

SIPPING OF FUEL ASSEMBLIES

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ABSTRACT

As a first safety barrier (fuel rod cladding), integrity of Fuel Assembly (FA) in operation is continuously monitored by observation of the primary coolant and after indication by Sipping at the beginning of an outage or later. To ensure fuel rod cladding integrity before re-loading a Fuel Assembly in the reactor core or duly spent fuel management, sipping is the most relevant inspection technique performed by NPP operators worldwide to meet safe and effective operation. In the last years needs have changed and technics are enhanced to follow NPP operators expectation. This paper presents the current available sipping technologies and options proposed by Framatome will be discussed. On-line to off-line sipping techniques as well as fixed and mobile solutions are parts of the content.

Sipping possibilities:

- Incore Sipping for BWR (Boiling Water Reactors) or WWER (Water Water Energetic Reactors)
- On-Line Sipping Equipment (for PWR (Pressurized Water Reactors), BWR or WWER)
- Off-Line Sipping:
 - Vacuum Mobile Sipping Cells
 - New Generation of Fixed or Mobile Heating Sipping Cells (inherently safe Fixed Off-Line Sipping System)

1. INTRODUCTION

Nuclear utilities are facing challenges with integrity of each Fuel Assembly, to ensure fuel rod cladding integrity before core re-loading, or spent fuel management, especially with regard to dry cask storage or external storage facilities.

Associated to these different types of transfer, Fuel Assemblies have to be characterized according to various regulatory requirements.

One of these conditions is the soundness (leak tightness) of the fuel rods within the Fuel

Assembly, which can be demonstrated by sipping.

There is a wide range of various Fuel Assembly designs, (PWR, BWR, WWER or others) with very short or very long storage times that requires an evaluation in prioritization of the sipping method.

Framatome has optimized sipping solutions to handle the various fuel designs and irradiated fuel conditions.

A short time after reactor shutdown, fuel rods contain a relatively high concentration of the fission products Xe-133, Kr-85, I-131 and Cs-134/137; the concentration of all fission products declines the longer the storage time is. After a very long storage time, only Cs-137 dominates the water phase.

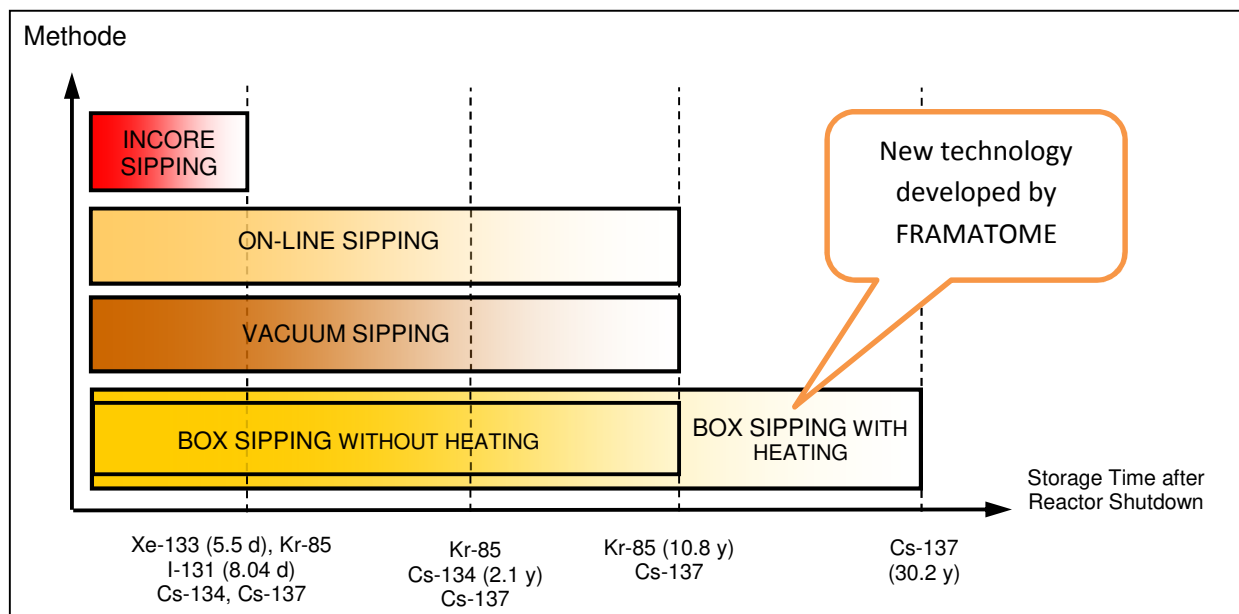


Fig 1. Application of Sipping Methods after Reactor Shutdown

At BWR's and WWER's, Incore Sipping could be of interest when quick sipping results are required before refueling or especially shuffling.

