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Full Scale Loop Seal Experiments with TRACE V5 Patch 1

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ABSTRACT

Full scale loop seal experiments have been simulated with thermal hydraulic simulation code TRACE V5 Patch 1. Multiple nodalizations were created different geometric accuracy. The main interest in the simulations was the residual water level in the horizontal pipe. Also pressure behaviour during the air blow to the loop seal and effects of different maximum time steps and initial liquid levels were studied.

Simulations revealed differencies in results obtained with different nodalizations. Most of the nodalizations produced reasonable results except a simple 90° bend that used grav terms elevation option (namelist variable ielev=0). This model cleared too much water out of the loop seal. A very similar model using cell angle elevation option didn't suffer from this problem.

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1 INTRODUCTION

In a Loss of Coolant (LOCA) situation loop seal behaviour has potentially a strong impact on core cooling as it causes pressure difference which disturbs flows in the core area. This pressure difference is at its highest when the ascending pipe of the loop seal is full of water and much lower when the flow in the pipe is stratified.

In this report full scale Loop Seal Facility tests are simulated with TRACE (V5p1) thermal hydraulic simulation code and the results are compared to the facility data. Multiple nodalizations were created different geometric accuracy. The main interest in the simulations was the residual water level in the horizontal pipe. Also the effects of different maximum timesteps and different initial liquid levels were studied.

For better comparability the water levels in these simulations are defined as a division of water level and pipe diameter (Figure 1).

$$\tilde{h}_l = \frac{h_l}{D} \quad (1)$$

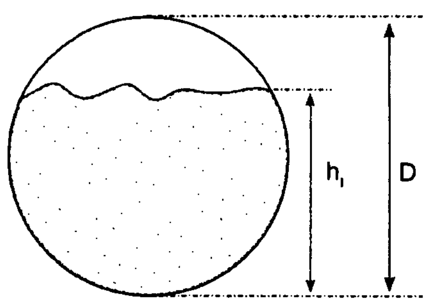

Figure 1. Cross section of a partially water filled pipe.

The Loop Seal facility tests were made in atmospheric pressure with cold water (~20°C) and air. These conditions are on the low end of the operational range of the simulation code. Therefore it should be kept in mind that the results may not be fully applicable at higher pressures and temperatures.

The Loop Seal Facility is presented in Chapter 2. The used geometries in TRACE simulations and their results are presented in Chapter 3. Similarly the APROS geometries and results can be found from Chapter 4. Summary is in Chapter 5.

2 THE LOOP SEAL FACILITY

The Loop Seal facility models a VVER-1000 primary circuit with a rupture in the cold leg. It has a speed-controlled fan which provides up to 9 m/s superficial velocities and a 10 m^3 buffer tank to dampen the pressure oscillations. The loop seal part of the facility has a inner diameter of 0.85 m and length of 6,98 m between the vertical pipe centers. The vertical pipe which rises to the (non-existant) reactor coolant pump has elevation difference of 2,9 meters. The loop seal bottom bends have a radius of 1,34 m (Ref. 1). The facility is presented in Figure 2.

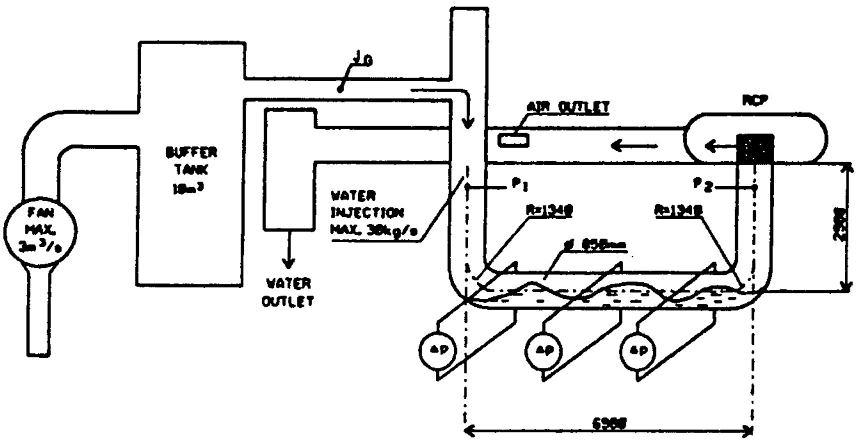

Figure 2. The loop seal facility /1/.

