MANUFACTURING IMPROVEMENTS FOR FUEL RELIABILITY

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ABSTRACT

Nuclear fuel manufacturing includes an important number of processes, some of them very specific, requiring a high degree attention to safety, quality and efficiency. The paper presents the developments on manufacturing processes in Juzbado, and how they contribute to accomplish high reliability performance in the reactor. The paper also discusses a Nuclear Fuel Fabrication Knowledge Management Data Base developed by ENUSA to link fuel failure and performance mechanisms with the product Critical Fuel Reliability Attributes and the key manufacturing process parameters.

1. Introduction

ENUSA nuclear fuel manufacturing plant in Juzbado (Salamanca, Spain) began to supply fuel assemblies to the Spanish PWR and BWR nuclear power plants in 1985. Now fuel assemblies manufactured by ENUSA operate in 42 plants in Europe with excellent reliability. Improvements in manufacturing, in conjunction with loading pattern risk analysis and the evolution of the product design are key factors for achieving reliability goals.

Nuclear fuel manufacturing includes an important number of processes, some of them very specific, requiring a high degree attention to safety, quality and efficiency. This paper presents the last developments on manufacturing processes in Juzbado, and how they contribute to accomplish high reliability performance in the reactor. The fuel failure and performance mechanisms identified in EPRI's "Critical Fuel Reliability Attributes for Fuel Fabrication Surveillance" (1) are addressed:

- Debris;
- Pellet Cladding Interaction (PCI);
- Grid-to-Rod Fretting (GTRF);
- Fuel Assembly/Cladding Corrosion;
- Crud Induced Localized Corrosion (CILC) and Crud Induced Power Shift (CIPS);
- Manufacturing defects
- Fuel Rod, Fuel Assembly, BWR Channel and Core Component Distortion

Manufacturing improvements in production and inspection are discussed in relation to each one of these fuel failure and performance mechanisms.

The paper also discusses a Nuclear Fuel Fabrication Knowledge Management Data Base developed by ENUSA to link fuel failure and performance mechanisms with the product Critical Fuel Reliability Attributes and the key manufacturing process parameters.

2. Developments on manufacturing processes in Juzbado

Reference (1) ranks the impact of each Critical Fuel Reliability Attribute (CFRA) on each failure mechanism or performance issue as High, Medium, Low or Not Applicable. This section presents the developments to address the CFRAs ranked high for the processes carried out in Juzbado (fuel pellet, fuel rod, skeleton assembly, fuel assembly).

2.1 Debris

Debris filters are incorporated to PWR and BWR fuel assemblies. Hardened coating is used in the lower part of the PWR fuel rod cladding to mitigate debris fretting. This coating in combination with the Robust Protective Grid and the Debris Filter Bottom Nozzle constitutes a three-layer anti-debris protection system. In addition, strict Foreign Material Exclusion practices are followed in the manufacturing plant.

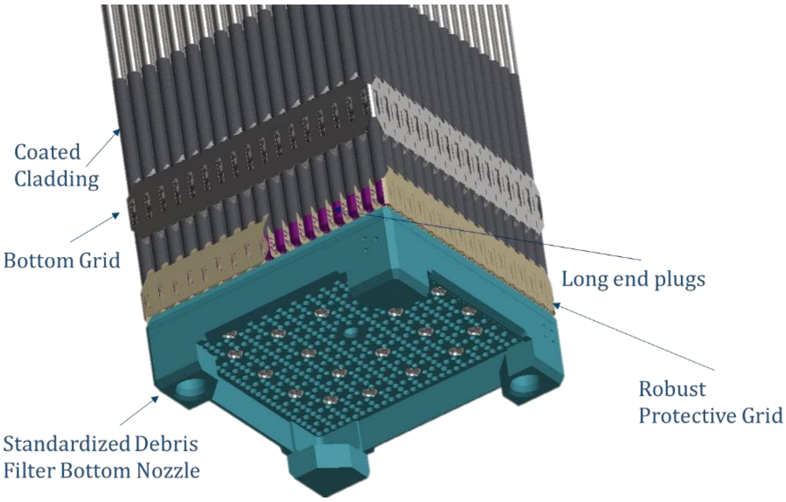

Figure 1. Anti-debris protection

The coating is Zirconium dioxide (ZrO_2) produced in Juzbado by thermal oxidization of the clad in an air environment. During the fuel rod manufacturing process, the bottom end plug is first pressed and then welded into the fuel tube. Then the coating process of the fuel tube is performed by oxidation of the lower part of the rod in a furnace. In order to avoid manual handling, a new lay-out was developed to insert this new process into the fuel rods manufacturing flow chart.

