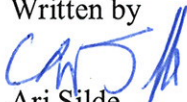






VALIDATION OF APROS CONTAINMENT MODEL AGAINST PPOOLEX EXPERIMENTS STR-1, STR-4 AND WLL-5-2, **REVISION 1.0**

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<p>Summary</p> <p>This report is a complementary version of the earlier VTT report no. VTT-R-06068-09 where the APROS containment model has been used to simulate the PPOOLEX experiments conducted in Lappeenranta University of Technology. The revised parts of the report are related to the calculation of the wall condensation experiment WLL-5-2 (Sections 2.3, 3, 3.3, 4.3 and 6).</p> <p>The facility is a scaled model of a BWR containment including a suppression pool. Experiments in question were STR-1, STR-4 and WLL-5-2. Each experiment had a slightly different area of interest. The main objective of experiment STR-1 was to study the natural cooling of the wetwell suppression pool and associated heat losses to the environment. Experiment STR-4 concentrated on long-term thermalhydraulics behaviour of the facility and temperature stratification of the suppression pool. The WLL-5-2 was a short-term sequence where steam condensation on the drywell wall structure during the steam discharge was studied.</p> <p>A code change has been made to APROS during the project to correct the defective time step dependency of the pool stratification model. Also some development needs of the stratification model are described.</p> <p>The calculation results showed that the general thermalhydraulics behaviour of the drywell and wetwell was well predicted. Especially in test WLL5-2- the pressures as well as the steam condensation rate to the lower collection wall were predicted extremely well taking into account the uncertainties of the boundary conditions. Also the suppression pool temperature stratification could be simulated qualitatively reasonably, when the conductance layer thickness of the water was defined to be 0.01 m. Thermal stratification in the wetwell atmosphere could not be modelled, because a very simple lumped-parameter nodalisation was used in the simulations.</p>	
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Contents

1	INTRODUCTION	3
2	PPOOLEX TEST FACILITY AND CALCULATED EXPERIMENTS.....	4
2.1	STR-1	5
2.2	STR-4	6
2.3	WLL-5-2.....	8
3	APROS MODELS OF PPOOLEX TEST FACILITY AND CALCULATION CASES	10
3.1	STR-1	12
3.2	STR-4	12
3.3	WLL-5-2.....	12
4	COMPARISON OF CALCULATIONS AND MEASUREMENTS.....	13
4.1	STR-1	13
4.2	STR-4	14
4.3	WLL-5-2.....	18
5	APROS CODE MODIFICATIONS AND DEVELOPMENT NEEDS	24
6	CONCLUSION.....	25
	REFERENCES.....	26

1 INTRODUCTION

Nuclear Safety Research Unit in Lappeenranta University of Technology (LUT) has performed several experiments at their new PPOOLEX test facility. This report introduces the facility and the simulation results of three experiments using the APROS containment model version 5.09. This report is a complementary version of the earlier VTT report no. VTT-R-06068-09. The revised parts of the report are related to the calculation of the wall condensation experiment WLL-5-2 (Sections 2.3, 3, 3.3, 4.3 and 6).

The containment model of APROS is developed for simulating the conditions in nuclear power plant containment during reactor accidents including e.g. atmospheric thermodynamics, condensation and evaporation phenomena as well as heat transfer on heat structure surfaces /1/. The use of APROS and other simulation tools is essential with nuclear power plants, as full-scale experiments would be highly expensive and the most serious accident types are so rare, that extensive experimental testing of these phenomena would be unwise. Therefore continuous improvement of simulation codes is relevant, as they can reduce the amount of experimental research needed.

2 PPOOLEX TEST FACILITY AND CALCULATED EXPERIMENTS

PPOOLEX test facility is located in Lappeenranta University of Technology (LUT) (Figure 1). It was commissioned in the end of 2006, when it replaced the old POOLEX facility. The purpose of the test facility is to act as a scaled model of a BWR containment. The phenomena occurring inside the containment during accident transients need to be studied to improve safety. Primary component of the test facility is the cylindrical stainless steel vessel (31 m³), which is divided into the drywell and wetwell compartments separated by an intermediate floor. The free volume of drywell is 13 m³. The facility consists also of a suppression pool system with a vent pipe. The main difference to the old POOLEX facility is the fact that PPOOLEX is a closed vessel and can be pressurized. The external wall structures are not insulated, so heat losses to the environment are substantial.

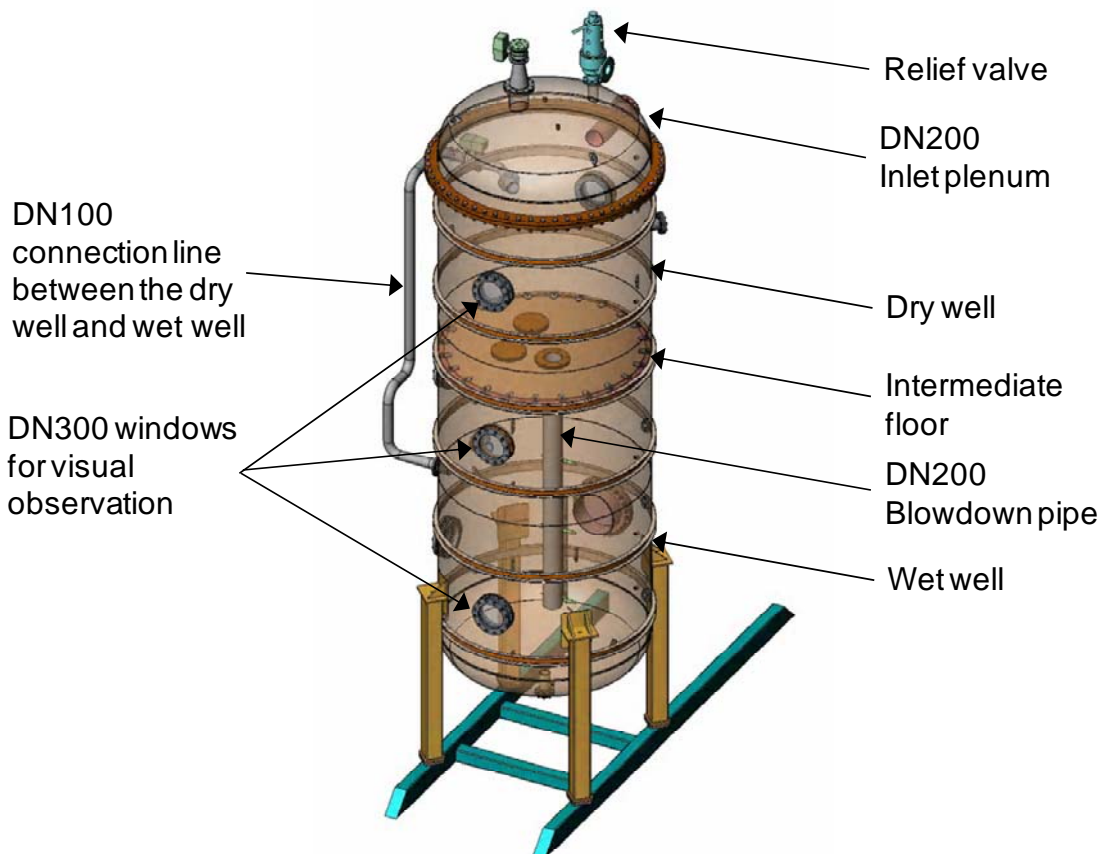


Figure 1. PPOOLEX test vessel /2/

The PPOOLEX experiments performed so far have mainly been related to the CONDEX research project, started in 2007 within SAFIR2010 program. Goal of the project is to gain a better understanding of the phenomena occurring inside drywell and wetwell compartments during steam discharge (e.g. steam line break), as well as provide controlled conditions for data acquisition. Reliable measurement data is needed for improving and validating simulation models and numerical methods developed by VTT, KTH and LUT.

The experiments considered in this report are from two different test series. STR-1 and STR-4 are from a test series which primarily studied the temperature stratification in the suppression

pool during steam injection. WLL-5-2 is from a test series which concentrated on the condensation phenomena on the drywell wall /2/, /3/, /4/. The special features of each experiment are described in the following sections.

2.1 STR-1

The thermal stratification and mixing experiments were conducted in September – October 2008. As the primary objective was to study thermohydraulic loading of the wetwell structures, the test vessel was appropriately instrumented with thermocouples. The first experiment in the thermal stratification series was a simple cooling experiment with no steam injection. Wetwell was filled to its nominal water volume of 8.38 m³ with 50 °C tap water and let to cool down for almost 45 hours. This experiment was useful in creating the APROS simulation model, especially in defining the heat losses to the environment. The most important measured variable was the water temperature of the suppression pool of the wetwell (Figure 2).

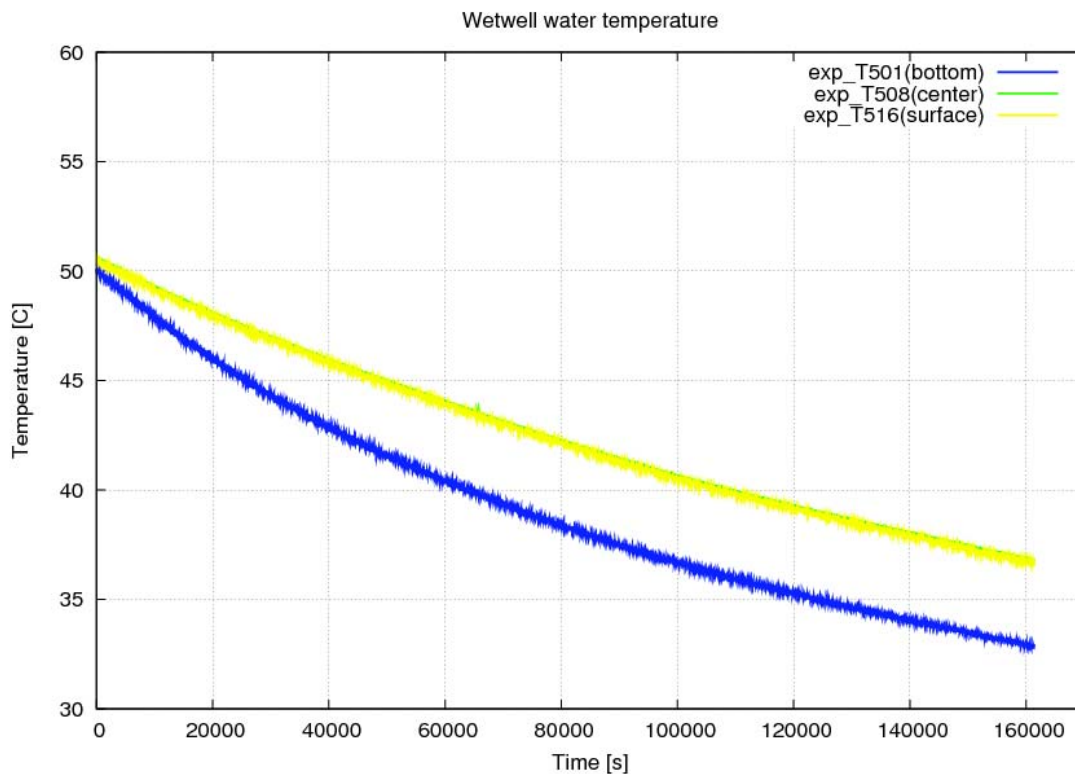


Figure 2. Vertical temperature distribution of the suppression pool water in STR-1 experiment.

