NPP Krško Containment Response Following Main Steam Line Break

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ABSTRACT

This paper presents the calculation of thermohydraulic environmental parameters (pressure and temperature) inside containment of Krško NPP after postulated Main Steam Line Break (MSLB) accident. This analysis was done as a part of the ambient parameters specification in the frame of the NPP Krško Equipment Qualification (EQ) project.

The RELAP5/mod2 computer code was used for the determination of MSLB mass and energy release and computer code GOTHIC was used to calculate pressure and temperature profiles inside NPP Krško containment. The analysis was performed for spectrum of break sizes to account for possible steam superheating during accidents with smaller break sizes.

INTRODUCTION

During the process of Equipment Qualification (EQ) the necessary step is the determination of EQ parameters for both normal and accident conditions. The EQ parameters (temperature, pressure, relative humidity, chemical spray, submergence, radiation) should be defined for all locations of the plant containing equipment important to safety

Harsh environment conditions must be defined to demonstrate equipment performance during the accident. A harsh environment is the environment where a significant increase above the normal plant environmental conditions during and following Design Basis Accident (DBA) occurs. Harsh environmental conditions are limiting for environmental qualification of electrical equipment. Accidents that produce such conditions are pipe breaks in the reactor coolant system or other plant process systems, including Main Steam Line Break (MSLB). However, other accidents can produce harsh environments: e.g., rod ejection, radioactive waste processing system failures.

Two accidents are limiting for the Reactor Containment (RC): LOCA and MSLB. In the frame of NEK EQ project calculation was performed for both accidents and only the analysis of MSLB is presented within this paper. The analysis considered the same containment mass and energy input and the same assumptions as in the USAR 6.2. Additionally, MSLB mass and energy releases were calculated with RELAP5/mod2 for spectrum of break sizes to account for possible steam superheating during accidents with smaller break sizes. Such analyses are required and highlighted in the basic EQ references, such as [3].

The assumptions for RELAP calculation were conservatively chosen in order to maximise the release of mass and energy to the containment. According to those results, a calculation of thermohydraulic environmental parameters (temperature, pressure), in the NPP Krško containment, was performed using GOTHIC computer code. The final results of such analysis are the temperature and pressure envelopes for Main Steam Line Break in the containment.

MATHEMATICAL MODEL AND INPUT ASSUMPTIONS

Mass and energy release for the MSLB include the flow from the ruptured steam generator and flow from the non-faulted steam generator until isolation. The mass and energy releases from the faulted steam generator depend on the initial inventory and will continue until the inventory is depleted. The mass and energy releases from the intact steam generator depend on the break location and main steam isolation valve (MSIV) operation.

The analysis of mass and energy release during MSLB was performed with RELAP5/mod2 computer code, using standard FER nodalization for NPP Krško (ref. [11] and ref. [12]) with the following assumptions:

- "old" plant condition (1882 MWt, 18% steam generator tube plugging level).
- 100 % power,
- break upstream of the Main Steam Isolation Valve (MSIV) on Steam Line 1
- maximum allowed Main and Auxiliary Feedwater addition to faulted SG in order to maximize mass and energy release
- MSIV closing time = 5 sec
- spectrum of break sizes, indicated on the Table 1, to take into account possible steam superheating during accidents with smaller break sizes

CASE #	BREAK	AREA (m^2)
1	Double Ended Break	2 x 0.336 (area limited with flow restrictor - 0.1301 m^2)
2	100 % Flow Restrictor Area	0.1301
3	80 % Flow Restrictor Area	0.10408
4	70 % Flow Restrictor Area	0.09107
5	60 % Flow Restrictor Area	0.07806
6	50 % Flow Restrictor Area	0.06505
7	35 % Flow Restrictor Area	0.04554

Table 1. Analyzed cases for MSLB mass and energy release

For the double-ended SLB (case 1) the break mass flow rate is limited with flow restrictors on the top of steam generators. For all other cases the flow is limited by the break size. MSIV can not terminate the flow from the faulted steam generator, while intact steam generator is isolated few seconds after beginning of accident. After the initial rapid increase, the break flow stabilises on the value of Auxiliary Feedwater flow.

