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On the impact of the fuel assembly design evolution in the spent fuel management

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INTRODUCTION: SPENT FUEL MANAGEMENT IN SPAIN

- Spanish model based on **Dry Storage**
- **Current situation**: some NPPs storing fuel assemblies in casks
- **Near future**: Spanish spent fuel (9 spent fuel pools) transported to a centralized interim storage facility (ATC)
- **Regulation** by Spanish National Safety Council (CSN). Based on dry storage and transportation US NRC 10 CFR parts 72 and 71
- Damage fuel definition in **ISG-1 Rev.2**:

Damaged fuel is any fuel rod or fuel assembly that cannot fulfill its fuel-specific or system-related functions

INTRODUCTION: ENUSA IN THE NUCLEAR FUEL CYCLE

ENUSA state owned company:

- Engineering
- Manufacturing (350 Tm, PWR and BWR)
- On-Site services

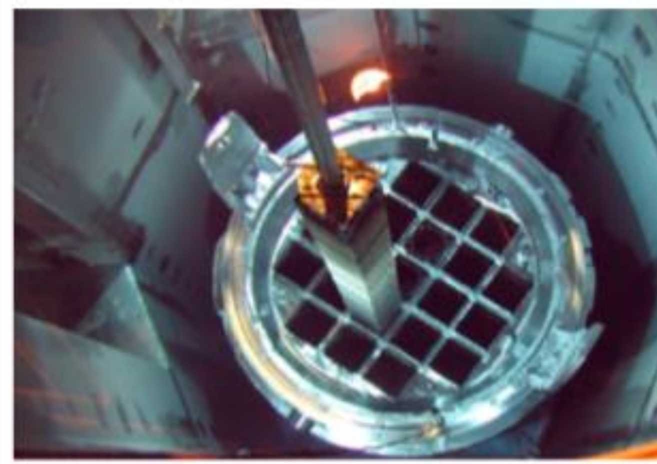
➢ **Madrid:** Engineering and Commercial

➢ **Juzbado (Salamanca):** Fuel Assembly Manufacturing and On-Site Services

INTRODUCTION: ENUSA IN THE NUCLEAR FUEL CYCLE

- **> 40 years** on design, manufacturing, follow up, on-site services, etc. of **PWR** and **BWR** fuel in several **European NPPs**
- **>10 years** on **spent fuel** characterization, inspection, conditioning, classification and loading into dry storage casks in Spanish NPPs

ENUSA has deep **knowledge** and **experience** of the entire nuclear **fuel cycle** and possible effects of different steps of the fuel cycle in late steps



OBJECTIVE OF THE PRESENTATION

Effects of the **evolution** of fuel assembly design in the **spent fuel management.** Through three representative examples on PWR fuel:

1. **Fuel rod design**: rod internal pressures,
2. **Assembly materials**: stress corrosion cracking,
3. **Fuel rod materials**: Zr oxide layer spalling.

For each example: spent fuel **regulation basis**, phenomena **description**, **impact** on spent fuel management and ENUSA **solutions**.

1.-FUEL ROD DESIGN: HIGH FUEL ROD INTERNAL PRESSURE

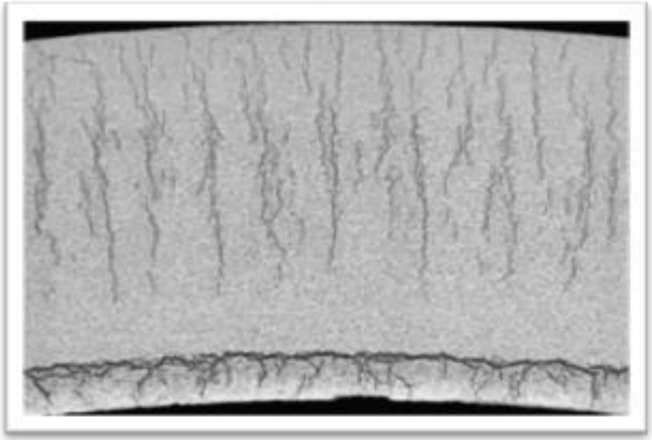
ISG 11 Rev. 3 "Cladding Considerations for the Transportation and Storage of Spent Fuel"