The main parameter in the tests was the residual water level. Also pressure difference over the loop seal was measured. In a publication "Two-Phase Flow in a Full-Scale Loop Seal Facility" (Ref. 2) Tuomisto and Kajanto present the Figure 3 which represents the pressure oscillations at superficial velocity of 5-6 m/s. The marked flow regimes in the figure are A) initial wavy stratified flow, B) transition to slug flow, C) slug flow period, D) transition back to stratified flow and E) stratified flow.

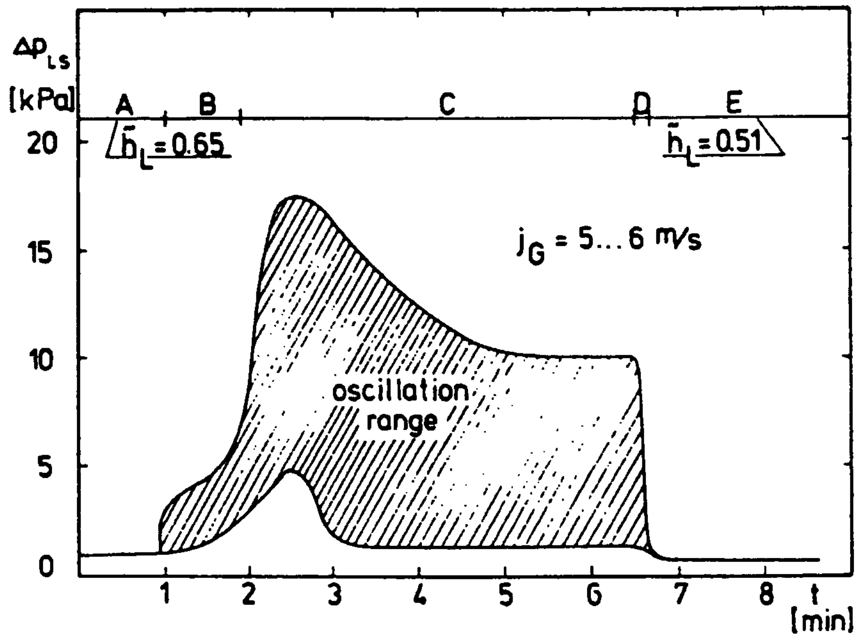

Figure 3. Pressure oscillations in the loop seal experiment (Ref. 2).

3 MODELED PIPE GEOMETRIES FOR THE SIMULATIONS

Five different nodalizations were used. All of the nodalizations had the same flow area of 0,567 m^2 and the same hydraulic diameter of 0,85 m. All of the models also had the same elevations changes of 2,9 m and length between vertical pipe center lines was 6,98 m. Because the bottom bends of the pipe were modeled differently the straight horizontal and vertical lengths varied between the models.

The first geometry was modeled using grav terms elevation option (IELEV=0), using approximately 1 m long nodes and had its bottom bends modeled with a single 90° bent node. This geometry is presented in Figure 4 and Table 1.

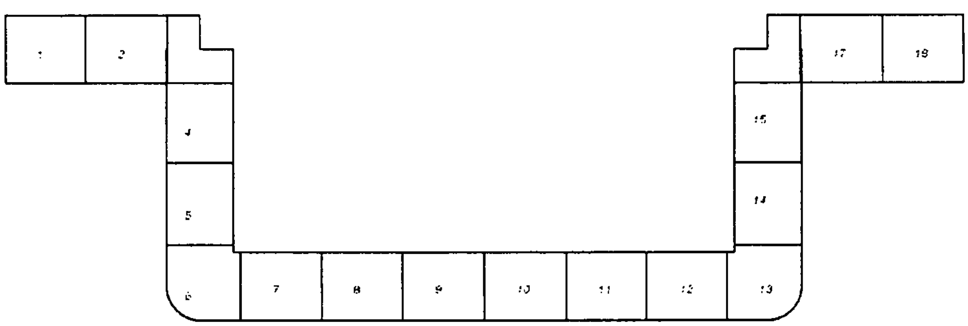

Figure 4. The model with single corner node (grav terms elevation option).

Table 1. Node geometries: Grav terms elevation option, one corner node.