The parameters on the Figures 1 and 2 show the mass and energy release during SLB accidents and they are necessary inputs for GOTHIC calculation of ambient conditions in the containment of NE Krško. The cases 2 to 7 are presented since for the double-ended SLB the mass and energy release from USAR [7] was considered as GOTHIC input.

Version 3.4e of the GOTHIC containment analysis package was used in calculation of pressure and temperature in the containment following MSLB. One compartment is used to model free volume of the containment, one is used for containment sump modelling, and one for containment annulus. The free volume of the containment is 40776 m^3. Annulus region has volume of 10987 m^3. These and data for containment heat structures and material properties are taken from [7]. Initial conditions in all compartments are: 49 ^{o}C, 101.325 kPa, 30% RH, zero liquid fraction. The heat transfer coefficient is Uchida condensation coefficient plus natural convection heat transfer coefficient and radiation. The ambient temperature (outside air) is 35 ^{o}C, and heat transfer coefficient on outer surface of the containment is 11.356 W/m^2K. Reactor Containment Fan Coolers (RCFC) are used and the spray is started on high containment pressure signal.

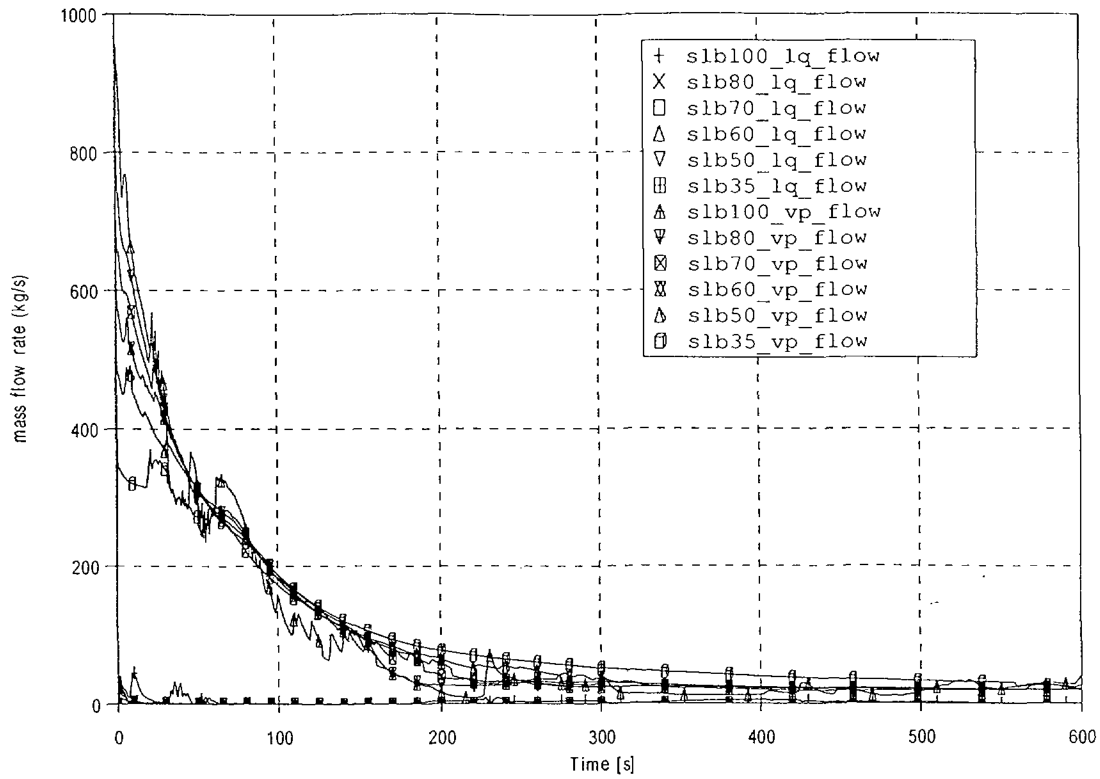

Figure 1. Break Liquid and Vapour Mass Flow Rates

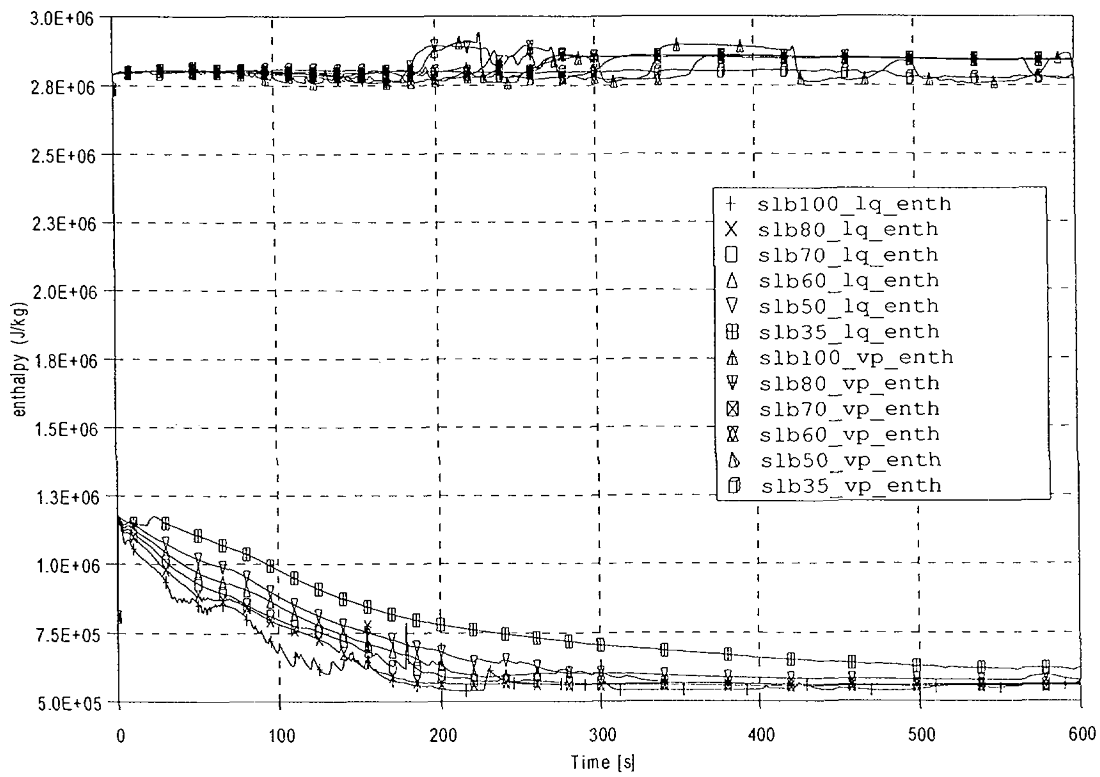

Figure 2. Break Vapour and Liquid Enthalpy

RESULTS

In double-ended MSLB case heat and mass input in the containment is prepared using data from NEK USAR. The boundary conditions are introduced in GOTHIC model using two flow boundary conditions (one for faulted and one for non-faulted SG). RCFC units are active from 45 s (3 RCFCs) and spray system is active from 96 s (2 spray lines). The volumetric flow of the spray is 0.0671 m^3/s (per pump). Temperature of the RWST water is 32 °C. Non-faulted SG was isolated at 10 s. Duration of MSLB analysis is 1800 s.

In order to check the correctness of the developed GOTHIC model the results for the containment response after double-ended MSLB were compared to the USAR results. The USAR calculation of containment pressure and temperature transients was accomplished using the CONTEMPT-LT computer code. In both cases the same input data and assumptions were used, as described above. The predictions obtained by both codes are very similar. Generally speaking, peak pressure and temperature values are greater in CONTEMPT case, that means more conservative, but in later phase of the accident GOTHIC calculates higher values.