Low burnup fuel *(BU < 45 MWd/kgU)*

- *Cladding T < 400ºC for normal conditions and short-term loading operations*
- *If short-term loading operations cladding T > 400 °C , $\sigma_\theta \leq 90$ MPa (σ_θ, hoop stress, should be calculated)*

Goal:

Avoid hydride reorientation = cladding with lower mechanical properties



1.-FUEL ROD DESIGN: HIGH FUEL ROD INTERNAL PRESSURE

- **First PWR fuel rods** had:
  - High as-built internal pressure to avoid cladding collapse
  - Low plenum length to compensate irradiation growth
  - Non-controlled pellet porosity
  - Constant pitch plenum spring

Low volume to accommodate FGR

- **Impact on spent fuel management** : several assemblies having first rod designs for which σ_θ<90 MPa should be justified

- **ENUSA** has developed a hoop stress calculation **methodology:**
  - By **thermomechanical code** calculations
  - Cladding **axial temperature profile** inside the cask

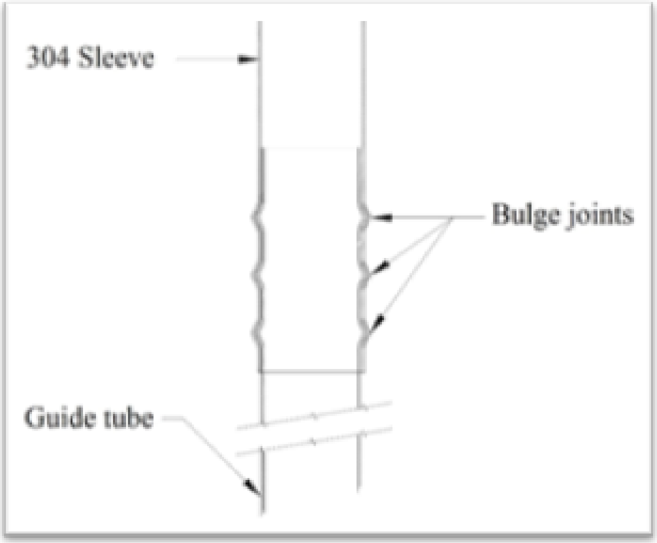
2.- ASSEMBLY MATERIALS: STRESS CORROSION CRACKING

ISG 2 Rev. 1 "Fuel Retrievability"

- *Fuel assemblies must be retrievable by normal means (grapple and hook). Those assemblies that cannot meet this criterion should be placed in a can for damaged fuel or modified, so the assembly or can may be ready retrievable from the storage canister by normal means".*

- First **PWR** designs SCC of SS304 top nozzle sleeves

  - **Material**: sensitized 304 stainless steel
  - Residual **stresses** after cold bulge deformation
  - **Environment**: non controlled sulfate concentration in the SFP



2.- ASSEMBLY MATERIALS: STRESS CORROSION CRACKING

- Risk of top nozzle detachment, affecting to ready retrievability requirement

- **Impact on spent fuel management:**

  - More than 18000 affected assemblies worldwide
  - Sleeves visual inspections
  - Handling limitations
  - Handling using special tooling
  - Conditioning to be handled by normal means