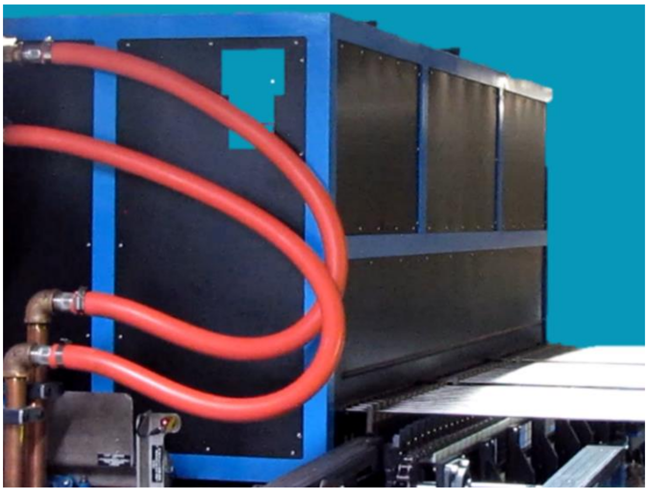
Figure 2. Coating furnace

2.2 Pellet Cladding Interaction (PCI)

Missing pellet surface (MPS) rises clad stresses due to pellet clad interaction and increases the risk of PCI failure during a transient or in the ascension to power after refueling.

To improve the MPS detection capability, there are two Pellet Automatic Inspection machines (IAP, Inspección Automática de Pastillas) working in Juzbado facility. The IAP have a LED light system and a CCD linear camera that scans the generatrix of around 20 pellets in a row. As pellets are being turned, it is possible to take a photograph of the pellet surface. Each defect in the pellets is characterized by brightness, area, location, etc. Depending on the combination of these parameters the system identifies the defect and compares it with visual standards using algorithms specially developed. The system stores the location of each rejectable pellet, then pellets are transferred in the same relative position to the extraction area where a grip retires the rejectable pellets.

The rate and magnitude of the Missing Pellet present in the pellets accepted by the equipment is well below the values that would contribute to the risk of PCI failure.

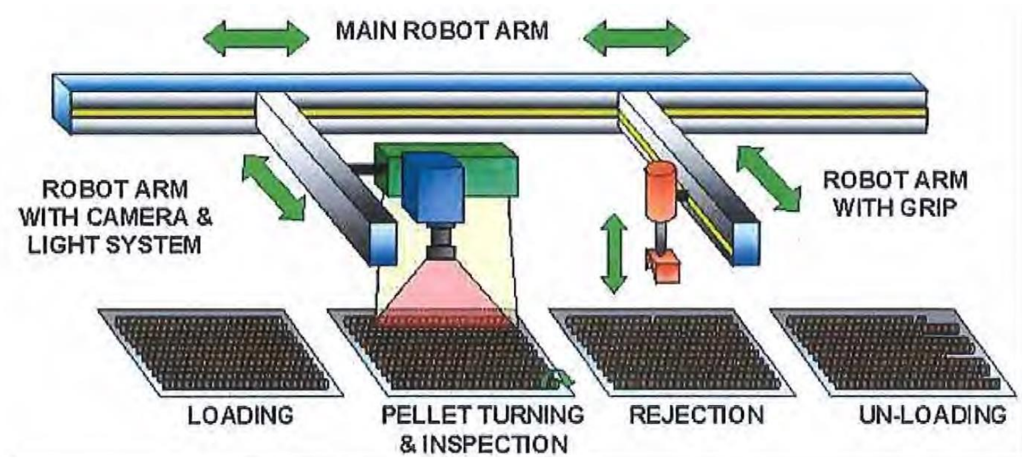

Figure 3. Pellet Automatic Inspection (IAP)

2.3 Grid-to-Rod Fretting (GTRF)

Cell deformation during rod loading can result in inadequate grid spring contact, leading to flow induced vibrations and a risk for GTRF.

To avoid improper fuel rod interaction with the grid spring during fuel rod loading, a very accurate alignment is required between three parts:

- magazine: box that stores the fuel rods to be loaded in the skeleton
- strongback: beam that support the skeleton
- pulling equipment: equipment that holds the bars and the mechanism that pulls the rods from the magazine into the skeleton.

