The pressurizer relief and safety valve system provides the reactor coolant system overpressure protection and, therefore, it is fundamental for the security of a nuclear plant. This paper discusses the safety valve loop seal strategies adopted by other nuclear power plants over the world in order to attend the recommendations of NUREG-0578 (TMI-2 Lessons Learned Task Force Status Report and Short Term Recommendations). The technical option adopted for Angra 1 consists in making specific modifications on the original piping and support configuration of the pressurizer relief and safety valve system. These modifications were proposed in order to reduce the high stress levels induced by the thermal-hydrodynamic loads caused by the discharge of the sub-cooled water during the opening of the relief or the safety valves. Several thermal-hydraulic models were tested to assess the influence of the seal water heating and the simultaneous opening of the valves in order to minimize the thermal hydrodynamic loads effects. The piping structural analysis was performed, using the computer program system KWUROHR, to satisfy the requirements of the appropriate equations of the code ASME Section III, Subsections NB3650 and NC3650.

Keywords: structural, analysis, strategies, pressurizer, valves.

I. INTRODUCTION

The pressurizer relief and safety valve system provides the reactor coolant system overpressure protection and, therefore, it is fundamental for the security of a nuclear plant. This paper discusses the safety valve loop seal strategies adopted by other nuclear power plants over the world in order to attend the recommendations of NUREG-0578 (TMI-2 Lessons Learned Task Force Status Report and Short Term Recommendations) [1]. Additionally, it presents the technical option adopted for Angra 1 that consists in making specific modifications on the original piping and support configuration of the pressurizer relief and safety valve system. These modifications were proposed in order to reduce the high stress levels induced by the thermal-hydrodynamic loads caused by the discharge of the sub-cooled water during the relief or safety valve opening.

The thermal-hydrodynamic loads were calculated using the computer codes RELAP5/MOD2 [2], PREPREF and REFORC [3]. Several thermal-hydraulics models were tested considering the influence of the seal water heating and the simultaneous opening of the valves in order to reduce the thermal-hydrodynamic loads effects. The piping structural analysis was performed using the computer program system KWUROHR [4].

The proposed piping configuration stresses were in accordance with the requirements of the code ASME-Section III, Subsections NB3650 and NC3650 [5].

II. GENERAL SYSTEM ASPECTS

The Fig. 1 shows the discharge piping simplified flow diagram. The system contains two safety valves (SV), two block valves (BV) and two relief valves (RV) in the nuclear class 1 part of the piping. Each safety valve is connected to the pressurizer nozzle by a 6-inch pipe. The relief line is also connected to the pressurizer nozzle by a 6-inch pipe, which is divided in two 3-inch lines. The safety and relief valves discharge into piping that is routed through a common header to a relief tank. The header is a 10-inch pipe which presents a loop before to be connected to the relief tank nozzle by a 12-inch pipe, as showed schematically in the Fig. 2. The Table 1 presents the geometrical properties and the design condition of the piping.

III. SAFETY VALVE LOOP SEAL STRATEGIES

Background. The safety valves must provide maximum seat tightness to prevent loss of the loop seal and excessive
Figure 1. Simplified Flow-Diagram of Pressurizer Discharge Piping System.

TABLE 1. Geometrical Properties and Design Condition of the Piping

<table>
<thead>
<tr>
<th>Nominal Diameter (in)</th>
<th>Class</th>
<th>Material</th>
<th>External Diameter (in)</th>
<th>Schedule</th>
<th>Wall Thickness (in)</th>
<th>Design Condition</th>
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</table>

PZR - Pressurizer
SV - Safety Valve
RV - Relief Valve
BV - Block Valve
RT - Relief Tank

- PZR - Pressurizer
- SV - Safety Valve
- RV - Relief Valve
- BV - Block Valve
- RT - Relief Tank
leakage in the pressurizer relief tank. It is worth to mention that seat leakage on pressurizer safety valves with standard geometry stellite seals has occurred on the early PWR plants designed without water seals. The leakage was attributed to the presence of the hydrogen gas in the steam that initiated leak paths and subsequent seat distortion due to thermal gradients from hot steam on the seat inlet and ambient conditions at the seat outlet. Water seals were incorporated into the plant design to keep gases and steam away from the seats and to keep the seals cool in order to minimize thermal distortion. The valve seat leakage problem was solved by the adoption of this change, resulting in reliable safety valve performance. However, the safety and relief valve test program conducted by the
Electric Power Research Institute (EPRI) [6] [7] has demonstrated that the forces imposed on the safety valve piping by the discharge of the cold loop seal water were more significant than previously believed.

