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ATHLET calculations for PANDA benchmark

Test L 5.3 and H 5.3

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Dissemination level : RE: restricted to a group specified by the partners of the NACUSP project

1 Introduction

Within the NACUSP project the thermohydraulic code ATHLET, which has been developed by GRS (Gesellschaft für Anlagen- und Reaktorsicherheit mbH), was used for the calculation of natural circulation experiments at the PANDA test facility. Two experiments were defined as a benchmark to validate thermohydraulic computer codes. In this report the ATHLET calculations for the PANDA tests L 5.3 and H 5.3 and in addition a calculation with higher core power and lower RPV level are presented. For the calculations the code version ATHLET Mod 1.2 CYCLE B was used [1].

2 The PANDA test facility

PANDA is a large-scale thermohydraulic test facility located at Paul Scherrer Institute Villigen, Switzerland (PSI). The test facility was designed to investigate the system behavior of Light Water Reactors (LWR) and to study containment phenomena. The Reactor Pressure Vessel (RPV) has an inner diameter of 1,23m and a height of 19,2m. The core is simulated by 115 electrical heater elements with a total power of 1,5 MW. The RPV simulates a riser and downcomer, both separated by a shroud. The riser has an inner diameter of 1,05m. The pressure inside the vessel is limited to 10 bar.

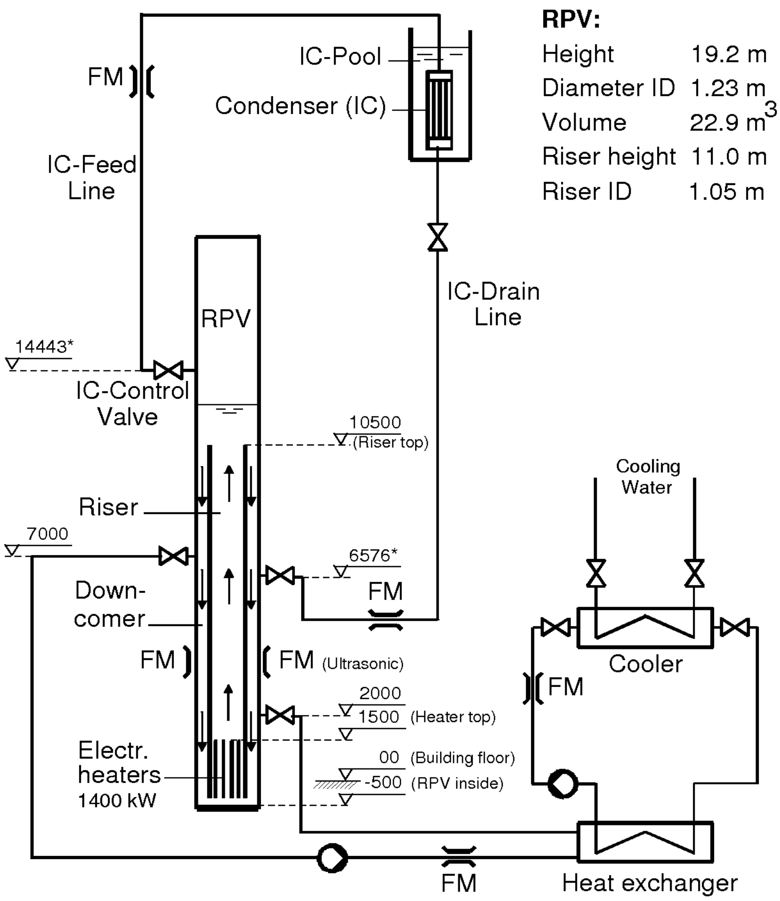


Fig. 1 Overview about PANDA test facility, [2]

Within the NACUSP project the test facility was modified and only a few parts of the facility were used for the tests (Fig. 1). For the natural circulation experiments the RPV is connected to the isolation condensor (IC). The steam produced in the reactor core flows to the Isolation Condensor and the condensate flows back to the downcomer. The subcooling at the core inlet can be controlled by the Auxiliary Water System, which is connected to the downcomer. For different natural circulation experiments the core inlet hydraulic resistance coefficient can be varied over a wide range by adjusting the gap between the lower edge of the shroud and the bottom of the RPV. A detailed description of the test facility is given in Ref. [2].

3 Thermohydraulic model

The presented calculations were performed with ATHLET Mod 1.2 Cycle B. The ATHLET input dataset models all main parts of the PANDA configuration used for the NACUSP natural circulation experiments (see Fig. 2).

