FLÜS – Leak Detection on CANDU Secondary Side Piping: Experience at Point Lepreau and Gentilly-2

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Abstract

Due to regulatory concerns for the protection of the Control Rooms (CR) against the possible consequences of a Steam/Feedwater pipe break at the Point Lepreau Generating Station (PLGS) and at Gentilly-2 (G2), NB Power and Hydro Québec have each installed an on-line leak detection system on their Secondary Side Piping (SSP) in close proximity to these rooms.

After laboratory testing three prospective systems, the Siemens FLÜS system was selected and installed in 1999 at both sites. Both systems have been in-service since December 1999 (G2) and June 2000 (PLGS), and both have met the necessary requirements.

The main features of the FLÜS system are:

- a robust and low maintenance design
- simple installation of all field components
- high sensitivity (2.5 kg/h leak rate and better)
- short response time (40 minutes and better)
- high locating accuracy (few meters)

Both FLÜS systems are of identical design, except for the amount of tubing connected. The system at PLGS is the largest FLÜS system ever installed, operating 1700 m of total tubing (700m of monitored pipes and 1000 m of connector tubes).

Background

The idea of leak detection on the SSP was based on a regulatory commitment by NB Power and Hydro Québec for installing an on-line system that could detect leakage from a crack or defect on the secondary side pipes that run in close proximity to the CR's at Point Lepreau and Gentilly-2.

A CANDU Owners Group (COG) project was initiated to perform a survey of the available leak detection technology and come up with some recommendations.

The three prospective leak detection systems identified by this survey were subjected to a laboratory testing program at the Research and Productivity Council (RPC) facilities in Fredericton, NB. These tests simulated a series of pipe leaks and compared the systems' performances under different operating conditions. Based on these test results, all three were found acceptable and were invited to tender.

All relevant information was gathered and analyzed from the Tender bids, the laboratory test results, field visits to see similar applications of leak detection technology (by NB Power), and industry literature and technical reviews. To this end, a final recommendation was made by both Hydro-Quebec and NB Power for the purchase of the Siemens FLÜS system because of:

- its proven leak detection method (previously installed at 4 other locations since 1995)
- its robust and low maintenance design
- low overall cost for the life of the station

Monitoring Scope

The FLÜS system was required to meet the following design specifications:

- Monitoring of all SSP pipes running over the Service Building roof. At PLGS these are Main Steam, Feedwater and Reheater pipes to all four boilers. At G2, only Main Steam Pipe 4 is involved.
- Monitoring of additional vertical sections of Feedwater and Reheater pipes inside the Turbine Building (only at PLGS).
- Monitoring of the Main Steam Header inside the Turbine Building (both at PLGS and at G2).
- Operation on outdoor pipes in a riverside or coastal environment under extremely harsh ambient conditions (-40° to +40°C ambient temperature, 100% humidity, etc.)
- Failsafe operation against ingress of ≤ 0.5 kg/h of water (rain, molten snow, etc.) into the exterior insulation.
- Detection of leak rates ≥ 2.5 kg/h (PLGS) and 3.0 kg/h (G2)
- Response time ≤ 40 minutes (PLGS)
- Non-availability of the FLÜS system ≤ 0.01

The Siemens FLÜS System

Operating Principle

The Siemens FLÜS system operates on the principle of humidity detection. The key to the FLÜS system is the "Sensor Tube" that is installed in direct contact with the affected steam/water pipes. The sensor tube has porous sintered metal elements (see Fig. 1) placed at 1 m intervals. The differential in the water vapor concentration causes the moisture in the piping insulation to diffuse through the porous elements and into the dry air inside the sensor tube.

The individual sensor tube segments are joined end-to-end to cover a section of pipe, and the ends of these sections are connected back to the FLÜS Measuring Station using normal stainless steel tubing. Two of these Monitoring Lines are installed at G2, and six at PLGS, but up to 8 Lines can be handled by one Measuring Station. Every 15-20 minutes, the air inside each of the Monitoring Lines is purged with dry air, and the humid air is routed through a humidity instrument (Sensor Module). By plotting the humidity measurement trace against the purge time, the humidity at any point along the sensor tubing can be traced back to a precise position on the pipe, and high humidity measurements over a localized area will trigger the leak detection alarm.

Location information is obtained from measuring the air flow velocity vs. time during every purge process. The time integral of the flow velocity gives the FLÜS tube location axis for all humidity profile curves shown by the FLÜS system.

Also, with every measuring cycle, a Calibration Module injects a precise amount of moisture into the end of the air stream. This shows up as a clear peak ("test peak") at the end of the humidity measurement trace, which confirms that the system is working properly and allows the system to calibrate the location axis to the correct scale.