Cell number	Cell volume [m³]	Cell length [m]	Cell flow area [m²]	Cell elevation change [m]
1	0,567	1,000	0,567	0,000
2	0,567	1,000	0,567	0,000
3	0,454	0,800	0,567	-0,400
4	0,567	1,000	0,567	-1,000
5	0,567	1,000	0,567	-1,000
6	0,567	1,000	0,567	-0,500
7	0,562	0,990	0,567	0,000
8	0,567	1,000	0,567	0,000
9	0,567	1,000	0,567	0,000
10	0,567	1,000	0,567	0,000
11	0,567	1,000	0,567	0,000
12	0,562	0,990	0,567	0,000
13	0,567	1,000	0,567	0,500
14	0,567	1,000	0,567	1,000
15	0,567	1,000	0,567	1,000
16	0,454	0,800	0,567	0,400
17	0,567	1,000	0,567	0,000
18	0,567	1,000	0,567	0,000

In the second geometry grav terms elevation option was also used, but the bottom bends were modeled with three nodes. This was one of the two nodings that were close to the original since they had the same bend radius of 1,34 m. The geometry is presented in Figure 5 and Table 2.

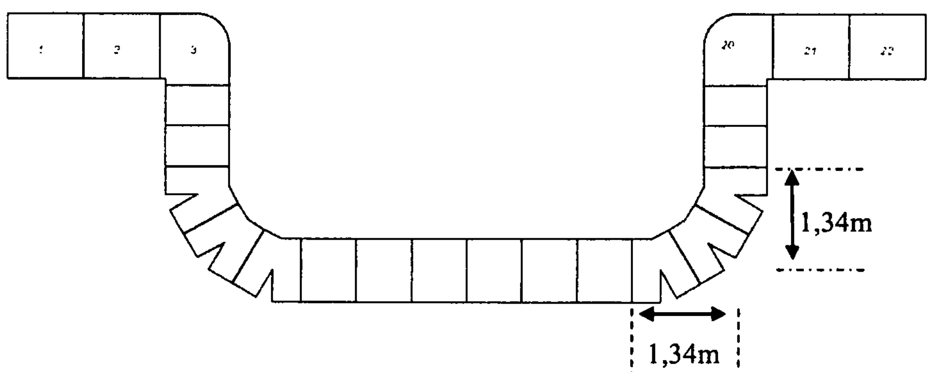

Figure 5. The model with three corner nodes (grav terms elevation option).

Table 2. Node geometries: Grav terms elevation option, three corner nodes.

Cell number	Cell volume [m^3]	Cell length [m]	Cell flow area [m^2]	Cell elevation change [m]
1	0,567	1,000	0,567	0,000
2	0,567	1,000	0,567	0,000
3	0,567	1,000	0,567	-0,500
4	0,301	0,530	0,567	-0,530
5	0,301	0,530	0,567	-0,530
6	0,407	0,718	0,567	-0,670
7	0,407	0,718	0,567	-0,491
8	0,407	0,718	0,567	-0,180
9	0,407	0,717	0,567	0,000
10	0,407	0,717	0,567	0,000
11	0,407	0,717	0,567	0,000
12	0,407	0,717	0,567	0,000
13	0,407	0,717	0,567	0,000
14	0,407	0,717	0,567	0,000
15	0,407	0,718	0,567	0,180
16	0,407	0,718	0,567	0,491
17	0,407	0,718	0,567	0,670
18	0,301	0,530	0,567	0,530
19	0,301	0,530	0,567	0,530
20	0,567	1,000	0,567	0,500
21	0,567	1,000	0,567	0,000
22	0,567	1,000	0,567	0,000

The third geometry is using cell angle elevation option (IELEV=2) and is, along with the first geometry (grav terms, one corner node), one of the simpliest of the tested geometries. This geometry is presented in Figure 6 and Table 3.

