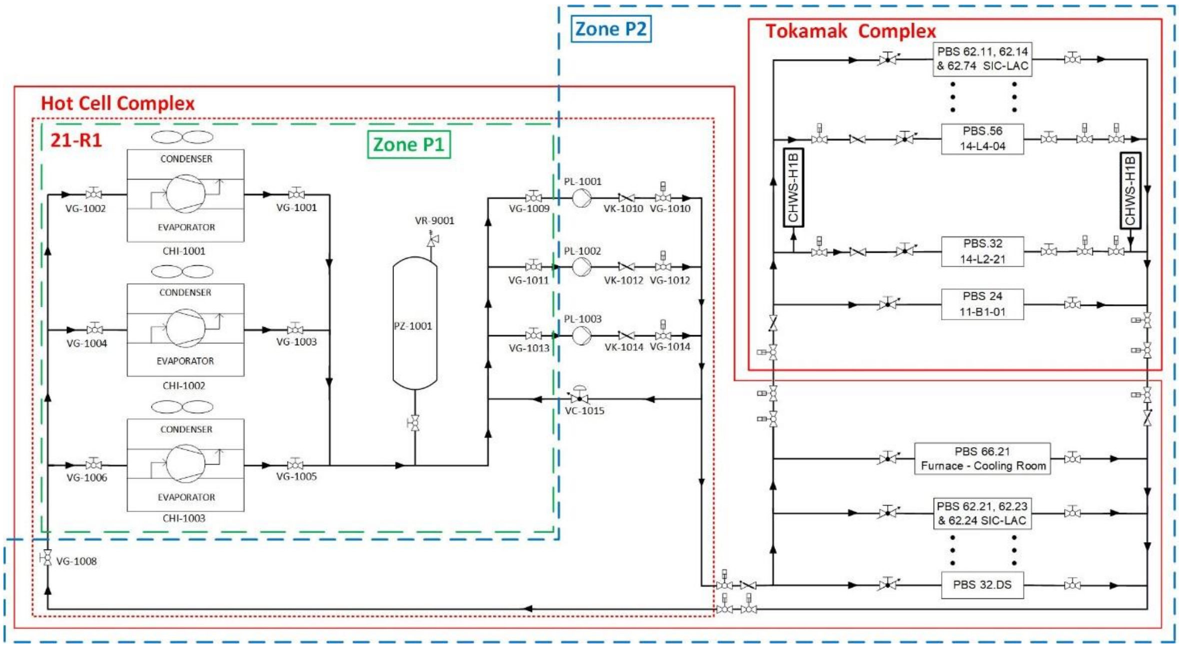

Figure A2- 1: CHWS-1A Pressure Zones

Details about these pressure zones and their design pressures are provided in the following subsections.

A2.1.1. Pressure Zone P1

This pressure zone is delimited by the isolation valve VG-1008, located in the main inlet line of the chillers (the valve is excluded from zone P1) up to the suction of the cooling pumps.

Zone P1 includes pressurizer and chillers. Pump bypass line is partially included from the branch of the suction header to the outlet of the flow control valve VC-1015 (valve excluded), including the orifice plate.

Due to the presence of the control valve VC-5501, single failure *"stuck open"* need to be assumed. Failure of VC-5501 leads to pressure increase up to the maximum nitrogen supply pressure.
The operating pressure is expected to be around 0.7 MPa,g (required value at the Interface between Liquid & Gas Distribution (PBS 65) and Cooling Water System).

According to requirements of the Nitrogen Distribution System, the maximum nitrogen pressure upstream N_2 pressure control valve is 0.865 MPa,g (= 0.965 MPa absolute).
Pipes and components, which are part of this pressure zone, are protected by the relief valve VR-9001 located at the top of the pressurizer. Therefore, the design pressure in this zone corresponds to the set pressure of the relief valve (see **§4.4.3**).

$$\boldsymbol{Design\ Pressure\ P1}: \quad P1_{Design} = 0.9\ MPa$$

The design pressure P1 envelope the case of overpressurization due to demineralized water

overfilling failure.
The demineralized water system connection is controlled by the valve VG-5503. The operating pressure is 0.6 MPa,g (= 0.7 $\mathrm{MPa}_{\mathrm{absolute}}$). Therefore, in case of failure of the valve VG-5503 (*"stuck-open"*) maximum peak pressure will lower than the design pressure of Pressure Zone 1.

