# SPENT FUEL PREPARATION BEFORE DISPOSAL

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## ABSTRACT

At the end of the life-cycle of nuclear fuel or the NPP there are challenges to remove irradiated fuel from the sites' wet storage pool and making the right and forward-looking steps in preparation of spent fuel for interim or final storage. Framatome's fuel business unit resources are prepared with customized solutions to manage spent fuel and other high activated core components to characterize and condition the fuel and components to meet the industry requirements taking into account local and regulatory requirements. This paper will exemplarily present activities as evaluation of behavior of highly irradiated fuel rods for long-term storage; supporting the customer in analyzing, classification and documentation of the fuel inventory; repair of fuel assemblies with minor or more special damages at the skeleton, sipping techniques for fuel assemblies with extreme long storage time, handling techniques for broken fuel rods or fuel particles and encapsulation of defective fuel rods.

## 1. Introduction

At the end of the life-cycle of nuclear fuel or the NPP there are challenges to remove irradiated fuel from the sites wet storage pool. There are two primary reasons for removal; maximum storage capacity reached or plant decommissioning. There are many technical and regulatory requirements to consider dispositioning the spent fuel and associated fuel related components. Framatome's fuel business unit resources are prepared with customized solutions to manage spent fuel and other core components to characterize and condition the fuel assemblies and components to meet the industry requirements. Framatome's vast knowledge being a nuclear reactor and fuel assembly designer coupled with extensive reactor plant service experience and capabilities bring proven solutions for these specific needs going forward. Leveraging this expertise and that of our partnerships, Framatome works to place the right solutions on the market. This paper presents various techniques and solutions to assist the customers in an early stage to license technologies and making the right and forward-looking steps in preparation of spent as well as unirradiated fuel. Framatome retains expertise to provide assistance in the following processes:

- Preparation of irradiated fuel assemblies for reprocessing by fuel rod replacement and shipment of unirradiated fuel assemblies to a fuel manufacturing site or another reactor (depending of the country-specific laws and allowance for transportation of fuel)
- Record study of fuel operating cycles, End-of-Life (EOL) cycle data and forecast (physical and mechanical constitution, forecast for long-term storage)

- Fuel inventory (analyzing, classification and documentation of the fuel inventory based on the regulatory imposed requirements, to demonstrate the expected performance or to define treatments to satisfy cask licensing for transportation and storage or fuel processing)
- Preparation of fuel assemblies and fuel for interim storage or final disposal (repair / recaging of a fuel assembly, measurements on fuel assemblies and fuel rods as required, treatment and handling of defect fuel rods and fuel, fresh fuel recovery, sampling and analyses)
- Sipping techniques (Mast-Sipping, Box-Sipping with heating, Vacuum Sipping, Single Rod Sipping)
- Encapsulation techniques (hot cell capsule, particle / gas tight capsule (screwed or welded))
- Disassembling / cutting / compacting / conditioning and packaging of core internals (high activated parts), rod cluster control assemblies (PWR), control assemblies (BWR) and fuel channels
- Assistance in special affairs (e.g. unusual defects of a fuel assembly)
- Project management and reporting, supervision and training

## 2. Preparation for reprocessing, fuel rod retraction/replacement

Depending of the country-specific laws and allowance for transportation and/or reprocessing of fuel, Framatome is able to propose:

- Preparation in the NPP of fuel assemblies or of defective fuel rods in dedicated capsules and capsules loaded in a capsule canister, ready for transport
- Replacement of defective fuel rods – preparation (encapsulation), exchange of defective fuel rods to sound fuel rods with similar geometry and physical requirements
- Preparation of unirradiated fuel assemblies or rods in the NPP and shipment to fresh fuel fabrication plant (retraction) for extraction of the fuel and processing for future use. Alternatively, if applicable, shipment to another operating reactor including rework of necessary design adaptations

## 3. Fuel operating cycle history records, EOL cycle data and forecast of spent fuel behavior

Framatome, as a fuel vendor for many NPP´s knows about the state of the fuel, physically and based on inspections, measurements or repair work, also to hot cell examinations of spent fuel and by permanent fuel design work and improvements up to very high burnup of the fuel assemblies (fuel rod burnup up to more than 100 MWd/kgHM /6/).