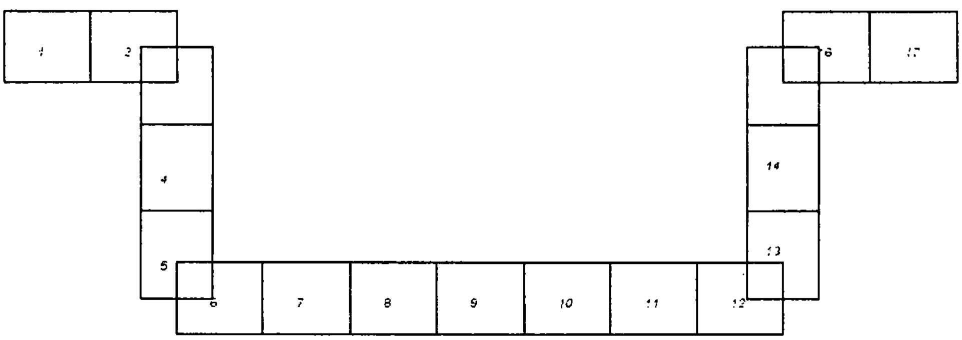

Figure 6. The model with no dedicated corner nodes (cell angle elevation option).

Table 3. Cell geometries: Cell angle elevation option, no corner node, long nodes.

Cell number	Cell volume [m³]	Cell length [m]	Cell flow area [m²]	Cell elevation change [m]
1	0,567	1,000	0,567	0,000
2	0,567	1,000	0,567	0,000
3	0,511	0,900	0,567	-0,900
4	0,567	1,000	0,567	-1,000
5	0,567	1,000	0,567	-1,000
6	0,562	0,990	0,567	0,000
7	0,567	1,000	0,567	0,000
8	0,567	1,000	0,567	0,000
9	0,567	1,000	0,567	0,000
10	0,567	1,000	0,567	0,000
11	0,567	1,000	0,567	0,000
12	0,562	0,990	0,567	0,000
13	0,567	1,000	0,567	1,000
14	0,567	1,000	0,567	1,000
15	0,511	0,900	0,567	0,900
16	0,567	1,000	0,567	0,000
17	0,567	1,000	0,567	0,000

Also a three corner node version was modeled using the cell angle elevation option. Along with the grav terms using three corner node version, this was closest to the test facility geometry. This geometry is presented in Figure 7 and Table 4.

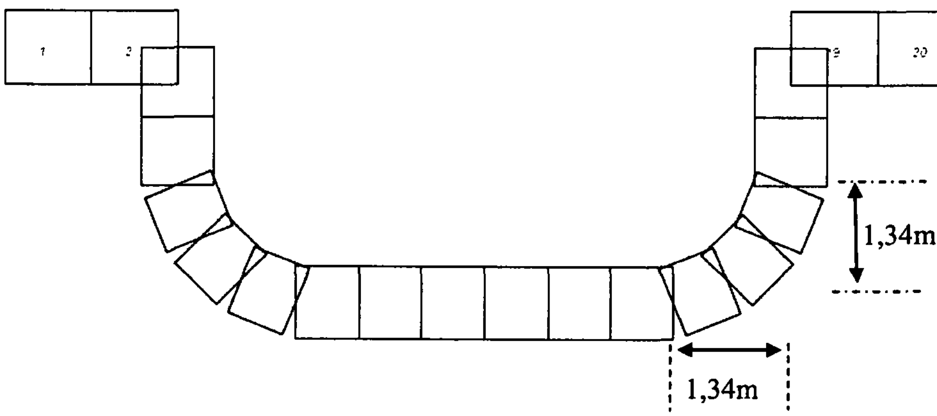

Figure 7. The model with three corner nodes (cell angle elevation option).

Table 4. Cell geometries: Cell angle elevation option, three corner nodes.

Cell number	Cell volume [m³]	Cell length [m]	Cell flow area [m²]	Cell elevation change [m]
1	0,567	1,000	0,567	0,000
2	0,567	1,000	0,567	0,000
3	0,443	0,780	0,567	-0,780
4	0,443	0,780	0,567	-0,780
5	0,378	0,665	0,567	-0,615
6	0,378	0,665	0,567	-0,470
7	0,378	0,665	0,567	-0,255
8	0,407	0,717	0,567	0,000
9	0,407	0,717	0,567	0,000
10	0,407	0,717	0,567	0,000
11	0,407	0,717	0,567	0,000
12	0,407	0,717	0,567	0,000
13	0,407	0,717	0,567	0,000
14	0,378	0,665	0,567	0,255
15	0,378	0,665	0,567	0,470
16	0,378	0,665	0,567	0,615
17	0,443	0,780	0,567	0,780
18	0,443	0,780	0,567	0,780
19	0,567	1,000	0,567	0,000
20	0,567	1,000	0,567	0,000

The last modeled geometry is a variation of the cell angle version without dedicated corner nodes. That version was renodalized and had most of its nodes split in three. This geometry is presented in Figure 8 and Table 5.

