Research Report
LTKK / Nuclear Safety Research Unit

SUPPLEMENTING CONDENSATION POOL EXPERIMENTS WITH NON-CONDENSABLE GAS

YTY-01/2002

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Lappeenranta, 21.10.2002

LTKK

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Diary code	**Order reference** 808902/SJLL
Project title and reference code SUPPLEMENTING CONDENSATION POOL EXPERIMENTS 23407	**Report identification & Pages** / **Date** YTY-01/2002 14 p. 21.10.2002

Report title and author(s)

SUPPLEMENTING CONDENSATION POOL EXPERIMENTS WITH NON-CONDENSABLE GAS, Jani Laine

Abstract

The behavior of non-condensable gas in the condensation pools of the Olkiluoto nuclear power plant (NPP) in a possible loss-of-coolant accident (LOCA) was studied experimentally with a scaled down test facility. The main objective was to determine the effect of velocity on the penetration of airflow jets from the blowdown pipes into the condensation pool and to study the internal circulation of small air bubbles from the pool surface to the level of the emergency core cooling system (ECCS) strainer. The experiments were supplementary to the previous test series with the same condensation pool test facility.

The experiments were carried out in two stages. Compressed air from pressure tanks was blown to the pool through DN150 blowdown pipes in both stages. Throttle valves in the blowdown lines were used to control the maximum airflow velocities. In addition to this, the ECCS pump was sucking water through the ECCS strainer with a constant volumetric flow rate of 11 l/s (scaled to Olkiluoto plant conditions) in stage two.

When the maximum velocity of the airflow was between 15-32 m/s the first airflow jet out of the blowdown pipe hit the bottom of the pool clearly and broke up into a cloud of small bubbles, which started to rise up slowly. The airflow jet didn't touch the pool bottom, if the maximum velocity was limited to the value of 5 m/s.

In the high velocity cases, there were a lot of small air bubbles on the level of the ECCS strainer during the first 30 seconds. The contact of the first jet with the pool bottom as well as the internal circulation i.e.water backflow close to the pool wall carrying down small air bubbles soon after the initiation of the blowdown contributed to this. The internal circulation of air bubbles continued to some degree as long as air was blown to the pool. Air bubbles were detected also inside the strainer. The amount of them was, however, negligible after 30 seconds. The ECCS pump head and water flow rate didn't decline due to the air bubbles drifting inside the pump in any test. In the low velocity cases, only negligible amounts of air bubbles were detected inside the strainer or in the intake pipe of the pump.

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Approved by	**Availability statement**
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CONTENTS

1 INTRODUCTION

In a possible LOCA, a large amount of non-condensable (nitrogen) and condensable (steam) gas will be blown from the upper drywell to the condensation pool through the blown-down pipes in Olkiluoto 1 and 2 NPPs. There might be a risk that the gas discharging to the condensation pool could push to the ECC systems and undermine their performance.

Previously, the behavior of non-condensable gas (air) bubbles in the condensation pool has been studied experimentally with a scaled down test facility designed and constructed in Lappeenranta University of Technology (LTKK). The work has been documented in the research report Condensation Pool Experiments with Non-Condensable Gas [1].

The behavior of air bubbles with smaller airflow velocities than in reference 1 was examined in a supplementing series of experiments. The main objective was to find out what kind of effect the airflow velocity has to the amount of air bubbles in the pool. The findings of these supplementing experiments are reported here.

2 TEST FACILITY

The same condensation pool test facility was used as in the tests documented in reference 1. The only modification made to the test facility was the installation of the throttle valves. The valves were installed to the blowdown lines that connected the pressure tanks to the blowdown pipes. By using the valves it was possible to control airflow maximum velocities. Air was blown down to the pool through DN150 (Ø168.3x3.0) blowdown pipes. Airflow velocities were measured by using vortex flowmeters installed to the blowdown lines. These vortex flowmeters use a low pass filter. For this reason maximum airflow velocities can be higher than presented in this report. Figure 1 shows a 3D-figure of the test facility.