Measurements of selected thermocouples shown in Fig. 2 represent the highest, center and lowest temperature measurements in the vertical rod inside the water pool. The bottom parts of the pool below the lower end of the vent pipe cool down faster than the top part of the pool. One explanation might be that the pool water is stratified i.e. the colder water near the vessel wall flows downwards to the bottom of pool.

2.2 STR-4

Fourth test in the thermal stratification series included a steam injection, which lasted about three hours. Mass flow of the injection was so small, that it did not effectively mix the water in the suppression pool, and hence, a stable thermal stratification was created. The mass flow rate and specific enthalpy of steam discharge are shown in Figures 3 and 4. The enthalpy is determined from the measured steam temperature in the injection line assuming saturation conditions. The vertical temperature distribution of the wetwell pool is shown in Figure 5 where the measurements on three different elevations are presented.

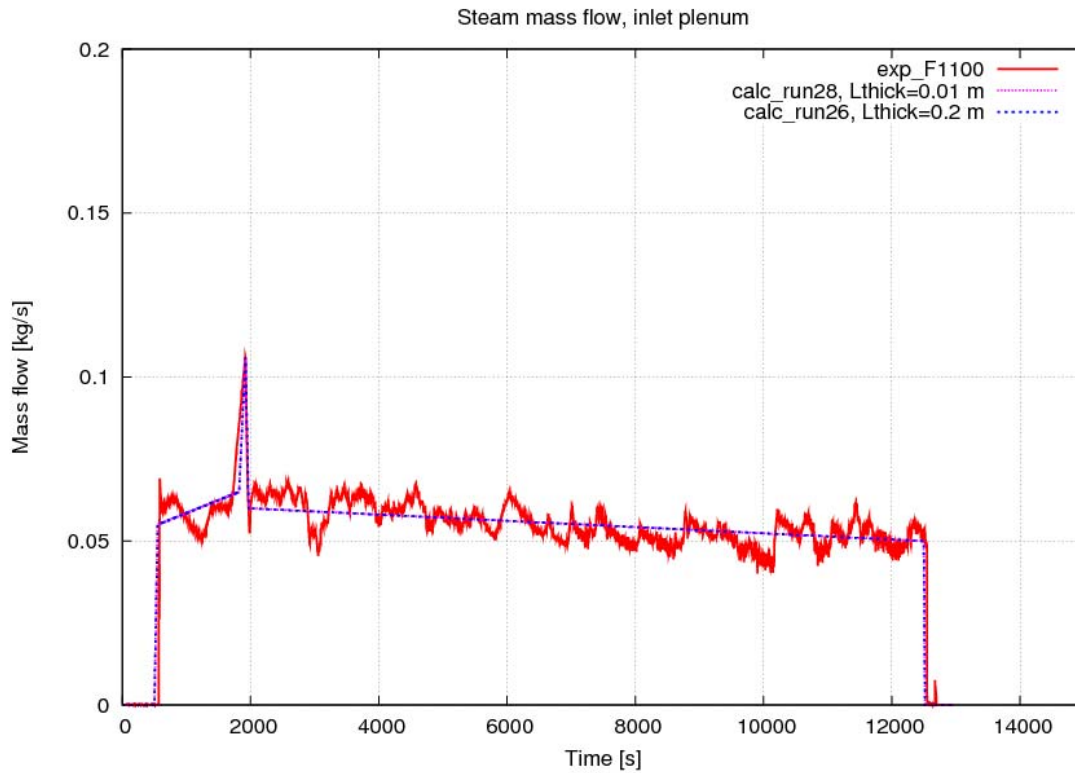


Figure 3. Mass flow rate of steam discharge in experiment STR-4.

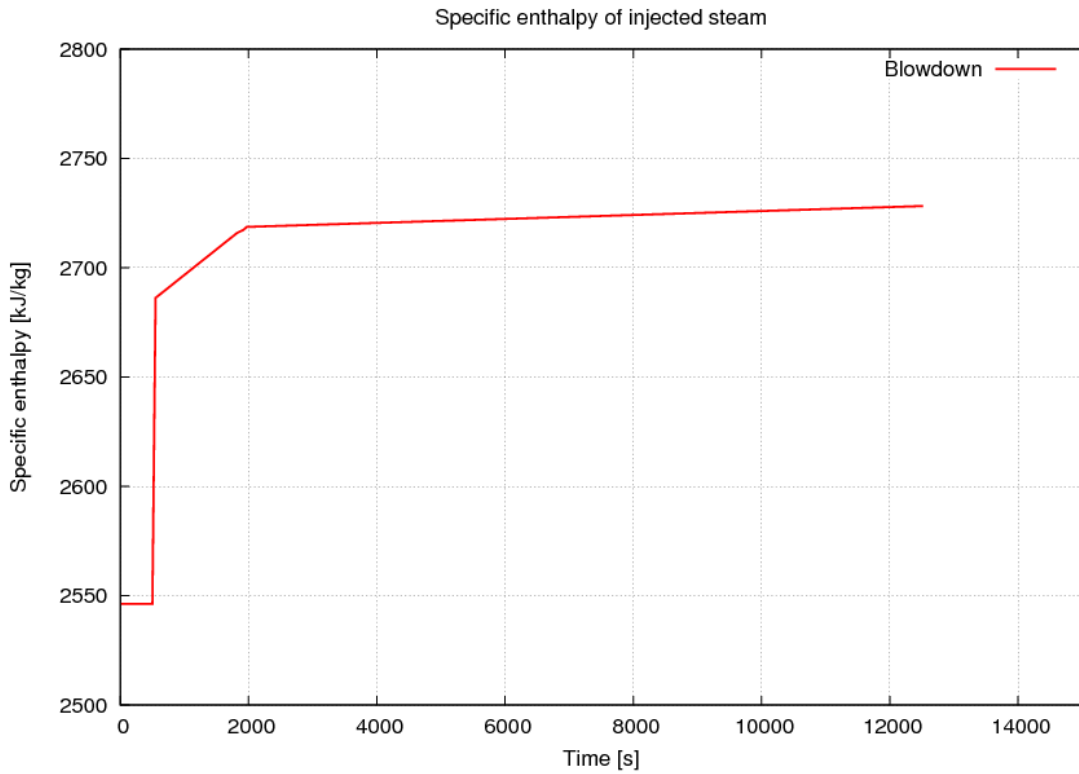


Figure 4. Specific enthalpy of steam discharge in experiment STR-4.

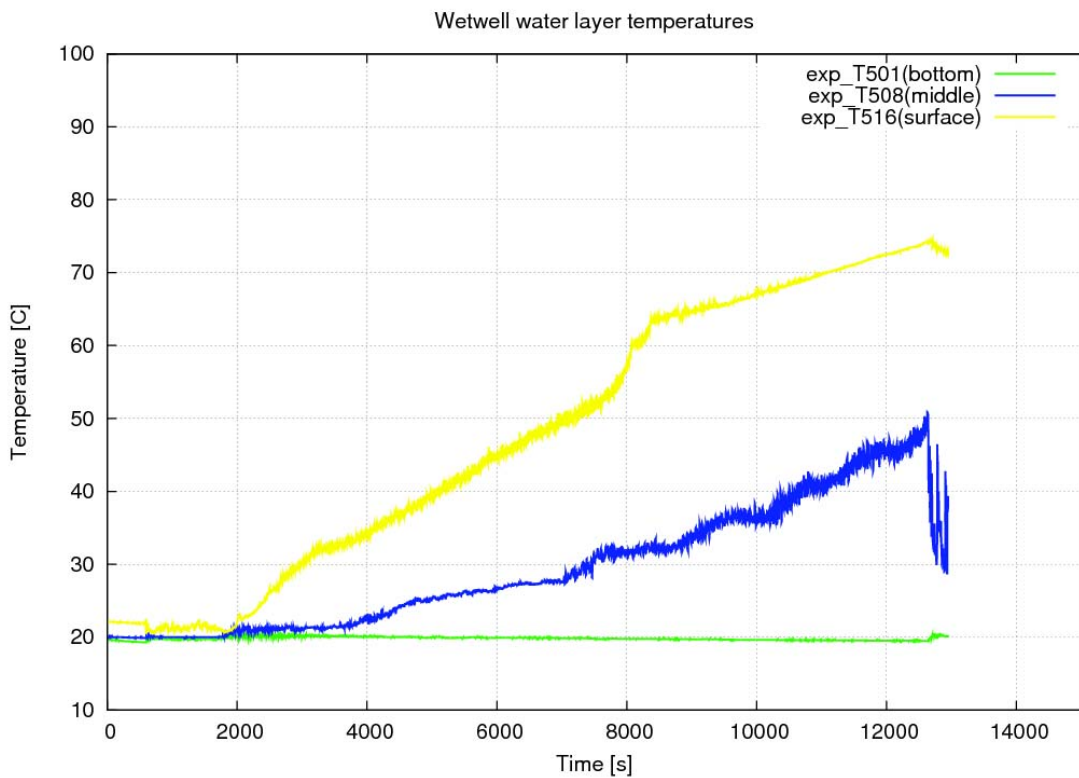


Figure 5. Vertical temperature distribution of the suppression pool in experiment STR-4

The temperature at the bottom of the water pool remained practically unchanged during the blowdown, whereas the temperatures above the lower end of the vent pipe increased significantly during the steam discharge. Temperature difference between the pool surface and bottom was over 50 °C when steam injection ended.

2.3 WLL-5-2

Wall condensation tests were conducted in December 2008 and January 2009. Main objectives of the test series were to study steam condensation on the drywell wall, and obtain comparison data for CFD simulations. The condensate water was collected in two gutters located on different vertical position of the drywell wall, and water was gathered to four small tanks outside the vessel. Steam injection duration in test WLL-5-2 was 240 s with injection pressure of 0.65 MPa and mass flow rate of 470 – 550 g/s. The mass flow rate and specific enthalpy of steam discharge is shown in Figures 6 and 7. The enthalpy is determined from the measured steam temperature of the injection line assuming saturation conditions. The collection surface was limited to the vertical wall section of the drywell, excluding the lowermost part of the wall by height of 0.45 m. However, the possible condensate water flow from the dome ceiling to the collection surface of the vertical wall was not prevented, because only the lower gutter was originally designed for measuring the wall condensation rate. Therefore, the amount of condensate water mass flowing down from the ceiling to the collection wall and further to the upper gutter was unknown, and that made it difficult to compare the calculated condensation rates to the measured data in the upper collection gutter. The total condensate mass and the masses measured in four gathering tanks are shown in Figure 8.