- Avoided by **design evolution** to a different top nozzle joint concept

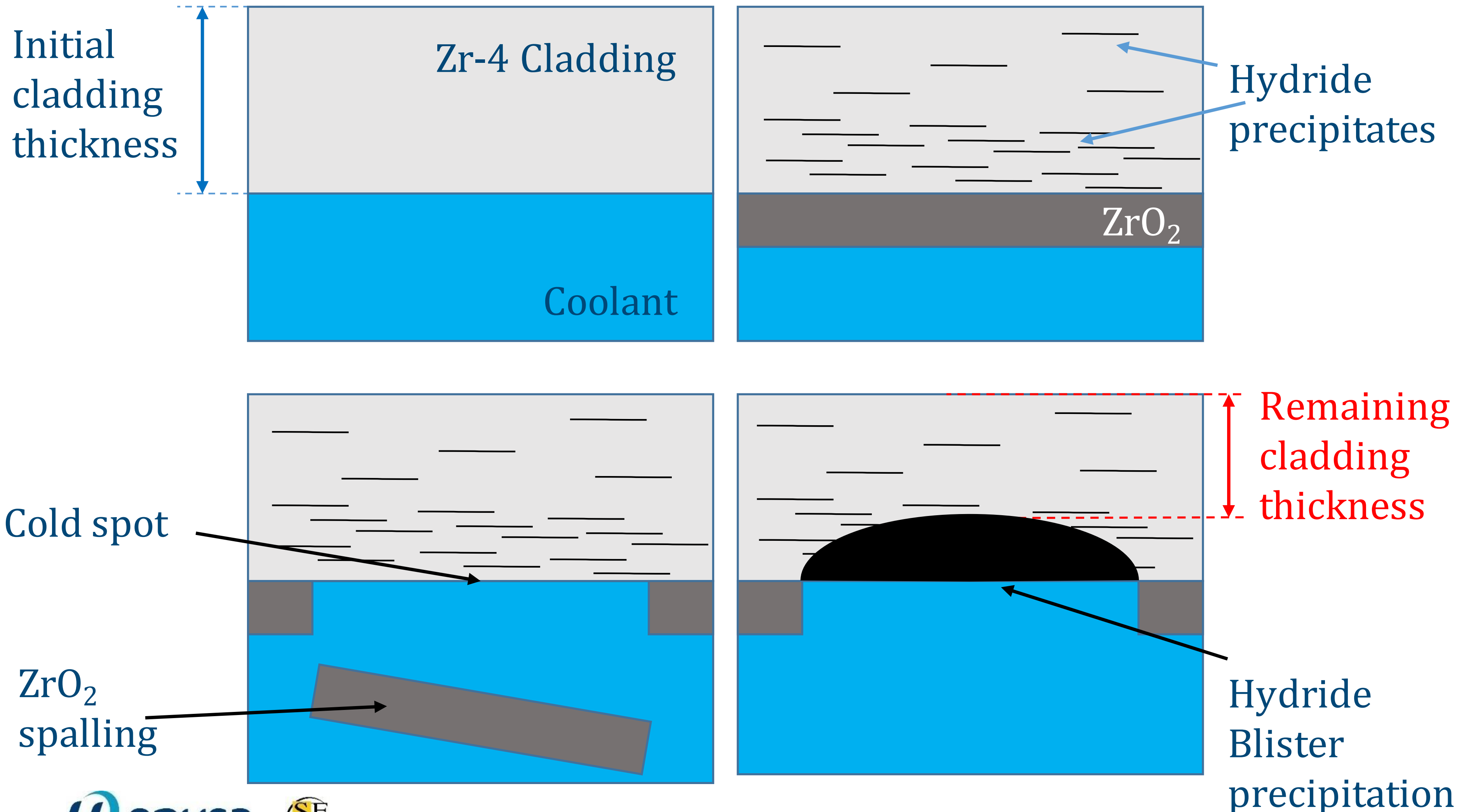
- For the old designs, **ENUSA** is currently performing visual inspections and handling with limitations the Spanish fuel affected by SCC

3.- IMPACT OF CLADDING MATERIALS: OXIDE SPALLING

ISG 1 Rev. 2 "Classifying the Condition of Spent Nuclear Fuel for Interim Storage and Transportation Based on Function"

- *The spent fuel cladding must be protected during storage against degradation that leads to gross ruptures*.
- *The geometric form of the package would not be substantially altered.*