3 EXPERIMENTS

Experiments were executed in two different stages:

1. Experiments to find out airflow boundary velocity
2. Experiments to examine air bubbles behavior

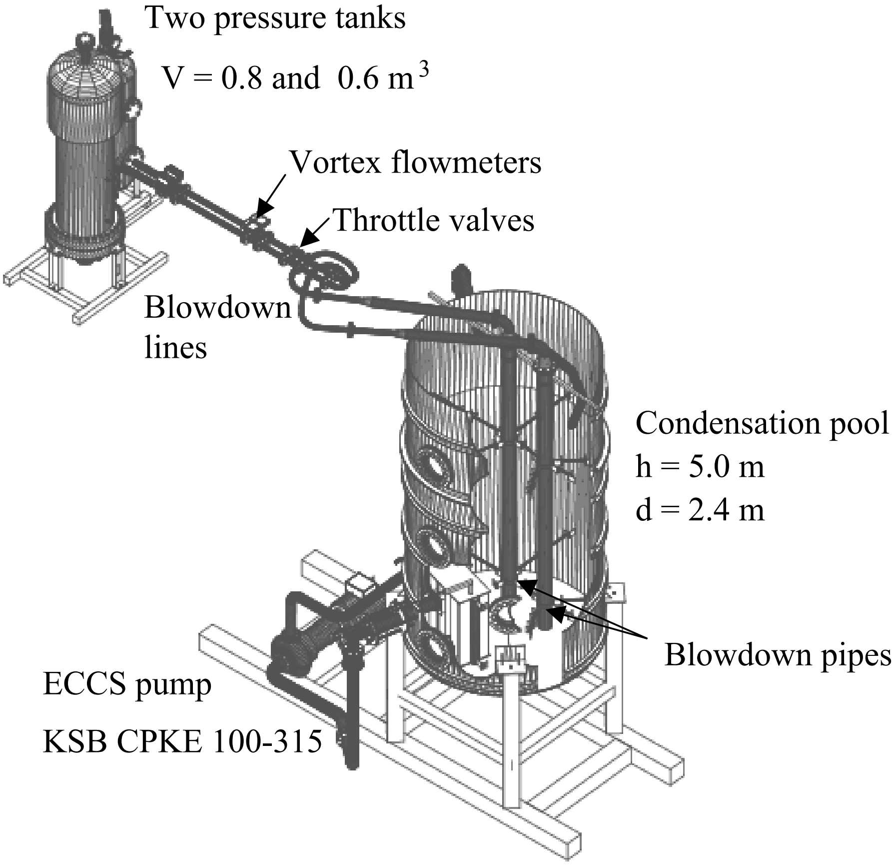

Figure 1. Condensation pool test facility.

3.1 EXPERIMENTS TO FIND OUT AIRFLOW BOUNDARY VELOCITY

In test series 3.01-3.09 (reported in reference 1) compressed air was blown to the pool through DN150 (Ø168.3x3.0) blowdown pipes. The maximum airflow velocities in those tests were 65-80 m/s when airflow pressure was normalized to 1 bar pressure. The higher the pressure of the pressure tanks was, the higher was the airflow velocity. In tests 3.01, 3.02, 3.05 and 3.06, the blowdown pipes were initially filled with water to the pool level (4.2 m) before air was blown down to the pool. Airflows pushed the water plugs from the pipes to the bottom of the pool so hard that very noisy bangs were heard. Also, the airflows hit to the bottom very clearly.

The idea of the first stage experiments of this supplementing test series was to find out the airflow velocity threshold in the beginning of the blast when gas has no contact with the bottom of the pool as in tests 3.01, 3.02, 3.05 and 3.06 in reference 1.

3.1.1 Tests 14.01-14.10

One experiment series consisting of ten separate tests with a blowdown pipe size DN150 was executed. Compressed air was blown to the pool filled with water only through one blowdown pipe at a time. Throttle valves were used to control airflow velocities in the beginning of the blasts.

During the tests the water level in the pool was 3.2 m and the temperature 18°C. The pipes were initially filled with water to the pool level. Air wasn't refilled from the pneumatic system during the blasts and the pump wasn't running either.

Two video cameras were used in the first stage to detect if airflows had a contact with the bottom of the pool or not. The test matrix for first stage experiments is shown in Table 1.

Table 1. Test matrix for experiments in series 14.

Test	Pressure in tanks (bar)	Air refill during test (Y/N)	Pipe (1/ 2/ 1&2)	Throttle valve position (4 is full open, 0 is closing position)
14.01	7.7	N	1	4
14.02	7.5	N	2	4
14.03	7.5	N	1	3
14.04	7.5	N	2	3
14.05	7.5	N	1	2
14.06	7.5	N	2	2
14.07	7.8	N	1	1
14.08	7.4	N	2	1
14.09	7.6	N	1	0.5
14.10	7.5	N	2	0.5

Tests 14.01-14.02

In the first two tests, the throttle valves were in position 4 (full open). In the beginning of the blows, airflow velocities were approx. 32 m/s (airflow pressure normalized to 1 bar pressure). In both cases, water plug hit strongly to the bottom of the pool. Also, the first airflow jet touched the bottom clearly. It broke up into small bubbles, which formed circular patterns on the bottom of the pool. These patterns expanded quickly towards the poolside. The contact between the first airflow jet and the bottom of the pool lasted no longer than 0.2 s. It took approx. 5 s before all small air bubbles had risen up from the bottom to the level of the pipe outlets.