The time of MSLB peak pressure and maximum calculated pressure are almost the same for USAR and for GOTHIC data (USAR 373.7 kPa at 70.6 s, GOTHIC 369.4 kPa at 76.3 s). Peak pressure calculated by GOTHIC is slightly lower, but at the end of accident pressure in the GOTHIC case decreases slower. Containment pressure transient is shown in Figure 3. Containment atmosphere temperature during MSLB in containment is shown in Figure 4 (FSAR 127.7 °C at 70.6 s, GOTHIC 126.9 °C at 73 s). The sump water temperatures (Figure 5) are always higher in GOTHIC case. That is partially caused by GOTHIC calculation scheme based on liquid, vapour and droplet phases. The droplet condensation model deliver condensate at higher temperature to the water pool in containment sump. The pressure and temperature calculated in containment are higher than in LOCA case. That is mainly caused by partially superheated steam flow from faulted steam generator.

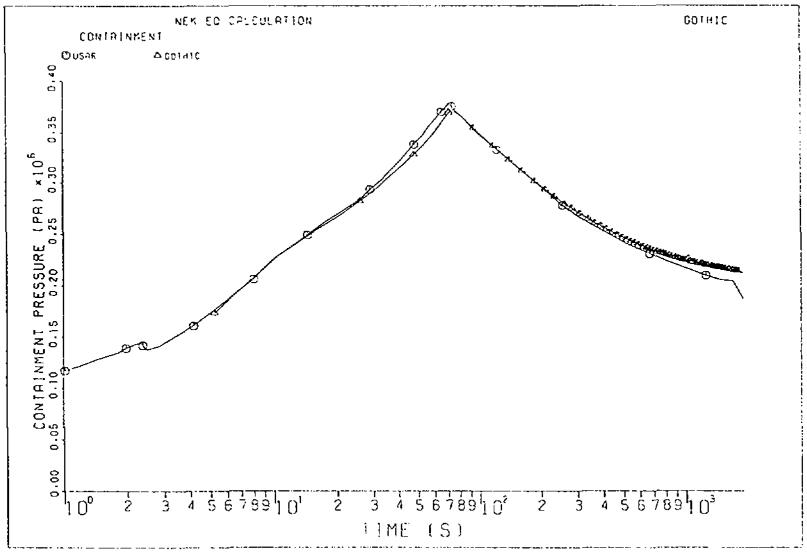

Figure 3. Containment pressures used in USAR and calculated by GOTHIC code, double-ended MSLB case

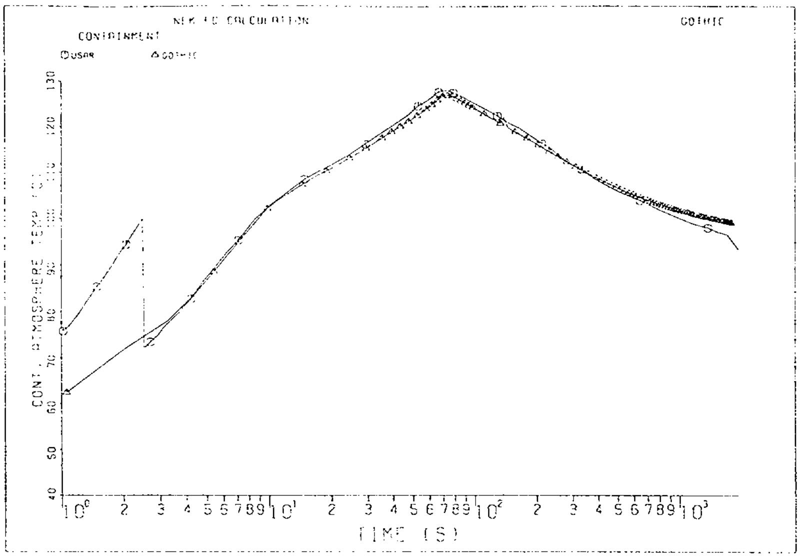

Figure 4. ***Containment atmosphere temperature used in USAR and calculated by GOTHIC code, double-ended MSLB case***

