Competitive Outage Lengths when Servicing the Liquid Relief Valves of the Heat Transport System

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ABSTRACT. Conservative engineering judgement has been frequently used to decide how early into an outage certain type of maintenance work for key elements of the Heat Transport System (HTS) can be conducted. The immediate consequence of this approach is that the length of the outages is increased unnecessarily because this maintenance work often becomes the critical path and, in an environment of competition such as the up coming open market for electricity in Ontario, short duration outages provide great strategic advantages.
This paper presents the work done to relax the 30-day waiting period to block closed the LRVs.
A detailed model of the HTS which includes the SDCS and the LCH piping connection to the D_2O Storage Tank was developed for the state-of-the-art Two Unequal Fluids (TUF) computer code. The results of the simulations with the TUF code have shown that the LCH can be credited as the overpressure relief path as early as two days after unit shutdown in case of loss of forced circulation (e.g., loss of Class III Power to the SDCS pumps). The financial savings and the additional flexibility in planning outage work due to the reduction of the waiting period by a factor of 15 are apparent.

1. INTRODUCTION

The use of empirical or engineering judgement in plant operations is mainly due to the lack of analysis that addresses incidents or accidents when a Unit is in a state such as low power critical or the Guaranteed Shutdown State (GSS). In the case of the Liquid Relief Valves (LRVs), engineering judgement demands a 30-day waiting period after reactor shutdown before blocking them closed for their maintenance work. That is to say, during the initial period of the outage the only credited overpressure relief protection path for the HTS is the LRVs. This same waiting period applies whenever (i) the Bleed Condenser must be removed from service since the LRVs discharged into it and (ii) fuel channel work is performed because some equipment (e.g., CIGAR) is only registered to operate up to 2.7 MPa(g). After the conclusion of the 30-day period, the piping connection between the suction of the Shutdown Cooling System (SDCS) pumps and the D_2O Storage Tank — the Level Control Header (LCH) — is credited as the alternate overpressure protection path.

Thus, the purpose of this work is to determined the maximum HTS pressure and the maximum fuel and fuel sheath temperatures following a loss of SDC flow for various decay power levels assuming that the overpressure protection of the HTS is only provided by the LCH.

2. ASSUMPTIONS

In this work, the following conditions of the HTS were assumed:

a) The Unit was operating at 100 %FP before shutdown.
b) The HTS is in GSS.
c) The East SDC quadrants are used as the heat sink and consequently, the HTS temperature and pressure are approximately 40 °C and 280 kPa(a), respectively.
d) The decay power for one, two and three days after shutdown is 0.5704, 0.4493 and 0.3820 %FP, respectively [1].
e) Three full boilers are available in the West side of each HTS Loop.
f) The HTS Liquid Relief Valves are unavailable.
g) The D_2O Storage Tank pressure and level are 200 kPa(a) and 0.5 m, respectively.

h) The set point of D_2O Storage Tank relief valve 3333-RV205 is 377 kPa(a).
i) The bounding initiating event is a Design Basis Earthquake (DBE).

3. MODELING

For this work, a detailed model of the HTS which includes all the fuel channels, two East SDC quadrants and the LCH piping connection to the D_2O Storage Tank was developed for the state-of-the-art Two Unequal Fluids (TUF) computer code [2].

3.1 Fuel Channels

The 380 channels in the reactor core are modeled with twelve different fuel channel average regions. These 12 regions are subsequently divided in two groups that represent all the channels with nominal forced flow in the East to West and West to East directions. Using the symmetry of the Calandria, Figure 1 shows only the groups for the North HTS Loop. Since the mass flowrates are considerably lower than at full power, the average change of elevation of the fuel channel groups with respect to the reactor headers becomes a very important parameter compared to frictional or form losses, especially in the cases of loss of forced flow:

Group	Number of Fuel Channels	Average Elevation (m)
1	32	-5.938
2	32	-7.299
3	32	-8.508
4	32	-5.140
5	30	-7.549
6	32	-9.675

3.2 Shutdown Cooling System

A detailed model of the SDC loop which includes the flowpath, valves, a simplified pump and an explicit model of the heat exchanger was developed to simulate the steady state of the HTS at different decay powers before the initiating event.

3.3 Level Control Header

The piping connection between the East SDC quadrants to the Storage Tank was modeled since this was considered as the credited HTS overpressure relief path when LRVs are unavailable during the accident conditions.

A sketch of the model used in this assessment is shown in Figure 2.

4. RESULTS AND DISCUSSIONS

Three cases have been simulated to determine an adequate waiting period before crediting the LCH as the overpressure relief path in the case of a DBE. Cases 1, 2 and 3 are simulated assuming that the decay power level corresponds to one, two and three days after Unit shutdown, respectively.

4.1 Acceptance Criterion

The new waiting period to be determined in this assessment must satisfy the following requirements:

- Maximum fuel and fuel sheath temperatures must not exceed their "Return To Service" criteria for low HTS pressure [1].
- The D_2O Storage Tank must be able to accommodate the coolant discharged from the HTS due to thermal swell.

- The maximum HTS pressure must not exceed the discharge pressure of the Emergency Water System (EWS) pumps to allow injection to the West RIHs [3].