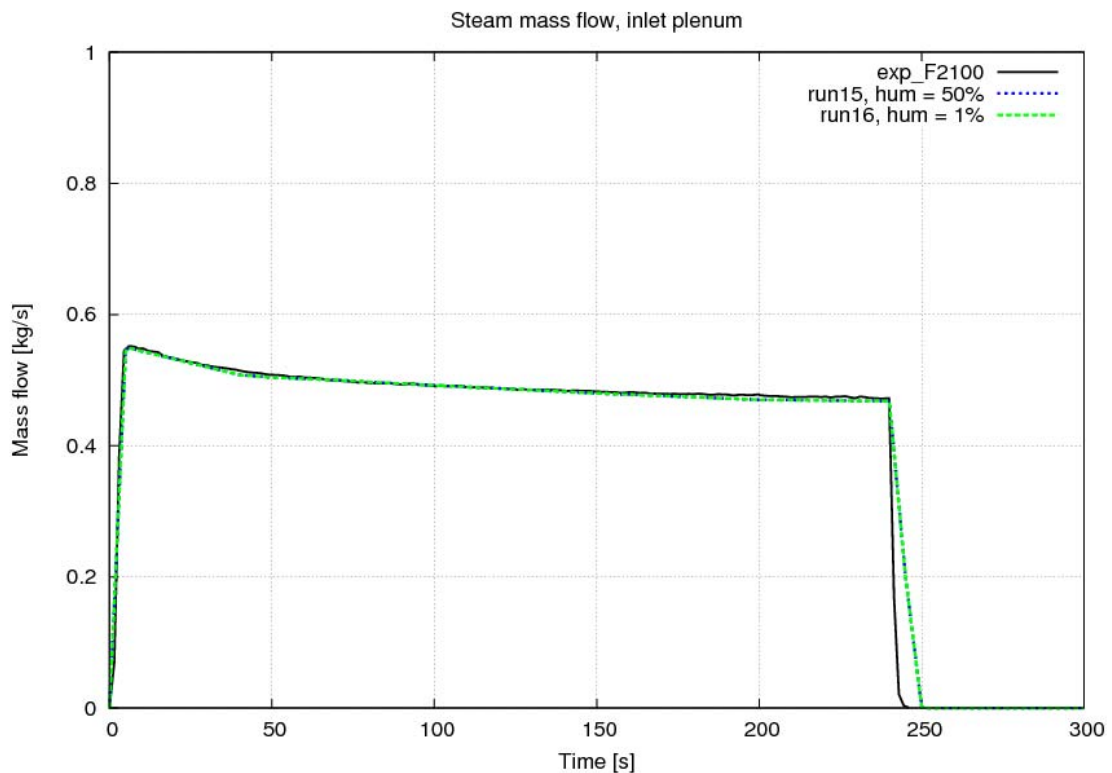


Figure 6. Mass flow rate of steam discharge in experiment WLL-5-2.

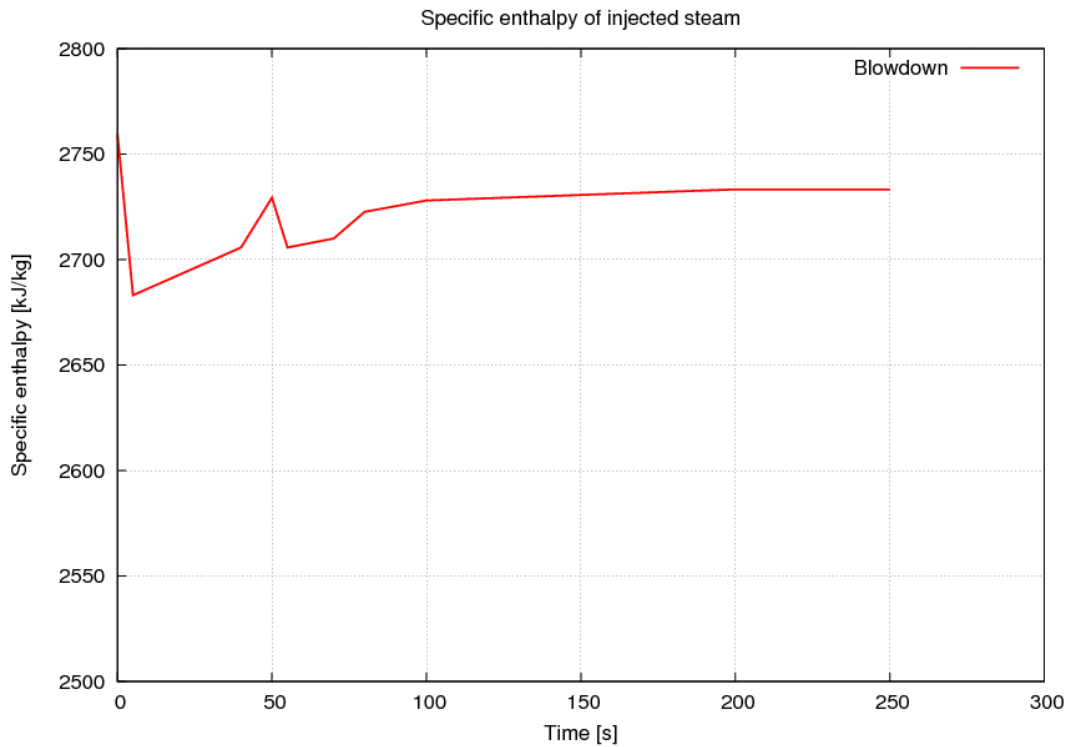


Figure 7. Specific enthalpy of steam discharge in experiment WLL-5-2.

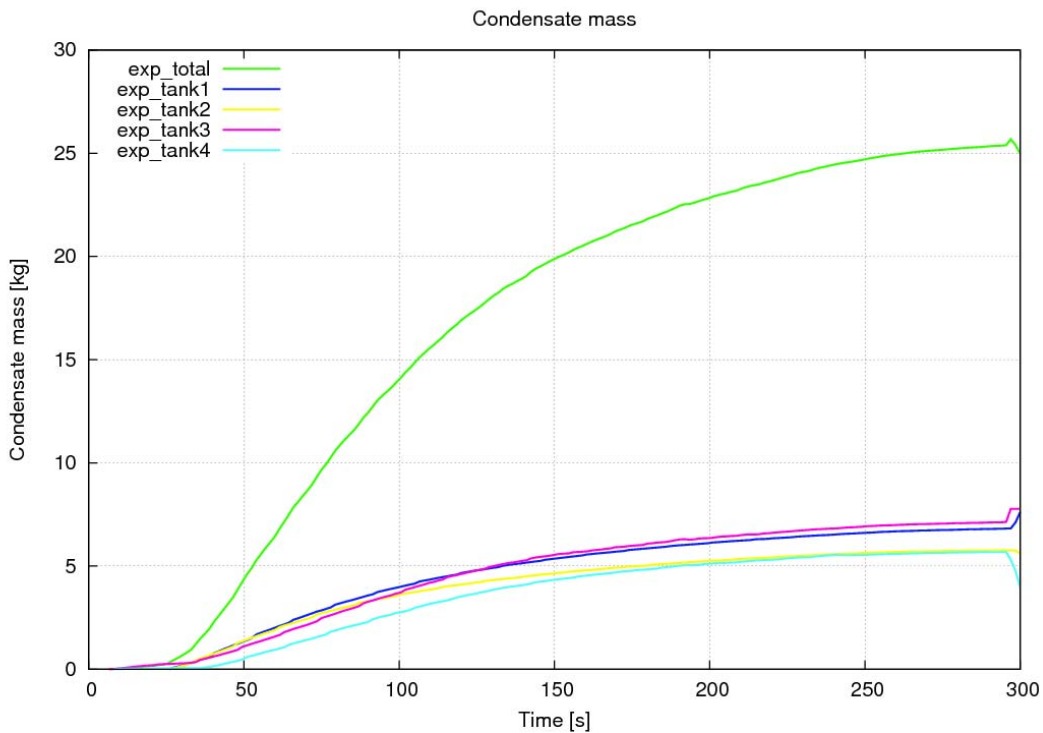


Figure 8. Condensate mass in WLL-5-2

Condensate mass was fairly evenly distributed across the four collection tanks. The largest mass accumulated into the tanks which collected condensate from the upper section of the drywell.

3 APROS MODELS OF PPOOLEX TEST FACILITY AND CALCULATION CASES

Two different nodalisation models were made for the calculations. The basic model was made as simple as possible, with very few nodes (Figure 9). Reason for this was to assess the capabilities of the simulation model in such a simple case. Reasonably accurate results with a simple model would be of use in training purposes, or when preliminary results are needed fast. For example, when studying the basics of plant behaviour, students could make their own models instead of having to use a ready-made more complex model, and still be able to get results that are feasible. The basic model consisted of three nodes: drywell, wetwell and environment. Altogether six separate heat structures were modelled. A suppression pool was located on the bottom of wetwell. Drywell and wetwell nodes were coupled together using three gas flow paths and one water flow path. Two gas paths represented the vacuum breakers and one the vent pipe.

