TESTING OF ACOUSTIC CAMERAS TO DETECT LEAKAGE THROUGH A CONCRETE STRUCTURE

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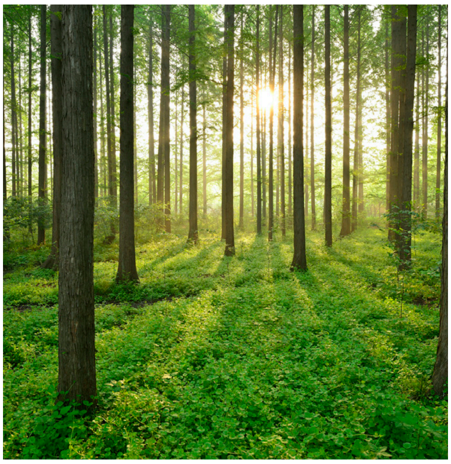

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Testing of acoustic cameras to detect leakage through a concrete structure

Testing performed during a leak rate test of Vercors

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Foreword

This study aimed to evaluate the capability of acoustic cameras to detect leakage through concrete containment structures. Testing was performed during controlled leak rate tests at the VERCORS containment mock-up, using different camera models and operating conditions.

Leak tightness of nuclear power plant containments is essential for preventing radioactive releases during accident conditions. Reliable methods for detecting leakage in concrete structures are therefore critical, particularly in areas that are difficult or impossible to inspect directly.

The results show that acoustic cameras can successfully locate leakage points, but their effectiveness depends on leakage characteristics and operator experience. The study concludes that acoustic cameras should be used as a complementary method together with leakage spray and other inspection techniques.

This report forms the results of a project performed within the Energiforsk Nuclear Power Concrete Program, which is financed by Vattenfall, Uniper, Fortum, TVO, Skellefteå Kraft, Karlstads Energi, the Swedish Radiation Safety Authority and SKB. The Concrete Program aims to increase the knowledge of aspects affecting safety, maintenance and development of concrete structures in the Nordic nuclear power plants.

The study was carried out by Fredrik Tropp, Gabriella Wölfinger and Johanna Spåls, Ringhals AB.

Summary

The containment is designed to protect the surrounding from radioactive release in the event of an accident. Depending on the type of reactor (boiling- or pressurized water), different designs are chosen regarding size, shape and function of the reactor containment. To meet those conditions, the containment must be able to withstand hot steam at high pressure and remain leak tightness. Tests of the leak tightness of the containment are carried out according to the requirements. In these leak rate tests, acoustic cameras are used to identify leaks.

This project evaluated the performance of acoustic cameras in detecting leakage through concrete containment structures, using the VERCORS mock-up facility as a test site. The containment, a scaled-down replica of a French nuclear reactor building, was tested at two pressure levels (4.3 and 4.8 bar).

Two acoustic camera models—NL Acoustics and Fluke II910, were assessed by experienced personnel from Ringhals NPP. During the same test also EPRI joined and tested a camera from FLIR.

Based on the findings of this study, the following recommendations are proposed:

1. **Use acoustic cameras as a complementary tool** – They are effective for locating leakage points but should always be supplemented with other methods such as leakage spray or visual inspection.
2. **Apply leakage spray selectively** – While it enhances detection of small leaks, excessive use may cause false indications due to bubble noise. Use it strategically, especially around large leaks to uncover smaller ones.
3. **Train personnel thoroughly** – Accurate interpretation of acoustic camera results requires experience. Users should be trained to recognize reflections, differentiate between actual leakage and environmental noise, and understand the limitations of the equipment.
4. **Avoid relying on leakage rate values from cameras** – These values are not calibrated for concrete structures and should only be used for relative comparison, not for quantifying actual leakage.
5. **Investigate areas with large leaks carefully** – Large leaks can mask smaller ones. Use multiple angles and methods to ensure no minor leaks are overlooked.
6. **Consider camera ergonomics and usability** – Differences in handling and interface may affect efficiency. Choose equipment based on user preference and operational context.

In conclusion, acoustic cameras are a useful addition to the leak detection toolkit for nuclear containment structures. Their value lies in their ability to visualize sound and pinpoint leakage locations, but their limitations must be understood and mitigated through complementary methods and skilled operation.

Sammanfattning

Inneslutningens uppgift är att skydda omgivningen från radioaktiva utsläpp vid en olycka. Beroende på typ av reaktor (kok- eller tryckvattenreaktor), kan inneslutningens utformning skilja, vad gäller storlek, utformning och funktion. För att klara av sin uppgift krävs att inneslutningen är tät och kan innesluta trycksatt ånga med högt tryck. Tester av inneslutningens täthet utförs enligt ställda krav. Vid dessa täthetsprovningar nyttjas akustiska kameror för att identifiera läckage.

Projektets syfte är att utvärdera prestandan hos akustiska kameror vid detektering av läckage genom betonginneslutningar, med hjälp av VERCORS inneslutnings mock-up. Inneslutningen, en nerskalad kopia av en fransk reaktorinneslutning, testades vid två trycknivåer (4,3 och 4,8 bar).

Två akustiska kameramodeller – NL Acoustics och Fluke II910 – bedömdes av erfaren personal från Ringhals kärnkraftverk. Under samma test anslöt sig även EPRI och testade en kamera från FLIR.

