Materials Reliability Program: Survey of On-Line PWR Primary Coolant Leak Detection Technologies (MRP-187)

1012947

WARNING: Please read the Export Control Agreement on the back cover.

Materials Reliability Program: Survey of On-Line PWR Primary Coolant Leak Detection Technologies (MRP-187)

1012947

Technical Update, November 2005

EPRI Project Manager

C. King

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

ORGANIZATION(S) THAT PREPARED THIS DOCUMENT

EPRI Solutions, Inc.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

ORDERING INFORMATION

Requests for copies of this report should be directed to EPRI Orders and Conferences, 1355 Willow Way, Suite 278, Concord, CA 94520. Toll-free number: 800.313.3774, press 2, or internally x5379; voice: 925.609.9169; fax: 925.609.1310.

CITATIONS

This document was prepared by

EPRI Solutions, Inc.
942 Corridor Park Blvd.
Knoxville, Tennessee 37932

Principal Investigator
S. Chu

This document describes research sponsored by the Electric Power Research Institute (EPRI).

This publication is a corporate document that should be cited in the literature in the following manner:

Materials Reliability Program: Survey of On-Line PWR Primary Coolant Leak Detection Technologies (MRP-187). EPRI, Palo Alto, CA: 2005. 1012947.

ABSTRACT

In recent years, the nuclear power industry has responded to several incidents involving Alloy 600 cracking and associated boric acid attack to the reactor pressure vessel components in Pressurized Water Reactor (PWR) plants. EPRI, through the Materials Reliability Project (MRP), is addressing issues related to ALLOY 600 Primary Water Stress Corrosion Cracking (PWSCC) and the potential resulting degradation of carbon steel components as a result of primary coolant leakage and subsequent boric acid attack. As part of this industry program, bare metal visual (BMV) and non-destructive examination (NDE) inspections of the vessel head area are being carried out during plant outages using a risk informed approach to define the extent and periodicity of such inspections.

Additional assurance that significant PWSCC and potential boric acid attack does not occur between outages (inspections) could be obtained by implementing a highly sensitive and reliable on-line leak detection system directed toward areas where Alloy 600 is found within the plant. Areas of key initial interest were the reactor vessel upper and lower head regions; this technical update represents an expansion to evaluate leak technologies for other areas in the plant where Alloy 600/82/182 materials are installed.

The purpose of this report is to document current and potential enhanced technologies for on-line detection of PWR primary coolant leakage. This information will allow utilities to objectively weigh the advantages and disadvantages of each technology. This report documents the current state of technology and current industry activities. Additional updates will be prepared as new technologies become available and or new industry activities in the area of primary coolant leak detection are initiated.

CONTENTS

1 **INTRODUCTION 1-1**

2 **CURRENT ON-LINE LEAK DETECTION TECHNOLOGIES 2-1**

Primary On-Line Leak Detection Methods 2-1
Containment Air Particulate Activity Monitors 2-1
Containment Noble Gas Activity Monitors 2-1
Containment Sump Level and Rate 2-1
Containment Air Cooler Condensate Flow Monitors 2-1
Other On-Line Leak Detection Methods Currently in Use 2-2
Reactor Coolant System Liquid Inventory Accounting 2-2
Containment Humidity Monitors 2-2
Containment Air Cooler Thermal Performance 2-2
Visual Inspection (walkdowns) 2-2

3 **POTENTIAL ENHANCED ON-LINE LEAK DETECTION METHODS 3-1**

Local Radiation Detection 3-1
N13-F18 Detection 3-1
Local Particle Detectors 3-3
Local Moisture Detection 3-4
FLÜS Humidity Monitor 3-4
Plant Experience at Davis Besse 3-7
Installation and Qualification 3-7
Maintenance 3-8
Alarming 3-8
In-Situ Sensitivity Testing 3-8
Fiber Optic Laser Light Absorption 3-9
Local Acoustic Emission 3-10
Metal Borne Noise Triangulation 3-10
Acoustic Emission Monitors 3-11
Physical Acoustics Corporation 3-12
Acoustic Emission Consulting, Inc. 3-13
Matrix Inspection & Engineering, Inc 3-14
Margan 3-15
Watts Bar Unit 1 Nuclear Experience 3-19
Local Boron Detection 3-20
Prompt Gamma Neutron Analysis 3-20
Monitoring Boron Concentration in Containment Air Cooler Condensate 3-20
Remotely Operated Cameras/Videoscopes 3-21
Key Features and Benefits 3-22

Key Features and Benefits 3-26
Radiation Tolerant Videoscopes 3-28
Olympus Series 5 Videoscopes (IV6C5 / IV6C5X1) 3-28

LIST OF FIGURES

Figure 3-1 SPLR 201 Primary Coolant Leak Detection System 3-3
Figure 3-2 Section of a FLÜS Sensor Tube (flexible type) 3-4
Figure 3-3 FLÜS Monitoring Line 3-5
Figure 3-4 Typical FLÜS Test Loop and Schematic 3-6
Figure 3-5 Principle of FLÜS Operation 3-7
Figure 3-6 Laser Physics Dye Detector 3-10
Figure 3-7 Physical Acoustics Corporation Leak Detection Equipment 3-12
Figure 3-8 Hand Held Acoustic Emission Detector 3-14
Figure 3-9 AEC's 8-channel AET 5500 system 3-14
Figure 3-10 Quantitative Acoustic Emission Non Destructive Inspection Measurement Points 3-16
Figure 3-11 Measurement Point Components: Sensor (A), Preamplifier (B), and Waveguide (C) 3-17
Figure 3-12 Ellipses of Dispersion 3-17
Figure 3-13 Zones of Active Flaw Development 3-18
Figure 3-14 Typical Moisture-Sensitive Tape Installation 3-20
Figure 3-15 Inuktun Magnetic Crawler 3-21
Figure 3-16 Radiation Tolerant Color Camera 3-22
Figure 3-17 Radiation Tolerant Color Cameras-IST Corp Model RC991 3-23
Figure 3-18 Spectrum 60 PT 3-24
Figure 3-19 VICTR Robotic Crawler (front view) 3-25
Figure 3-20 VICTR Robotic Crawler (side view) 3-25
Figure 3-21 PTZ140 and PTZ100 Pan-Tilt-Zoom camera 3-26
Figure 3-22 ROVVER 400, 600, and 900 Robotic Crawler 3-27
Figure 3-23 Oylmpus Ultra-long Videoscope 3-28

1

INTRODUCTION

In recent years, the nuclear power industry has responded to several incidents involving Alloy 600 cracking and associated boric acid attack to the reactor pressure vessel components in Pressurized Water Reactor (PWR) plants. EPRI, through the Materials Reliability Project (MRP), is addressing issues related to ALLOY 600 Primary Water Stress Corrosion Cracking (PWSCC) and the potential resulting degradation of carbon steel components as a result of primary coolant leakage and subsequent boric acid attack. As part of this industry program, inspection guidelines are being developed that determine the bare metal visual (BMV) and non-destructive examination (NDE) inspections necessary and the extent and periodicity of such inspections.

Additional assurance that significant PWSCC and potential boric acid attack does not occur between outages (inspections) could be obtained by implementing a highly sensitive and reliable on-line leak detection system directed toward areas where Alloy 600 is found within the plant. Areas of key initial interest were the reactor vessel upper and lower head regions; this technical update represents an expansion to evaluate leak technologies for other areas in the plant where Alloy 600/82/182 materials are installed.

In general, on-line methods currently in use for detecting leakage of PWR primary coolant do not have the capability to detect the very small leakage rates (<0.01 GPM) that can, without early detection, result in significant boric acid corrosion damage to low alloy carbon steel components. Typically, the effects of very small leaks of primary coolant are detected by visual inspection during outages by looking for white boric acid crystal deposits. This method is most useful for components that are located in open areas offering easy access for inspection. However, inspection can be difficult, as is the case of the vessel upper and lower head areas due to the high radiation environment, the presence of multiple penetration nozzles obscuring the view and minimal clearance between the vessel and insulation. The purpose of this report is to document current and potential enhanced technologies for detection of PWR primary coolant leakage. This information will allow utilities to objectively weigh the advantages and disadvantages of each technology and will form the basis for assessing additional research needs.

2
CURRENT ON-LINE LEAK DETECTION TECHNOLOGIES

Primary On-Line Leak Detection Methods

Containment Air Particulate Activity Monitors

All PWRs now have containment air particulate activity monitors to detect general leakage into the containment volume. The sensitivity of these monitors is a function of the containment volume, coolant activity level, and background activity level. Assuming nominal corrosion product activity and no failed fuel, a primary coolant leak of 1 GPM (3.8 L/min) can be detected in about 10 minutes using air particulate monitors. As these systems monitor the entire containment volume they are unable to provide leak location information.