Tests 14.03-14.04

Before the next two tests were made the throttle valves were turned slightly back to position 3. As a result, the maximum airflow velocities were now approx. 23 m/s. Water plugs hit to the bottom also this time. First airflows from the pipe outlets were noticeably narrower that in previous tests. Airflows also hit to the bottom. The contact between these airflows and the pool bottom lasted 0.15 s. As in previous tests, it took about 5 s before all small bubbles had risen up from the bottom to the level of the pipe outlets. The pool surface behavior was more stable than during previous tests.

Tests 14.05-14.06

The throttle valves were screwed to position 2. The maximum airflow velocities were only approx. 15 m/s. Nevertheless, both water plugs hit to the bottom hard. First forming airflows were much narrower than in the two preceding tests. The first airflows had a contact with the pool bottom no longer than 0.1 s. Again it took approx. 5 s before all small air bubbles had risen up from the bottom of the pool to the level of the pipe outlets.

Tests 14.07-14.08

The throttle valves were turned to position 1. This limited airflow velocities to the value of approx. 7 m/s. First airflows were as wide as the blowdown pipe diameter. Water plugs still hit to the pool bottom. The contact between the airflows and the pool bottom lasted no longer than 0.05 s. In these cases, it took also 5 s before small bubbles had risen up from the bottom to the level of the pipe outlets.

Tests 14.09-14.10

The last two tests were made with the throttle valves turned to position 0.5. Airflows reached a velocity of approx. 5 m/s. Now the airflows didn't penetrate to the bottom of the pool. Instead they rose up from the pipe outlet towards the pool surface. The pool water level was so stable that it was easy to see from above water coming up close to the pipes and flowing back to the lower part of the pool close to the poolside.

Figure 2 shows airflow velocities in the blowdown pipes in tests 14.01-14.10. Mass flow rates were measured by using the vortex flowmeters installed to the blowdown lines. Velocities in the blowdown pipes were calculated by using continuity equation. Velocity was normalized to 1 bar pressure:

$$v = \frac{4\dot{m}}{\pi d_s^2 \rho} \qquad (1)$$

where $\dot{m}$ is mass flow rate of air,
d_s is inner diameter of the blowdown pipe (162.3 mm),
ρ is density of air (1.2 kg/m^3).

Maximum airflow velocities can be higher than presented in Fig. 2 because the vortex flowmeters use a low pass filter. Fig. 3 shows how the first airflow jet penetrated to the pool in tests 14.01-14.10.