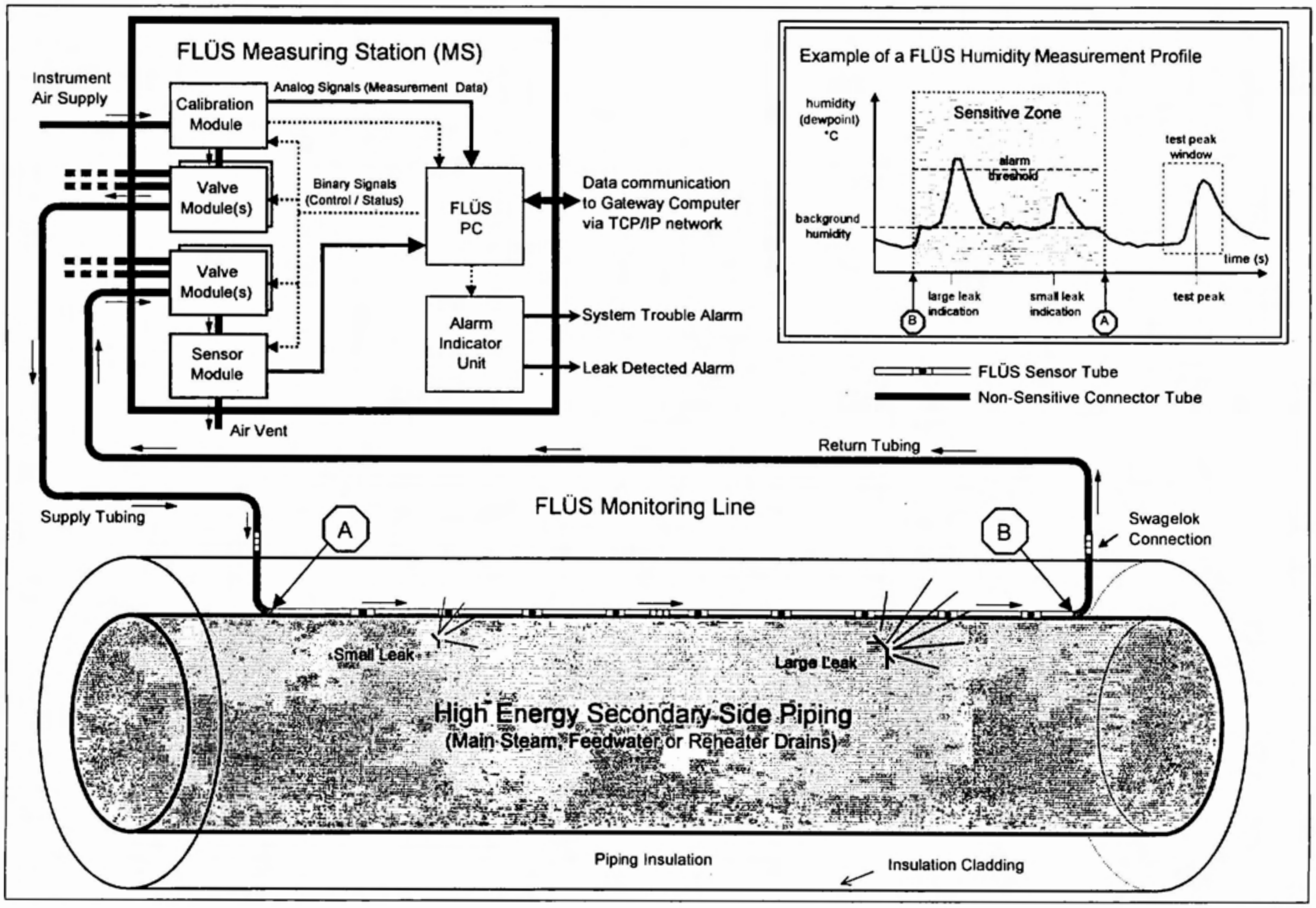

Fig. 1 FLÜS Leak Monitoring – Principle

Routing of the air to specific Monitoring Lines is accomplished by multiplexing the air through solenoid Valve Modules. The operation of each solenoid is timed to ensure that each Monitoring Line is purged in the proper sequence to allow a fixed diffusion time.

Main Components

The main components of a FLÜS system as shown in Fig. 1 are:

- FLÜS Sensor Tube:

  Nickel cylinders with *sintered Nickel pellets* (i.e.: sensor elements), connected by pieces of either *corrugated* tubing (flexible type - see Fig. 2) or *rigid* stainless steel tubing.

  Spacing of cylinders: 1 m
  Outer tube diameter: max. 17 mm
  Segment length: 6 m

- Connector Tube:

  Standard stainless steel tubes for connecting individual sections of Sensor Tube.

- FLÜS Measuring Station (see Fig. 3) for measurement control and data analysis.

Fig. 2 A piece of FLÜS Sensor Tube (flexible)