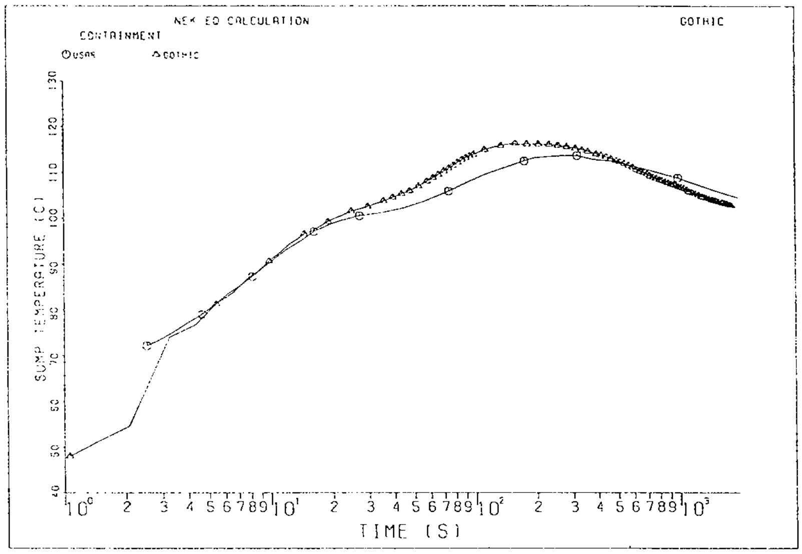

Figure 5. ***Containment sump temperature used in USAR and calculated by GOTHIC code, double-ended MSLB case***

To determine containment environmental conditions during spectrum of SLB breaks additional calculations were performed using heat and mass sources calculated with RELAP5/mod2 for breaks 100%, 80%, 70%, 60%, 50%, and 35% (cases 2 to 7 from table 1). The containment model is exactly the same as in previous calculation, but only one train of RCFCs is used, with start at 41 s, and spray is started on HI-3 signal + 7 s delay. The result, pressures and temperatures in the containment atmosphere, for spectrum of breaks and for USAR MSLB input are shown in Figure 6. to 9.

From Figures 6 and 7 is clear that USAR MSLB pressure profile is limiting in all cases. The reason for this is very high mass flow rate of dry steam (double-ended SLB) in the early phase of the transient.

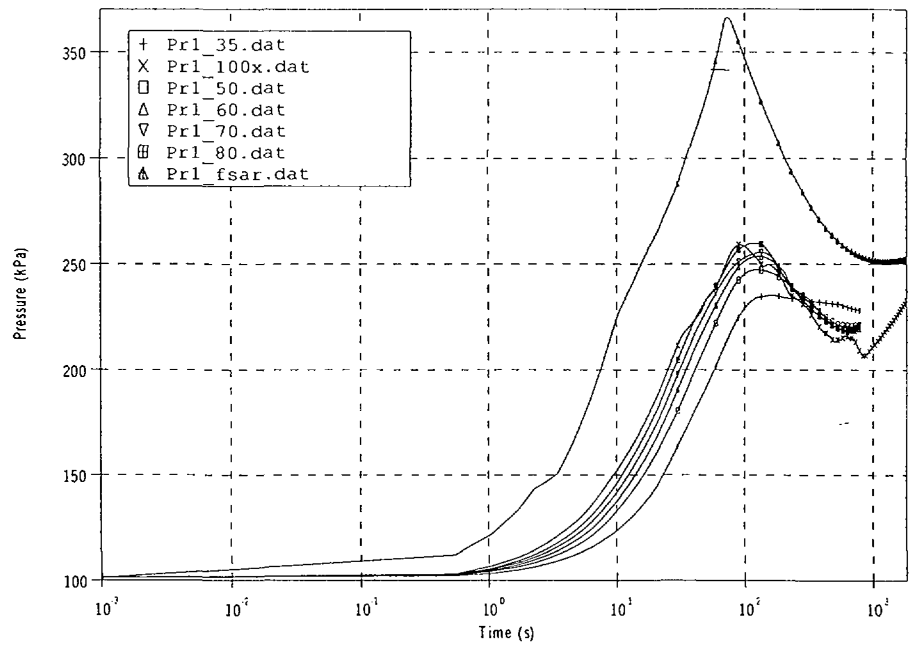

Figure 6. Containment pressure for spectrum of SLB breaks and USAR MSLB (log scale)