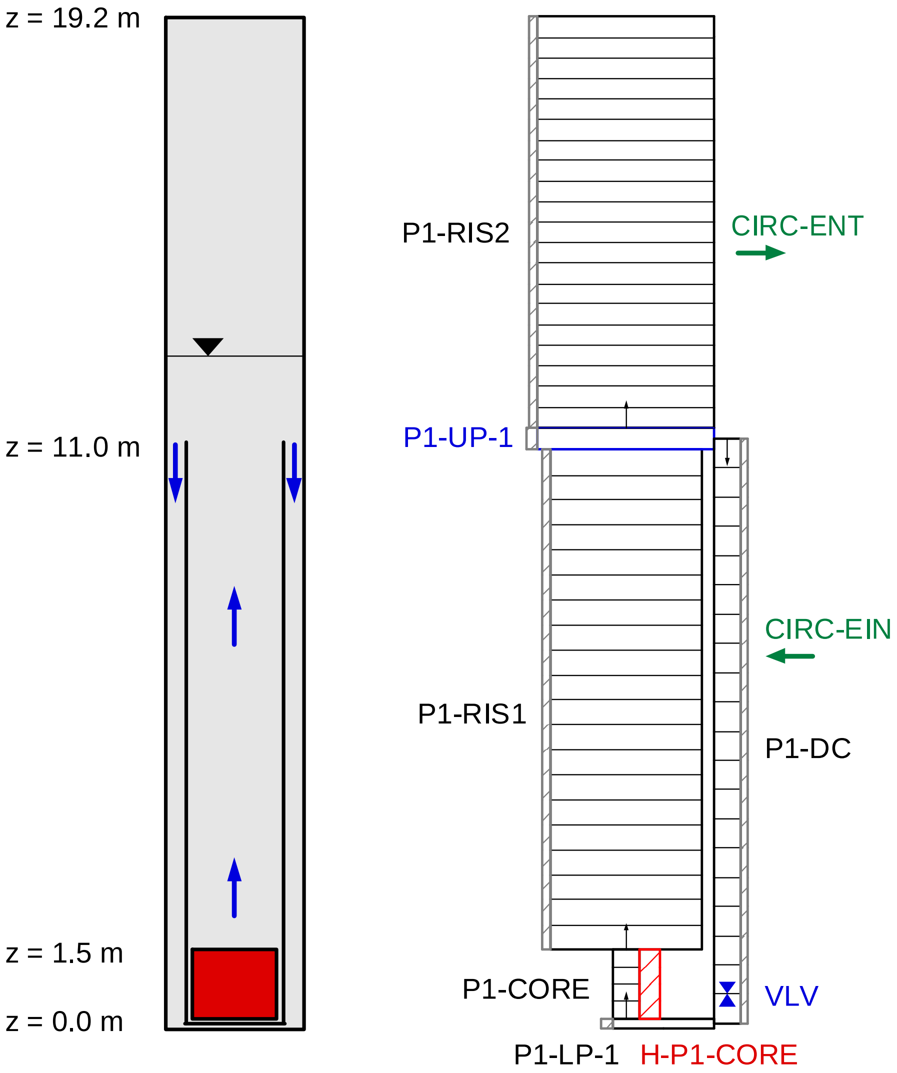


Fig. 2: Schematic representation and nodalization scheme of PANDA test facility

Table 1 shows the structure of the priority chains from the ATHLET input. The ATHLET model consists of the lower plenum (P1-LP-1), the core section (P1-CORE) with 115 electrical heater elements, the riser (P1-RIS1), upper plenum (P1-UP-1), downcomer (P1-DC) and the upper part of the RPV (P1-RIS2). The Isolation Condensor is not modeled. Therefore a bypass (CIRC-ENT, CIRC-EIN) is connected to the upper part of the RPV and to the downcomer, modeling the IC-feed and drain lines by fills with constant mass flows and given enthalpy (only drain line). In all control volumes the 5-equation model (separate conservation equations for liquid and vapour mass and energy, mixture momentum equation) and the full-range drift-flux model of ATHLET are used. A valve at the lower end of the downcomer (VLV, see Fig. 2) is used to model different k-factors of the core inlet. The cross section of this valve can be changed to adjust the core inlet flow resistance.

```
----- LOOP1                                                        @
@                                                                  @
@     IPRI0   ISYS0                                                @
      1       1                                                    @
@                                                                  @
@     SBO0    ANAMO       SEO0     IARTO                           @
      0.0     P1-LP-1     0.000    1                               @
      0.0     P1-CORE     1.300    1                               @
      0.0     P1-RIS1     9.500    1                               @
      0.0     P1-UP-1     0.000    1                               @
      0.0     P1-DC       11.115   1                               @
      0.0     P1-LP-1     0.000    1                               @
@                                                                  @
----- LOOP2                                                        @
@                                                                  @
@     IPRI0   ISYS0                                                @
      2       1                                                    @
@                                                                  @
@     SBO0    ANAMO       SEO0     IARTO                           @
      0.0     P1-UP-1     0.000    1                               @
      0.0     P1-RIS2     7.800    1                               @
@                                                                  @
----- CIRCENT                                                      @
@                                                                  @
@     IPRI0   ISYS0                                                @
      -4      1                                                    @
@                                                                  @
@     SBO0    ANAMO       SEO0     IARTO                           @
      0.000   P1-RIS2     3.513    1                               @
      0.500   CIRC-ENT    0.000    1                               @
@                                                                  @
----- CIRCEIN                                                      @
@                                                                  @
@     IPRI0   ISYS0                                                @
      -5      1                                                    @
@                                                                  @
@     SBO0    ANAMO       SEO0     IARTO                           @
      0.000   P1-DC       4.139    1                               @
      0.500   CIRC-EIN    0.000    1                               @
```

Table 1: Structure of the priority chains in the ATHLET dataset

4 Experiments

Different experiments were carried out at the PANDA test facility to study the natural circulation behavior of a LWR at low pressure conditions and to provide a data base on which basis thermal-hydraulic codes can be validated, Ref. [3]. The experiments selected for the benchmark were performed at a pressure of 5 bar, appr. 900 kW core power and with different core inlet hydraulic resistance coefficients (k=7 and k=500). During each experiment the core power and system pressure were kept constant over the whole measuring period of appr. 18000 seconds. Table 2 shows the specification for the two benchmark tests H 5.3 and L 5.3.