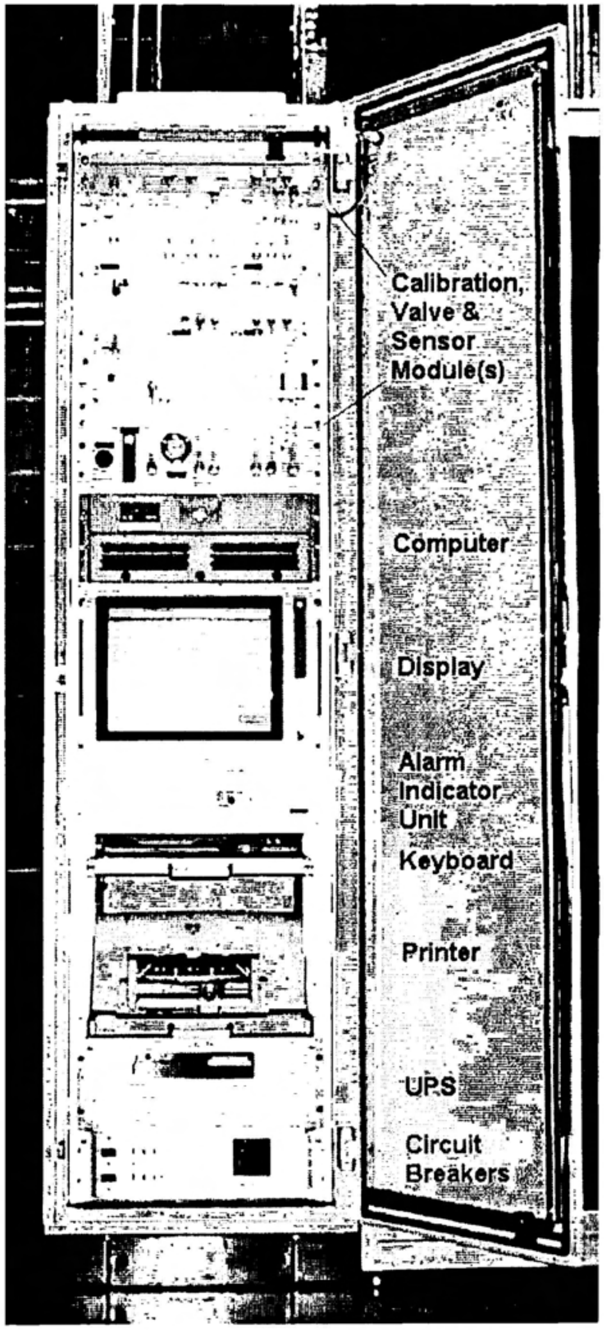

Fig. 3 FLÜS Measuring Station (PLGS)

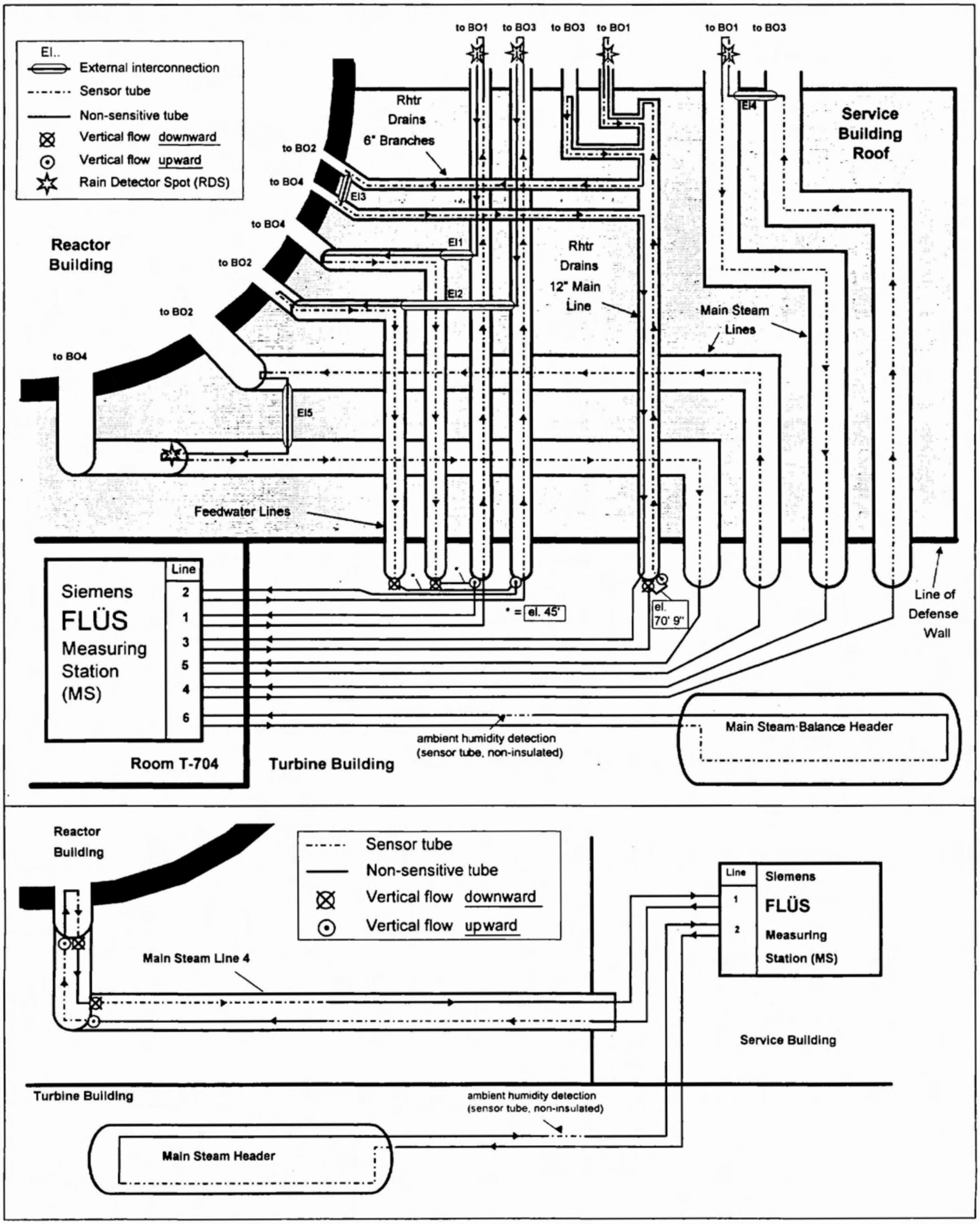

Fig. 4 Schematic Layout overview of the FLÜS systems at PLGS (top) and G2 (bottom)

System Layout

Fig. 4. shows the layouts of both FLÜS systems. It is obvious, that - compared to the complex layout at PLGS - the G2 system represents a subset with only 2 Monitoring Lines.