Therefore, a huge data base for evaluation of the irradiated fuel rod behavior for long term dry storage is available. Important mechanisms considered in licensing, which have a potential influence on fuel rod degradation during long term dry storage are:

- Oxide layer on cladding (metal wall thickness reduction)
- Hydrogen uptake of cladding
- Swelling of fuel during irradiation
- Hydrogen degradation mechanisms during dry storage
- Fast neutron fluence of cladding (irradiation hardening)
- Fuel rod inner gas pressure (due to fission gas release in reactor)
- Free volume available inside the fuel rod after service for determination of gas pressure reduction

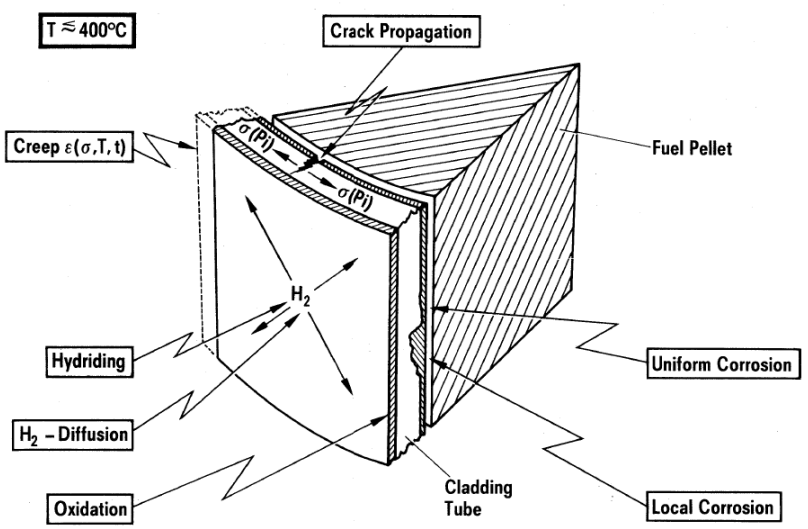


Fig 1. Postulated degradation mechanisms

Knowing in detail about the mechanisms during in-reactor operation (see Fig. 1) gives comprehensive know-how also about dry storage determination of the behavior of fuel rods. Some of the effects on the cladding important for dry storage licensing can be assessed:

- Cladding corrosion
- Zr-hydride cracking / Zr-hydride reorientation in cladding
- Cladding thermal creep taking into account irradiation hardening of the material
- Cladding ductility evaluation
- Fuel rod fracture behavior (from hot cell examinations)

## 4. Fuel inventory

At the end of the fuel life-cycle within the NPP it is recommended to analyze the fuel inventory on actual condition of the fuel assemblies and fuel rods, stored separately in canisters, by studying the existing NPP documentations and, if necessary, making some visual inspections or non-destructive measurements. The focus is, after a clear classification and documentation of the fuel inventory based on the regulatory imposed requirements, to demonstrate the expected performance or to define additional treatments to satisfy cask licensing for transportation and storage or fuel processing. Framatome Fuel Services, as a service provider and in some plants typically having accompanied the fuel during the whole operation time, has the background knowledge of fuel for evaluation available to perform the inventory.

## 5. Preparation of fuel assemblies and fuel for interim storage or final disposal

According the country-specific requirements for interim storage or final disposal the expected condition and documentation of the fuel assemblies or separated defective fuel rods could be different. Framatome Fuel Services has an extensive portfolio and is able to fulfill all the expectations of the country-specific and customer requirements for LWR plants.
Below is a representative overview of Framatome Fuel Services portfolio and capabilities for fuel assemblies and fuel rods, several of them are patented:

- Repair / preparation of a fuel assembly
    - Removal of debris and CRUD (if required)
    - Extraction of defective / broken fuel rods (special tools) and reconstitution of fuel rods with missing end plug
    - Exchange of fuel rods (dummy-, donor rod), structure parts of a fuel assembly (bottom-, top end nozzle, hold down spring, nuts and connection pieces) and exchange of fuel channel
    - Conditioning of the outer fuel assembly structure components of displaced material (grinding, cutting, back bending etc.)
    - Reconstitution of spacers and contingency measures (manufacturing and placing of a spacer segment, placing of corner part (sleeve, see Fig. 2)), setting of clips at the

outer fuel rod structure) /2/

- Expanding of spacer cells in a fuel assembly skeleton for placing a capsule (hot cell capsule containing a dry fuel rod)

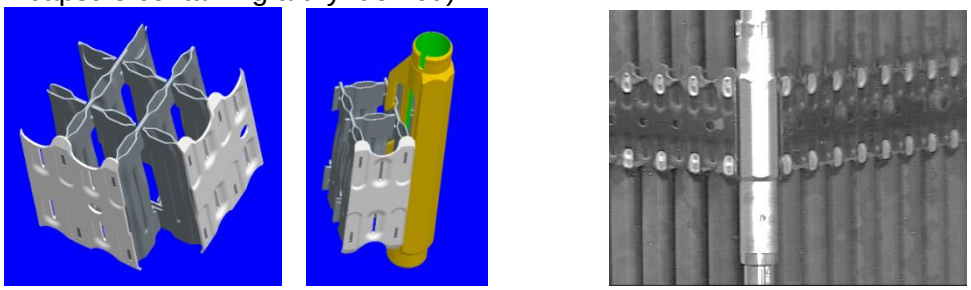

Fig 2. Cut damaged spacer corner (left) and insertion of an undetachable sleeve /2/

- Recaging of a fuel assembly (placing the fuel rods into a new or used skeleton)
- Preparation of fuel and fuel rods
  - Movement of fuel pellets with gripping tools and collection/management of fuel particles (during repair and for emptying a tube within a fuel rod canister) into a cartridge and later into a fuel rod capsule
  - Opening of the fuel rod plena (see Fig. 3) for better drying (preparation before encapsulation)
  - Movement of parts of a broken fuel rod into a handling tube
  - Encapsulation of fuel rods (see chapter 7)

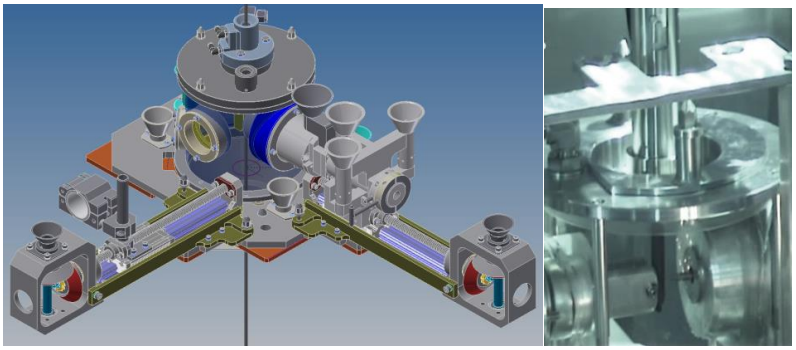

Fig 3. Tool for opening of a fuel rod plena /3/

- Measurements at a fuel assembly and fuel rod
  - Dimensional measurements at a fuel assembly (bow, twist, bulge, length)
  - Measurements at a peripheral fuel rod (length – gap to top end-/bottom nozzle, diameter, oxide layer thickness) or inner fuel rod (oxide measurement), see Fig. 4
  - Measurements at a single fuel rod (oxide layer thickness, residual cladding thickness – with/without dominant oxide layer, damage examination by eddy current (wear marks, cracks, outer/inner cladding failures etc.)

