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SOLVING REACTOR WATER CLEAN-UP SYSTEM ANOMALIES USING RELAP5 MOD3.3

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ABSTRACT

To allow the plant to enter the cold shut down phase of operation sooner, the Reactor Water Clean-Up System (RWCU) is used to remove heat from the reactor during shutdown. The RWCU is normally used in a Boiling Water Reactor (BWR) to remove impurities and maintain high reactor water purity during normal operation. The RWCU system contains, in addition to other components, 3 pumps and 7 heat exchangers. Normally, the RWCU has 1 pump in service and 2 pumps in standby. The 5 in service heat exchangers consist of 3 tube/shells for the Regenerative heat exchangers and 2 tube/shells for the Non-Regenerative heat exchangers. Additionally, 2 tube/shells Non-Regenerative heat exchangers are in standby.

During the early part of shutdown of a BWR, the plant is cooled down by depressurizing the reactor to the main condenser. In some cases, during shutdown and the cool down phase of the reactor, the RWCU heat exchangers are used to remove energy from the reactor water prior to the initiation of Residual Heat Removal (RHR) phase. This use of the RWCU system for shutdown depressurize is important in reducing the time it takes to arrive at shutdown conditions. This helps in reducing the outage length because there are many systems that can not be taken out-of-service until the plant is in cold shutdown mode. RHR cooling is started when the reactor water is about 149^o C (300^o F). The RHR is used to cool the reactor from 149^o C (300^o F) to 93^o C (200^o F), which is the Technical Specification defined temperature for cold shutdown conditions. The RWCU pumps can be used at all temperatures of normal operation, therefore the RWCU pumps and heat exchangers can be used to pump and cool the hot water (i.e., greater than 149^o C (300^o F) during the cool down phase to 149^o C (300^o F)). After the reactor water reaches about 149^o C (300^o F), the RWCU is no longer needed for shutdown cooling, since RHR can remove the heat and reduce the reactor water temperature to a cold shutdown state.

During this cool down phase of operation, parts of the RWCU system experienced significant vibrations and cavitations in the RWCU piping and at the inlet of the RWCU pump. These vibrations could damage the containment penetrations that the RWCU piping passes through and the cavitation at the RWCU pump inlet could damage the pump and degrade flow. The utility operators wanted to understand the anomalies and develop a root cause and corrective action to eliminate

the RWCU anomalies.

RELAP5 MOD3.3 (Ref. 1) was used to simulate the RWCU system so the problem could be reviewed and sensitivity studies could be performed. From these studies, a root cause for the anomalies was found and proposed corrective actions to eliminate the anomalies were presented.

In reviewing the RELAP5 cases analyzed, it was determined that the case used to simulate 189 liters/m (50 gpm) of water recirculated from the discharge of the RWCU demineralizer to the RWCU piping just down stream of the containment penetrations, provided the most likely solution for eliminating the RWCU anomalies. By providing 189 liters/m (50 gpm) of 49^o C (120^o F) water into the piping leaving the containment penetration (i.e. RELAP5 Volume 101250000 – see nodal diagram in Fig. 1), the vibration and cavitation problems are reduced significantly.

1. INTRODUCTION

In an effort to become more efficient and cost effective in the operation of nuclear power plants, there is an emphasis on bringing the plants up faster during start-up and shutting them down sooner when going into an outage. A plant in the northeast USA experienced anomalies on several occasions when they were shutting their plant down. This paper discusses the anomalies, possible root cause and potential modifications to eliminate these anomalies.

2. DISCUSSION

In some instances, during the cool down phase using the RWCU system, pipe vibration and pump cavitation occurred at a BWR plant. The pipe vibration could damage the piping restraints and containment penetrations used for the RWCU piping. Pump cavitation could damage the RWCU pumps and degrade their performance. The RWCU is normally used in a Boiling Water Reactor (BWR) to remove impurities during normal operation. The RWCU system contains, in addition to other components, 3 pumps and 7 heat exchangers. Normally, the RWCU has 1 pump in service and 2 pumps in standby. The 5 in service heat exchangers consist of 3 tube/shells for the Regenerative heat exchangers and 2 tube/shells for the Non-Regenerative heat exchangers. Additionally, 2 tube/shells Non-Regenerative heat exchangers are in standby.

During the early part of shutdown of a BWR (Ref. 2), the plant is cooled down by depressurizing to the main condenser. In some cases, during shutdown and the cool down phase of the reactor, the RWCU heat exchangers are used to remove energy from the reactor water prior to the initiation of Residual Heat Removal (RHR) phase. The use of the RWCU system for shutdown depressurization and cool down is important in reducing the time it takes to arrive at shutdown conditions. This helps in reducing the outage length because there are many systems that can not be taken out-of-service until the plant is in cold shutdown mode. RHR cooling is started when the reactor water is about 149^o C (300^o F). The RHR is used to cool the reactor from 149^o C (300^o F) to 93^o C (200^o F), which is the Technical Specification defined temperature for cold shutdown conditions. The RWCU pumps can be used at all temperatures of normal operation, therefore the RWCU system can be used to pump and cool the hot water (i.e., greater than 149^o C (300^o F)) during the cool down phase to 149^o C (300^o F).

