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[1.] Diana Laura ICLEANU, [2.] Ilie PRISECARU, [3.] Iulia Nicoleta JIANU

COOLING THE INTACT LOOP OF PRIMARY HEAT TRANSPORT SYSTEM USING SHUT DOWN COOLING SYSTEM AFTER EVENTS SUCH AS LOCA

[1-3.] Polytechnic University of Bucharest, Splaiul Independenței, nr. 313, Bucharest, ROMANIA

Abstract: *Power and energy industries have their unique challenges but they all need to rely on the efficient running of their piping systems and therefore optimum design and continual effective maintenance are essential. The ability to ensure accurate delivery of a product and raw materials, especially over long distances and significant elevation change is vital to the overall operation and success of a process plant. For such analysis Flowmaster is a useful code. The purpose of this paper is to model the shutdown cooling system (SDCS) operation for CANDU 6 nuclear power plant in case of LOCA accident, using Flowmaster calculation code by delimitating models and setting calculation assumptions, input data for hydraulic analysis, assumptions for the calculation and input data for calculating thermal performance check for heat exchangers that are part of this system.*
Keywords: *CANDU, HYDRAULIC, LOCA, THERMAL*

INTRODUCTION

Power and energy industries have their unique challenges but they all need to rely on the efficient running of their piping systems and therefore optimum design and continual effective maintenance are essential. The ability to ensure accurate delivery of a product and raw materials, especially over long distances and significant elevation change is vital to the overall operation and success of a process plant. For such analysis Flowmaster is a useful code. This code has been applied for analysis of systems of CANDU reactors because of the possibility of defining by the user the incompressible and compressible fluids and also the solid materials based on thermodynamic and thermo-physical properties of these models based on the corresponding generic database of the program.

Considering this, the following paper has analyzed the failure operating modes for loss of coolant accident (LOCA) defined in the design documentation.

The first chapter of the study provides an overview of the shutdown cooling system and an overview of the operating modes of the system. Also in this section is presented a summary of the LOCA accident, both general considerations and aspects of nuclear safety.

Furthermore is performed the modeling of the Shutdown Cooling System (SDCS) in case of accident mode, using Flowmaster calculation code, by delimiting models and developing supportable computing assumptions of the geometric configuration and input data for hydraulic analysis and the calculation assumptions and input data for thermal calculation in order to verify the functioning of the heat exchangers that are part of this system.

Abnormal operating conditions for the Shutdown Cooling System were analyzed using Flowmaster calculation code and then was made a comparison of the results with data obtained from a series of models developed in PIPENET.

From the results of thermal-hydraulic analysis and comparison with data from the runnings performed with PIPENET was found that in all operating conditions of the system in case of LOCA accident type, performance requirements specified in the design documentation are confirmed by analysis. After modeling the Shutdown Cooling System, its functionality was demonstrated by achieving the required performance.

OVERVIEW OF THE SHUTDOWN COOLING SYSTEM AND THE COMPUTER CODE USED FOR ANALYSIS

The Shutdown Cooling System (SDCS) is provided to cool the Primary Heat Transport System (PHTS) from 177°C to 54°C and hold the system at 54°C for an indefinite period of time.

During normal operation with the reactor at power, the SDCS is kept full with heavy water at 38°C (100°F) and pressure at or just above atmospheric.

There are two cool down options available. The initial phase of the two options is similar and involves the use of the CSDV's (Condenser Steam Discharge Valves) to lower the PHTS temperature from 260°C at the rate of 2.8°C/min. During this phase, the PHTS pumps circulate the coolant through the steam generators. If the SDCS pumps are to be used in the next phase of cool down, the PHTS temperature has to be brought down to 149°C first through the CSDV's. Cool down to 54°C at the rate of 2.8°C/min is carried out using the SDCS pumps and heat exchangers (HX).

A. Operating the SDCS in case of LOCA

Following a Large LOCA, with or without Class IV power, SDCS is required to cool the PHTS intact loop. For the first 900 seconds (15 minutes) upon receipt of the LOCA signal, the Moderator Temperature Control (MTC) program controls the "moderator rapid cool down". Following the first 900 seconds after LOCA, the re-circulated cooling water flow rate of 200 L/s, is made available to the SDCS by limiting the opening of the large temperature control valves (an MTC program action) to limit the flow to the heat exchangers.