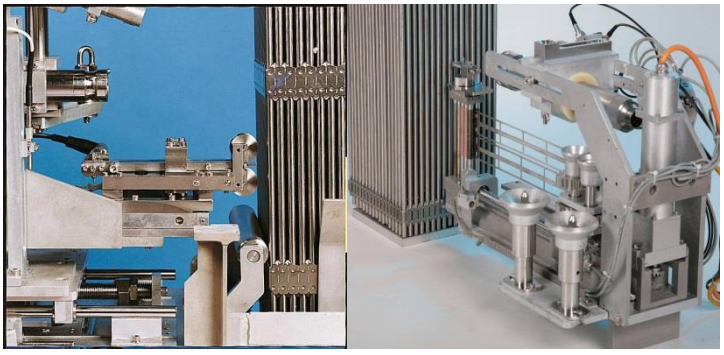

Fig 4. Fuel rod diameter measuring device for peripheral fuel rods (left) and measurement device for oxide measurement at inner fuel rods (right)

- Sipping (Box-Sipping – for long pool storage time, Ultrasonic Failed Fuel Detection, Single Rod Sipping – during fuel assembly repair), see chapter 6

- Fresh fuel recovery (see chapter 2)
    - Preparation of uncontaminated (fresh fuel taken from the NPP´s) fuel assemblies and contaminated fuel assemblies/fuel rods (fuel pool) for reshipment to a fuel manufacturing site or NPP for further use of the fuel

## 6. Sipping techniques

The objective of Sipping is to identify fuel assemblies with leaking fuel rods. For that the most used Sipping technique world-wide is Mast Sipping conducted during refueling activities. Framatome has a great experience in Mast Sipping (see Fig. 6) with high detection sensitivity and excellent customer feedback. For fuel assemblies with short storage times, showing a relatively high concentration of the fission products Xe-133 and Kr-85, the procedure of Mast Sipping is very effective. The concentration of all fission products declines with increasing storage time. After decades, only Kr-85 gas and/or Cs-137 dominated in the water phase remain for detection. Fuel assemblies with this condition can be clearly proven by Framatome's Box Sipping System with integrated heating (see Fig. 5 and 6) or Vacuum Sipping System. For challenging fuel rod failures during a repair campaign with long and short storage times it could be also helpful, for a clear identification of a defective fuel rod, to use the Framatome Single Rod Sipping technique.

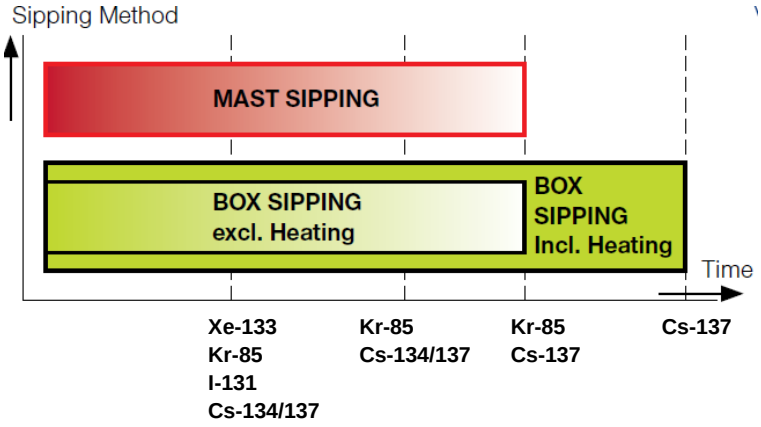


Fig 5. Sipping significant fission products depending on storage time of the fuel assemblies