Containment Noble Gas Activity Monitors

All PWRs now have containment air noble gas activity monitors to detect general leakage into the containment volume. As with particulate activity monitors, their sensitivity is a function of the containment volume, coolant activity level, and background activity level. Assuming nominal corrosion product activity and no failed fuel, a primary coolant leak of 1 GPM (3.8 L/min) can be detected in about 80 minutes using noble gas activity monitors. As these systems monitor the entire containment volume they are unable to provide leak location information.

Containment Sump Level and Rate

Sump level is monitored to determine total leakage from all containment systems including the RCS, service water system, component cooling system, steam lines, feedwater lines and condensation from the humidity in the containment atmosphere. A typical sump detector can detect changes of about 7.5 GPM (28 L). Accordingly, a 1 GPM (3.8 L) leak would be detectable in less than 10 minutes. However, this approach does not differentiate between RCS and leaks from other systems.

Containment Air Cooler Condensate Flow Monitors

The containment air coolers typically circulate the entire PWR containment through the coolers every 5 minutes. As humid air is circulated through the coolers some of the moisture is condensed on the cooling coils. PWRs typically are equipped with a system for monitoring cooler condensate that consist of a drain system, vertical stand pipe, and standpipe differential pressure sensors. These systems are used to detect changes in the amount of moisture in the containment air that could be the result of leakage from the RCS and/or other containment systems. It is reported that such systems can detect a leak of 1 GPM (3.8 L/min) within approximately 1 hour. As with sump level monitoring, this approach does not differentiate between RCS and other potential leak sources and as a result is of limited value in identifying RCS leaks.

Other On-Line Leak Detection Methods Currently in Use

Reactor Coolant System Liquid Inventory Accounting

During steady state operation, changes in the liquid inventory of the RCS, considering makeup water added to the system, known leakage and any change in pressurizer level can be used to estimate unidentified leakage. Due to the large RCS volume and instrument inaccuracies, this approach is not as sensitive as others. It is reported that a 1 GPM (3.8 L/min) leak is detectable in about 6 hours using this approach. Again, this approach does not provide leak location.

Containment Humidity Monitors

Global containment relative humidity can be monitored to detect changes in containment air moisture that may be related to RCS or other leakage. Such measurements can also be affected by changes in moisture that are not due to leaks (varying amounts of condensation with the containment in general, changes in containment cooler performance, changes in inlet air temperature and moisture content, etc). As such, measurements can include leaks from systems other than the RCS, and even from sources other than leaks, they are of limited value in detecting and localizing primary coolant leaks. **Note:** The FLÜS system is designed to detect localized leakage in the RPV vessel head region. This system detects small local changes in humidity and is discussed in detail in Section 3.

Containment Air Cooler Thermal Performance

Boric acid is soluble in steam and can be transported within the containment by the containment cooler fans. As condensate forms, boric acid can be deposited on the cooling coils of the coolers and degrade their thermal performance. Conoseal leakage was discovered at one plant be this means, however, a RCS leak would have to exist for a significant period of time (or be very large) to produce sufficient boric acid deposition to be detectable using this method. **Note**: Monitoring the boric acid content of containment cooler condensate may be a more sensitive method as is discussed further in Section 3.

Visual Inspection (walkdowns)

Visual inspection in containment during operation can be made and can be effective in detecting leaks and boric acid crystal accumulations in accessible areas. However, the areas above and below the reactor pressure vessel are not accessible during plant operation. Also, pipes with Alloy 82/182 may be covered with insulation that would prevent detection of low levels of leakage with the insulation installed. Accordingly, walkdowns are of limited value for on-line detection of RCS leaks in these areas.

3
POTENTIAL ENHANCED ON-LINE LEAK DETECTION METHODS

Local Radiation Detection

N13-F18 Detection

In the early 1990s a RPV Head penetration leak was discovered at the Bugey plant in France. Cracking in the Alloy 600 control rod drive (CRD) guide tube caused the leak. The regulator in France eventually mandated that all RPV heads be replaced with heads incorporating Alloy 690 CRD guide tubes that had been shown to be less susceptible to PWSCC. The French Regulator also mandated that until new heads could be installed, EdF be obliged to install systems for on-line detection of RPV head leakage.

EdF teamed with MGP Instruments Inc. to develop a system for detecting the photons (gamma) emitted by gaseous Nitrogen 13 and Fluorine 18. N13 and F18 are present in the primary coolant and would be released in gaseous form at the site of a primary coolant leak. N13 has a half-life of 10 minutes and F18 a half-life of 110 minutes. These half-lives are short enough to minimize the build up of N13 or F18 in the containment but are long enough to allow time for transport of the sample from the leak location to be detected at the sensing unit.

The detector is very sensitive. It is reported to be able to detect a leak in containment as low as 0.13 Gal/min if taking suction from the entire containment volume. This sensitivity would be greatly improved if it where taking suction from a small volume in the area of interest (i.e. from within the shroud area above the head and below the insulation.

Since its original application in the EdF plants, the system has been updated with improved alarming and display capabilities. The current system (MGP Instruments SPLR 201) is comprised of the following components:

- A NaI(TI) Detector shielded in a 9 liter lead vessel
- A local processing unit (LPU) located on the system skid that processes the signal from the detector, generates the measurement, manages alarm status and provides data links for a computer or a display unit.
- A local display Unit (LDU)
- A pump for drawing the sample from the area of interest
- A pump control panel
- A filter and pressure gage placed in the sample inlet
- A flowmeter and regulation valve
- Inlet and outlet isolation valves for maintenance
- A remote display unit (RDU) for remote monitoring

The system is mounted on a skid as shown in Figure 3-1. Because of the shielding requirements, the skid is quite heavy (over 2000 lbs). The skid measures 60 inches high by 52 inches wide by 27.5 inches deep. The unit has undergone extensive testing to demonstrate its resistance to electromagnetic disturbances, ionizing radiation, vibration and fire. In the EdF application, the skid was mounted in containment but this need not be the case if the samples can be fed through containment penetrations. If the skid is mounted inside containment, the signal can be sent outside containment via telephone line (modem) or hardwired. The system can be set up with a multiplexing valve to take suction from several areas sequentially.

In the EdF application, the system took suction only from the flow past the region above the insulation above the head. In considering potential US application this becomes important for the following reasons:

1. The maximum allowable detector temperature is only +40 to +60 C. This approach was acceptable in the EdF application in as suction was taken from relatively cool air (above the insulation). However, if US plants want to take suction closer to potential leak locations (below the insulation) they will need to cool the sample from 500-600 F to less than 40-60 C.
2. Sampling above the insulation may not provide sufficient sensitivity to detect very small leaks in the head region since the sensor is taking suction from a high flow area pulling in large volumes of containment air.

In addition, new applications should consider taking a “control” sample from the open containment volume to differentiate the local signal from background.

The system was used extensively in the early 1990’s at EdF plants. As the heads were replaced the monitors were removed. Apparently, these systems are currently no longer in use in EdF plants.

Contacts:

Mr. Mike Edelman
MGP Instruments
Atlanta, GA
Phone: 770-432-2744 x132
E-mail: medelman@mgpi.com

Mr. François Champigny
EdF
Phone: 00-1-43-69-33-89
E-mail: francios.champigny@edf.fr

Figure 3-1
SPLR 201 Primary Coolant Leak Detection System

Local Particle Detectors

Containment air particulate activity monitors are now in use to detect overall containment activity levels. These detectors can also be used to monitor specific areas of interest (e.g.. above the head and below the insulation) by taking suction directly from these areas and comparing the activity level to the background level in the containment. In such applications their sensitivity is greatly improved. Florida Power and Light has used such a system for local monitoring of the head region its Turkey Point and St. Lucie plants since 1994. The system takes suction from the head area both below and above the insulation and compares the readings to one taken on the operating deck (bulk containment reading).

The system used by FP&L uses a Victoreen 943 Radiation Detector that includes a filter/sampler and a bellows pump. The detector itself is a Beta scintillation detector model 843-25 and uses lead shielding to stop gamma rays.

The units operated continuously from 1994 to 1999 but where switched to intermittent operation due to high rates of filter clogging. The units now operate one 24-hour period every 2 weeks.

During periods of operation, the unit switches from the local to bulk and back to local every 5 hours.

The system is reported to have good sensitivity and can detect leaks as small as 0.01 GPM.

Since installation, no head leaks have been detected using the system. Some cases of elevated containment bulk activity have occurred, but in all cases the local and bulk readings tracked together.

Contact:

Paul Banazak
Florida Power and Light
Phone: 305-246-6072

Local Moisture Detection

FLÜS Humidity Monitor

The following information was provided by Framatome ANP and describes a local humidity monitor (FLÜS) that can be used to detect and localize small primary coolant leaks.