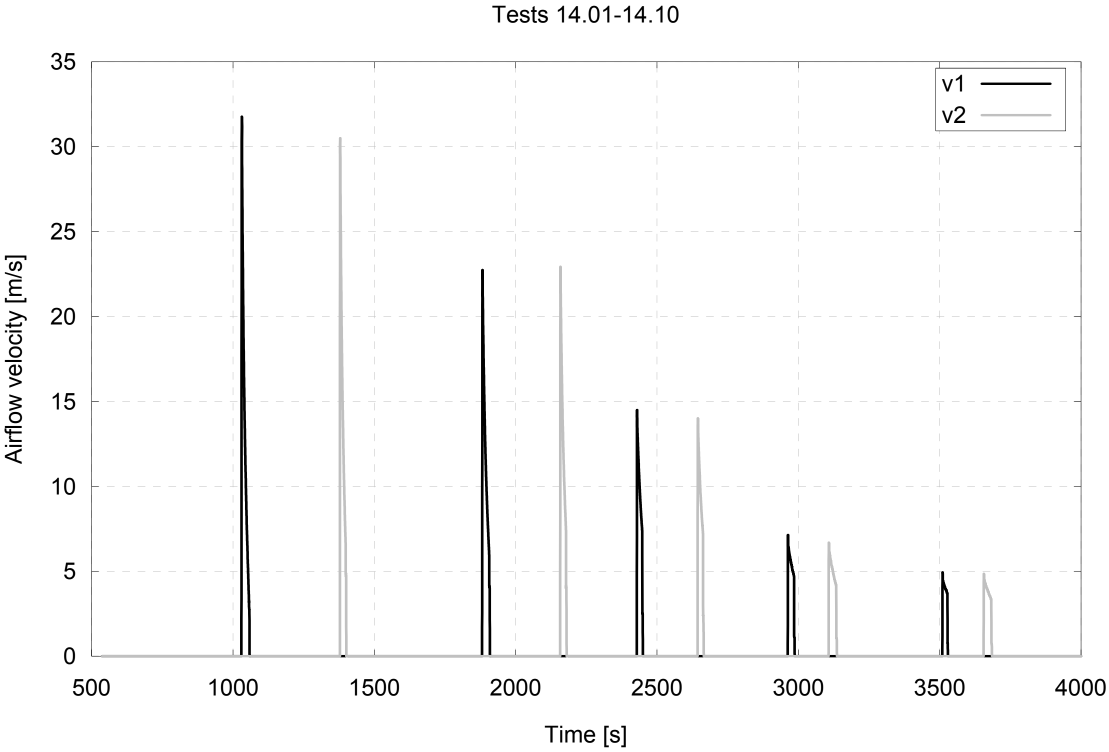

Figure 2. Airflow velocities in tests 14.01-14.10 (v1 refers to blowdown pipe 1 and v2 to blowdown pipe 2).

3.2 EXPERIMENTS TO EXAMINE AIR BUBBLES BEHAVIOR

In reference 1, compressed air was blown to the pool approx. for 30-40 s when two DN150 blowdown pipes were used simultaneously. Air was also refilled from the pneumatic system. In those tests, during the first 20 s the lower part of the pool was so full of the air bubbles that the blowdown pipes weren't visible from the pool windows. After that airflows could be seen rising upwards close to the pipes. The amount of air bubbles in the level of the ECCS strainer was negligible after 30 s.

The main objective of the second stage experiments was to study how long water backflow carries small air bubbles from the upper part of the pool down to the lower part. Compared to the tests executed in reference 1 air was now blown to the pool much longer than 30-40 s and the maximum velocities of airflows were smaller than 65-80 m/s.

3.2.1 Tests 15.01-15.05

The second experiment series consisted of five separate tests with a blowdown pipe size DN150. The water level in the pool was again 3.2 m and the temperature 16°C. The blowdown pipes were initially filled with water to the pool level and air was refilled from the pneumatic system during the blasts. Again, throttle valves were used to control airflow velocities in the beginning of the blasts. Compressed air was blown to the pool in parallel with both pipes. During the blasts the ECCS pump sucked water through the ECCS strainer with a constant volumetric flow rate of 11 l/s. This flow rate corresponds to Olkiluoto plant conditions. The test matrix for experiments in series 15 is shown in Table 2.

The pool before air was blown

Test 14.02

Test 14.04

Test 14.06

Test 14.08

Test 14.10

Figure 3. The first airflow jet penetrating to the pool during tests 14.01-14.10.

Table 2. Test matrix for experiments in series 15.

Test	Pressure in tanks (bar)	Air refill during test (Y/N)	Pipe (1/ 2/ 1&2)	Throttle valve position (4 is full open, 0 is closing position)
15.01	7.7	Y	1 & 2	4
15.02	7.9	Y	1 & 2	3
15.03	7.7	Y	1 & 2	2
15.04	7.6	Y	1 & 2	1
15.05	7.7	Y	1 & 2	0.5

Five video cameras were used in the second stage experiments. Three of the cameras were focused to the pool so that airflows coming from the pipe outlets could be observed and, also, the drift of small bubbles from the surface to the level of the ECCS strainer could be detected. One camera was inside the ECCS strainer and one pointed to the transparent intake pipe.

Test 15.01

In the first test, the throttle valve was fully open and air was blown to the pool for 64 seconds. After that the pressure tanks were almost empty. The maximum airflow velocity was about 32 m/s. Airflows from both blowdown pipes hit to the bottom of the pool very clearly.

During the first 20 seconds the blowdown pipes were not visible from the pool windows. The reason for this was the large amount of small air bubbles in the pool. These bubbles came from two sources. First, small air bubbles formed at the bottom of the pool during the initial blow (as the jet hit the bottom) were still slowly rising up. Second, air jet penetrating to the pool lifted a lot of water from the lower part of the pool towards the surface. An internal circulation pattern was created as water flowed down close to the walls of the pool. This backflow carried small air bubbles to the level of the ECCS strainer.

