Accident Safety Analysis of Helium Purge System using the Code RELAP5.

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11MMET03

DEPARTMENT OF MECHANICAL ENGINEERING

AHMEDABAD-382481

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For the degree of

Master of Technology in Mechanical Engineering

(Thermal Engineering)

By

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DEPARTMENT OF MECHANICAL ENGINEERING

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MAY 2013

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This is to certify that

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Abstract

Lead Lithium cooled Ceramic Breeder (LLCB) Test Blanket System (TBS) is the prototype of the proposed Indian DEMO fusion reactor to be tested in the International Thermonuclear Experimental Reactor (ITER) in France. LLCB TBS consists of a tritium breeding blanket module made of Reduced Activation Ferritic Martensitic Steel (RAFMS), the Test Blanket Module (TBM) structure is cooled by high pressure helium gas. TBM consists of Lead Lithium (Pb-Li) liquid metal and Ceramic Breeder (CB) zones alternately arranged inside the box. Pb-Li liquid metal acts as neutron multiplier, tritium breeder and coolant for the CB zones which also produce tritium by nuclear reactions of neutrons with lithium. Low pressure helium gas is purged through the CB pebble beds to collect the tritium produced during reactor operation. LLCB TBS consists of a TBM and its ancillary systems viz. First Wall Helium Cooling System (FWHCS), Lead Lithium Liquid metal System (LLCS), Helium Purge System (HPS) which is a part of Tritium Extraction System (TES) and Lead Lithium Helium Cooling System (LLHCS). Safety licensing requires accident safety analysis of all these systems to be carried out to prove robustness of the design in case of various accident/incident scenarios. The accident safety analysis of Helium Purge system is carried out in this project using RELAP5. Reactor Excursion Leak Analysis program which is a highly generic thermal hydraulics and safety analysis tool and is widely used publicly to study the fluid behaviour at steady state and transient conditions of the system. Loss of coolant accident (LOCA) is performed for 3 cases. To simulate transient thermo-hydraulic behavior of the TBM for the selected scenarios, the helium passage including the TBM and HPS was modeled. LOCA leads to the pressurization of single volume but it was under the design limit of port cell. Based on the results of RELAP5 programming it was found HPS loop is designed properly for accident scenarios and fulfills the safety requirements of ITER.

Abbreviations

AEU	Auxiliary Equipment Unit
BT	Buffer Tank
CB	Ceramic Breeder
CHWS	Chilled Water System
DC	Detritiation Column
EH	Electric Heater
EU	Europian Union
FMS	Ferritic Martensitic Steel
FW	First Wall
FWHCS	First Wall Helium Cooling System
HCS	Helium Cooling System
He	Helium
HPS	Helium Purge System
HRS	Heat Rejection System
HTC	Heat Transfer Coefficients
HX	Heat Exchanger
ITER	International Thermonuclear Experimental Reactor
LLCB	Lead Lithium Ceramic Breeder
LLCS	Lead Lithium Liquid metal System (LLCS)
LOCA	Loss of Coolant Accident
MHD	Magneto Hydrodynamics
Pb-Li	Lead-Lithium
PC	Port Cell
PCS	Pressure Control System
PHCS	Primary Helium Cooling System
RAFMS	Reduced Activation Ferritic Martensitic Steel
RELAP5	Reactor Excursion Leak Analysis Program 5
SHCS	Secondary Helium Cooling System
TBM	Test Blanket Module

TBS .... Test Blanket System

TCWS .... Tokomak Cooling Water System

TES .... Tritium Extraction System

VV .... Vacuum Vessel

Nomenclature

A .... Area, m^2

Cp .... Specific Heat, $(J/(g*K))$

d .... Diameter,m

d .... Diameter of bend

f_T .... Friction factor

h .... Heat Transfer Coefficient, $\frac{W}{m^2*K}$

K .... Thermal Conductivity, $(W/(m*K))$

k .... Resistance coefficient

l .... Length, m

m .... Mass Flow Rate,Kg/sec

μ .... Viscosity, Pa*sec

P .... Pressure, MPa

Q .... Heat Transfer, $(W/(m*K))$

r .... Radius of pipe

ρ .... Density, Kg/m^3

T .... Temperature, K

v .... Velocity, (m/sec)

Contents

Declaration **iii**

Undertaking **iv**

Certificate **v**

Acknowledgements **vi**

ABSTRACT **vii**

Abbreviations **viii**

Nomenclature **x**

Contents **xi**

List of Figures **xiv**

List of Tables **xv**

1 Introduction **1**
- 1.1 About International Thermonuclear Experimental Reactor (ITER) . . 2
- 1.2 Plasma 3
- 1.3 Nuclear Fusion 4
  - 1.3.1 Nuclear Fusion Reaction 4
- 1.4 Test Blanket Module Concept 5
  - 1.4.1 Description of Lead-Lithium Cooled Ceramic Breeder (LLCB) Test Blanket Module 5
  - 1.4.2 Function of Test Blanket Module 6
- 1.5 Test Blanket Module Systems 6
  - 1.5.1 Helium Purge System 6
- 1.6 RELAP5 Code 7
  - 1.6.1 Capabilty of RELAP5 Code 9
- 1.7 About Institute for Plasma Research (IPR) 9
- 1.8 Need of Safety Analysis 10
- 1.9 Objective of The Present Study 10

2 Literature Survey **11**
2.1 Test blanket Module 11
2.1.1 Design Description of Test Blanket Module 11
2.2 Helium Purge System 14
2.3 Major Components of Solid Breeder Loop of Helium Purge System . 17
2.3.1 Test Blanket Module cooling coil 17
2.3.2 Helium-Water Heat Exchanger 18
2.3.3 Dust Filter 18
2.3.4 Compressor 18
2.3.5 Helium Storage and Make-up Tank 18
2.3.6 Source Tank 19
2.3.7 Buffer Tank 19
2.3.8 Hydrogen Make-up Unit 19
2.3.9 Test Blanket Module gas mixer 19
2.3.10 Heat Tracing 20
2.3.11 Tritium Monitoring System 20
2.4 Major Components of The Purge System in Liquid Breeder Loop . . 20
2.4.1 Detritiation Column 20
2.4.2 Detritiation Column Cooling Coil 20
2.4.3 Heat Tracing 21
2.4.4 Detritiation Column Gas Mixer 21
2.4.5 Tritium Monitoring System 21
2.4.6 Helium Purge System - Associated Piping and Valves 21
2.4.7 Summary of Literature Survey 22

3 Helium Purge System Description **24**
3.1 Helium Purge System 24
3.2 System Description 24
3.2.1 Charging of Helium Purge Gas 25
3.2.2 Pressurization of Purge Gas 25
3.2.3 Pressure and Flow Maintenance 26
3.2.4 Cooling of Purge Gas 26
3.2.5 Impurity Removal 26
3.3 Process Parameters for Helium Purge System 26
3.4 Process Control Philosophy of Helium Purge System 27
3.4.1 Pressure Control 27
3.4.2 Flow Control 27
3.4.3 Temperature Control 28
3.5 Equipment for HPS 28

4 Thermal-Hydraulic Analysis of Helium Purge System **30**
4.1 Hydrodynamic Modelling of Helium Purge System Components and Piping 33
4.1.1 Test Blanket Module Hydrodynamic Model 34
4.1.2 Piping Hydrodynamic Model 34
4.1.3 Detritiation Column Hydrodynamic Model 35

4.1.4 Buffer Tank Hydrodynamic Model 36
4.1.5 Circulator Hydrodynamic Model 36
4.1.6 Electric Heater Hydrodynamic Model 36
4.2 Double Pipe Heat Exchanger Hydraulic Model 36
4.2.1 Tube Side- Helium 36
4.2.2 Annulus Side- Water 37
4.3 Additional Components for Transient Analysis 38
4.4 Heat Structure of HPS 38
4.4.1 Electric Heater Heat Structure 39
4.4.2 Heat Exchanger Heat structure 40
4.5 Heat Structure Thermal Property Data 40

5 Results **41**
5.1 Transient-State Analysis 41
5.1.1 Case -I Single Volume Attached Above TBM 41
5.1.2 Case-II Test Cell Attached above D.C 43
5.1.3 Case-III Test Cell Attached After HX 45

6 Conclusions and Future Scope **48**
6.1 Conclusions 48
6.2 Future Scope of Work 48

References **50**

A Fluid Properties Table **52**

B RELAP5 Input Deck **54**
B.0.1 Flow Chart for Analysis 54
B.1 RELAP5 Input Deck 55
B.1.1 Input Deck for Nodalisation Diagram of Simple Loop 55
B.1.2 Input Deck for Helium Water HX 69
B.1.3 Input Deck for Detritiation Column Inlet Heater 72
B.1.4 Input Deck for Test Blanket Module Heater 75
B.1.5 The Graph Obtained from RELAP5 Input Deck 77

List of Figures

1.1 ITER Tokomak[18] 3
1.2 Plasma-forth state of matter[1] 3
1.3 Deuterium and tritium reaction [1] 4
1.4 Reactor structure 7
1.5 Schematic of helium purge system[8] 8

2.1 Different component of TBM module[5] 12
2.2 A sectional view (internal) of the LLCB blanket module[5] 13
2.3 Schematic of HPS[3] 16

4.1 Flow chart of modelling in RELAP5. 31
4.2 Nodalization diagram for HPS 33
4.3 Nodalization diagram for Heater 37
4.4 Nodalization diagram for Heat exchanger 38
4.5 LOCA analysis nodalization in RELAP5 39
4.6 Nodalization of electric heater heat structure 40

5.1 Pressure of Test Cell 600 above TBM during LOCA 42
5.2 Temperature of Test Cell 600 above TBM during LOCA 42
5.3 Mass flow rate of component 800 above TBM during LOCA 43
5.4 Pressure of Test Cell 600 above D.C during LOCA 44
5.5 Temperature of Test Cell 600 above D.C during LOCA 44
5.6 Mass flow rate of component 800 above D.C during LOCA 45
5.7 Pressure of Test Cell after HX during LOCA 46
5.8 Temperature of Test Cell after HX during LOCA 46
5.9 Mass flow rate of component 800 after HX during LOCA 47

B.1 Flow chart for Analysis 54
B.2 HX Graph for outlet pressure of Helium 77
B.3 HX Graph for outlet Temperature of Helium 78
B.4 HX Graph for outlet pressure of Water 78
B.5 HX Graph for outlet Temperature of Water 79
B.6 DC Heat Tracing Temperature 79
B.7 DC Heat Tracing Pressure 80
B.8 TBM Heat Tracing Pressure 80
B.9 TBM Heat Tracing Temperature 81
B.10 TBM Mass Flow Rate 81

List of Tables

I LLCB TBM parameters[9] 12
II Literature survey summary 22

I Components of HPS[4] 25
II Process parameters of HPS[4] 27
III HPS Flow condition[7] 28
IV Temperature requirement[4] 28
V Equipment of HPS[7] 29

I Table for pipe dimensions[6] 34
II Standard junction loss coefficient for 90^0 bends [13] 35
III Pipe friction data for clean commercial SS316L [13] 35
IV Heat structure material overview 40

I Property Table For Helium 52
II Property Table For Water 53

I Syntax for RELAP5 Coding 55

Chapter 1

Introduction

This world faces an energy crisis because coal and crude oil, the main resources for producing electricity, are diminishing in this century and the energy demand rising with increasing population, industrialization and technological development. Apart from these, alternative energy source like solar and wind are also used but the output and efficiency of these sources are low. Another source for producing electricity is nuclear power plants which are based on fission process but it is costly and hazardous as it can produce nuclear radiation. So, new and more sustainable sources of energy will be necessary to research and develop in order to meet the global energy needs. Fusion power has the potential to provide sufficient energy to satisfy mounting demand. Nuclear fusion has many potential attractions. Firstly, its hydrogen isotope fuels, which are in plasma state, are relatively abundant - one of the necessary isotopes, deuterium, can be extracted from seawater, while the other fuel, tritium, could possibly be created using neutrons produced in the fusion reaction itself. Furthermore, a fusion reactor would produce virtually no $C0_2$ or other atmospheric pollutants, and its other waste products would be very short-lived compared to those produced by conventional nuclear reactors. The most important thing is, it will produce nearly 10 times more power than it consumes. So as it is best option among other sources available, more and more research are needed in plasma based fusion power development.

1.1 About International Thermonuclear Experimental Reactor (ITER)

The International Thermonuclear Experimental Reactor (ITER) is an international nuclear fusion research and engineering project, which is currently building the world's largest and most advanced experimental Tokamak nuclear fusion reactor at the Cadarache facility in the south of France. The ITER project aims to make the long-awaited transition from experimental studies of plasma physics to full-scale electricity-producing fusion power plants. The project is funded and run by seven member entities the European Union (EU), India, Japan, China, Russia, South Korea and the United States. The EU, as host party for the ITER complex, is contributing 45% of the cost, with the other six parties contributing 9% each. On November 21 2006, the seven participants (European Union, India, Japan, Korea, China, Russia and USA) formally agreed to fund the project called International Thermonuclear Experimental Reactor (ITER) which means "The Way" in Latin. The ITER programme is anticipated to last for 30 years - 10 years for construction, and 20 years of operation. It will be based in Cadarache, France. It is technically ready to start construction and the first plasma operation is expected in 2016.[18]

ITER is an international Tokamak research/engineering project designed to prove the scientific and technological feasibility of a full-scale fusion power reactor. It is an experimental step between today's studies of plasma physics and future electricity-producing fusion power plants. ITER will be the first fusion device to produce thermal energy at the level of an electricity-producing power station. It will provide the next major step for the advancement of fusion science and technology, and is the key element in the strategy to reach Demonstration Electricity Generating Power Plant (DEMO) in a single experimental step. The heart of ITER is a superconducting tokamak facility with striking design similarities to JET, but twice the linear dimensions. It will have a plasma volume of around 840 m^3. It is designed to produce approximately 500 MW of fusion power sustained for more than 400 seconds. ITER is proposed to be the first fusion experiment with an output power higher than the input power.

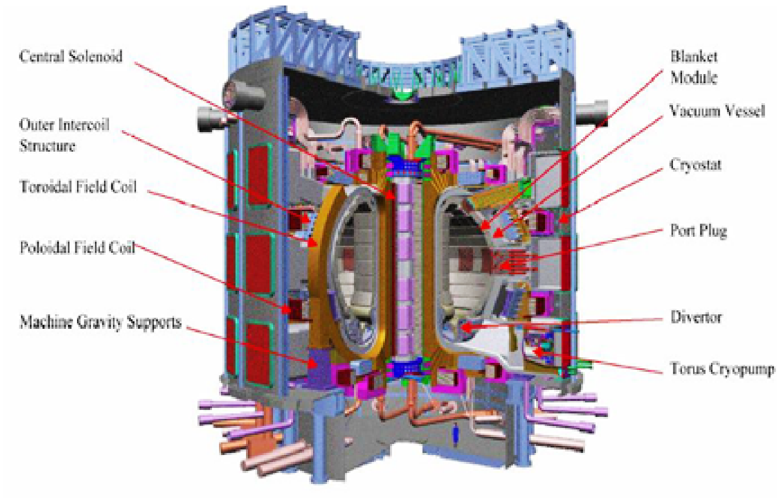

Figure 1.1: ITER Tokomak[18]

1.2 Plasma

Sir William Crookes, an English physicist, identified a fourth state of matter, now called plasma, in 1879. The word 'PLASMA' was first applied to ionized gas by Dr. Irving Langmuir, an American chemist and physicist, in 1929. Figure 1.2 shows various state of matter and distinguish plasma with other state of matter. Plasma

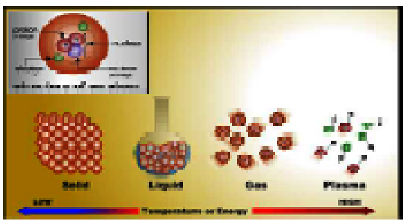

Figure 1.2: Plasma-forth state of matter[1]

refers to an ionized gas, in which a certain proportion of electrons are free, rather than being bound to an atom or molecule. This allows positive and negative charges to move somewhat independently and makes plasma electrically conductive so that it responds strongly to electromagnetic fields. Plasma can be accelerated and steered by electric and magnetic fields, which allows it to be controlled and applied. Plasma therefore has properties quite unlike those of solids, liquids or gases and is considered to be a 'fourth state of matter'. Fusion-oriented high temperature plasma physics is concerned with ionized hydrogen.

1.3 Nuclear Fusion

Nuclear fusion is a nuclear reaction in which two or more atomic nuclei join together, or "fuse", to form a single heavier nucleus. It is the reaction in which two atoms of hydrogen combine together, or fuse, to form an atom of helium. In the process some of the mass of the hydrogen is converted into energy. The easiest fusion reaction to make happen is combining deuterium (or heavy hydrogen) with tritium (or heavy hydrogen) to make helium and a neutron. Deuterium is plentifully available in ordinary water. Tritium can be produced by combining the fusion neutron with the abundant light metal lithium. Thus fusion has the potential to be an inexhaustible source of energy.

1.3.1 Nuclear Fusion Reaction

The reaction involved in the Nuclear fusion is as follows:
$^2D +^3 T \rightarrow^4 He + n + 17.6MeV$

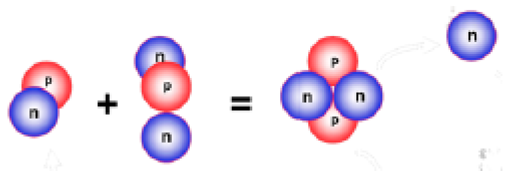

Figure 1.3: Deuterium and tritium reaction [1]

1.4 Test Blanket Module Concept

Breeding blanket is one of the major technological breakthrough required to pass from International Thermonuclear Experimental Reactor (ITER) to the next step called DEMO Fusion Power Reactor (FPR) which need to breed the tritium required for D-T reaction and to convert nuclear energy into heat extracted by a coolant under pressure and temperature conditions appropriate to drive an acceptable thermodynamic cycle for electricity production. Tritium Breeding Blanket is a critical component exposed to severe working condition, which is required for DEMO power reactor. ITER is a unique opportunity to test the Blanket mock-ups, which is known as Test Blanket Modules (TBMs). Indian TBM program in ITER is one of the major steps in its fusion reactor program towards DEMO and future Fusion Power Reactor (FPR) vision. Indian blanket concept is based on liquid breeder type known as Lead-Lithium cooled Ceramic Breeder (LLCB) TBM.