Baserat på resultaten från denna studie ges följande rekommendationer:

1. **Använd akustiska kameror som ett kompletterande verktyg** – De är effektiva för att lokalisera läckagepunkter men bör alltid kompletteras med andra metoder som läckagespray eller visuell inspektion.
2. **Applicera läckagespray selektivt** – Även om det förbättrar upptäckten av små läckor kan överdriven användning orsaka falska indikationer på grund av brus från bubblor som spricker. Använd läcksprayen strategiskt, särskilt runt stora läckor för att upptäcka mindre.
3. **Utbilda personalen** – Tolkning av akustiska kameraresultat kräver erfarenhet. Användare bör utbildas i att känna igen reflektioner, skilja mellan faktiskt läckage och omgivningsbuller och förstå utrustningens begränsningar.
4. **Betrakta inte kamerans läckagevärden som sanna** – Dessa värden är inte kalibrerade för betongkonstruktioner och bör endast användas för relativ jämförelse, inte för att kvantifiera faktiskt läckage.
5. **Undersök områden med stora läckage noggrant** – Stora läckor kan maskera mindre. Använd flera vinklar och metoder för att säkerställa att inga mindre läckor förbises.
6. **Beakta kamerans ergonomi och användbarhet** – Skillnader i hantering och gränssnitt kan påverka effektiviteten. Välj utrustning baserat på användarpreferenser och driftssammanhang.

Sammanfattningsvis är nyttjande av akustisk kamera en användbar kompletterande metod för läckagedetektering för reaktorinneslutningar. Värdet ligger i deras förmåga att visualisera ljud och lokalisera läckageplatser, men deras begränsningar måste förstås och mildras genom kompletterande metoder och yrkesmannaskap.

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1 Introduction

The containment of a nuclear powerplant (NPP) is one of the safety barriers to protect the surroundings from radioactive releases in the event of an accident. To ensure that the containment possesses the required leak tightness it is periodically tested by pressurizing the structure. At Swedish NPP the containment consists of a thick pre-stressed concrete structure. The leak tightness is provided by a steel liner that, for the larger parts, is embedded in concrete. The parts of the liner that are embedded are not possible to inspect. The use of acoustic camera in risk areas during the containment leak rate test is a method that has been introduced at Ringhals NPP to be able to detect a defect in embedded liner.

1.1 VERCORS

The mock-up containment building was completed by EDF in 2015 and is built to be a downscaled replica of the pre-stressed concrete containment building of Nogent sur Seine. This containment mock-up has a mechanical behaviour that represents an average P’4-reactor (1300 MWe), which is common in nuclear power plants, NPP, of the French fleet. The containment is double walled containment without steel liner. A section of the containment is shown in Figure 1. A leak rate test is performed for the inner concrete structure.

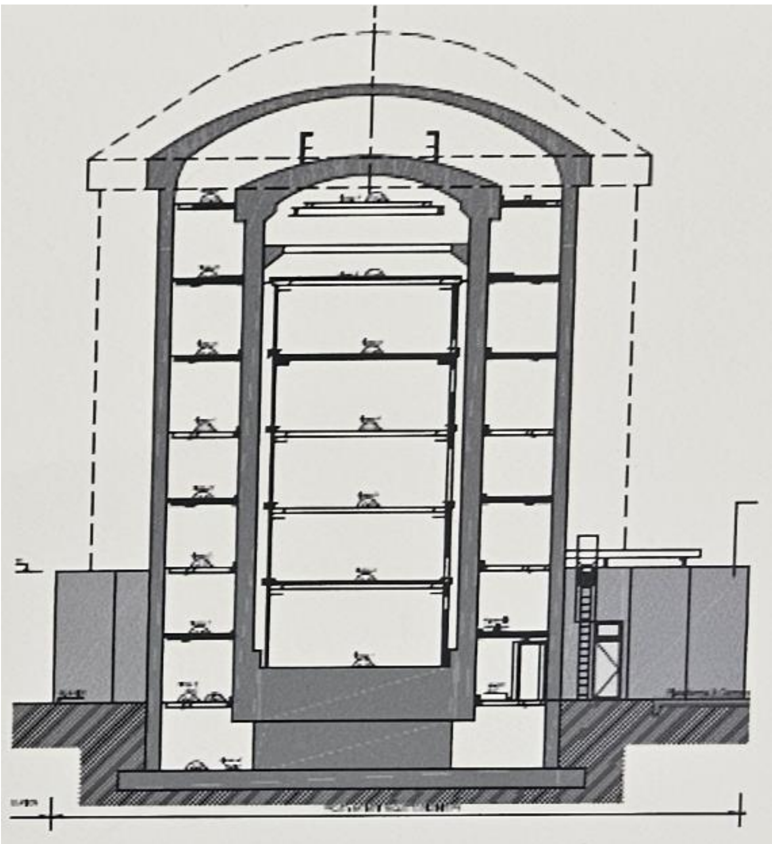

Figure 1 Section of the double wall containment of the mock-up

The VERCORS mock-up containment building consists of the following

- A double-wall containment (H=27m, Ø=17m),
- 5000 ton of concrete,
- 700 sensors, 2 km of fibre optic cables and over 1000 concrete test specimens,
- 4 penetrations: material hatch, personal hatch, and two penetrations of large pipes (steam generators main feedwater flow control system and main steam system, vents valves and steam generator vents and valves),
- 1 auxiliary building (ventilation, heating, measurements).

1.2 TESTING OF ACOUSTIC CAMERAS

Since the Vercors mock-up consists of a concrete containment with known leakage through the structure it gives a good opportunity to find out how well acoustic camera can detect leakage through concrete. During this study cameras from different manufacturers were tested.

The acoustic cameras were tested by personnel from Ringhals NPP with earlier experience from using acoustic camera during containment leak rate test.

2 Equipment

An acoustic camera is a hand-held instrument that turns sounds into a picture so you can see where a leak is coming from. The devices from the different manufacturers are all based on the same principles: a microphone array, signal processing, and a visual overlay on a camera image. The key parts and principles are:

- Microphone array
  The camera contains many small microphones arranged in a grid or ring. Each mic hears the same sound slightly differently depending on its distance and direction from the source.
- Time-delay and phase differences
  A sound from a leak reaches each microphone at slightly different times. The system measures these tiny time or phase differences between microphones.
- Beamforming / acoustic imaging
  Software uses the time differences to compute which direction and location the sound came from. This process (beamforming) produces a 2D map of sound intensity across the camera's field of view.
- Camera + overlay
  The instrument usually has a visible-light camera. The computed sound map is overlaid as a coloured "heatmap" on the real image so you can point the device at a machine, pipe, or joint and instantly see the loudest spot.
- Frequency filtering (ultrasonic detection)
  Many leaks produce high-frequency or ultrasonic noise (well above human hearing). The camera filters and focuses on those frequencies to improve sensitivity and ignore irrelevant low-frequency noise.