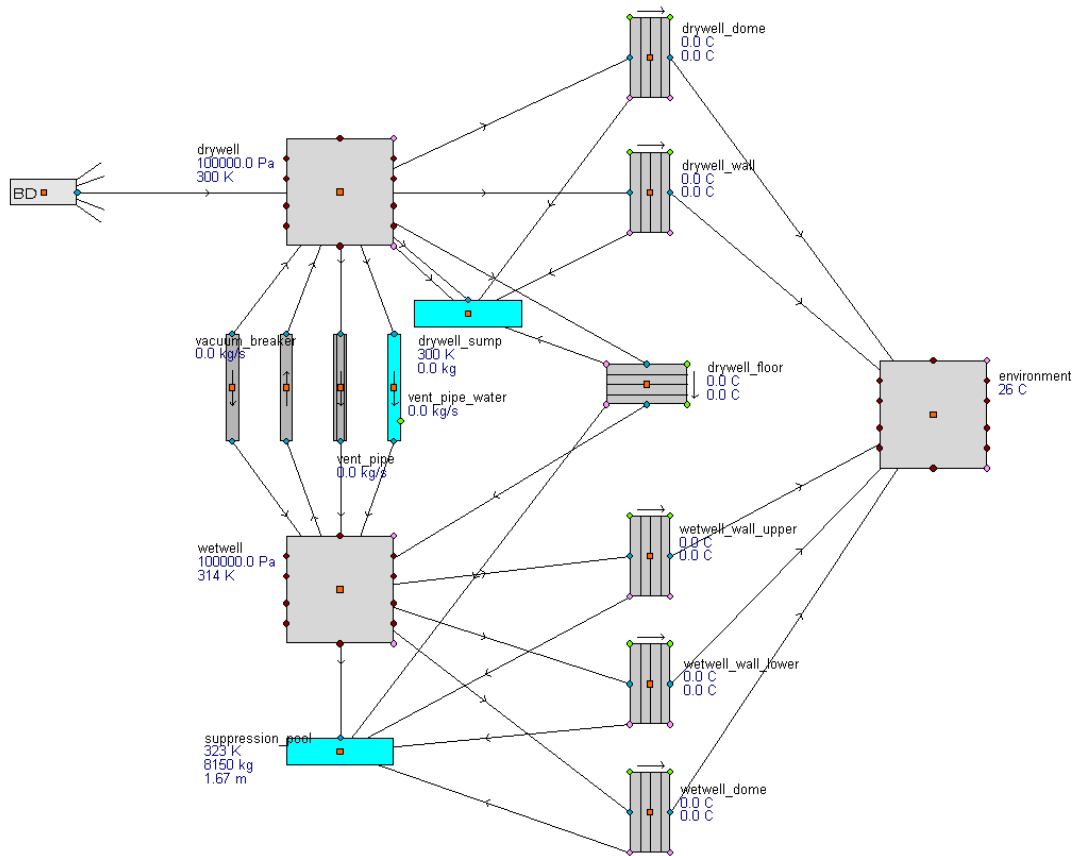


Figure 9. APROS model of the STR-1 and STR-4 experiments.

The simulations for the experiments STR-1 and STR-4 were done with the basic model. For the wall condensation experiment WLL-5-2 a more detailed heat structure modelling in the drywell was used (Figure 10). The nodalization is basically similar to the one used for experiments STR-1 and STR-4, but the drywell wall was divided into 8 structures. One structure represented the dome ceiling. Two of the structures presented the liner of the drywell wall where the steam condensation was measured. One structure presented the thicker parts of the vessel wall (flange) connecting the drywell dome to the cylindrical liner and one structure was the lower part of the liner where the steam condensation was not measured. The main pipe connections and valves were modelled as separate lumped masses. The specific

assumptions used in the calculation of each experiment are described in the following sections. Node data used in the basic model is shown in Table 1 and heat structure data is shown in Table 2.

Table 1. Node data of the APROS simulation model

Node	Volume [m ³]	Elevation [m]	Height [m]
Drywell	13.3	4.66	2.09
Wetwell	17.8	1.805	3.61
Environment	-	3.5	10

Table 2. Heat structure data of the APROS simulation model

Structure	Inside node	Outside node	Surface area [m ²]
Drywell_dome	Drywell	ENV	9.0601
Drywell_wall	Drywell	ENV	15.7586
Drywell_floor	Drywell	Wetwell	4.5369
Wetwell_wall_upper	Wetwell	ENV	18.1488
Wetwell_wall_lower	Wetwell	ENV	9.0706
Wetwell_dome	Wetwell	ENV	9.0601

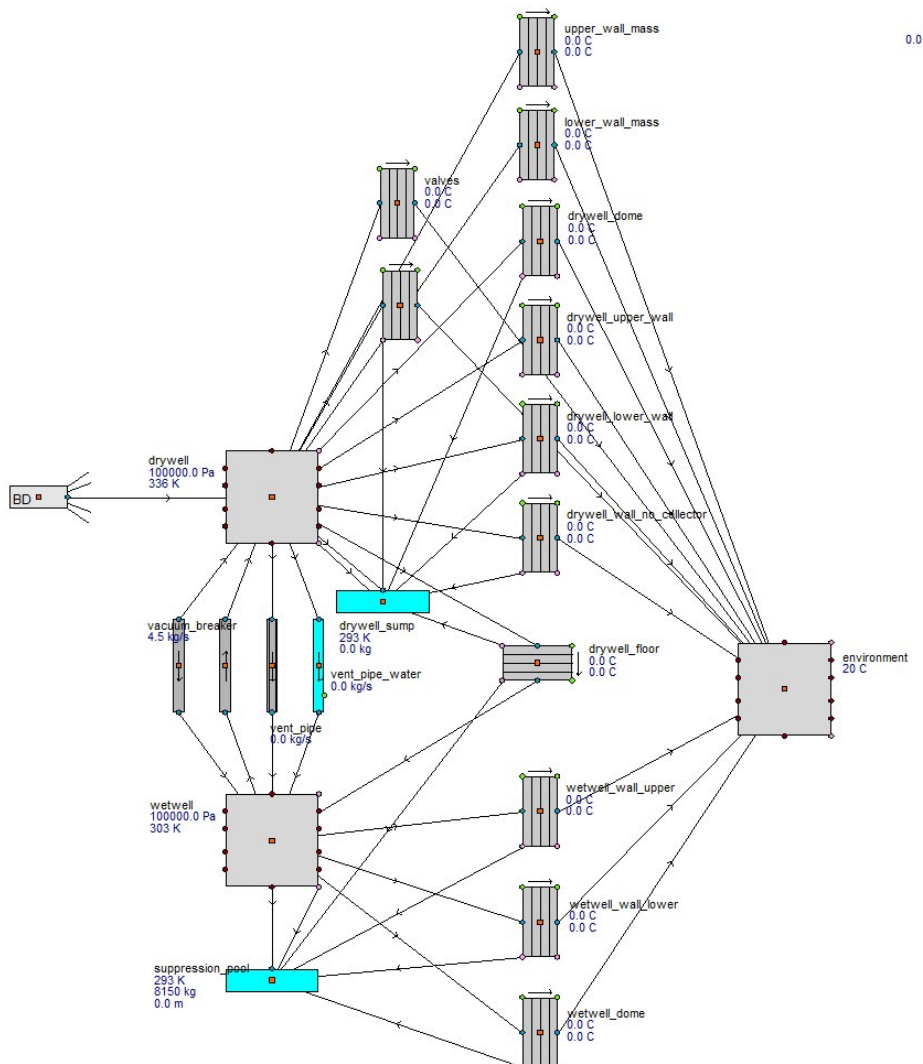


Figure 10. APROS model of the WLL-5-2 experiment.

3.1 STR-1

Since the STR-1 was a simple cooling experiment, no additional modifications to the model were needed, and the model was identical to the one shown in Figure 9. Despite this experiment did not have a steam injection, the blowdown module was included in APROS model nevertheless, as it would be required for the other simulations. To save time, calculations were done with as few changes to the basic model as possible. In STR-1 simulations, the steam injection was simply turned off. The most interesting calculation results were the suppression pool temperatures, which were compared to the experiment data to determine the input parameters for an accurate estimation of the heat losses to the environment. Because there was no temperature measurement of the environment, the simulations were done with a few different temperatures. Input parameters for the simulations are shown in Table 3.

Table 3. Input parameters for STR-1 simulation.

Simulation case	Run15	Run18
Environmental temperature [°C]	20	26
Initial relative humidity of drywell [-]	0.3	0.3

3.2 STR-4

No structural modifications to the basic model were needed in the simulation of experiment STR-4. The biggest difference from the STR-1 calculation was the steam injection to the drywell, which was now activated. In addition to the pool water temperature, the wetwell and drywell pressures and gas temperatures were of special interest, as well as the structure temperatures. Input parameters for the simulations are shown in Table 4.

Table 4. Input parameters for STR-4 simulation.

Simulation case	Run26	Run28
Condensation layer thickness [m]	0.2	0.01
Environmental temperature [°C]	20	20
Initial relative humidity of drywell [-]	0.5	0.5

3.3 WLL-5-2

Wall condensation experiments required some modifications to the basic model. Because the collection surface excluded the lowermost 0.45 m section of the vertical drywell wall, the heat structure modelling of the wall liner had to be separated into different sections as well. It was also found out that some thicker parts on the vessel wall play an important role in the wall condensation, because they remain cooler than the surrounding structures. Therefore, the flange connecting the drywell dome to the cylindrical wall was modelled with a separate heat structure. The collection surface was modelled by two different structures. The condensate mass from the upper structure is comparable to the measured condensation mass in the upper gutter, and the mass from the lower structures is compared to the measurement of the lower gutter. Three different variations were calculated with different initial humidity of the drywell (1%, 50% and 100%) as explained in more detail in Section 4.3. In one sensitivity calculation, the steam source was assumed to be saturated all the time during the injection.

4 COMPARISON OF CALCULATIONS AND MEASUREMENTS

4.1 STR-1

STR-1 was a fairly straightforward experiment and the main purpose was to study the natural cooling of the suppression pool. The suppression pool mean temperature from two calculations with different atmospheric temperature is compared to measurement in Figure 11. The environmental temperature of the experiment was not known, therefore, several calculations with different temperatures had to be done, because the temperature clearly affected the cooling significantly.

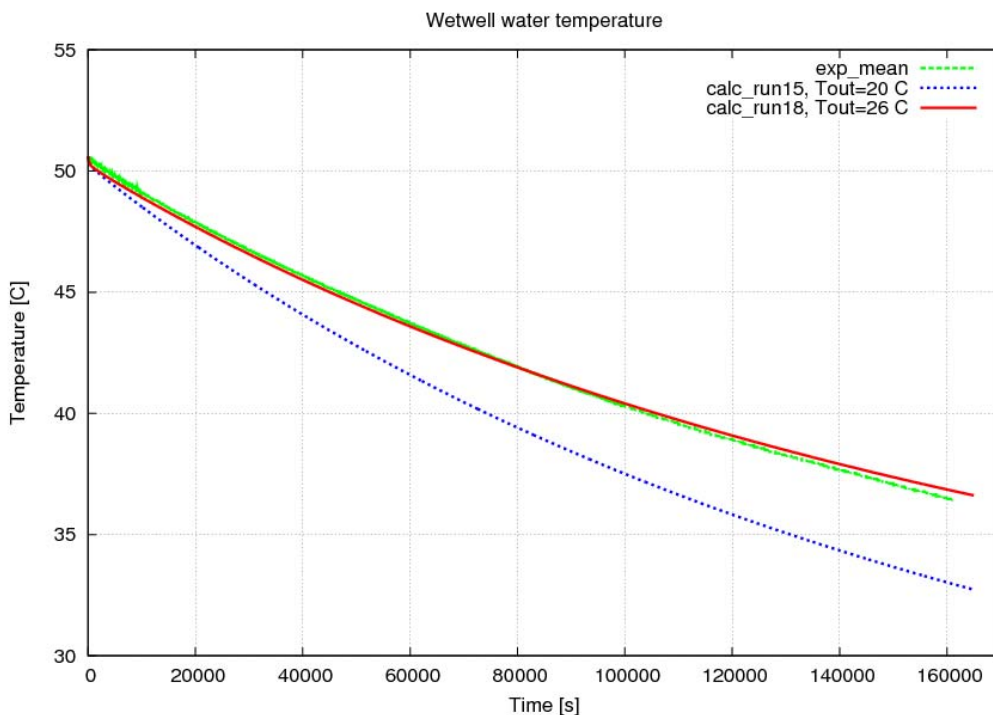


Figure 11. Pool water mean temperature in STR-1

The only difference between the two simulations shown in Fig. 11 is the environmental temperature, which was 20 °C in run 15 and 26 °C in run 18. The usual indoors temperature of 20 °C resulted in pool cooling that was noticeably faster than in the experiment. Increasing the temperature to 26 °C led to much better results. Even higher environment temperatures were tried, but they resulted in too low cooling rate of the pool. It was reasonable to assume that the environment was warmer than the standard 20 °C. The pool was filled with warm (50 °C) water, and the experiment lasted for 45 hours, so the immediate environment around the vessel was surely affected. It is worth noting, that the inner and outer heat transfer coefficients of the wall structures were calculated internally by APROS. The simulation results using 26 °C temperature for the environment match the experiment very accurately.