1.4.1 Description of Lead-Lithium Cooled Ceramic Breeder (LLCB) Test Blanket Module

The Lead-Lithium cooled Ceramic Breeder (LLCB) blanket module has to breed tritium and extract heat from the fusion reactor. This module will be kept in front of the fusion plasma, which is volumetrically heated by the 14 MeV neutrons and the surface heat flux from the fusion plasma. In the lead-lithium cooled ceramic breeder module the coolant is Lead-Lithium (LL) flowing around the ceramic breeder zone. The ceramic breeder (CB) zone is filled with Lithium ceramic pebbles. The plasma-facing surface of the module is called First Wall (FW) made of Ferritic Martensitic steel. The high pressure helium gas is used as coolant for the FW to extract the surface heat flux from plasma and partially, the neutronic heat deposited in the FMS box structure and Pb-Li interface locations. Effectively there is no helium cooling in the interface FMS between the Pb-Li and ceramic breeder container. The tritium produced in the ceramic breeder zones is extracted by low-pressure purge helium at 1.2 bar + 0.1 % of hydrogen to enhance the catalytic exchange of H and T. The tritium produced in the Pb-Li circuit is extracted separately by an external system.

The flowing LL experiences very high magnetic field in the reactor environment (4 Tesla) in transverse direction and develops high MHD pressure drops due to induced currents interaction with the magnetic field. This modifies the flow velocity profiles and turbulence characteristics, and hence the heat transfer and MHD pressure drop in the flow channels and manifolds. The first level engineering design of the LLCB TBM has been completed in various aspects.[5]
Such as, mechanical, thermal, structural, thermal hydraulics, thermo-mechanics, Magneto hydrodynamic pressure drops and electromagnetic loads. The LLCB TBM system includes the manifold design for all the coolants, Helium Cooling System, Lead-Lithium loop system, Helium purge gas system, piping arrangement with Remote Handling compatibility and safety equipment systems.

1.4.2 Function of Test Blanket Module

- Tritium production (breeding) and extraction (purging).
- Transforming neutron power into heat and collection of the heat .
- Shielding of the Vacuum Vessel and Toroidal Field Coils.

1.5 Test Blanket Module Systems

TBM Systems (TBS) consist of three systems namely Helium Cooling System (HCS), Lead-lithium Cooling System (LLCS) and Helium Purge System (HPS).

1.5.1 Helium Purge System

The helium from HPS is used to purge the tritium bred in the ceramic breeder zones in-situ and continuously processed externally for tritium extraction from the line. The purge gas helium is low pressure and less flow rate in order to sweep the tritium from the pebbles through catalytic exchange reactions.

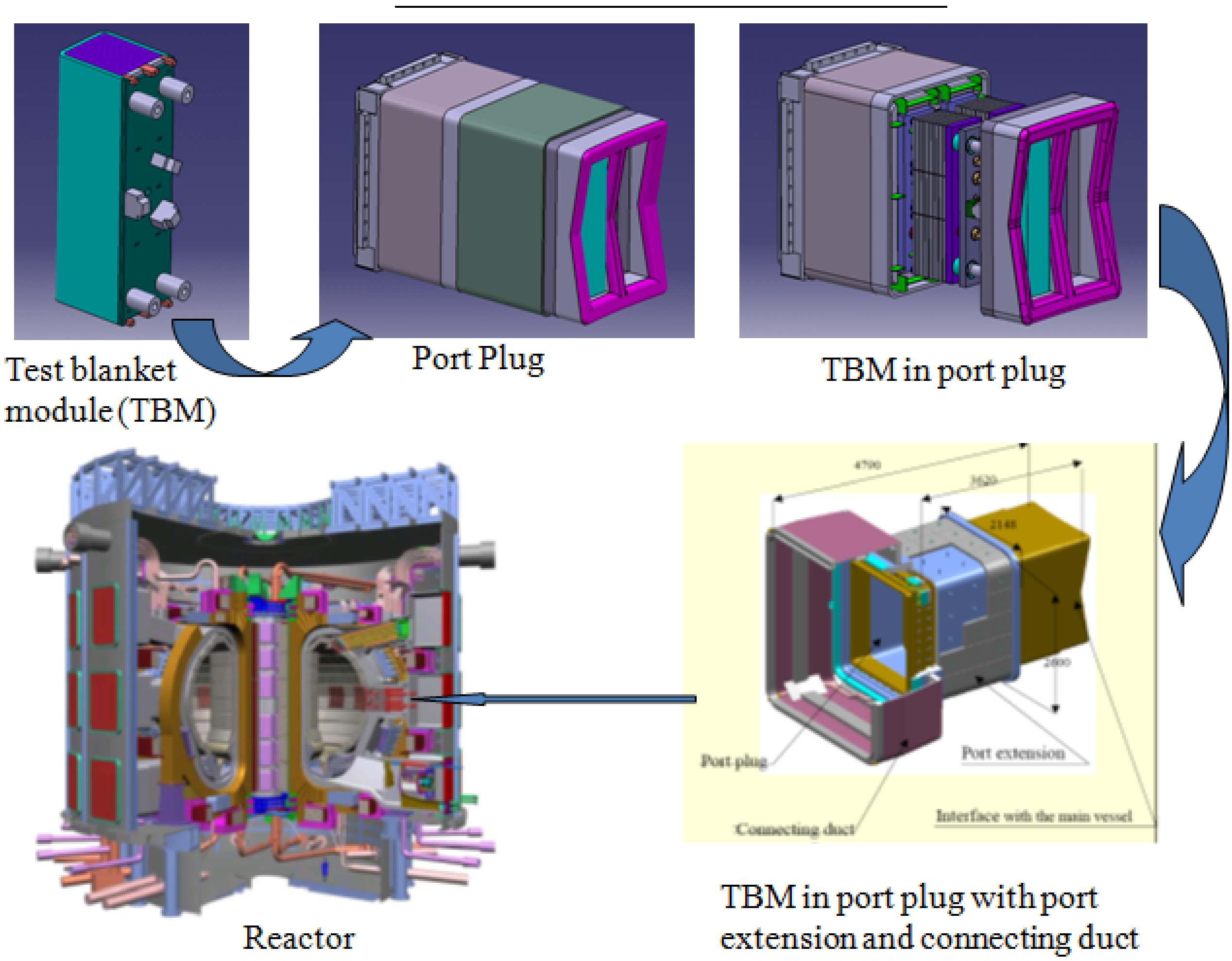

Figure 1.4: Reactor structure

1.6 RELAP5 Code

Reaction Excursion Leak Analysis Program 5 (RELAP5) has been developed for the best estimate transient simulation for light water reactor coolant systems during postulated accidents. The code models the couple behaviour of reactor coolant systems and the core for loss of coolants accidents and operational transients. It is highly generic code and allows to simulate a wide range of hydraulic and thermal transients in both nuclear and non nuclear systems. The basic field equations contains two phase continuity equations,two phase momentum equations and two phase energy equations. The system is solved numerically using semi-implicit or nearly implicit finite difference methods. The RELAP5 code has been used to support basic research

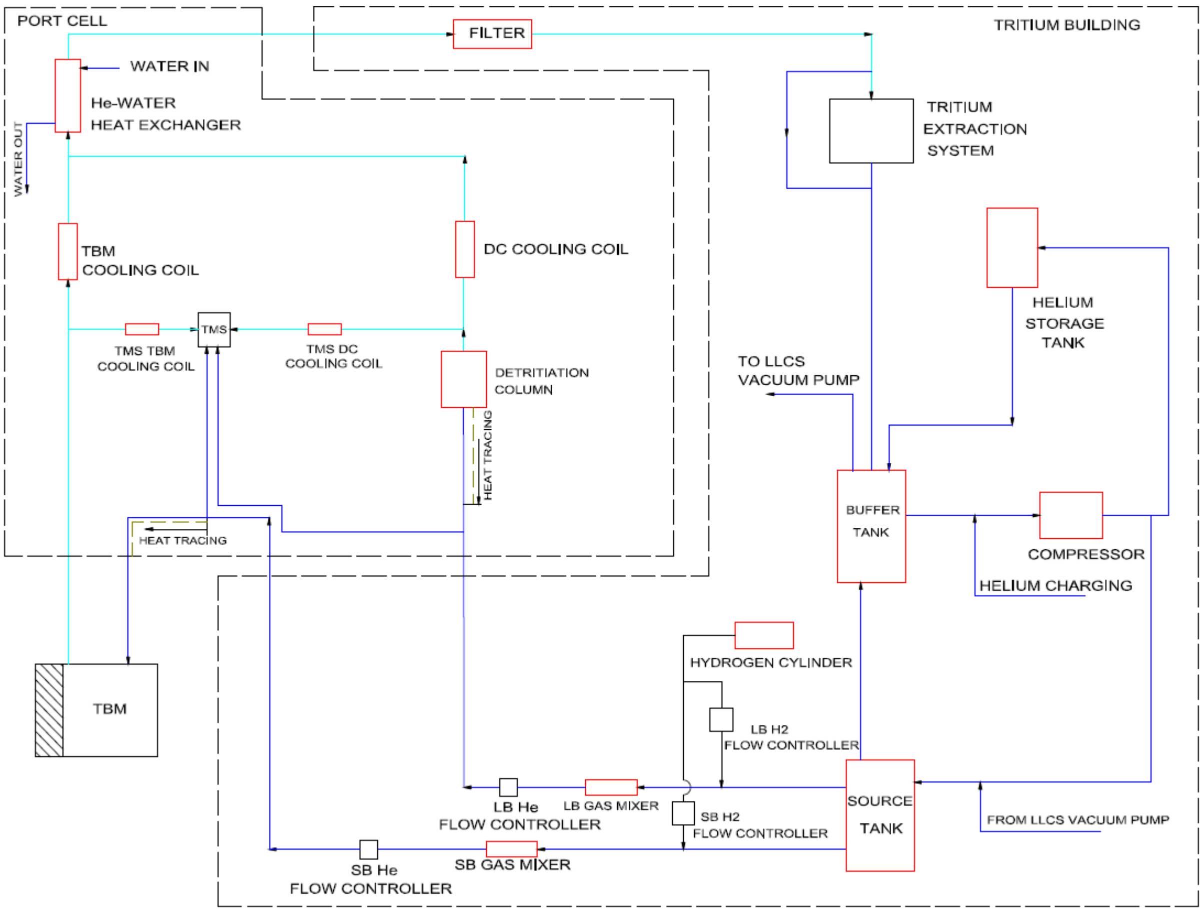

Figure 1.5: Schematic of helium purge system[8]

on two-phase thermal-hydraulics, to design small and large-scale thermal-hydraulic experimental facilities, research reactors, commercial power plants, and to assess the safety of nuclear plants. RELAP5 was one of the most widely used versions of the software and is still used to support the regulation of commercial power plants in the United States, Europe, and Asia. RELAP5, which was initially released in the late 1980's, is the most advanced major version of the code and is still under active development in the United States by the U.S. Department of Energy and Nuclear Regulatory Commission (USNRC). RELAP5 is currently the latest publicly available version of the code. RELAP5 use multidimensional thermal-hydraulic, heat transfer, generic and special component, control systems, and other models to describe the behavior of complex systems under single and two-phase conditions. The hydrodynamic models track the flow of liquid, vapor, and non-condensable gases including air, hydrogen, helium and nitrogen. The heat transfer models describe 1D/2D heat conduction in system structures and connective and radiative heat transfer between the structures and the fluid.[15] The generic component models include valves, separators, dryers, pumps, electric heaters, turbines, and accumulators. Control system models include arithmetic functions, integrating and differentiating functions, proportional-integral, lead, and lead-lag controllers, and trip logic. Special component models in RELAP5, developed for the analysis of nuclear reactors, include fuel element, control rod/blade,and other core structure models, debris bed models, and general models for porous structures.

1.6.1 Capabilty of RELAP5 Code

The capability of the code is vast, it offers to model : Hydrodynamic components like pipes, valves, branches, separators, pumps, multiple branches and junctions, bellows and others. Heat structures which involve conduction,convection and radiation. Heat sources from nuclear heat and thermal can be well modelled using this code. Reactor kinetics, point kinetics which are involved in nuclear reactions. Metal reactions, mainly metal steam reactions. There are four main steps involved while modelling the systems in RELAP5.[14]

- Nodalization of the systems into volumes for computation.
- Tabulation of parameters for each components involved in modelling which are given as input to the code.
- Running the code for steady /transient state.

1.7 About Institute for Plasma Research (IPR)

The Institute was established as an autonomous institution in 1986. The major objectives of the Institute have been to carry out experimental and theoretical research in plasma physics with emphasis on the physics of magnetically confined hot plasmas and non-linear plasma phenomena.

The Institute has a broad charter of objectives to carry out experimental and theoretical research in plasma sciences with emphasis on the physics of magnetically confined plasmas and certain aspects of nonlinear phenomena. The Institute also has a mandate to stimulate plasma research and development activities in the Universities and the industrial sector. It is also expected to contribute in the training of plasma physicists and technologists in the country. Since its inception the Institute has pursued these goals in an active manner and made some effective contributions. The Institute in its second phase of experimental activity has embarked on an ambitious project of building the first Indian Steady State Superconducting (SST1) Tokamak.[1]

1.8 Need of Safety Analysis

- Biological hazards .
- Investment protection.
- prediction of failure at shorter level.
- ITER safety guidelines.
- Providing signals for instrumentation and control unit for necessary action.

1.9 Objective of The Present Study

The objective of dissertation is to analyse the Thermal hydraulics of Helium Purge System which is an integrated part of Lead Lithium Ceramic Breeder Test Blanket System by using the computational tool RELAP5 for safety purpose of the system.

Chapter 2

Literature Survey

A literature survey for the current dissertation work has been carried out in which Various research papers, web articles, theories have been studied relevant to the topic of work.

2.1 Test blanket Module

2.1.1 Design Description of Test Blanket Module

The overall dimensions of the LLCB TBM are 1.66 m (pol)*0.484 m (tor)*0.534 m (rad). Fig. 2.1 shows the different components of LLCB TBM includes the FW, top, bottom, and back plate and the ceramic breeder assembly inside the module. PbLi eutectic is flowing around all CB zones extracts heat from them as well as the heat generated within it as shown in Fig 2.2. This figure shows the details of all five CB zones and the path of six PbLi channels around these CB zones. The PbLi flow velocity is moderate enough such that its self generated heat and the heat transferred from ceramic breeder bed is extracted effectively. Effectively there is no separate helium cooling in the interface RAFMS plates between the PbLi and ceramic breeder.[10]

The FW is designed to withstand the energetic particle fluxes and heat fluxes from the plasma, high thermal and mechanical stresses and magnetic forces during plasma disruptions. The FW of TBM is coated with 2 mm beryllium as the plasma

Table I: LLCB TBM parameters[9]

Structural material	IN-RAFMS
Breeder material	PbLi, Li_2TiO_3
Lithium enrichment	90% in PbLi 60% in Li_2TiO_3
Coolants Helium	PbLi
Helium temperature (inlet/outlet)	573/673 K
Helium gas pressure	8 MPa
PbLi temperature (inlet/outlet)	598/723 K
Purge gas for tritium extraction	Helium with 0.1% hydrogen at 0.12 MPa

facing material on the plasma facing side of the FW structure. The FW structure is actively cooled by helium gas flowing through the cooling channels which are running in radial/toroidal/radial direction and designed to withstand the He pressure of 8 MPa. The heat transfer coefficients (HTC) obtained form the correlations revealed that required cooling could be achieved by artificially roughened surface towards the plasma side wall of He cooling channel which helps to keep the RAFMS temperatures below the allowable limit[16]. The LLCB blanket concept consists of lithium titanate

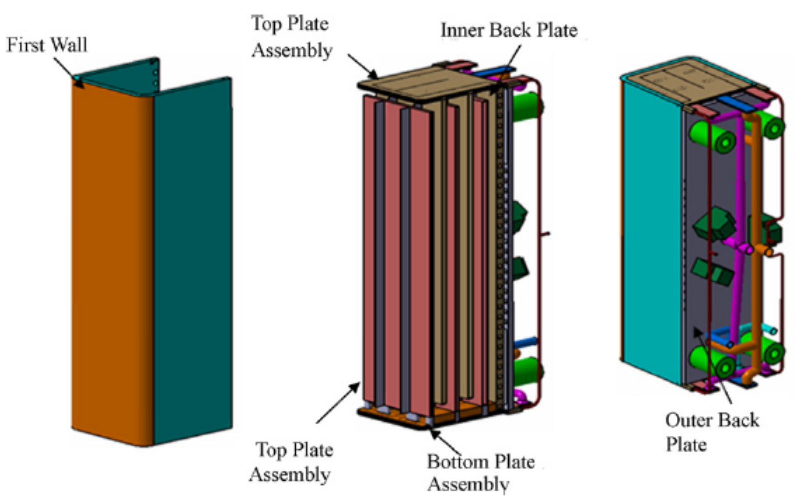

Fig. 1. Different components of LLCB TBM module.

