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Sensitivity and Uncertainty Analysis for Ignalina NPP Confinement in Case of Loss of Coolant Accident

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ABSTRACT

At present the best-estimate approach in the safety analysis of nuclear power plants is widely used around the world. The application of such approach requires to estimate the uncertainty of the calculated results. Various methodologies are applied in order to determine the uncertainty with the required accuracy. One of them is the statistical methodology developed at GRS mbH in Germany and integrated into the SUSA tool, which was applied for the sensitivity and uncertainty analysis of the thermal-hydraulic parameters inside the confinement (Accident Localisation System) of Ignalina NPP with RBMK-1500 reactor in case of Maximum Design Basis Accident (break of 900 mm diameter pipe). Several parameters that could potentially influence the calculated results were selected for the analysis. A set of input data with different initial values of the selected parameters was generated. In order to receive the results with 95 % probability and 95 % accuracy, 100 runs were performed with COCOSYS code developed at GRS mbH. The calculated results were processed with SUSA tool. The performed analysis showed a rather low dispersion of the results and only in the initial period of the accident. Besides, the analysis showed that there is no threat to the building structures of Ignalina NPP confinement in case of the considered accident scenario.

1 INTRODUCTION

Up to now conservative accident analysis methodology has been applied for the safety assessment of nuclear power plants, i.e. calculations are performed applying conservative initial and boundary conditions, conservative models of computational tools and data about operation of the system. However, conservative analyses do not show how much they are conservative, i.e. uncertainty about the real progression of the accident processes in the NPP remains.

The other NPP safety assessment method is best-estimate analysis, which employs the most probable initial and boundary conditions and the experimentally derived correlations. However, when performing such an analysis the uncertainty of the results has to be estimated. Such a combined approach (best-estimate analysis together with uncertainty analysis) provides a possibility to calculate the most probable accident sequence progression as well as to assess the realistic safety margin to acceptance criteria.

The paper presents the thermal-hydraulic analysis of Ignalina NPP confinement (Accident Localisation System) in case of Maximum Design Basis Accident (MDBA), i.e. guillotine rupture of pressure header of a Main Circulation Pump (MCP). COCOSYS code was applied for the analysis of ALS and SUSA code applied for the sensitivity and uncertainty analysis.

2 DESCRIPTION OF IGNALINA NPP CONFINEMENT

A characteristic feature of nuclear power plants built in the Western countries is the containment. This is a large, especially strong, steel and reinforced concrete building, usually semi cylindrical in shape, which encloses the reactor and its cooling circuits. Ignalina NPP does not have such a containment structure but the major part of the Main Cooling Circuit (MCC) is enclosed by the ALS.

Ignalina Nuclear Power Plant consists of two units commissioned in December 1983 and August 1987. Both units are equipped with RBMK-1500 reactors. The Accident Localisation System (ALS) of Ignalina NPP consists of a number of interconnected compartments with 10 condensing pools to condense the accident-generated steam and to reduce the peak pressures that can be reached during any LOCA (Figure 1). In this respect, the ALS of Ignalina NPP may be attributed to pressure suppression type containments. The condensing pools are located at five elevations in two ALS towers. In the case of MCP pressure header rupture the accident-generated steam is directed to four bottom condensing pools in both ALS towers. The other pools are designed for the condensation of steam released through the MCC overpressure protection system and do not participate in the accident sequence. A detailed description of Ignalina NPP may be found in [1].

The model of Ignalina NPP ALS for the code COCOSYS used in the analysis consists of 22 nodes, 59 junctions of different type, 9 pump systems and 77 structures for the simulation of heat transfer to building structures. The model includes all the accident-affected ALS compartments, condenser tray cooling system (CTCS), drainage and other related systems. The model includes the Emergency Core Cooling System (ECCS), which uses ALS as a water reservoir. The coolant release through the break is calculated employing RELAP5 code. The assumptions concerning different systems activation and their capacity are made in correspondence to the assumptions made in RELAP5 analysis. A detailed description of the ALS model for COCOSYS code is presented in [2].

3 SENSITIVITY AND UNCERTAINTY ANALYSIS

3.1 Methodology

There are several uncertainty analysis methodologies around the world and they are described in [3]. The statistical uncertainty analysis methodology developed at GRS mbH company (Germany) was selected for the analysis of MCP pressure header rupture at Ignalina NPP. The uncertainty and sensitivity analysis was performed using a two-sided tolerance limit (with 0.95 probability and 0.95 confidence). According to Wilk's formula [4] in order to reach such probability and confidence limits at least 93 code runs should be performed. For the ALS behaviour analysis during MCP pressure header rupture 100 runs were performed. Each code run includes different sets of initial and boundary conditions defined in the input for the code.