The governing principle for this layout was to build up a minimum of Monitoring Lines with a minimum of non-sensitive connector tubing in order to minimize the duration of one monitoring cycle. As a result, each Monitoring Line (except for that one on the Main Steam Header) has to cover at least two separate pipes and therefore, so-called "External Interconnections" (EI) for the FLÜS tubes were required to connect a Monitoring Line between two pipes. These EI's were made of a piece of connector tube, insulated and equipped with a heating cable and mechanically protected by a 200mm steel tube (see Fig. 5).

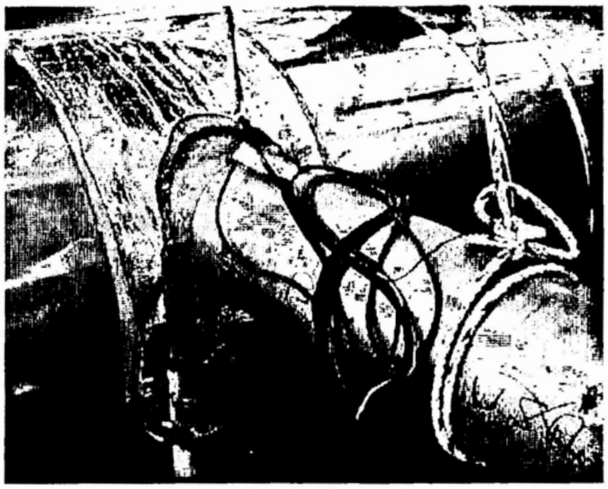

Fig. 5 External Interconnection "EI5" between Main Steam Lines 2 & 4 (PLGS) during installation; cables are for heating and temperature measurement

Finally, a couple of "Test Injection Tubes" were installed at significant locations to the pipes, which were made of short stainless steel tubes directly strapped to the pipe surface (see Fig. 6). The inlets of these tubes are accessible from outside the cladding for water / steam injection experiments.

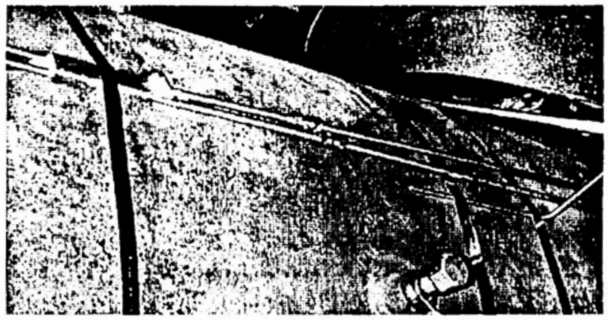

Fig. 6 Sensor Tube (rigid) and non-sensitive return tube on Main Steam Header (G2); 3rd piece of tube is a test injection tube

FLÜS Installation

Installation was done during the 1999 spring outages at G2 (April) and PLGS (May/June). Although the FLÜS tubing is easy to handle, robust and maintenance free, the installation was very labor-intensive because it required the removal and replacement of all the piping insulation. However, installation did not have a big impact on other outage activities. The installation sequence involved removing all of the piping insulation, strapping the sensor tube to the surface of the pipe, and then covering the sensor tubes with a new insulation system.

Insulation Setup

Each plant had selected a completely different setup of the insulation on the outdoor pipes:

- G2: Foam glass insulation with standard cladding.
- PLGS: Mineral fiber insulation, stainless-steel cladding. Also, a weather-proof barrier (Pittwrap), and galvanized steel half-shells (on the top of horizontal sections) were installed on the exterior pipes.

Fixing of FLÜS Tubes

All FLÜS tubing was strapped to the pipes using simple metal brackets as fixtures. On horizontal pipe sections the sensor tube was installed at or close to 12 o'clock position (see **Fig. 7**). Routing along elbows and around pipe supports, hangers, nozzles, etc. was very simple by using flexible tube sections there.

A precisely defined QA program (pressure tests, flow tests) was followed during tube installation in order to avoid any leak or blockage in the FLÜS tubing.

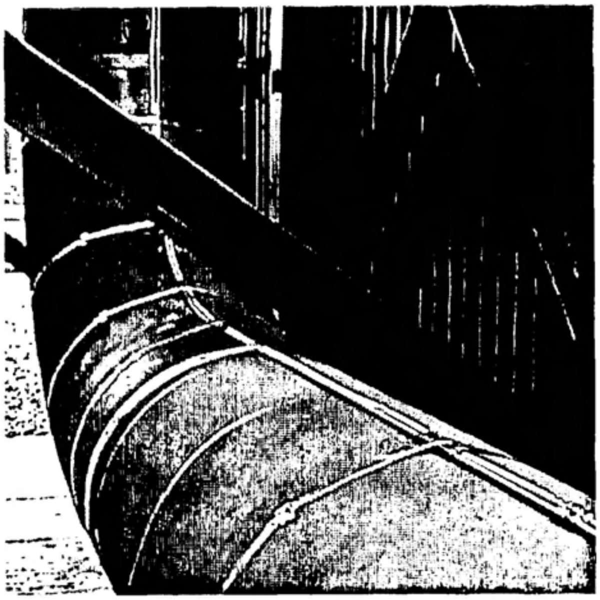

Fig. 7 Sensor Tube (flexible) and non-sensitive return tube on Main Steam Line (G2)

Operating Experience

Both systems are in permanent operation since October 1999[1] and all components were running with high reliability. This experience confirms the low non-availability figure of < 0.003 (design target: 0.01) that was obtained from NB Power's reliability study for the FLÜS system.