Fig. 3 shows the measured core power, RPV level, system pressure and temperature in case of test H 5.3 and Fig. 4 shows the typical mass flow for both experiments within a period of 1500 seconds.

Test	Power MW.RP.7	Pressure MP.RP.1	RPV Level ML.RP.1	DC Temp. MTL.RP.1	DC Mass flow MVE.DC.1	k-factor
L 5.3	909 kW	5.0 bar	12.82 m	152.0 °C	0.31 m/s	7
H 5.3	902 kW	5.0 bar	12.81 m	151.5 °C	0.15 m/s	500

Table 2: Test specification for benchmark tests H 5.3 and L 5.3

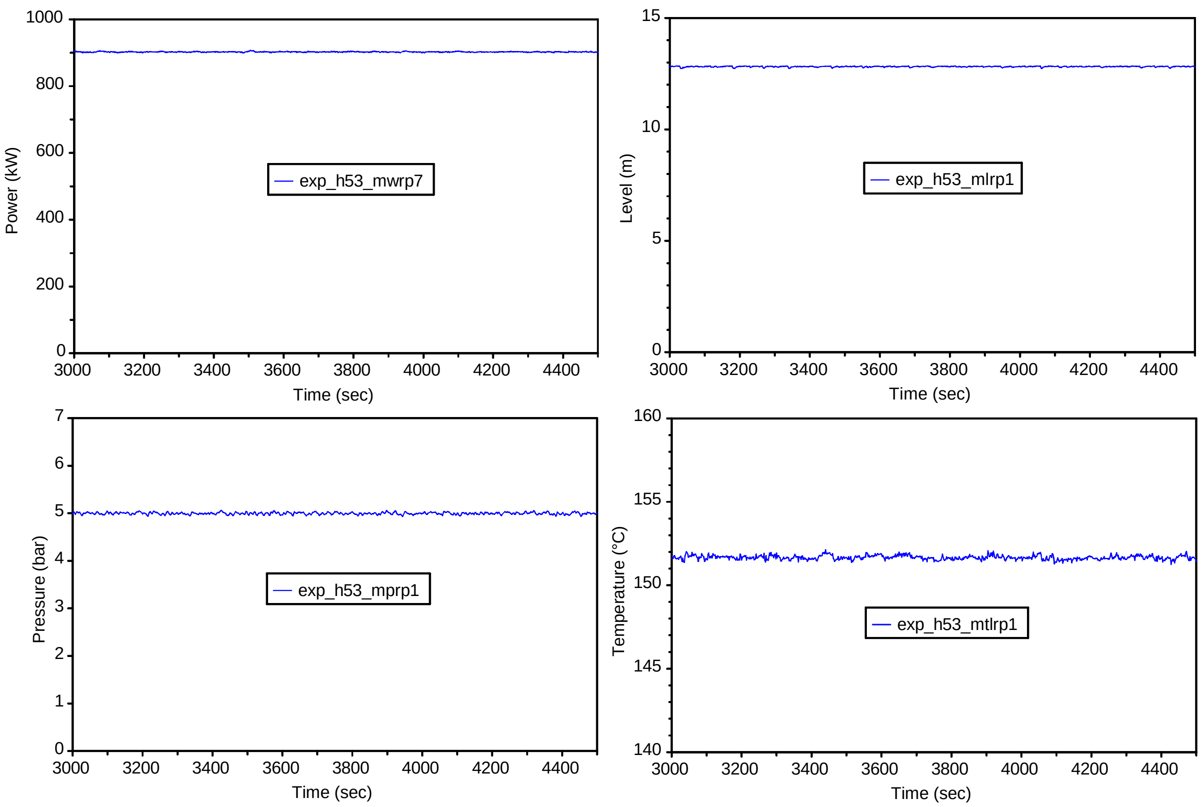


Fig. 3: Measured core power, RPV level, system pressure and temperature for test H 5.3