Figure 2.1: Different component of TBM module[5]

as ceramic breeder material in the form of packed pebble beds. There are two coolant circuits for the FW and CBs. The FW structural material is ferritic steel and is cooled by helium gas and the Pb-Li eutectic, flowing separately around the lithium ceramic breeder pebble bed extracts heat from the CBs. The Pb-Li flow velocity is moderate enough such that its self generated heat and the heat transferred from ceramic breeder bed is extracted effectively. The helium is coolant for the external box structure to extract the surface heat flux from plasma and partially, the neutronic heat deposited in the FMS box structure and Pb-Li interface locations. Figure-2.2 shows the sectional view of LLCB including cooling circuits. Effectively there is no helium cooling in the interface FMS between the Pb-Li and ceramic breeder container. This avoids the complication in the fabrication of the helium channels for inside grid structure. The tritium produced in the ceramic breeder zones is extracted by low-pressure purge helium at 1.2 bar + 0.1 % of hydrogen to enhance the catalytic exchange of H and T. The tritium produced in the Pb-Li circuit is extracted separately by an external system.[2]

Paritosh Chaudhuri, et al[16] discusses concepts of tritium breeding blankets rel-

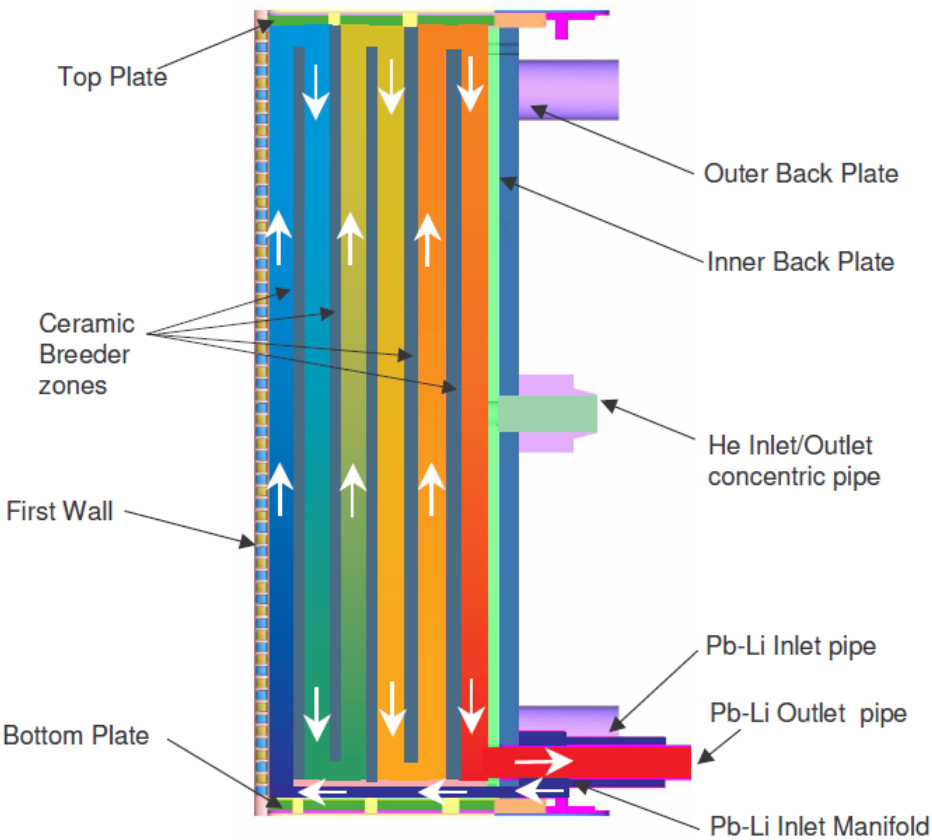

Figure 2.2: A sectional view (internal) of the LLCB blanket module[5]

evant to a power-producing reactor like DEMO. India has developed two breeding blanket concepts such as, lead lithium cooled ceramic breeder (LLCB) and helium cooled ceramic breeder (HCCB) for its DEMO. LLCB concept will be tested in ITER where ceramic breeder (CB) in the form of packed pebble beds is used as a tritium breeding material and PbLi eutectic is used as multiplier, breeder, and coolant for the CB zones. A detail engineering design and analysis has been executed for the LLCB TBM to optimize the flow parameters for helium and PbLi circuits, to estimate the temperature distribution in the various breeding zones and to ensure the thermal design limits for structural material and temperature window in ceramic breeder for effective tritium extraction.

In the paper by G. Rampal,, et al[11] latest design of the final TBM is presented. The most recent developments consist in geometrical optimisations and modifications needed to have a realistic manufacturing sequence, in defining the attachments to the port frame, and in assessing the integration of the testing instrumentation required for each mock-up. The status of studies on sub-components fabrication is presented. Preliminary proposals for the design of the initial TBM are also discussed.

E. Rajendra Kumar, T. Jayakumar, A.K. Suri[10] This paper will provide an overview of LLCB TBM Research and Development activities under progress in India.The LLCB TBM will be tested from the first phase of ITER operation (H-H phase) in one-half of an ITER port No. 2. The Indian TBM Research and Development program is focused on the development of blanket materials and critical technologies: structural material (IN-RAFMS), breeding materials (PbLi, Li_2TiO_3), development of technologies for Lead Lithium cooling system (LLCS), helium cooling system (HCS), tritium extraction system (TES) and TBM related fabrication technologies.

2.2 Helium Purge System

The Helium purge gas system (HPS) is used to extract the tritium produced in solid ceramic breeder as well as in the liquid Pb-Li loop. For schematic refer Figure 2.3. The purge gas helium is low pressure and less flow rate in order to sweep the tritium from pebble bed through isotopic exchange reaction. In HPS system, it is required to control parameters like temperature, pressure, flow of purge gas and concentration of hydrogen. Since helium purge gas is not intended for taking out any heat from TBM, therefore pulse and dwell mode of ITER operation do not affect HPS system. So system parameters like temperature, pressure and flow rate do not change in pulse or dwell mode.

For developing the flow in the loop a reciprocating compressor is used which takes suction form Buffer Tank and discharges to Source Tank. Source Tank pressure is maintained at 0.3 MPa with the help of PRV. The excess discharge from compressor goes back to Buffer Tank through this PRV. The supplies of helium to solid breeder and liquid breeder are taken from Source Tank, where inlet pressure to TBM and Detritiation column are maintained by PRVs. For flow control to individual loops digital mass flow controllers are used. Hydrogen concentrations to individual loops are controlled by individual controllers. Inlet temperature to TBM and Detritiation column (DC) are maintained by heat tracing. Helium after passing through the TBM and DC, where the purge helium picks up tritium, are combined and after removing heat in cooling coils and water heat exchanger sent back to Buffer Tank through dust filter. For tritium extraction the purge gas is passed through tritium extraction system (TES) before coming to Buffer Tank[7]. Helium Purge system, located in Tritium Building, consists of the following loops:

- Solid breeder loop (Purge gas connection for TBM).
- Liquid breeder loop (Purge gas connection for Detritiation column)

In the paper by E. Rajendra Kumar, et al[9], the design description, preliminary analysis and some of the related ancillary systems and Research and development activities for LLCB TBM are presented. Presently the primary focus is on the design and analysis of the LLCB TBM to assess the performance of LLCB concept for DEMO relevance. The LLCB TBM will be tested from day 1 operation of ITER in one-half of a designated test port. The tests in ITER include the simultaneous function of all subsystems including the TBM as well as its ancillary system. The tritium produced in PbLi and ceramic breeder zones will be extracted by separate external ancillary systems.

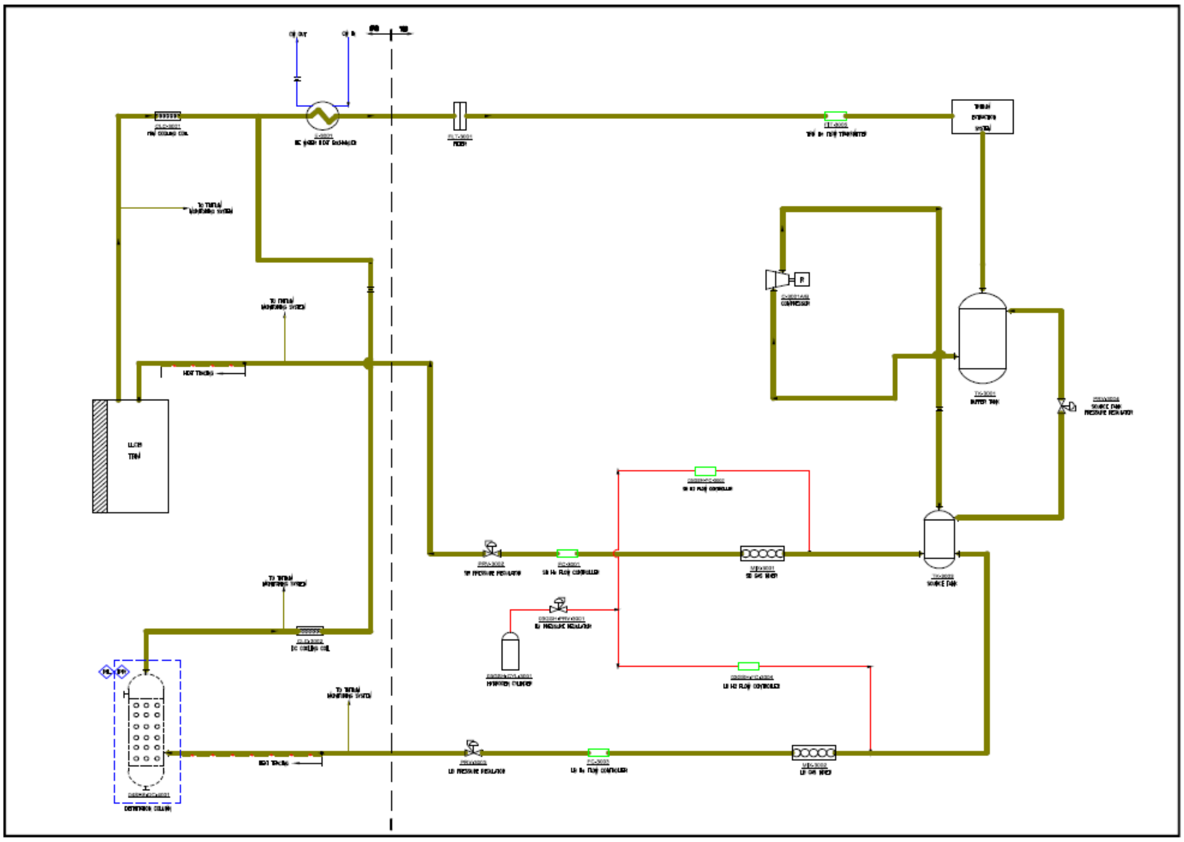

Figure 2.3: Schematic of HPS[3]

In the paper by V.A. Chuyanov, et al[17]] an initial assessment of the TBM and ITER interface requirements was done and four areas of interface were identified. The first area is the port cell interface area, including components like the port plug frame, backside shield, dummy TBM and corresponding tools needed for the TBM maintenance and replacement. The second area is the hot cell, including the needed additional hardware for the service of TBMs, additional remote handling tools, and additional building space needed for the maintenance of the TBM ancillary equipment and the corresponding testing utilities and tools. The third area is the tokamak cooling water system (TCWS) with the need to accommodate six TBM heat transfer systems, each with a footprint of $57m^2$. The fourth area of interface is the tritium plant. In all these areas modifications in the current ITER design are needed to accommodate the TMB testing. These changes must be incorporated in the new ITER baseline design which is now under preparation. The latest experiments on JET re-

vealed unexpectedly high sensitivity of plasmas in H-mode of confinement to ripples of the magnetic field. The ferromagnetic test modules can create additional ripples. This new issue of interface between ITER and TBMs is also addressed.[12]
In the paper by C.A. Chen, et al.[12] the main goal of an international thermonuclear experimental reactor (ITER) test blanket module (TBM) is to test the feasibility of tritium production and extraction. China has designed two types of TBMs to put in a whole test port, which are the helium-cooled solid breeder (HCSB) TBM and the dual-function lithium lead (DFLL) TBM. A set of common tritium processing systems was designed for the two types of TBMs, including the tritium extraction system (TES), the helium coolant system and the coolant purification system (CPS). Tritium in the TBMs and the ancillary systems should be controlled for the sake of radiological safety. The design of a few key parameters, such as the partial pressures of tritium in the coolant and above the breeder, the flux of carrier gas for tritium extraction, the efficiency of tritium extraction, the selection of the structure material together with the surface coating, etc., depend on the structure of the TBMs and the control of tritium release into the environment. A set of calculation models, based on the tritium mass balance among the TBMs, and different ancillary systems were developed to appraise the tritium safety in the common tritium systems and the Chinese TBMs. A tritium permeation barrier coating on the structure material of some components, a double-wall design for some tritium containers, and the establishment of a glove-box atmosphere detritiation system are all necessary to control the release of tritium into the environment.

2.3 Major Components of Solid Breeder Loop of Helium Purge System

2.3.1 Test Blanket Module cooling coil

The hot purge gas stream coming out from TBM is cooled from 500^0C to 80^0C by using TBM cooling coil. Since purge gas flow rate is very less, the heat content is also negligible and without employing any dedicated heat exchanger this heat is dissipated to atmosphere through a cooling coil. Heat transfer from coil takes place by both convection and radiation.[6]

2.3.2 Helium-Water Heat Exchanger

The combined purge gas stream coming out of TBM and Detritiation Column is cooled by using Helium water heat exchanger from 80^0C to 35^0C. Since area requirement for heat exchanger is very small; a double pipe heat exchanger (counter current type) is used. This is cooled by water entering at 28^0C. Helium flows in tube side whereas water is placed in shell side.

2.3.3 Dust Filter

Dust filter is used to remove particulate materials in purge gas which might be carried out from solid breeder or liquid breeder. This is a sintered stainless steel filter with particulate filtering of up to 3 micron.

2.3.4 Compressor

This is major component in the HPS which is the driving equipment for the closed loop. The helium gas coming from ITER source is pressurized to fill Storage Tank at required pressure and also maintains required pressure in Source Tank. This is reciprocating compressor which is cooled by water. Compressors are used in 2 x 100% mode i.e. one operating and one standby in full capacity.

2.3.5 Helium Storage and Make-up Tank

Initial charging of helium is done in Helium storage and make up tank, which is maintained at higher pressure compared to system pressure to reduce the storage volume. It also acts as a helium make-up in normal operation of system to compensate helium leakages in the system and inventory required for TMS. This tank is filled by compressor.

2.3.6 Source Tank

The Source Tank is used to maintain required pressure in the loop and acts as source of helium for the flow in loop. The pressure in the tank is inlet pressure required to TBM and DC plus pressure drop across line.

2.3.7 Buffer Tank

The Buffer Tank is used to receive helium coming from all sources like TES, Source Tank, storage and makeup tank etc. Buffer Tank has the function to store helium gas i.e. inventory of helium gas required for detritiation column (liquid breeder) and TBM (solid breeder) and serves as a header for suction of compressors and helps in dampening the fluctuations in the loop[6].

2.3.8 Hydrogen Make-up Unit

Hydrogen is added in the purge gas stream coming out after extraction of tritium using Hydrogen make-up unit. Hydrogen addition in both the loops is carried out with single make-up unit. Hydrogen make-up unit consists of Hydrogen cylinder, digital mass flow controllers and hydrogen sensors. Hydrogen is added in the stream just before the gas mixer so that proper mixing of helium and hydrogen is being done. Hydrogen concentration at downstream of gas mixer is measured using hydrogen sensor. Hydrogen sensor measures the hydrogen concentration and gives signal to control system, so that depending on that signal required quantity of hydrogen flow is maintained through digital mass flow controller.

2.3.9 Test Blanket Module gas mixer

Hydrogen is added in the purge gas. It is required to mix both gases together. For the purpose, static gas mixer is used. Hydrogen is added in the stream just before the gas mixer so that proper mixing of helium and hydrogen is being done. Static gas mixer consists of series of mixing elements.

2.3.10 Heat Tracing

As per process requirement, operating temperature required to be maintained at inlet of TBM is 300^0C. As heat required to rise temperature of purge gas from room temperature to required temperature is very less, electric heat tracing to pipeline is used as heating media. Monitoring of this temperature is done in main control room.

2.3.11 Tritium Monitoring System

Tritium monitoring system is provided at the outlet of TBM to monitor the quantity of tritium formed. It is located in Port Cell, so that tritium can be measured as soon as it comes out of VV. A small tapping from main flow is cooled by using cooling coil and sent to TMS for tritium concentration measurement. Another tritium monitoring system is provided in Port Cell which gives initial tritium concentration before entering into the TBM.

2.4 Major Components of The Purge System in Liquid Breeder Loop

2.4.1 Detritiation Column

In detritiation column, the tritium produced in liquid Pb-Li is carried out by using purge gas. The connection of purge gas is given to the column from Source Tank. The tritium rich purge gas from detritiation unit, after cooling coil, combines with purge gas stream coming out of TBM in port cell for further processing[16].

2.4.2 Detritiation Column Cooling Coil

The hot purge gas stream coming out from DC is cooled from 300^0C to 80^0C by using DC cooling coil. Since the flow through the coil is very less, the heat content is also negligible and without employing any dedicated heat exchanger this heat is dissipated to atmosphere through a cooling coil. Heat transfer from coil takes place by both convection and radiation.

2.4.3 Heat Tracing

As per process requirement, operating temperature required to be maintained at inlet of DC is 300^0C. As heat required to rise temperature of purge gas from room temperature to required temperature is very less, electric heat tracing to pipeline is used as heating media. Monitoring of this temperature is done in main control room.

2.4.4 Detritiation Column Gas Mixer

Hydrogen is added in the purge gas. It is required to mix both gases together. For the purpose static gas mixer is used. Hydrogen is added in the stream just before the gas mixer so that proper mixing of helium and hydrogen is being done. Static gas mixer consists of series of mixing elements.

2.4.5 Tritium Monitoring System

Tritium monitoring system is provided at the outlet of DC to monitor the quantity of tritium formed. It is located in Port Cell, so that tritium can be measured as soon as it comes out of DC. A small tapping from main flow is cooled by using cooling coil and sent to TMS for tritium concentration measurement. Another tritium monitoring system is provided in Port Cell which gives initial tritium concentration before entering to the DC.

2.4.6 Helium Purge System - Associated Piping and Valves

All the equipment to be interconnected by piping and valves are required for different controlling purpose and isolation. Helium being highly diffusive, as far possible flange joints will be avoided and welded joints are used to have leak tightness. Since the piping is having high temperature fluid, proper bends/supports in piping is provided for taking care of thermal expansion. Insulation is provided for conservation of heat energy and personnel protection.