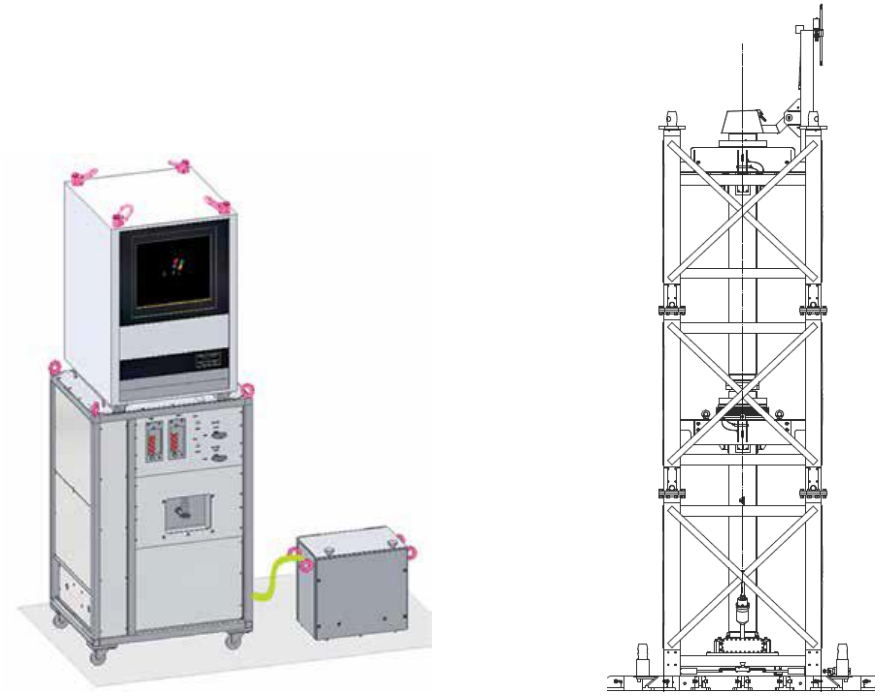

Fig 6. Main control, hydraulic and measuring unit for MAST-SIPPING (left side) and Mobile Box Sipping System with integrated heating (right side)

## 7. Encapsulation techniques

Framatome has developed several encapsulation techniques which are customized to fulfill the expectation and need. To be more flexible in further handling of fuel and to be adaptable to the requirements of packaging from onsite in a NPP, after post irradiation examination (PIE) within a hot cell up to longer wet storage time in a pool or to middle and long-term storage at a dry / wet interim storage facility or final storage, Framatome has favored the single rod encapsulation solution to be more flexible in further packaging.

Framatome is experienced and can provide the following solutions (see Fig. 7):

- Hot Cell Capsule, welded or screwable
- Particle Tight Capsule, drainable
- Gas Tight Capsule, water-filled
- Gas Tight Capsule, drainable /3/
- Gas Tight Capsule, dried /4/, /5/, see Fig. 8

For handling and collecting of displaced fuel fragments (fuel pellet fragments descended from a defective fuel rod), tools are available to manage and transfer the fragments to a cartridge (see chapter 5). The cartridge is compatible to encapsulation solutions proposed by Framatome.