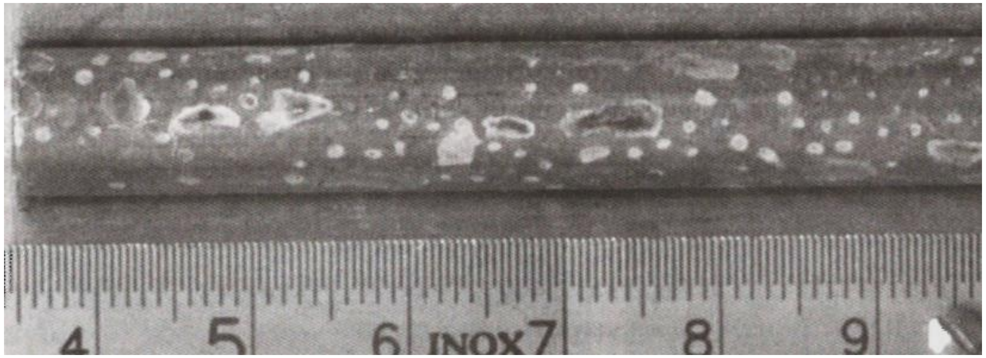
3.- IMPACT OF CLADDING MATERIALS: OXIDE SPALLING



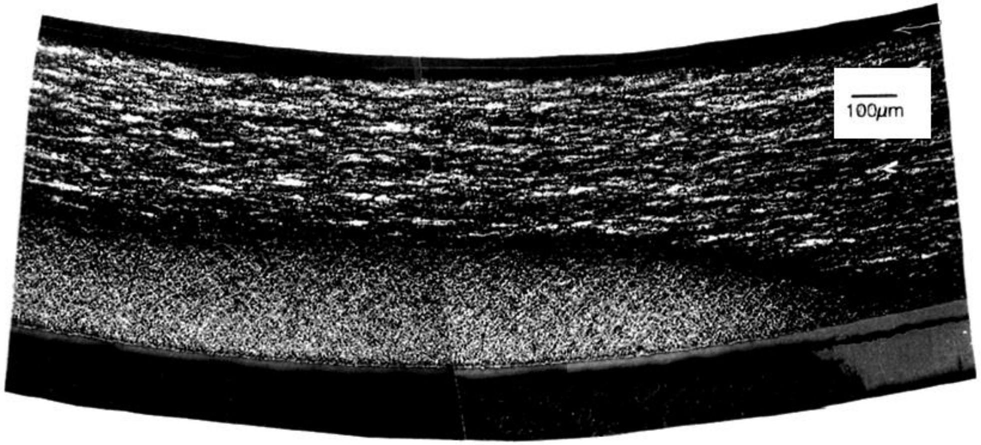
3.- IMPACT OF CLADDING MATERIALS: OXIDE SPALLING

- Zircaloy-4 cladding oxide layer spalling

  - Primary coolant contacts the base metal: **cold spot**
  - Local ΔT → massive Zr hydride precipitation: **hydride blister** (brittle)



P. Bossis, ASTM STP 1467 (2006)



A.M. Garde, ASTM STP 1295 (1996)

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IMPACT OF CLADDING MATERIALS: OXIDE SPALLING

- Possible local decrease of cladding mechanical integrity for storage and transportation in the spalled areas

- **Impact on spent fuel management:**

  - Several Zircaloy-4 cladding assemblies are affected (not observed in ZIRLO cladding)
  - Cladding visual inspections

- **ENUSA,** in collaboration with other partners in the Spanish nuclear industry, has analyzed this effect by conservative calculation

- Besides, **ENUSA** is involved in **R&D programs** focused in obtaining knowledge and data about the fracture modes during dry storage and transportation of fuel cladding affected by hydride blister precipitation.

SUMMARY

- Analysis of the evolution of three main PWR fuel assembly design fields and their **impact on spent fuel management**:

    - High rod internal pressures in transportation and storage,
    - Stress corrosion cracking in spent fuel retrievability,
    - Zr oxide layer spalling in transportation and storage.

- **Knowledge** of the past and current designs and the potential effects of future **design changes** are fundamental in order to accomplish an optimum spent fuel management.

- The **design process** should **include** an analysis of the **impact of the design changes** in the future spent fuel management.

THANK YOU FOR YOUR ATTENTION

QUESTIONS?

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