A2.2. Pressure Zone P2

This pressure zone is delimited by the suction of the up to the outlet of the manual isolation valve VG-1008, located in the main inlet line of the chillers.
It includes the pumps discharge lines and associated valves (check and isolation valves). The pump bypass line is partially included from the branch of the discharge header to the outlet of the flow control valve VC-1015.

The peak pressure of P2 is determined during Plasma Operating States (POS):

- Each pump conveys a flow rate of 36.415 kg/s generating a pressure head of 0.91 MPa,
- 26CH1A-PZ-0001 is expected to not exceed 0.25 MPa.

The components exposed to the highest hydrostatic pressure in zone P2 correspond to SIC-LACs located in the Hot Cell Complex at level B2 (plant elevation of -10.45 m). In fact, it coincides with the lowest point in the system and therefore, it is subjected to the maximum geodetic head (31.3 m).

Direct overpressurization due to the failure of the pressure control valve VC-5501during operation (pump running at nominal condition) needs to be considered also for the zone P2. For this scenario, the maximum pressure that could be reached in the PZR is 0.9 MPa based on the set pressure of the relief valve located at the top of the pressurizer (see **§4.4.3**). Therefore, the peak pressure at lowest point in the system is:

$$P2_{peak} = 0.9 + 0.86 + \frac{1000 \times 9.81 \times 31.3}{1E6} = 2.07\ MPa \tag{1}$$

$$P2_{Design} = 1.1 \times P2_{peak} = 2.27\ MPa \tag{2}$$

Considering the fact that the SIC-LACs are sized to withstand a design pressure of 2.0 MPa,g (2.1 MPa absolute), to avoid the installation of pressure relief valves in each branch, the design pressure will be identical to that of the SIC LACs, namely:

$$\boldsymbol{Design\ Pressure\ P2}\text{:}\ \ P2_{Design} = 2.1\ MPa$$

<u>*Assessment of Pressure Zone P2*</u>

Potential overpressure scenarios were identified analysing the P&ID of CHWS-1A;
this procedure has been done in order to assess that the scenario of direct pressurization,

due to the failure of the N2 supply control valve (stuck open), is the design scenario for the pressure zone P2.

Analysed scenarios are listed below.

1. Because of zone P2 is bounded by the manual isolation valve VG-1008 and the pumps, the possibility of isolating the supply pipelines and part of the return pipelines from the pressurizer exists.
   In case of closure of this valve (e.g. by human error) the pressure in the zone P2 will raise up to the shutoff head of the pump at the maximum process pressure in the PZR.

   The primary pump inlet pressure is considered equal to the PZR pressure minus hydrostatic head of 1.13 m. Pressure losses from PZR to pump suction are conservatively not credited.

   The maximum process pressure of PZR is 0.25 MPa. The primary pump shutoff head is 98 m and the lowest point of P2 is located, as mentioned above, at -10.45 m, whilst considered PZR elevation is at 20.85 m.

   Therefore, additional hydrostatic head is added 31.3 m (= 20.85 m + 10.45 m).

   The minimum temperature considered to compute the water density is 6 °C. Thus the water density is 1000 kg/m^3.

   $$\mathrm{P2_{peak}} = 0.25 + \frac{1000 \times 9.81 \times (98 + 31.3)}{1\mathrm{E}6} = 1.52\ \mathrm{MPa} \qquad (3)$$

   The peak pressure computed by Eq.(3) is lower than the one calculated in Eq.(1). Accordingly, **P2$_{\mathbf{Design}}$ = 2.1 MPa** envelop this overpressure scenario.

2. In the zone P2 there are hydraulic paths crossing nuclear confinement boundary.
   In case of spurious closure of the isolation valves those pipelines are isolated; therefore, water solid condition occurs. In case of thermal expansion, resulting from chilled water temperature change in the bounded pipeline, pressure rises.
   Consequently, to avoid that the pressure increase will exceed the design conditions, those zones are equipped with overpressure protection systems such as thermal pressure
   relief valves and expansion lines.