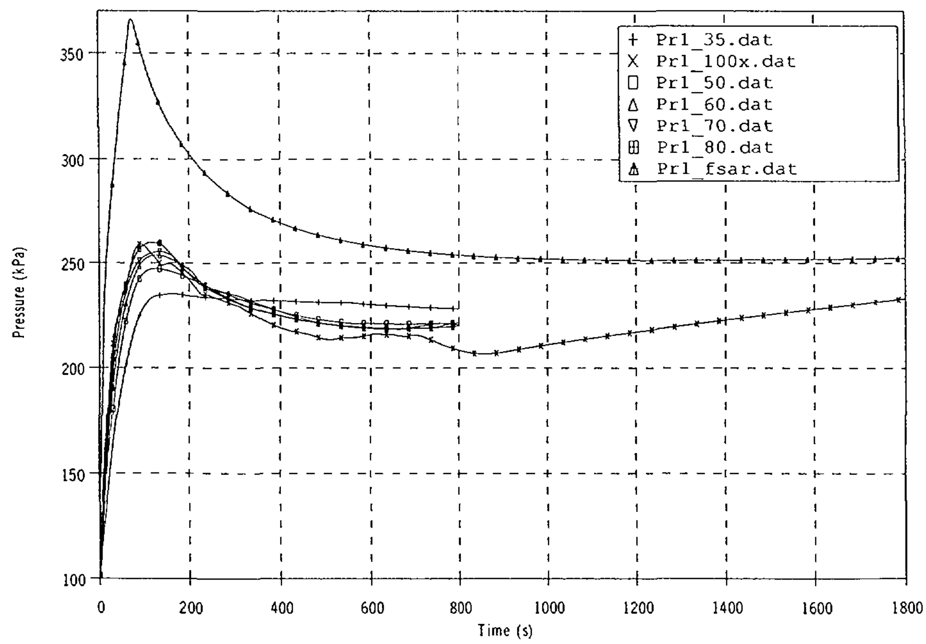

Figure 7. Containment pressure for spectrum of SLB breaks and USAR MSLB (lin scale)

Regarding temperature of the containment atmosphere, Figure 8 and 9, in the initial phase of SLB transient, up to 160 s, the temperatures calculated for spectrum of breaks are higher. The explanation for such behaviour is superheated steam release for those cases, while for the USAR case the steam is not superheated in that phase of transient. The maximum reached temperature is for 80% break and value at 46.95 s is 148.7 °C, what is caused by the large steam flow rate with some superheat from the faulted steam generator.