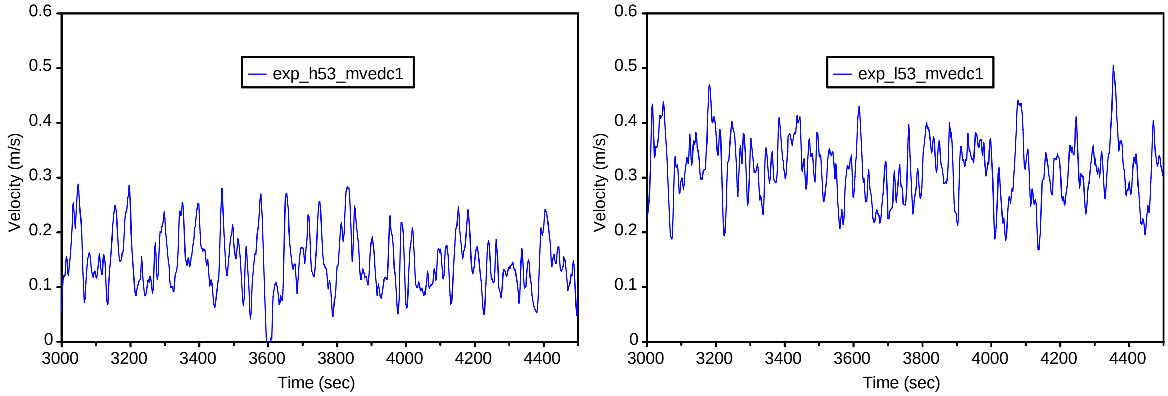


Fig. 4: Downcomer mass flow for benchmark test H 5.3 and L 5.3

5 Results

5.1 Steady state calculation

At first a steady state calculation with constant boundary conditions was performed. With help of this calculation the pressure losses, heat losses, the RPV water level and the temperature distribution were adjusted. The steady state calculation starts with zero power. After a few seconds the core power is switched on and the power is increased with time. The steady steate calculation is stopped if stable conditions are reached. The results of the steady state calculation are presented in Fig. 5.

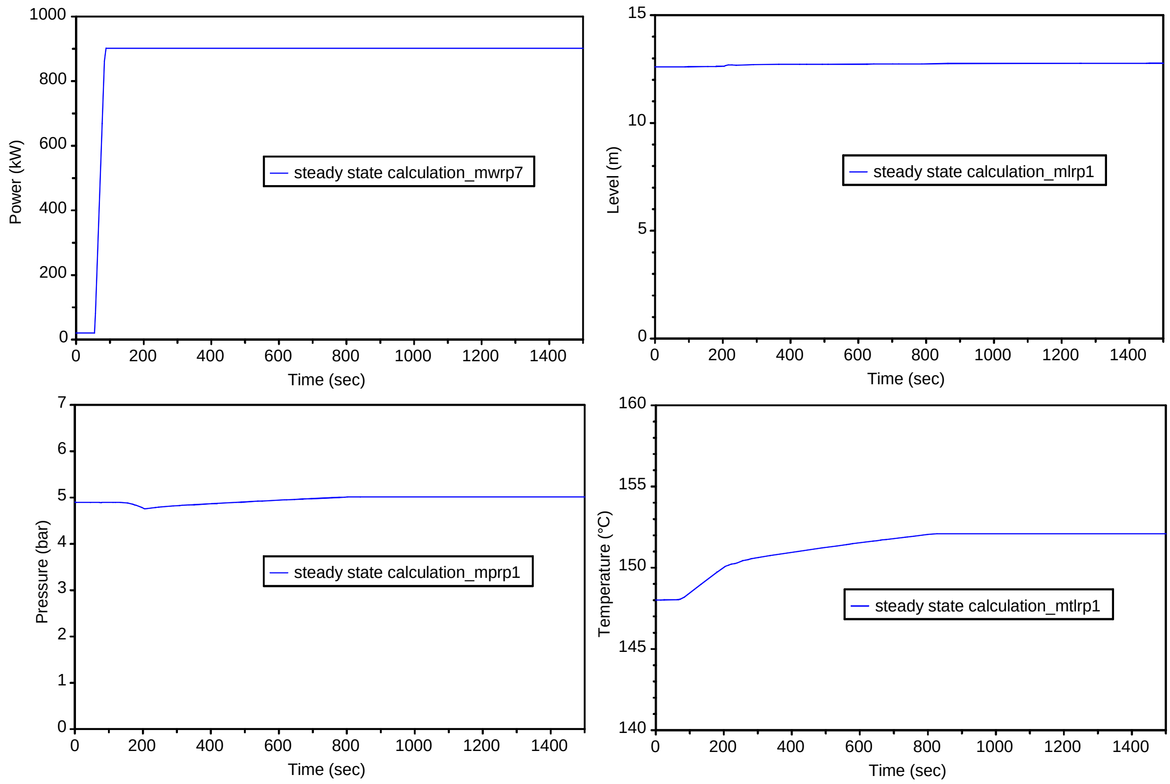


Fig. 5: Results of the steady state calculation (core power, RPV level, system pressure and temperature)

5.2 Transient calculations

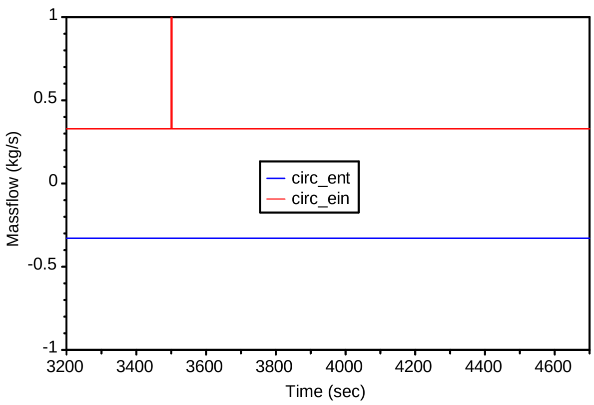
Both transient calculations start from a steady state calculation as described in chapter 5.1. For the calculation it was not possible to specify a certain k-factor for the core inlet, because the form loss coefficients are changed within the algorithm of the ATHLET code during the steady state calculation. Therefore a valve at the lower end of the downcomer with changing cross section was used to adjust the core inlet flow resistance during the transient calculation. The cross section of this valve was reduced to a value, which leads to DC velocities corresponding to the measured data. In the transient calculation the valve cross section was reduced at t=1520s.