A RELAP5 model (Refs. 1 & 2) was constructed to simulate this cool down process and to help develop a root cause and corrective action plan to eliminate the anomalies. The RELAP5 MOD3.3 (Ref. 1) model was based on the nodal diagram presented in Fig. 1. Time Dependent Volumes (TDVs) 1 & 2 represent the reactor vessel. TDV1 represents the reactor vessel pressure and temperature conditions as a function of time at the recirculation system exit point for the RWCU system. TDV2 represents the reactor vessel pressure and temperature conditions as a function of time at the bottom of the reactor vessel, which is another exit point for the RWCU system. TDV2 is slightly elevated above TDV1, therefore the pressure is slightly different. As seen in Fig. 1, the RWCU pipe that exits TDV2 is 5.1 centimeters (2-inches) in diameter, which increases to 10.2 centimeters (4-inches) pipe. This pipe is designated RELAP5 component 102. The RWCU pipe that exits TDV1 is 15.2 centimeters (6-inches) in diameter and is designated RELAP5 component 101. The 10.2 centimeters (4-inch) RWCU piping that leaves the bottom of the reactor vessel connects to the 15.2 centimeters (6-inches) piping that leaves the TDV1 at Component 101040000 as shown in Fig. 1. From there the RWCU piping continues until it enters the RWCU pump, which is represented by TDV4. The base RELAP5 model designated as Case 1 simulated the depressurization of the reactor to 1551 kilopascals (225 psia). The review of the transient was started when the reactor pressure was about 3620 kilopascals (525 psia) and the temperature was at 245^o C (473^o F). The pressure was decreased by 13.8 kilopascals/sec (2 psi/sec) until the reactor pressure was less than 1551 kilopascals (225 psia).

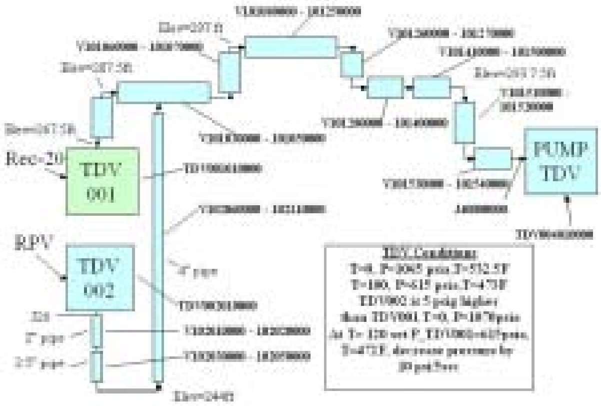

Figure 1 RELAP5 Nodal Diagram of RWCU Suction Piping From Reactor Vessel

The RELAP5 model was used to simulate the possible alternative corrective action scenarios and compare these results to determine the best corrective action.

Several possible corrective actions were proposed, which considered changes to the physical layout of the plant. These included 1) providing pure recirculation water into the upstream piping of the RWCU system, 2) lower the flow through the RWCU pumps, 3) change the split flow ratio leaving the reactor through the RWCU system, 4) change the heat transfer conditions on the RWCU piping, and 5) change the cool down rate of the reactor. The alternative explored here is to provide pure recirculation water into the upstream piping of the RWCU system.

The following RELAP5 Simulations were performed:

RWCU Studies:

•Case 1: Original case with reactor depressurization to Saturation Conditions in the RPV. This case represents the base case depressurization to 1551 kilopascals (225 psia) in the reactor vessel.

•Case 2: Reactor depressurization to 1551 kilopascals (225 psia) with a flow of 95 liters/m (25 gpm) of 49 ^{o} C (120 ^{o} F) water into V101040000 (See Fig. 1). This case represented water taken at 95 liters/m (25 gpm) from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping inside the containment. To implement this modification, an extra penetration through the containment must be used to pipe the water from the RWCU heat exchangers to the RWCU piping inside containment. This additional requirement adds significant cost to the modification and this additional cost should be considered when deciding on a final solution.

•Case 3: Reactor depressurization to 1551 kilopascals (225 psia) with a flow of 189 liters/m (50 gpm) of 49 ^{o} C (120 ^{o} F) water into V101040000 (See Fig. 1). This case represented water taken from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping inside the containment. To implement this modification, an extra penetration through the containment must be used to pipe the water from the RWCU heat exchangers to the RWCU piping inside containment. This potential modification has the same restrictions as Case 2.