The uncertain parameters are defined as random values generated from the interval of values with a defined probability distribution function [5]. Thus, prior to performing uncertainty analysis the list of parameters that could influence the results is created, the intervals of values and probability distribution function are defined for each parameter. Furthermore, it is assumed that each parameter is independent and the sets of initial and boundary conditions for each code run are created.

The advantage of the statistical uncertainty analysis is that the reliability of uncertainty assessment does not depend on the number of selected parameters [4], [5].

The mentioned steps of the uncertainty analysis are integrated into the code SUSA (Software System for Uncertainty and Sensitivity Analyses) developed at GRS mbH. This code is used to generate the sets of initial and boundary conditions as well as to analyse the received results.

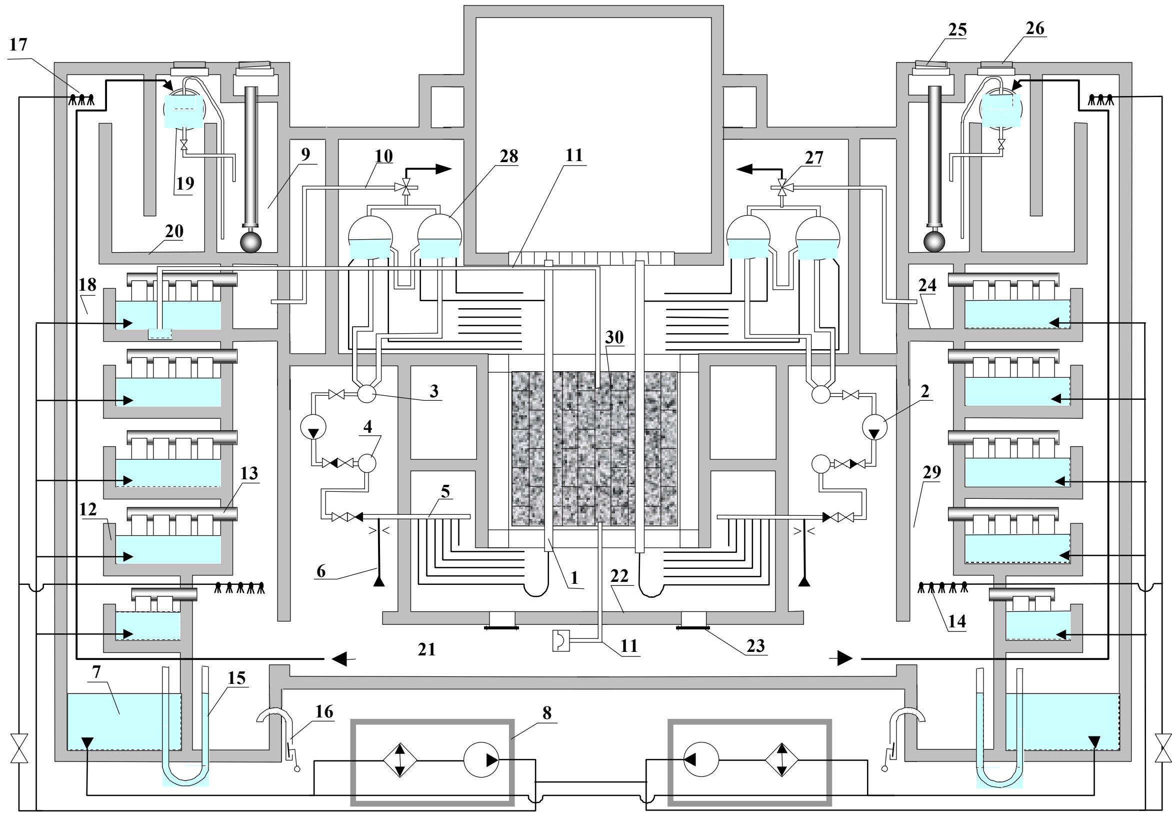

Figure 1: Principal scheme of the Ignalina Accident Localisation System

1. fuel channel
2. main circulation pumps
3. MCP suction header
4. MCP pressure header
5. group distribution header
6. ECCS headers
7. hot condensate chamber (HCC)
8. CTCS pumps and heat exchangers
9. discharge pipes section
10. pipe from the steam relief valves
11. steam gas mixture from the reactor cavity
12. condensing pools
13. steam distribution headers
14. bottom steam reception chamber (BSRC) sprays.
15. water seals/S traps between HCC and BSRC
16. BSRC vacuum breakers
17. air removal corridor sprays
18. air venting channel
19. gas delay chamber tank
20. gas delay chamber
21. reinforced, leak tight compartments
22. Lower Water Piping compartments
23. steam relief valves from Lower Water Piping to reinforced leak tight compartments
24. top steam reception chamber
25. tip up hatches
26. knock down hatches
27. main safety valve and fast acting steam discharge valve
28. drum separators
29. BSRC steam distribution corridors
30. reactor

The main safety parameter for the safety analysis of the containment is the maximum pressure reached during the accident. Eight parameters that could influence the pressure evolution during the accident were selected for the uncertainty analysis. These parameters with initial values, the interval of values and their distribution laws are presented in Table 1.