2.1 ACOUSTIC CAMERAS

During the test cameras from two different manufacturers were tested. The camera from NL ACOUSTICS, see Figure 2 a, is the camera that Ringhals NPP uses during containment leak rate tests and the camera from FLUKE II910, see Figure 2 b, was borrowed from Forsmark NPP. In addition, during the test at VERCORS, also EPRI tested a camera from a third manufacturer (FLIR), see Figure 2 c.

EDF has during earlier tests also tried to find leakage by using acoustic camera. In previous discussions with EDF, it has been indicated that the camera has worked well for locating leaks, but that quantitative leak measurements are not reliable. Also during this test they had personnel that used an acoustic camera from the manufacturer Distran, see Figure 2 d.

a) NL ACOUSTICS

b) FLUKE

c) FLIR

d) DISTRAN

Figure 2 Acoustic cameras from the different manufacturers

For the purpose of this project, to detect leakage through the concrete, the functionality of the cameras is considered equivalent. There are, however, some differences that mainly affect user-friendliness but where individual preference rather than one model being considered better. Some examples of differences:

- FLUKE needs a two hand grip, the other models only needs one. The weight for FLUKE is also more than the other models.
- NL ACOUSTICS and FLIR gives a value of leakage rate while FLUKE only gives the value in decibel. For a concrete structure, it is however, uncertain how reliable the value of a leakage rate is.
- FLUKE measures the distance automatically while the span of distance needs to be adjusted manually for NL ACOUSTICS and FLIR.
- The frequency span is easy to adjust directly on the screen with FLUKE. For NL ACOUSTICS and FLIR its selectable predefined spans.

A comparison of the technical specifications of the different cameras are found in Table 1.

None of the acoustic cameras are designed to measure leakage through the concrete. The calculated leakage values given by NL ACOUSTICS and FLIR cannot be considered as a true value but can be used for comparison between different measurements.

Table 1 Comparison of technical data of the acoustic cameras from different manufacturers

Manufacturer	**NL ACOUSTIC**	**FLUKE II910**	**FLIR**
Detected gases	Detecting compressed air leaks	Compressed air, gas, steam and vacuum leaks	Detects all gases provided they are under sufficient pressure. Quantifies leak rate costs for compressed air, ammonia, argon, carbon dioxide, helium, hydrogen, methane, natural gas, and nitrogen.
Measuring range[1]	Below -15 dB (frequency-dependent) 120 dB (frequency-dependent)	12,1 - 114,6 dB SPL (±1 dB SPL 2 kHz) 4,4 - 101,2 dB SPL (±2 dB SPL 19 kHz) 12,8 - 119,2 dB SPL (±1 dB SPL 35 kHz) 19,8 - 116,1 dB SPL (±3 dB SPL 52 kHz) 41,4 - 129,0 dB SPL (±1 dB SPL 80 kHz) 54,4 - 135,5 dB SPL (±1 dB SPL 100 kHz)	20 kHz: -7 dB SPL 35 kHz: 4 dB SPL 50 kHz: 10 dB SPL 80 kHz: 36 dB SPL 100 kHz: 51 dB SPL
Bandwidth	2 – 35 kHz	2 kHz - 100 kHz	2 – 130 kHz
Distance	From 0.3 m (1.0 ft) up to and above 130 m (430 ft)	0,5 m till > 120 m Beroende på omgivningsförhållanden a	From 0.3 m (1.0 ft) up to 200 m (656 ft)
Leak rate	In typical industrial environment: >0.032 l/min @ 3 bar from 3 m (9.8 ft) >0.05 l/min @ 3 bar from 10 m (32.8 ft) Absolute minimum detection in a quiet environment: 0.016 l/min @ 1.2 bar from 0.3 m (1.0 ft)		0.0032 l/min from 2.5 m, 0.0044 l/min from 6 m
Operating temperature range	-10°C to 50°C (14°F to 122°F)	-10 °C till 40 °C	-10°C to 50°C (14°F to 122°F)

[1] Measuring range: The span of sound pressure levels (SPL) that the acoustic camera can detect and accurately visualize, from its minimum detectable level to its maximum undistorted level. Frequency affects the camera's ability to localize sound which makes the measuring range frequency-dependent.

3 Containment leak rate test at Vercors

The containment leak rate test took place 7:th to 10:th of April 2025. During the first part of the test the containment was pressurised to 4.3 bar. After that the pressure was held at this level and the area around the containment was accessible. During this time a first test with the cameras was performed. After approximately 10 hours the pressure was increased once more, this time to 4.8 bar. Also at this level the area around the containment was accessible and it was possible to perform a second test with the cameras. The first schedule for the pressurizing of the containment is shown in Figure 3. Timeline marked with red indicates when the area around the containment is accessible.

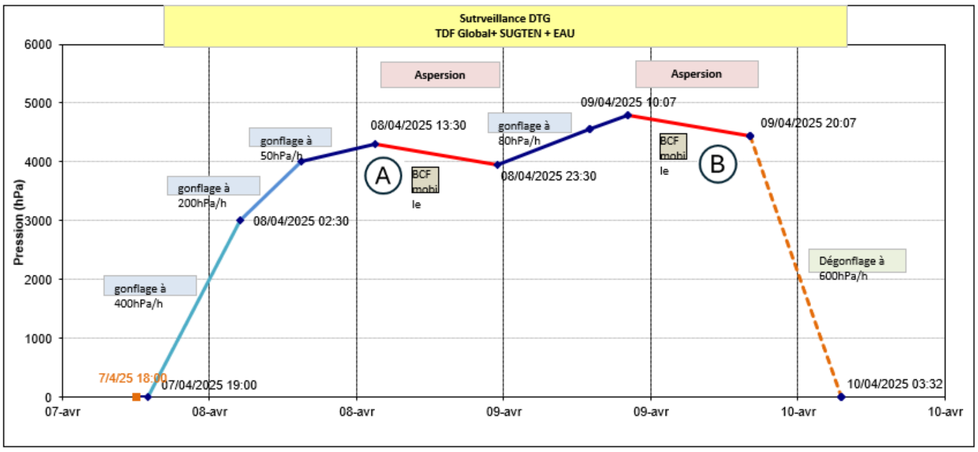

Figure 3 Time schedule for pressurizing the containment. A) first entry at 4.3 bar and B) second entry at 4.8 bar.