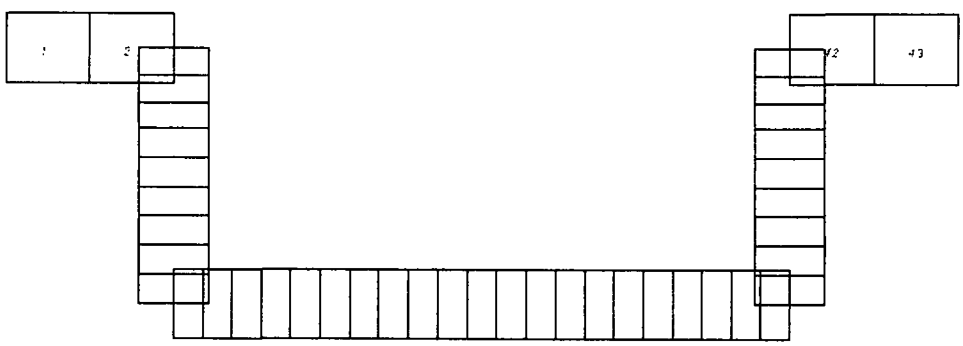

Figure 8. The model with short nodes, no dedicated corner nodes (cell angle elevation option).

Table 5. Cell geometries: Cell angle elevation option, no corner node, short nodes.

Cell number	Cell volume [m³]	Cell length [m]	Cell flow area [m²]	Cell elevation change [m]
1	0,567	1,000	0,567	0,000
2	0,567	1,000	0,567	0,000
3	0,170	0,300	0,567	-0,300
4	0,170	0,300	0,567	-0,300
5	0,170	0,300	0,567	-0,300
6	0,189	0,333	0,567	-0,333
7	0,189	0,333	0,567	-0,333
8	0,189	0,333	0,567	-0,333
9	0,189	0,333	0,567	-0,333
10	0,189	0,333	0,567	-0,333
11	0,189	0,333	0,567	-0,333
12	0,187	0,330	0,567	0,000
13	0,187	0,330	0,567	0,000
14	0,187	0,330	0,567	0,000
15	0,189	0,333	0,567	0,000
16	0,189	0,333	0,567	0,000
17	0,189	0,333	0,567	0,000
18	0,189	0,333	0,567	0,000
19	0,189	0,333	0,567	0,000
20	0,189	0,333	0,567	0,000
21	0,189	0,333	0,567	0,000
22	0,189	0,333	0,567	0,000
23	0,189	0,333	0,567	0,000
24	0,189	0,333	0,567	0,000
25	0,189	0,333	0,567	0,000
26	0,189	0,333	0,567	0,000
27	0,189	0,333	0,567	0,000
28	0,189	0,333	0,567	0,000
29	0,189	0,333	0,567	0,000
30	0,187	0,330	0,567	0,000
31	0,187	0,330	0,567	0,000
32	0,187	0,330	0,567	0,000
33	0,189	0,333	0,567	0,333
34	0,189	0,333	0,567	0,333
35	0,189	0,333	0,567	0,333
36	0,189	0,333	0,567	0,333
37	0,189	0,333	0,567	0,333
38	0,189	0,333	0,567	0,333
39	0,170	0,300	0,567	0,300
40	0,170	0,300	0,567	0,300
41	0,170	0,300	0,567	0,300
42	0,567	1,000	0,567	0,000
43	0,567	1,000	0,567	0,000

4 RESULTS OF THE SIMULATIONS

The inlet component had a state of 20 °C temperature and 1 bar pressure. Its void fraction was set to be 1 and the gas was fully noncondensible. The simulations initiated with a 50 second ramp from zero velocity to the currently simulated superficial velocity. Then followed a steady 650 second period when the flow was kept steady. After this the velocity was dropped back to zero and once the possible oscillations had soothed down the residual void fractions were read. After this the residual water levels were solved numerically.