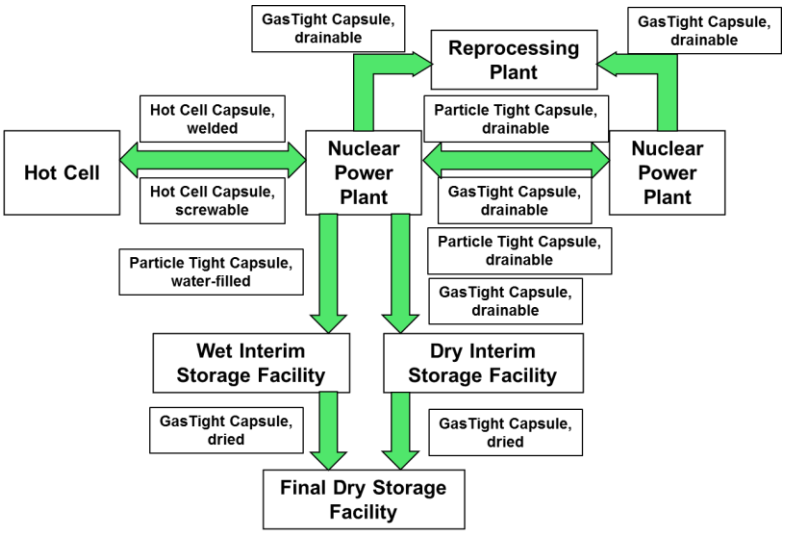


Fig 7. Customized single rod encapsulation solutions

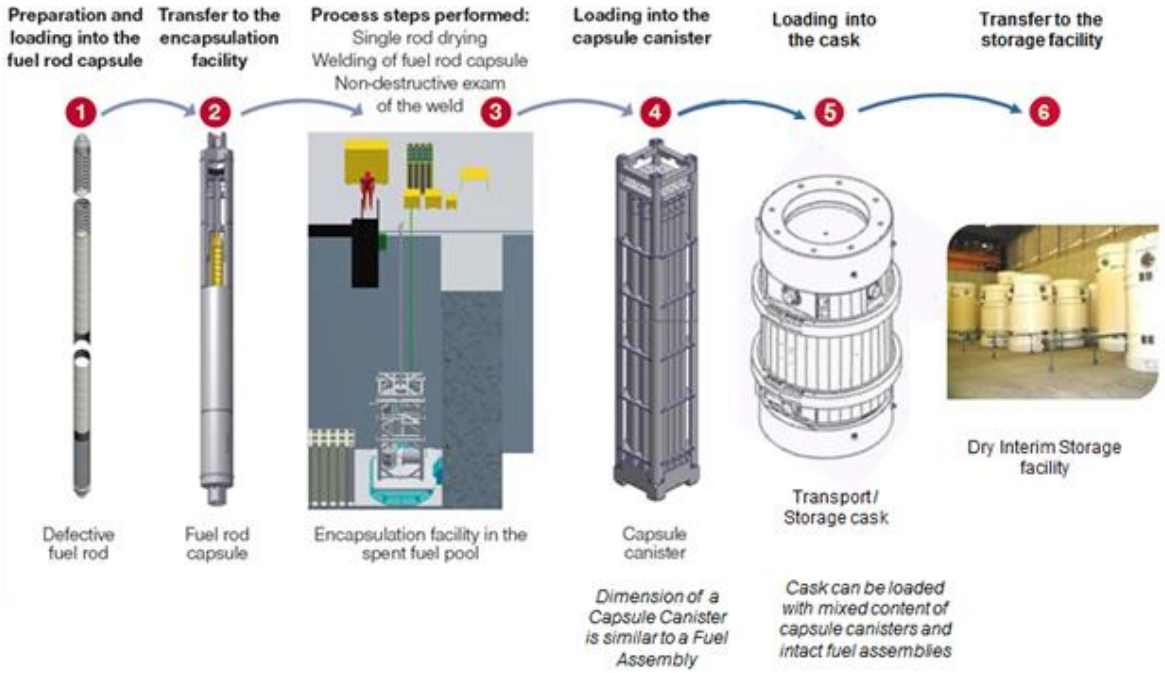


Fig 8. Process of a “Gastight capsule, dried” to move a defective fuel rod to an interim or final storage facility /4/, /5/

## 8. Preparation of fuel assembly skeletons, fuel channels and high activated core internals for final disposal

This paper is focused to spent fuel preparation. However, Framatome´s Fuel Services, in partnership and cooperation with other internal and external entities, can provide tools and technologies for:

- Characterization (sampling, measurement, material analyzing etc.)
- Treatment (cutting, compaction, conditioning, handling etc.) /1/, see Fig. 9
- Declaration, optimization in loading and on-site management
- Licensing and supply of casks and containers, handling and drying tools
- Loading, preparation and transportation