4.2 STR-4

STR-4 was a pool stratification experiment with steam injection into the drywell. The simulation results for the thermal stratification in the suppression pool were of special interest, because the stratification model of APROS should be further tested and developed if needed. In addition, some simulation results of basic process variables (pressures, gas temperatures) are given and compared to the measurements. The results of two different calculations are presented. They are otherwise identical, except that the conductance layer thickness needed to model the heat conduction between the pool layers of different temperatures is varied. Run 26 used the default value of 0.2 m for the conductance thickness, whereas run 28 used value of 0.01 m. The conductance layer thickness is an input parameter of APROS pool stratification model. The value defines the calculation length through which the heat conduction occurs inside the water pool. An increase in the thickness results in lower heat conduction rate, and correspondingly lower thermal mixing of the pool layers of different temperatures.

Predicted drywell pressure is compared to the experiment in Figure 12. Both simulation cases produce very similar pressures. Calculated pressure seems to be slightly lower than the measured one. Calculated pressure follows the experiment results well during the first 1500 seconds, but then results start to deviate. The pressure is underestimated about 0.2 bar at the end of the experiment. One possible explanation to the deviation may be the uncertainties related to the wall condensation, which are explained later. It might also be plausible that the amount of non-condensable gases inside the vessel is too low in the APROS model. For example, if the steam injection line was filled with air before the experiment, it was neglected in calculating the drywell atmosphere in the simulation. In addition, the relative initial humidity of the air in the vessel was not known, and the value of 50% was used in the simulation. If the experimental value was lower, the amount of non-condensable gases is underestimated in the simulation.

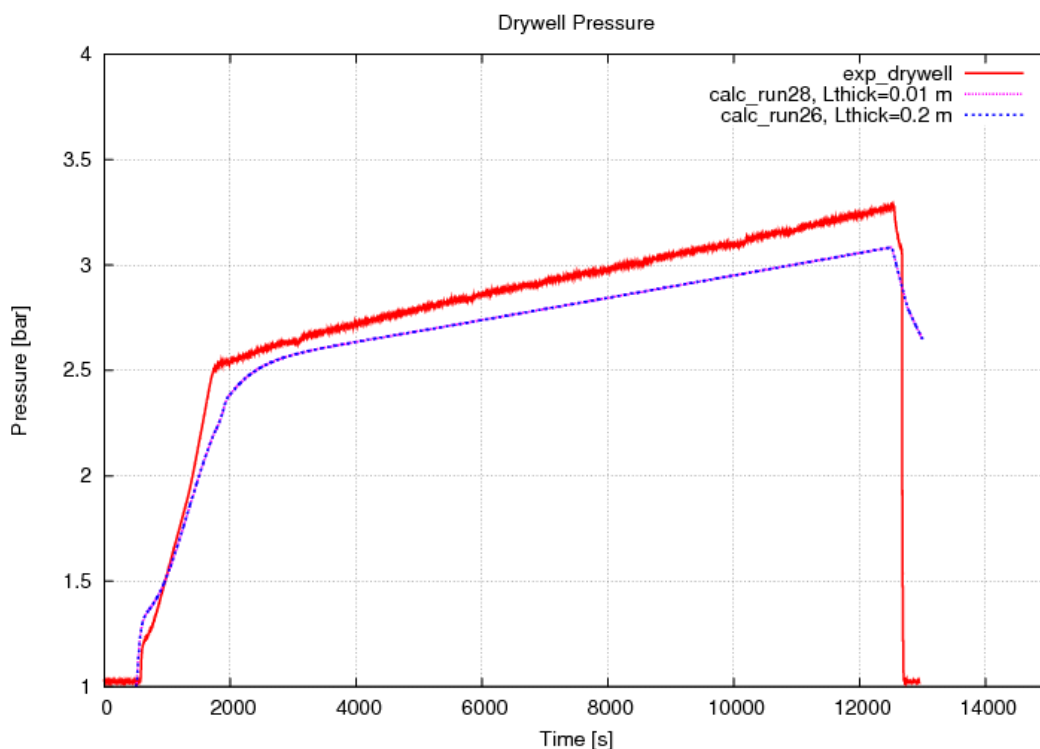


Figure 12. Drywell pressure in experiment STR-4.

Wetwell pressure is shown in Figure 13. Results in the wetwell follow the same pattern with the drywell pressure. Both simulation cases produce lower pressures than was measured in the experiment. Deviation starts at about 1500 seconds and the pressure difference between the calculation and the experiment is 0.2 bar at the end of the experiment.

Some explanation for the deviation may be the way the interaction of steam and non-condensables with pool water is modelled. As default, APROS assumes that all steam that flows through the vent pipe to the suppression pool condenses in the pool. Another default assumption is the thermal equilibrium of pool water and non-condensables flowing from the vent pipe to the pool. This means that the non-condensables leave the pool surface at the water temperature. These assumptions can be affected by input parameters, but because no corresponding experimental information was available, the default values/assumptions were used in the simulations.

The explanation for the underestimated pressure was also searched in the steam injection itself. The injected steam was assumed to be saturated corresponding to measured temperature in the steam injection line. However, according to measurements steam appeared to be occasionally in superheated state, but exact temperature was difficult to detect due to measurement signal noise. To check that the possible degree of superheating did not have any significant effect on the simulation results, a sensitivity calculation was done with different properties of the steam discharge. In the sensitivity study, the enthalpy of injected steam was defined according to the measured pressure of the injection line, but instead of assumption of saturation state, 5 °C higher temperature than measured was assumed in the injection line. The change in enthalpy of injected steam did not have any significant effect on the calculation results.

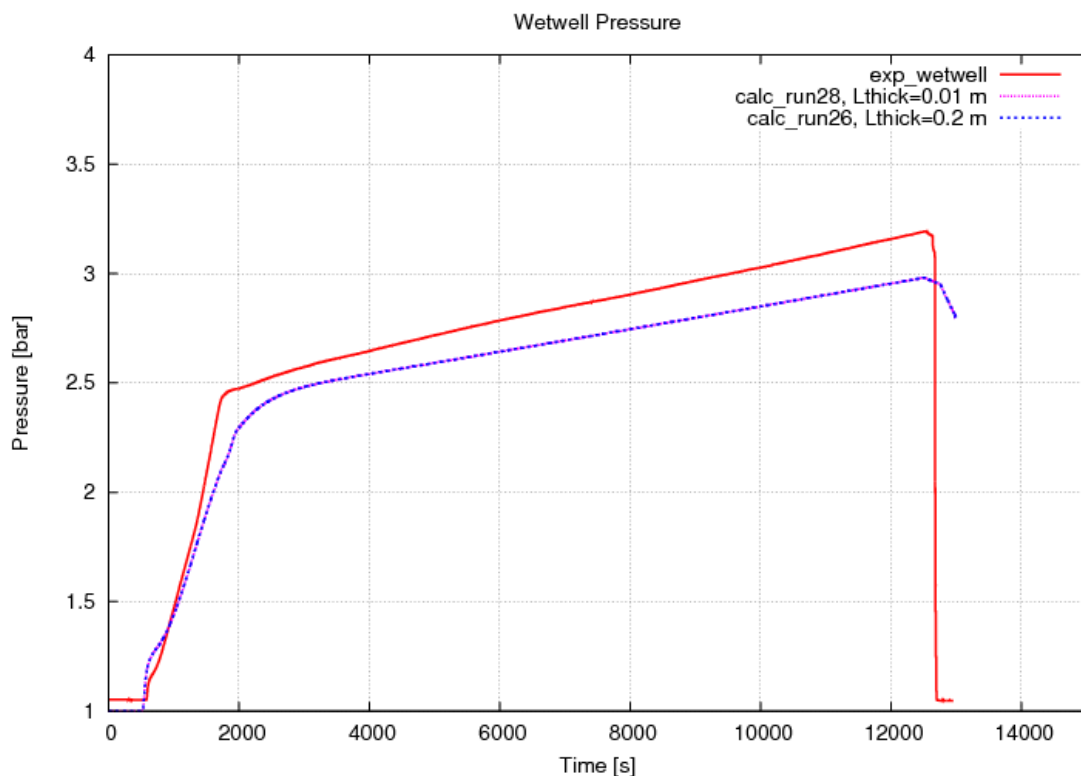


Figure 13. Wetwell pressure in STR-4 experiment.

Drywell gas temperature is shown in Figure 14. Both simulation cases produce identical results which agree well with the measurements within signal noise and accuracy of measurements. It's worth mentioning that the three thermocouples gave extremely uniform temperatures after the first 1500 seconds. This well mixed situation suited well for the APROS simulations with such a simple node structure.