In order to verify leak tightness of Fuel Assemblies with shorter storage times, the On-Line Sipping is recommended, that allows testing during refueling at PWR's, BWR's and WWER's.

The leak testing of Fuel Assemblies with longer storage times comes to a limit with On-Line Sipping, Vacuum Sipping and Box Sipping (without heating) (see Figure 1). In such situations Box Sipping with heater, gives clear testing results.

Framatome's solutions for On-Line Sipping and mobile or fixed Box Sipping with Heating are complementary because they can use same measuring unit.



Fig 2. On-Line Sipping and Box Sipping with heating can share same measuring unit

2. INCORE SIPPING

2.1 General background of system

Framatome's BWR and WWER in-core fuel sipping method and equipment has been used extensively for accurate and reliable detection of leaking Fuel Assemblies for many years.

Sipping is carried out in the core and is conducted simultaneously on several Fuel Assemblies by sampling water, degasifying and analyzing the gas samples. A single position hood for testing assemblies located on the core periphery could be also available. The system creates an air cushion in the hood which disables widely the heat transfer and therefore the Fuel Assembly is heated up, thereby causing any failed rods exposing fission products.

Incore Sipping solution is adaptable from single to multi-position hoods according customer expectation and according core array to optimize the sipping step sequence.

2.2 System description

After placing the hood at the upper core support grid (top guide) using the refueling platform and before the measurement can start, the natural circulation of the coolant through the fuel bundle is interrupted using the sipping hood. Air is injected into the sipping hood which dispels water from the hood until the top of the fuel channels, but not Fuel Rods, become uncovered. This "separates" the individual Fuel Assemblies inside the hood. The air cushion interrupts natural convection, resulting in a rise in temperature and consequently also a rise in the pressure inside the fuel rods of the Fuel Assemblies. This causes fission products to be expelled from leaking fuel 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. Extendable suction tubes extract water samples from the individual Fuel Assembly that pass through hoses to a gas separation and scanning system in a control unit located close to the pool. Leaking fuel is identified by scanning the gases from the samples for Kr-85 and Xe-133. A water sample could also be taken for additional radio-chemical analysis.

The main components of the Incore Sipping System are:

- Sipping Hood
- Control cabinet containing all pneumatic and hydraulic equipment
- Second control cabinet houses two industrial PCs and the electronic equipment. Automated sipping operations are monitored at an industrial PC and controlled by a PLC, the entire process being displayed on a screen
- Beta Scintillation Detectors

The sipping hood configuration can cover a number of BWR or WWER Fuel Assemblies up to its design capacity.

The sipping hood comprises a box open at the bottom and divided internally into quadrants matching the core cells in the reactor. It can be coupled to the refueling platform's telescoping mast. Set down is facilitated by two alignment guides which engage the handles of adjacent Fuel Assemblies and support the two underwater TV cameras.

The suction tubes, which can be inserted into each individual Fuel Assembly, are attached to the top of the hood and equipped with thermo-couples for monitoring Fuel Assembly heat up. Two cable bundles provide a flexible connection between the hood and the control unit and are fitted with floats to facilitate hood movement above the core.

2.3 Activity measurement

Scanning for gaseous fission products is initiated by the main computer and performed continuously as soon as Fuel Assembly heat up has been in progress for a certain time. First the gases separated from the water samples from four core cells (each comprising four Fuel Assemblies) are scanned by four, parallel scintillation counters. If the measurements reveal that one of the cells contains defective fuel, all four gas scanning systems are switched over to that cell in order to determine which Fuel Assembly is leaking fission products. A fifth scintillation detector is used to scan the air from the four quadrants of the sipping hood. All measured data and sipping parameters are analyzed at the second industrial PC and displayed on screen.

3. Framatome On-Line Sipping Technology

3.1 Challenge

Framatome On-Line Sipping Equipment called Mast Sipping Equipment (MSE) is an on-line technique developed to detect defective Fuel Assemblies during NPP core unloading in order to be used in all LWR (Light Water reactor) types: PWR, BWR or WWER.

3.2 Solution

The system follows the fuel handling machine cycle but has no interference with the normal functions of it.