Table 3 shows the initial conditions calculated with ATHLET and the measured data for PANDA tests L 5.3 and H 5.3 (mean values).

		PANDA Test L 5.3		PANDA Test H 5.3	
		Experiment	ATHLET	Experiment	ATHLET
Power	MW.RP.7	909 kW	909 kW	902 kW	902 kW
Pressure	MP.RP.1	5.0 bar	5.0 bar	5.0 bar	5.0 bar
RPV Level	ML.RP.1	12.82 m	12.80 m	12.81 m	12.80m
DC Temp.	MTL.RP.1	152.0 °C	152.0 °C	151.5 °C	151.2°C
DC Mass flow	MVE.DC.1	0.31 m/s	0.31 m/s	0.15 m/s	0.15 m/s

Table 3: Initial conditions and experimental results for benchmark tests L 5.3 and H 5.3

To simulate the system behavior with respect to natural circulation stability a short disturbance of the drain line mass flow was used in order to stimulate oscillations in the loop (Fig. 6, left). The response of the system can be seen in the riser mass flow (Fig. 6, right).



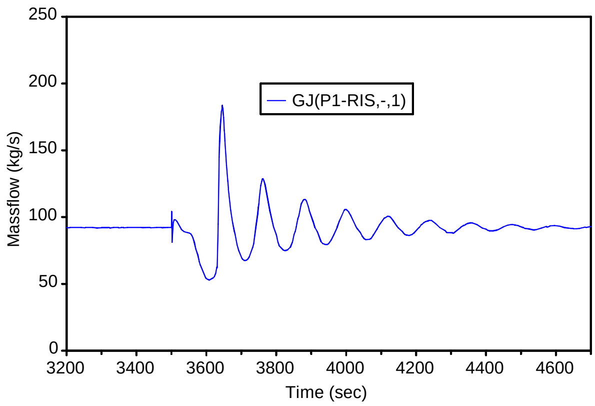


Fig. 6: Mass flow in IC-feed and drain lines and riser mass flow

Fig. 7 and 8 show the downcomer velocity, the spectrum and the auto-correlation-function (ACF) for both ATHLET calculations. As in the experiments the DC velocities were used to calculate the spectrum and the decay ratio.