After 20 seconds, the amount of small air bubbles on the level of the ECCS strainer was reduced and airflows rising upwards around the blowdown pipe were visible again. After 30 s the amount of air bubbles on the level of the strainer was quite small. However, water backflow carried small air bubbles down as long as air was blown to the pool. During the test the pool surface splashed strongly.

Inside the strainer, a lot of small air bubbles were detected during the first 20 s. After 30 seconds, the amount of bubbles was negligible. Small air bubbles were also seen inside the transparent intake pipe during the first 30 s. The amount of these bubbles was, however, so small that the performance of the pump didn't decline. Pressure difference over the pump and water flow rate remained constant during the test.

Test 15.02

In the beginning of the second blow the airflows reached velocities of approx. 25 m/s. Air was blown down to the pool for 81 s. Again both airflows hit to the pool bottom clearly. The splashing of the surface was, however, considerably less fierce than during the previous test. The level of the strainer was full of air bubbles during the first 20 s. After that moment the pipes were visible again and airflows could be seen rising towards the surface close to the pipes. It was also observed that it took about 3.5 s before water backflow had carried the first small bubbles to the lower part of the pool. After 30 s, the backflow carried only slightly small bubbles to the level of the strainer.

The camera inside the strainer showed that after 25 s the amount of bubbles was negligible. As in the previous test, the bubbles had no effect on the performance of the pump.

Test 15.03

The maximum airflow velocities were reduced to 15 m/s and air was blown down to the pool for 127 s. The level of the strainer was full of air bubbles during the first 12 s. After 30 s, the amount of air bubbles on the level of the strainer was negligible. After that the backflow carried only a small amount of air bubbles to the level of the strainer for the rest of the test.

Some air bubbles were detected during the first 20 s inside the strainer and in the intake pipe. Pressure difference over the pump and water flow rate remained, however, constant during the test.

Test 15.04

The maximum airflow velocities were about 7 m/s and air was blown down to the pool for 350 s. Only a little of air bubbles rose from the bottom of the pool. Water backflow carried down small bubbles only slightly. As a result, the pipes were visible all the time. Upwards rising airflows close to pipes could be seen clearly. After 30 s, the amount of bubbles was negligible. The backflow carried small gushes of air bubbles to the level of the strainer occasionally.

Inside the strainer and in the intake pipe only negligible amount of air bubbles was detected during the test.

Test 15.05

The maximum airflow velocities were limited to 5 m/s and air was blown down to the pool as long as 368 s. In the beginning of the blow, the airflows didn't touch the bottom of the pool. Between 7-20 s water backflow carried plenty of small bubbles to the front of the strainer. After that, the backflow carried only a little of air bubbles to the level of the ECCS strainer.

The amount of air bubbles inside the strainer and in the intake pipe was negligible during the test.

Figure 4 shows airflow velocities, pressure differences over the pump and water volume flow rates in tests 15.01-15.05. Airflow pressures have been normalized to 1 bar pressure. Neither pressure difference nor water volume flow rate declined when air was blown to the pool. Table 3 shows some comparison between tests 15.01-15.05. Figures 5 and 6 show how much air bubbles were detected in the pool during tests 15.01 and 15.05.