In this case, for cool down of PHTS intact loop, the operator has to bring in the SDCS manually following a large LOCA, which will act, as a backup heat sink for thermo-syphoning for intact loop.

In this paper was analyzed the case of cooling the intact loop of the PHTS, using the SDCS after 15 minutes or 30 minutes from the initiation of LOCA, using both pumps and heat exchangers of shutdown cooling system and also the case when can be used only one pump and one heat exchanger (Class IV or Class III available).

Loss of coolant accident, LOCA is the most severe challenge of all security systems asking for the majority of project requirements for these systems.

B. Fundamentals in FLOWMASTER

For the development of thermal-hydraulic analysis of the shutdown cooling system was used the computing program Flowmaster V7.8. Mentor Graphics, from Wilsonville, Oregon, USA, is the software manufacturer. Flowmaster is a one-dimensional thermal-hydraulic calculation code for dimensioning, analyzing and verifying the pipeline systems operation.

This code provides a graphical virtual working environment and allows the design, redefine and test the whole system of the fluid flow.

Steady state or transient modules of Flowmaster code for single-phase fluids were designed specifically in order to model the heat transfer effects in many application areas. The modules allow users to develop transient analysis for such kind of events.

Each component of Flowmaster is a mathematical model for an equipment that is included in a facility.

Selected components are connected via nodes in order to form a network, which constitutes a computerized model of the system.

The equations which govern the mathematical model developed in Flowmaster are:

- the mass conservation equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x}(\rho u)+\frac{\partial}{\partial y}(\rho v)+\frac{\partial}{\partial z}(\rho w)=0 \qquad (1)$$

- energy conservation equation:

$$E_{in}+E_g-E_{out}=E_{st}, \qquad (2)$$

where: E_{in} is the energy entered into the system; E_g is the energy generated by the fluid volume within the system; E_{out} is the energy discharged from the system; E_{st} is the energy stored in the fluid volume.

- momentum conservation equation:

$$\rho g_x-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)=\rho\frac{du}{dt} \qquad (3)$$

$$\rho g_y-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)=\rho\frac{dv}{dt} \qquad (4)$$

$$\rho g_z-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)=\rho\frac{dw}{dt} \qquad (5)$$

These equations require that the same amount of energy, mass and momentum that enters into a volume must leave the volume. Equations (3), (4) and (5) are the Navier-Stokes equations. From the Navier-Stokes equation can be derived Bernoulli (6). This is a relationship between the pressure and the velocity along the height of a volume of fluid.

$$\frac{v^2}{2g}+z+\frac{p}{\rho g}=C \qquad (6)$$

where: v=velocity; g=gravity acceleration; z = height; p = static pressure; ρ = density; c = constant.

A Flowmaster network contains a number of components (pipes, tubing, pumps, fans, flow and pressure sources, etc.) and links between them. Points in which some components are linked to other components are called nodes.

When a network is prepared for simulation, each component and node must have a unique label. Filling the entire schematic representation (Flowmaster network) is an essential part of any simulations.

The nodal diagram (Flowmaster network) achieved consisted of a sequence of segments separated by nodes, which represent portions of pipe trails sections, without diameter or branches variations along them. Various equipments or components (except for retaining tabs) are represented by pressure loss coefficients.

For simulating, using Flowmaster code, the heavy water flow in the SDCS in order to determine the variation of pressure and flow at various points of the circuit, it was done a nodal scheme - Flowmaster network.

Flowmaster computing code is confirmed with an exact calculation of the thermal side of the analyze and with PIPENET program on the hydraulic side of it.

APPLICATION OF FLOWMASTER CODE IN THERMAL-HYDRAULIC ANALYSIS OF THE SDCS

A. Models and computing hypotheses

In order to develop the thermal-hydraulic analysis of the shutdown cooling system, in case of LOCA, were done the following calculation models that cover the requirements of the design theme.