FLÜS is a system that can be used in nuclear power plants to monitor for potential leakage in pressurized water or steam carrying components. It can be installed inside of the reactor containment and monitor conditions during plant operation. The FLÜS system was developed by Framatome ANP German Nuclear Services Instrumentation and Diagnostics Group. FLÜS is a German acronym for the trade name: Feuchtigkeit Leckage Uberwachungs System, meaning humidity-leakage monitoring system.

FLÜS is a humidity monitoring system that can be used to detect small leaks in components. In the event that a leak occurs and develops, FLÜS provides early detection of the leak and will allow monitoring the leak progression even during normal operation of the plant. A particularly important feature of the FLÜS system is its high detection sensitivity and its ability to locate the position of leaks within a few meters.

The FLÜS system by FANP operates on the principle of humidity detection. The system is an area leak detector, which can over time detect changes in the environment resulting from leaking water or steam.

The key to the FLÜS system is the "**Sensor Tube**" that can be installed in close proximity to pressurized water/steam containing components that are suspect to leakage. This sensor tube (see Figure 3-2) has porous sintered metal elements, typically located at one-foot intervals, and is resistant to both high temperature and high radiation levels.

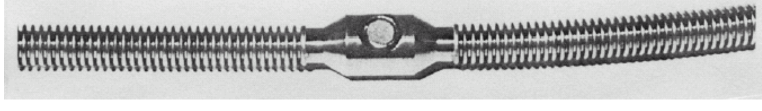

Figure 3-2
Section of a FLÜS Sensor Tube (flexible type)

A number of **Sensor Tube** sections are joined end-to-end to form a "sensitive section" which is connected within a closed loop "monitoring line" (see Figure 3-3) initially filled with dry air. An existing differential in the water vapor concentration causes the moisture outside of the sensor tube to diffuse through the porous elements and into the dry air inside the sensitive section, thus forming a "humidity image" (humidity profile) of the air around the sensor tube

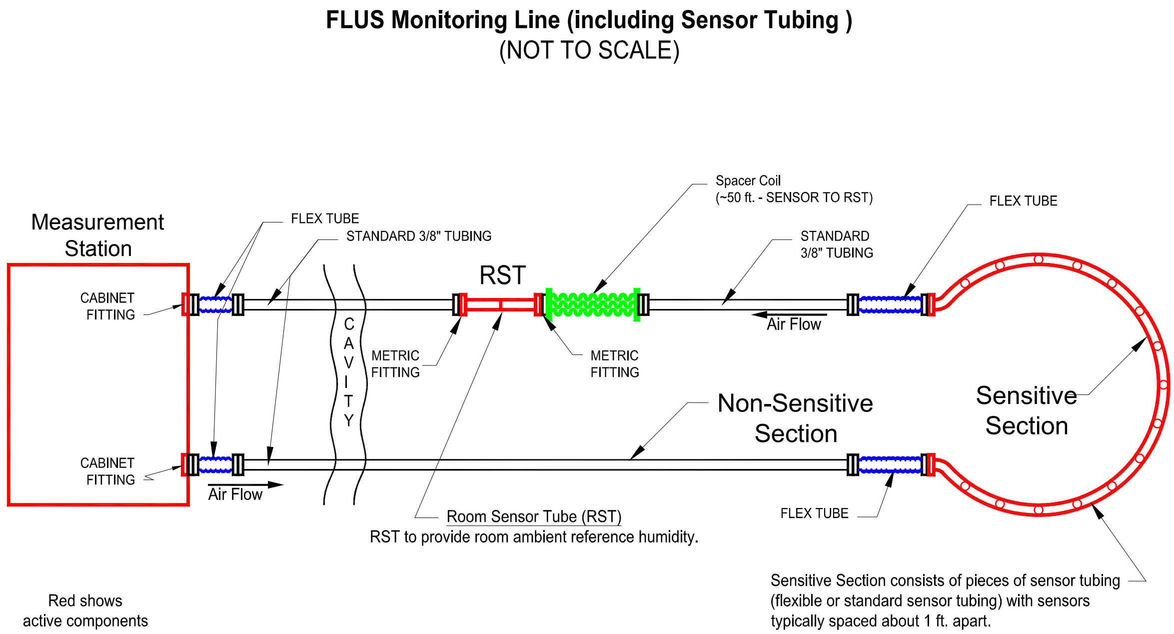

Figure 3-3
FLÜS Monitoring Line

The ends of the "sensitive section" are routed back to the FLÜS Measurement Station (see Figure 3-4) using normal stainless steel ("non-sensitive section") tubing. The sensors are allowed to "soak" for a defined time (15 min to 1 hr) and then during the measurement cycle the monitoring line is purged and the moist air (if moisture is present) is pumped through the humidity detector for measurement.

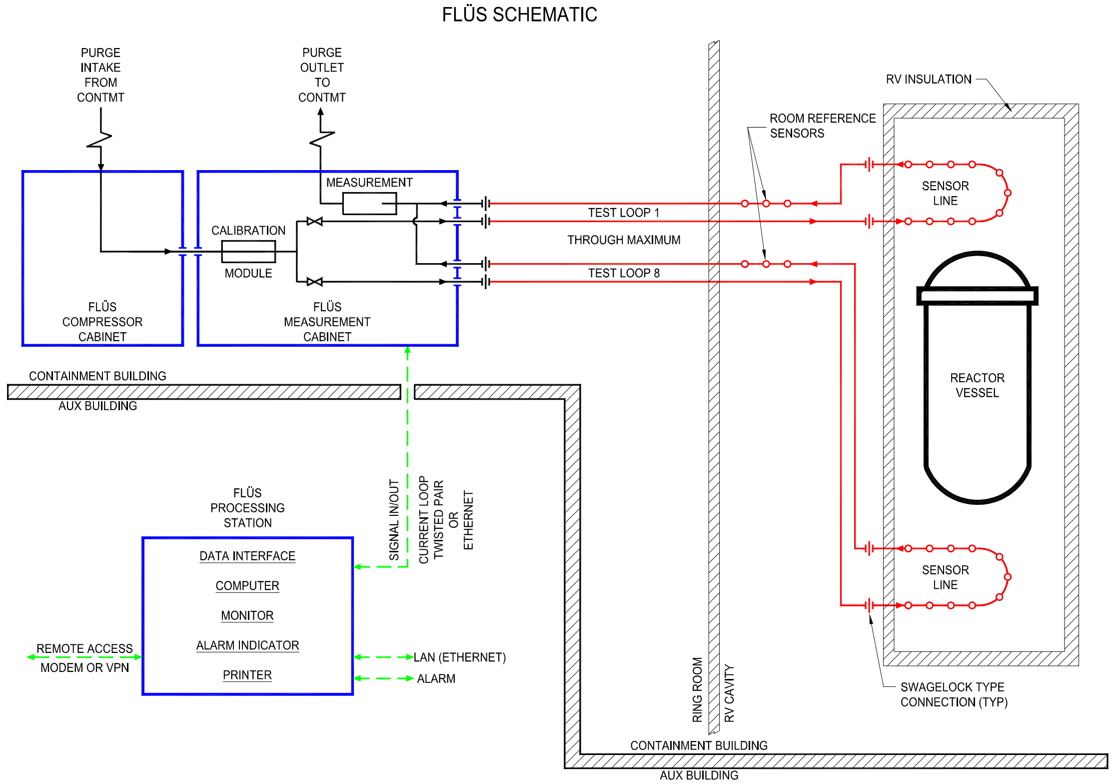

Figure 3-4
Typical FLÜS Test Loop and Schematic

The monitoring line includes a room-sensor-tube (RST) that measures the reference ambient conditions ("background") of a location sharing the same air space but not susceptible to leaks. Also, with every measurement cycle, a calibration module injects a precise amount of moisture into the end of the air stream, which shows up as a clear peak ("test peak") at the end of the humidity measurement trace. This allows the system to normalize the location (time) axis to the correct scale to allow the correlation of data-time to measurement loop distance (see Figure 3-5). The comparison of the monitored "peaks" from the reference RST and the "test peak" allow discrimination of potential leaks in the sensitive region being monitored.

The repeatability of this process, the comparison of the reference RST and "test peak" to the sensor area indication, allows for internal diagnostics to automatically detect system problems as well as account for changes in the "background" resulting from seasonal and operational changes in ambient. Analysis of the data can prevent any false indication of leaks or spurious alarms.

FLÜS is designed to allow all sensitive tubing and measurement components to be located inside of reactor containment and communicate with a data processing station outside via network link or current loops. The data and alarms can be maintained locally or made available on the plant LAN. The user interface includes real-time and historical access to data and is presented in a windows environment running on NT or WIN 2000.