•Case 4: Reactor depressurization to 1551 kilopascals (225 psia) with a flow of 95 liters/m (25 gpm) of 49 ^{o} C (120 ^{o} F) water into V101250000 (See Fig. 1). This case represented water taken from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping that exits the containment penetration. This would be a less expensive modification since all work would be outside containment.

•Case 5: Reactor depressurization to 1551 kilopascals (225 psia) with a flow of 189 liters/m (50 gpm) of 49 ^{o} C (120 ^{o} F) water into V101250000 (See Fig. 1). This case represented water taken from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping that exits the containment penetration. This would be a less expensive modification since all work would be outside containment.

3. RESULTS

Figs. 2 & 3 show the simulation results of the base case, Case 1, which represents a reactor depressurization from 3620 kilopascals (525 psia) to below 1551 kilopascals (225 psia) at a rate of 13.8 kilopascals/sec (2 psi/sec). The high point of the RWCU piping is represented by V101250000 (See Fig. 1) and the inlet to the RWCU pump is represented by V101540000. Fig. 2 show the pressure and temperature variation at the reactor vessel for the base case. As shown in Fig. 3 for the base case, the water densities at the high point and at the RWCU pump inlet fall to almost zero at 200 seconds. This causes significant cavitations at the RWCU pump suction (i.e., V10154000) and at the high point close to the containment penetration (i.e., V101250000). As shown in Figure 3, the flow to the pump (i.e., mflow_40000000) is almost zero because of the voiding in the pump.

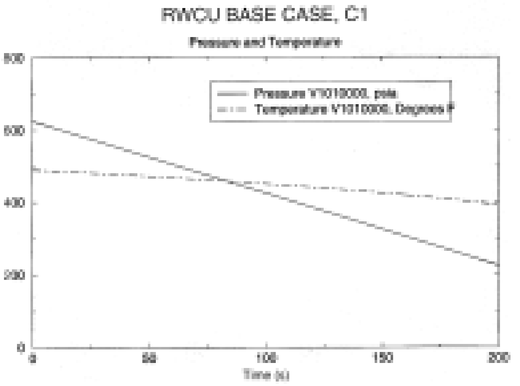

Figure 2 Case 1–Base Case Shutdown Depressurization, Pressure & Temperature

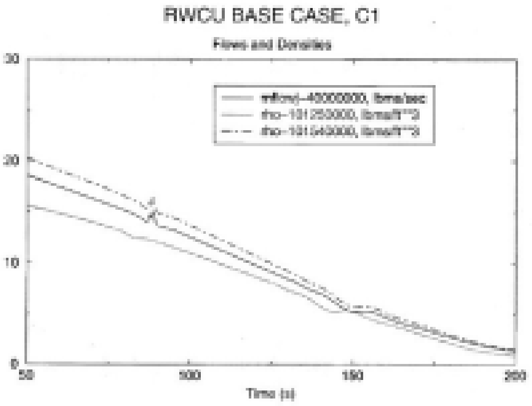

Figure 3 Case 1–Base Case Shutdown Depressurization, Flow & Densities

Fig. 4 presents the water density variation at the RWCU high point for Cases 1 through 5. As shown in Fig. 4, the base case (i.e., Case 1) high point RWCU water density falls from 256 kg/m^3 (16 lbms/ft^3) to almost 32 kg/m^3 (2 lbms/ft^3) at 175 seconds. This shows that, in the base case depressurization of the reactor, significant voiding occurs in the high point piping of the RWCU system. Cases 2 through 5 were simulated to explore alternative solutions to eliminating or reducing this significant voiding. One can see from the water density comparisons in Fig. 4 that the Case 3 simulation produces the best results. This case is represented by 49^o C (120^o F) water taken at 189 liters/m (50 gpm) from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping inside the containment. This case shows that the water density of the RWCU can be maintained at high levels during the depressurization. The Case 2 simulation maintains a high density and then falls abruptly at 175 seconds indicating voiding in V101250000 (i.e., RWCU high point). Case 2 is represented by 49^o C (120^o F) water taken at 95 liters/m (25 gpm) from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping inside the containment. It is interesting to note that the Case 5 simulation shows the density at the RWCU high point to remain relatively flat. Case 5 represents water taken at 189 liters/m (50 gpm) from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping that exits the containment penetration. Cases 4 and 5 modifications are more cost effective than Cases 2 and 3 modifications, since the Cases 4 and 5 modifications would be performed outside the containment. Case 5 shows that the proposed modification that pipes 189 liters/m (50 gpm) RWCU water from the discharge of the RWCU heat exchangers to the 15.2 centimeters (6-inches) RWCU piping that exits the containment penetration, could prevent significant voiding in the RWCU high point piping (i.e., piping nodes V101080000 - V101250000).

