RINGHALS-2 CORE MONITORING EXPERIENCE

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Abstract

The paper presents the core monitoring system CROSS developed for Ringhals-2. The experience with the fixed in-core Radcal gamma thermometer sensors is discussed and the main features of the CROSS system are highlighted.

Comparisons made over many cycles show a very good agreement between the movable detector system and the fixed detector system with regard to measured peaking factors. An additional benefit with the fixed system is a quicker and a simpler way to calibrate the ex-core detectors.

Introduction

The upgraded CoRe On-line Supervision System (CROSS) for the Westinghouse 950 MW PWR Ringhals Unit 2 was installed in May 1995. The system is based upon fixed in-core Radcal gamma thermometer detectors. The software system consists of five distinctive parts:

- NETPAC Software Package for control and surveillance of the equipment (Data logger) for data acquisition of gamma thermometer signals.
- RADCAL Software Package for processing of the detector signals and calculation of core parameters for the instrumented fuel positions.
- CECOR Software Package for the extrapolation of the input from RADCAL to non-instrumented fuel positions.
- SCORPIO Software Package for providing a best estimate of the core status based on a combination of measurement and on-line simulation. Further, SCORPIO contains efficient predictive capabilities to calculate the core behaviour in planned power transients. All the results both in monitoring and predictive mode of SCORPIO are checked against operational limits.
- PICASSO-2 Software Package is the graphical display system used for the Man-Machine Interface in CROSS.

Radcal gamma thermometer experience

Radcal design experience

Four Radcal gamma thermometer strings, having a length in the range 34-36 meters and containing nine power-measuring sensors each, were installed in Ringhals-2 for the first time in 1984. The basic design of the Radcal gamma thermometer PWR string is visualised in Fig. 1.

In 1987 additional four Radcal strings from another manufacturer were installed. These had a slightly modified design in the respect that the Jacket Tube consisted of three parts that were welded together prior to the draw down onto the Core Rod while the Jacket Tube for those installed in 1984 had fully drawn seamless tubing as start-out. The Core Rod had only 8 meters length for those strings installed in 1987 while it extended over the whole length of the string for those installed in 1984. Apart from that the design and manufacturing was very similar.

At the end of 1993 six new strings were installed, two of which replaced two failed 1987 strings. The new strings had mainly the same specifications as those installed in 1984, with the main difference being that the Argon gas pressure had been increased to 10 bars.

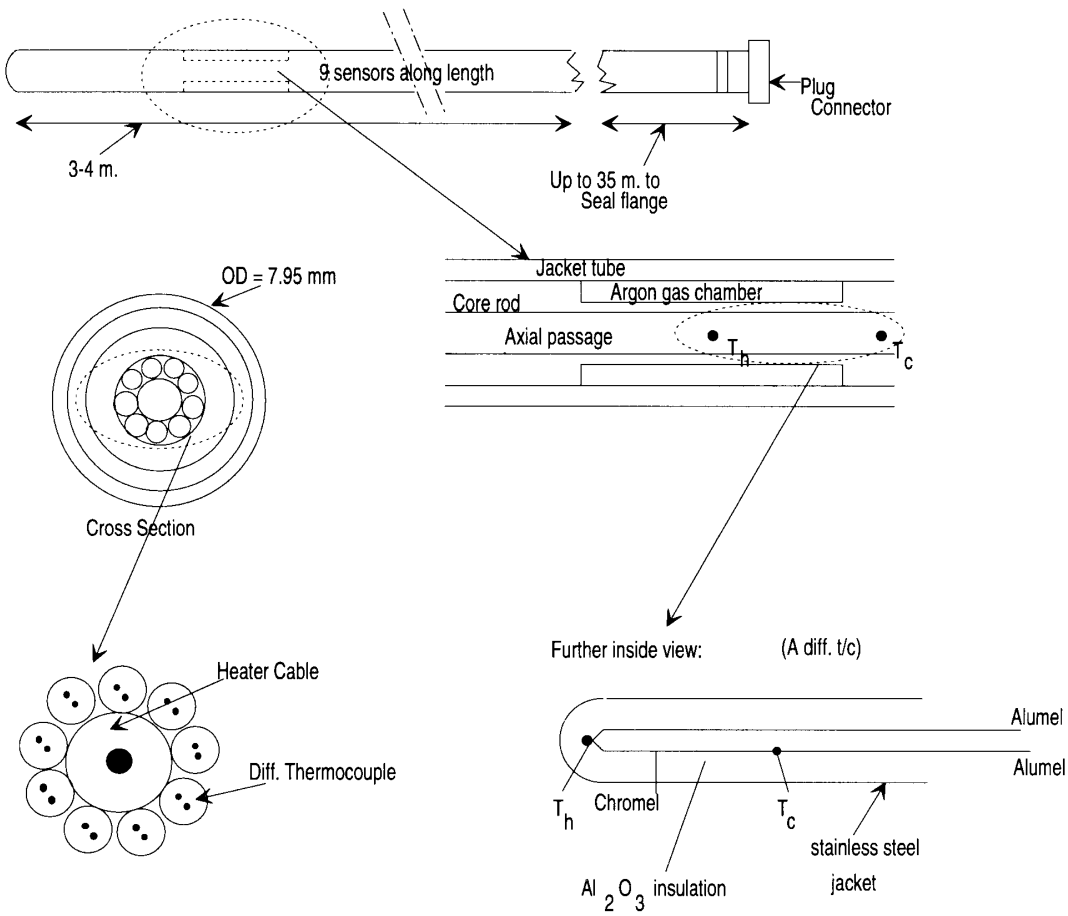
In the summer of 1996 three new strings were installed, two replacing the remaining two strings from 1987 and one replacing one of the strings from 1984. In the latter the central heater cable had failed while all the sensors were working.