Typical system characteristics are (at insulated components installations):

- Detection sensitivity: 0.005 to 0.05 gpm; 1 to 10 kg/h
- Locating accuracy: 2 - 4 m
- Response time: twice the cycle time selected
- Cycle time: 15 minutes (repetition period) to 1 hr
- Air flow velocity: 1 - 1.5 m/s (equal to approx. 2.5 liters/minute)
- Air input pressure: 3 - 7 psi gauge
- Maximum length of sense Line: 1000 ft
- Temperature of sensor tube ≤ 750 deg F; 400 °C

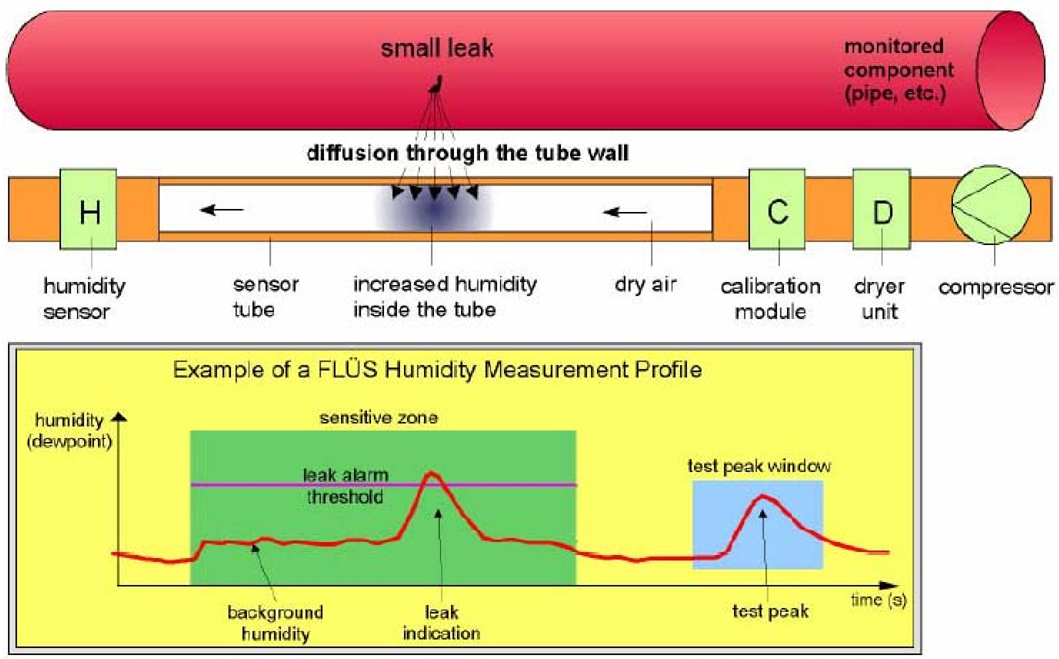

Figure 3-5
Principle of FLÜS Operation

The FLÜS system is currently in operation at 12 nuclear plants worldwide. The first US installation is at the Davis-Besse plant. The initial installation is monitoring the lower head area. Plans call for the expansion of the system to monitor the upper head area (below the insulation) and potentially the pressurizer nozzle region.

Plant Experience at Davis Besse

Installation and Qualification

The main engineering effort for installation was qualification for potential interactions with other systems (components, paint in containment, seismic mounting, etc.) The software testing is performed by the vendor. For system installation, a site acceptance test was prepared which primarily served to verify the software worked in the plant environment and gave the expected system outputs. Site installation was performed by the plant, although the vendor does offer this service. The primary groups involved in the installation effort were pipe fitters and electricians. The installation of the tubing and routing electrical and instrumentation are the main time consuming elements.

Maintenance

The system reportedly requires minimal day to day effort. The system automatically takes hourly measurement and sends out a computer generated message after each reading, the values are reviewed daily and trended monthly to ensure the measurements are normal.

The system is relatively maintenance free. System parameters are adjusted occasionally for seasonal changes. The primary maintenance activity is to replace the humidity sensor and refill water.

The vendor specified calibration frequency is yearly, however, Davis Besse is exploring a justification to change this to be performed at every outage since it requires a containment entry at power to replace the sensor.

There are also additional functionality tests that are performed periodically from the computer.

Many of the spare parts are available commercially, and the vendor does offer a spare parts package.

Alarming

The system alarm is set at 0.01 gpm for under vessel leakage. Through trending, leaks of 0.005 gpm could likely be detected.

The plant experiences periodic false alarms during Containment Air Cooler testing. Typically this will clear during the next measurement and it's easy to determine the cause of the false alarm.

In-Situ Sensitivity Testing

The as-installed sensitivity of the system was tested by Davis-Besse in November 2003. At normal operating power, steam was injected at a known leakage rate into the area below the vessel and above the insulation to determine the minimum leak rate that can be detected in this specific configuration. The FLÜS sensing line was also located in this region. Preliminary results show excellent sensitivity allowing detection of leak rates as low as 0.004-0.005 GPM.

Contacts:

Richard (Dick) Schemmel
Framatome ANP
Lynchburg, VA
Phone: 434-832-2913
E-mail: Richard.Schemmel@framatome-anp.com

Steven Brouwers
Davis-Besse Nuclear Station
Phone: 419-321-7511
E-mail: brouwers@firstenergycorp.com

Fiber Optic Laser Light Absorption

Fiber optic systems are available today that will detect gaseous substances including water vapor. The systems operate by emitting a laser light at the "absorption" wavelength of the desired substance. By placing a fiber optic in the area of interest and another in the open containment to obtain a background water vapor concentration, the system can compare the moisture content of the air at each location to detect local leakage. Use of fiber optics has the advantage of eliminating the need for locating sensitive electronic equipment in a high radiation area. Existing systems could provide an indication of leakage in the general area of interest but would not pinpoint the leak location. Innovative placement of mirrors or perhaps a scanning system could be incorporated to allow improved leak location capability.

Fiber optic cable can "brown" under exposure to high levels of radiation. This effect would need to be investigated prior to implementation.

The sensitivity of such a system would depend on many factors including the general humidity level and the geometry and distances involved. . A mock-up of such a system could be set-up and the sensitivity established for a prototypic geometry and range of leak rates.

An example of a system that could be modified to detect water vapor is shown in Figure 3-6. This system is manufactured by Laser Physics LTD and is used to detect various dyes that are added to fluids or gases to "mark" transitions. For example such a system has been used to mark the transition from one type of oil to another as it speeds along hundreds of miles of pipeline. The same principles used in this application can be applied to the detection of changes in water vapor concentration.

Figure 3-6
Laser Physics Dye Detector

Contact:

Mr. David Infante
Laser Physics LTD
Phone: 706-693-4168
E-mail: laserphysics@altel.net

Local Acoustic Emission

Metal Borne Noise Triangulation

Framatome ANP- also offers an acoustic system for detecting and locating leaks. The system is called ALUS. The system measures metal borne acoustic emission from several sensors located around the area of interest. By measuring the relative magnitude of the signals the system can then triangulate to obtain an estimated location of the leak.

This system is primarily for detection of leaks in a shutdown condition. During plant operation the system leak detection sensitivity is approximately 1 GPM near the reactor vessel due to high background acoustic emission at power.

Acoustic Emission Monitors

Acoustic Emission (AE) instruments and noise detectors are non-destructive testing (NDT) equipment for monitoring conditions and detecting changes in mechanical, electrical and process systems. In mechanical systems, flaws provide specific acoustic or vibration responses. For example, if a break, deformation or other failure occurs, acoustic emission sensors can detect the burst of high frequency caused by the event. Noise detectors are used to detect leaks or changes in process components such as steam traps, pipes, valves, and pressure vessels.

AE is the class of phenomena whereby an elastic wave, in the range of ultrasound usually between 20 KHz and 1 MHz, is generated by the rapid release of energy from the source within a material. The elastic wave propagates through the solid to the surface, where it can be recorded by one or more sensors. The sensor is a transducer that converts the mechanical wave into an electrical signal. In this way information about the existence and location of possible sources is obtained. The basis for quantitative methods is a localization technique to extract the source coordinates of the AE events as accurately as possible. AE differs from ultrasonic testing, which actively probes the structure; acoustic emission listens for emissions from active defects and is very sensitive to defect activity when a structure is loaded beyond its service load in a proof test. AE analysis is a useful method for the investigation of local damage in materials. One of the advantages compared to other NDE techniques is the possibility to observe damage processes during the entire load history without any disturbance to the specimen.

The disadvantage of AE is that commercial AE systems can only estimate qualitatively how much damage is in the material and approximately how long the components will last. So, other NDE methods are still needed to do more thorough examinations and provide quantitative results. Moreover, service environments are generally very noisy, and the AE signals are usually very weak. Thus, signal discrimination and noise reduction are very difficult, yet extremely important for successful AE applications. Many different tests have concluded that this difficulty can be overcome in the reactor coolant system environment.