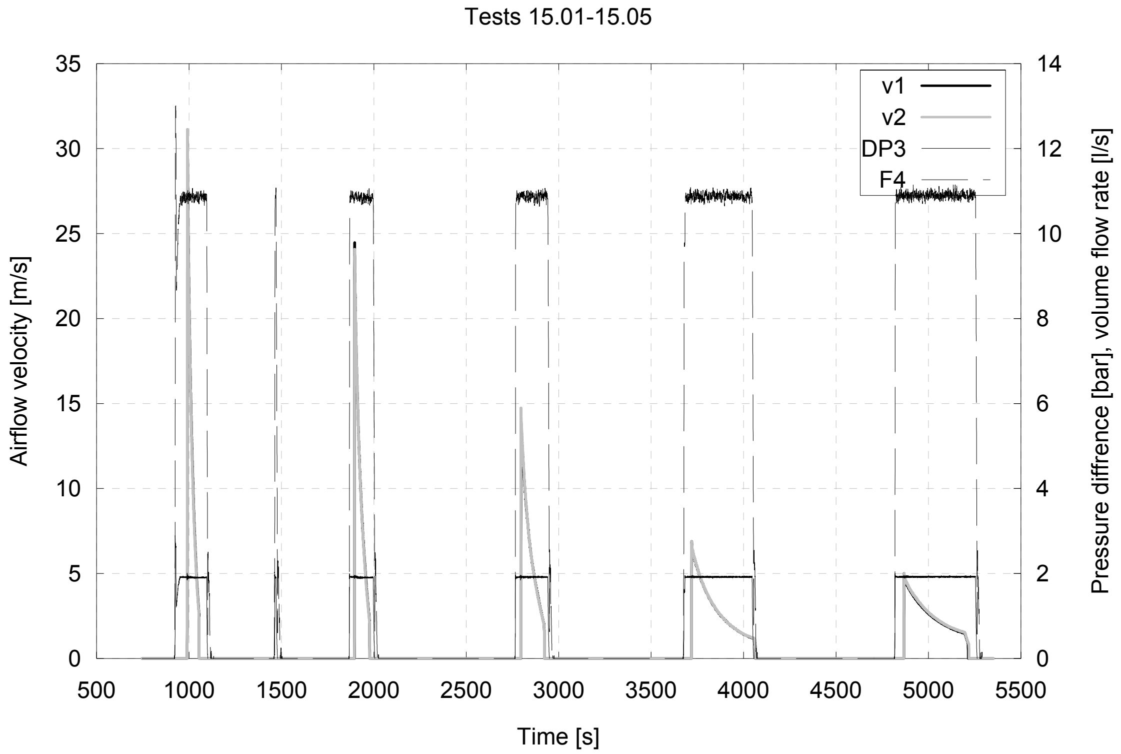

Figure 4. Airflow velocities (v1 and v2), pressure difference over the pump (DP3) and water volume flow rate (F4) during tests 15.01-15.05 (v1 is not clearly visible, because it is equal to v2).

Table 3. Comparison between tests 15.01-15.05.

Test	Max. airflow velocity (m/s)	A contact with the pool bottom (Y/N)	Blowdown pipes weren't visible from the pool windows (s)	Bubbles observed inside the strainer and in the intake pipe (s)
15.01	32	Y	20	30
15.02	25	Y	20	25
15.03	15	Y	12	20
15.04	7	Y	Visible all the time	Not observed
15.05	5	N	Visible all the time	Not observed

The pool before air was blown.

The first airflow jets hit to the bottom of the pool.

1 s

20 s

40 s

60 s

Figure 5. Airflows penetrating to the pool during test 15.01.

The pool before air was blown.

The first airflow jets didn’t hit to the bottom of the pool.

1 s

20 s

40 s

60 s

Figure 6. Airflows penetrating to the pool during test 15.05.

4 SUMMARY

A supplementary two stage test series to the previous condensation pool experiments in LTKK was carried out. The behavior of airflows penetrating to the condensation pool from the blowdown pipes (stage 1) and the internal circulation of small air bubbles in the pool (stage 2) was studied experimentally with the scaled down test facility. The throttle valves in the blowdown lines were used to control airflow maximum velocities. Depending on the positions of the throttle valves it was possible to blow compressed air to the pool for 64-368 s before the pressure tanks were almost empty. In the stage two tests, the ECCS pump was sucking water through the ECCS strainer with a constant volume flow rate of 11 l/s (scaled to Olkiluoto plant conditions) when compressed air was blown to the test pool through the blowdown pipes.

In tests, where the maximum airflow velocity was between 15-32 m/s, the first airflow jet penetrating to the pool hit to the bottom. The level of the ECCS strainer was so full of small air bubbles that the blowdown pipes weren't visible from the pool windows during the first 20 s. After that, airflows were seen rising upwards very close to the pipes. The backflow of water carried small air bubbles to the level of the ECCS strainer as long as air was blown to the pool. After 30 s, the amount of bubbles was, nevertheless, quite small. Some bubbles were also seen inside the strainer and in the intake pipe during the first 30 s.

When the maximum airflow velocity was limited to 5 m/s the first airflow jet didn't touch the bottom of the pool. The pipes were visible all the time and it was seen how airflows rose towards the surface close to the pipes. It took approx. 20 s before the amount of air bubbles was negligible on the level of the strainer. Inside the strainer and in the pump intake pipe air bubbles weren't detected.

The amount of air bubbles drifting inside the pump was so small in all tests that the pump head and flow didn't decline.

5 REFERENCES

1. Laine, J.: Research Report: Condensation Pool Experiments with Non-Condensable Gas. Lappeenranta, 2002.