2.4.7 Summary of Literature Survey

The summary of the literature reviewed is presented in Table II.

Table II: Literature survey summary

Author/Publisher	Title	Summary
Document of Institute for Plasma Research	Design Description Document for Indian Lead-Lithium cooled Ceramic Breeder (LLCB) Blanket	Over all description of integrated structure and Details of test blanket module.
Document of Institute for Plasma Research	Helium Purge System Block Diagram	Loop of HPS
Document of Institute for Plasma Research	Design Basis Of Helium Purge System	Operating Parameters of HPS
Document of Institute for Plasma Research	Process Control Philosophy Of Helium Purge System	Ancillary components of HPS , Functions of components and Operating parameters
Information Systems Laboratories, Rockville, Idaho Client:-Division of Systems Research Office of Nuclear Regulatory Research U. S. Nuclear Regulatory Commission Washington.	RELAP5/MOD3.3 CODE MANUAL VOLUME 5 USERS GUIDELINES	RELAP5 modeling, details for various components like Pipe, , Heat structure etc.

Information Systems Laboratories ,Rockville, Idaho Client:-Division of Systems Research Office of Nuclear Regulatory Research U. S. Nuclear Regulatory Commission Washington, DC.	Input deck manual RELAP5	Input codes for transient analysis. Input code for each and every structure, Major and minor input codes.
Vilas Chaudhari, Chandan Danani, Paritosh Chaudhuri, R. Srinivasan, E. Rajendra Kumar, S.P. Deshpande,*Fusion Engineering Design* 85 (2010) 19661969.	Current status of design and engineering analysis of Indian LLCB TBM	LLCB TBM design; Optimize the flow & parameter. Temperature variation in FW in Ceramic breeder.
E. Rajendra Kumara, T. Jayakumarb, A.K. Suric, *Fusion Engineering and Design*87 (2012) 461465	Overview of TBM R&D activities in India	Liquid breeder flow type and effect on pressure drop.
C.A. Chen, D.L. Luo, Y. Sun, Z.Y. Huang, Y.F. Xiong, *Fusion Engineering and Design* 83 (2008) 14551460	Tritium safety consideration in the design of tritium systems for China HCSB and DFLL TBMs	Permeation of tritium from HPS Tritium measurement system.
V. Chaudhari,E. Rajendra Kumar, C. Danani, I.Sandeep, Ch.Chakrapani,N. Ravi Pragash, C. Rotti, P.M. Raole,, J. Alphonsa, S.P. Deshpande *Fusion Engineering and Design* 83 (2008) 11691172	Preliminary design of Indian Test Blanket Module for ITER	Test blanket concepts for testing in ITER. Tritium production rate and extraction.
V.A Chuyanov,S.C Kin, L.M Giancarli *Fusion Engineering design*(2008)817-823	The integration of TBM systems in ITER	Port cell interface Tokamak cooling water system interface.

Chapter 3

Helium Purge System Description

3.1 Helium Purge System

The helium purge system (HPS) is one of the major systems of LLCB TBM systems. Its function is to extract the helium produced in solid ceramic breeder as well as in the liquid pb-li loop (detritiation column). The helium purge gas is low pressure and low flow system in order to sweep tritium from the pebbles through isotopic exchange reactions.

3.2 System Description

As per ITER operational philosophy , it will operate various phases like D-T, D-H etc. In D-T plasma phase ; tritium will be produced in the ceramic breeder zones. As tritium is used for plasma reaction , it has to be separated. For this purpose , helium with 0.1% hydrogen is used as purge gas. Because of isotopic exchange between hydrogen and tritium produced in the ceramic breeder and goes to tritium extraction system to separate it from purge gas. As tritium is produced in pb-li also, in the detritiation column separate purge gas stream is passed to remove it. In the view of the process requirement , some major components identified are given in Table I.[4]

Detailed description of system is as follows:

Table I: Components of HPS[4]

Component	Redundancy required	quantities in No.
TBM cooling coil	No	1
Dc cooling coil	No	1
He-water heat exchanger	No	1
Filter	No	1
Gas mixer	No	2
Helium storage and make up tank	No	1
Buffer Tank	No	1
Source tank	No	1
Compressor	yes	2
Hydrogen Cylinder	No	1
Associated pipe works and valves	No	As per requirement

3.2.1 Charging of Helium Purge Gas

In this phase, we will see initial charging of helium gas in to the system. Helium is stored in the helium storage and make up tank at high pressure taking supply from ITER by using compressor. Helium is then charged buffer tank at required pressure. Pressure reducing valve is provided in the line so that helium will be supplied at required pressure. Initial charging of source tank is done from buffer tank. One bypass line is provided for the same. From source tank whole loop is charged. As per process requirement , for both solid breeder stream and liquid breeder stream, required hydrogen concentration may differ therefore two separate purge gas loop are used[4].

3.2.2 Pressurization of Purge Gas

At inlet of TBM and DC, 0.13 MPa (abs) pressure of purge gas is maintained. Compressor is used to pressurise the purge gas. Source tank is used to maintain required pressure in the loops. So a bypass between two tank is provided through PRV, which is set at 0.3 MPa pressure. This is the same compressor which is used for charging helium storage tank. Source tank will work as header for solid breeder loop and liquid breeder loop.

3.2.3 Pressure and Flow Maintenance

Purge gas pressure at inlet of TBM and detritiation column is maintained by pressure regulators. Considering pressure drop in equipments, piping and components , valves in TBM set pressure range is given to pressure regulators. Required flow rate in TBM and DC is maintained by digital mass flow controllers.

3.2.4 Cooling of Purge Gas

Cooling gas outlet temperature AEU area is restricted to 35^0C. Hot helium purge system Coming out from TBM and DC is cooled by using separate cooling coils to 80^0C and by combining both streams ; it further cooled to 35^0C by using helium water heat exchanger.

3.2.5 Impurity Removal

Tritium extraction system itself acts as impurity removal system. So there is no requirement for separate purification system for HPS. Initially , to build up tritium concentration in purge gas , bypass line is provided to TES.

3.3 Process Parameters for Helium Purge System

- Inlet temperature and pressure of TBM and DC should be 300^0C and 0.13 MPa (abs).

- The purge gas mass flow rate in the solid breeder loop through TBM is 1.9 Nm^3/hr (0.094 g/sec)and in DC is 2.8 Nm^3/hr (0.139 g/sec).

The typical parameters of the helium purge gas are listed in table II .

Table II: Process parameters of HPS[4]

Description	value for normal operation	Value or range for design
Temprature at TBM inlet	300^0C	$RT/300^0C$
Temprature at TBM outlet	500^0C	$RT/525^0C$
Pressure at TBM inlet	0.13 Mpa	0.1-0.2 MPa
TBM steam flow rate	$1.9\frac{Nm^3}{hr}$	$1-2\frac{Nm^3}{hr}$
Temperature at DC inlet	300^0C	$RT/300^0C$
Temperature at DC outlet	300^0C	$300-525^0C$
pressure at DC inlet	0.13 Mpa	0.1-0.2 MPa
DC steam flow rate	$2.8\frac{Nm^3}{hr}$	$1.5-3\frac{Nm^3}{hr}$

3.4 Process Control Philosophy of Helium Purge System

It deals with the methodology of controlling the key parameters , defining execution of the necessary actions considering the process requirement, operational and safety philosophy.

The main controlling parameters of loop are as described:

3.4.1 Pressure Control

The helium gas system is a closed loop low pressure system. Inlet pressure for TBM and DC is 0.13 MPa. The compressor is used to develop pressure in the system. Inlet pressure of TBM is maintained by pressure regulator at the downstream of gas mixer located at Tritium building[4].

3.4.2 Flow Control

To control flow of HPS , digital mass flow controller is used at downstream of gas mixer. Required pressure is build by using compressor. Required flow rate is given as at set point to digital mass flow controller[7].

Flow condition for HPS are given in Table III:

Table III: HPS Flow condition[7]

Flow Condition	Value, g/sec
Purge gas TBM mass flow rate	0.094
Purge gas detritiation mass flow rate	0.139

3.4.3 Temperature Control

The temperature at the inlet of TBM and DC is maintained by using electric heat tracing. As heat required is low, heat tracing is sufficient to maintain required inlet temperature of purge gas. So any additional heat source may not be required. similarly required inlet temperature of DC is maintained by electric heat tracing.

Outlet temperature of helium from AEU to Tritium building will be restricted to room temperature. To achieve this the first temperature of helium coming out of VV or DC will be reduced by using cooling coils and then further will be reduced to RT by using helium water heat exchanger. Helium outlet temperature of Helium-Water heat exchanger will be maintained by the flow of cooling water[7].
Operating temperature required is given in table IV:

Table IV: Temperature requirement[4]

	Temperature
At TBM inlet	300^0C
At detritiation column inlet	300^0C

3.5 Equipment for HPS

Details of equipment used in HPS loop are given below in table V:

Table V: Equipment of HPS[7]

Equipment No.	equipment name	Description
03GSL-TK-3002	Helium storage and make up tank	helium storage for initial start up and make up
03GSL-C-3001	Compressor	Filling of helium gas in storage tank
03GSL-TK-3001	Buffer tank	Takes care for pressure flluctuation and temporary cushioning of flow fluctuation
03GSL-TK-3003	source tank	maintain purge gas pressure to 0.3 Mpa
03GSL-CLC-3002	TBM cooling coil	cooling for TBM purge gas steam
03GSH-CYL-3001	Hydrogen cylinder	Hydrogen addition in purge gas
03GSL-FLT-3001	Filter	To remove purge particles in purge gas
03GSL-CLC-3003	TB cooling coil	Cooling for combined purge gas stream
03GSL-TRP-3002	Pb-Li vapor trap	Trapping of Li vapor from pure gas stream
03GSL-TRP-3002	Hg vapor trap	Trapping of Hg vapor from pure gas stream
03GSL-CLC-3002	DC cooling coil	Cooling for DC purge gas stream in tritium building
03GSL-MIX-3001	TB gas mixer	To mix helium and hydrogen
03GSL-MIX-3001	DC gas mixer	To mix helium and hydrogen

Chapter 4

Thermal-Hydraulic Analysis of Helium Purge System

The RELAP5 hydrodynamic model is a one-dimensional, transient, two-fluid model for flow of a two-phase steam-water mixture that can contain non-condensable components in the steam phase and a soluble component in the water phase. The RELAP5 hydrodynamic model contains several options for invoking simpler hydrodynamic models. These include homogeneous flow, thermal equilibrium, and frictionless flow models. These options can be used independently or in combination. The homogeneous and equilibrium models were included primarily to be able to compare code results with calculations from the older codes based on the homogeneous equilibrium model.

- Neglects fluid velocity and shear force effects that are external to the flow path.
- Assumes a one-dimensional uniform cross-sectional area control volume.
- Approximates the normal stress by the quasi-steady change in the momentum.
- Represents uniformly the fluid velocity, density, and pressure over the local cross-sectional area and the shear over the local control-volume surface area.

Flow chart of modelling in RELAP5 is given below. Once the analyst has decided

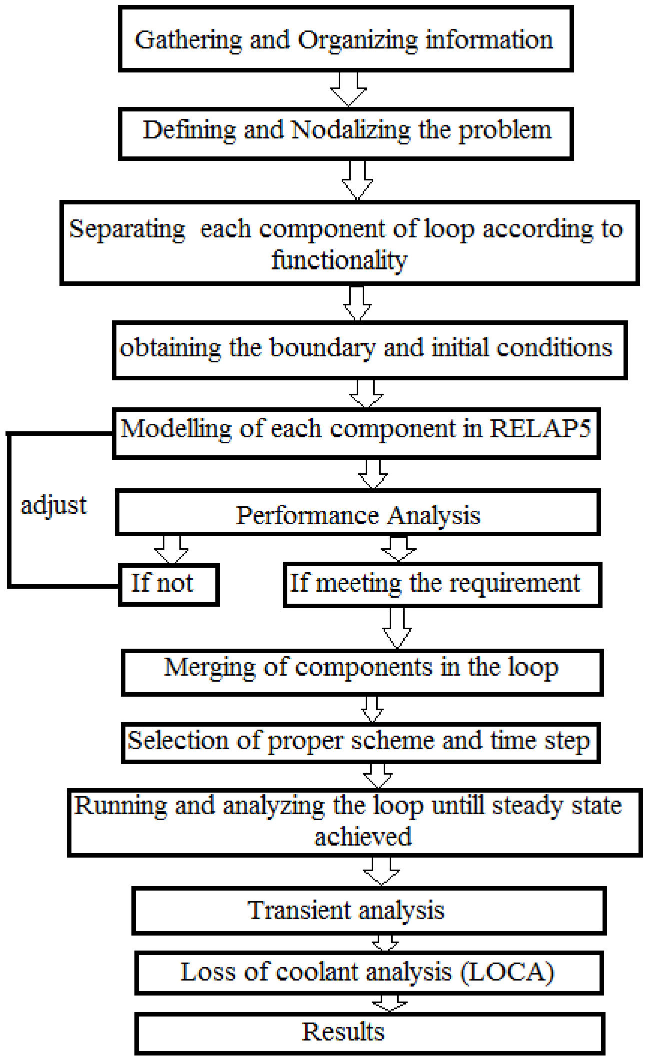

Figure 4.1: Flow chart of modelling in RELAP5.

to use RELAP5 to analyze a problem, obtaining the problem solution consists of the following stages[15]:

- Gathering and organizing information that defines the initial and boundary conditions. All the available information must be divided into two categories: pertinent and non-pertinent. Missing information must then be obtained from sources such as vendors, utilities, or consultants to provide the complete spectrum of needs for the code. A problem description and solution notebook is started to document the problem solution and chronology of the work.

- Defining and nodalizing the problem. The code input nodalization should be defined so the most complete information set concerning the questions that motivated the study will be available. The solution approach, assumptions, and final model nodalization are recorded in the problem description and solution notebook. This stage also includes the formation of a design review committee to conduct reviews of the model nodalization and the analysis approach.

- Inputting the problem. The initial and boundary conditions are placed in a computer file. The model is then initialized to secure the desired starting point for the problem investigation and the proper boundary conditions. The experience is recorded in the problem description and solution notebook.

- Quality-assuring the model. An independent review is performed of the input and the problem description and solution notebook. This review verifies that information sources are documented, derived quantities accurately calculated, and modeling assumptions are valid.

- Running the code and analyzing the problem. The code is run until completed, and the solution is analyzed. All analysis procedures, findings, and observations are recorded in the problem description and solution notebook.

4.1 Hydrodynamic Modelling of Helium Purge System Components and Piping

The Hydrodynamic model and associated numerical scheme are based on the use of the fluid control volumes and junctions to represent the spatial character of the flow. The control volumes can be viewed as stream tubes having inlet and outlet junction. The control volume has a direction associated with it that is positive from inlet to outlet velocities are located at the junction and are associated with mass and energy flow between control volume. Control volumes are connected in series, using junction to represent a flow path. The Nodalization of HPS is given in the fig.4.2.

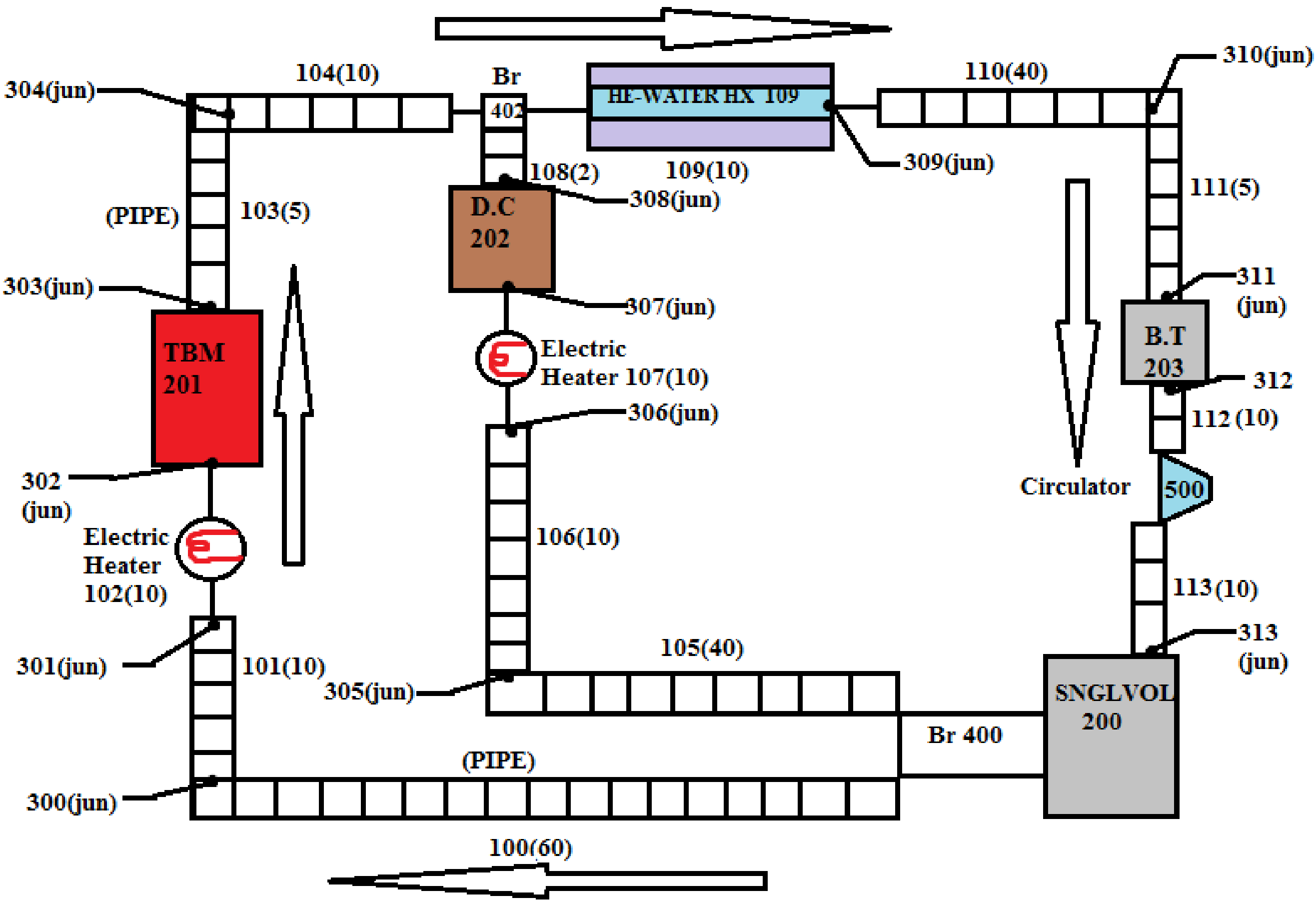

Figure 4.2: Nodalization diagram for HPS

4.1.1 Test Blanket Module Hydrodynamic Model

There are numerous channels , branches , sub channels, bends , transitions , orifices etc. Hence, for RELAP5 analysis the components must be strongly simplified and groups of channels and sub channels have to be lumped together to give manageable numbers of components. Likewise TBM is considered as single volume component as 201 having definite volume. These model are equivalent to real component in terms of mass , power, hydraulic performance and mass distribution.