During the first visit, EDF already started their activities in the area. To detect leakage they shower the containment with leakage spray, see Figure 4. This meant that the larger parts of the containment was covered with leakage spray before the test of the cameras started. During the second time. At 4.8 bar, it was possible to perform the test before the leakage spray was applied.

Figure 4 Dome and wall covered by leakage spray

3.1 SELECTION OF REFERENCE POINTS

During the first visit a walkdown around the containment at the different levels was performed. The cameras identified leakage at many different locations, and leakage could also be seen by the applied leakage spray. Some areas were also marked by EDF since earlier performed leak rate tests. Three different locations, reference points, were selected to be able to compare the results between the two different occasions for the test. Two additional reference points were selected on the second occasion. The location of the reference points are seen in Figure 5.

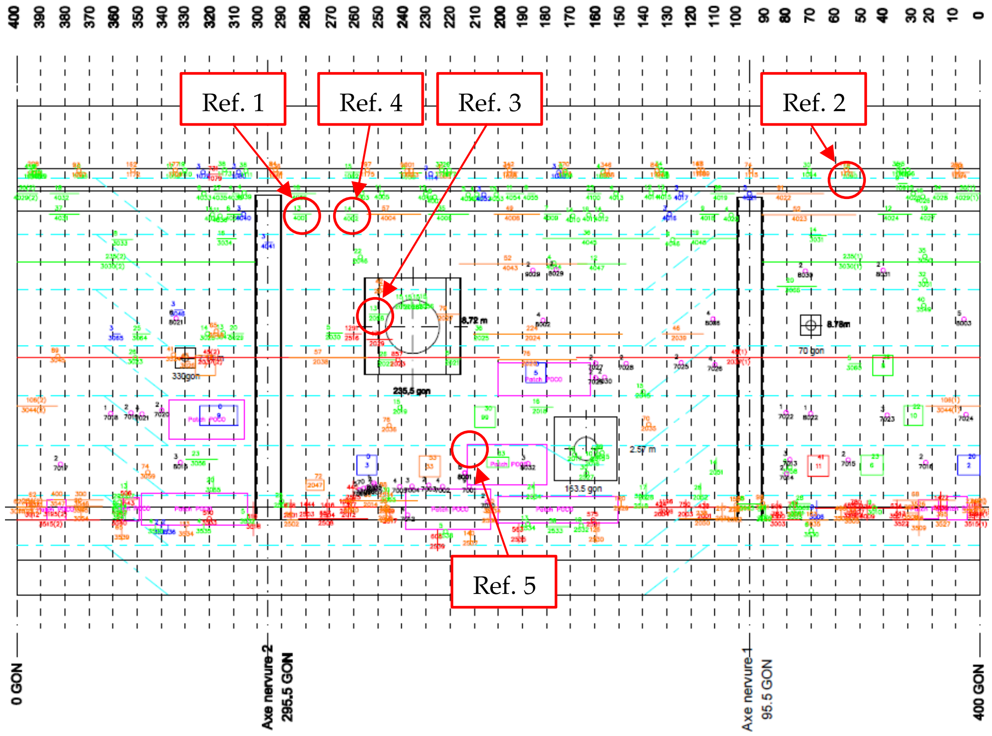

Figure 5 Location of the reference points

Reference point 1 was selected as an example with a smaller leakage. In this area there is a joint in the construction with a deviation of the used material.

Reference point 2 was selected as an example were leakage could be found in an area without leakage spray added during the first visit.

Reference point 3 was selected as an example there the leakage is detected next to a detail that is embedded in the concrete.

Reference point 4 was selected as an example were the camera is not able to detect leakage but other methods are. This location was only investigated during the second occasion.

Reference point 5 was selected as an location to compare the differences when using the camera at different distances. This is also an example that illustrates that the leakage finds the easiest way through the structure. In this area a surface treatment is applied to reduce the leakage through the structure. This location was only investigated during the second occasion.

3.2 RESULT AT 4.3 BAR – 08/04/25

The first test of the cameras was done at 4.3 bar, see Figure 3A. At this time leakage spray was applied to large part of the structure.

3.2.1 Reference Point 1

At this reference point, leakage spray was applied. In this location there is a small leakage that all cameras can identify. Photos with leakage indications from two different cameras are found in Figure 6.

At this occasion FLUKE measured a leakage of 26 dB and NL ACOUSTICS measured a leakage of 21,9 dB.