Figure 9 shows the residual water levels of simulations with different geometries. In all of the cases the maximum time step was 1 ms and only the horizontal tube was filled with water. The only model that produced results that clearly differed from the rest was the simple 90° bend using grav terms elevation option (the first nodalization).

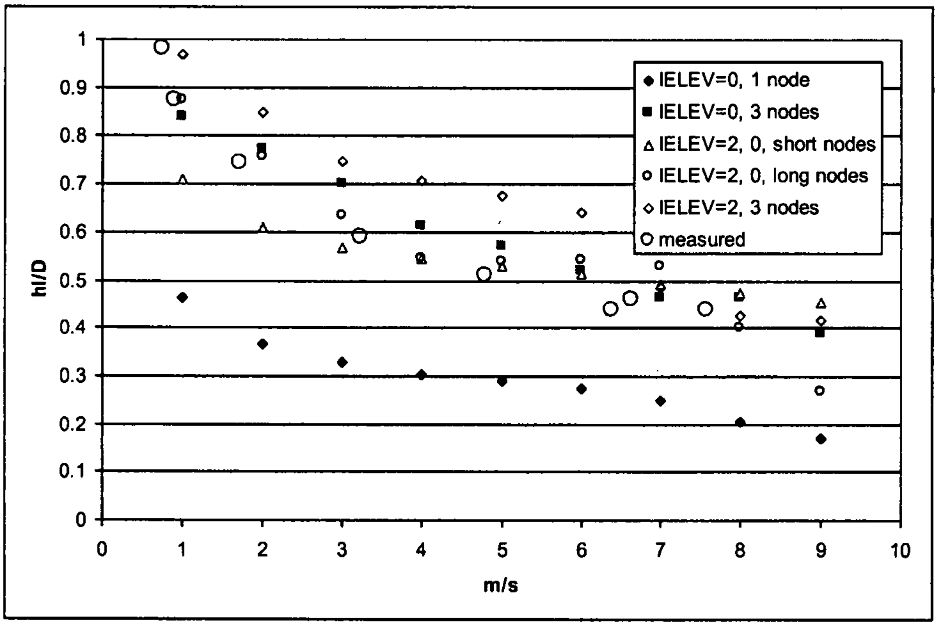

Figure 9. Residual water level with different simulated geometries.

The effect of maximum time steps (1 ms, 10 ms and 100 ms) was tested with the 90° bend model that used grav terms. All of the the results, however, turned to be identical. This same simulation was then run with the 3 corner nodes grav terms using model. The results of the latter simulation are presented in Figure 10.

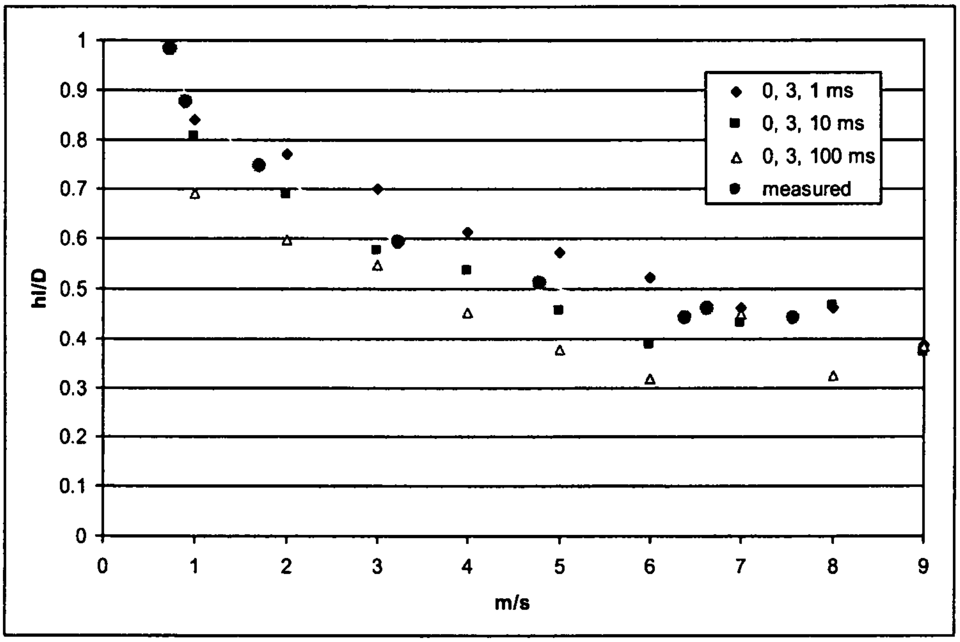

Figure 10. Residual water level. The effect different maximum time steps (IELEV=0, 3 corner nodes).