4.1.2 Piping Hydrodynamic Model

The architecture of the pipe work of the helium cooling system is determined by the space allocation given by the ITER team. All together the piping has a total length of about 199 m (92 m for the cold leg and 93 m for the hot leg, and 14 m between HPS components). An inner diameter have been chosen for all pipes, except for some short sections between components which have bigger diameter.The pipe dimension are shown in table I.

pipes are generally modelled as RELAP5 pipe components consisting of several vol-

Table I: Table for pipe dimensions[6]

Pipe no	ID of pipe mm	pipe length m	No of bends	no of valves
30052EEA1HC	15.8	3.3646	3	0
30001ESA1PP	15.8	46.9437	11	0
30002ESA1PP	15.8	3.4749	1	1
30005ESA1	15.8	2.1649	1	1
300003BSA1PP	15.8	3.0949	1	1
30004BSA1	15.8	55.95	2	0
300006BSA1CP	15.8	4.824	5	1
30007BSA1	15.8	40.4069	1	1
30012BSA1	15.8	0.4079	1	1
30014BSA1	15.8	55.95	2	0
30021BSA1	26.64	1.0639	1	0
30023BSA1	15.8	5.4244	5	1

umes junctions between volumes have been placed at all pipe bends . In RELAP5 all pipe bends cannot be modelled because even a micro gap in closing the loop will create an obstacle in running the program so instead of considering all bends in loop the junction loss coefficient is given to compensate the effect of all 90 degree bends. Junction loss coefficient for various pipes is given in the table II and friction factor f_T for all pipe is chosen from table III.

Table II: Standard junction loss coefficient for 90^0 bends [13]

r/d	k	r/d	k
1	20 f_T	8	24 f_T
1.5	14 f_T	10	30 f_T
2	12 f_T	12	34 f_T
3	12 f_T	14	38 f_T
4	14 f_T	16	42 f_T
6	17 f_T	20	50 f_T

Table III: Pipe friction data for clean commercial SS316L [13]

Nominal size (inch)	Friction factor (f_T)
1/2	0.027
3/4	0.025
1	0.023
5/4	0.022
3/2	0.021
2	0.019
5/2 , 3	0.018
4	0.017
5	0.016
6	0.015
8-10	0.014
12-16	0.013
18-24	0.012

4.1.3 Detritiation Column Hydrodynamic Model

In detritiation column, the tritium produced in liquid Pb-Li is carried out by using purge gas. In RELAP5 detritiation column is modelled as single volume as component 202 having mass flow rate of 0.139 g/sec. There is no heat generated in detritiation column.

4.1.4 Buffer Tank Hydrodynamic Model

The Buffer Tank is used to receive helium coming from all sources like TES, Source Tank, storage and makeup tank etc. Buffer Tank has the function to store helium gas i.e. inventory of helium gas required for detritiation column (liquid breeder) and TBM (solid breeder) and serves as a header for suction of compressors and helps in dampening the fluctuations in the loop. In RELAP5 modelling of buffer Tank it is modelled as single volume component No. 203 having pressure of about 1.1 bar.

4.1.5 Circulator Hydrodynamic Model

The helium circulator is identified by a RELAP5 pump component(500). The hydrodynamic model consists of one volume and two associated junctions. Suction of circulator is connected to pipe 112 and the discharge goes into 113. A trip is provided for circulator which cut-off the power of supply when pressure of buffer tank exceeds 0.3 MPa.

4.1.6 Electric Heater Hydrodynamic Model

Two electric heaters in helium purge system has been used, one is for maintaining TBM inlet temperature and other is for detritiation column. TBM electric heater is component 102 divided into 10 volumes and DC heater is component No.107 divided in 10 volumes.

4.2 Double Pipe Heat Exchanger Hydraulic Model

The Helium water heat exchanger is modelled as counter flow heat exchanger in RELAP5. Hot fliud Helium flows inside of the tube and cold fliud water flows annulus side.

4.2.1 Tube Side- Helium

- In the preliminary design the tubes are connected to two time dependent volume(TMDPVOL) on either side of tube and simulated till the desired temper-

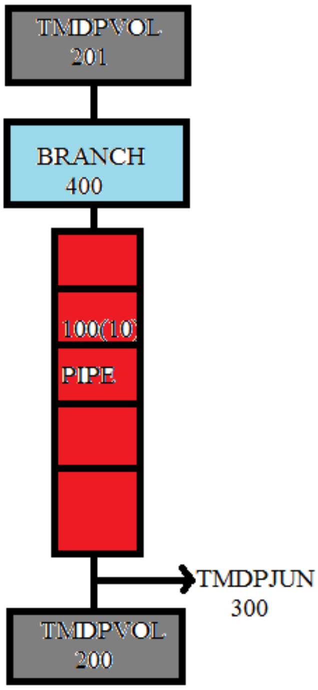

Figure 4.3: Nodalization diagram for Heater

ature is achieved thus it has been inserted in the main loop .

- A source and sink is connected to tube side for continuous flow of helium inlet to 1.2 bar, 573 K and outlet to 1.15 bar and 298 K.
- Helium side pipe is connected to two time dependent volume (TMDPVOL) one is acting as source component No. as 205 and other TMDPVOL is acting as sink component No. as 206.
- Hydraulic and equivalent diameter of helium side tube is 0.0158 m.
- Mass flow rate of helium side = 0.233 gm/sec

4.2.2 Annulus Side- Water

- A source and sink is connected to annulus side for continuous flow of water inlet to 12 bar, 288 K and outlet to 11.92 bar and 293 K.
- Water side pipe is connected to two time dependent volume (TMDPVOL) one

is acting as source component No. as 207 and other TMDPVOL is acting as sink component No. as 208.

- Hydraulic and equivalent diameter of Water side tube is 0.00996 m and 0.02456 m respectively.
- Mass flow rate of water = 0.01472 kg/sec

Nodalization Diagram for HX of HPS is Given Below:

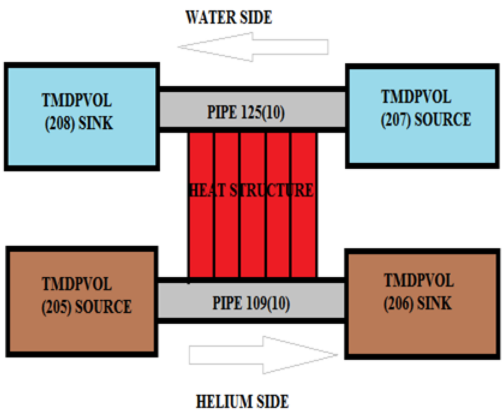

Figure 4.4: Nodalization diagram for Heat exchanger

4.3 Additional Components for Transient Analysis

For accident analysis of helium purge system additional components are attached to the model of helium purge system. There is a single volume attached for analysis as component No.600 and a trip valve 700. A pipe component 800 is also attached for checking the mass flow rate at the junction.

4.4 Heat Structure of HPS

Heat structures provided in RELAP5 permit calculation of the heat transferred across solid boundaries of hydrodynamic volumes. Modeling capabilities of heat structures are general and include fuel pins or plates with nuclear or electrical heating, heat

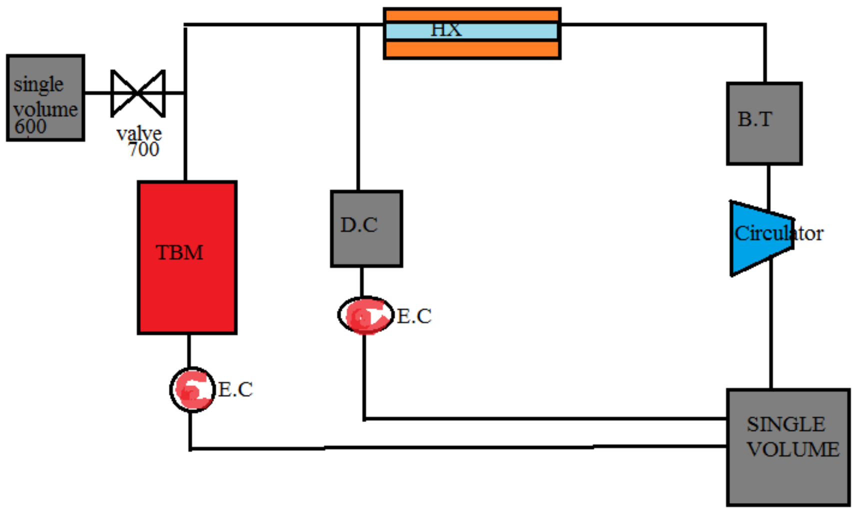

Figure 4.5: LOCA analysis nodalization in RELAP5

transfer across steam generator tubes, and heat transfer from pipe and vessel walls. Heat structures are assumed to be represented by one-dimensional heat conduction in rectangular, cylindrical, or spherical geometry. Surface multipliers are used to convert the unit surface of the one-dimensional calculation to the actual surface of the heat structure. Temperature dependent thermal conductivities and volumetric heat capacities are provided in tabular or functional form either from built-in or user-supplied data.

4.4.1 Electric Heater Heat Structure

For Detritiation column electric heater the heat input required is 198.387 W. 199 W Heater is applied. The heater is divided into 10 parts which is connected to flow , power of each heat structure is 199/10 which is equal to 19.9 W.
Where as for TBM electric heater heat input given is 134.16 W. Thus 134.16 W Heater is applied. The heater is divided into 10 parts which is connected to flow . Power of each heat structure is 134.16/10 which is equal to 13.416 W.

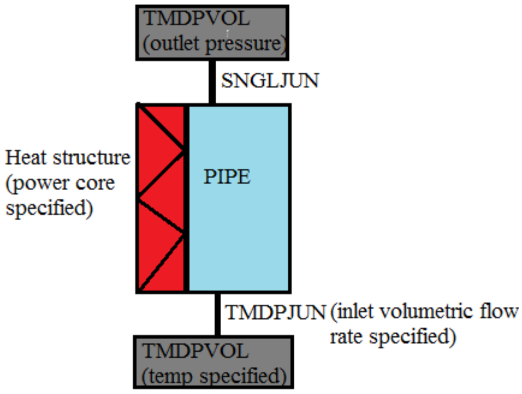

Figure 4.6: Nodalization of electric heater heat structure

4.4.2 Heat Exchanger Heat structure

In heat structure of heat exchanger cold fluid is flowing on annulus which get heat from hot fluid (tube side). Total resistance of heat transfer comprises of convective resistance due to flow of water, conduction resistance offer by tubes of incoloy steel and convective resistance of helium.

4.5 Heat Structure Thermal Property Data

The material data are entered with cards of the type 201mmmnn, where the sub-field mmm is the composition identification. Besides this, the code needs the thermal conductivity and the volumetric heat capacity and density. These quantities need to be entered as function of temperature, either in forms of table or as equations below table is given showing heat structure material overview.

Table IV: Heat structure material overview

Material name	Application
AISI 316L	Piping and components
INCOLOY 800	Heat exchanger tubes
MANET(EUROFER)	TBM structure

Chapter 5

Results

5.1 Transient-State Analysis

After running the loop for steady state. Accident analysis of the HPS is carried out. A Trip valve component 700 , Test cell modelled as single volume component No. 600 and a pipe component 800 have been attached for accident analysis. Transient state analysis for various three cases results are given below when LOCA happens in HPS loop.

5.1.1 Case -I Single Volume Attached Above TBM

The pipe component 103 above TBM is attached with a Test cell modelled as single volume (600) through pipe component 800 to the third volume of component 103 . The single volume is of $20m^3$ volume. The initial pressure of single volume is 0.1 bar. The below graphs shows the pressure, temperature and mass flow rate of the single volume during accident happens.

In fig 5.1 When LOCA happens in the port cell area, pressurization of test cell occurs until the loop reaches to steady state.

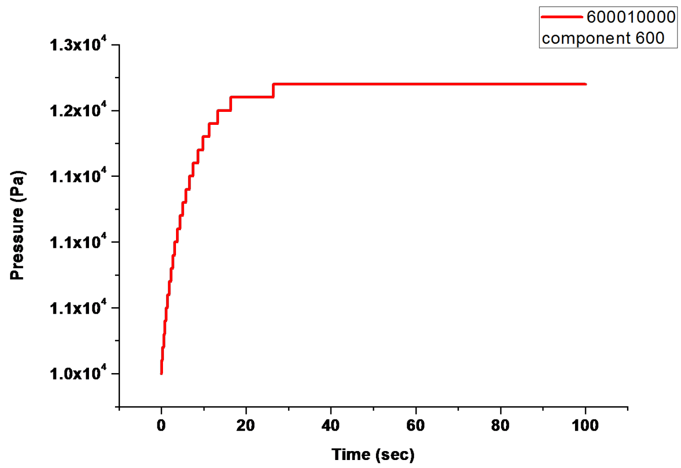

Figure 5.1: Pressure of Test Cell 600 above TBM during LOCA

The graph 5.2 shows the test cell temperature with TBM helium coolant leak included as a function of time when LOCA happens in port cell. There is a evolution of temperature, it increases and then achieves steady state.

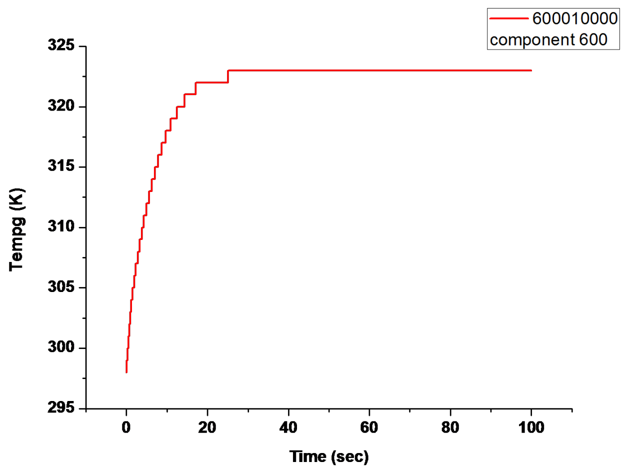

Figure 5.2: Temperature of Test Cell 600 above TBM during LOCA

In fig 5.3. when LOCA happens in port cell the mass flow rate of pipe 800 suddenly increases and finally comes to zero.

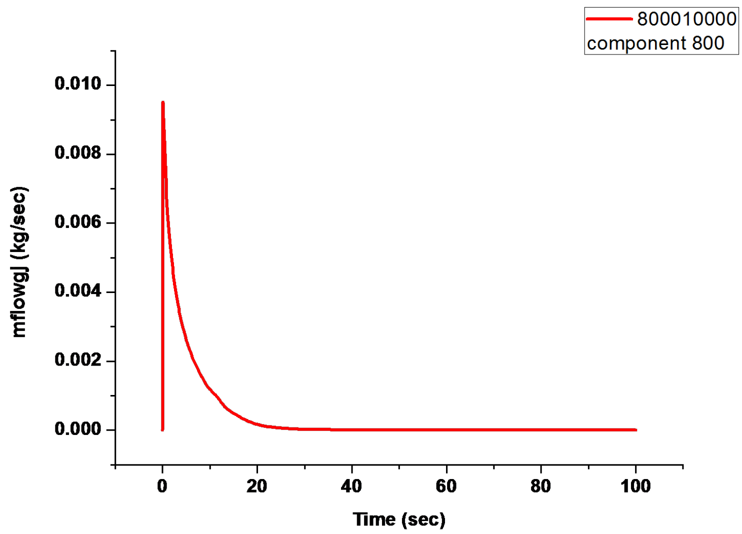

Figure 5.3: Mass flow rate of component 800 above TBM during LOCA

5.1.2 Case-II Test Cell Attached above D.C

The pipe component 108 above DC is attached with a Test cell modelled as single volume (600) through pipe component 800 to the first volume of component 108 . The single volume is of $20m^3$ volume. The initial pressure of single volume is 0.1 bar. The below graphs shows the pressure, temperature and mass flow rate of the Test cell when LOCA happens.

In fig 5.4 shows the increase in pressure of the test cell, when LOCA happens in port cell .

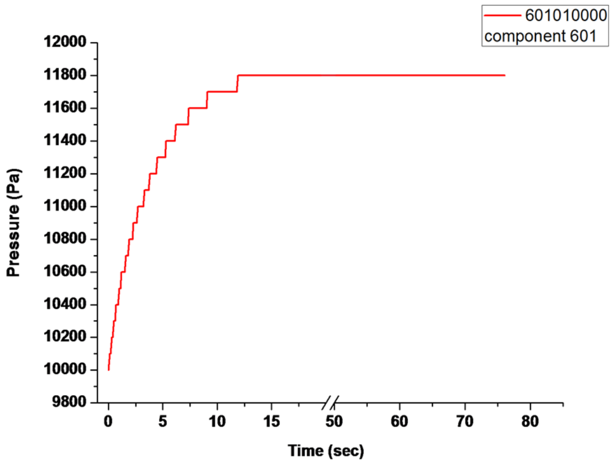

Figure 5.4: Pressure of Test Cell 600 above D.C during LOCA

In fig 5.5 when LOCA happens in port cell there is a temperature evolution in test cell which was initially at a temperature of 298K and then achieves steady state.