At the restart of Ringhals-2 in August 1996 after the refuelling outage there will be 12 Radcal gamma thermometer strings with a total of 108 sensors in the reactor core. Three Radcal strings have then been in the reactor all since 1984.

Radcal hot lab investigations

One of the Radcal strings installed in 1987, L05, lost all sensor signals after some years of operation and it was removed from the reactor in 1993 together with another 1987 string, G09, that had shown degraded performance. A 4-meter part of L05 located just under the core when installed in the reactor, was subjected to hot lab investigations at Studsvik, Sweden.

Figure 1.



Severe cracks were found in the Jacket Tube. They were all located over a part where the string also had Core Rod, therefore no leak path up to the Seal Table had developed. Due to this experience it was decided to remove the remaining two 1987 strings, L11 and E11, from the reactor in 1995 although they were performing well. The 1984 string, J10, removed together with these two, was investigated in hot lab. Both the 4-meter part where the sensors are located and the first 4 meters below the core were inspected. No cracks or damage to the string were observed.

The exact reason why cracks developed in L05 has not been discovered. It has been decided, however, that future strings shall have the same design as those installed in 1984 which is the original Radcal gamma thermometer PWR design.

Radcal drift problems

As reported earlier [1] a slow downward drift of the sensor sensitivity has been observed during the first cycle of operation for new Radcal strings. For the Radcal strings installed in 1984 and 1987 the sensitivity decreased by 10-15% before stabilising after several months of operation. During the following refuelling outage the sensitivity was found to increase to practically initial value and in the next cycle it decreased over a relatively short time, weeks, to the stable value from the previous cycle. The drift has never created any problem for the operation of the instruments as these can be conveniently and quickly calibrated using the central heater cable to perturb the heat rate.

It is believed that the drift has to do with contamination of the argon gas in the sensor gas chamber from hydrogen intrusion. During the initial design of the Radcal instruments it was anticipated that the hydrogen partial pressure at operating conditions in a PWR is about 0.02 bar. The gas chamber argon pressure was therefore specified to be 2 bars which should make the influence of hydrogen intrusion negligible.