A water sample is taken from the Fuel Assembly via the refueling machine mast and drawn into the hydraulic cabinet. Here, the gaseous fission products in the water are separated and analyzed. Evaluation of the measured data and controlling of the whole system are performed by a control cabinet. At the completion of the fuel handling (lifting and set down) deposition of each inspected Fuel Assembly, leaking or sound, can be determined.

3.3 Technical information

The Framatome On-Line Sipping Equipment consists of:

- One cabinet (mobile) comprised of
 - One control unit with automation based on PLC and PC
 - One hydraulic unit
- One measuring unit (mobile),
- One remote control (optional/ mobile)
- One set of tubing on the mast of the refueling machine (fixated).

The system can be quickly and easily installed and de-installed.

3.4 NPP benefit

Framatome On-Line Sipping Equipment provides the following benefit to the NPP:

- Following of the fuel handling machine cycle with minimal or no hold times
- Provides immediate information on the condition of the inspected Fuel Assembly
- Provides online evaluation, automatic display and documentation of results
- Radiation exposure is reduced due to remote control, if requested
- No interference with the normal functions of the fuel handling machine
- System can provide an additional water sample for each inspected Fuel Assembly for further radiochemical analysis by the NPP, if requested

3.5 Key-figures

Framatome USA Services:

- 12764 Fuel Assemblies inspected since 2002,
- 110 Fuel Assemblies identified as leakers,
- 99,9% of leakers detected during usual On-Line Sipping campaigns.

Framatome Germany Services:

- More than 8000 Fuel assemblies inspected since 1997,
- More than 60 Fuel Assemblies identified as leakers,
- 100% of leakers detected during usual On-Line Sipping campaigns.

Framatome On-Line Sipping Technology was chosen by New EPR NPP operators.

4. VACUUM MOBILE SIPPING

4.1 Technical description

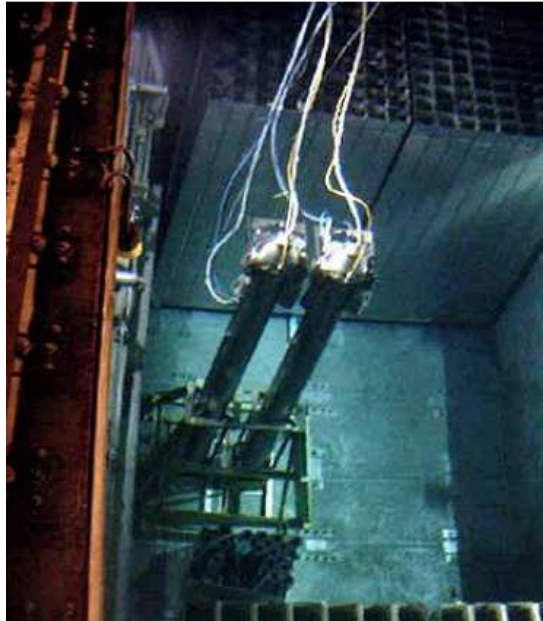


Fig 3. Framatome vacuum mobile sipping cells

Vacuum sipping is the most widespread sipping technology utilized on NPPs.

Vacuum sipping identifies failed fuel by isolating individual assemblies in a sipping canister, reducing canister pressure, and sampling for released fission gas.

Framatome's vacuum canister sipping system delivers high reliability for detecting leaking fuel in Boiling Water Reactors (BWR) or Pressurized Water Reactors (PWR) during routine Fuel Assembly off-loading or during dry cask storage preparation operation.

The vacuum sipping principle is to create a vacuum at the top of the canister in order to draw fission gases from leaking fuel rods.

System efficiency is enhanced by the recirculation of the fission gases through the system, and the detectors housing, by allowing stabilization of the fission gas count rate.

The analysis system assesses the integrity of each Fuel Assembly and identifies leaking Fuel Assemblies to the operator.

The status of each Fuel Assembly is documented.

The system consists of two separate, independently operated sipping units and may be used at either BWRs or PWRs.

The PWR and BWR systems utilize different canisters but share control systems.

The sipping canisters are designed to be located in the spent fuel pool. They may be adapted to unique facility requirements such as freestanding installations in the spent fuel pool, transfer canal, in the vessel or specific spent fuel storage rack locations with sufficient size to

accommodate the canisters.



Fig 4. Framatome sipping electrical console

Control consoles and electronic equipment are located at poolside within a 75-foot distance from the in-pool canisters.