A2.3. CHWS-1B Design Pressure

CHWS-1B is divided into 3 pressure zones which are numbered P1 to P3. They are shown in Figure A2- 2.

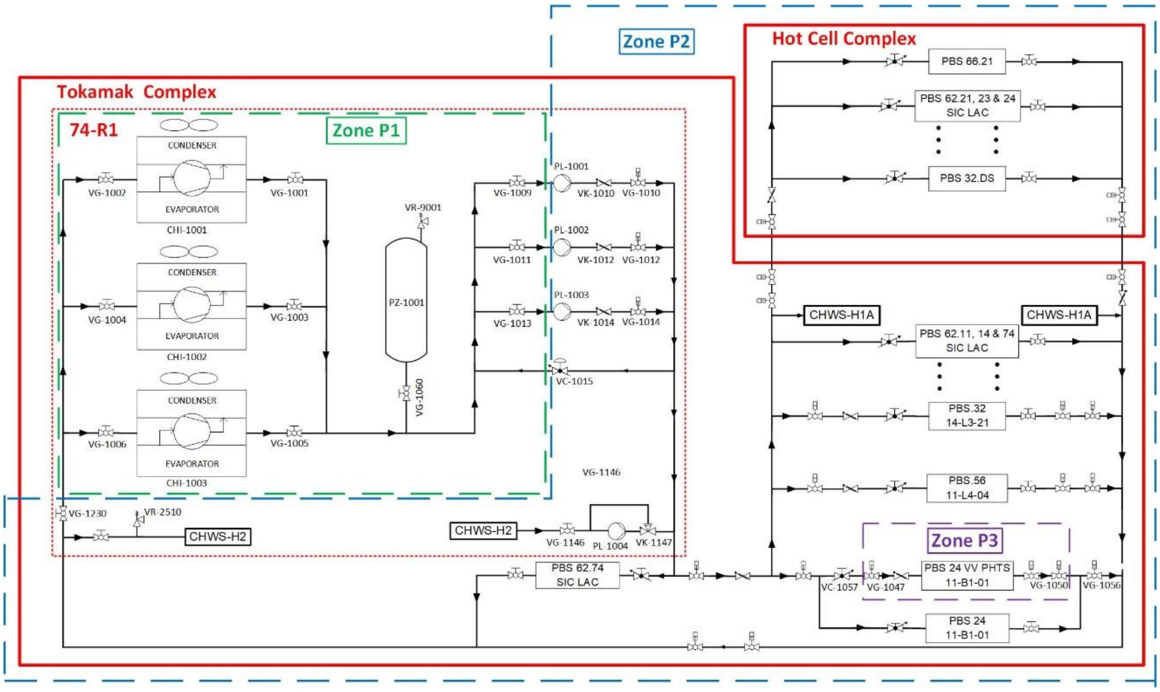

Figure A2- 2: CHWS-1B Pressure Zones

Details about these pressure zones and their design pressures are provided in the following subsections.

A2.4. Pressure Zone P1

This pressure zone is delimited by the isolation valve VG-1230 (the valve is excluded from zone P1) up to the suction of the cooling pumps.

Zone P1 includes the pressurizer and chillers. Pump bypass line is partially included from the branch of the suction header to the outlet of the flow control valve VC-1015 including the orifice plate.

Pipes and components, which are part of this pressure zone, are protected by the relief valve VR-9001. Therefore, the design pressure in this zone corresponds to the set pressure of the relief valve.

$$\boldsymbol{Design\ Pressure\ of\ P1}: \quad P1_{Design} = 0.9\ MPa$$

The nitrogen supply line and the DW make up line could produce overpressure scenario in the pressurizer 26CH1B-PZ-0001 due to the failure (“stuck-open”) of the either the control valve VC-5501 or the valve VG-5503 (single failure criterion). In both scenarios, direct nitrogen pressurization or demineralized water overfilling, the overpressurization of the system is prevented thanks to the pressure relief valve VR-9001.