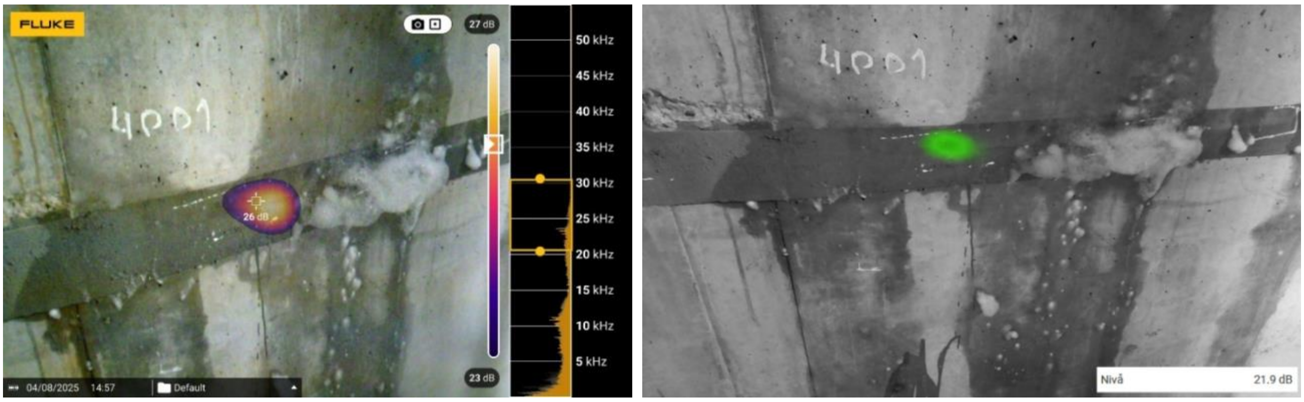

Figure 6 Pictures from the cameras of the leakage at reference point 1. On the left FLUKE ii910 and on the right NL ACOUSTICS

3.2.2 Reference Point 2

At this reference point, leakage spray has not yet been applied. This reference point has a small leakage that can be detected by both cameras. Photos with leakage indications from two different cameras are found in Figure 7.

During this occasion FLUKE measures a leakage of 20 dB and NL ACOUSTICS measured a leakage of 17,8 dB.

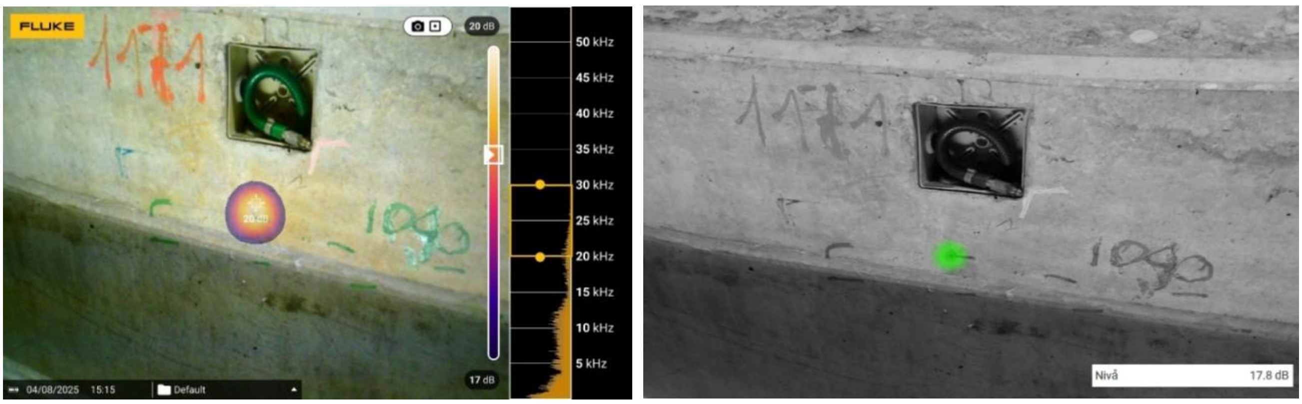

Figure 7 Pictures from the cameras of the leakage at reference point 2. On the left FLUKE ii910 and on the right NL ACOUSTICS

3.2.3 Reference Point 3

A smaller penetration with a hose was selected as a reference point; this was a large leak that all cameras identified. At this point, leakage spray has not yet been applied. This is a rather large leakage that can be heard by ears and felt by the hand. Photos with leakage indications from two different cameras are found in Figure 8.

During this occasion FLUKE measures a leakage of 51 dB and NL ACOUSTICS measured a leakage of 50,2 dB.

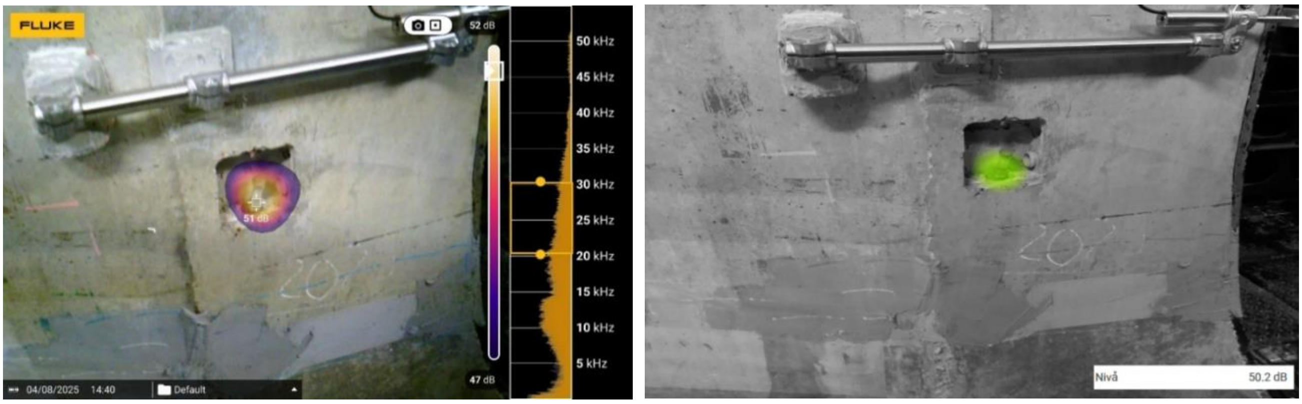

Figure 8 Pictures from the cameras of the leakage at reference point 2. On the left FLUKE ii910 and on the right NL ACOUSTICS

3.3 RESULTS AT 4,8 BAR – 09/04/25

The second entry was at pressure of 4.8 bar, see Figure 3B. At this time, no leakage spray was applied.

3.3.1 Reference Point 1

No leakage was identified by any of the cameras, see Figure 9. Both cameras give a value in this area but it is not possible to see if it is the leakage or a reflection of other sounds.