AE instrumentation typically consists of:

- Sensor that converts a stress (sound) wave to an electrical signal
- Low noise amplifier that raises the signal to a usable level
- Signal processing electronics for feature extraction and waveform capture
- Microprocessor and processing instrumentation
- Knowledge-based software for analysis, defect correlation and development of expert systems
- Decision and feedback electronics to utilize the information

How is AE used to monitor leaks?

An Acoustic Sensor mounted on the exterior surface of a structural component detects leak-associated sounds which are generated by the leak source and in turn transmitted through the structure. The leak detector amplifies the acoustical signal, filters it, and then displays it.

How do you locate the source?

The acoustic energy propagating from the lead source decreases in amplitude as a function of distance from the source, known as signal attenuation. Knowing the attenuation characteristics of the structure in question and detecting the leak noise at several locations allows the location of the leak to be known.

Equipment by several manufacturers is shown below:

Physical Acoustics Corporation

Physical Acoustics Corporation (PAC) has equipment to address leak detection. PAC leak detection instruments and systems are used in applications including the detection and location of both gaseous and liquid leaks in valves, vessels, pipelines and tanks.

Figure 3-7
Physical Acoustics Corporation Leak Detection Equipment

Portable Leak Detectors

PAC portable leak detectors offer ease of use for quick set up and simple operation. Visual and audio indicators alert the operator to changing conditions and indicators of leaks. Battery power allows mobility for access to areas requiring inspection.

Digital Leak Detector

Digital electronics enhance the performance of this instrument. Data storage locks in the visual and audio indicators of changing conditions and indications of leaks. Computer interface downloads stores readings for permanent record, archiving or further analysis. High sensitivity over a broadband of frequencies is used for diverse applications of leaks in a variety of structures.

Multi-channel Computerized Systems

Used for permanent monitoring of large structures and pipelines and for integration in control room systems, these computer-based systems utilize unique software for tracking long-term monitoring conditions, while simultaneously reflecting instantaneous results and alarm status.

Contact:

Physical Acoustics Corp.
195 Clarksville Road
Princeton Jct, NJ 08550
Phone: 609-716-4000
Fax: 609-716-0706
E-mail: sales@pacndt.com

Acoustic Emission Consulting, Inc.

Acoustic Emission Consulting, Inc. works in the fossil power industry assessing the structural integrity of high energy piping systems and has been involved with EPRI-sponsored R&D and development of EPRI Guidelines for seam-welded hot reheat piping. They have gathered a database of test results on over 100 piping systems. They are also involved in writing an ASTM standard for AE testing of high energy seam welded piping.

The vendor specializes in acoustic emission inspection services and testing, and acoustic emission instrumentation, sensors, and probes. The vendor's instrumentation is focused on portable hand held instrumentation. They provide a probe for leak detection.

The hand-held instrument meets the needs of a variety of field industrial applications. It is the first field instrument to combine threshold event detection for "burst-type" signals and RMS (signal level) processing for continuous emission sources.

Figure 3-8
Hand Held Acoustic Emission Detector

The vendor uses the 8-channel system for online monitoring of high energy piping systems.

Figure 3-9
AEC's 8-channel AET 5500 system

Matrix Inspection & Engineering, Inc

Matrix Inspection & Engineering, Inc. currently employs two types of digital AE systems. The first (DSP-4) is a four channel plug-in replacement card for the existing multi-channel "Spartan-AT" systems. The second (DISP) is a new system based on the PCI-DSP four channel processing board. The main difference between the two is that the PCI-DSP card uses the PCI data bus allowing greater throughput of data. Both variants are fully compatible with the widely used analog systems. This means that the data sets produced by the DSP/DISP boards are analyzed with well-established software and procedures.

Both types of board have a wide dynamic range and low noise characteristics. This, coupled with the "Smart Threshold" feature produces about 6dB (double) more sensitivity for tank bottom assessment work and does a much better job in optimizing sensitivity for on-line monitoring and cooldown testing than a human operator.

The vendor is participating in a four-year development program and has sponsored university research work to improve AE testing of process equipment. The goal is to precisely locate defects and determine fitness for service directly from the AE test data. This technology relies on determining the nature of an AE source from the wave properties. In this case the capabilities of the 'DISP' system are essential, in fact the new procedure and software is based exclusively on the 'DISP' system.

Contact:

Matrix Inspection and Engineering, Inc.
Phone: (713) 722-7177
Fax: (713) 722-7677
10607 Haddington Street
Suite 100
Houston, TX 77043

Margan

Margan developed the Quantitative Acoustic Emission (QAE) Non Destructive Inspection (NDI) technology. The QAE NDI technology is used for inspecting High Energy Piping (HEP) and other critical plant components for cracks and other types of flaws. QAE NDI is capable of inspecting the HEP during operation, locating flaws, identifying their type, quantitatively assessing their stress intensity (danger level), and monitoring the dynamics of their development. All this is done at less than 20% of the current NDI cost. The vendor completed the development and successfully applied it to a variety of structures and has been focusing on the inspection of HEP in fossil power stations.

Measurement points are typically spaced 15 ft from each other and in potential high stress zones. Each measurement point includes: sensor, preamplifier, and waveguide.

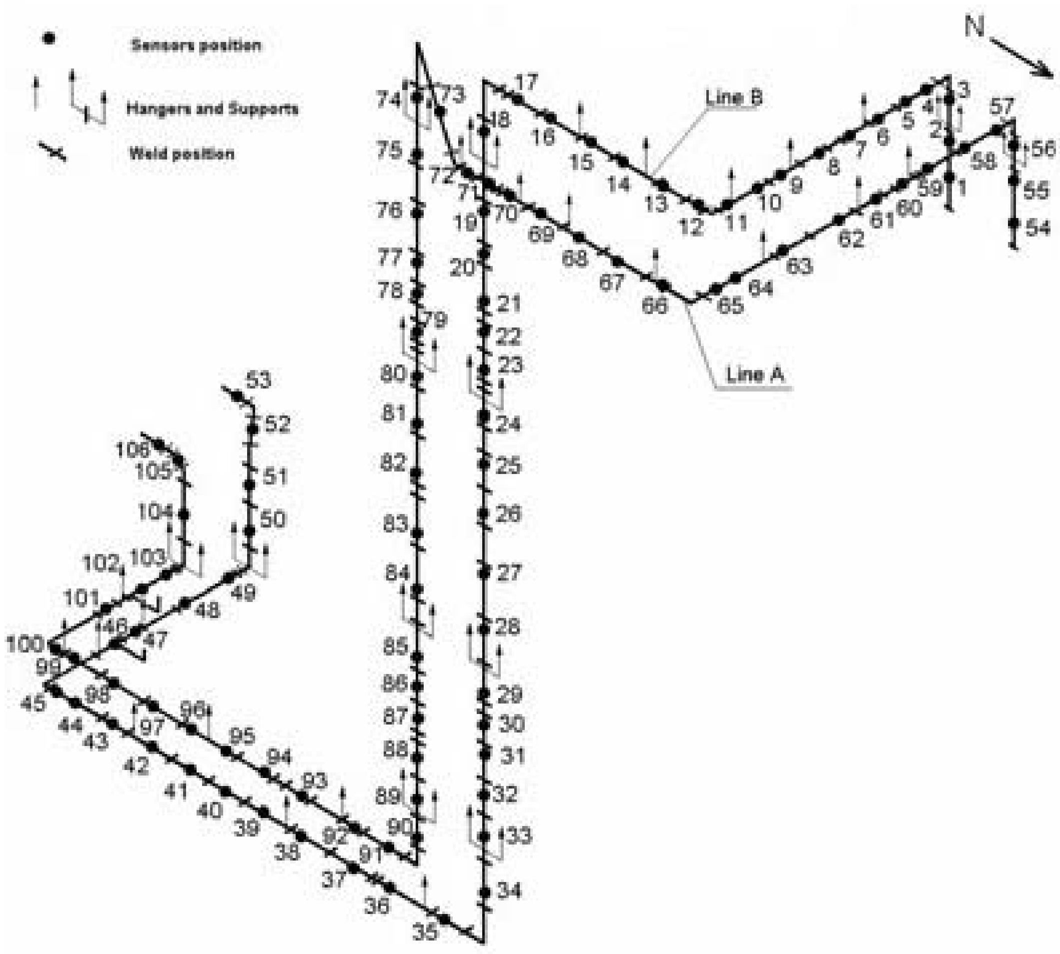

Figure 3-10
Quantitative Acoustic Emission Non Destructive Inspection Measurement Points

The waveguides are welded to the line by a stud welding gun. The sensor is installed at the waveguide tip. The preamplifier amplifies the signal, which is then transmitted to the data recording computer through coaxial cables. Installation of the entire system is done on running lines without scaffolds.