A2.5. Pressure Zone P2

This pressure zone is delimited by the suction of the pumps up to the outlet of the manual isolation valve VG-1230.
It includes the pumps discharge lines and associated valves (check and isolation valves). Pump bypass line is partially included from the branch of the discharge header to the outlet of the flow control valve VC-1015. The pipeline from the inlet of the isolation valve VG-1047 up to the outlet of the isolation valve VG-1050 is excluded from pressure zone P2 (this line is part of the pressure zone P3).
The temporary connection to CHWS-H2 including the booster pump, recirculation line and both manual isolation valves are part of this zone.
Peak pressure of P2 is determined during POS. During plasma operation and during test and conditioning state each pump conveys a flow rate of 47.9 kg/s generating a pressure head of 0.91 MPa, whilst the PZR is expected to not exceed 0.25 MPa.

The weakest components in the zone P2 are the SIC-LACs located in the Hot Cell Complex at level B2 at lowest point in the system, therefore subject to the maximum geodetic head (27.17 m).
The design scenario that has been selected is the same as that considered for CHWS-1A. Namely, single failure of the pressure control valve VC-5501 which *"stuck open"* during operation (pump running at nominal condition) has been credited, since the failure of this valve can overpressurize the system.
As already explained in the CHWS-1A analysis the following data have been considered:

- Operating pressure is 0.7 MPa,g.
- The maximum nitrogen pressure upstream N_2 pressure control valve is 0.865 MPa,g (0.965 MPa absolute).
- The maximum pressure that could be reached in the PZR is 0.9 MPa (PRV setpoint).
- The lowest point of P2 is located at a plant elevation of -10.45 m, whilst the primary discharge point is at 16.72 m. Therefore, additional hydrostatic head is added 27.17 m (= 16.72 m + 10.45 m).

Therefore, the peak pressure at lowest point in the system is:

$$P2_{peak} = 0.9 + 0.86 + \frac{1000 \times 9.81 \times 31.3}{1E6} = 2.07\ MPa \tag{4}$$

$$P2_{Design} = 1.1 \times P2_{peak} = 2.27\ MPa \tag{5}$$

Considering the fact that the SIC-LACs are sized to withstand a design pressure of 2.0 MPa,g, (2.1 MPa absolute), to avoid the installation of pressure relief valves in each branch, the design pressure will be identical to that of the SIC LACs, namely:

$$\boldsymbol{Design\ Pressure\ P2}\text{:}\ \ P2_{Design} = 2.1\ MPa$$

Assessment of Pressure Zone P2

In order to assess the design pressure in zone P2, potential overpressure scenarios have been identified looking to the P&ID of CHWS-1B and identifying the one which envelope all.

1. Direct pressurization can occur in case of VV-PHTS heat exchanger leak during loss of offsite power accident in case of baking operation.
   In case of baking operation, VV-PHTS is operating at a pressure of 1.95 MPa and at a temperature of 195 °C. In such conditions, with the primary pump still running, CHWS-1B will be pressurized until primary and secondary side pressure will be equalized. The pressure rise could exceed the design pressure.
   Overpressurization of the system is prevented by means of the pressure relief valve VR-9001 installed in the pressurizer.
2. Considering that the zone P2 is bounded by the manual isolation valve VG-1230 and the pumping station, the possibility of isolating (e.g. by human error) the supply pipelines and part of the return pipelines from the pressurizer exists. Therefore, in case of closure of VG-1230 (e.g. operator error) the pressure in the zone P2 will raise up to the shutoff head of the pump at the maximum process pressure in the PZR.
   - Primary pump inlet pressure is considered equal to the PZR pressure minus hydrostatic head of 0.05 m. Pressure losses from PZR to pump suction are conservatively not credited. The maximum process pressure of PZR is 0.25 MPa.
   - Primary pump shutoff head is 106 m.
     The lowest point of P2 is located, as mentioned above, in B21 at level B2 at a plant elevation of -10.45 m, whilst the primary discharge point is at 16.72 m.
     Therefore, additional hydrostatic head is added 27.17 m (= 16.72 m + 10.45 m).

Minimum temperature considered to compute the water density is 6 °C. Thus the water density is 1000 kg/m^3-

$$P2_{peak} = 0.24 + \frac{1000 \times 9.81 \times (103.2 + 27.17)}{1E6} = 1.52\ MPa \qquad (6)$$

3. In the zone P2 there are hydraulic paths crossing nuclear confinement. In case of spurious closure of the isolation valves those pipelines are isolated and therefore, water solid condition occurs. In case of thermal expansion resulting from chiller water temperature change in the bounded pipeline, pressure rises. Consequently, to avoid that the pressure increase will exceed the design conditions, those zone are equipped with overpressure protection systems such as thermal pressure relief valves and expansion lines.