Influence of Insulation Setup

In general, FLÜS needs an insulation setup that has sufficient vent orifices in order to let out vapor (and condensed water). This will ensure a minimum relaxation time and avoid accumulation of moisture.

The most relevant lesson learned from the systems' test operation phases was that the insulation used at G2 (foam glass, simple cladding) is almost the optimum solution in respect to the FLÜS requirements as stated above. This is because any liquid water that should enter the insulation will run through the gaps between the foam glass sections, and find a way out at the bottom without getting vaporized in the proximity of the Sensor Tube. Even when being vaporized, the moisture will disappear very quickly with zero absorption by the insulation material. This was verified during the final test injection experiments in December 1999.

On the other hand, the PLGS insulation system was an extremely sealed-off environment which stores moisture for a long time. The "Pittwrap" was applied over the external insulation material to provide an additional measure of weather protection, but its metal foil backing acted as an efficient vapor barrier. This trapped residual moisture from the installation phase inside the insulation, and as a consequence, there was an extremely high background humidity level (saturated atmosphere) inside the insulation. Also, the absolute humidity of this saturated system changed drastically, depending on the cladding temperature (see **Fig. 9**, curves A and B). Therefore, the FLÜS humidity background levels covered the entire dynamic range over the course of the first months of operation (very low levels in winter, almost signal saturation in summer).

In order to allow proper leak monitoring by FLÜS, PLGS did a rework on the entire exterior piping in June 2000, removing the cladding and the Pittwrap and – after having dried out the insulation sufficiently – re-installed the cladding without the Pittwrap. In addition, ¼" vent holes were drilled into the cladding every 1-2 ft at the bottom of all horizontal pipe sections.

Normal Operation and Ambient Effects

As a typical curve, the background humidity profile of Monitoring Line 3 at PLGS is shown in **Fig. 8** with all individual sensitive zones marked. Note that because of transportation effects in the FLÜS tubes, the profiles exhibit an integration-like behavior, and therefore, each constant humidity level from a sensitive zone is converted to a rising signal flank in the FLÜS plot.

The reaction of the FLÜS systems to the most common ambient parameters is as follows:

1. Precipitation (rain, snow, ice):

   Integrity of the cladding is essential for avoiding false alarms. However, all alarm thresholds are set in order to tolerate small humidity peaks resulting from water ingress rates ≤ 0.5 kg/h (see **Fig. 10**, curve C). At G2 the relaxation time until a "rain peak" has disappeared is shortest (< 2 hours).

2. Ambient air humidity:

   In the G2 system the background humidity level follows quicker any change in the ambient humidity (by seams in insulation and cladding – curves see **Fig. 10**, curves A & B). The PLGS system did not show significant reactions to external humidity changes because the only path for humidity exchange are the vent holes at the bottom.

3. Ambient temperature:

   Changes in ambient temperature are not clearly visible in the G2 system because FLÜS measures the absolute humidity.

[1] The system at PLGS commenced operation in October 1999, but was not officially declared "In-Service" until June 2000.