- **Model I.** Hydraulic calculation model for operating in failure mode type LOCA for the shutdown cooling system, model in which the cooling of the PHTS is started at 177 °C using heat exchangers, HX1 and HX2, to provide the cold source, while the circulation will be maintained by the SDCS pumps, P1 and P2.
- **Model II.** Hydraulic calculation model for operating in failure mode type LOCA for the shutdown cooling system, model in which the cooling of the PHTS is started at 177 ° C using one heat exchanger, HX1 or HX2, to provide the cold source, while the circulation will be maintained by one of the SDCS pumps, P1 or P2.

- ≡ ***Model III.*** *Thermal calculation model for the heat exchangers, HX1 and HX2, related to the shutdown cooling system, for operating in failure mode of the shutdown cooling system. For this case the heat exchangers HX1 and HX2 are cooled with water flow coming from the intermediate cooling water system. The inlet temperature considered on the secondary side of the heat exchangers is 30°C. In model III, the shutdown cooling system is working with its associated pumps, P1 and P2.*
- ≡ ***Model IV.*** *Thermal calculation model for the heat exchangers, HX1 and HX2, related to the shutdown cooling system, for operating in failure mode of the shutdown cooling system. The heat exchangers HX1 and HX2 are also cooled with water flow coming from the intermediate cooling water system. The difference between model III and model IV is that the inlet temperature on the secondary side of the heat exchangers is 35 °C. In model IV, the shutdown cooling system is working with both shutdown cooling system pumps.*
- ≡ ***Model V.*** *Thermal calculation model for the heat exchangers, related to the shutdown cooling system, for operating in failure mode of the shutdown cooling system (in which case it is used only one pump and one heat exchanger related to the shutdown cooling system). For this case the inlet temperature on the secondary side of the heat exchangers is 30 °C.*
- ≡ ***Model VI.*** *Thermal calculation model for the heat exchangers related to the shutdown cooling system, for operating in failure mode of the shutdown cooling system (in which case they only use one pump and one heat exchanger related to the shutdown cooling system). The inlet temperature on the secondary side of the heat exchangers according to the manual design of the cooling water system is 35 °C.*

For the considered analysis were made a set of design assumptions. For the hydraulic analysis the hypotheses are as follows:

- » *System condition at the baseline of cooling is a state of stationary hydraulic regime;*
- » *Hydraulic resistances of PHTS lines are determined taking into account the pressure drop values on these lines, for nominal operating regime;*
- » *Hydraulic resistances of SDCS lines are determined taking into account the dimensional characteristics and their composition (fittings on these lines);*
- » *Pumps that do not work are modeled as lines with hydraulic resistance determined from the curve of increasing pressure for the respective pumps;*
- » *For the heat exchangers and steam generators we will consider only the primary circuit, that is modeled as a pipeline with the hydraulic resistance;*
- » *Pressure in the system is fixed at one of the output collectors of the reactor by boundary condition.*
- » *Interfaces with other systems were neglected, connecting pipes to these systems are not functional for the analyzed regimes.*

Assumptions considered for calculating thermal analysis were also set as it follows:

- » *The accumulated energy in metal tubes and shell is neglected;*
- » *The compressibility of the agents is neglected;*
- » *In the shell and in the heat exchanger's tubes, the flow is single phase;*
- » *The initial thermal condition is that the temperature in the entire system is considered the same.*
- » *The paper does not take into account the preparatory steps aimed at achieving either of the necessary cooling configurations, thus neglecting transient hydraulic regimes preceding the making of one or another of the cooling schemes analyzed.*

For the accomplishment of the hydraulic calculation with the help of the calculating code Flowmaster V7, pressure values have been entered, corresponding to hydrostatic pressure determined at the output collector of the reactor by boundary condition. Thus, for all hydraulic calculation models were considered appropriate pressure values for the inlet/outlet components of the nodal scheme according to Table I.