In conclusion, the design pressure of zone P2 envelope the overpressure scenarios identified in the bullets from 1 to 3.

A2.6. First Plasma Operational State

During first plasma operation, CHWS-1B is served by CHWS-H2 (NON SIC system). A temporary connection is located on the roof of Diagnostic Building (B74).

The cooling train composed by pump station, pressurizer and chillers are excluded from first

plasma operation.
Due to valve 26CHH2-VG-1146 (Figure A2- 2) it is possible to isolate CHWS-1B. In this case, thanks to the Automatic Recirculation Vale VK-1147 the pump PL-1004 will operate at minimum flow rate.
The associated head will depend on the scenario to be considered, namely either Case 1 or Case 2 as described below. Therefore, the lowest point in the system, which is located in the Tokamak Building level B2 (plant elevation of -7.54 m), will be subject to the pump head plus the hydrostatic head.
The booster pump discharge point is at 16.72 m. Then, additional hydrostatic head is added 24.26 m (= 16.72 m + 7.54 m).

During first plasma, all the LACs in the CHWS-1 are fed with cooling water.
The booster pumps works with a head of 45 m at minimum flow of 22.62 kg/s.

$$P_{peak,FP} = P_{CH2} + \frac{1000 \times 9.81 \times (45 + 24.26)}{1E6} = 1.46\ MPa \tag{7}$$

$$P_{Design,FP} = 1.1 \times P_{peak,FP} = 1.6\ MPa \tag{8}$$

Where P_{CH2} (= 0.78 MPa) is the pressure upstream the booster pump at the interface between CHWS-H2 and CHWS-1B.
Design pressure is lower than 2.1 MPa.
In order to be conservative, the temporary connections to CHWS-H2 are considered at P2 pressure.

A2.7. Pressure Zone P3

This pressure zone is delimited by the valve VG-1047 up to valve VG-1050. It consists of CHWS-1B piping connected to the secondary side of VV PHTS decay heat exchanger.
Isolation valves are located upstream the CHWS-1B supply header and downstream the CHWS-1B return header; these valves should be closed in case of one or several tube ruptures in the decay heat exchanger. In such a case, pressure would then equalize between primary and secondary sides.
Pipe break of CHWS-1B in between the confinement valves VG-1047/VG-1050) in case of heat exchanger leak is prevented by sizing zone P3 to the design pressure of VV-PHTS secondary side, which is 2.6 MPa.

$$\boldsymbol{Design\ Pressure\ of\ P3}:\ P3_{Design} = 2.6\ MPa$$

A3. Design Temperature Calculation

The overall methodology for determining the design temperature is as follows:

- CHWS-1 sub-systems A&B are divided is divided into zones based on the peak temperature seen by the piping and equipment for their most-limiting operating modes.
- Single failure affecting any of the CHWS-1A&B components (e.g. spurious opening of an isolation valve normally closed) must not result in a consequent pipe break. This is considered when defining the boundaries between the temperature zones,
- A minimum of 10% margin is then applied to the peak temperature in order to determine the design temperature for these different temperature zones. The design temperatures are rounded up with a precision of 10°C.

A3.1. CHWS-1A Design Temperature Calculation

CHWS-1A has only one temperature zone, as shown in Figure A3- 1.