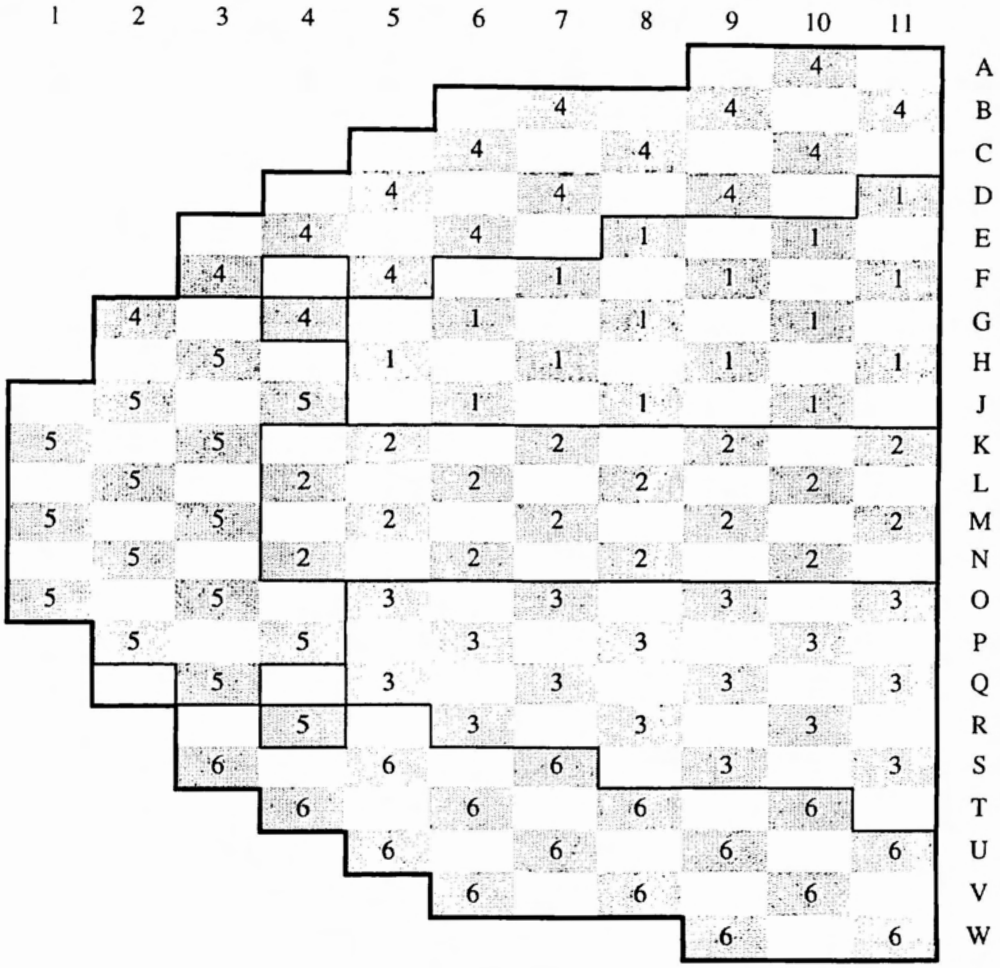

Figure 1. Channel groups in the core.

4.2 Steady State

Briefly, for a given decay power level, the HPSW flow to the secondary side of the SDC HX is controlled to provide a tube side outlet temperature of approximately 38°C. As indicated before, the SDC pump discharge flow is determined by the hydraulic resistances in the flowpath. For this analyzed HTS configuration of the East SDC pump operating and three boilers in the West side, the flow in each HTS loop is approximately 220 kg/s. The steady state pressure and temperature distribution in both HTS loop during this initial period are as follows:

Location	Pressure [kPa(a)]	Temperature [°C]
D_2O Storage Tank	200.0	40.0
East RIH	299.0	37.0
West ROH	288.0	39.5
West RIH	284.0	39.5
East ROH	272.0	42.0