Technical Solution Options. Three technical solution options adopted by the nuclear power plants over the world, in order to attend the recommendations of NUREG-0578 (TMI-2 Lessons Learned Task Force Status Report and Short Term Recommendations), are presented in the following.

a) Cold Water Loop Seal - This technical solution option consists of making no modification neither in the safety valves nor in the water loop seal (operate as-is).

Consequently, several support modifications have to be made in order to cope with the increasing hydraulic load values, imposed on the piping by the discharge of the cold loop seal water during the safety valve opening.

b) Hot Water Loop Seal - This technical solution option consists in increasing the seal water temperature by insulating and/or heating the loop seal piping.

Consequently, less support modifications have to be made in relationship to the previous option, due to the reduction of hydraulic loads on the piping by the discharge of the hot loop seal water during the safety valve opening.

The main disadvantage of this option is the operational valve leakage produced by the temperature increase which can in some cases result in unscheduled outages.

c) No Water Loop Seal (Steam) - This technical solution option consists in the elimination of water loop seal by a continuous draining. This option requires the installation of flexidisc internals in the safety valves for operation on steam.

Consequently, a minimal or even no support modifications are required, due to the low hydraulic loads on the piping by the discharge of the steam during the safety valve opening.

The main disadvantages of this option are the installation of a new drain line and its supports, the valve modification and the steam testing procedure.

Technical option adopted for Angra 1. The technical option adopted for Angra 1, in order to attend the recommendations of NUREG-0578 (TMI-2 Lessons Learned Task Force Status Report and Short Term Recommendations), corresponded to maintain the cold water loop seal of the safety valve and, consequently, to make several modifications on the original piping and support configuration in order to withstand the high thermal hydrodynamic loads.

The overstress in the region of the pipe loop, located above the relief tank, could not be solved only by pipe support modifications due to the high values of thermal-hydrodynamic forces acting at the pipe loop elbows. The modification on the original piping configuration consisted in the elimination of the pipe loop by rerouting the piping in order to relieve the overstress condition in this area.

The modifications on the original support configuration consisted, basically, in the installation of five new supports and the reinforcement of the five existing supports in the non-nuclear piping region.

IV. THERMAL-HYDRODYNAMIC FORCES CALCULATION

The thermal-hydrodynamic forces on pressurizer relief and safety piping were calculated with the RELAP5/MOD2, PREPREF and REFORC Code System.

The relief or safety valve opening was simulated with the RELAP5/MOD2 thermal hydraulic computer program. The results of this analysis are given in terms of the parameters time history, such as pressure, liquid and steam phase densities and liquid and steam phase velocities in the selected points of the relief and safety line. The input of the PREPREF interface computer program is the time history obtained from the RELAP5/MOD2 output. The PREPREF also prepares the REFORC input data, which calculates the thermal-hydrodynamic forces.

The thermal-hydrodynamic forces analysis considered one model corresponding to the opening of the relief valves and another one corresponding to the opening of the safety valves. It should be noted that the forces calculated due to the safety valves opening are more significant for the piping stress analysis than the ones calculated due to the relief valves opening.

Programs System Description. RELAP5/MOD2 is an improvement of the RELAP5/MOD1 Version. This code is used at the Idaho National Engineering Laboratory (INEL) for pretest prediction and posttest analysis.

The RELAP5/MOD2 thermal-hydrodynamic model is a one-dimensional, transient two-fluid model for simulation of the two-phase system behavior. It employs three equations (mass continuity, energy and momentum conservation) for each phase that could be in/out thermal-dynamic equilibrium.

PREPREF is an interface computer program that reads the RELAP5/MOD1 output and prepares the input data for the REFORC program. This program was modified to read the RELAP5/MOD2 output.

REFORC is a computer program that calculates thermal-hydrodynamic forces based on RELAP5 output (time history of the flow and state variables). It was developed as one part of the EPRI (Electric Power Research Institute) Pressurizer Water Reactor Safety/Relief Valve Test Program [8]. The piping forces equations (wave, blowdown and gravity forces equations) used in this program were obtained from an application of Newton’s second Law of Motion. These forces must be calculated for each volume and the bounding junctions. The net force on the pipe segment will be a summation of the forces on the volumes that comprise the segment.