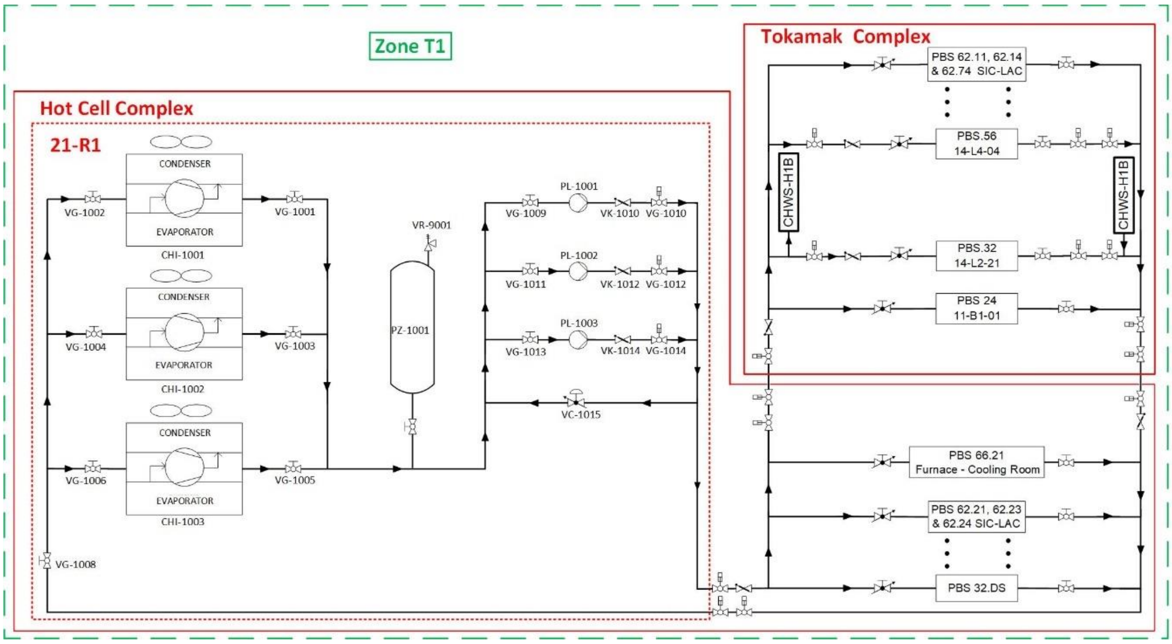

Figure A3- 1: CHWS-1A Temperature Zones

A3.1.1. Temperature Zone T1

During off mode, chilled water is at ambient temperature. It is up to 45 °C (extreme hot environmental temperature) for water contained in piping between buildings; it represents the maximum temperature reached in Zone T1.

$$\boldsymbol{Design\ Pressure\ of\ T1}:\quad \boldsymbol{T1}_{Design} = 1.1 \times 45\ ^{\circ}C = 50\ ^{\circ}C$$

A3.2. CHWS-1B Design Temperature Calculation

CHWS-1B is divided into 2 temperature zones which are numbered T1 and T2. They are shown in Figure A3- 2.