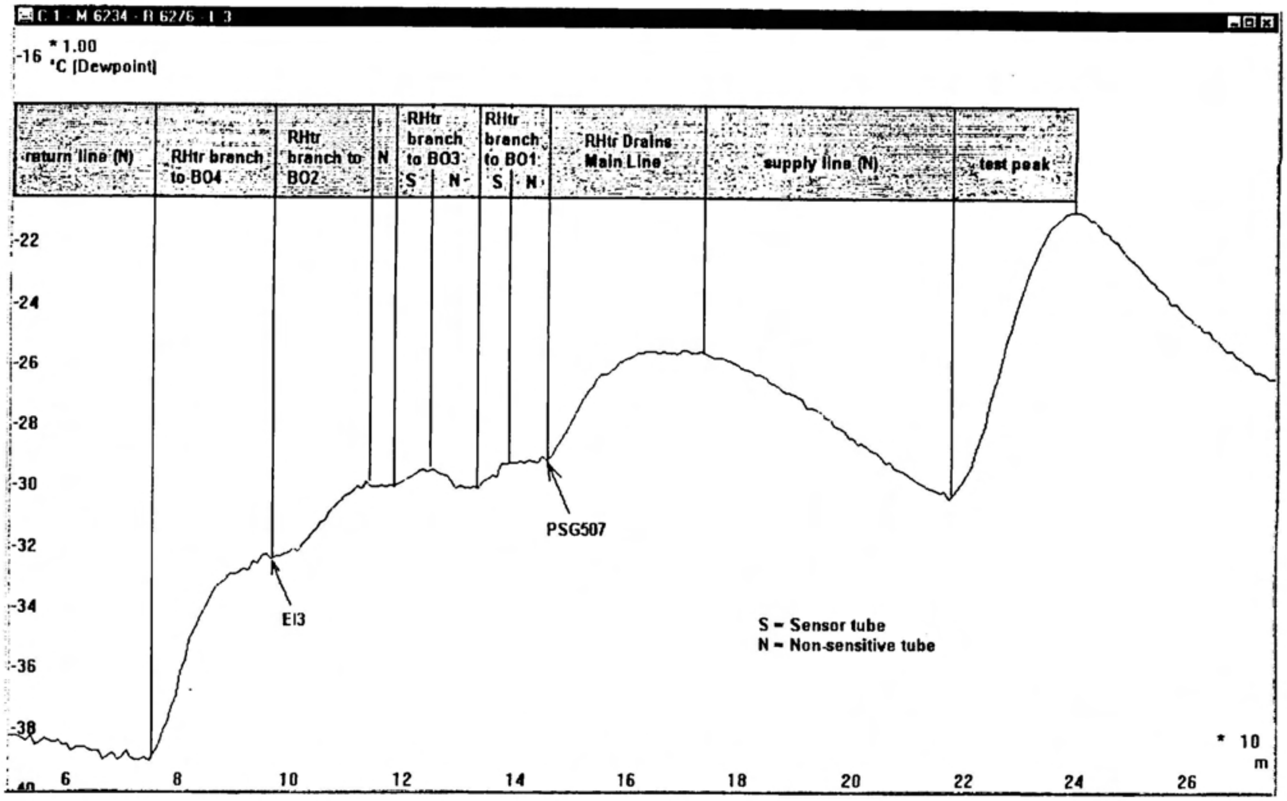

Fig. 8 Typical background humidity profile with locations of individual sensitive zones shown (PLGS, Monitoring Line 3, i.e. Reheater Drain Pipes)

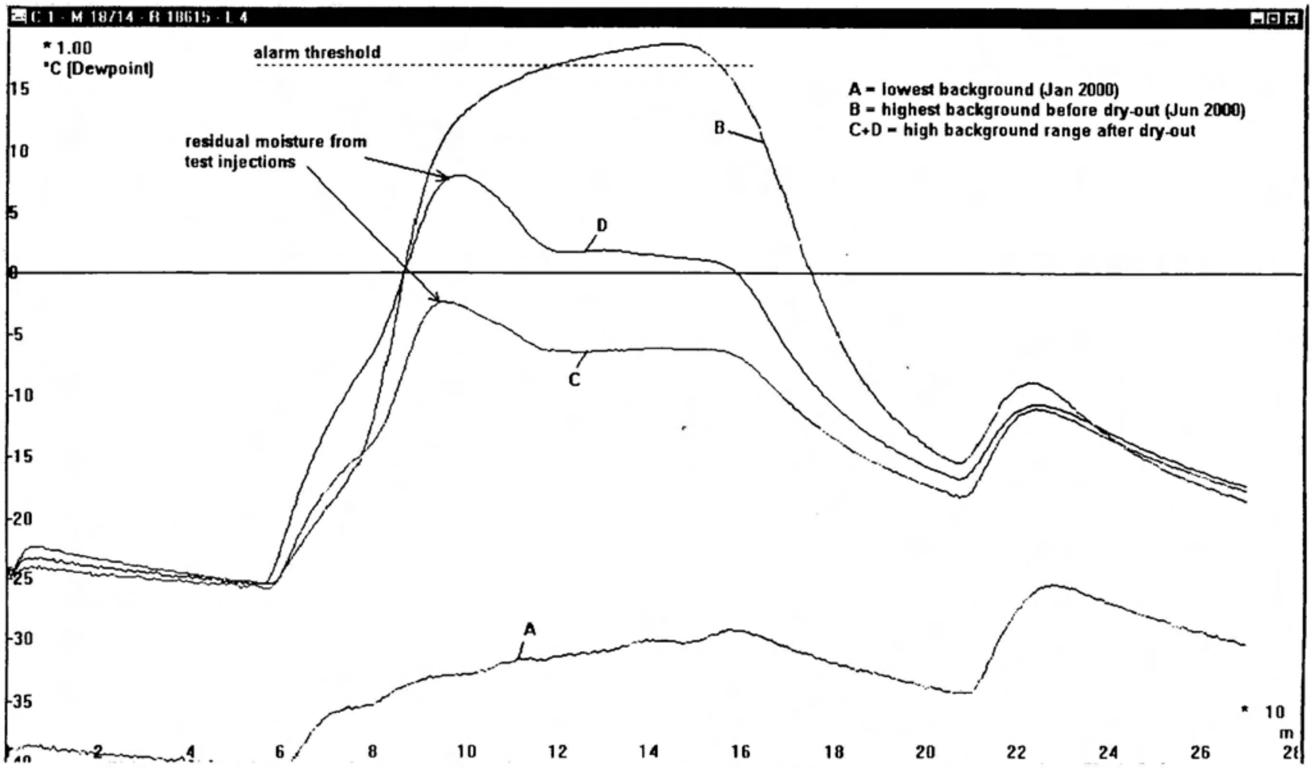

Fig. 9 Fluctuation range of background humidity profiles against FLÜS tube location (PLGS, Monitoring Line 4, i.e. Main Steam Pipes 1 & 3)

In the PLGS system, however, the background humidity levels still change significantly (see **Fig. 11**) depending on the cladding temperature (which is a function of ambient temperature and wind speed)!

With the actual settings, any of the situations as described leads to humidity levels still below the alarm thresholds (see **Fig. 9** and **Fig. 10**). Therefore, both systems did not issue a false leak alarm since they are in-service.

Leak Detection Properties

In both plants, a series of test injection experiments were performed during normal plant operation in order to verify the system performance. Injections of water (PLGS) and steam (G2), respectively, of various injection rates were done through the test injection tubes. The results were evaluated with respect to:

- Detection sensitivity
- Response time
- Locating accuracy

<u>Detection sensitivity:</u>

Fig. 10 shows a representative curve from injection of 0.5 kg/h (curve C, simulating rain) and 2.5 kg/h (curve D, simulating a minimum leak) at G2. It is obvious, that the "rain" indication stays within the range of normal background fluctuation, because of the already described properties of the foam glass insulation (note the alarm threshold set to +10°C dewpoint).

