Recent Experience with In-Core Sipping Techniques

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Based on the service-proven can sipping systems mainly installed in PWR spent fuel storage pools as well as in-core sipping techniques deployed for BWR fuel assemblies, FRAMATOME ANP GmbH has developed two new sipping systems suitable for both PWR and BWR fuel. The new sipping techniques provide on-line results based on fission gas measurements of samples of the water surrounding a fuel assembly.

The Mast Sipping technique makes use of the reduction in pressure which occurs when fuel assemblies are lifted out of the reactor pressure vessel. Gaseous fission products expelled into the water are continuously degassed from the water surrounding a fuel assembly and then measured and evaluated.

The SIPPING 16 technique makes use of the temperature increase occurring when thermal convection is stopped by a sipping hood placed over 16 fuel assemblies at a time. This temperature increase and the resultant rise in fuel rod internal pressure as well as a higher rate of diffusion drive gaseous and water-soluble fission products out of any fuel leakers. Scanning the gas samples for Kr-85 and Xe-133 provides immediate, on-line information as to the presence of defective fuel rods under the hood.

KEYWORDS: Fuel assembly, sipping, activity measurements

I. Introduction

Innovative inspection systems from FRAMATOME ANP can significantly contribute towards shortening the time needed for refueling outages. FRAMATOME ANP can now offer utilities its in-core SIPPING 16 system for boiling water reactors (BWRs) as well as on-line Mast Sipping systems for either BWRs or pressurized water reactors (PWRs).

The Mast Sipping technique makes use of the reduction in pressure which occurs when fuel assemblies are lifted out of the reactor vessel. The resulting pressure differential drives water-soluble or gaseous fission products out of any defective fuel rods. This technique – the preferred method for PWRs – is used during core unloading or shuffling, and eliminates the time needed in the past for separate leak tests.

The in-core SIPPING 16 system allows up to 16 BWR fuel assemblies at a time to be tested simultaneously for leak-tightness without the fuel assemblies having to be lifted or moved in any way. Only 16 hours are needed to inspect an entire core configuration with 784 fuel assemblies of a 1300 MW reactor similar to that for which the system was originally developed. A study is also underway to verify the suitability of the SIPPING 16 system for use in Advanced Boiling Water Reactors (ABWRs) as well.

II. Description of Sipping Systems in Use Today

Whereas sipping tests in PWRs were normally performed in the past inside a sipping can located in the fuel pool following removal of the fuel assemblies from the reactor, similar tests can now be performed today while the fuel assemblies are being unloaded from or shuffled in the core. In BWRs, the hood sipping technique was traditionally used for testing four or eight fuel assemblies at a time. The results of the sipping tests were obtained later on by means of activity measurements taken in the radiochemistry laboratory. FRAMATOME ANP’s latest sipping techniques, now being deployed in numerous reactors, are described below.

1. Mast Sipping

The Mast Sipping technique makes use of the pressure differential arising between the fuel rods and the surrounding water when a fuel assembly is lifted out of the core using the mast of the refueling machine. A sample of the water inside the mast is continuously removed and analyzed for gaseous fission products expelled into the water from leaking fuel rods. The principle diagram of the Mast Sipping System is shown in Figure 1. The activity of the fission products is scanned and displayed on a screen. Any changes in the count rates are automatically detected and evaluated. The measured data and evaluation results are stored and printed out together with the test parameters.

Fig. 1 Schematic diagram of the Mast Sipping System

1 Water sample suction line
2 Air exhaust system
3 Sample conditioning system
4 Water sample extraction
5 Gas detector
6 Sample evaluation system
7 Printer for measurement result
8 Mast of refueling machine
9 Fuel assembly
All electronic components, control systems and measuring equipment are integrated into the control cabinet shown in Figure 2. Control is centered on a SIMATIC S7 programmable logic controller (PLC), with the system operated and monitored by means of menu-driven software from an operator panel connected to the PLC. The condition of all components (valves, pumps and instrumentation) is graphically displayed on an LCD screen as shown in Figure 3.

Fig. 2 Mast Sipping control cabinet on the refueling machine during an inspection

The gas (Kr-85 alone or together with Xe-133) is fed to a measuring chamber equipped with plastic scintillation detectors for scanning. Printouts of the results are immediately available on-line.

The fuel channels and handles of the fuel assemblies project several centimeters above the grid. Air is injected into the sipping hood which dispels water from the hood until the tops of the fuel channels become uncovered. This "separates" the individual fuel assemblies inside the hood. The air cushion disrupts natural convection, resulting in a rise in temperature and consequently also a rise in the pressure inside the fuel rods of the 16 fuel assemblies. This causes fission products to be expelled from leaking fuel rods and dissolve in the water inside the fuel assembly. The fuel channels serve as a barrier preventing further migration of the released fission products into adjacent fuel assemblies. Gas bubbles rise upwards and collect inside the sipping hood. Extendable suction tubes extract water samples from the individual fuel assemblies that pass through hoses to gas separation and scanning systems in a control unit located close to the reactor well (Fig. 5). Leaking fuel is identified by scanning the gases from the samples for Kr-85 and Xe-133. The process of the SIPPING 16 System is illustrated in Figure 6 as a schematic diagram. The first step to identify the core cell in which a leaking fuel assembly may be located is shown on the left side of this diagram. The water drawn from four fuel assemblies is mixed, degassed, analyzed and evaluated. If a leaking fuel assembly within one core cell is found by an indication signal the four degassing and measuring channels are automatically switched onto this core cell. The process by drawing, degassing and measuring is now directed to identify the leaking fuel assembly. At the end of each sipping step the results are printed out and are available when the hood is moved to the next core position.
Fig. 5 The in-core Sipping 16 system consists of a hood for 16 fuel assemblies, a pneumatic/hydraulic control cabinet, an electronic control cabinet including the data evaluation system, and a mobile detector housing.