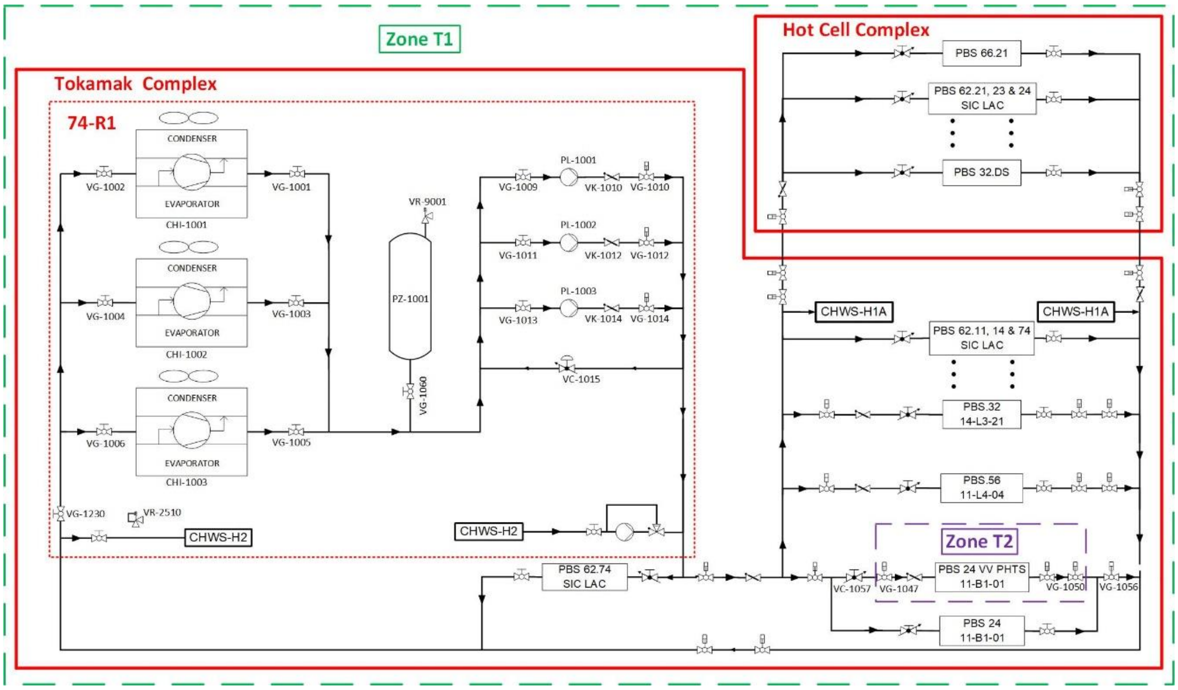

Figure A3- 2: CHWS-1B Temperature Zones

A3.2.1. Temperature Zone T1

This zone includes CHWS-1B system, except for a part of the CHWS-1B line bounded by the isolation valves VG-1047 and 26CH1B-VG-1050 included.

The design temperature has been calculated considering the extreme hot ambient temperature of 45 °C for water contained in piping between buildings. it represents the maximum temperature reached in Zone T1.

$$\boldsymbol{Design\ Pressure\ of\ T1}:\quad T1_{Design} = 1.1 \times 45\ ^{\circ}C = 50\ ^{\circ}C$$

A3.2.2. Temperature Zone T2

This temperature zone was calculated for CHWS-1B, from valve VG-1047 up to valve VG-1050. It consists of CHWS-1 piping connected to VV PHTS secondary piping.

In order to calculate the maximum temperature reached in this zone, VV-PHTS heat exchanger leakage during water baking operation has been considered.

During VV-PHTS water baking operation, the temperature in the primary side of HX is 195 °C; in such thermal condition in the case of heat exchanger leakage the temperature on the secondary side can reach also 195 °C. The total length of supply and return lines to and from the HX is approximately 86 m (= 43 m supply line plus 43 m return line) so could be that the overall pipe routing will not be full heated up to 195 °C because of the heat losses but, in order to be conservative, this value has been considered up to the isolation valves.

$$\boldsymbol{Design\ Pressure\ of\ T2}\text{:}\ \ T2_{Design} = 1.1 \times 200\ °C = 220\ °C$$

A4. CHWS-1B Nodalization in RELAP5-3D

Figure A4- 1and Figure A4- 2 show a the complete nodalization of the CHWS-1 model created in RELAP-3D.