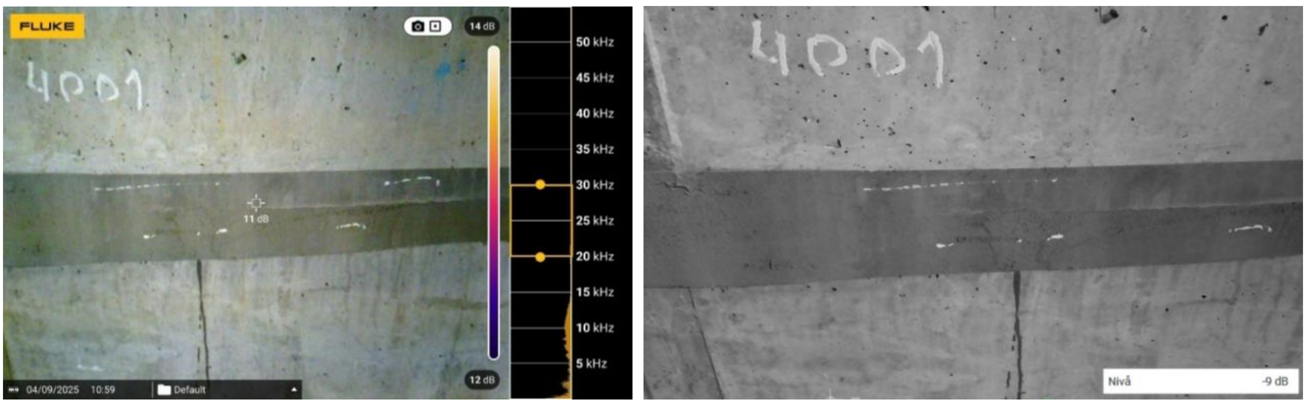

Figure 9 Pictures from the cameras of the leakage at reference point 1. On the left FLUKE ii910 and on the right NL ACOUSTICS

3.3.2 Reference Point 2

In reference point 2 all cameras identifies leakage, both with and without leakage spray, see Figure 10 and Figure 11. The cameras indicates a slightly higher leakage than during the first test.

During this occasion FLUKE measures 28 dB without leakage spray and 48 dB with.

NL ACOUSTICS measures 28,2 dB without leakage spray and 42,8 dB with.

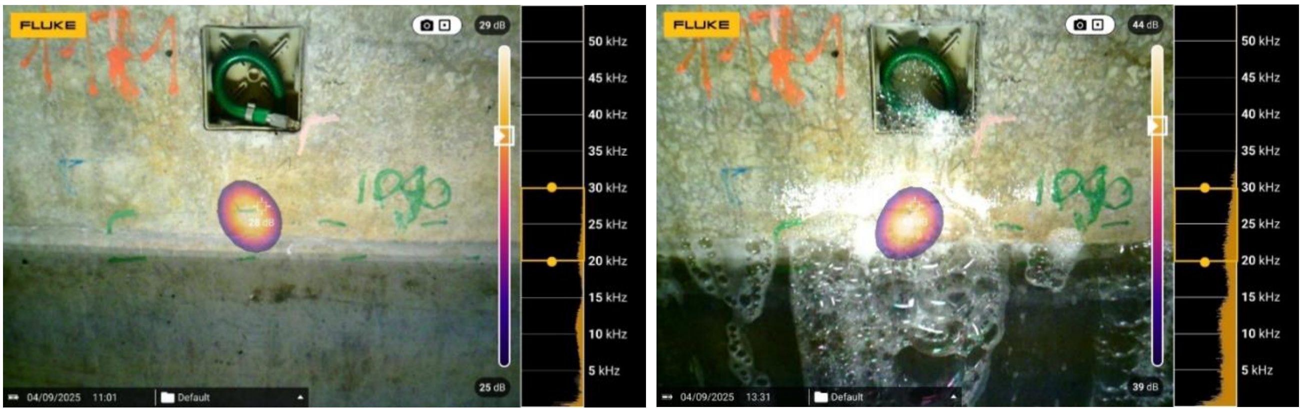

Figure 10 Picture from FLUKE ii910 at reference point 2, with and without leakage spray

Figure 11 Pictures from NL ACOUSTICS at reference point 2, without and with leakage spray.

3.3.3 Reference Point 3

In reference point 3 the amount of leakage is equal to the leakage during the first test.

Figure 12 Picture from the cameras of the leakage at reference point 3. On the left FLUKE ii910 and on the right NL ACOUSTICS

3.3.4 Reference Point 4

At reference point 4, none of the cameras could identify any leakage, but you can feel a leakage with your hand. Leakage spray was applied over the surface and the bubbles from this allow the cameras to capture the leakage.

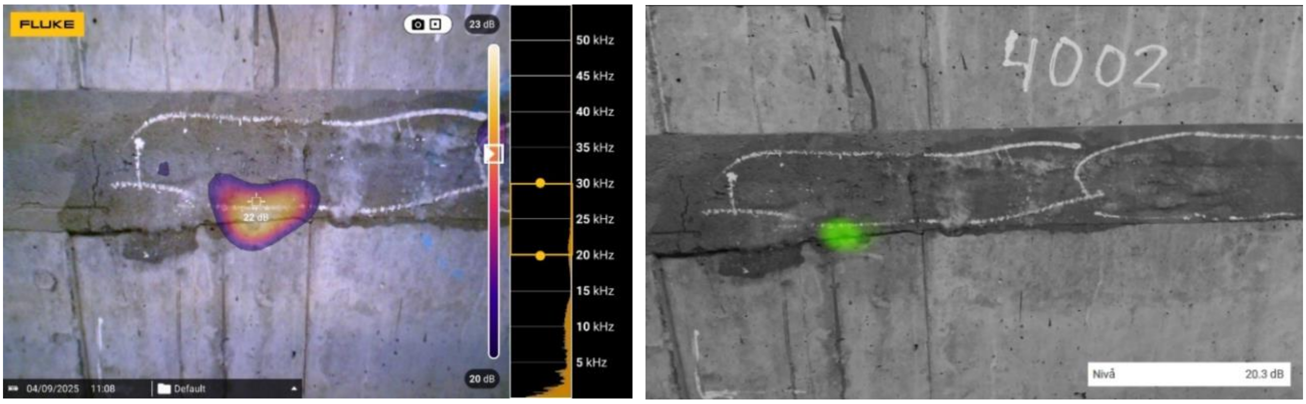

Figure 13 Picture from the cameras of the leakage at reference point 4. On the left FLUKE ii910 and on the right NL ACOUSTICS

3.3.5 Reference Point 5

At this reference point, the amount of leakage given by the camera was tested at different distances. The leakage value is dependent of the distance which implies that the value for the amount of leakage should not be taken as "true".