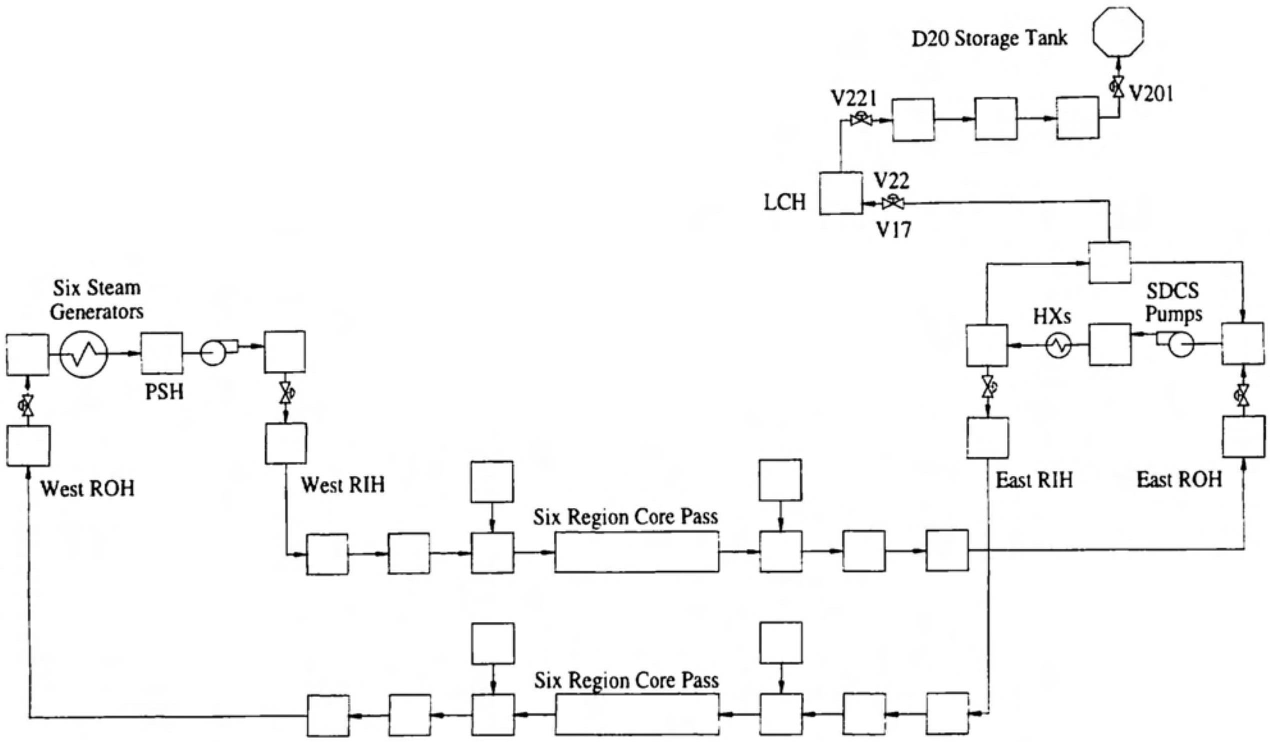

Figure 2. Sketch of the HTS model used in this assessment.

4.3 Transient Conditions

Initially, for each of the three cases, the simulation is allowed to run for 300 s to ensure that steady state conditions have been reached in the HTS. During this period of operation with the SDC pump, an average mass flowrate of 1.16 kg/s flows through every fuel channel.

At 300 s into the simulation, a DBE is assumed to occur. Power supply to the SDC pumps is interrupted and forced flow is lost almost immediately. Consequently, the coolant flow approaches stagnation conditions throughout the HTS for the following 400 s. In this period, the coolant temperature in every fuel channel group steadily increases from 40 °C to a range of 70 to 120 °C, as shown in Figures 3(a), 3(b) and 3(c), because the decay power available in the fuel is still being transferred to the stagnant coolant.

The temperature gradients in the inlet and outlet feeders established during SDCS operation in conjunction with the thermal swell of the coolant due to heat up are factors that encourage the development of thermosyphoning in the core. Thus, towards 700 s into the simulation, a new flow pattern starts to emerge. Figure 4 illustrates a typical flow distribution in the fuel channels for this HTS configuration. As shown, reverse and forward flows are predicted for the fuel channels in the upper (Groups 1 and 4) and lower (Groups 2, 3, 5 and 6) halves of the Calandria, respectively. In all the analyzed cases, the long term flow magnitude per channel group in either direction reaches a nearly constant value between of 10 to 17 kg/s.

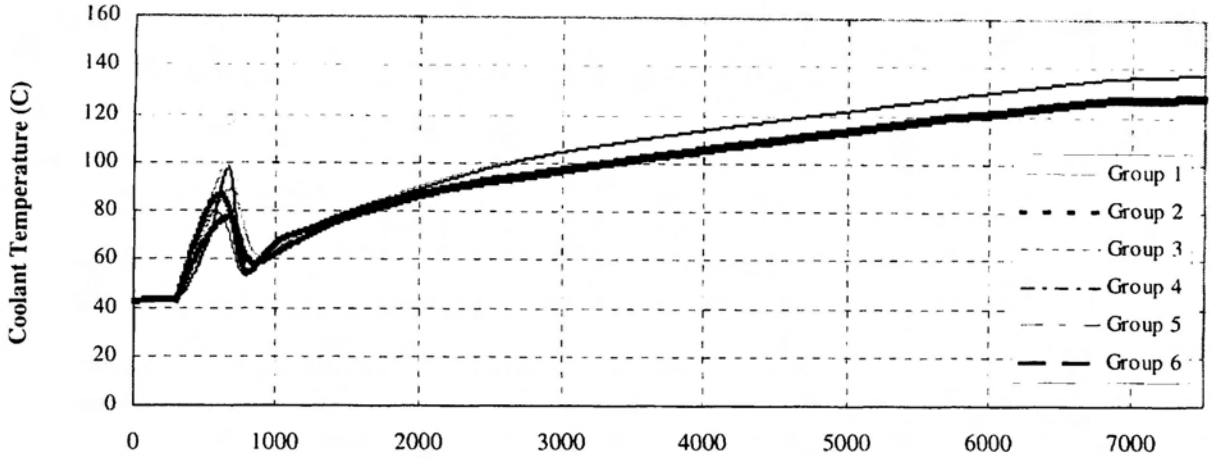

Figure 3(a). Fuel channel coolant temperature for Case 1.