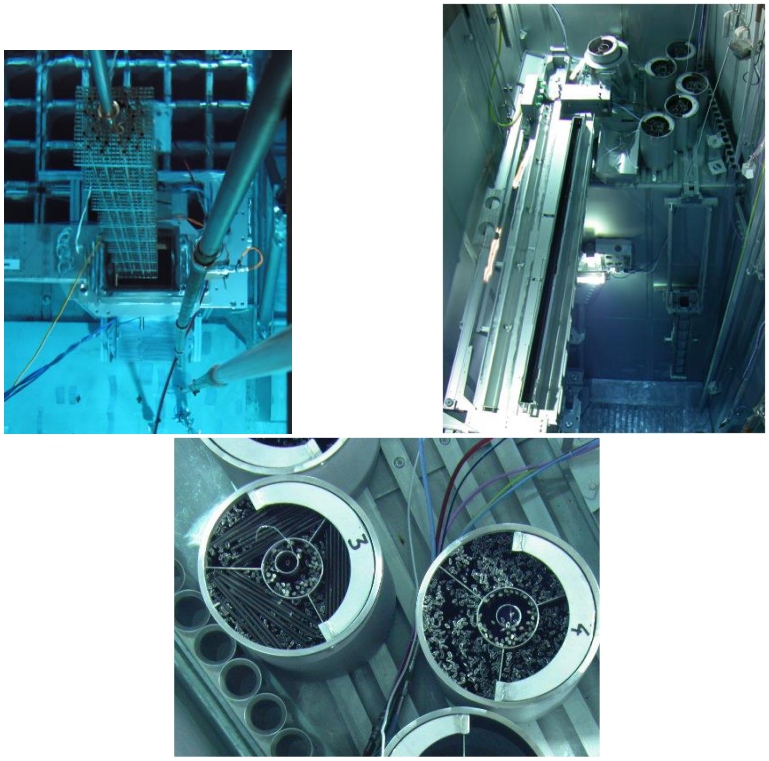

Fig 9. Conditioning of a fuel assembly skeleton (left), device for conditioning longitudinal core scrap and filled baskets with core scrap (mid and right)

## 9. Assistance in special solutions

It could happen that a fuel assembly, fuel channel or other core component comes in an abnormal condition that does not allow normal repair and it demands special actions e.g. to extract the fuel rods and to treat or to machine the fuel assembly skeleton. Framatome Fuel Services is experienced for such situations and is able to analyze the situation, provide or to develop special tools (see Fig. 10), to assist the customer in presentation of the solutions to the authority for licensing, to procure and qualify the tools and equipment according rules and regulations, to make the service on-site and to manage the whole project with providing the necessary documentation of equipment and tools as well as the service. Fuel Services can also assist in accidental scenarios (minor or major) at the NPP and prepare the spent fuel for its disposal

Some examples of special solutions are:

- Cutting of a fuel channel because of a tight interference with the fuel structure of a BWR fuel assembly
- Installation of an outer support structure to replace the wear structure of a PWR fuel assembly
- Pulling out the fuel rods of a PWR fuel assembly with extremely deformed top end nozzle

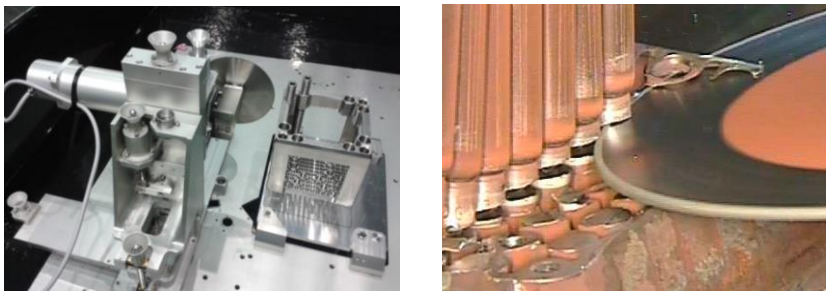

Fig 10. Test of a special cutting tool (left), bottom nozzle (BWR) – cut of tight fuel rod end plugs (right)

## 10. Project management and reporting, supervision and training

Due to Framatome Fuel Services large portfolio, experience in international projects and thereby necessarily qualified project managers our customers can be assisted to manage on-site projects and prepare necessary reporting. During implementation of new techniques and tools within the NPP´s Framatome can provide supervision or training on the job. Framatome has also training areas available to give classroom trainings with associated practical exercise.

## 11. Summary

Framatome´s capability, portfolio and experience fulfills all customer needs and expectations to get the NPP´s free of fuel and to assist in questions associated with fuel and fuel rod cladding behavior. Framatome's vast knowledge being a nuclear reactor and fuel assembly designer coupled with extensive reactor plant service experience and capabilities in NPP´s worldwide, bring proven customized solutions for these specific needs going forward. Leveraging these expertise and that of our partnerships, Framatome works to place right solutions on the market.

## 12. References


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