The PWR final assembling equipment is designed to facilitate the alignment between these parts.

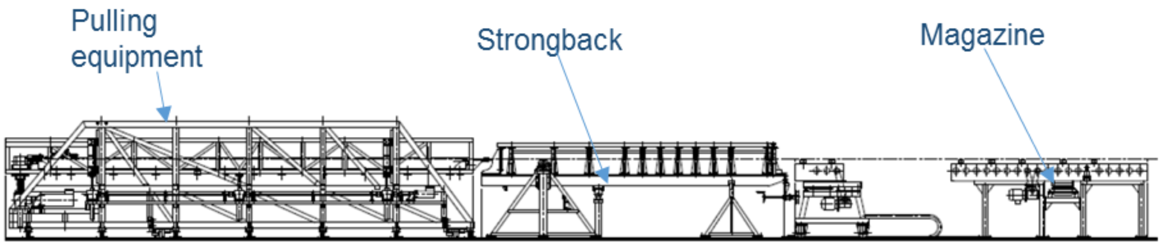

Figure 4. PWR Final Assembling Equipment

2.4 Corrosion/Crud

High enrichment, lower than specified absorber, pellet to pellet gaps, improper burnable absorber distribution can lead to high local power that would enhance corrosion and crud deposition in the fuel rods.

In ENUSA, the absorber distribution defined by the nuclear designer (nuclear model) is transferred by digital means from the nuclear code to the fuel rod magazine or storage from which the fuel rods are loaded in the skeleton.

The nuclear design code provides a file to the Automatic Bill of Materials software (ALMA). ALMA reads this information and supplies it, also digitally, to the Manufacturing Management System (MEDEA).

The "Automated Rod Loading of Magazines" equipment loads automatically the magazine with the fuel rods arranged inside the magazine with the same configuration that they will have in the fuel assembly. The equipment is designed to load any type of matrix up to a maximum of 264 rods (17x17 matrix) or VVER matrix which is supplied by the Manufacturing Management System (MEDEA). The equipment is able to communicate with MEDEA, read and write in its data base.

The equipment is made up of an infeed ramp with a bar code reader, a reject tray, a support for the magazine, a positioning system to introduce the rod in the correct position, an automatic and an electric system to control the equipment.

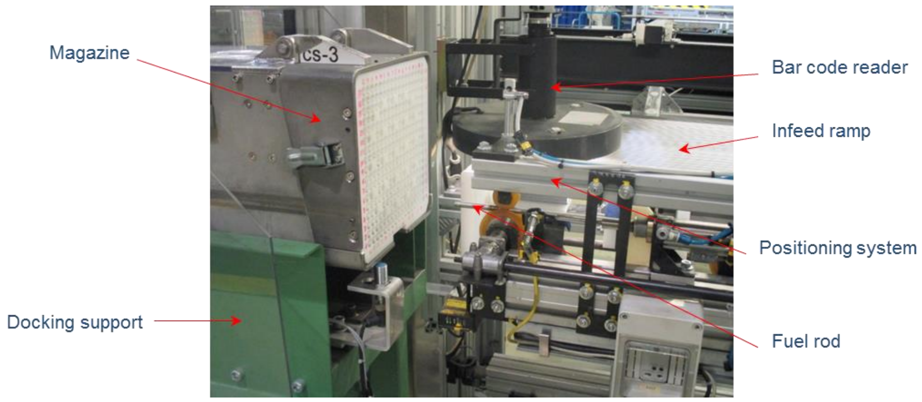

Figure 5. Automated Rod Loading of Magazines

Enrichment, absorber concentration and pellet-to-pellet gaps are controlled with gamma scanners.

A new High Speed Passive Gamma Scanner is being qualified at the Juzbado facility. This new scanner is going to replace the current active scanner.