The reaction of the PLGS system is similar, but even more sensitive because of the much more closed vapor space and the absorption properties of the insulation. Therefore, the alarm thresholds at PLGS had to be set up to +17°C, which is already very close to the upper signal limit of +20°C.

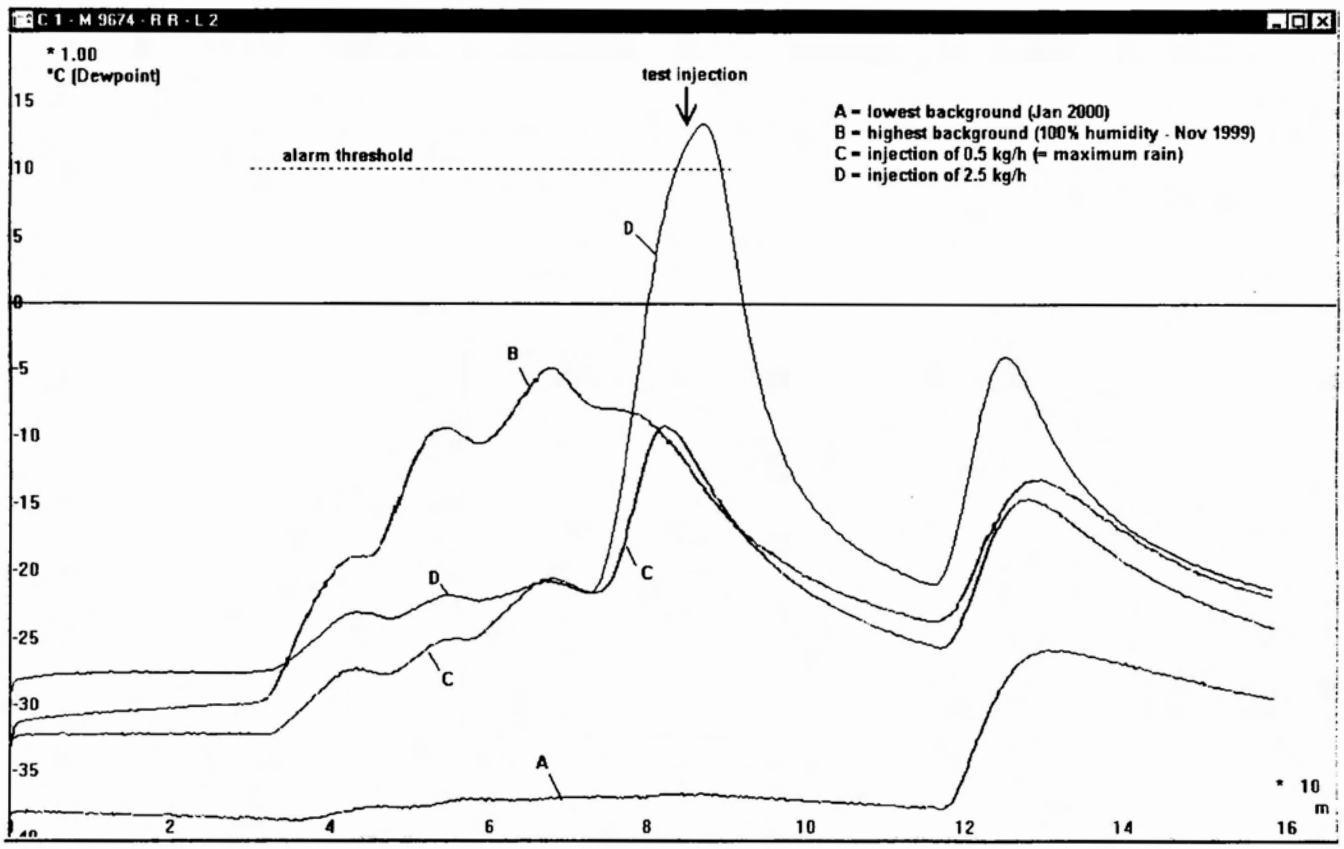

Fig. 10 Fluctuation range of background humidity profiles (A & B) as well as indications from rain simulation (C) and leak simulation (D) (G2, Monitoring Line 2, i.e. Main Steam Pipe 4)