The first parameter is the volume of the accident compartment. It is difficult to calculate the volume of the compartment accurately due to the presence of the reactor cooling circuit piping, pumps and other equipment.

The attention to the water carry-over phenomenon and its influence on the results was already raised in [6], [7]. Investigation of the experiment, which corresponds to a Group Distribution Header (300 mm diameter pipe) rupture in NPP with RBMK-1000, showed that the average coefficient of water carry-over with atmospheric flow is 0.05 [8]. Considering that this paper presents the analysis of MCP pressure header (900 mm diameter pipe) rupture the maximum value of water carry-over coefficient was assumed equal to 0.5.

Parameters 3 and 4 are the initial water level in the condensing pools. In the analysis it was assumed that initial water levels in both ALS towers could be different. The lowest water level (0.95 m) when the make-up of condensing pools starts automatically, whereas the highest level (1.05 m) corresponds to location of water overflow holes.

The leakage area of both ALS towers and of reinforced leaktight compartments were chosen according to measurements performed at Ignalina NPP.

The temperature in the ALS compartments could vary depending on the season. The IAEA document [9] indicates that the maximum pressure is inverse proportional to the initial temperature of the air.

Table 1: Selection of parameters

No.	Parameter	Interval of values		Basic value	Distribution
1.	Volume of accident compartment (PBB5), m^3	3750	5350	4550	Normal
2.	Coefficient of Water carry-over via atmospheric junctions	0	0,5	0,25	Normal
3.	Initial water level in left condensing pool, m	0,95	1,05	1,0	Normal
4.	Initial water level in right condensing pool, m	0,95	1,05	1,0	Normal
5.	Leakage of reinforced leaktight compartments, m^2	0,01	0,035	0,023	Normal
6.	Leakage of ALS towers, m^2	0,002	0,02	0,011	Normal
7.	Initial air temperature in drywell, ^0C	20	50	35	Normal
8.	Initial air temperature in wetwell, ^0C	20	35	27,5	Normal

3.2 Results

The break of MCP pressure header (see *4* in Figure 1) of the left MCC loop was selected for the analysis. The most representative compartments of ALS in this case are: 1) the accident compartment, which is located in the reinforced leaktight compartments that are designed for an absolute pressure of 400 kPa; 2) The Bottom Steam Reception Chamber *29*, which is the last compartment before condensing pools *12* and is designed for 200 kPa of absolute pressure; 3) the Air Venting Channel *18* is located beyond condensing pools (wetwell) and is designed for 180 kPa of absolute pressure. The BSRC and AVC of the left ALS tower, which is closer to assumed break location and have to withstand higher loads, were selected for the analysis.

The results of the analysis are presented in Figure 2 – Figure 4. The figures present the results of all 100 code runs. The calculated results show that the pressure sharply increases in the first 3 seconds of the accident and then gradually decreases. In ~50 s all the calculated variants show almost the same pressure in the accident compartment (Figure 2). The calculated pressure difference for BSRC (Figure 3) and AVC (Figure 4) is even lower. The calculated pressure in AVC (Figure 4) after 20 s is the same for all the code runs and is slightly above the atmospheric. The low pressure in the wetwell shows the peculiarity of the Ignalina NPP ALS when the clean air in the initial phase of the accident is pushed off the wetwell to the environment, i.e. the air from the drywell is pushed to the wetwell and locked in the ALS towers.

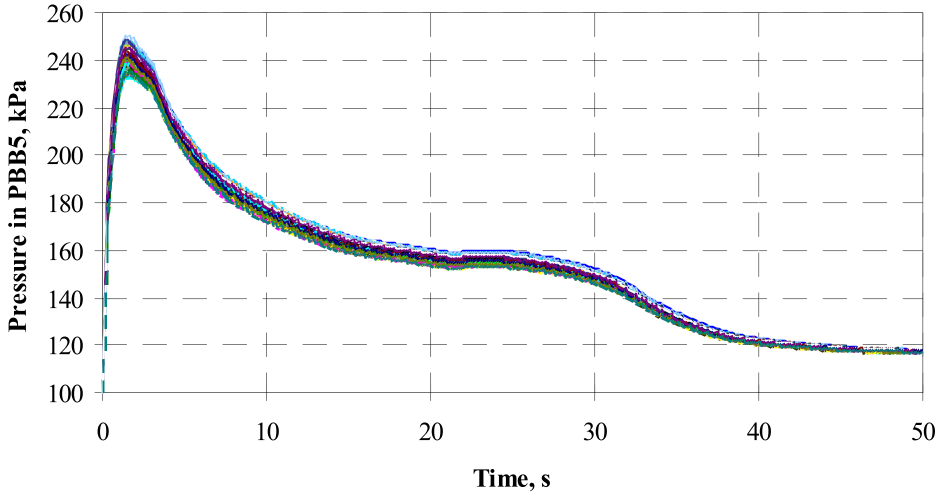

Figure 2: Pressure in accident compartment (drywell)