The scanner is equipped with two independent inspection lines. Each inspection line has:

- A rod transport system that receives a fuel rod from the rod inspection line and sends it for inspection to one of the two scanner lines.
- Enrichment detectors that collect spontaneous gamma emissions from uranium isotopes. The processed signal gives the enrichment and is used to identify defects in the fuel stack and to measure fuel enrichment and zone lengths.
- A double Americium-241 densitometer that measures incoming gamma rays from the radiation source through a small collimator and through a fuel rod. The software composes a signal of the two densitometer profiles along the fuel rod length. This density profile is analysed for all the dimensional measurements: rod length, column length, plenum length, retainer spring compression length and gaps.
- Magnetic and non-magnetic gadolinium detectors. The system measures the Eddy current induced in the fuel by a rapidly alternating magnetic field to produce the gadolinium content dependent signals.
- Software: the computer processes all the signals received from the enrichment, Americium and Gadolinium detectors and provides digitally the results, signals and evaluation parameter records.

Figure 6. Passive Gamma Scanner High Speed

2.5 Manufacturing defects

Lack of fuel rod welds integrity could lead to weld and rod failure. A helium leak check is important to verify that the rod is tight, but the lack of helium backfill gas can negate the leak check as it relies on helium being present.

In ENUSA's Juzbado manufacturing plant, a laser micrometer is incorporated in the pressurization equipment. The fuel tube diameter increases as helium goes into the rod during the sealing process. The process stops if a problem with the pressurization is detected.

2.6 Distortion

Out of specification fuel rod length could result in rod distortion due to decreased gap for growth.

Thanks to an automatic visual inspection, the length of every rod is recorded and checked. The automatic rod length measurement equipment inspects the length of PWR fuel rods through a multi-camera artificial vision system to certify the product manufactured in ENUSA. During the equipment adjustment, a total length is obtained using a certified PWR standard.

The artificial vision system captures the distances to the ends of the PWR standard inside each inspection window as images and converts them from digital format (pixel) to millimeters. In the subsequent length measurement operation, this total length is used to obtained the length of the PWR fuel rod by subtracting the distances to the ends of the PWR fuel rod. Finally the obtained length is transferred to the Manufacturing Management System (MEDEA).

The automatic rod length measurement equipment is made up of the next elements: a barcode reader that assigns the identification of the PWR fuel rod to the measured length; a cradle where the PWR fuel rod is deposited for the length measurement; one CCD camera (camera 1) with fixed position at the top of the upper end of the fuel rod, one CCD camera (camera 2) with adjusted position at the top of the lower end of the fuel rod.; retro illumination; a controller unit that calculates the length measurement of the PWR fuel rod.

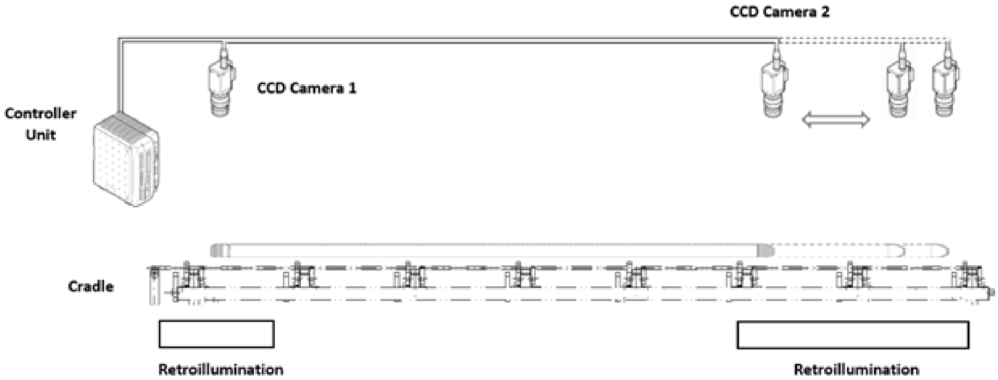

Figure 7. Automatic rod length measurement

3. Nuclear Fuel Fabrication Knowledge Management Data Base

ENUSA Product Design together with the Production Units has performed an exhaustive study of the fuel manufacturing process to develop a Nuclear Fuel Fabrication Knowledge Management Data Base.

The study begins with the ranking of the CFRA for importance relative to impacting one of the failure or performance issues. Then, for each step of the process, the effect of each process parameter on each CFRA is analyzed considering its failure mode and the probability of the failure passing undetected.

The result of the process is a database that is used to identify:

- Which parameters of the process have the greater impact on each CFRA;
- Which CFRAs are more dependent on each process.

This database permits to prioritize the process improvement plans and helps to identify the causes of emerging issues.

4. References

1 Critical Fuel Reliability Attributes for Fuel Fabrication Surveillance. EPRI, Palo Alto, CA: 2015. 3002005549