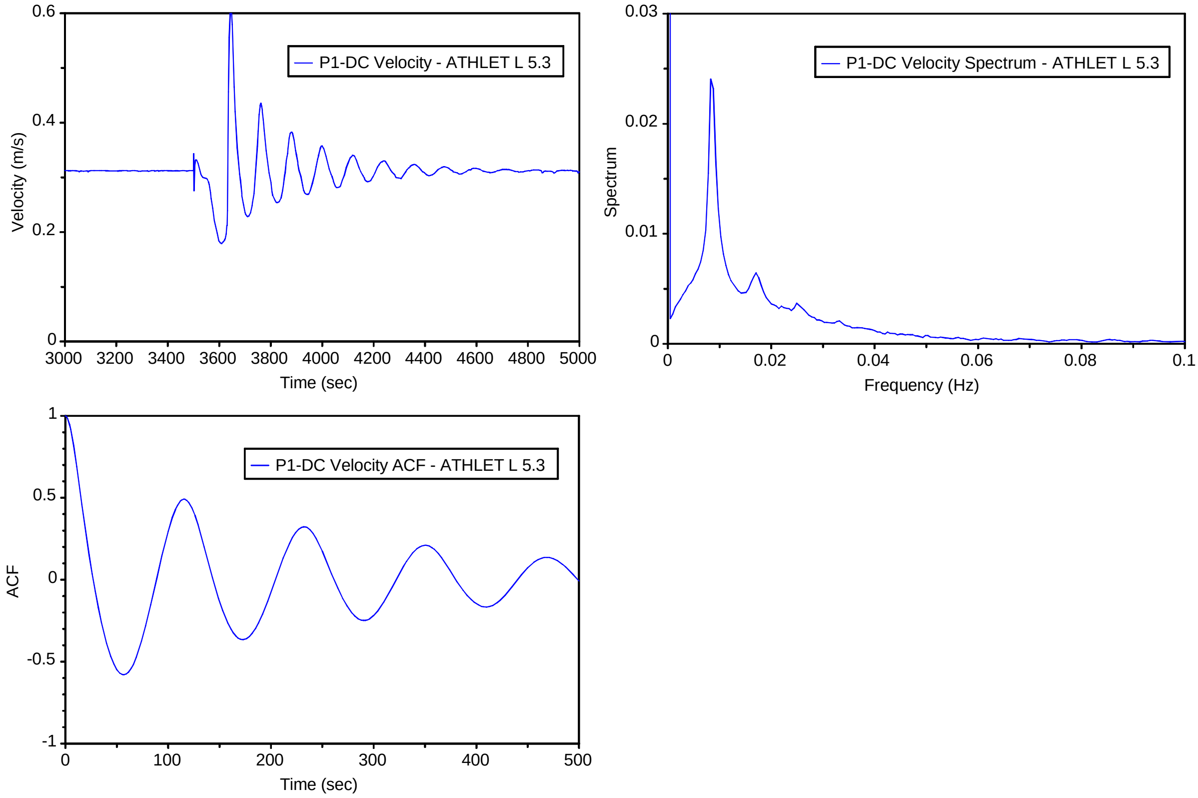


Fig. 7: DC velocity, spectrum and ACF for the ATHLET calculation of test L 5.3

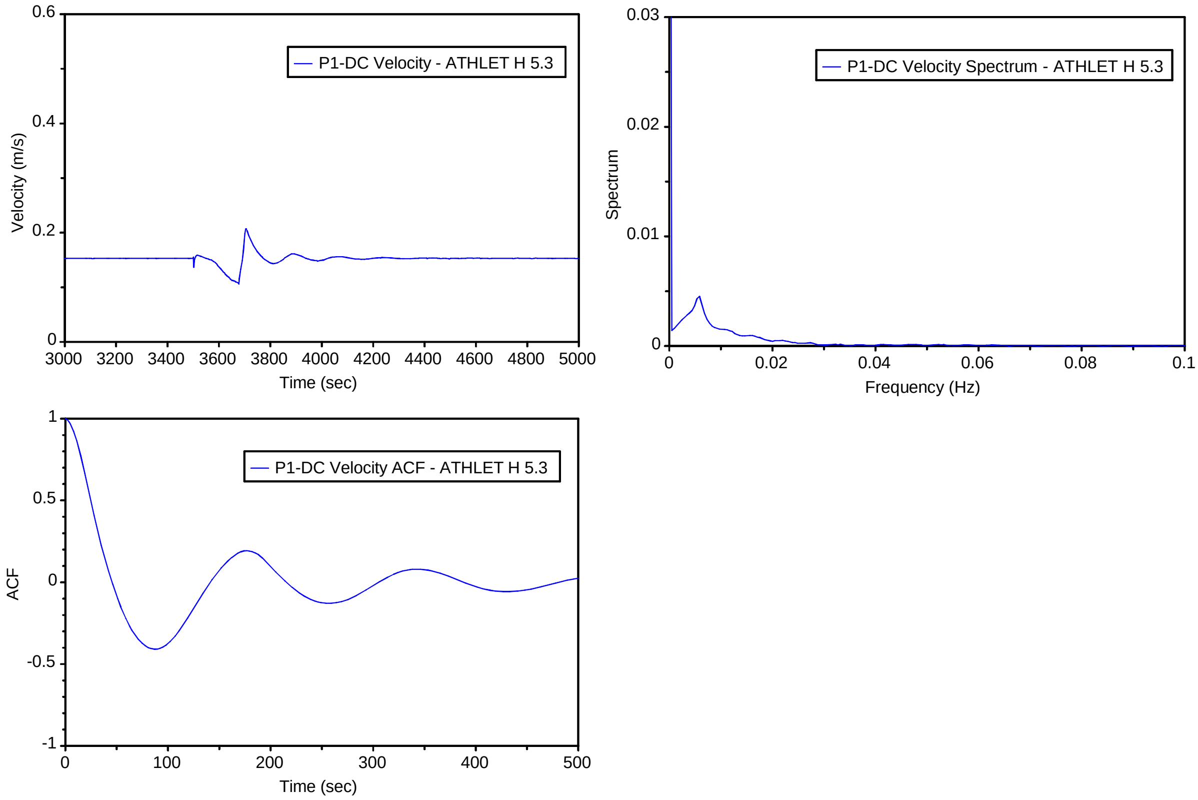


Fig. 8: DC velocity, spectrum and ACF for the ATHLET calculation of test H 5.3

The ATHLET calculations predict stable behavior for both tests and no limit-cycle oscillations occur. In case of test L 5.3 the disturbance leads to strong flow oscillations with decreasing amplitude for more than 1000 seconds. In case of test H 5.3 the oscillations are suppressed due to the higher core inlet loss coefficient. Table 4 gives a comparison between measured data and calculated results. PANDA test H 5.3 shows no major peak in the power spectrum and no decay ratio could be calculated for this experiment. Although the oscillations were supressed very fast in the corresponding ATHLET calculation, a oscillation period and also a decay ratio can be calculated from the DC mass flow.

	PANDA Test L 5.3		PANDA Test H 5.3	
	Experiment	ATHLET	Experiment	ATHLET
DC Mass flow	0.31 m/s	0.31 m/s	0.15 m/s	0.15 m/s
Oscillation period	120s	120s	-	171s
Decay ratio	0.68	0.66	-	0.41

Table 4: Experimental and calculated results for benchmark test L 5.3 and H 5.3

The results of the experiments and also the ATHLET calculations show that the oscillation period decreases with increasing DC velocity. Fig. 9 shows the oscillation period as a function of the DC velocity for the PANDA tests [3] and the ATHLET simulations. Both ATHLET calculations show a good agreement with the experimental results.