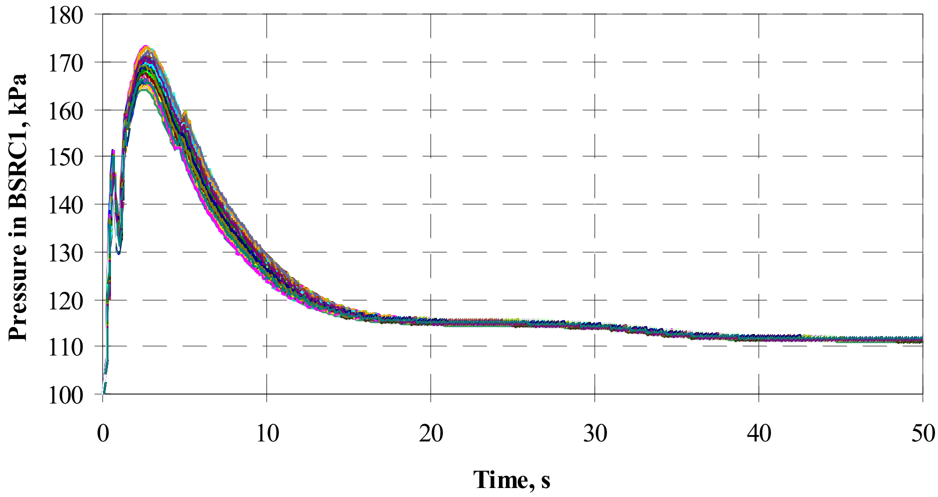

Figure 3: Pressure in Bottom Steam Reception Chamber (drywell)

The difference of maximum calculated pressure in different code runs is 8-18 kPa, i.e. 12-15 % of the excess pressure. During the accident the uncertainty of calculated pressure decreases. The obtained results show that the developed model of ALS is not very sensitive to the selected parameters. This is not surprising considering the large volume of ALS compartments and rather large cross sections for the air/steam mixture flows.

The calculated margin to design pressure for reinforced leaktight compartments is 150 kPa or 50 % of the excess pressure, for BSRC – 26 kPa or 26 % of the excess pressure and for AVC – 20 kPa or 25 % of the excess pressure. Thus, in case of MDBA there are sufficient safety margins to acceptance criteria.

It should be noted that for this sensitivity analysis a confinement-conservative coolant release was considered, i.e. the release was calculated with RELAP5 code making assumptions in such a way that the release to ALS is maximum.

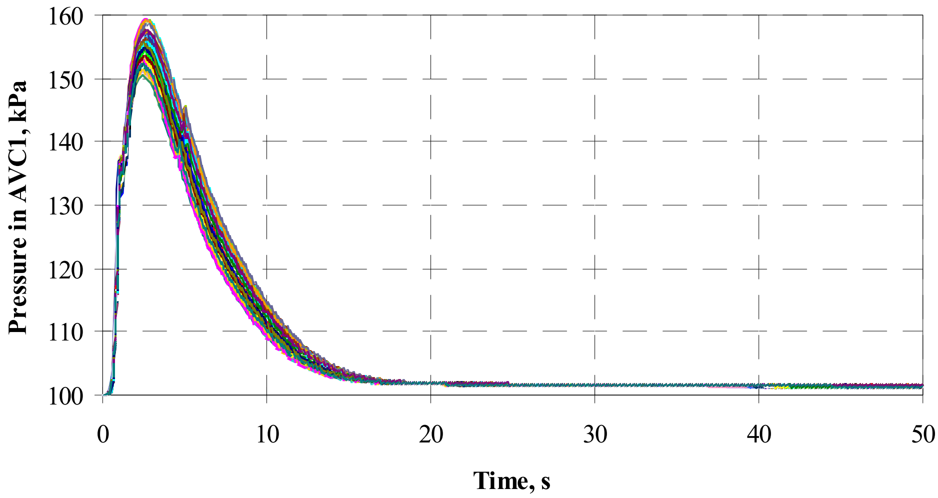

Figure 4**:** Pressure in Air venting Channel (wetwell)

4 CONCLUSIONS

- The performed analysis show that the developed model of ALS is not very sensitive to the selected modelling parameters.
- The calculated maximum pressure uncertainty is in the range of 12-15 % of the excess pressure.
- The design pressures in any ALS compartment are not reached and there are sufficient safety margins to acceptance criteria in case of Maximum Design Basis Accident.

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