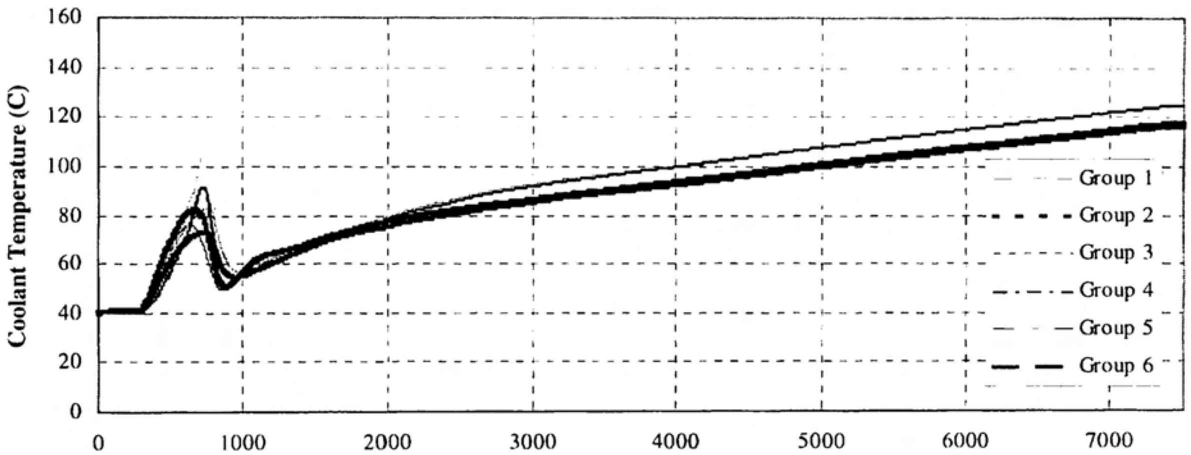

Figure 3(b). Fuel channel coolant temperature for Case 2.

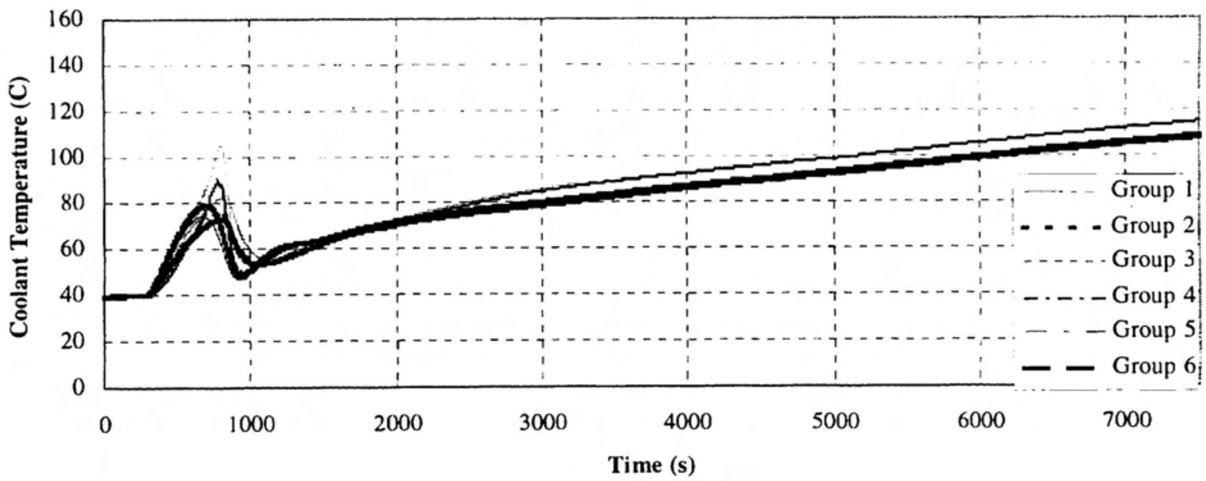

Figure 3(c). Fuel channel coolant temperature for Case 3.

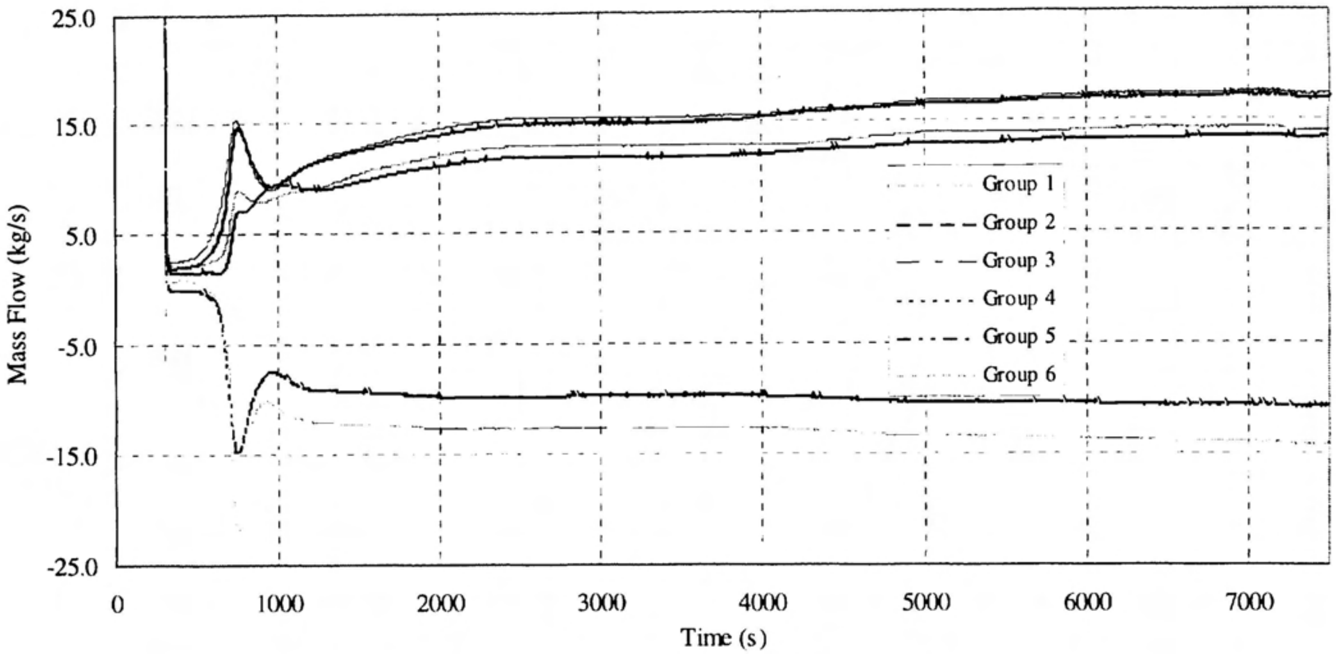

Figure 4. Typical flow distribution in the fuel channels.