TABLE I. *Boundary conditions for the hydraulic analysis*

Operation mode	Point position	Temperature (^0C)	Pressure (bar)
Model I	Output collector from the reactor (pressure source: 314)	177	95
Model II	Output collector from the reactor (pressure source: 314)	177	95

B. Description of collected data and output files

Output files for the thermo-hydraulic calculation with the Flowmaster program are structured according to the type of simulation (hydraulic or thermal) as follows:

- » *Hydraulic calculation results for each component (flow, velocity, Reynolds number, pressure loss, etc.);*
- » *Hydraulic calculation results in each node (pressure);*
- » *Thermal calculation results suitable for components in which heat transfer occurs (thermal load, overall heat transfer coefficient , temperature difference between input and output);*
- » *Thermal calculation results in each node (temperature).*

TABLE II. *Hydraulic analyze. Model I*

Component	Flow rate (l/s)
Flow through P1 SDCS	115 l/s
Flow through P2 SDCS	114 l/s
Flow through HX1 SDCS	104 l/s
Flow through HX2 SDCS	103 l/s
Flow through inlet collectors HD6, HD2, HD4, HD8	HD6 – 104 l/s HD2–$1.4*10^{-10}$ l/s HD4–$2.27*10^{-9}$ l/s HD8 - 103 l/s
Flow through outlet collectors HD5, HD1, HD3, HD7	HD5 - 104l/s HD1- $1.85*10^{-9}$ l/s HD3–$1.73*10^{-9}$ l/s HD7 – 103 l/s
Flow through P1, P2, P3, P4 PHTS	P1 – $4*10^{-10}$ l/s P2–$1.55*10^{-9}$l/s P3 – 54 l/s P4 – 54 l/s
Flow through fuel channels R1, R2, R3 and R4	R1 – $2.15*10^{-10}$ l/s R2 – 50 l/s R3 – $1.79*10^{-9}$ l/s R4 – 50 l/s

≡ ***Model I.*** *Hydraulic calculation model for operating in failure mode for the shutdown cooling system, model in which the cooling of the PHTS starts at 177°C using heat exchangers, HX1 and HX2, (water is circulated by SDCS's pumps, P1 and P2). According to the results, calculated hydraulic parameter values are in Table II.*

≡ ***Model II.*** *Hydraulic calculation model for operating in failure mode for the shutdown cooling system, model in which the cooling of the PHTS is done at 177 °C using one heat exchanger, HX1 or HX2, to provide the cold source, while the circulation will be maintained by one of SDCS's pumps, P1 or P2.*

According to the results, calculated hydraulic parameter values are in Table III.

TABLE III*. Hydraulic analyze. Model II*

Component	Flow rate (l/s)
Flow through P1 SDCS	115 l/s
Flow through P2 SDCS	1.7 l/s
Flow through HX1 SDCS	104 l/s
Flow through HX2 SDCS	1.9 l/s
Flow through inlet collectors HD6, HD2, HD4, HD8	HD6 – 104 l/s HD2–$7.75*10^{-12}$ l/s HD4–$7.3*10^{-12}$ l/s HD8 – 1.9 l/s
Flow through outlet collectors HD5, HD1, HD3, HD7	HD5 - 104l/s HD1- $4.14*10^{-12}$ l/s HD3–$4.11*10^{-12}$ l/s HD7 – 1.9 l/s
Flow through P1, P2, P3, P4 PHTS	P1–$4.97*10^{-12}$l/s P2–$5.2*10^{-12}$l/s P3 – 67 l/s P4 – 34.8 l/s
Flow through fuel channels R1, R2, R3 and R4	R1–$6.9*10^{-12}$ l/s R2 – 36.7 l/s R3–$5*10^{-12}$ l/s R4 – 36.7 l/s

≡ ***Model III.*** *Thermal calculation model for the heat exchangers, HX1 and HX2, related to the shutdown cooling system, for operating in failure mode of the shutdown cooling system. This model concerns the time evolution of the temperature in PHTS.*

According to the results the parameter values for the heat transfer of heat exchangers HX1 and HX2, at the moment of achieving the cooling requirement for PHTS (temperature in PHTS must be 54°C) are in Table IV.

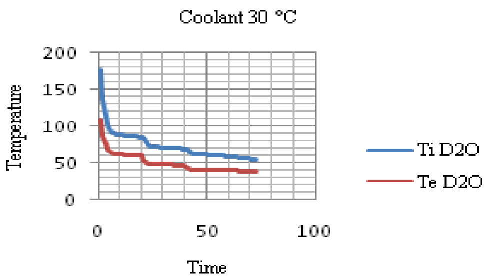

Figure1*. Examination for 2 HX for cooling agent 30 °C*

TABLE IV*. Thermal analysis. Model III*

Thermal load of SDCS HX1/ HX2	10.99 MW(th)
Outlet temperature for D_2O of PHTS	54.06 °C
Outlet temperature for the cooling water of SDCS HX1 and HX2	30.165 °C

In figure 1 is highlighted a plot of temperature decrease of PHTS coolant for inlet and outlet of the SDCS heat exchangers.