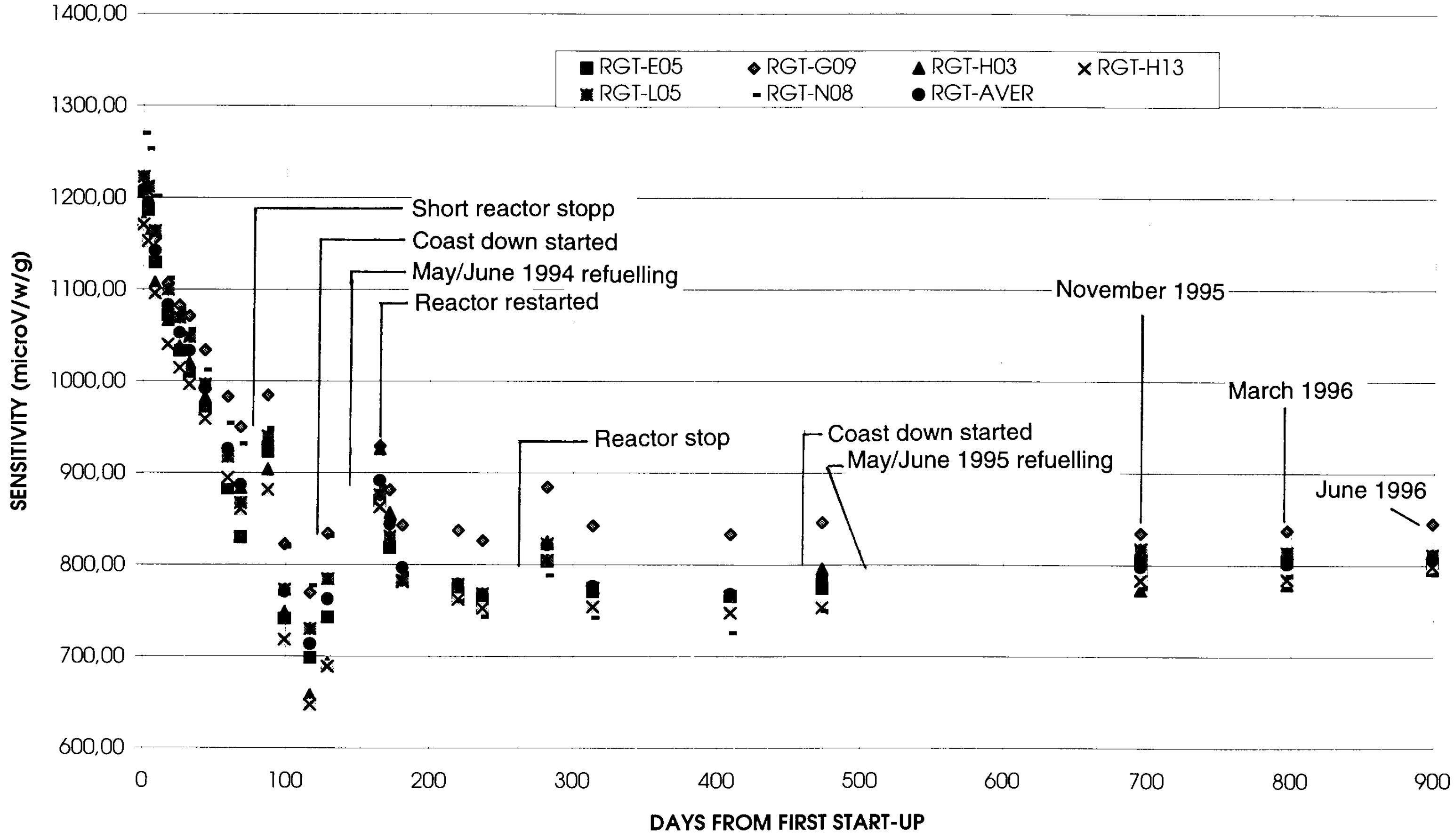
As the Radcal strings installed in 1984 and 1987 both showed drift, it was decided to increase the argon pressure to 10 bars for the Radcal strings installed in 1993 (and 1996). Based upon hydrogen solubility data obtained from [2] it seems that the hydrogen partial pressure was underestimated by a factor of 10 during the initial Radcal design. The hydrogen partial pressure is probably about 0.4 bar at PWR operating conditions. From Radcal model calculations such a high hydrogen content can explain a sensitivity drift in the range 15-20% when the gas chamber argon pressure is only 2 bars. If the argon pressure is raised to 10 bars, however, the model shows that the drift should be very small, a few percent only.

Quite surprisingly, however, the six Radcal gamma thermometer strings installed towards the end of 1993, having argon gas pressure 10 bars, showed a high and consistent drift for all the sensors over the first short cycle from Christmas 1993 until the refuelling outage in May 1994. Figure 2 shows the average sensitivity for the 9 sensors in each of the six Radcal strings together with the average sensitivity for all the sensors. From the figure it is seen that the initial drift was in the range 30-40 %. After the reactor restart in June 1994 the sensitivity stabilised rather quickly and it has stayed very constant over the next two cycles of operation.