Simulation corresponding to the Opening of the Safety Valves. The pressurizer was simulated containing saturated steam at constant pressure of 2500 psi. The piping upstream safety valve, from the pressurizer up to the beginning of the hydraulic loop seal was filled of
saturated steam at constant pressure of 2500 psi., and the hydraulic loop seal itself was full of subcooled water. Conservatively, it was assumed that the seal water was at constant temperature of 150°F. The piping from the safety valves up to the relief tank was filled with air at temperature of 60°F and pressure of 700 psi. The two safety valves opened at 0.0 sec, simultaneously, and the simulation time was 1.0 sec, sufficient to cover the critical phase of the transient. It was assumed that the safety valves open full in 40 milliseconds, according to the results of the transient. It was assumed that the safety valves open full in 40 milliseconds, according to the phase of the transient. Therefore, an adiabatic system was considered. The containment was simulated at constant pressure and quality of 14.7 psi and 1.0, respectively.

**Results.** The highest thermal-hydrodynamic forces due to the opening of the safety valves were calculated on the piping next to the relief tank (see Fig.3).

![Figure 3. Maximum Thermal-Hydrodynamic Force.](image)

V. STRESS ANALYSIS

**Structural Model.** The three-dimensional finite beam-elements structural model represents the relief and safety piping (Fig. 2) and it is based on the piping isometric and specific drawings of the pipe supports. It should be noted that the modified piping configuration was considered in this model.

The load cases as defined in the design specifications [9] [10] combined with the thermal-hydrodynamic loads were considered in the stress evaluation. The piping structural analysis was performed using the computer program system KWUROHR in order to satisfy the requirements of the appropriate equations of the code ASME Section III, Subsections NB-3650 and NC-3650.

**Dynamic Analysis.** The thermal-hydrodynamic loads are used as input of the computer program KWUROHR. The dynamic structural analysis was performed using the direct integration Newmark method, with an integration time step of 0.0006 seconds (thermal-hydrodynamic load due to the opening of the relief valves) and 0.0008 seconds (thermal-hydrodynamic load due to the opening of the safety valves). The Rayleigh coefficients were calculated to produce 5% of critical damping at the first natural piping system frequency of 9.6 Hz and at the cutoff frequency of 80 Hz.

**Stress Analysis Results.** The primary stresses, caused by the actuation of the internal design pressure, dead weight and thermal-hydrodynamic loads, were evaluated according to the Equation 9 of the code ASME Section III (Subsections NB-3650 and NC-3650) given by the following expressions:

\[
B_1 \frac{PD_0}{2t} + B_2 \frac{D_0 M_i}{2I} \leq 1.5 S_m \quad \text{(Class 1)}
\]

\[
\frac{P_{max}}{4t} + 0.75 \left( \frac{M_A + M_B}{Z} \right) \leq 1.2 S_b \quad \text{(non-nuclear)}
\]

Where \(B_1\) and \(B_2\) are the primary stress indices for the class 1 components (subscript 1 is for pressure loads and 2 for moment loads), \(i\) is the stress intensification factor for the non-nuclear components, \(P\) and \(P_{max}\) are the design and peak pressure, \(M_i\) is the resultant moment due to the dead weight and thermal-hydrodynamic loads, \(M_A\) and \(M_B\) are the resultant moment due to the dead weight and thermal-hydrodynamic loads, respectively. \(S_m\) is the allowable design stress intensity value and \(S_b\) is the basic material allowable stress at design temperature. \(D_0\), \(t\), \(I\), \(M\), and \(Z\) are the outside diameter, the wall thickness, the flexure moment of inertia and the section modulus of pipe, respectively. The calculated stresses in the pressurizer relief and safety piping are lower than the allowable limits.

It should be noted that the thermal-hydrodynamic load due to the relief valves opening was classified as upset operating condition [11]. The thermal-hydrodynamic load due to the safety valves opening was more significant for the piping stress analysis and it was classified as faulted condition, as adopted by others nuclear power plants [12].

VI. CONCLUSIONS

It was observed that the thermal-hydrodynamic load values, caused by the discharge of the sub-cooled water during the opening of the relief or safety valves, were significantly higher than the ones considered in the original piping design. These load values were calculated in accordance with the recommendations of NUREG-0578 (TMI-2 Lessons Learned Task Force Status Report and Short-Term Recommendations). Therefore, it was verified the occurrence of some primary stresses values higher than the admissible ones in the original piping configuration.

The technical solution option adopted for Angra 1 was to maintain the cold water loop seal of the safety valves and to make several modifications on the original piping and support configuration in order to satisfy the requirements of the appropriate equations of the code.
ASME Section III, Subsections NB3650 and NC3650 and to qualify the relief and safety discharge piping for future operation. It should be noted that this solution allows to maintain the original conception of the safety valves and, consequently, their set point adjustment procedure, performed annually.

The thermal-hydrodynamic forces corresponding to the safety valves opening were more significant for the piping stress analysis in relationship to the forces corresponding to the relief valves opening and they were classified as faulted condition.

REFERENCES