Fig. 6 Schematic diagram of the Sipping 16 process. Situation 1 shows the identification of the core cell in which a leaking fuel assembly may be located. Situation 2 shows the final step to identify the individual leaking fuel assembly.

III. Experience with Sipping Techniques

Pool-side inspections together with fuel sipping and fuel reconstitution services during refueling outages are established methods for light water reactor (LWR) owners to ensure safe and economical operation of their power plants. The quality of the applied service techniques and the proficiency of the personnel involved generate mutual confidence between plant operators, licensing authorities and service providers. Feedback of service experience from pool-side inspections and reconstitution campaigns is and has been a key factor contributing towards the steady improvements that have been made in fuel performance and reliability over decades. [1]

Standard designs of sipping equipment for identifying fuel assemblies containing leaking fuel rods have proven their high level of reliability since 1970 in both PWR and BWR plants, either as pool-side installations or as mobile in-core systems.

1. Mast Sipping Experience

The Mast Sipping technique, originally developed for PWRs, has been successfully deployed in numerous plants in both Germany and abroad since 1996. Each and every leaking fuel assembly was able to be reliably identified using this method and provisionally removed from further service. Coolant activity measurements taken during reactor operation after Mast Sipping campaigns confirmed the excellent reliability of this sipping technique. [2]

Fig. 7 Count rates from leaking fuel assembly in Reactor A measured by Mast Sipping technique

Fig. 8 Results of measurements taken with high background activity during unloading of Reactor B

Fig. 9 Results of measurements taken with low background activity during fuel shuffling in Reactor C

Figures 7 to 9 show typical PWR fuel sipping test results obtained by Mast Sipping. It is quite clear that the sipping factor (quotient obtained by dividing maximum activity $A$ by background activity $A_0$) can differ considerably.
One of the causes for this can be found in the different levels of background activity, while another cause lies in the fact that the magnitude of activity released depends on the nature and the location of the defect(s).

Fig. 10 Example of a Mast Sipping results for a BWR fuel assembly next to a picture of the defect

Figure 10 shows a record of Mast Sipping results obtained for a BWR fuel assembly together with a video image of the defect after the fuel rod had been pulled from the fuel assembly for purposes of fuel reconstitution.

2. Experience with SIPPING 16

The SIPPING 16 system was developed, manufactured and delivered in 2001 under a contract received from the operator of the twin-unit BWR plant Gundremmingen. This SIPPING 16 system was then initially deployed in both units' reactors to verify the geometrical compatibility of the system with the reactor and core configuration and to give plant personnel additional practice in operating the equipment. The very first "hot" runs – i.e. actual sipping tests – performed with the SIPPING 16 system to look for defective fuel rods took place in 2002. During these campaigns, all 784 fuel assemblies in each of the twin units were able to be inspected in just 16 hours.

The same SIPPING 16 system was then deployed at Krümmel Nuclear Power Station (twice) and also, in April 2003, at Isar 1. In all five sipping tests performed with this system to date, all leaking fuel rods that were actually present in the cores have been reliably detected. This was verified by coolant activity measurements taken during subsequent plant operation which showed that the reactors obviously no longer contained any defective fuel.

The experience gained from these sipping campaigns was duly taken into consideration in analyzing the measured data and has been incorporated into the SIPPING 16 system through minor design modifications. This led to extremely valuable improvements in data acquisition sensitivity as well as in the clarity of measured data display. One example of how clearly the results of a sipping campaign are now depicted is shown in Figure 11.

Fig. 11 On-line degassing results obtained with in-core SIPPING 16 system for an entire core cell and for a single fuel assembly

IV. Conclusion

FRAMATOMEANP's on-line Mast Sipping system – originally developed for PWRs and deployed for the first time in 1996 – has proven to be so reliable that most plant operators now prefer Mast Sipping over the can sipping systems they used in the past. With this technique the fuel assemblies are checked for leaking fuel rods while they are being lifted out of the reactor core or shuffled to other core positions. Apart from the highly dependable information thus obtained, the time saved during reactor refueling outages by deploying this technique is a major benefit for plant operators. The Mast Sipping technique is also qualified for application in a BWR core to check fuel assemblies which cannot be reached with a sipping hood.

The SIPPING 16 technique introduced for the first time in 2001 was developed on the basis of the Mast Sipping method. Apart from the very short periods of time needed for testing a core with fuel leakers using SIPPING 16, another extremely important feature is the fact that the test results are available immediately on-line. On the basis of these on-line results, decisions can be made at once regarding the possible need for further inspections or changes in the core loading pattern. Another major advantage afforded by this new technique is that the large number of fuel assemblies contained in a BWR core no longer have to be moved in order for their integrity to be checked by sipping.

Following the great success of the SIPPING 16 system in German BWRs, a large Japanese utility has now also contracted a study to be performed by FRAMATOMEANP to investigate the possibility of deploying the system in ABWRs as well.

References

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