Radiolytic effects

It is fairly obvious that the partial pressure of the hydrogen dissolved in the coolant water can not explain the initial sensor drift observed for the six Radcal strings installed at the end of 1993. If hydrogen contamination of the argon gas is the reason for the drift, other mechanisms must be sought to explain the presence of hydrogen in the sensor gas chamber. A possibility is the radiolysis of the core coolant water. In this process hydrogen (H, H_2), hydrogen ions (H^+) and hydrogen containing ions are generated [3]. By diffusion

Figure 2. RGT sensitivity drift vs. time from initial start-up



these products will penetrate into the Radcal Jacket Tube and sensor gas chamber and possibly recombine to hydrogen. A stable gas chamber hydrogen pressure is reached when the diffusion of produced hydrogen gas out to coolant is in equilibrium with the hydrogen gas production rate from recombination. A higher hydrogen gas pressure in the gas chamber (several bars) might result as compared to 0.4 bars resulting from the partial pressure of dissolved hydrogen.

The above assumptions are somewhat speculative. Independent inspections of other core components have indicated, however, that hydrogen-related reactions play a greater role internally in these components than earlier expected. Maybe the effect of diffusion of radiolytic products into the core materials has been underestimated.

The CROSS system

The CoRe On-line Supervision System (CROSS) has a modular design and the various software modules are integrated in the UNIX system environment with a unified man-machine interface based on X-windows. This flexible design makes it easy to apply and replace modules. The system is designed for the reactor operators with easy access to display formats and dialogue functions using mouse and soft keys. Further, special functions related to maintenance of physics models and calibration of gamma thermometers are protected and only available to the reactor physicists.

The pre-processing and calibration of gamma thermometer signals are performed by the RADCAL Software package. Calculation of thermal margins (DNB and FQ) are done in the CECOR module. In SCORPIO ex-core and gamma signals are compared with the on-line 3D core simulation providing diverse techniques for power determination and signal validation.

Further, SCORPIO provides a simulator used for predictive analysis such as optimisation of planned power changes, axial power distribution control and coast down operation by varying the temperature program. A strategy generator is available to assist in planning constant axial offset operation.

Several users at a plant may be interested in running CROSS and they may be located in different offices and buildings on-site and even off-site. A software package (PGWIP) has been developed to be able to run multiple CROSSes without interfering with each other.

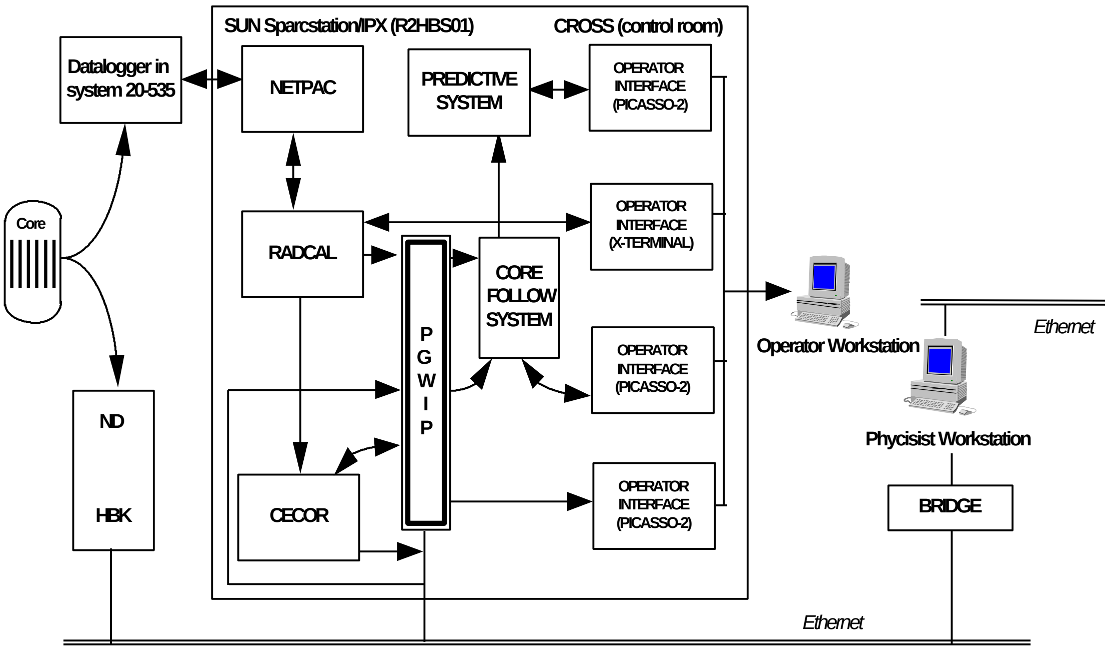
Figure 3 shows the CROSS system overview at Ringhals unit 2.