The establishment of a new flow pattern, whether in the forward or reverse direction, provides cooling that prevents any void generation in the channels and promotes mixing in the HTS. However, since no heat sink is assumed available, the coolant temperature continues to increase due to the addition of decay power. Figures 5(a), 5(b) and 5(c) show the monotonic trend of heat up of the coolant in each of the analyzed cases. Towards the end of the simulation, the maximum coolant temperatures approximately are 130 °C, 120 °C and 110 °C for Cases 1, 2 and 3, respectively.

Figures 5 also show that in each Case, for the current HTS configuration the highest temperatures are found in the East RIHs and West ROHs. This is mostly due to the lack of symmetry in the flowpaths: in the East side, the ROHs and RIHs are connected by the 10" SDC piping while in the West side, the ROHs and RIHs are connected via the three boilers and the Pump Suction Header. Therefore, with an average coolant flow of 18 kg/s in each HTS loop, the time required by the flow to travel between the reactor headers in the East side is approximately 40 s. In contrast to this, a travel time of nearly 1000 s is needed for the flow to travel between the headers in the West side. Figures 5 indicate that after the first 2500 s of the simulation, all reactor headers experience a constant heat up rate of approximately 0.6, 0.5 and 0.4 °C/min for Cases 1, 2 and 3, respectively. It also shows that a temperature difference of up to 25 °C can be established between the hottest and coldest headers.

Figures 6(a), 6(b) and 6(c) present the fuel center temperatures during the transient. After their initial increase due to the loss of forced flow, the improved cooling temporarily decreases its temperature to a range of 60 to 70 °C, but the lower heat removal rate causes again the monotonic increase in temperature. However, the fuel center never exceeds the temperature of 150 °C during the entire simulation in any of the analyzed cases.

As indicated before, the increase in coolant temperature causes its thermal swell and forces the flow towards the Storage Tank via the LCH. The discharge flow noticeably increases the initial mass

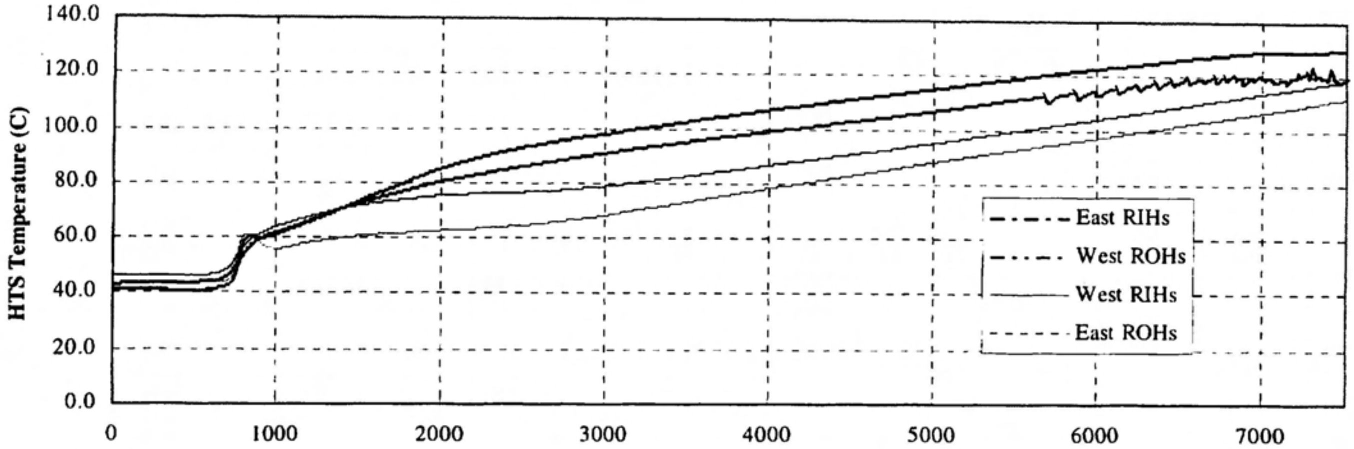

Figure 5(a). HTS temperature for Case 1.