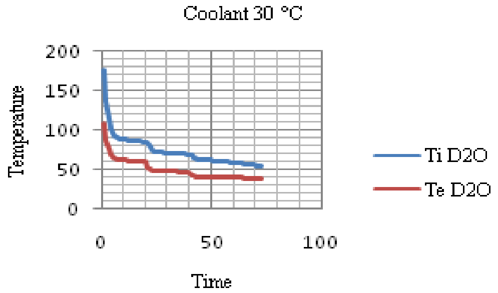

Figure1*. Examination for 2 HX for cooling agent 30 °C*

≡ ***Model IV.*** *Thermal calculation model for the heat exchangers, HX1 and HX2, related to the shutdown cooling system, for operating in failure mode of the shutdown cooling system. (LOCA). The inlet temperature on the secondary side of the heat exchangers is 35 °C. In modelul IV, the shutdown cooling system is working with his own pumps, P1 and P2. The result are shown in tabel V:*

TABLE V*. Thermal analysis. Model IV*

Thermal load of SDCS HX1/ HX2	8.95 MW(th)
Outlet temperature for D_2O of PHTS	54.16 °C
Outlet temperature for the cooling water of SDCS HX1 and HX2	41.32 °C

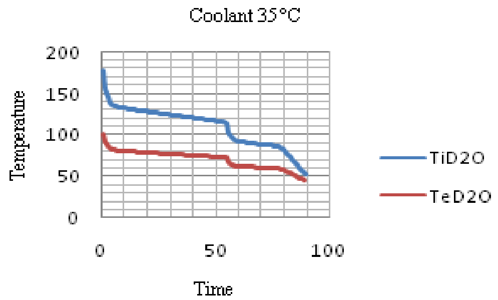

Figure 2*. Examination for 2 HX for cooling agent 35 °C*

In figure 2 is highlighted a plot of temperature decrease as it is shown in figure 1. The difference between model III and model IV is the inlet temperature of the cooling water that passes through the heat exchangers.

≡ ***Model V.*** *Thermal calculation model for the heat exchangers, HX1 or HX2, related to the shutdown cooling system, for operating in failure mode of the shutdown cooling system (LOCA).*

In model V, the SDCS is working with one heat exchanger and one of the shutdown cooling system pumps, P1 or P2. In tabel VI are provided the mainly results for this case of operating.

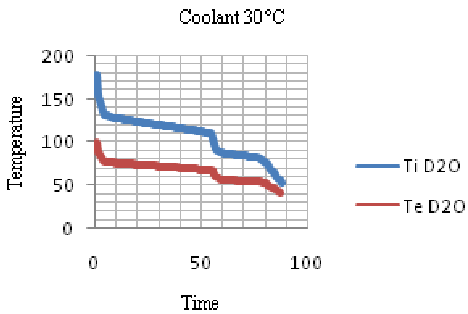

Figure 3*. Examination for 1 HX for cooling agent 30 °C*

TABLE VI. Thermal analysis. Model V

Thermal load of SDCS HX1/ HX2	5.4 MW(th)
Outlet temperature for D_2O of PHTS	52.43 ºC
Outlet temperature for the cooling water of SDCS HX1 and HX2	41.18 ºC

Figure 3 is also highlighted a plot of temperature decrease of PHTS coolant for inlet and outlet of the SDCS heat exchangers.

- **Model VI.** Thermal calculation model for the heat exchangers, HX1 and HX2, related to the shutdown cooling system, for operating in failure mode of the shutdown cooling system (LOCA). In this modelul, the SDCS is working with one heat exchanger and one of the shutdown cooling system pumps, P1 or P2.

The inlet temperature on the secondary side of the heat exchangers is 35°C. In table VII are shown the results of this analyze.