Examples of utilisation of CROSS functions

The following are examples of typical tasks supported by the upgraded CoRe On-line Supervision System (CROSS).

- **Criticality calculations**. If the power prehistory is complex, it is difficult to calculate critical boron concentration as a function of time. With CROSS, this type of calculation is made in minutes, covering up to 48 hours ahead.

Figure 3. CROSS system overview



- **Optimisation of planned power changes**. Power reductions, load following and start-up after shutdown are transients which are more efficiently performed if planned hours ahead with CROSS' predictive functions. Critical passages can be detected and anticipated.

- **Axial power distribution control**. Operation outside the delta-flux operating band is only permitted for a limited period. Various control strategies to deal with axial xenon redistribution are efficiently and rapidly evaluated with CROSS.

- **Coast-down operation support**. Operation at low boron concentration is difficult for a number of reasons. Return to power after a trip might create problems with the delta-flux operating band. With CROSS, the consequences of power manoeuvres at coast-down or low boron concentration can be fully investigated.

- **Trend analysis**. Reactivity related parameters are available for trend analysis. The relationship, for example, between temperature variations and impact on the power distribution might be investigated in detail with CROSS' monitoring functions.

- **Xenon transients**. The general behaviour of transients might also be investigated. CROSS output shows xenon transient during load follow operation.

- **Power distribution (local, global)**. The CROSS 3D-power distribution functions make it possible to see how the power distribution varies radially and axially, locally as well as globally, during transients.

- **Thermal margin limits**. The impact of the control rods and the power level on the thermal margins is easily illustrated for a number of transients. CROSS output shows that $F\Delta H$ increases with rod insertion.

- **Training**. Many core related parameters are difficult to simulate on full scale training simulators. CROSS provides an efficient way to demonstrate the impact of various strategies and the consequences of inappropriate actions.

Core monitoring operational experience

Hybrid system

The 12 fixed in-core detectors are primarily used for measurement of the power peaking factors and DNB-margin. The movable detector system is used periodically for detailed measurement of local power. The Tech. Spec. operability requirement for the hybrid system requires the following: $\geq$ 5 detectors per string operable, $\geq$ 75% of fixed in-core strings operable, electrical calibration of fixed detectors at least once per month and $\geq$ 32 (out of 38) movable detector thimbles operable.

A transient and uncertainty analysis of the system has been performed in compliance with Westinghouse methodologies. The analysis shows that the regular Delta-Flux operating band can be removed with the fixed detector system operable. The analysis also shows that the net gain in DNB-margin compared with the movable detector system is approximately 10%.

Comparisons made over many cycles show a very good agreement between the movable detector system and the fixed detector system with regard to measured peaking factors. An additional benefit with the fixed system is a quicker and a simpler way to calibrate the ex-core detectors.

Functional improvements

The following functional improvements are presently underway:

- **New 3D core simulator**. The present CROSS core simulator will be replaced with the same simulator which is used for ICFM calculations (SIMULATE).

- **Operability verification**. A special function will verify that all the aforementioned Tech. Spec. operability requirements for the system are met and inform the operator of the operability status.

- **Semi-automatic calibration**. The fixed detectors will be calibrated automatically in sequence at command.

- **Improved response function**. Variations in enrichment, axial temperature profile and fuel type will be accounted for in the detector response function.

Related issues

As a result of the experience gained with the system, a number of related issued have been raised:

- Measurement uncertainty as a function of fixed in-core strings. Uncertainty studies show that an increase in the number of fixed in-core strings from the present number only marginally will reduce the measurement uncertainty. The question raised is what criteria should be applied with respect to instrument coverage of the core?

- Movable detector measurement frequency. The present Tech. Spec. requires that the movable detectors are used once per 31 full power days to determine the peaking factors. With continuous monitoring of the peaking factors, the movable detectors provide an independent verification of fixed in-core detector results. This verification could be done with a frequency less than the present Tech. Spec. requirement.

REFERENCES

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