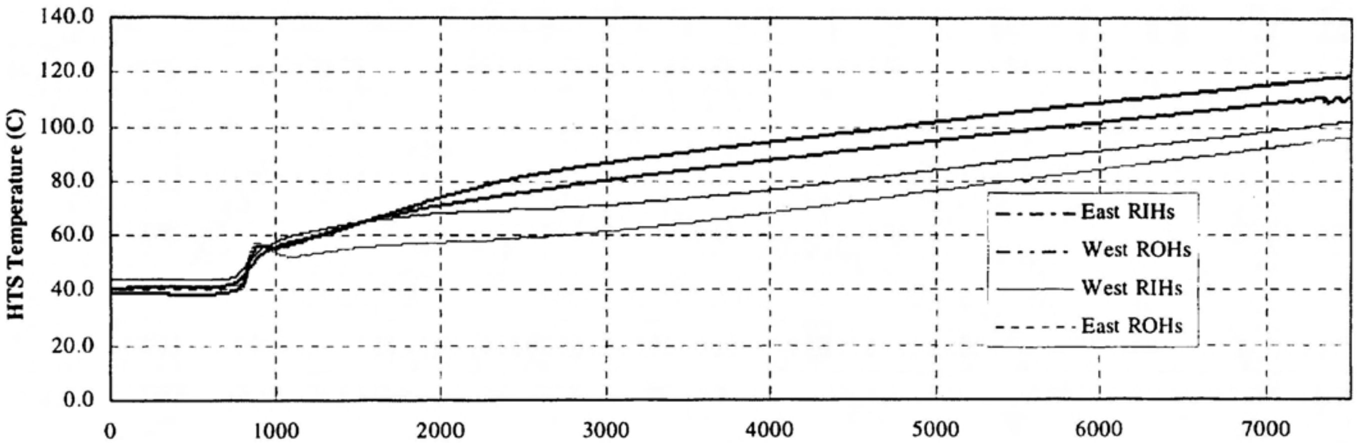

Figure 5(b). HTS temperature for Case 2.

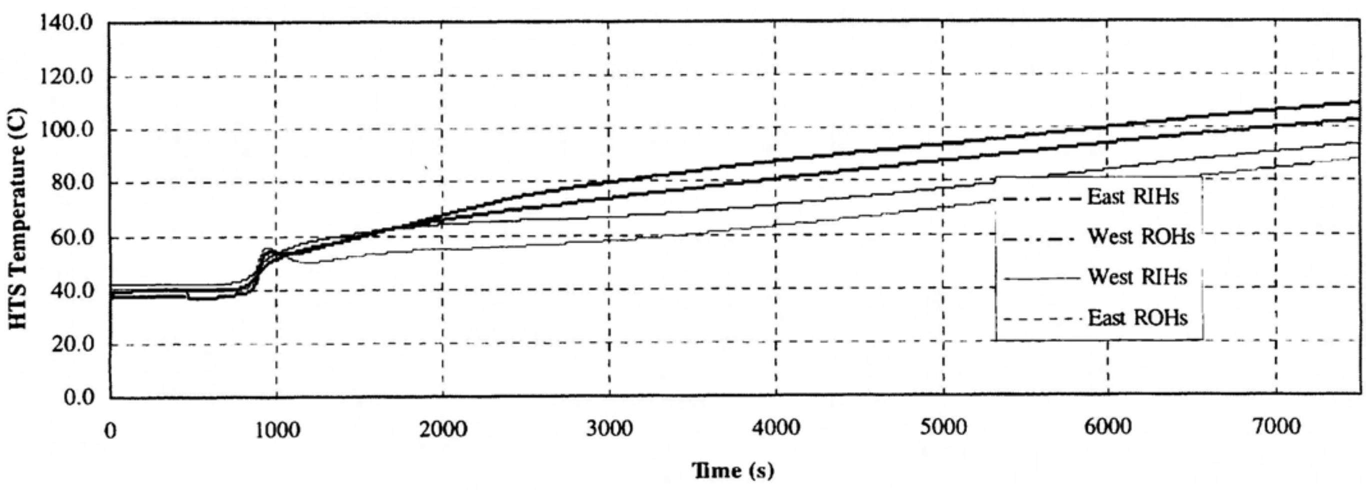

Figure 5(c). HTS temperature for Case 3.

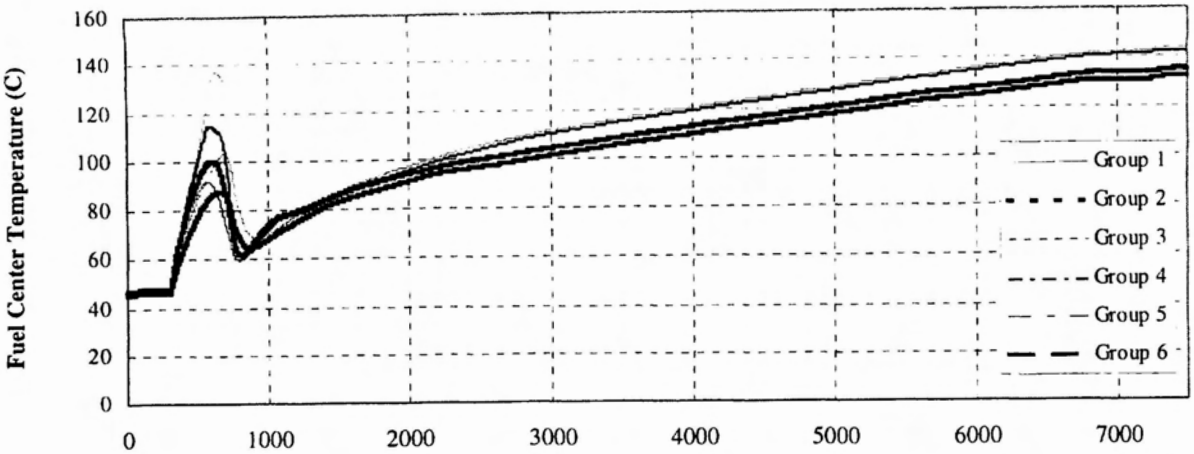

Figure 6(a). Fuel Center temperature for Case 1.