TABLE VII. Thermal analysis. Model VI

Thermal load of SDCS HX1/ HX2	4.17 MW(th)
Outlet temperature for D_2O of PHTS	52.2 ºC
Outlet temperature for the cooling water of SDCS HX1 and HX2	43.5 ºC

In figure 4 is also revealed a graphic of the temperature decrease for PHTS coolant.

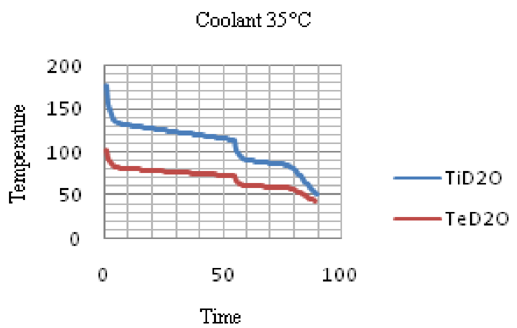

Figure 4. Examination for 1 HX for cooling agent 35 °C

TABLE VIII. Comparative results for hydraulic analyze. Model I

	Data obtained by using PIPENET code	Data obtained in by using FLOWMASTER
Flow through P1	118.4 l/s	115 l/s
Flow through P2	118.4 l/s	114 l/s
Flow through HX1 SDCS	106.6 l/s	104 l/s
Flow through HX2 SDCS	106.6 l/s	103 l/s
Flow through inlet collectors HD6, HD2, HD4, HD8	HD6 – 106.6 l/s HD2 – 0 l/s HD4 - 0 l/s HD8 – 106.6 l/s	HD6 – 104 l/s HD2–1.4*10^{-10} l/s HD4–2.27*10^{-9} l/s HD8 - 103 l/s
Flow through outlet collectors HD5, HD1, HD3, HD7	HD5 – 106.6 l/s HD1- 0 l/s HD3 - 0 l/s HD7 – 106.6 l/s	HD5 - 104l/s HD1- 1.85*10^{-9} l/s HD3–1.73*10^{-9} l/s HD7 – 103 l/s
Flow through PHTS-P1, P2, P3, P4	P1 – 0 l/s P2 – 0 l/s P3 – 58.6 l/s P4 – 58.6 l/s	P1 – 4*10^{-10} l/s P2–1.55*10^{-9}l/s P3 – 54 l/s P4 – 54 l/s
Flow through fuel channels R1, R2, R3 şi R4	R1 – 0l/s R2 – 53 l/s R3 – 0 l/s R4 – 53 l/s	R1 – 2.15*10^{-10} l/s R2 – 50 l/s R3 – 1.79*10^{-9} l/s R4 – 50 l/s

For hydraulic analyzes there were built two PIPENET models considered in order to verify the results obtained in Flowmaster. The results are as follows in Table VIII or IX.

TABLE IX. Comparative results for hydraulic analyze. Model II

	Data obtained by using PIPENET code	Data obtained by using FLOWMASTER
Flow through P1	118.4 l/s	115 l/s
Flow through P2	0 l/s	1.7 l/s
Flow through HX1 SDCS	106.6 l/s	104 l/s
Flow through HX2 SDCS	0.3 l/s	1.9 l/s
Flow through inlet collectors HD6, HD2, HD4, HD8	HD6 – 106.6 l/s HD2 – 0 l/s HD4 - 0 l/s HD8 – 0.3 l/s	HD6 – 104 l/s HD2–7.75*10^{-12} l/s HD4–7.3*10^{-12} l/s HD8 – 1.9 l/s
Flow through outlet collectors HD5, HD1, HD3, HD7	HD5 – 106.6 l/s HD1- 0 l/s HD3 - 0 l/s HD7 – 0.3 l/s	HD5 - 104l/s HD1- 4.14*10^{-12} l/s HD3–4.11*10^{-12} l/s HD7 – 1.9 l/s
Flow through PHTS-P1, P2, P3, P4	P1 – 0 l/s P2 – 0 l/s P3 – 71 l/s P4 – 35.4 l/s	P1–4.97*10^{-12}l/s P2–5.2*10^{-12} l/s P3 – 67 l/s P4 – 34.8 l/s
Flow through fuel channels R1, R2, R3 şi R4	R1 – 0l/s R2 – 38 l/s R3 – 0 l/s R4 – 37.9 l/s	R1–6.9*10^{-12} l/s R2 – 36.7 l/s R3–5*10^{-12} l/s R4 – 36.7 l/s

CONCLUSIONS

Under the present paper, there was carried out the thermal-hydraulic analysis of the simultaneous operation of the shutdown cooling system and of the primary heat transport system, associated to a CANDU 6 NPP (nuclear power plant), in LOCA accident regime, using Flowmaster calculation code.