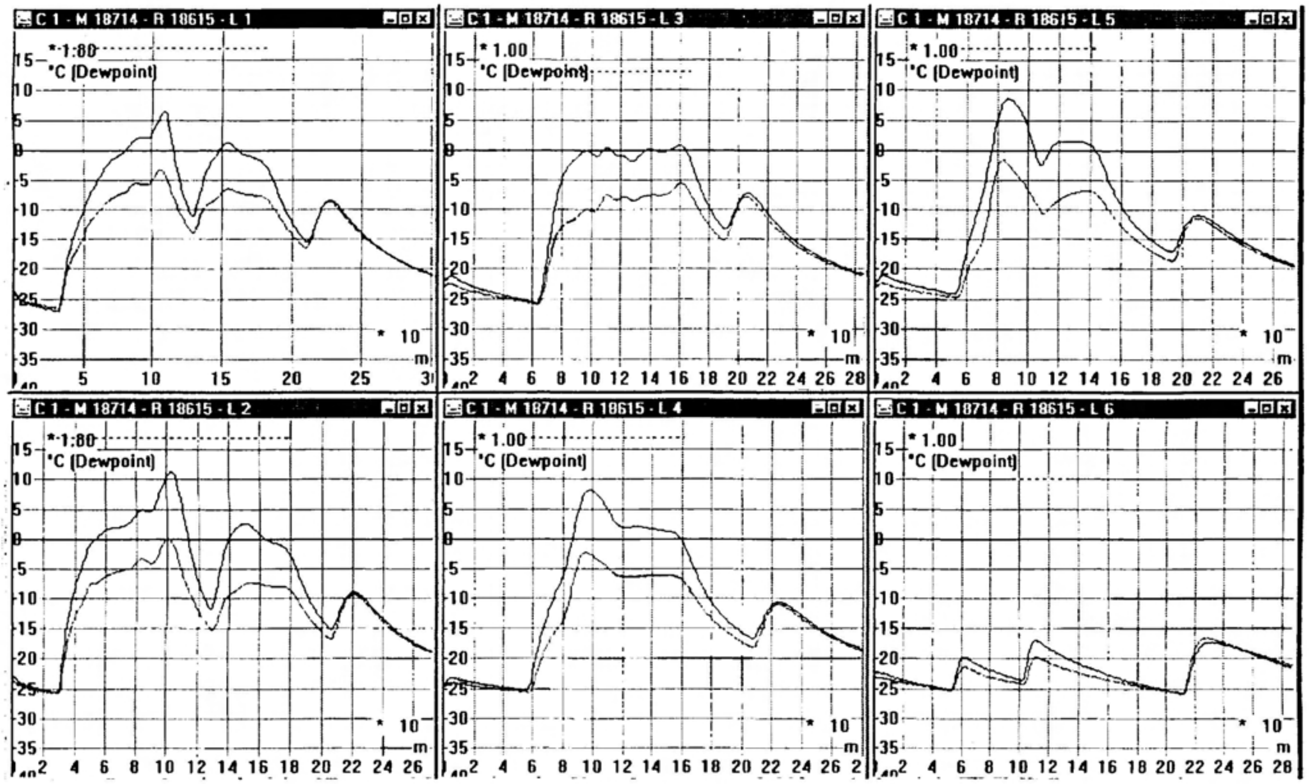

Fig. 11 Typical range of background humidity profiles in summer after dry-out (PLGS, all 6 Monitoring Lines, still with residual indications from test injections!)

Response time:

The typical response time for both systems between onset of a detectable minimum leak and leak alarm by FLÜS is in the range of 40-90 minutes. Only on the Main Steam Header, detection of 2.5 kg/h may last up to 4 hours if the leak is located opposite to the Sensor Tube (i.e: propagation of steam around the large pipe circumference).

If a shorter response time were required on the Main Steam Header as well, it could be easily achieved by replacing the non-sensitive return tubes on the Header by FLÜS Sensor Tube running on the opposite side.

Locating accuracy:

The leak location has to be taken from the deflection point of the rising flank (quasi-integrated signal) instead of the humidity peak. It was found that manual analysis comparing the first humidity curve after leak onset to the last curve without leak still gives the best locating results. Additional improvement can be achieved by measuring the relative distance of the leak peak to the closest known background detail (e.g. the start point of the affected sensitive zone - see **Fig. 8**).

This leads to a manually achievable locating accuracy of ±1.5 ... 2 m for both systems.

System Maintenance

The centralized electronic equipment (i.e. one common humidity sensor for all Sensor Tubes), combined with the robust in-field components (stainless steel tubes) ensure an almost maintenance-free operation of the FLÜS system regardless of the total amount of Sensor Tubing connected. In case of a hardware failure, the system design allows for quick module replacement from the spare part pool – partly even with the system staying in-service.

Although the FLÜS operating experience at G2 and PLGS is still comparably low, the total scope for preventive and routine maintenance can be estimated to 40 man-hours per year and is focussed on:

- Re-filling a water container in the Calibration Module (moisture for test peak generation)
- Maintaining the computer
- Re-calibrating the humidity sensor

All FLÜS tubes can easily be moved away from the pipe surface or temporarily dismounted for any inspection and/or NDT activities at the affected pipes. After re-installation the integrity of the Monitoring Line can be assured by pressure and flow tests. Fig. 12 shows such a situation which occurred during the 2000 outage at PLGS: the steel straps are removed and the non-sensitive return tube is bent upward. This allows the FLÜS Monitoring Line to stay closed during pipe testing.

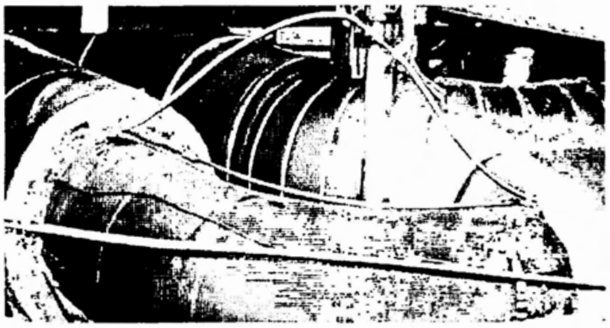

Fig. 12 Temporary displacement of FLÜS tubes (at 12 o'clock position of the pipe elbow) during Ultrasonic Testing

Installation References

Before installation at G2 and PLGS, the FLÜS system was already installed and operating successfully on the following Nuclear Power Plants:

- Obrigheim / Germany (1995): monitoring on the nozzle head of the reactor vessel
- Ringhals-1 / Sweden (1997): monitoring of the Main Coolant Pipes
- Mochovce-1&2 / Slovak Republic (1998/99): monitoring on the Primary Circuit components and pipes