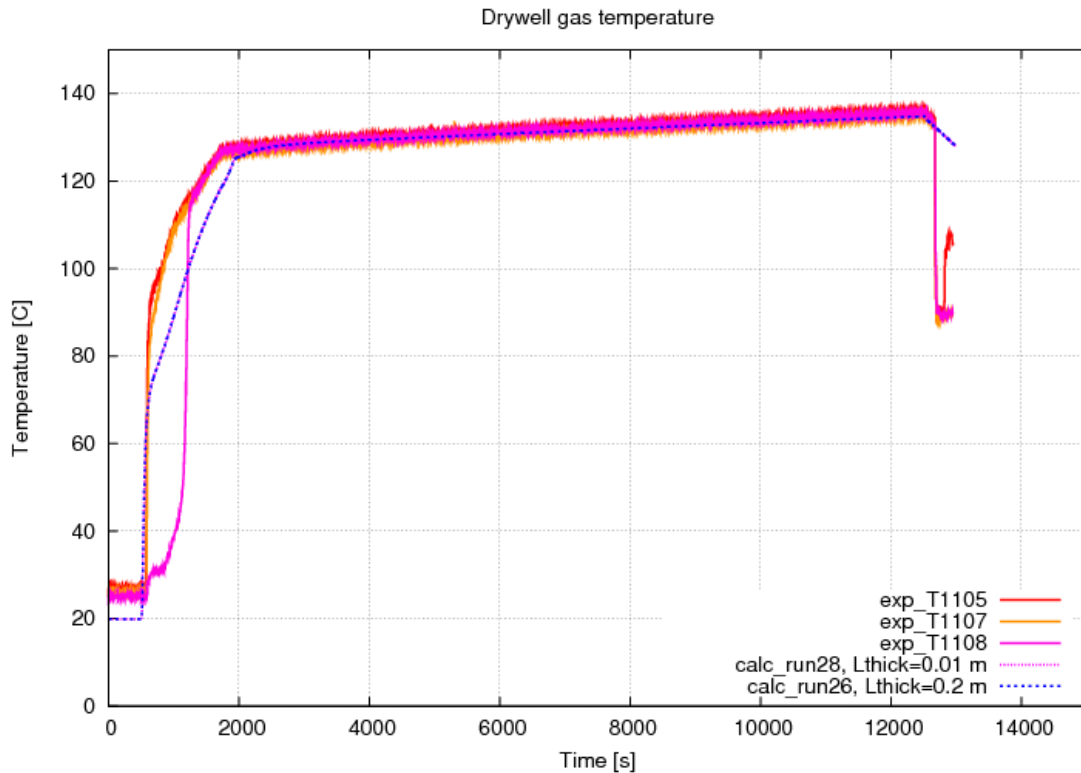


Figure 14. Drywell gas temperature in STR-4.

Wetwell gas temperature is shown in Figure 15. Once again, both simulations gave identical results. The gas temperature was overestimated in the early stages, and underestimated after around 5000 seconds. Deviation between the calculations and the experiment is maximally about 10 °C and is greater than was observed in the drywell gas temperatures. One possible explanation for this is the fact that there was noticeable thermal stratification in the wetwell gas space during the experiment. The higher areas were warmed by the heat coming from the drywell through the intermediate floor, and the areas near the water surface remained cooler. The mean temperature used in Figure 15 is calculated as a volume-weighted average of three measurements located on different elevations in the wetwell gas space. Sudden jumps in the experimental mean temperature between 5000-6000 seconds are odd, and no definite explanation was found for them during this work. Blowdown mass flow rate remained fairly steady during that period, so there is a possibility that some measurements show an inappropriate value. For example, water droplets may condensate on and later evaporate from the thermocouple, and hence, disturb the temperature measurement. But this remains only speculation.

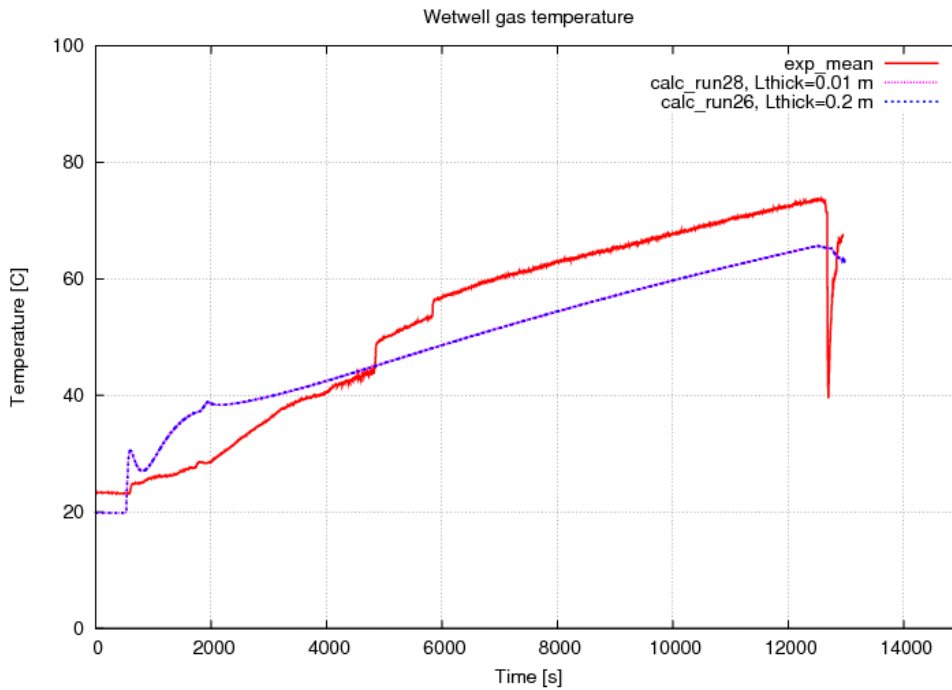


Figure 15. Wetwell gas temperature in experiment STR-4.

In the APROS pool stratification model, the pool is divided into two water layers which can have different temperatures. Mean temperatures of the water layers of the suppression pool above and below the lower end of the vent pipe are shown in Figure 16. The temperature measurements were taken from 16 thermocouples installed into the vertical measurement rod. The mean temperature of the layers above and below the lower end of the vent pipe was an arithmetic mean value from the measurements.

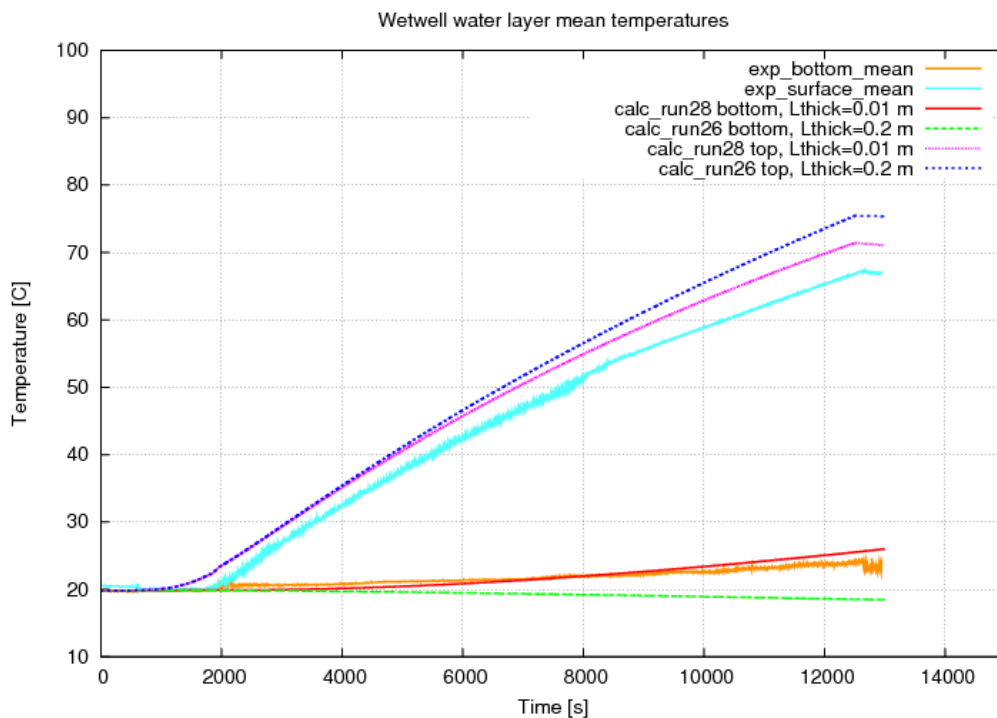


Figure 16. Suppression pool layer temperatures in experiment STR-4.

Figure 16 shows that the pool stratification can be simulated reasonably with the APROS model. However, use of APROS default value for the conduction thickness (0.2 m in run26) resulted in underestimated mixing between the pool layers and hence too strong stratification. The temperature in the bottom layer remained fairly constant, when it should warm up noticeably. When the conductance thickness was reduced to value of 0.01 m, better agreement was obtained with the experiment. Since similar trend was obtained also in the previous study /5/, APROS default value for the conductance thickness should be revised in the future.

Both simulation cases overestimated the overall mean temperature of the suppression pool, maximally about 10 °C in the end of the sequence. The basic reason for that remained unclear in this work. One explanation may be that too much energy is transferred from the steam and gas flow of the vent pipe to the pool water. As mentioned before, APROS assumes that all steam coming from the vent pipe condenses in the pool, and all non-condensables flowing out from the pool to the wetwell gas space have a 100% humidity and are in thermal equilibrium with the water.

4.3 WLL-5-2

In test WLL-5-2 the facility was dried out before the first run of each test series by injecting hot dry air through the facility. The successive tests were done without the long-term driving procedure, and hence, possible humidity was left in the drywell. Because the humidity was not measured, the initial humidity that exists in the facility at the beginning of the experiment was unknown. Therefore, three different base case calculations were carried out with APROS using 1% 50% or 100% initial humidity in the drywell to see the influence on the results.

The amount of condensate water collected from the drywell wall segment to the gutters and tanks was the most important measured variable. The upper gutter collects condensate water from the upper part of the segment wall and also from the dome. It is suspected that only some portion of condensate from the dome flowed to the wall and to the upper gutter. Because this portion is unknown that makes difficult to compare the measured condensate mass of the upper gutter with the calculation. The lower gutter collects condensate only from that part of the segment wall, which is between the lower and upper gutter. These results can be compared well with the simulation results.

Measured and simulated results of the condensate mass in the lower gutter are shown in Figure 17. This final condensate mass is estimated extremely well. The initial humidity of drywell has a minor influence on the simulation results.

Measured and simulated results of the condensate mass in the upper gutter are shown in Figure 18. Because amount of the condensate water that flows down in the experiment from the dome ceiling to the collection wall and upper gutter was unknown, two different calculation results are shown. In one result, only wall condensate is taken into account i.e. no water flow from the roof to the upper gutter is allowed (red line in Figure 18). In other case, all condensate from the roof is allowed to flow to the upper gutter (green line in Figure 18). The simulation results which neglect the roof condensate underestimates clearly the condensate mass. On the contrary, if all condensate from the roof is taken into account, APROS overestimates slightly the condensate mass. These results can be considered acceptable, since the truth is probably somewhere between i.e. only certain portion of roof condensate can flow to the segment wall and the upper gutter.