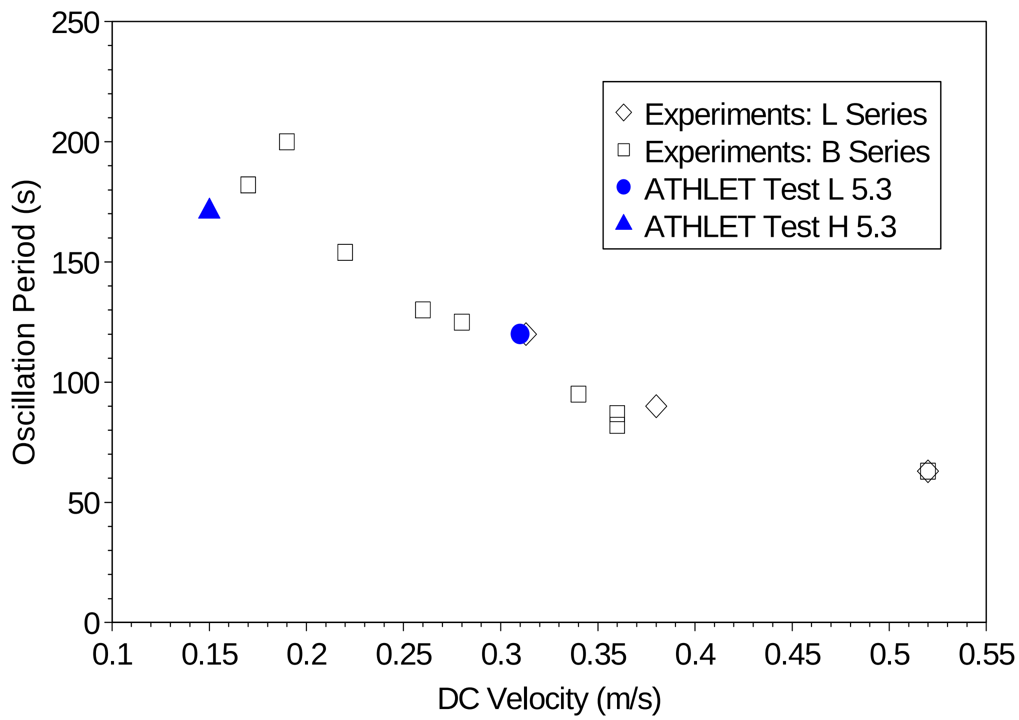


Fig. 9: Oscillation period as a function of the DC velocity – experiments and ATHLET calculations (experimental data from [3])

5.3 Additional calculation

To demonstrate the ability of ATHLET to calculate an unstable behavior with the PANDA model an additional calculation with higher core power and lower RPV level was performed. Table 5 shows the initial conditions for this calculation.

Power	MW.RP.7	1308 kW
Pressure	MP.RP.1	4.9 bar
RPV Level	ML.RP.1	11.43 m
DC Temp.	MTL.RP.1	151.2 °C
DC Mass flow	MVE.DC.1	0.6 m/s