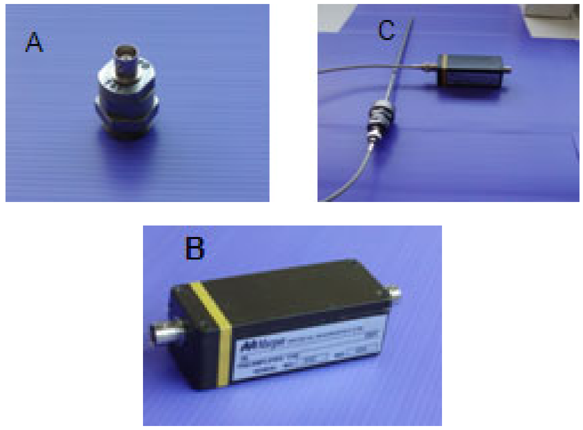

Figure 3-11
Measurement Point Components: Sensor (A), Preamplifier (B), and Waveguide (C)

The vendor developed a unique statistical approach to the AE signals analysis. This includes, among variety of statistical tools, the ellipse of dispersion, which is used for:

1. Creation of laboratory made flaw material and flaw stage specific AE finger prints.
2. Characterization and classification of different groups of AE Signals.
3. Characterization of the background noise.

Ellipses of dispersion are used in the analysis process for accurate separation and filtration of the background noise, friction noise and other non-related signals, already in the field. The remaining signals which are related to flaw-development (crack propagation, creep development, fracturing of hard inclusions, etc.) are analyzed to determine flaw-types and their danger level. This is done by comparing their ellipses (the solid ellipse in the example) to the lab-made AE "finger-prints" (the transparent ellipses).

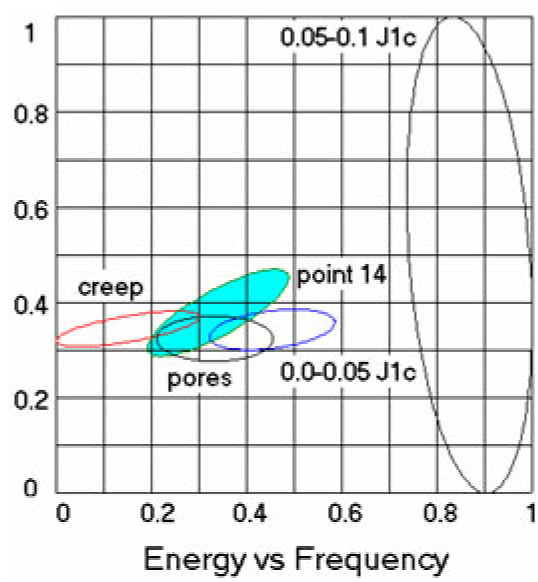

Figure 3-12
Ellipses of Dispersion

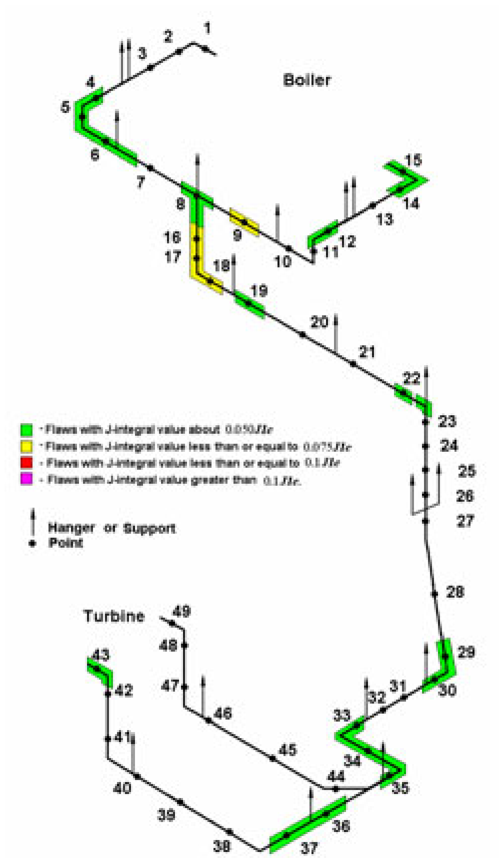

Figure 3-13
Zones of Active Flaw Development

The analysis process results and recommendations include:

1. Location of zones of active flaw development in the line (color coded).
2. Flaw 'type'.
3. Determination of their danger level in terms of fracture mechanics criteria (J-integral value).
4. Recommendations for further monitoring intervals.

Contact:

Margan, Inc.
PO Box 81467
Atlanta, GA 30366
Phone: (770) 936-5848
Website: http://www.margan.com/

Watts Bar Unit 1 Nuclear Experience

An acoustic emission (AE) testing program was conducted at the Tennessee Valley Authority (TVA) Watts Bar Nuclear Station during hot functional testing. AE continuous surveillance of reactor coolant pressure boundaries was used to detect flaw growth. The initial phase developed the technology in the laboratory to identify AE from crack growth and utilize the information in estimating flaw severity. Two subsequent phases evaluated and finalized the technology through testing on an intermediate scale test vessel and demonstration on the operating reactor. Three areas were instrumented:

- Reactor coolant inlet nozzle
- Loop No. 2 accumulator safety injection piping near the connection to the loop No. 2 cold leg
- Section of the reactor pressure vessel bounded at the top by the loop No. 2 inlet and outlet nozzles

The AE equipment used consisted of:

- Steel waveguide sensors tuned to a selected frequency response
- Signal conditioner
- Commercial data acquisition system
- Waveform recorder for signal pattern recognition analysis

The results obtained were very significant to the objective of continuous AE monitoring. Reactor system temperature and coolant flow noise during hot functional are similar to that during reactor operation, and under these conditions it was demonstrated that:

- Coolant flow noise can be overcome as an obstacle to monitoring.
- AE signals from a fracture specimen were detected under essentially operating conditions.
- Spontaneous acoustic information was detected and located on the No. 2 inlet nozzle.

At coolant flow conditions of 350 deg F and 400 psig and above, the waveguide sensors show only limited response to coolant flow noise. However, they readily detected AE signals from a fracture specimen mounted on piping in the vicinity of the sensors. Spontaneous AE from the No. 2 inlet nozzle was also detected and located. Both detection functions were accomplished at operating conditions. The sensors and associated electronic amplifiers did not show any deterioration from exposure to the high temperature environment.

The significance of these results is that they resolve what have been cited as primary obstacles to AE monitoring during reactor operation. The results demonstrate the feasibility of continuous AE monitoring to detect growing flaws in reactor pressure boundaries.

Tape moisture sensors

Monitoring leakage with moisture-sensitive tape is a continuous monitoring method consisting of a sensing element that is normally placed next to the insulation of process piping. The element provides an electrical signal when activated by moisture, which may be used with an indicating device that generates an alarm signal. These sensors can detect leakage quickly from the piping on which they are mounted and localize the leak area fairly precisely, depending on the length of individual tape segments. However, the amount of leakage cannot be measured.

Figure 3-14 illustrates a typical installation method.

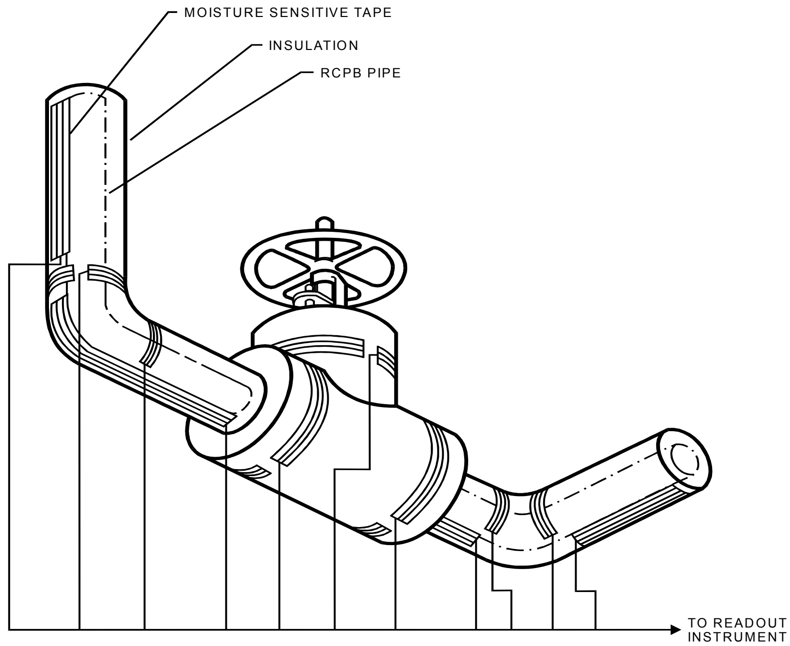

Figure 3-14
Typical Moisture-Sensitive Tape Installation

Local Boron Detection

Prompt Gamma Neutron Analysis

Westinghouse is currently developing a system to detect the presence of Boron using Prompt Gamma Neutron Analysis. The system is meant for use only during outages and would allow the detection of Boron/Boric Acid deposits hidden under insulation e.g. under the upper head insulation. The technology involves bombardment of insulation with neutron radiation and measurement of gamma (photon) emission from any Boron hidden beneath the insulation. Additional development and testing are needed before this technology is ready for plant application.