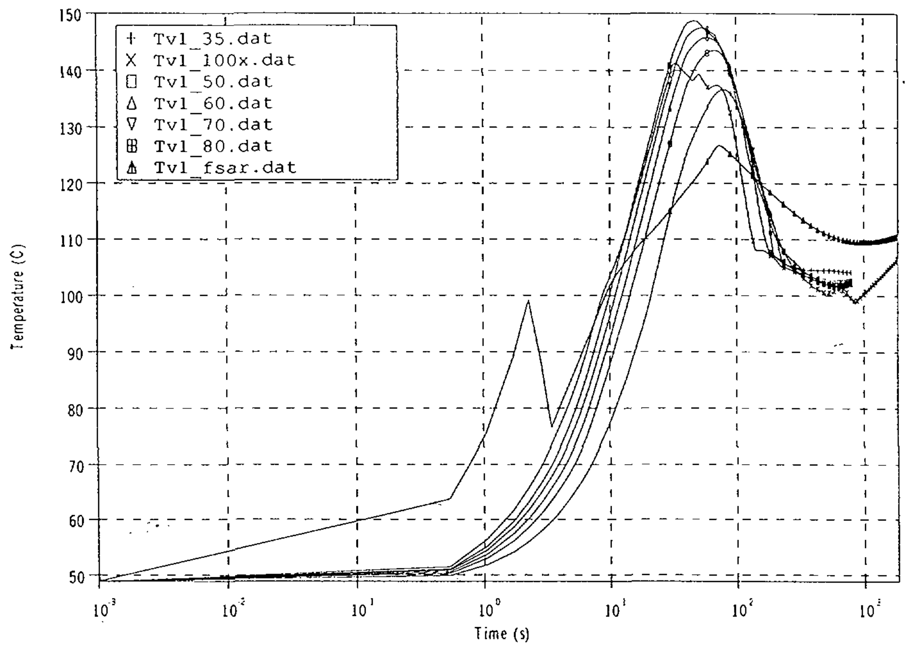

Figure 8. Containment temperature for spectrum of SLB breaks and USAR MSLB (log scale)

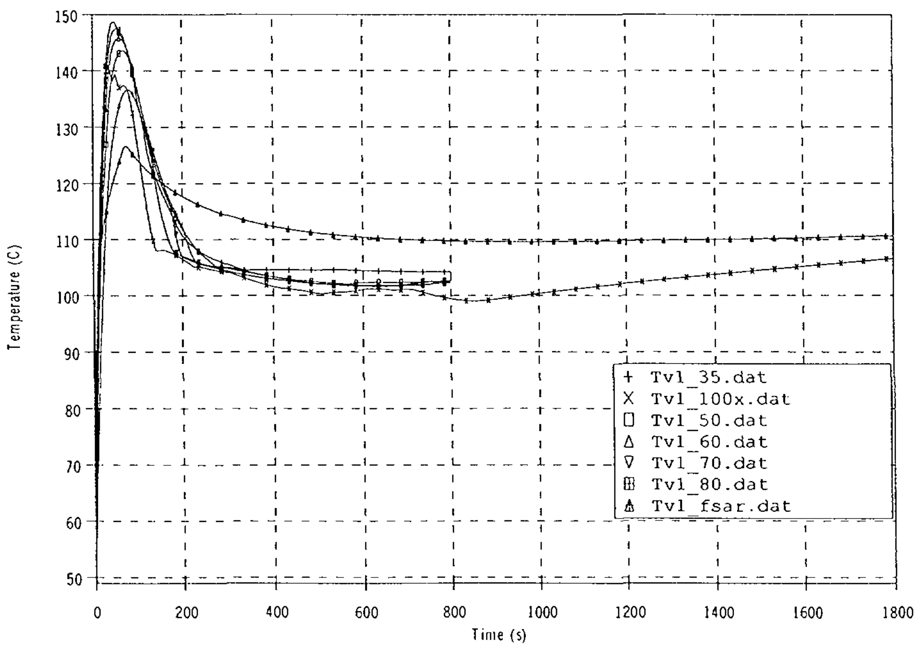

Figure 9. Containment temperature for spectrum of SLB breaks and USAR MSLB (lin scale)

CONCLUSION

Thermohydraulic environmental parameters (pressure and temperature) inside containment of Krško NPP after postulated Main Steam Line Break (MSLB) accident were analyzed. The study was performed for spectrum of break sizes to account for possible steam superheating during accidents with smaller break sizes, as required in [3], based on the USAR and RELAP5/mod2 heat and mass release. The GOTHIC calculation resulted in maximum containment pressure for USAR double-ended SLB cased by very high flow rate of dry steam in the beginning of the accident. The maximum temperatures in containment are observed for 80% break size what is caused by large and superheated steam flow rate from the faulted steam generator.

Based on this analysis, and together with the results from LOCA and Feed Line Break (FLB) accident, envelopes of the containment environmental parameters are developed and used as the input to the Equipment Qualification (EQ) program for NPP Krško.

REFERENCES

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