Figure 15 Picture from NL ACOUSTICS of the leakage at reference point 5 – Short distance

Figure 14 Picture from NL ACOUSTICS of the leakage at reference point 5 – Long distance

3.4 REFLECTIONS OF THE RESULTS

3.4.1 Reference Point 1

During the test at 4.3 bar a leakage was identified in this location. During this next test, none of the cameras identified a leakage. The difference was that during the first test leakage spray was applied but during the second the area was dry. When leakage spray was applied during the second test the leakage was detected by the cameras. When leakage spray is applied, bubbles bursts which gives a sound. It is probably this sound that gives an indication in the cameras.

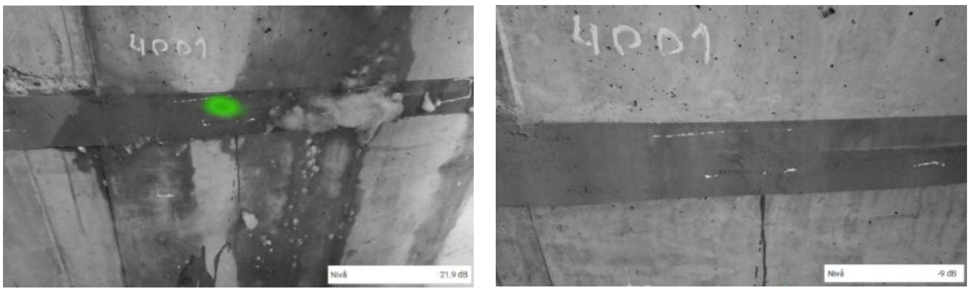

Figure 16 Comparison of Reference Point 1 during the first and second occasion

3.4.2 Reference Point 2

A leakage was detected in this area at both occasions. During the first occasion FLUKE measured a result of 20 dB and at the second 28 dB, see Figure 17. A similar difference was detected with NL ACOUSTIC that indicated a leakage of 17,8 dB during the first occasion and 28,2 dB during the second. Because of the higher pressure inside the containment during the second occasion it is expected that the leakage will be higher.

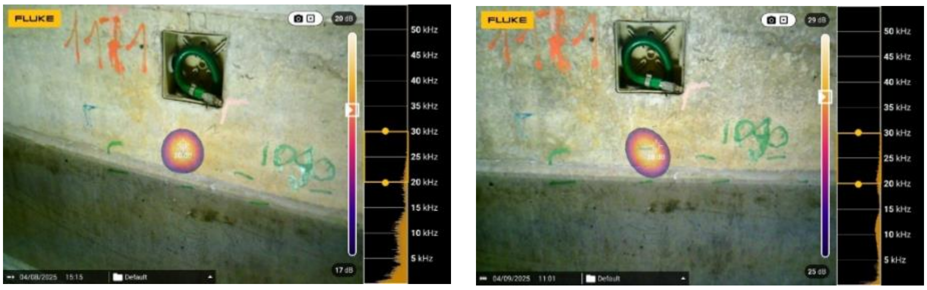

Figure 17 Comparison of Reference Point 2 during the first and second occasion

3.4.3 Reference Point 3

This leakage is found next to a smaller penetration with a hose. The leakage was found at both occasions. Even if there was a higher pressure during the second occasion, the leakage rate stayed at the same level.

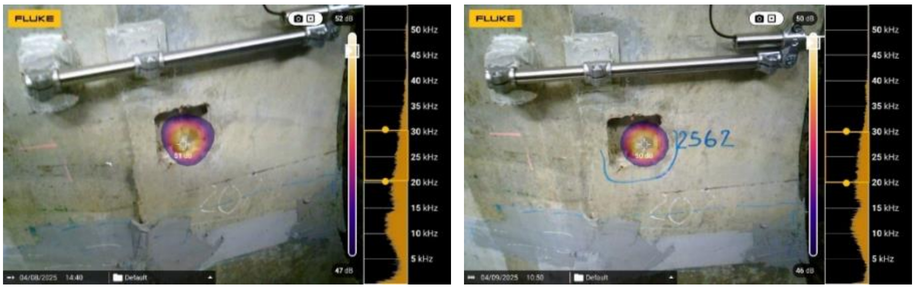

Figure 18 Comparison of Reference Point 3 during the first and second occasion

3.4.4 Reference Point 4

This reference point was only measured during the second occasion. This area was marked by EDF from inspections performed earlier years. The leakage is small in this area but you can feel it with your hand. It is however hard to say if you by your hand would notice the difference without having the area marked. By adding leakage spray to the area it can be seen that there are a leakage in the area. When the leakage spray is added the cameras are able to detect a sound. The phenomena that the cameras are catching is the sound that appears when the bubbles from the leakage spray bursts.

3.4.5 Reference Point 5

In this area EDF has applied a surface treatment to increase leak tightness. As can be seen the leakage now instead appears at the edge of the treated area. The writers of this report have not further detail regarding how well the surface treatment works, if the leakage is decreased. But what is clearly illustrated is that the leakage finds the easiest way through the structure.

3.4.6 General

When going into the containment during the first occasion, leakage spray was already applied over large areas. Roof and walls were showered by leakage spray, see Figure 19. It was therefore hard to know it the sound that was measured by the cameras was the sound of leakage or if it was the sound of bubbles from the leakage spray that burst. In some cases bubbles burst in areas without leakage.