The vacuum sipping systems incorporate several features to ensure safe and reliable operation:

- Visible and audible alarms indicate loss of service water or compressed air,
- High canister temperature,
- Insufficient vacuum or loss of the canister lid seal.

The Vacuum Sipping system utilizes high resolution beta scintillation detectors in order to measure activity of Kr-85.

Based on a 20-minute fuel movement time and a 10-minute test cycle for each assembly, a typical throughput for the two-unit system is 4 assemblies per hour; a throughput of 5-6 assemblies per hour can be achieved if the utility can support a 10-minute fuel movement time.

4.2 Features

The Framatome Vacuum Mobile Sipping Cell can sip both BWR and PWR fuel.

The Framatome Vacuum Mobile Sipping Cell has been proven on leaking fuel up to 30 years old, over 6750 Fuel Assemblies have been inspected during twenty-five (25) campaigns since 1991, it detects hard-to-find leaks, and has yields ~99.9% efficiency.

The Framatome Vacuum Mobile Sipping Cell requires no plant modification, has a short set-up time – only one 12-hour shift.

Control consoles can be set up 75 feet from the in-pool components to lower personnel dose.

5. NEW GENERATION OF BOX SIPPING WITH EATING

Utilities of nuclear power plants are facing challenges with refueling spent fuel pool storage, especially with regard to dry cask storage or external storage facilities. In some cases, Fuel Assemblies may only be reloaded or transferred to storage when all rods are leak tight.

5.1 Technical description

Framatome developed a new and flexible sipping box with simple or double-cell, Heating Box Sipping, fixed or mobile equipment (see figure 6), serving PWR, BWR and WWER requirements. It offers the following features:

- No vacuum-tight box necessary - effective insulation

The technology is based on the heat up of the Fuel Assembly with the aid of an additional heater, installed at the bottom of the cell. Therefore a vacuum tight cell is not necessary. To reduce the sipping time/speed-up the heating time, an effective, hermetically closed thermal insulation of the cell at the sides, the bottom and the hood, is installed. The gas buffer inside the hood implies an additional insulation effect during operation.

- High sensitivity

This state-of-the-art technique has a higher sensitivity than Vacuum Sipping for very long stored fuel, because after longer storage times, Cs-137 will be the predominant fission product which can be only analyzed in water sample, and because for leaking rods completely filled with water and/or grossly damage fuel rods with no gas inventory, only the heat up process provokes fission product release.

- Gas/water sampling, Gamma and Beta detection

Water samples can be taken from the region inside the hood for online measurement as well as water samples for laboratory analysis. Gaseous fission products in water (Xe-133, Kr-85) can be separated, dried and will be analyzed by beta detection; water samples (Cs-134/137, I-131) are analyzed by Gamma-ray spectrometry in radiochemical NPP laboratory.

- Mobile Box Sipping can be set up temporarily, for example where the transportation and storage cask is placed. Space requirements are similar, but the load is extremely lower. The supporting structure is designed to withstand a substantial level of seismic impacts. Additional structural measures can be implemented, if higher seismic requirements are necessary.

- Passive fail safe system – inherently safe

It is structurally assured that, after insertion and encasing of the Fuel Assembly in the sipping cell, in minimum the fuel rods are always covered by water. During filling the hood with gas for insulation, no overfilling (free overrun) of the cell or an uncovering of the fuel

rods is possible. At the lower end of the hood and at the bottom of the cell, there are free entries for the surrounding water, to ensure water expansion without pressure increase during heating. This also assures that dry out of Fuel Assembly by overheating is not possible.

- Concentration of fission products

Gaseous fission products from the leaking fuel rod(s) caused by the heating up, concentrate in a small sample space (hood) above the top of the Fuel Assembly within the sipping cell. The concentration is also driven by water convection provoked by the heating device at the bottom of the sipping cell below the Fuel Assembly.