The effect of initial water level was studied with the 90° bend model that used grav terms. In the first case the loop seal was fully filled with water (zero void fraction in the vertical pipes). In the second case only the horizontal pipe was filled with water. In the third case the horizontal pipe had initial void fraction of 20%. All of the simulated cases produced identical results (Figure 11).

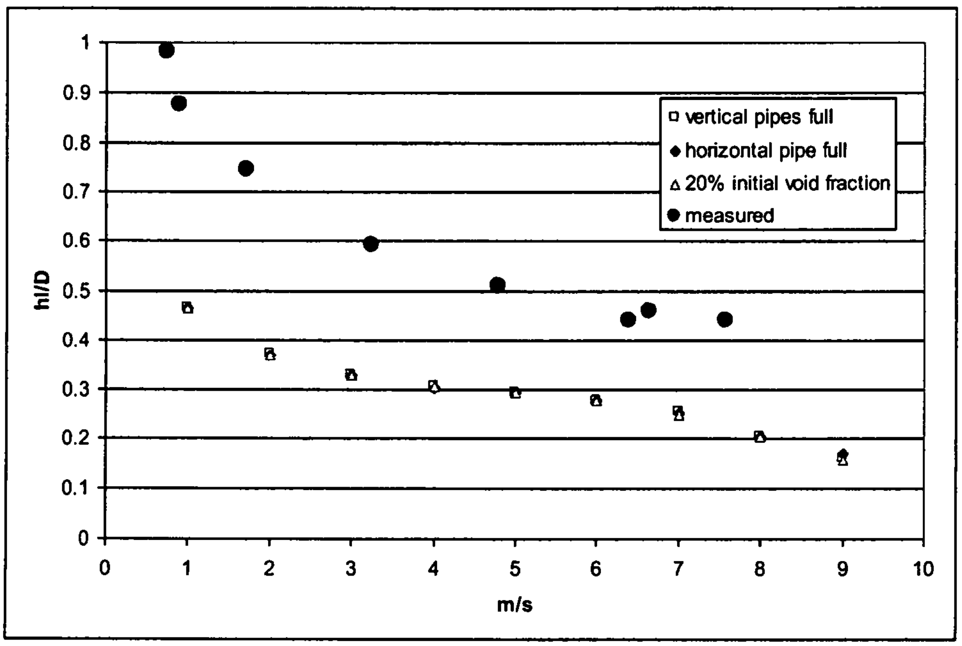

Figure 11. Residual water level. The effect of different initial water levels (IELEV=0, 1 corner node, 1 ms maximum timestep).

The pressure oscillation behaviour that was observed in the facility (Figure 3) was studied with the 90° bend and three corner node models that used grav terms. The results are presented in Figures 12 and 13. Transitions to slug flow and back to stratified flow are best seen in 5 m/s simulation of the three corner node model.