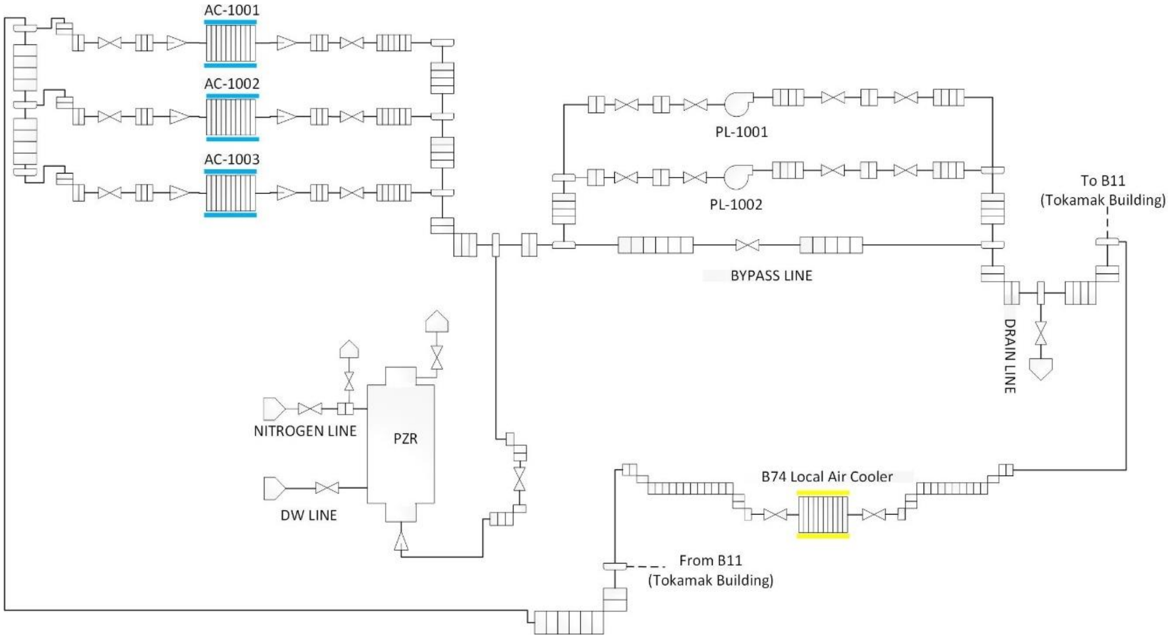

Figure A4- 1: Nodalization of CHWS-1B in RELAP5-3D (Detritiation Building)

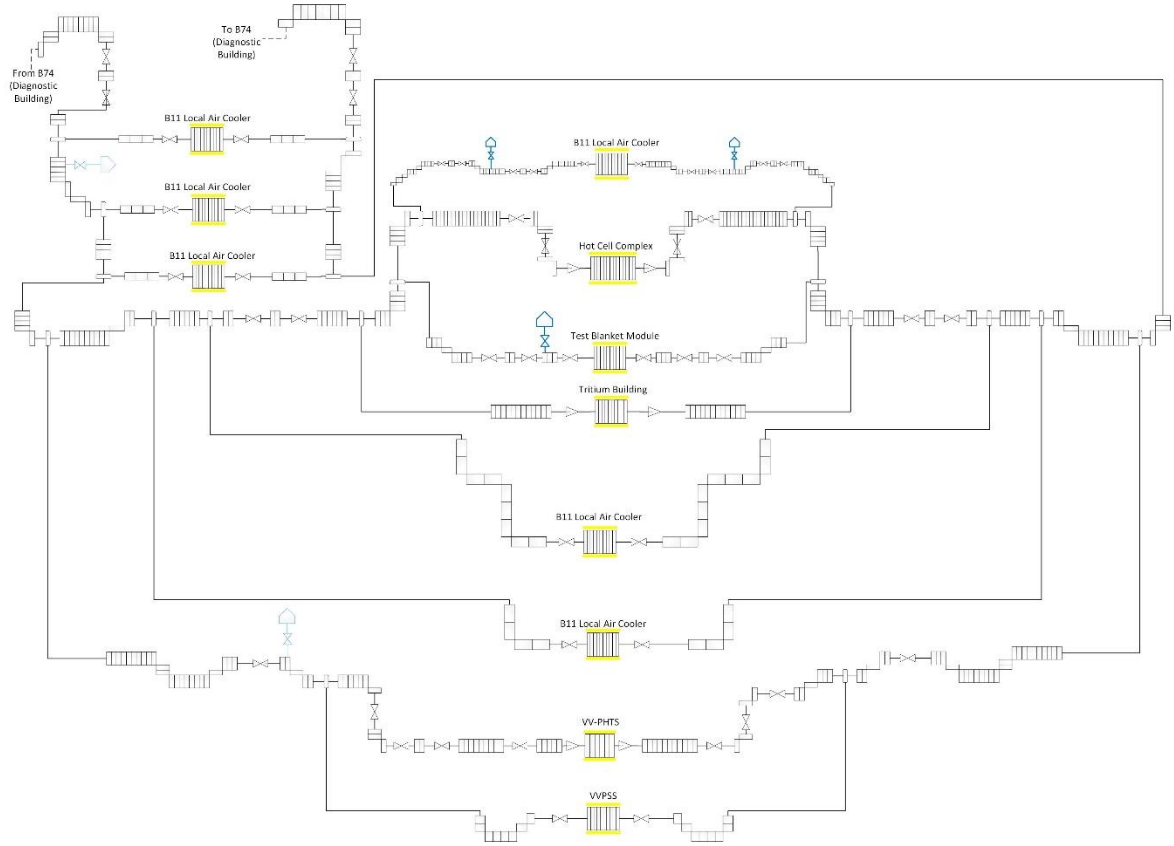

Figure A4- 2: Nodalization of CHWS-1B in RELAP5-3D (Tokamak Building, Tritium Building and Hot Cell Complex)