The modelling of heavy water flow through the shutdown cooling system and primary heat transport system was performed to determine the distribution of flows, pressure in various areas of the hydraulic circuit and the pressure loss corresponding to the components but also for the heat calculation of the heat exchangers related to the system.

The configurations corresponding to the shutdown cooling system coupled to the primary heat transport system are in accordance with the thermo-mechanical schemes of the systems similar to those at Cernavoda NPP.

Within this work there were performed complex hydraulic/thermo-hydraulic analyzes for the shutdown cooling system coupled with the primary heat transport system. Hydraulic analyzes developed using Flowmaster program aimed at the verification of the hydraulic models as well as the determination of flow and pressure loss in baseline cooling processes in degraded mode.

The results of the thermo-hydraulic analysis show that in all cases analyzed, for the LOCA accident regime, the performance requirements are confirmed by analysis.

The heat exchangers of the shutdown cooling system have the ability to perform the cooling of the primary heat transport system at 177°C to 54°C in approximately 79 minutes, if the inlet temperature at reactor cooling water (RCW) is 30°C.

After 79 minutes, the residual heat necessary to be extracted from the primary circuit by means of both heat exchangers of the shutdown cooling system is approx. 10 MW and the thermal load of the heat exchanger is 10.99 MW.

If the inlet temperature of the RCW heat exchangers is 35°C, then the cooling from 177°C to 54°C of the primary heat transport system will be made in approx. 86 minutes.

After 86 minutes, the residual heat necessary to be extracted from the primary circuit by means of a heat exchanger of the shutdown cooling system is approx. 4.85 MW and the thermal load of the heat exchanger is 8.95 MW.

For the model in which the PHTS cooling is provided only by one of the heat exchangers of the SDCS, if the inlet temperature of the RCW heat exchangers is 30°C, the residual heat necessary to be extracted has a value of 3.71 MW. By means of the heat exchanger having the heat load of 5.4 MW, cooling from 177°C to 54°C is achieved in approx. 88 minutes.

If the inlet temperature of the operating heat exchanger is 35°C, then cooling from 177°C to 54°C of the primary heat transport system will be achieved in approx. 90 minutes.

After 90 minutes, the residual heat necessary to be extracted from the primary circuit by means of a heat exchanger of the shutdown cooling system is approx. 2.87 MW and the thermal load of the heat exchanger is 4.17 MW.

As a result of this thermal analysis wherein the inlet temperature of the intermediate cooling water at the heat exchangers is 35°C, there were observed a series of differences compared to the data sheets of the heat exchangers, HX1 and HX2, namely:

≡ *thermal load taken by the heat exchangers is smaller, but above the necessary;*

≡ *primary heat transport system may be cooled to a temperature of 54°C, but it would take longer time;*

≡ *intermediate cooling water temperature at the outlet of the heat exchanger has a higher value.*

Another observation is that both the operation with two heat exchangers, as well as that with a heat exchanger, in LOCA accident regime, SPTC cooling can be achieved by using the SRO. The only difference noticed between the two models considered is that for the operation with a heat exchanger instead of two, cooling is done in a longer, but covering time.

Regarding the temperatures, it is found a normal evolution in the PHTS cooling process, but which cannot be measured accurately and precisely because of the lack of information on the conditions under which the analyses were developed as the basis for the evolution curves of the residual heat present in the reactor after 15 minutes, and 30 minutes, respectively, from the start of the accident of the coolant loss type.

Analyzing the parameters of the cooling system for all cooling processes considered it was found that the values obtained for thermal-hydraulic parameters, as well as the duration up to reaching specified limits fall within the design values of the system. Cooling speeds situated below the value of 2.8˚C/min at the reactor outlet for all cooling regimes in case of LOCA type accidents.

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