The experimental results in Figure 17 and

Figure 18 are shifted 20 seconds to the left. This is assumed to represent the time delay, which is needed when the condensate water flows from the gutters through the pipelines to the collection tanks where the water mass is measured.

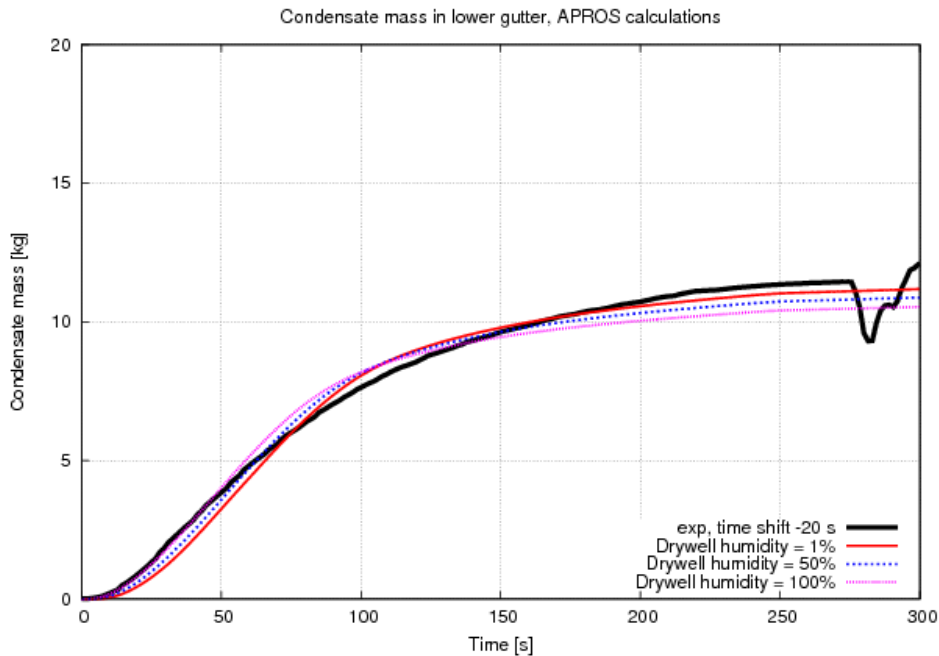


Figure 17. Condensate mass in the lower gutter: experiment WLL-5-2.

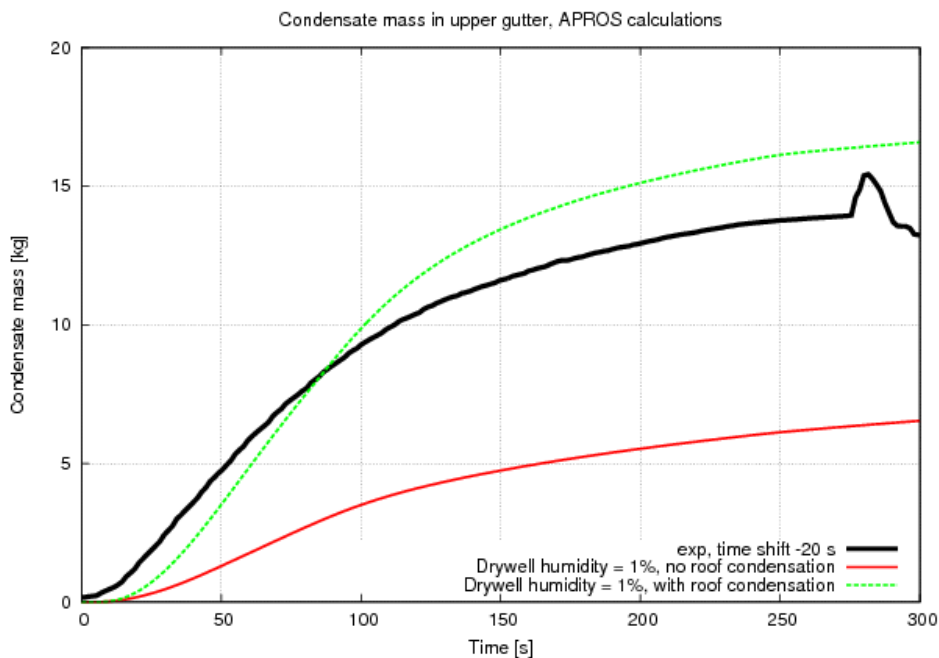


Figure 18. Condensate mass in the upper gutter: experiment WLL-5-2.

Predicted drywell pressures from three calculations with different initial humidity of drywell are shown in Figure 19. The simulation with 1% humidity seems to match the experiment

better, whereas the simulation with humidity of 100% gives a too low pressure because the amount of non-condensable gases is lower in the facility. Because accurate measurement of air humidity before the experiment was unavailable, any further analysis is speculation. Generally, taking into account the uncertainties in the boundary conditions, APROS manages to simulate the pressure development during the steam injection phase well.

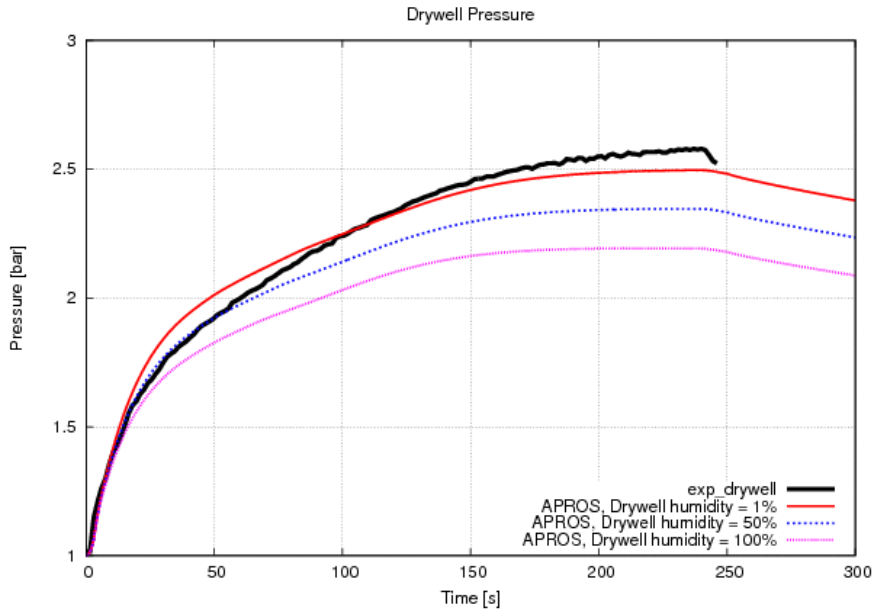


Figure 19. Drywell pressure in experiment WLL-5-2.

Wetwell pressure from two calculations with different initial humidity is shown in Figure 20. Once again, the calculation case using 1% humidity predicts the wetwell pressure very well, while the 100%-humidity case (run 15) clearly underestimates the pressure. The worst case scenario deviated about 15 % from the final pressure of the experiment.

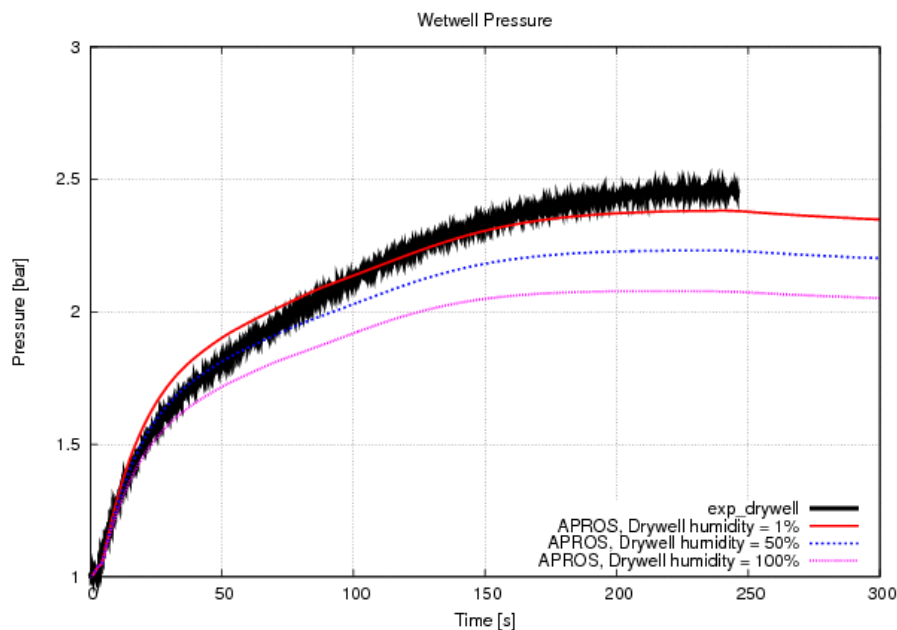


Figure 20. Wetwell pressure in experiment WLL-5-2.

Drywell temperature is shown in Figure 21. Two different calculation cases are shown in the figure. According to the measurement (thermocouple T2106) temperature of steam source in the inlet plenum of the steam injection line becomes suddenly superheated (at measured pressure) beyond time 70 s (Figure 22). At the same time, APROS start overpredicting the drywell gas temperature (red line in Figure 21). However, because the sudden jump in the steam injection temperature is somewhat confusing, an additional sensitivity calculation was performed where the injected steam was assumed to be saturated throughout the sequence (blue line in Figure 21). The simulation result using the saturated steam source predicts extremely well the drywell temperature, also beyond 70 s.

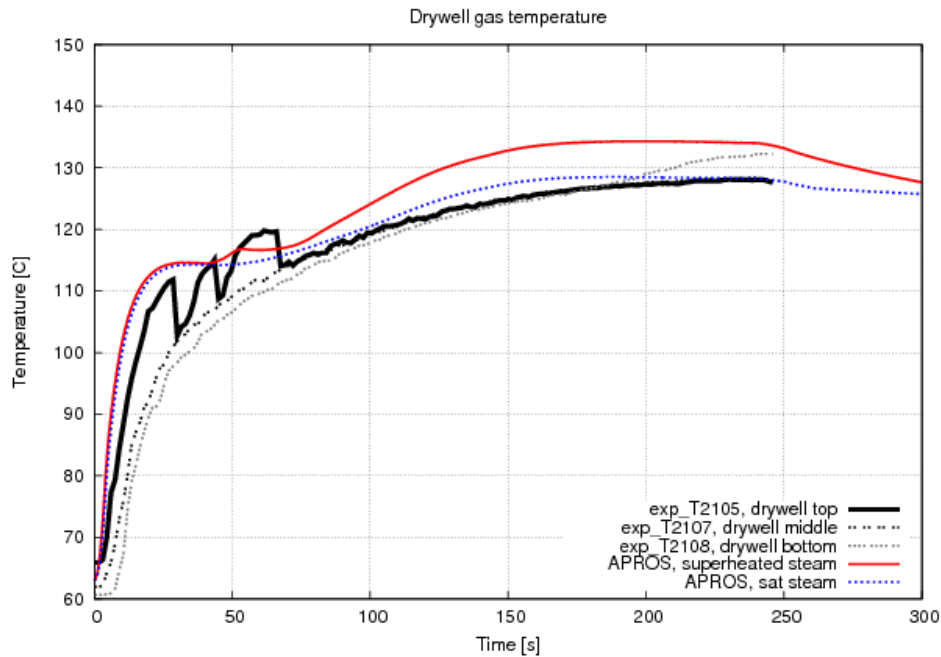


Figure 21. Drywell temperature in experiment WLL-5-2..