Figure 19 Applying leakage spray to the containment

It was also noted that in some areas where a larger leakage was found in one spot, smaller leakage next to it was not found with the cameras.

Reflections from other equipment might also been shown as leakage by the cameras. Usually it helps to move the camera and point at the surface in different angles. When it is a reflection the indication typically moves around when changing the position of the camera. A leakage is fixed to a specific point.

4 Discussion

This study was conducted at the VERCORS mock-up facility, which is a downscaled replica of the pre-stressed concrete containment building at Nogent-sur-Seine. Unlike Swedish nuclear containments, which incorporate a metallic liner embedded in the concrete, the VERCORS structure lacks such a liner. With a liner, leakage will be localized in one location, through a defect or deviation. Observations from Ringhals NPP indicate, however, that leakage through concrete tends to follow the path of least resistance, often occurring at casting joints and around penetrations rather than directly adjacent to defects in the liner. Similar behaviour was observed at VERCORS, where leakage was detected near penetrations (Ref. 3), joints (Ref. 1, 2 and 4), and the edges of surface-treated areas (Ref. 5). Acoustic cameras were able to identify these types of leakages regardless of manufacturer.

However, when leakage is diffuse and spread over a larger area with low flow rates, acoustic cameras struggle to detect it. In such cases, leakage spray proves more effective. The spray generates bubbles that burst, producing sound signals that can be picked up by the cameras. Given that Swedish containments have painted concrete surfaces and embedded liners, widespread leakage is less likely, but the use of leakage spray remains a valuable complement.

It is also important to note that in areas with significant leakage, smaller adjacent leaks may go undetected due to signal masking. Therefore, it is recommended to supplement acoustic camera inspections with additional methods, such as leakage spray, to ensure comprehensive detection.

Excessive use of leakage spray can mislead acoustic measurements, as bubble bursts may occur in areas without actual leakage. In such cases, the camera may falsely interpret these sounds as leak signals.

Leakage values presented in this report should not be considered absolute. The acoustic cameras and their software are primarily designed for detecting leaks in piping systems, where leakage is typically concentrated. In contrast, leakage through concrete surfaces is more diffuse. For Swedish containments, the primary objective of using acoustic cameras is to determine the presence of leakage, not to quantify it. The values provided by the cameras may be useful for comparative analysis between test occasions, but other methods should be employed to obtain accurate leakage rates.

This report summarizes the performance of acoustic cameras from NL Acoustics and Fluke. For the purpose of detecting leakage through concrete, their functionality is considered equivalent. Differences between models are mainly related to user-friendliness and individual preferences. Regardless of the manufacturer, it is essential that operators have thorough knowledge of the equipment to ensure accurate results. For example, reflections can mislead users, and proper handling is required to distinguish between actual leakage and artifacts.

5 Summary and conclusions

This project evaluated the performance of acoustic cameras in detecting leakage through concrete containment structures, using the VERCORS mock-up facility as a test site. The containment, a scaled-down replica of a French nuclear reactor building, was tested at two pressure levels (4.3 and 4.8 bar). Two acoustic camera models—NL Acoustics and Fluke II910, were assessed by experienced personnel from Ringhals NPP.

The study showed that all cameras could detect leakage at the same locations. Small, dispersed leaks were difficult to detect, especially without leakage spray. The spray improved visibility but also introduced the risk of false positives due to bubble noise. Large leaks could mask smaller ones nearby, and reflections from surrounding equipment sometimes misled the detection. User experience and camera handling were found to be critical for accurate results.

The containment leak rate tests revealed that acoustic cameras are valuable tools for identifying leakage, particularly in areas where direct inspection is not possible. However, they should not be relied upon as the sole method. A combination of acoustic imaging and leakage spray is recommended to ensure reliable detection. The cameras are not designed to measure leakage through concrete, and the values they provide should not be interpreted as absolute leakage rates. Instead, they can be used for comparative analysis between different test occasions.

Based on the findings of this study, the following recommendations are proposed:

1. **Use acoustic cameras as a complementary tool –** They are effective for locating leakage points but should always be supplemented with other methods such as leakage spray or visual inspection.
2. **Apply leakage spray selectively –** While it enhances detection of small leaks, excessive use may cause false indications due to bubble noise. Use it strategically, especially around large leaks to uncover smaller ones.
3. **Train personnel thoroughly –** Accurate interpretation of acoustic camera results requires experience. Users should be trained to recognize reflections, differentiate between actual leakage and environmental noise, and understand the limitations of the equipment.
4. **Avoid relying on leakage rate values from cameras –** These values are not calibrated for concrete structures and should only be used for relative comparison, not for quantifying actual leakage.
5. **Investigate areas with large leaks carefully –** Large leaks can mask smaller ones. Use multiple angles and methods to ensure no minor leaks are overlooked.
6. **Consider camera ergonomics and usability –** Differences in handling and interface may affect efficiency. Choose equipment based on user preference and operational context.

In conclusion, acoustic cameras are a useful addition to the leak detection toolkit for nuclear containment structures. Their value lies in their ability to visualize sound and pinpoint leakage locations, but their limitations must be understood and mitigated through complementary methods and skilled operation.

TESTING OF ACOUSTIC CAMERAS TO DETECT LEAKAGE THROUGH A CONCRETE STRUCTURE

This study aimed to evaluate the capability of acoustic cameras to detect leakage through concrete containment structures. Testing was performed during controlled leak rate tests at the VERCORS containment mock-up, using different camera models and operating conditions.

Leak tightness of nuclear power plant containments is essential for preventing radioactive releases during accident conditions. Reliable methods for detecting leakage in concrete structures are therefore critical, particularly in areas that are difficult or impossible to inspect directly.

The results show that acoustic cameras can successfully locate leakage points, but their effectiveness depends on leakage characteristics and operator experience. The study concludes that acoustic cameras should be used as a complementary method together with leakage spray and other inspection techniques.