Monitoring Boron Concentration in Containment Air Cooler Condensate

Condensate from the air coolers in containment is generally collected and rates of condensation measured. Thus condensate could potentially be analyzed to detect for the presence of Boron. If Boron is detected, this would be and indication that there was a primary coolant leak somewhere in the containment. This would not provide information as to the location of the leak.

However, using the same concept, a system could be developed that draws air samples from the area of interest (e.g. above and/or below the RP vessel), cools the air to condense any moisture present and analyzes the condensate for the presence of Boron. To improve sensitivity, a sample could also be taken from the containment volume and the Boron concentrations in the two samples compared to determine if leakage is occurring in the region of interest.

Remotely Operated Cameras/Videoscopes

Testing conducted by First Energy and Framatome-ANP has shown that even extremely small primary coolant leaks at penetrations (0.0004 - .015 GPM) leave residue in a short period of time (a couple of days) that can be visually identified. This opens the possibility of using remotely operated devices/robots to visually monitor for leaks on-line. However, additional work would be required to harden current visual monitoring systems against the high temperature and radiation environment during operation.

Video inspections using robotic crawler or pole-mounted cameras/video probes have been conducted in the RPV head area to look for boric acid crystal deposits during outages. One such device is shown in Figure 3-15.

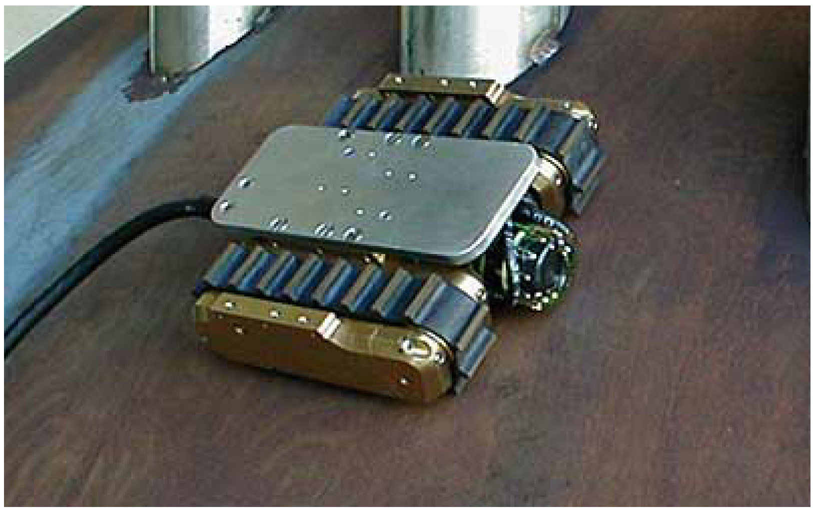

Figure 3-15
Inuktun Magnetic Crawler

The **Inuktun Magnetic Crawler** is a miniature, remotely operated inspection system that has the ability to travel +90 degrees vertically up a steel wall. The Magnetic Crawler vehicle is only 203 mm long, 165 mm wide and 63 mm high (8 x 6.5 x 2.5 inches) making it ideal for remotely accessing confined spaces. It is shown here on an RPV head with a CCD camera for inspections.

A more recent version of the MAG Crawler is the **Nano Mag** that is similar in appearance but measures only 4.15 x 6.24 x 1.9 inches. The **Nano Mag** has a front and rear-facing camera, a 100 ft. tether and offers remote focus and directional control.

Units such as these are ideal for head inspections during outages, but are not currently suitable for on-line head inspections. This is due primarily to the sensitivity of the cameras to the high local temperature in the head area and the high local radiation levels during plant operation.

Radiation levels in the upper and lower head areas during plant operation are estimated to be:

- 8000-10,000 Rads/hr Gamma Field
- 2-3 Rads/hr Neutron Field

Temperatures in the upper and lower head area during operation are in the **500-600 F** range.

It may be possible to resolve the radiation issue by use of a radiation tolerant camera. Such a cameras are available and an example is shown in Figure 3-16 below.

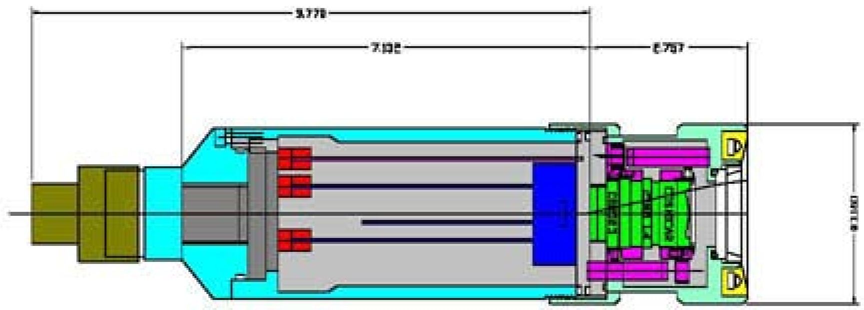

Figure 3-16
Radiation Tolerant Color Camera

The camera is offered in three versions:

1. **AquaRad** for underwater applications
2. **ColorRad** for dry applications and
3. **AiRad** for long term operation inside a nuclear containment

The **AquaRAD** is the world's first and only highly radiation resistant color solid state camera for use in underwater applications. Developed by Symphotic TII Corporation in partnership with Roper Resources, Spectra-Physics CIDTEC and Inuktun Services.

The new **ColorRAD** is the world's only solid state color radiation hardened camera. Monochrome versions are also available for applications where color is not required. These cameras provide excellent images at dose rates of $7x10^5$ rads/hour and have been tested from 1 to more than 2.5 megaRads, depending on the model.

The **AiRad** is a specially modified ColorRad camera with a nickel-plated copper case for improved heat dissipation

Key Features and Benefits

- Modular Design: Simple field replacement of imager and lens units.
- High Radiation Tolerance: 2.5 MegaRad total dose; 1 MegaRad/hr. dose rate
- 40 meter underwater cable-applicable for power reactor inspections
- Separate camera and control unit; compact camera head

Bases on discussions with Mr. Christopher Roper of Roper Resources, the radiation tolerant camera could be easily mated to a crawler such as the Nano Mag. The challenge is to provide sufficient cooling to the camera and other heat sensitive components of the crawler (e.g. the neoprene tracks) such that they could withstand the extreme temperatures on the vessel head during full power operation.

Contact:

Christopher Roper
Roper Resources Ltd.
USA Phone: (805) 798-0277
Canada Phone: (250) 361-9115
E-mail: Chris@RoperResources.com

Another radiation tolerant color camera is available from IST Imaging. The RC991 series of color cameras is designed for high radiation environments. The camera contains a 2/3" sensor tube which can operate in high radiation fields and survives a high accumulated dose. Recognizing the importance of field serviceability of components, the RC991 offers interchangeability of multiple heads and CCUs without difficult alignment procedures. The RC991 offers multiple fixed lens or zoom options with pan and tilt and lighting accessories.

Figure 3-17
Radiation Tolerant Color Cameras-IST Corp Model RC991

The camera is 12 inches long and has a diameter of 3.15 inches. It has a 400 TV lines resolution and can accommodate a dose rate of 1 x 10^5 Rads/hour and an accumulated dose of 1 x 10^8 Rads. It can be supplied with a non-browning lens with a focal length of 2.75 inches to infinity. The temperature limit is currently too low for on-line operation (40-55 ^{o}C).

Contact:

Jon Quartly
IST Imaging
204 IST Center
Horseheads, NY 14845
Phone: 607-562-4595
Website: http://www.istimaging.com/

The **Spectrum 60 PT** is a small and very robust remotely operated pan and tilt camera manufactured using lightweight corrosion resistant materials. This unique high performance camera is remarkable due to its ultra-small size and precision design. At only 6.3 cm (2.5 inches) in diameter the remote camera can be deployed through small openings for inspection in tanks, pipes and other confined spaces. The remote camera can be permanently installed for routine monitoring or used independently to access small openings for inspection within confined spaces. The Spectrum 60 PT is easily adapted to pipe crawler systems like the Inuktun Versatrax series or integrated with any number of remote vehicles that operate in confined spaces.

Figure 3-18
Spectrum 60 PT

The standard unit incorporates a high-resolution color camera at 570 TV lines resolution, with low light sensitivity of less than 1 lux and variable intensity lighting. The Spectrum 60 PT produces a standard video output that could be connected to most video recorders and television monitors. The intuitive joystick controlled system is compact and easily portable.