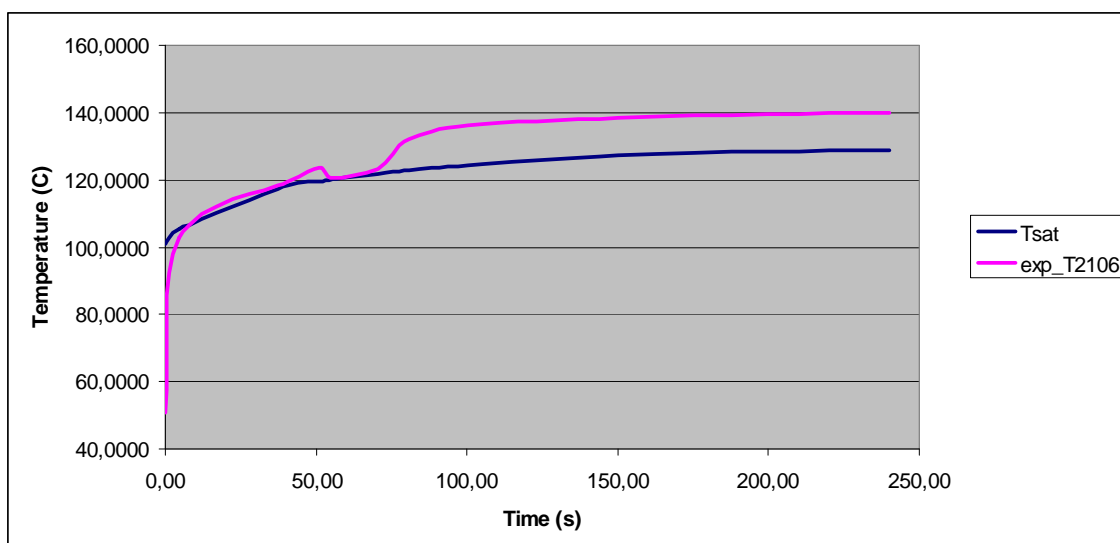


Figure 22. Measured versus saturation temperature of steam in the inlet plenum of the steam injection line in experiment WLL-5-2.

Wetwell gas temperature is shown in Figure 23. Simulation results seem to overestimate the wetwell gas mean temperature, especially in the early stages of the experiment. This hints that too much air flows and compresses to the wetwell gas space at that time. Towards the end of the experiment the difference decreases. Mean temperature for the experiment was calculated as a volume weighted average.

A clear stratification was created in the wetwell gas space in the experiment. Measurements for the wetwell gas temperature were limited to three thermocouples and they shows rather large differences depending on where they were placed. Because only one node represents the wetwell in the APROS model, these kinds of stratification phenomena could not be modelled.

It is worth noting that the upper layer of the suppression pool warms up only about 8 °C (from 20 °C to 28 °C) during the short experiment.

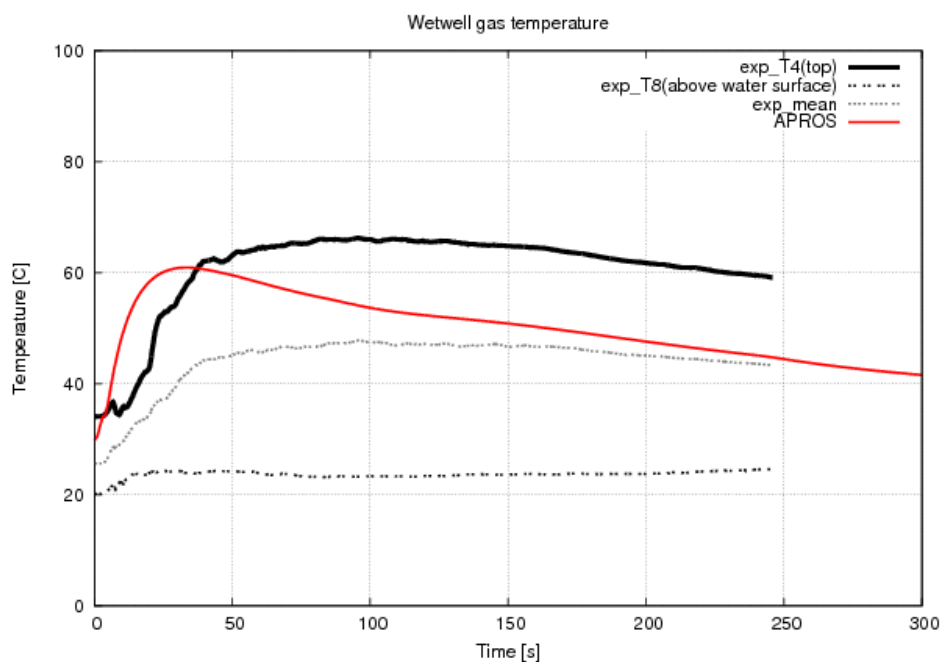


Figure 23. Wetwell gas temperature in experiment WLL-5-2.

Drywell wall outer temperature is shown in Figure 24. Wall temperature T2111 was measured directly on the opposite side of the steam inlet plenum. This measurement shows a higher temperature in the early stages of the experiment, because the injected steam hits this section of the wall first, before spreading into the other parts of the vessel. The simulation results match the other measurement from the outer wall (T2112) rather well throughout the experiment, as well as also the final temperature of the measurements.

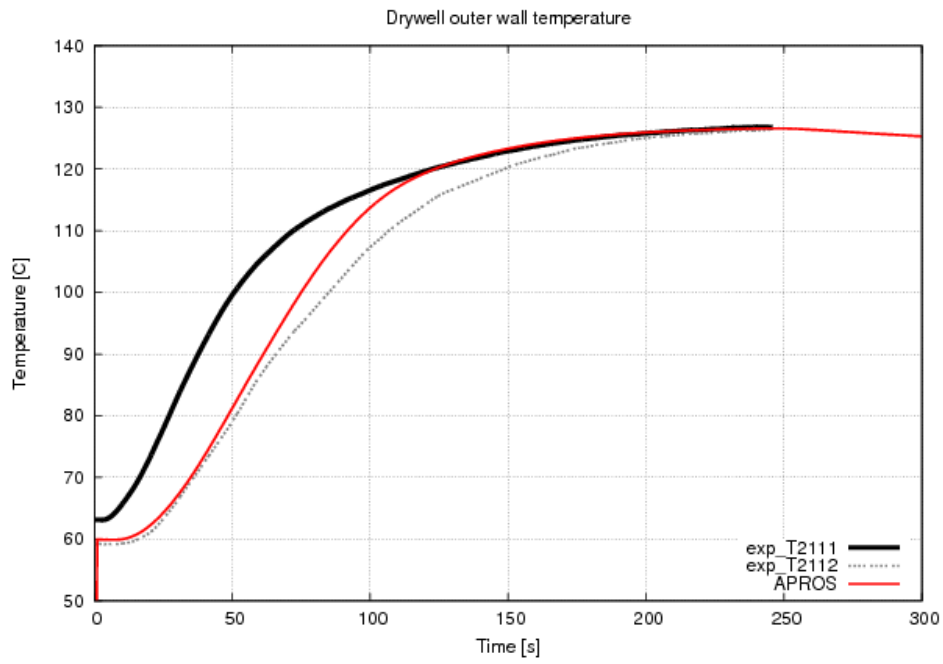


Figure 24. Drywell outer wall temperature in experiment WLL-5-2.

5 APROS CODE MODIFICATIONS AND DEVELOPMENT NEEDS

One code modification was made to the pool stratification model of APROS during this work. The heat conduction calculation between the pool layers with different temperatures was defectively sensitive to the time step used. The time-step dependency was removed in the code changes.

Some needs for further development of the pool stratification model also arose during the work. First of all, even if the pool stratification model is activated in APROS, the heat transfer calculation between the pool water and surrounding structures is based on the mean temperature of the pool. If the temperatures of pool layers deviate significantly from each other, this approach may lead to deficiencies in the heat transfer calculation. The solution could be improved and made more accurate, if the water-to-structure heat transfer is calculated separately for both pool layers using their specific temperatures. Another deficiency of the pool stratification model is that the iteration of pool surface temperature uses the pool mean temperature in formation of energy balance over the infinite small surface layer. A better and more accurate solution would be to use the temperature of the uppermost pool layer instead of mean temperature of the whole pool in the case where the stratification model is activated.

6 CONCLUSION

This report is a complementary version of the earlier VTT report no. VTT-R-06068-09 where APROS containment model was used to simulate three experiments conducted at the PPOOLEX test facility. The facility is a scaled model of a BWR containment including a suppression pool. The main objectives of calculations were to simulate the overall thermalhydraulics behaviour inside the vessel, steam condensation on the collection drywell wall structure, and thermal stratification of the suppression pool.

Overall performance of the simulation model was good, considering the fact that the simulation model was not “hand tweaked” with unrealistic input parameters to match the experiment results. On the contrary, all input parameters were kept as realistic as possible. The drywell and wetwell pressures were slightly underestimated in the long-term tests with a steam injection (STR-4), but in the short-term wall condensation test WLL-5-2 the pressures as well as the steam condensation rate to the lower collection wall were predicted extremely well taking into account the uncertainties of the boundary conditions. Also the suppression pool temperature stratification could be simulated reasonably, when the conductance layer thickness of the water was defined to be 0.01 m. Noticeable deviations between the experiment data and the simulation results were found in the wetwell gas temperatures of experiments STR-4 and WLL-5-2. One explanation for that may be a strong stratification of the wetwell gas space observed in the experiments. The APROS results represented always the gas mean temperature, because the wetwell was modelled only by one node. There was also some uncertainty in the specific enthalpy of injected steam in experiments STR-4 and WLL-5-2.

A defective time-step dependency of the heat conduction calculation of the pool stratification model was found out and corrected to the APROS code during this work. Also, some findings in the APROS stratification model that would require additional development were reported.

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