- Fuel Inspection Efficiency

4 Fuel Assemblies can be examined per hour by a double-cell.

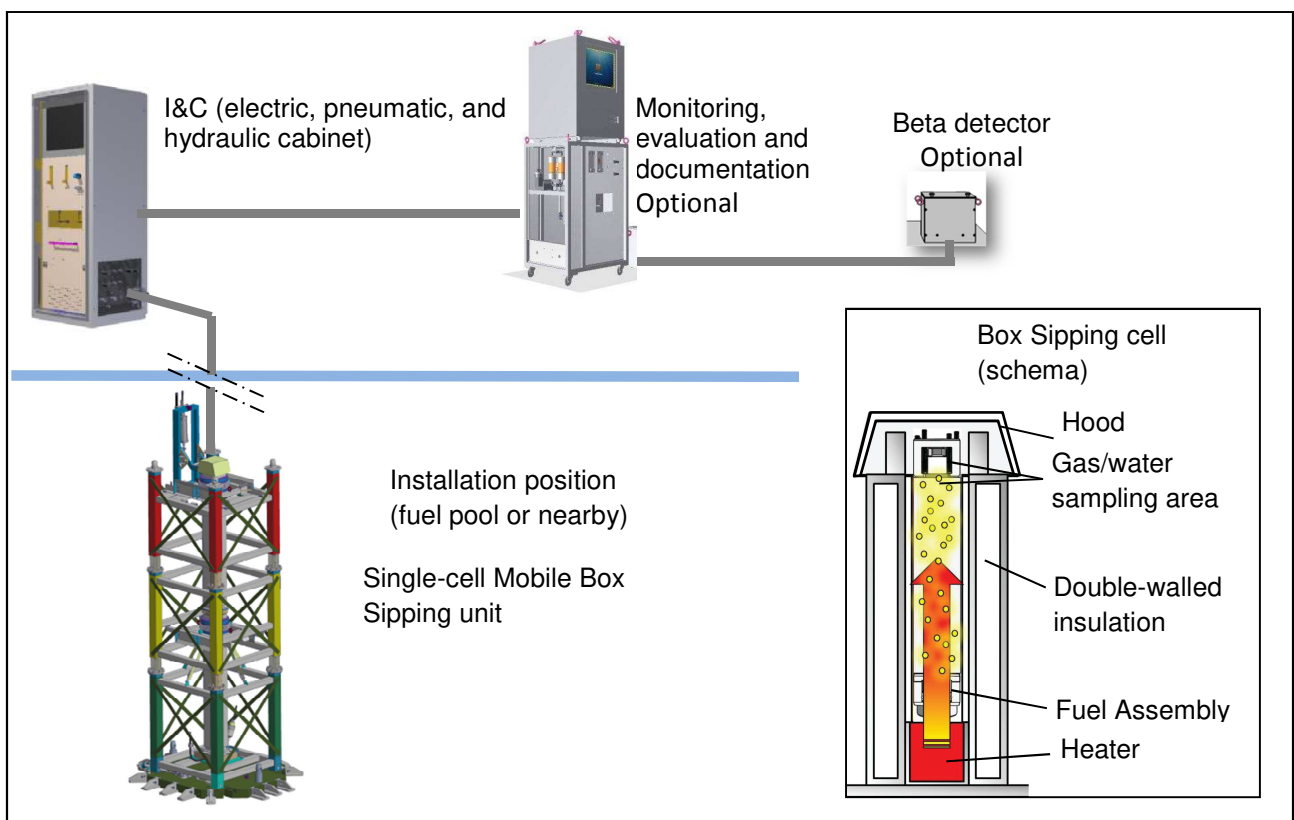


Fig 5. New generation of Box Sipping with Heating

5.2 Framatome references in Heating Box Sipping

Framatome has delivered 27 Heating Box Sipping Systems all over the world for more than 40 years, and 14191 Fuel Assemblies were tested with 100% reliability of leak tight examinations during this period.

5.3 Feature of the Heating Box Sipping

Main features of the Framatome Heating Box Sipping (Fixed or Mobile):

- Efficient inspection operation - 4 Fuel Assemblies can be examined per hour with two sipping cells
- Inherently safe
- Available for LWR and WWER Fuel Assemblies
- Online water-measuring (optional)

6. CONCLUSION

Framatome owns and masters all Sipping Technologies required to support the Nuclear Power Plant utility's needs:

- Incore Hood Sipping for BWR or WWER before core unloading
- Mast Sipping Equipment (PWR, BWR and WWER) to be performed during core unloading
- Vacuum Mobile Sipping Cells (Current Mobile Off-Line Sipping System) to be performed during core unloading or prior to cask loading campaign,
- New Generation of Box Sipping with Heating (fixed or mobile) (Inherently Safe Off-line Sipping System particularly adapted to very long time stored fuel, with completely filled in water), to be performed during core unloading or during casking campaign

Following longstanding experience on sipping technologies and measurement campaigns, Framatome is able to provide customized solution answering to specific regulatory, safety and/or economic requirements.