Versatility and size make the Spectrum 60 PT the perfect choice for visual inspection in a variety of limited access environments

Contact:

Grover Akre
541 South 50th Street
West Richmond, WA, 99353
Phone: 509-967-2683
Fax: 509-967-1252
E-mail: westecservices@verizon.net

The **VICTR** shown in Figure 3-19 and 3-20 is a robotic crawler designed for inspection of bottom mounted instrument (BMI) vessel penetrations. VICTR is a mobile camera platform capable of remote operation to distances of 250'. Many other features of VICTR include

- 360+ degree pan, 180+degree tilt
- 15x optical zoom
- Dual 35W Halogen Lights
- Tank style tracked drive mechanism for high maneuverability

Figure 3-19
VICTR Robotic Crawler
(Front View)

Figure 3-20
VICTR Robotic Crawler
(Side View)

The **RVIT** is not a robotic crawler but is a semi-remote inspection platform that can perform 360 degree continuous rotation inspection one nozzle at a time. Many of the RVIT features include:

- High quality camera with 10x optical zoom
- Dual high intensity light chips
- Auto/Manual

Contact:

Michael W. James
Director of Operations
Jamko Technical Solutions, Inc.
1100 Driving Park Avenue
Newark, New York 14513
Phone: 315-359-9090
Fax: 315-359-9045
E-mail: mjames@jamkosolutions.com

The **Ca-Zoom® -6.0** system is the world's most advanced industrial Pan-Tilt-Zoom camera. The **PTZ140 camera** can be deployed through 140 mm or 5.5 inch diameter openings, features high-powered 300x zoom, high-performance lighting capability and advanced camera setup features with Everest VIT's exclusive iView™ image management platform.

Figure 3-21
PTZ140 and PTZ100 Pan-Tilt-Zoom camera

Key Features and Benefits

- 25x optical zoom, 12x digital zoom for a total of 300x zoom capability or 10x optical zoom, 4x digital zoom for a total of 40x zoom capability
- Fits through 140m (5.5 in) or 100m (4.0 in) diameter opening
- High-powered dual-control lighting
- Resolving power of 0.5 mil (0.0005 in) diameter wire at 1.8 m (6 ft) distance
- High-resolution images (470 TV Lines)
- Hand-held controller with iVIEW image management system
- User-interface for camera feature set-up
- Unitized, all-in-one camera head construction
- In air or underwater operation
- Cable lengths up to 500 m (1640 ft)
- Home and Zero positions setting and up to 10 preset positions for pan/tilt/zoom
- Portable carrying/shipping case with industrial wheels

The **PTZ100 camera** can be deployed through 100 mm or 4.00 inch diameter openings, features high-powered 40x zoom, high-performance lighting capability and advanced camera setup features with Everest VIT's exclusive iVIEW™ image management platform.

Figure 3-22
ROVVER 400, 600, and 900 Robotic Crawler

Figure 3-22 shows the **ROVVER 400, 600, and 900** robotic crawler. The ROVVER® 400 robotic crawler system features a unique modular design and lighting for maximum adaptability. It provides full-directional viewing in a horizontal pipe or line with its pan-and-tilt or forward-viewing video camera. Both cameras have remote adjustable focus for a clear view at all times.

The ROVVER® 600 robotic crawler is the most portable and versatile inspection crawler on the market today. It is ideally suited for many applications due to its modular design and its ability to inspect inside pipes with diameters ranging from 150 mm (6 inches) to 900 mm (36 inches). It is the smallest crawler in its class, thereby giving it the ability to pass through restricted pipe, large offsets, and protruding pipe taps. The Product features include a small profile and modularity allows for long run and pan-and-tilt camera in 150 mm (6 inch) to 900 mm (36 inch) diameter pipe

The ROVVER® 900 system is the inspection crawler to use. For optimum large-diameter, 225 mm to 1500 mm (9 inch to 60 inch), pipe inspection, the ROVVER 900 system's pendant-controlled lift platform adjusts the camera height from 150 mm to 300 mm (6 inches to 12 inches). The camera can stay centered in the pipe for optimum magnification and undistorted inspection in any viewing direction. The ROVVER 900 carries pan-and-tilt or forward viewing color video cameras as well as retrieval, sensing or sampling equipment to distances up to 200 m (660 feet). The ROVVER system's remote pendant enables the operator to raise and lower the camera, control focus and lighting, engage the clutch and steer the crawler when obstacles such as debris or offsets are present.

Contact:

Sean Alexander
EverestVIT
Territory Sales Manager
Phone: (704)882-4598
E-mail: alexanders@everestvit.com

Radiation Tolerant Videoscopes

Another potential on-line visual inspect technique could involve the use of Videoscopes. An example of ultra long and radiation tolerant videoscopes are those offered by Olympus. Some features of these units are provided below.

Olympus Series 5 Videoscopes (IV6C5 / IV6C5X1)

The range of special purpose Series 5 industrial videoscopes includes 6mm (0.24 inch) diameter instruments up to lengths of 16m (52.5 feet) and up to 11m (36 feet) with a radiation resistance of 5000 RADs.

Using full color CCD technology, these instruments produce high resolution, real time images. Using an adaptor, the videoscopes are directly compatible with the IV-6A Camera Control Unit, as part of the compact and lightweight System Case 2. Modular in design, a complete system consists of the videoscope, a camera control unit, light source, video monitor and, optionally, a digital storage device (IW-R1 or DSM-2). The user has the choice of system configuration and packaging, matched to the inspection requirements. A number of features are then available to the user:

- Image freeze
- Image storage (with optional IW-R1 or DSM-2)
- Real time zoom (3x)
- Pan on a zoomed image
- Edge enhancement - 3 levels of digital enhancement
- Automatic image brightness control
- Exposure control from 1/20 seconds to 10 seconds - allows for bright images in large, dark voids
- Image reversal – a feature to correct the image orientation when using side-view tip adaptors

All models feature two-way articulation of the tip section and interchangeable optical tip adaptors to allow selection of the desired instrument field and direction of view.

Figure 3-23
Oylmpus Ultra-long Videoscope

The ultra-long IV6C5 models feature the proven Olympus TaperFlex four-layer construction, whereas the IV6C5X1 radiation resistant model has a resin coated insertion tube, designed specifically for ease of decontamination. Quartz light guide fibers are also specified in order to achieve radiation resistance.

The use of fiberscopes/endoscopes to deliver the image from the area of interest to the camera and associated electronics can significantly reduce the need for extremely heat and radiation tolerant cameras. Endoscopes can be made of materials that are both highly heat and radiation tolerant. Fiberscopes utilizing fused silica fibers have also been shown to be highly radiation and heat tolerant.

Contact:

Olympus USA, Central and South America
Olympus Industrial America Inc
One Corporate Drive
Orangeburg, New York 10962
USA
Phone: 845-398-9400
Fax: 800-233-0697
E-mail: Info@olympusindustrial.com

Sales Representatives:

David Rivera
Phone: 323-630-8193 (CA)

Paul Gabriel
Phone: 603-978-1427(NC)

WARNING: This Document contains information classified under U.S. Export control regulations as restricted from export outside the United States. You are under an obligation to ensure that you have a legal right to obtain access to this information and to ensure that you obtain an export license prior to any re-export of this information. Special restrictions apply to access by anyone that is not a United States citizen or a permanent United States resident. For further information regarding your obligations, please see the information contained below in the section entitled "Export Control Restrictions."

Export Control Restrictions

Access to and use of EPRI Intellectual Property is granted with the specific understanding and requirement that responsibility for ensuring full compliance with all applicable U.S. and foreign export laws and regulations is being undertaken by you and your company. This includes an obligation to ensure that any individual receiving access hereunder who is not a U.S. citizen or permanent U.S. resident is permitted access under applicable U.S. and foreign export laws and regulations. In the event you are uncertain whether you or your company may lawfully obtain access to this EPRI Intellectual Property, you acknowledge that it is your obligation to consult with your company's legal counsel to determine whether this access is lawful. Although EPRI may make available on a case-by-case basis an informal assessment of the applicable U.S. export classification for specific EPRI Intellectual Property, you and your company acknowledge that this assessment is solely for informational purposes and not for reliance purposes. You and your company acknowledge that it is still the obligation of you and your company to make your own assessment of the applicable U.S. export classification and ensure compliance accordingly. You and your company understand and acknowledge your obligations to make a prompt report to EPRI and the appropriate authorities regarding any access to or use of EPRI Intellectual Property hereunder that may be in violation of applicable U.S. or foreign export laws or regulations.

The Electric Power Research Institute (EPRI)

The Electric Power Research Institute (EPRI), with major locations in Palo Alto, California, and Charlotte, North Carolina, was established in 1973 as an independent, nonprofit center for public interest energy and environmental research. EPRI brings together members, participants, the Institute's scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power. These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment. EPRI's members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI's total research, development, and demonstration program.

Together…Shaping the Future of Electricity

Printed on recycled paper in the United States of America

1012947

ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com