Table 5: Initial conditions for the additional ATHLET calculation

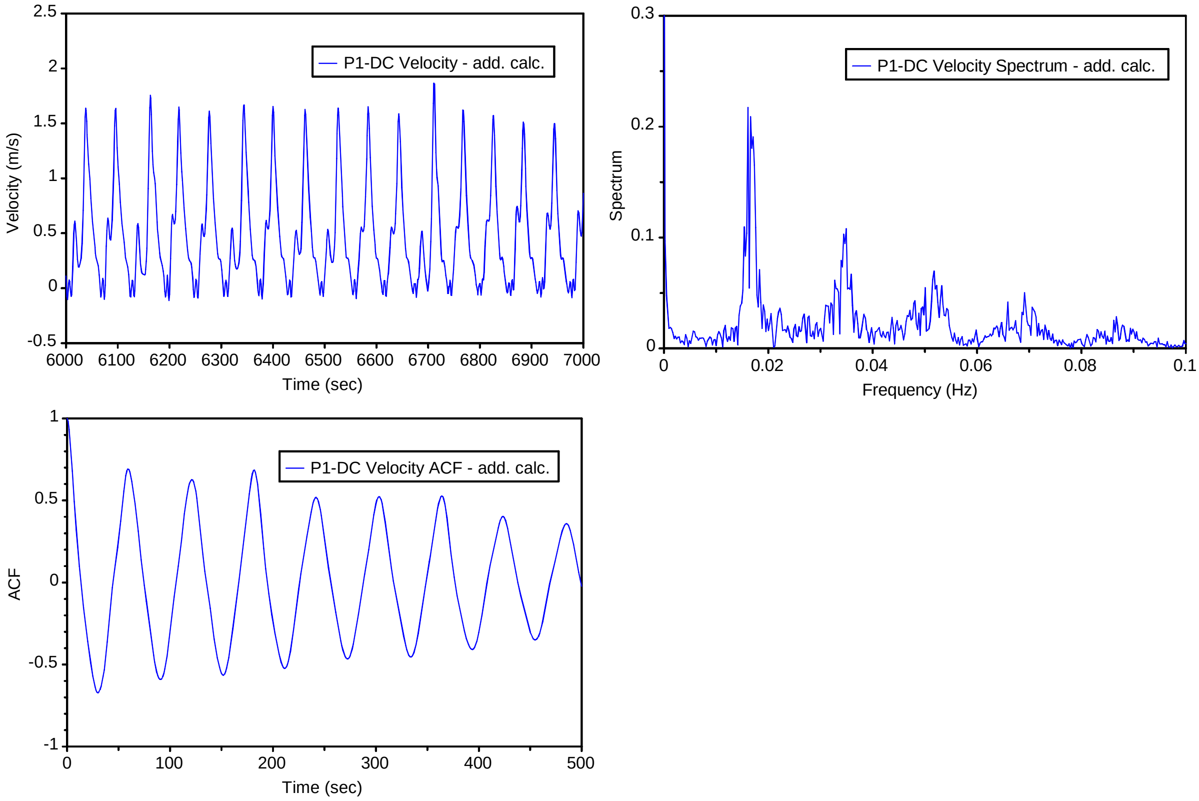


Fig. 10: DC velocity, spectrum and ACF for the additional ATHLET calculation with higher core power and lower RPV level

The results of the simulation show an unstable behavior with strong oscillations caused by flashing in the riser section. Fig. 10 shows the calculated DC mass flow, the spectrum and the auto-correlation-function. The oscillations have a period of 62s with a decay ratio > 0.9. In Fig. 11 the temperature distribution over the height of the PANDA model is illustrated for appr. t=5000s. At this point the dynamic behavior becomes unstable. The subcooling in the core is high and no void production takes place. Only above the middle of the riser section the temperature reaches saturation conditions and flashing induced oscillations occur.

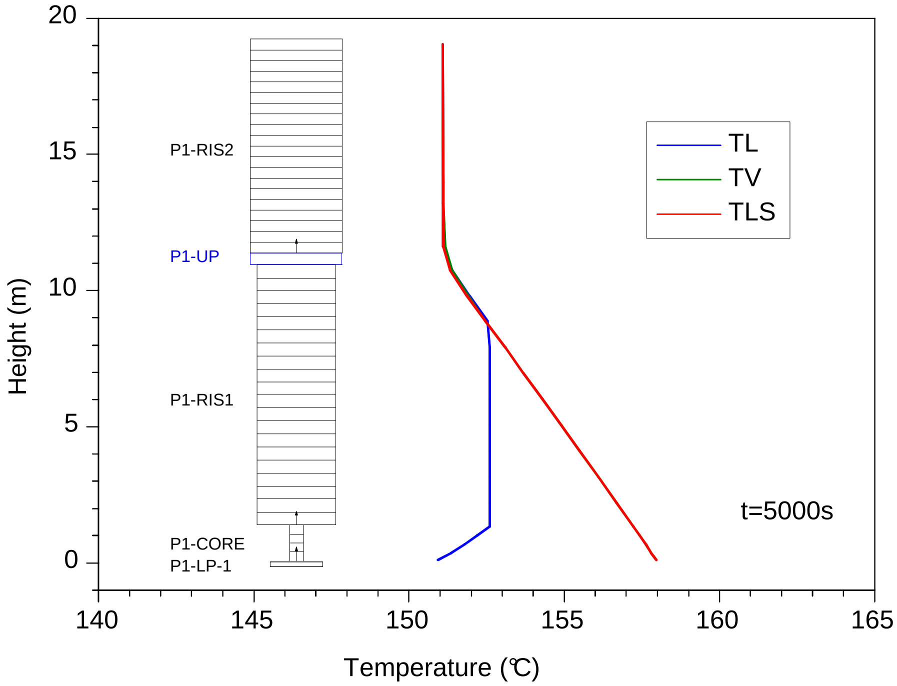


Fig. 11: Temperature distribution over the height of the PANDA model (TL=liquid, TV=vapour and TLS=saturation temperature)

6 Summary

The ATHLET simulations predict stable behavior for both PANDA tests. From the DC mass flow a decay ratio of 0.66 was calculated for test L 5.3. The calculation of test H 5.3 shows only a few oscillations with a decay ratio of 0.41. Due to the higher core inlet loss coefficient the oscillations were suppressed very fast. The calculated periods show a good agreement with the experimental results. It could be shown that ATHLET reproduces the dynamic behavior of both PANDA tests very well. With help of the additional calculation it could be demonstrated that ATHLET can also simulate an unstable behavior caused by flashing in the riser section.

7 References

[1] G. Lerchl, H. Austregesilo: ATHLET Mod 1.2 Cycle B: User's Manual, Gesellschaft für Anlagen und Reaktorsicherheit (GRS) mbH, August 1999

[2] D. Paladino, O. Auban, M. Huggenberger, P. Candreia, H.J. Strassberger, T. Bandurski: Description of PANDA Including Test Matrix, NACUSP Deliverable D08b, Paul Scherrer Institut, Switzerland, May, 2002

[3] D. Paladino, O. Auban, M. Huggenberger, P. Candreia, H.J. Strassberger: Results and Analysis of Tests in the PANDA Facility: Natural-Circulation and Stability at Low Pressure / Low Power Conditions, NACUSP Deliverable D11, Paul Scherrer Institut, Switzerland, August, 2003