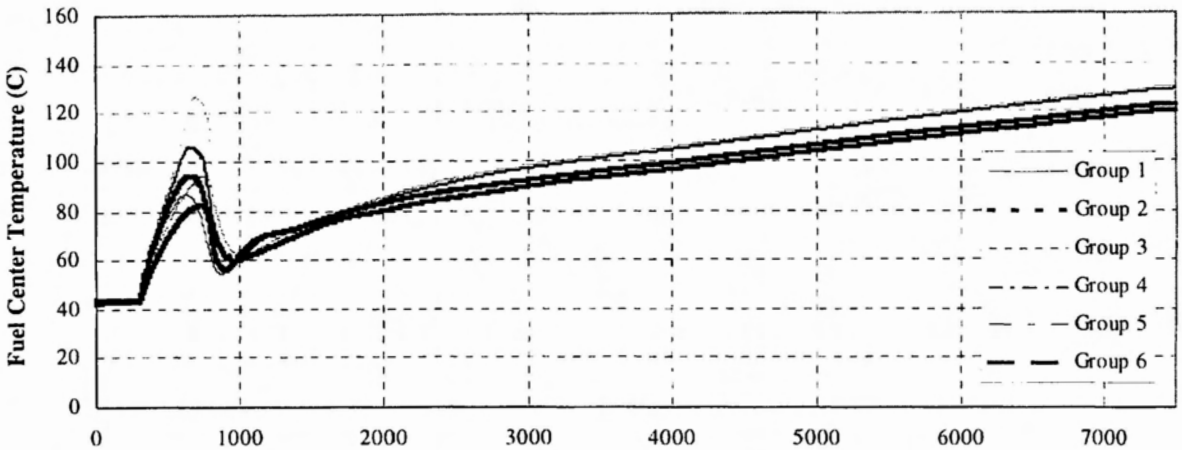

Figure 6(b). Fuel Center temperature for Case 2.

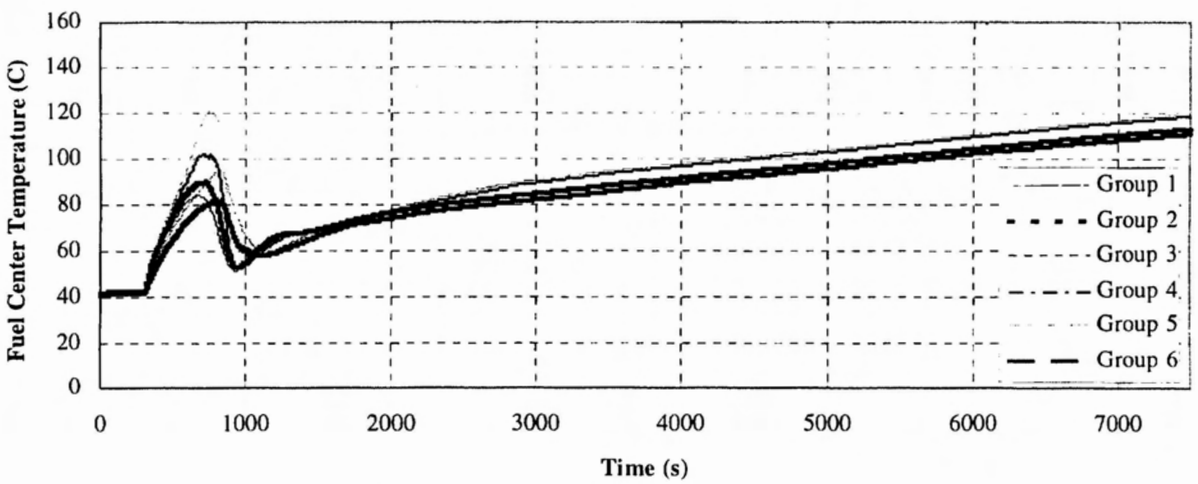

Figure 6(c). Fuel Center temperature for Case 3.

inventory as illustrated in Figure 7. Consequently, this discharge flow compresses the Storage Tank Cover Gas (Helium) causing a slow pressurization of the HTS as shown in Figure 8. Therefore, in spite of the constant heat up of the coolant, neither local nor bulk boiling in the HTS is predicted because the saturation temperature increases as a result of the HTS pressurization and thus, single-phase thermosyphoning prevails during these transients.