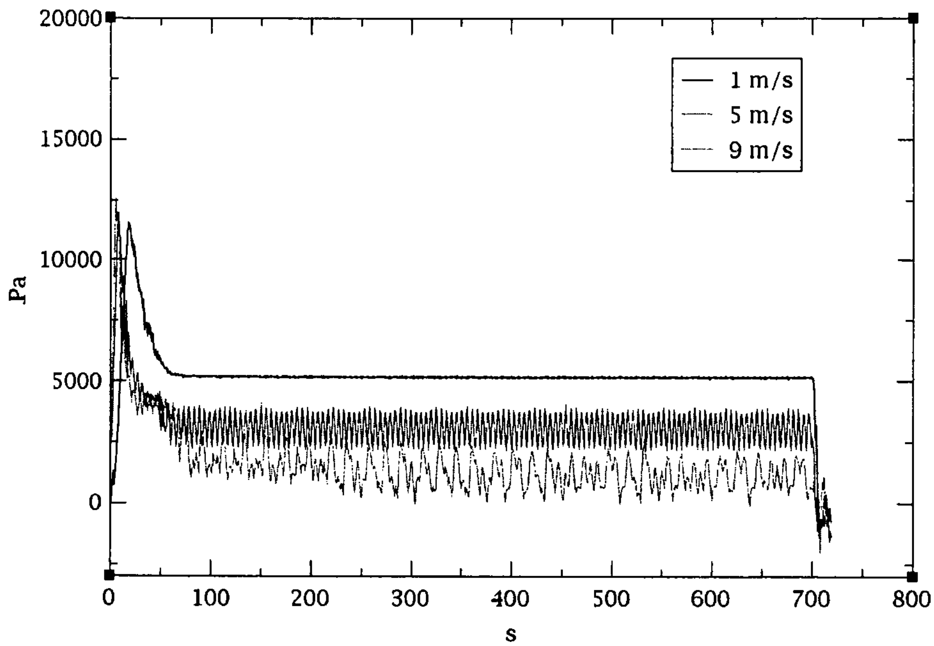

Figure 12. Pressure difference over the loop seal (IELEV=0, 1 corner node, 1 ms).

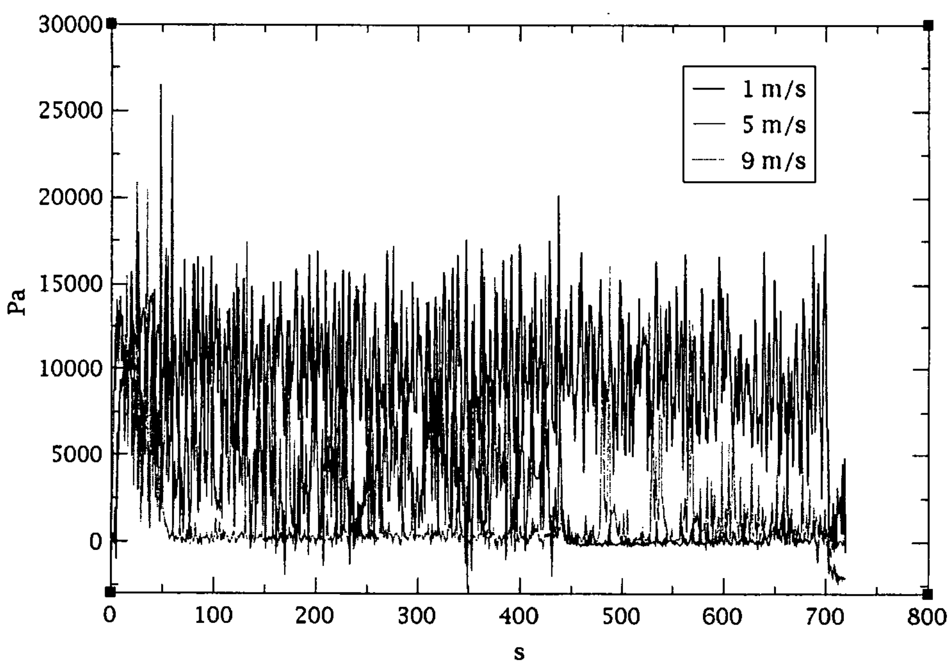

Figure 13. Pressure difference over the loop seal (IELEV=0, 3 nodes, 1 ms)

5 SUMMARY

Full scale loop seal experiments have been simulated with thermal hydraulic simulation code TRACE V5 Patch 1. Multiple nodalizations were created with different geometric accuracy. The main interest in the simulations was the residual water level in the horizontal pipe. Also pressure behaviour during the air blow to the loop seal and effects of different maximum time steps and initial liquid levels were studied.

Simulations revealed differencies in results obtained with different nodalizations. Most of the nodalizations produced reasonable results except a simple 90° bend that used grav terms elevation option (namelist variable ielev=0). This model cleared too much water out of the loop seal. A very similar model using cell angle elevation option didn't suffer from this problem.

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/2/ Tuomisto H., Kajanto P. 1988. TWO-PHASE FLOW IN A FULL SCALE LOOP SEAL FACILITY. Nuclear Engineering and Design 107 295-305.

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10. SUPPLEMENTARY NOTES
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11. ABSTRACT *(200 words or less)*
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