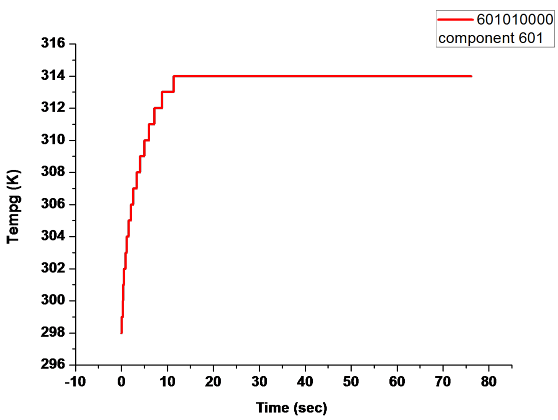

Figure 5.5: Temperature of Test Cell 600 above D.C during LOCA

In fig 5.6 when LOCA happens in mass flow rate of pipe 800 there is a sudden increase and decrease in the mass flow rate of pipe.

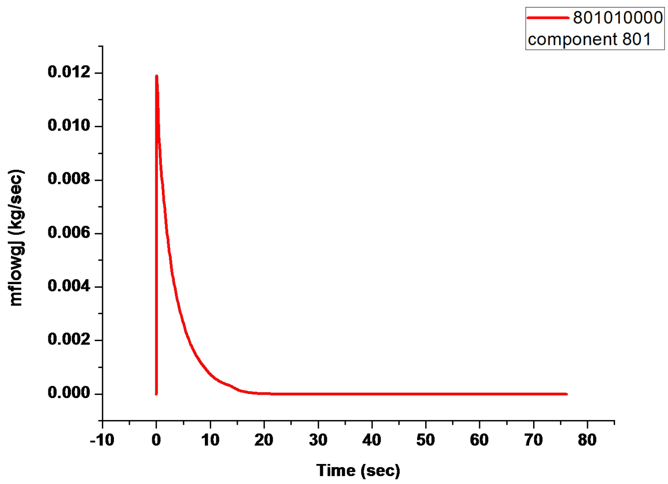

Figure 5.6: Mass flow rate of component 800 above D.C during LOCA

5.1.3 Case-III Test Cell Attached After HX

The pipe component 110 after HX is attached with a Test cell modelled as single volume (600) through pipe component 800 to the 38 volume of component 110. The single volume is of $20m^3$ volume. The initial pressure of single volume is 0.1 bar. The below graphs shows the pressure, temperature and mass flow rate of the Test cell when LOCA happens.

In fig 5.7 When LOCA occurs in Tritium building there is a increase in pressure of test cell and after some time achieves steady state .

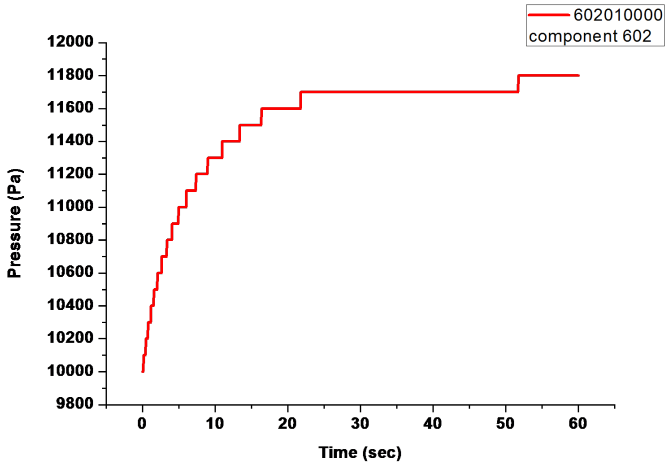

Figure 5.7: Pressure of Test Cell after HX during LOCA

In fig 5.8 there is a increase in the temperature of test cell when LOCA happens in Tritium building and then comes to steady state.

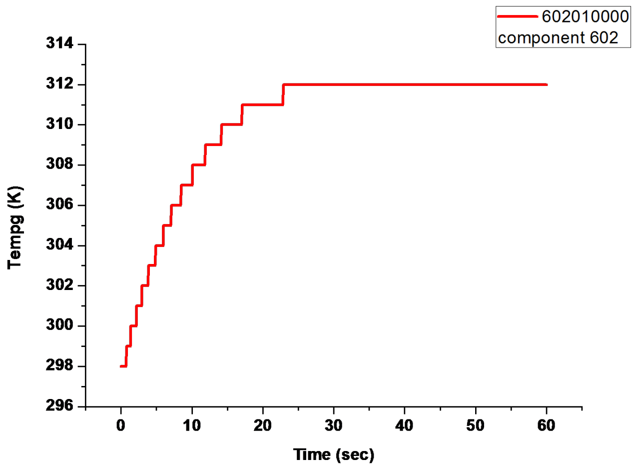

Figure 5.8: Temperature of Test Cell after HX during LOCA

In fig 5.9 when LOCA happens in Tritium building, mass flow rate at pipe junction drastically increases. As the loop reaches to steady state it comes to zero.

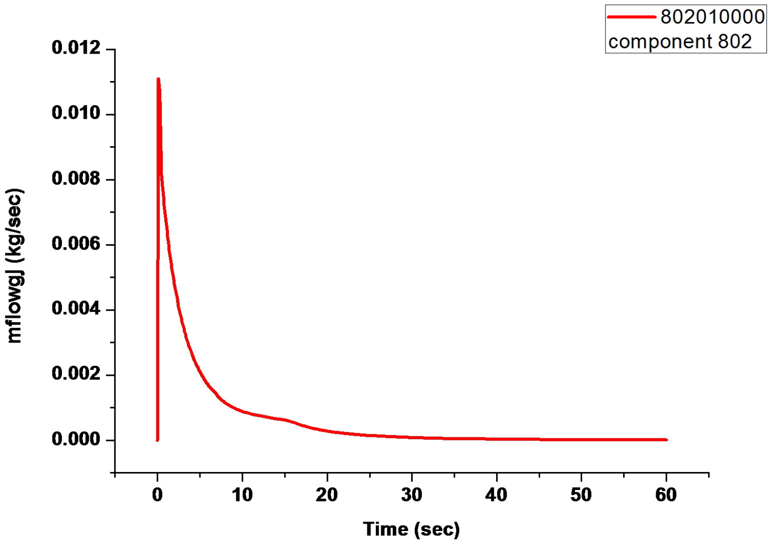

Figure 5.9: Mass flow rate of component 800 after HX during LOCA

Chapter 6

Conclusions and Future Scope

6.1 Conclusions

Based on the work done following conclusions are drawn:

- Accident analysis on the helium purge system was performed for three LOCA cases. To simulate transient thermo-hydraulic behavior of the TBM for the selected scenarios, the helium passage including the TBM and HPS was modeled.

- LOCA leads to the pressurization of Test cell which was under the design pressure of HPS loop.

- LOCA causes the temperature evolution in TBM but it was under the design limit of ITER.

- The mass flow rate of helium was under control during LOCA.

Based on the results of RELAP5 programming it was found that the HPS loop is designed properly for accident scenarios and fulfills the safety requirements of ITER.

6.2 Future Scope of Work

For the first time an Accident Analysis of HPS examined using RELAP5 . Since ITER is in trail phase, If any further changes occurs in this particular loop then by creating some changes in the input file the thermal-hydraulic analysis of HPS can be analysed.

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Appendix A

Fluid Properties Table

Isobaric property table for Helium and Water is given below:

Temperature (K)	Density $(kg/(m^3))$	Specific Heat $Cp(J/(g*K))$	Viscosity $(Pa*s)$	Thermal Cond. $(W/(m*K))$
330	10.86	5.18	$2.15*e^{-5}$	0.171
350	10.26	5.187	$2.23*e^{-5}$	0.178
370	9.722	5.186	$2.32*e^{-5}$	0.184
390	9.2383	5.1867	$2.40*e^{-5}$	0.191
410	8.800	5.186	$2.48*e^{-5}$	0.198
430	8.401	5.1866	$2.57*e^{-5}$	0.204
450	8.037	5.1866	$2.63*e^{-5}$	0.210
470	7.703	5.1867	$2.73*e^{-5}$	0.217
490	7.396	5.1868	$2.81*e^{-5}$	0.223
510	7.112	5.1869	$2.89*e^{-5}$	0.229
530	6.850	5.1870	$2.96*e^{-5}$	0.235
550	6.606	5.1871	$3.04*e^{-5}$	0.241
570	6.378	5.1872	$3.12*e^{-5}$	0.247
590	6.166	5.1875	$3.19*e^{-5}$	0.253
610	5.967	5.1875	$3.27*e^{-5}$	0.259

Table I: Property Table For Helium

Temperature (K)	Density $(kg/(m^3))$	Specific Heat $Cp(J/(g*K))$	Viscosity $(Pa*s)$	Thermal Cond. $(W/(m*K))$
310	993.76	4.1771	$69*e^{-5}$	0.62647
330	985.16	4.1818	$48*e^{-5}$	0.65162
350	974.11	4.1926	$36*e^{-5}$	0.668
370	960.99	4.2102	$29*e^{-5}$	0.678
390	946.00	4.2365	$23*e^{-5}$	.683
410	929.25	4.2738	$20*e^{-5}$	.683

Table II: Property Table For Water

Appendix B

RELAP5 Input Deck

B.0.1 Flow Chart for Analysis

The flow chart for modelling a loop in RELAP5 is given below:

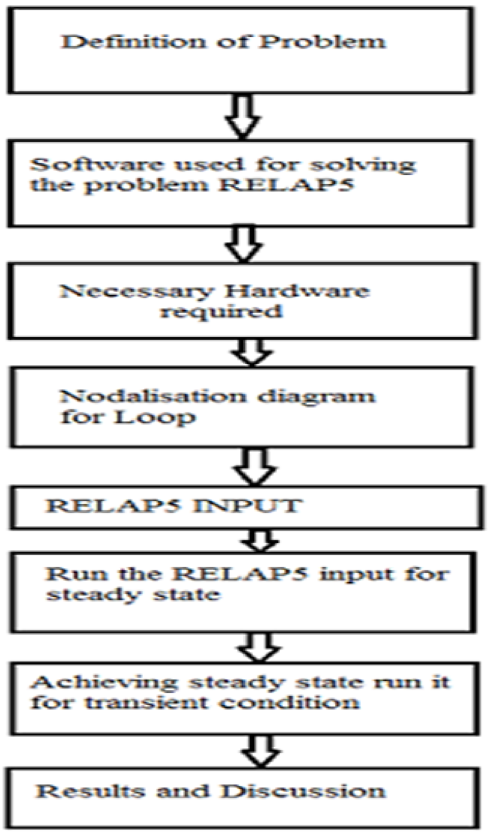

Figure B.1: Flow chart for Analysis

Component	Label	Primary uses
Pipe Or Annulus	Pipe	Represents a pipe in the system. PIPE can have 1 to 100 sub volumes.
Branch	Branch	Represents a stream-tube flow juncture that can have as many as 10 junctions defined.
Single-junction	SNGLJUN	Designed to connect one component to another.
Time-dependent Volume	TMDPVOL	Specifies boundary conditions on system model.
Heat Structure		Various type of heat exchangers
Valve	VALVE	Simulates six different valve types: check, trip, inertial, motor servo, and relief.
Pump	PUMP	Simulates the actions and presence of a centrifugal pump.
Steady state	stdy-st	
Transient	transt	
Time dependent junction	TMDPJUN	

Table I: Syntax for RELAP5 Coding

B.1 RELAP5 Input Deck

B.1.1 Input Deck for Nodalisation Diagram of Simple Loop

**** simple loop

*** simple loop

100 new transnt

110 helium

201 100.0 1.0e-12 0.1 3 1 1 1000

* trip

501 time 0 ge null 0 0.0 l

```
502 time 0 ge null 0 0.0 l
**source tank
2000000 so.TK snglvol
2000101 0.0314 0.8 0.0 0.0 -90.0 -0.8 1.6e-6 0.0 0011000
2000200 104 3.0e5 298.0 0.0
*branch connecting so.TK,100 and 104
4000000 branch1 branch
4000001 3 1
4000101 1.96e-4 0.5 0.0 180.0 0.0 0.0 1.6e-6 0.0 0011000
4000200 104 1.3e5 298.0 0.0
4001101 200010000 400000000 0.0 0.0 0.0 0001100
4001201 0.0 0.0 0.0
4002101 400010000 100000000 0.0 0.0 0.0 0001100
4002201 0.0 0.0 0.0
4003101 400010000 105000000 0.0 0.0 0.0 0001100
4003201 0.0 0.0 0.0
**** part one to TBM
1000000 pipe1 pipe
1000001 60
1000101 1.96e-4 60
1000301 1.0 60
1000501 180.0 60
1000601 0.0 60
1000801 1.6e-6 0.0 60
1001001 0011000 60
1001101 0001100 59
1001201 104 1.3e5 298.0 0.0 0.0 0.0 60
1001300 1
1001301 0.0 0.0 0.0 59
** junction b/w 100 and 101
3000000 sngljun1 sngljun
3000101 100010000 101000000 0.0 0.0 0.0 0001100
```

```
3000201 1 0.0 0.0 0.0
** pipe 101 goes to heat tracing
1010000 pipe2 pipe
1010001 10
1010101 1.96e-4 10
1010301 0.92 10
1010601 90.0 10
1010801 1.6e-6 0.0 10
1011001 0011000 10
1011101 0001100 9
1011201 104 1.3e5 298.0 0.0 0.0 0.0 10
1011300 1
1011301 0.0 0.0 0.0 9
**junction b/w 101 and 102
3010000 sngl2 sngljun
3010101 101010000 102000000 0.0 0.0 0.0 0001100
3010201 1 0.0 0.0 0.0
**heat tracing pipe
1020000 pipe3 pipe
1020001 10
1020101 1.96e-4 10
1020301 0.08 10
1020601 90.0 10
1020801 1.6e-6 0.0 10
1021001 0011000 10
1021101 0001100 9
1021201 104 1.3e5 298.0 0.0 0.0 0.0 10
1021300 1
1021301 0.0 0.0 0.0 9
***junctionb/w 102 and TBM
3020000 sngljun3 sngljun
3020101 102010000 201000000 0.0 0.0 0.0 0001100
```

3020201 1 0.0 0.0 0.0

**TBM

2010000 TBM snglvol

2010101 0.0314 1.5 0.0 0.0 90.0 1.5 1.6e-6 0.0 0011000

2010200 104 1.3e5 573.0 0.0

*junction b/w TBM and 103

3030000 sngljun4 sngljun

3030101 201010000 103000000 0.0 0.0 0.0 0001100

3030201 1 0.0 0.0 0.0

*pipe 103 coming from TBM

1030000 pipe4 pipe

1030001 5

1030101 1.96e-4 5

1030301 1.524 5

1030601 90.0 5

1030801 1.6e-6 0.0 5

1031001 0011000 5

1031101 0001100 4

1031201 104 1.3e5 573.0 0.0 0.0 0.0 5

1031300 1

1031301 0.0 0.0 0.0 4

**junction b/w 103 and 104

3040000 sngljun5 sngljun

3040101 103010000 104000000 0.0 0.0 0.0 0001100

3040201 1 0.0 0.0 0.0

**pipe 104 goes to mixing branch

1040000 pipe5 pipe

1040001 10

1040101 1.96e-4 10

1040301 1.65 10

1040601 0.0 10

1040801 1.6e-6 0.0 10

1041001 0011000 10

1041101 0001100 9

1041201 104 1.3e5 573.0 0.0 0.0 0.0 10

1041300 1

1041301 0.0 0.0 0.0 9

** part 2 source tank to D.C.

1050000 pipe6 pipe

1050001 40

1050101 1.96e-4 40

1050301 1.0875 40

1050501 180.0 40

1050601 0.0 40

1050801 1.6e-6 0.0 40

1051001 0011000 40

1051101 0001100 39

1051201 104 1.3e5 298.0 0.0 0.0 0.0 40

1051300 1

1051301 0.0 0.0 0.0 39

**junctionb/w 105 and 106

3050000 sngljun6 sngljun

3050101 105010000 106000000 0.0 0.0 0.0 0001100

3050201 1 0.0 0.0 0.0

**pipe 106 goes to heat tracing

1060000 pipe7 pipe

1060001 10

1060101 1.96e-4 10

1060301 1.4 10

1060601 90.0 10

1060801 1.6e-6 0.0 10

1061001 0011000 10

1061101 0001100 9

1061201 104 1.3e5 298.0 0.0 0.0 0.0 10

1061300 1

```
1061301 0.0 0.0 0.0 9
*junction b/w 106 and 107 heat tracing
3060000 sngjjun7 sngljun
3060101 106010000 107000000 0.0 0.0 0.0 0001100
3060201 1 0.0 0.0 0.0
*heat tracing pipe 107
1070000 pipe8 pipe
1070001 10
1070101 1.96e-4 10
1070301 0.08 10
1070601 90.0 10
1070801 1.6e-6 0.0 10
1071001 0011000 10
1071101 0001100 9
1071201 104 1.3e5 298.0 0.0 0.0 0.0 10
1071300 1
1071301 0.0 0.0 0.0 9
**junction b/w 107 and D.C.
3070000 sngljun8 sngljun
3070101 107010000 202000000 0.0 0.0 0.0 0001100
3070201 1 0.0 0.0 0.0
*D.C.
2020000 snglvol2 snglvol
2020101 0.0314 1.5 0.0 0.0 90.0 1.5 1.6e-6 0.0 0011000
2020200 104 1.3e5 573.0 0.0
* junction b/w D.C. and 108
3080000 sngljun8 sngljun
3080101 202010000 108000000 0.0 0.0 0.0 0001100
3080201 1 0.0 0.0 0.0
**pipe 108
1080000 pipe9 pipe
1080001 2
1080101 1.96e-4 2
```

```
1080301 1.41 2
1080601 90.0 2
1080801 1.6e-6 0.0 2
1081001 0011000 2
1081101 0001100 1
1081201 104 1.3e5 573.0 0.0 0.0 0.0 2
1081300 1
1081301 0.0 0.0 0.0 1
** branch mixing point of two streams
4010000 branch2 branch
4010001 3 1
4010101 1.96e-4 0.5 0.0 0.0 0.0 0.0 1.6e-6 0.0 0011000
4010200 104 1.3e5 573.0 0.0
4011101 104010000 401000000 0.0 0.0 0.0 0001100
4011201 0.0 0.0 0.0
4012101 108010000 401000000 0.0 0.0 0.0 0001100
4012201 0.0 0.0 0.0
4013101 401010000 109000000 0.0 0.0 0.0 0001100
4013201 0.0 0.0 0.0
*pipe 109 helium-water heat EX
1090000 pipe10 pipe
1090001 10
1090101 1.96e-4 10
1090301 0.2 10
1090601 0.0 10
1090801 1.6e-6 0.0 10
1091001 0011000 10
1091101 0001100 9
1091201 104 1.3e5 573.0 0.0 0.0 0.0 10
1091300 1
1091301 0.0 0.0 0.0 9
*junction b/w pipe 109 and 110
3090000 sngjun10 sngljun
```

```
3090101 109010000 110000000 0.0 0.0 0.0 0001100
3090201 1 0.0 0.0 0.0
*pipe 110
1100000 pipe10 pipe
1100001 40
1100101 1.96e-4 40
1100301 1.0375 40
1100601 0.0 40
1100801 1.6e-6 0.0 40
1101001 0011000 40
1101101 0001100 39
1101201 104 1.3e5 298.0 0.0 0.0 0.0 40
1101300 1
1101301 0.0 0.0 0.0 39
*junction b/w 110 and 111
3100000 sngjun11 sngljun
3100101 110010000 111000000 0.0 0.0 0.0 0001100
3100201 1 0.0 0.0 0.0
*pipe 111
1110000 pipe11 pipe
1110001 5
1110101 1.96e-4 5
1110301 1.4 5
1110601 -90.0 5
1110801 1.6e-6 0.0 5
1111001 0011000 5
1111101 0001100 4
1111201 104 1.3e5 298.0 0.0 0.0 0.0 5
1111300 1
1111301 0.0 0.0 0.0 4
**junction b/w 111 and buffer TK
3110000 sngjun12 sngljun
3110101 111010000 203000000 0.0 0.0 0.0 0001100
```