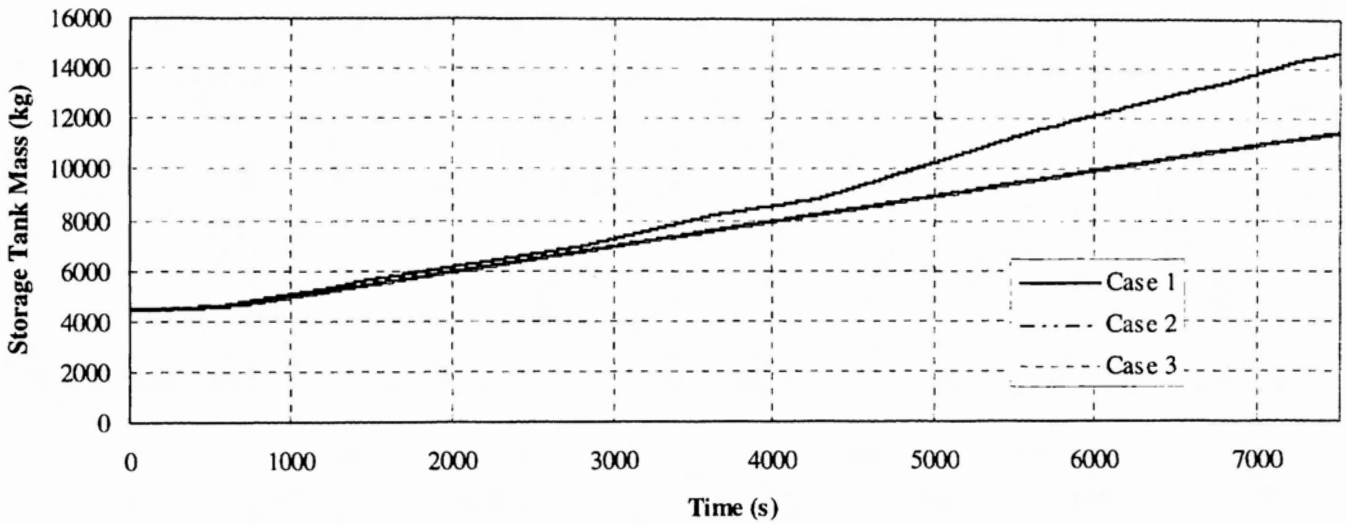

Figure 7. Increase in the Storage Tank inventory for the analyzed cases.

With respect to the Secondary Side, bulk boiling in shell side of the SDC heat exchanger is present once the HTS coolant heats up the service water beyond its saturation temperature. As shown towards the end of the simulation in Figure 5, the boiling causes oscillations in the temperature of the East RIHs due to their proximity to the heat exchanger. As for the boilers, their large coolant inventory and isolation prevent any boiling for the duration of the simulation in each analyzed Case.

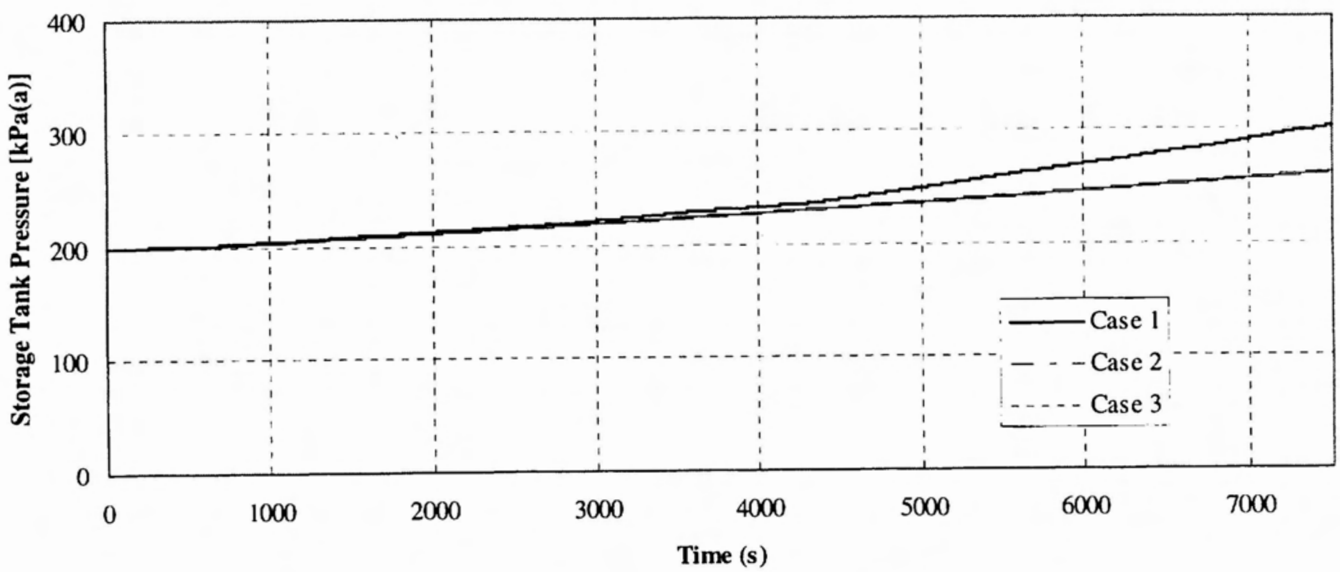

Figure 8. Pressurization of the Storage Tank.

5. CONCLUSIONS

The following conclusion can be drawn from the results obtained in this assessment:

- The waiting period of 30 days before crediting the Level Control Header as the overpressure relief path whenever the LRVs are being serviced is extremely conservative.
- The 3 cases analyzed successfully meet the Acceptance Criterion proposed in this work.
- This assessment supports the decision of substantially shortening the waiting period.
- Adequate recall time to start up the Standby Generators and allow EWS injection to both the boilers and HTS if required.

6. RECOMMENDATIONS

Based on the results obtained in this work, a two-day waiting period is recommended to credit the LCH as the overpressure relief path. This choice is realistic since it will allow to conduct all the prerequisite work to conduct LRVs or Bleed Condenser maintenance work or installation of fuel channel inspection/work equipment; it also present financial advantages over longer waiting periods.

Acknowledgements - The author wishes to express his gratitude to Wasfy Yousef (NOSS - OPG) for his assistance while preparing this work.

7. REFERENCES

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