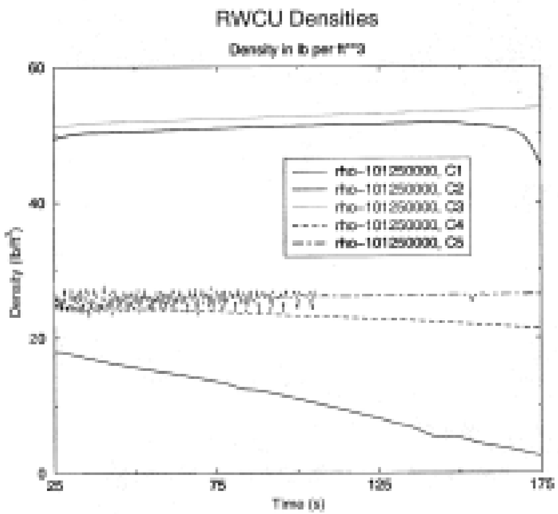

Figure 4 Case 1 through Case 5 Density Comparisons for V101250000

Fig. 5 presents the water density variation at the RWCU pump inlet for Cases 1 through 5. As shown in Fig. 5, the base case for the RWCU pump water density falls from 320 kg/m^3 (20 lbms/ft^3) to about 48 kg/m^3 (3 lbms/ft^3) at 175 seconds. This shows that, in the base case depressurization of the reactor, significant voiding occurs at the RWCU pump inlet. Cases 2 through 5 were simulated to explore alternative solutions to eliminating or reducing the significant voiding. One can see from the water density comparisons in Fig. 5 that the Cases 3 and 5 simulations produce the best results. Case 3 is represented by 49 ^{o} C (120^o F) water taken at 189 liters/m (50 gpm) from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping inside the containment and Case 5 is represented by 49^o C (120^o F) water taken at 189 liters/m (50 gpm) from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping that exits the containment penetration. These cases show that the water density at RWCU pump inlet can be maintained at high levels during the depressurization when using recirculation water at 189 liters/m (50 gpm) inserted outside the RWCU penetration. The Case 2 simulation maintains a high density and then falls slightly at 175 seconds indicating some voiding in V101540000 (i.e., RWCU pump inlet). Case 2 is represented by 49^o C (120^o F) water taken at 95 liters/m (25 gpm) from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping inside the containment. It is interesting to note that the Case 5 simulation shows the density at the RWCU pump inlet to remain relatively flat and stable. Case 5 represents water taken at 189 liters/m (50 gpm) from the discharge of the RWCU heat exchangers and piped to the 15.2 centimeters (6-inches) RWCU piping that exits the containment penetration. As noted previously, Cases 4 and 5 modifications are more cost effective than Cases 2 and 3 modifications, since the Cases 4 and 5 modifications would be performed outside the containment. Case 5 results show that the proposed modification, which pipes 189 liters/m (50 gpm) RWCU water from the discharge of the RWCU heat exchangers to the 15.2 centimeters (6-inches) RWCU piping that exits the containment penetration, could prevent significant voiding in the RWCU pump inlet.

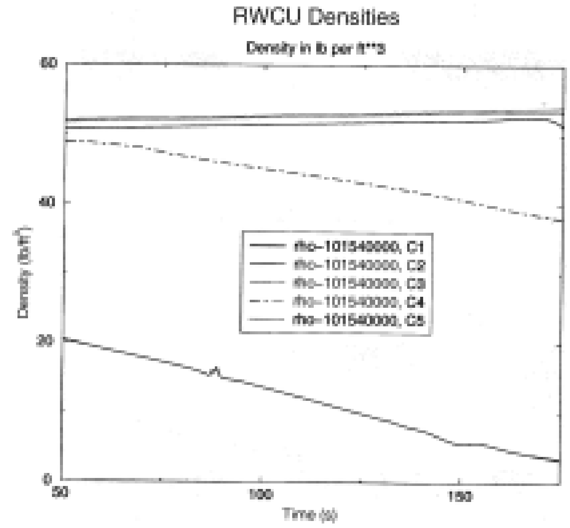

Figure 5 Case 1 through Case 5 Density Comparisons for V101540000

4. CONCLUSIONS

In reviewing these cases, it was determined that Case 3 (i.e., 189 liters/m (50 gpm) of 49 ^{o} C (120 ^{o} F) water into V101040000) provided the best solution to the cavitation anomalies. Additionally, Case 5 (i.e., 189 liters/m (50 gpm) of 49 ^{o} C (120 ^{o} F) water into V101250000) provided a possible solution with considerably less cost since the proposed modifications would be performed outside the containment. By providing 189 liters/m (50 gpm) of 49 ^{o} C (120 ^{o} F) water into the piping leaving the containment penetration (i.e., RELAP5 Volume 101250000 – see nodal diagram in Fig. 1), the vibration and cavitation problems can be reduced significantly.

5. REFERENCES

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