3110201 1 0.0 0.0 0.0

***buffer TANK

2030000 snglvol3 snglvol

2030101 0.073024 1.2 0.0 0.0 -90.0 -1.2 1.6e-6 0.0

0011000

2030200 104 1.3e5 298.0 0.0

*** junction b/w pipe 111 and buffer tank

3120000 sngjun12 sngljun

3120101 203010000 112000000 0.0 0.0 0.0 0001100

3120201 1 0.0 0.0 0.0

** pipe 112 coming from buffer tank goes to circulator

1120000 pipe12 pipe

1120001 5

1120101 1.96e-4 5

1120301 1.104 5

1120601 -90.0 5

1120801 1.6e-6 0.0 5

1121001 0011000 5

1121101 0001100 4

1121201 104 1.3e5 298.0 0.0 0.0 0.0 5

1121300 1

1121301 0.0 0.0 0.0 4

*circulator part

5000000 pump pump *5000101 0.0 0.6 0.005 0.0 -90.0 -0.6 0

5000108 112050002 0.0 0.0 0.0 0001100

5000109 113010001 0.0 0.0 0.0 0001100

5000200 104 1.3e5 298.0 0.0

5000201 1 0.0 0.0 0.0

5000202 1 0.0 0.0 0.0

5000301 -1 -1 -3 -1 -1 501 0

5000302 0.6283 0.86 0.25 3907.0 150.0 0.55 0.0 0.0 0.0 6.0 0.0 0.0

**junction b/w pipe 112 and 113

3140000 sngjun12 sngljun

3140101 112010000 113000000 0.0 0.0 0.0 0001100

3140201 1 0.0 0.0 0.0

*pipe 113

1130000 pipe13 pipe

1130001 5

1130101 1.96e-4 5

1130301 0.92 5

1130601 -90.0 5

1130801 1.6e-6 0.0 5

1131001 0011000 5

1131101 0001100 4

1131201 104 3.0e5 298.0 0.0 0.0 0.0 5

1131300 1

1131301 0.0 0.0 0.0 4

**junction b/w pipe 113 and 200 vol(source tank)

3130000 sngjun12 sngljun

3130101 113010000 200000000 0.0 0.0 0.0 0001100

3130201 1 0.0 0.0 0.0

*heat structure heat tracing to TBM

11020000 10 5 2 0 7.9e-3 0 0 128

11020100 0 1

11020101 4 10.67e-3

11020201 333 4

11020301 1.0 4

11020401 583.0 5

11020501 102010000 010000 1 1 0.08 10

11020601 0 0 0 1 0.08 10

11020701 444 1.0 0.0 0.0 10

11020800 0

11020801 0.0158 12.0 12.0 0.0 0.0 0.0 0.0 1.0 10

20133300 tbl/fctn 1 1

20133301 21.50

20133351 4.0e6

20244400 power

20244401 0.0 150.0

********** heat structure heat tracing to D.C.

11070000 10 5 2 0 7.9e-3 0 0 128

11070100 0 1

11070101 4 10.67e-3

11070201 111 4

11070301 1.0 4

11070401 298.0 5

11070501 107010000 010000 1 1 1.0 10

11070601 0 0 0 1 1.0 10

11070701 222 1.0 0.0 0.0 10

11070800 0

11070801 0.0 12.0 12.0 0.0 0.0 0.0 0.0 1.0 10

20111100 tbl/fctn 1 1

20111101 18.065

20111151 4.0e6

20222200 power

20222201 0.0 19.9

*helium water heat exchanger

water side

inlet tdmpvol

2040000 tmdpvol1 tmdpvol

2040101 1.0 0.5 0.0 0.0 90.0 0.5 1.6e-6 0.0 0

2040200 103

2040201 0.0 3.0e+5 288.0

inlet tmdpjun

3140000 tmdpjun1 tmdpjun

3140101 204010000 114000000 0.0

3140200 1

3140201 0.0 0.01472 0.0 0.0

pipe

1140000 pipe1 pipe

1140001 10

1140101 7.69e-4 10

1140301 0.2 10

1140601 90.0 10

1140801 1.6e-6 0.00996 10

1141001 0011000 10

1141101 0001100 9

1141201 103 3.0e+5 288.0 0.0 0.0 0.0 10

1141300 1

1141301 0.0 0.0 0.0 9

outlet singljun 1

3150000 singlju2 sngljun

3150101 114010000 205000000 0.0 0.0 0.0 0001100

3150201 1 0.0 0.0 0.0

outlet snglvol

2050000 snglvol2 snglvol

2050101 7.69e-4 0.2 0.0 0.0 90.0 0.2 1.6e-6 0.0 0

2050200 103 3.0e+5 288.0

outlet singljun 2

3160000 signjun sngljun

3160101 205010000 206000000 0.0 0.0 0.0 0

3160201 1 0.0 0.0 0.0

out let tmdpvol

2060000 tmdpvol2 tmdpvol

2060101 1.0 0.5 0.0 0.0 90.0 0.5 1.6e-6 0.0 0

2060200 103

2060201 0.0 2.92e+5 293.0

heat structure

helium side

11090000 10 5 2 0 0.0079 0 0 128

11090100 0 1

11090101 4 0.01067

11090201 111 4

11090301 0.0 4

11090401 573.0 5

11090501 109010000 010000 1 1 0.2 10

11090601 114100000 -010000 1 1 0.2 10

11090701 0 0.0 0.0 0.0 10

11090800 0

11090801 0.0779 12.0 12.0 0.0 0.0 0.0 0.0 1.0 10

11090901 0.02456 12.0 12.0 0.0 0.0 0.0 0.0 1.0 10

water side

11140000 10 5 2 0 0.0313 0 0 128

11140100 0 1

11140101 4 0.0381

11140201 111 4

11140301 0.0 4

11140401 288.0 5

11140501 114010000 010000 1 1 0.2 10

11140601 0 0 0 1 0.2 10

11140701 0 0.0 0.0 0.0 10

11140800 0

11140801 0.02456 12.0 12.0 0.0 0.0 0.0 0.0 1.0 10

thermal conductivity

thermal conductivity

20111100 tbl/fctn 1 1

20111101 15.08

20111151 4.0e6

****

**********leak

*******leak in v.v.

*valve connecting to leakage

7000000 valve valve

7000101 108020004 801000000 1.96e-4 0.0 0.0 0001100

7000201 1 0.0 0.0 0.0

7000300 trpvlv

```
7000301 502
******* pipe 800 for mass flow check
8010000 pipe7 pipe
8010001 2
8010101 1.96e-4 2
8010301 0.1 2
8010501 180.0 2
8010601 0.0 2
8010801 1.6e-6 0.0 2
8011001 0011000 2
8011101 0001100 1
8011201 104 1.0e4 298.0 0.0 0.0 0.0 2
8011300 1
8011301 0.0 0.0 0.0 1
***small pipe for checking mass flow
*junction b/w pipe 800 and vol 600
3200000 sngljun4 sngljun
3200101 801010000 601000000 1.96e-4 0.0 0.0 0001100
3200201 1 0.0 0.0 0.0
******8leakege volume
6010000 lvol snglvol
6010101 0.0 2.0 20.0 180.0 0.0 0.0 1.6e-6 0.0 0011000
6010200 104 1.0e4 298.0 0.0
*******plot request
301 p 601010000
302 tempg 601010000
303 mflowgj 801010000
20300010 p 601010000
20300020 tempg 601010000
20300030 mflowgj 801010000
.
```

B.1.2 Input Deck for Helium Water HX

```
100 new transnt
201 1000.0 1.0e-6 0.2 3 500 50 50
110 helium
115 1.0
helium side
inlet tdmpvol
2050000 tmdpvol1 tmdpvol
2050101 1.0 0.5 0.0 0.0 0.0 0.0 1.6e-6 0.0 0
2050200 104
2050201 0.0 1.2e5 573.0 0.0
inlet tmdpjun
3000000 tmdpjun1 tmdpjun
3000101 205010000 109000000 0.0
3000200 1
3000201 0.0 0.0 0.233e-3 0.0
pipe
1090000 pipe1 pipe
1090001 10
1090101 1.96e-4 10
1090301 0.20 10
1090601 0.0 10
1090801 1.6e-6 0.0158 10
1091001 0 10
1091101 0 9
1091201 104 1.2e5 573.0 0.0 0.0 0.0 10
1091300 1
1091301 0.0 0.0 0.0 9
** branch for checking
4000000 branch1 branch
4000001 2 1
4000101 1.96e-4 0.2 0.0 0.0 0.0 0.0 1.6e-6 0.0 0
```

```
4000200 104 1.2e5 573.0 0.0
4001101 109010000 400000000 0.0 0.0 0.0 0
4001201 0.0 0.0 0.0
4002101 400010000 206000000 0.0 0.0 0.0 0
4002201 0.0 0.0 0.0
out let tmdpvol
2060000 tmdpvol2 tmdpvol
2060101 1.0 0.5 0.0 0.0 0.0 0.0 1.6e-6 0.0 0
2060200 104
2060201 0.0 1.15e+5 298.0 0.0
water side
inlet tdmpvol
2070000 tmdpvol3 tmdpvol
2070101 1.0 0.5 0.0 180.0 0.0 0.0 1.6e-6 0.0 0
2070200 103
2070201 0.0 12.0e+5 288.0
inlet tmdpjun
3010000 tmdpjun1 tmdpjun
3010101 207010000 125000000 0.0
3010200 1
3010201 0.0 0.01472 0.0 0.0
pipe
1250000 pipe1 pipe
1250001 10
1250101 7.69e-4 10
1250301 0.20 10
1250501 180.0 10
1250601 0.0 10
1250801 1.6e-6 0.00996 10
1251001 0 10
1251101 0 9
1251201 103 12.0e5 288.0 0.0 0.0 0.0 10
1251300 1
```

1251301 0.0 0.0 0.0 9

*** branch for checking

4010000 branch2 branch

4010001 2 1

4010101 7.69e-4 0.2 0.0 180.0 0.0 0.0 1.6e-6 0.0 0

4010200 103 12.0e5 288.0

4011101 125010000 401000000 0.0 0.0 0.0 0

4011201 0.0 0.0 0.0

4012101 401010000 208000000 0.0 0.0 0.0 0

4012201 0.0 0.0 0.0

out let tmdpvol

2080000 tmdpvol4 tmdpvol

2080101 1.0 0.5 0.0 180.0 0.0 0.0 1.6e-6 0.0 0

2080200 103

2080201 0.0 11.92e5 293.0

heat structure

helium side

11090000 10 5 2 0 0.0079 0 0 128

11090100 0 1

11090101 4 0.01067

11090201 111 4

11090301 0.0 4

11090401 573.0 5

11090501 109010000 010000 1 1 0.20 10

11090601 125100000 -010000 1 1 0.20 10

11090701 0 0.0 0.0 0.0 10

11090800 0

11090801 0.0779 12.0 12.0 0.0 0.0 0.0 0.0 1.0 10

11090901 0.02456 12.0 12.0 0.0 0.0 0.0 0.0 1.0 10

water side

11250000 10 5 2 0 0.0313 0 0 128

11250100 0 1

11250101 4 0.0381

11250201 111 4

11250301 0.0 4

11250401 288.0 5

11250501 125010000 010000 1 1 0.20 10

11250601 0 0 0 1 0.20 10

11250701 0 0.0 0.0 0.0 10

11250800 0

11250801 0.02456 12.0 12.0 0.0 0.0 0.0 0.0 1.0 10

thermal conductivity

20111100 tbl/fctn 1 1

20111101 15.08

20111151 4.0e6

minor edit

301 tempg 400010000

302 tempf 401010000

303 p 400010000

304 p 401010000

305 mflowgj 400020000

plot requests

20300010 p 400010000

20300020 p 401010000

20300030 tempg 400010000

20300040 tempf 401010000

20300050 mflowgj 400020000 .

B.1.3 Input Deck for Detritiation Column Inlet Heater

***** first wall heater

100 new transnt

110 helium

115 1.0

```
201 5000.0 1.0e-6 0.2 3 100 100 100
*first Tmdpvol
2000000 tmdpvol1 tmdpvol
2000101 1.96e-2 1.0 0.0 0.0 90.0 1.0 1.6e-6 0.0 0
2000200 104
2000201 0.0 1.3e5 298.0 0.0
**tmdpjun b/w branch and tmdpvol
3000000 tmdpjun tmdpjun
3000101 200010000 400000000 0.0
3000200 1
3000201 0.0 0.0 0.139e-3 0.0
** branch for checking
4000000 branch1 branch
4000001 1 1
4000101 1.96e-4 0.2 0.0 0.0 90.0 0.2 1.6e-6 0.0 0
4000200 104 1.3e5 298.0 0.0
4001101 400010000 100000000 0.0 0.0 0.0 0
4001201 0.0 0.0 0.0
** pipe
1000000 pipe1 pipe
1000001 10
1000101 1.96e-4 10
1000301 0.08 10
1000601 90.0 10
1000801 1.6e-6 0.0 10
1001001 0 10
1001101 0 9
1001201 104 1.3e5 298.0 0.0 0.0 0.0 10
1001300 1
1001301 0.0 0.0 0.0 9
*branch for checking
4010000 branch1 branch
4010001 2 1
```

```
4010101 1.96e-4 0.2 0.0 0.0 90.0 0.2 1.6e-6 0.0 0
4010200 104 1.3e5 298.0 0.0
4011101 100010000 401000000 0.0 0.0 0.0 0
4011201 0.0 0.0 0.0
4012101 401010000 201000000 0.0 0.0 0.0 0
4012201 0.0 0.0 0.0
**last tmdpvol
2010000 tmdpvol2 tmdpvol
2010101 1.96e-2 1.0 0.0 0.0 90.0 1.0 1.6e-6 0.0 0
2010200 104
2010201 0.0 1.29e5 573.0 0.0
** heat structure
11000000 10 5 2 0 7.9e-3 0 0 128
11000100 0 1
11000101 4 10.67e-3
11000201 111 4
11000301 1.0 4
11000401 298.0 5
11000501 100010000 010000 1 1 0.08 10
11000601 0 0 0 1 0.08 10
11000701 222 0.0 1.0 0.0 10
11000801 0.0 12.0 12.0 0.0 0.0 0.0 0.0 1.0 10
20111100 tbl/fctn 1 1
20111101 25.70
20111151 43.0e5
20222200 power
20222201 0.0 19.9
**minor edit
301 tempg 400010000
302 tempg 401010000
303 p 400010000
```

304 p 401010000

305 mflowgj 401010000

** plot request

20300010 tempg 400010000

20300020 tempg 401010000

20300030 p 400010000

20300040 p 401010000

20300050 mflowgj 401010000

.

B.1.4 Input Deck for Test Blanket Module Heater

** program for calculating heat capacity of heat tracing TBM

100 new transnt

110 helium

201 50000.0 1.0e-6 0.2 3 1000 1000 1000

tmdpvol input

2000000 tmdpvol1 tmdpvol

2000101 1.9e-2 0.8 0.0 0.0 0.0 0.0 1.6e-6 0.0 0

2000200 104

2000201 0.0 1.3e5 298.0 0.0

*time dependent junction b/w tmdpvol and pipe

3000000 tmdpjun tmdpjun

3000101 200010000 100000000 0.0

3000200 1

3000201 0.0 0.0 0.094e-3 0.0

**pipe

1000000 pipe pipe

1000001 10

1000101 1.9e-4 10

1000301 0.08 10

1000601 0.0 10

1000801 1.6e-6 0.0 10

```
1001001 0 10
1001101 0 9
1001201 104 1.3e5 298.0 0.0 0.0 0.0 10
1001300 1
1001301 0.0 0.0 0.0 9
** branch for checking
4000000 branch1 branch
4000001 2 1
4000101 1.9e-4 0.2 0.0 0.0 0.0 0.0 1.6e-6 0.0 0
4000200 104 1.3e5 298.0 0.0
4001101 100010000 400000000 0.0 0.0 0.0 0
4001201 0.0 0.0 0.0
4002101 400010000 201000000 0.0 0.0 0.0 0
4002201 0.0 0.0 0.0
* last tmdpvol
2010000 tmdpvol1 tmdpvol
2010101 1.9e-2 0.8 0.0 0.0 0.0 0.0 1.6e-6 0.0 0
2010200 104
2010201 0.0 1.29e5 573.0 0.0
*heat exchanger
11000000 10 5 2 0 7.9e-3 0 0 128
11000100 0 1
11000101 4 10.67e-3
11000201 111 4
11000301 1.0 4
11000401 298.0 5
11000501 100010000 010000 1 1 1.0 10
11000601 0 0 0 1 1.0 10
11000701 222 1.0 0.0 0.0 10
11000800 0
11000801 0.0 12.0 12.0 0.0 0.0 0.0 0.0 1.0 10
20111100 tbl/fctn 1 1
20111101 18.065
```

20111151 4.0e6

20222200 power

20222201 0.0 13.5

*minoe edit and plot requested

301 tempg 400010000

302 p 400010000

303 mflowgj 400020000

20300010 tempg 400010000

20300020 p 400010000

20300030 mflowgj 400020000

.

B.1.5 The Graph Obtained from RELAP5 Input Deck

The graph obtained by running the RELAP5 input deck for various coding of components is given below:

Figure B.2: HX Graph for outlet pressure of Helium

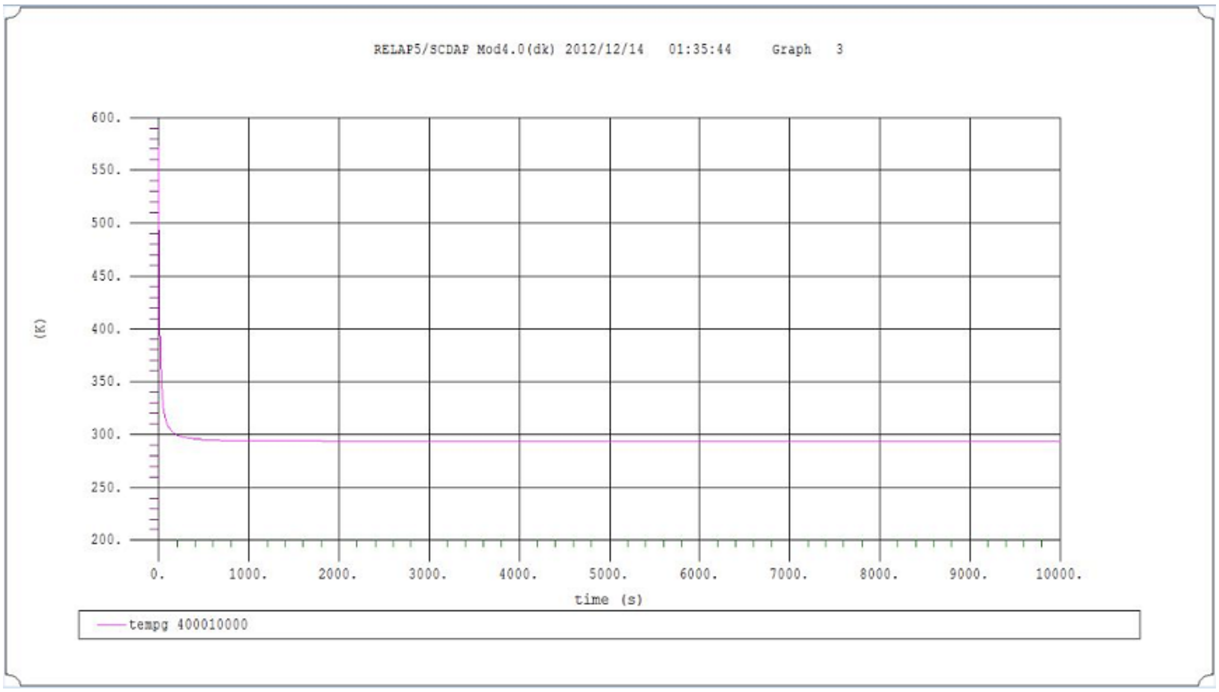

Figure B.3: HX Graph for outlet Temperature of Helium

Figure B.4: HX Graph for outlet pressure of Water

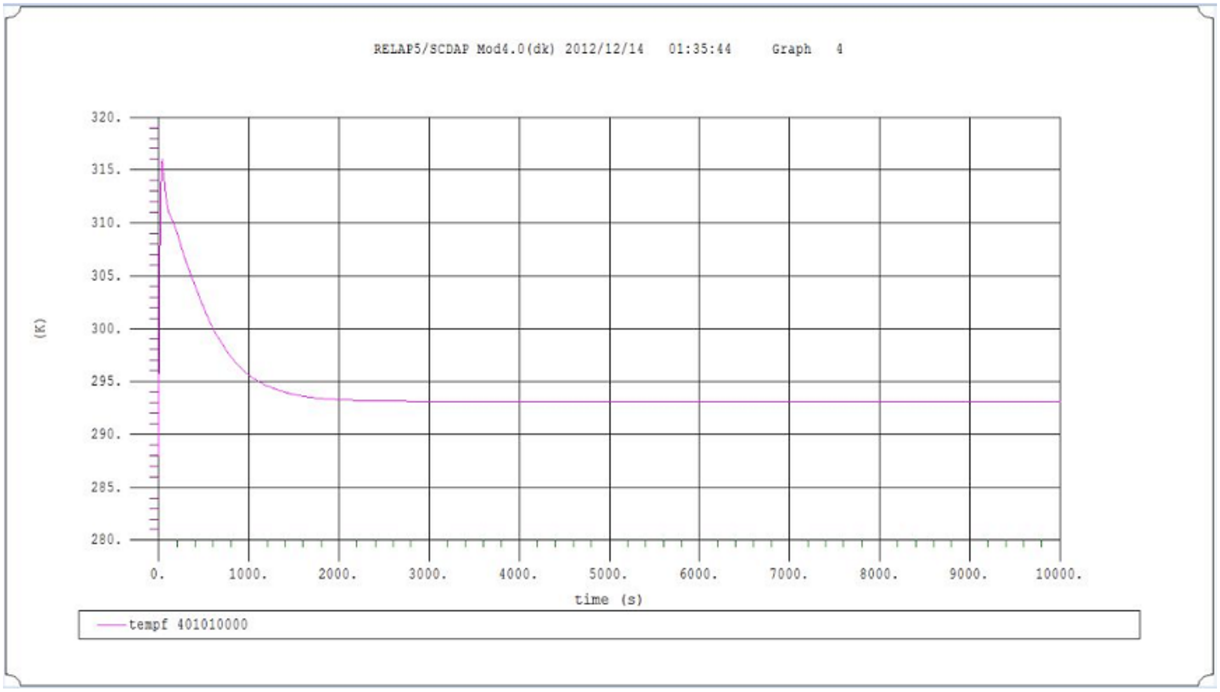

Figure B.5: HX Graph for outlet Temperature of Water

Figure B.6: DC Heat Tracing Temperature

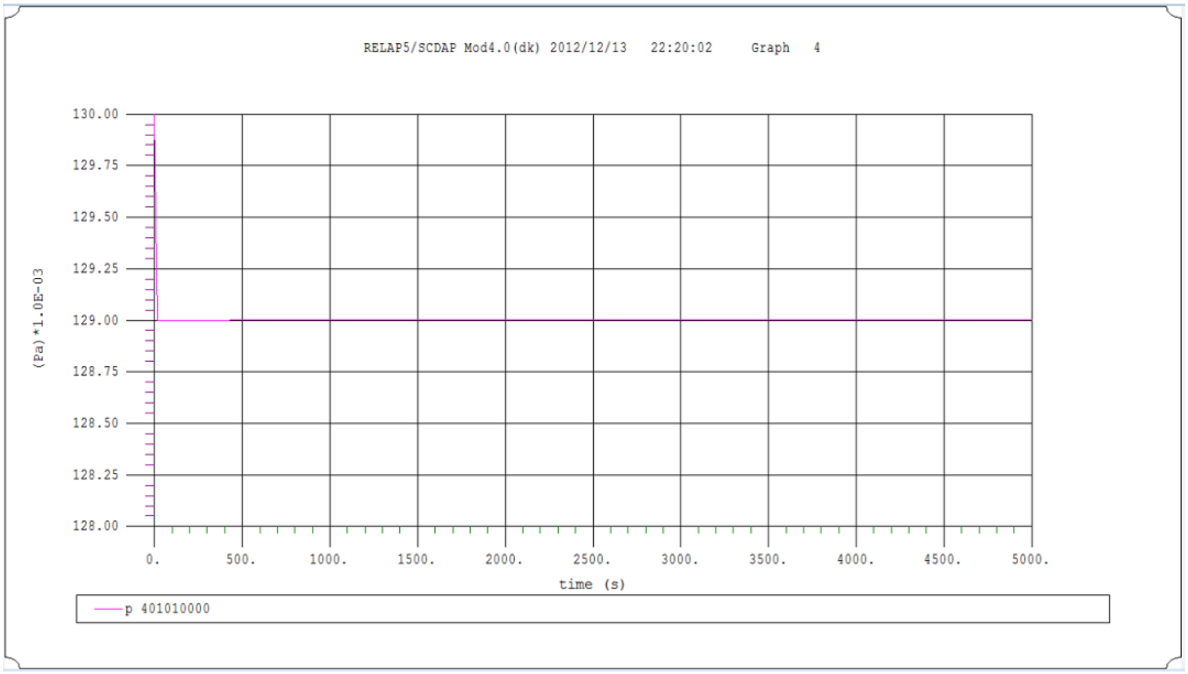

Figure B.7: DC Heat Tracing Pressure

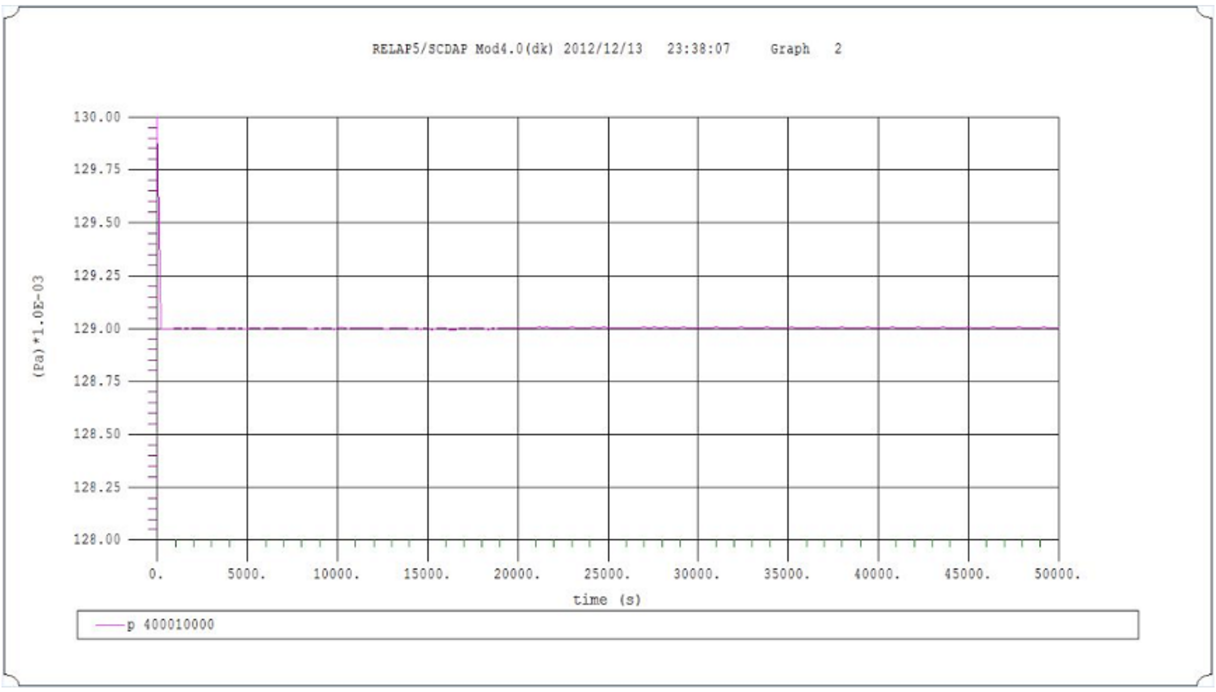

Figure B.8: TBM Heat Tracing Pressure

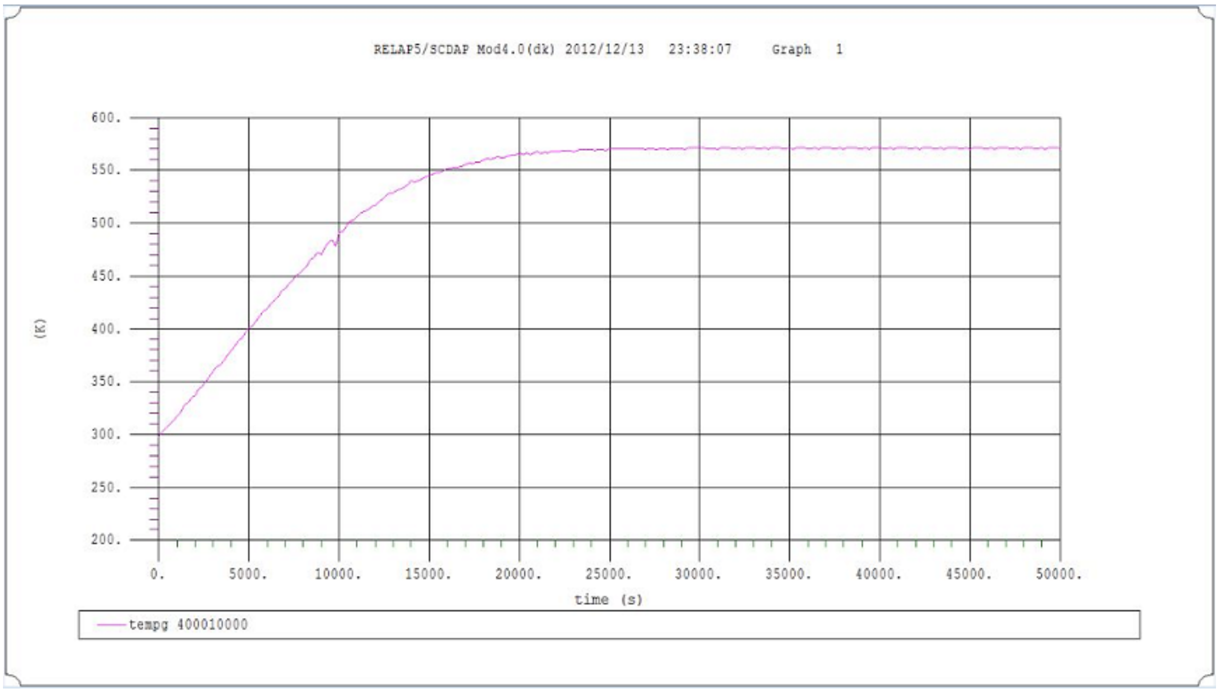

Figure B.9: TBM Heat Tracing Temperature

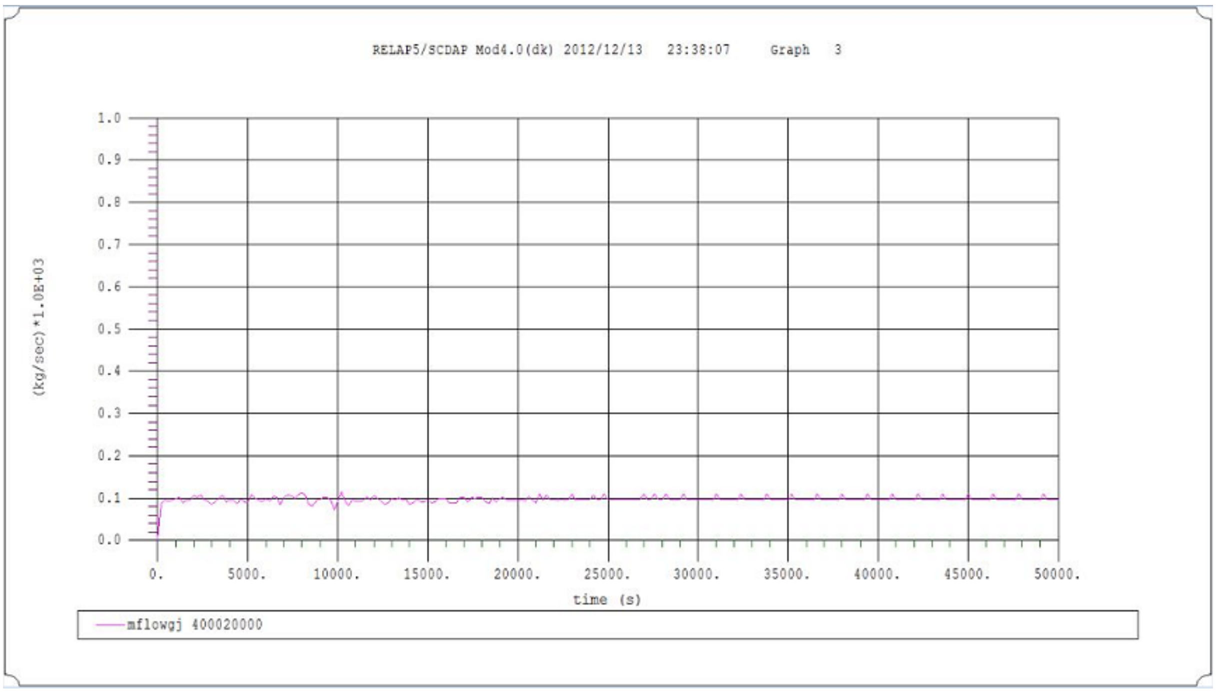

Figure B.10: TBM Mass Flow Rate