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FRAMATOME advanced solutions against grid-to-rod fretting wear risk

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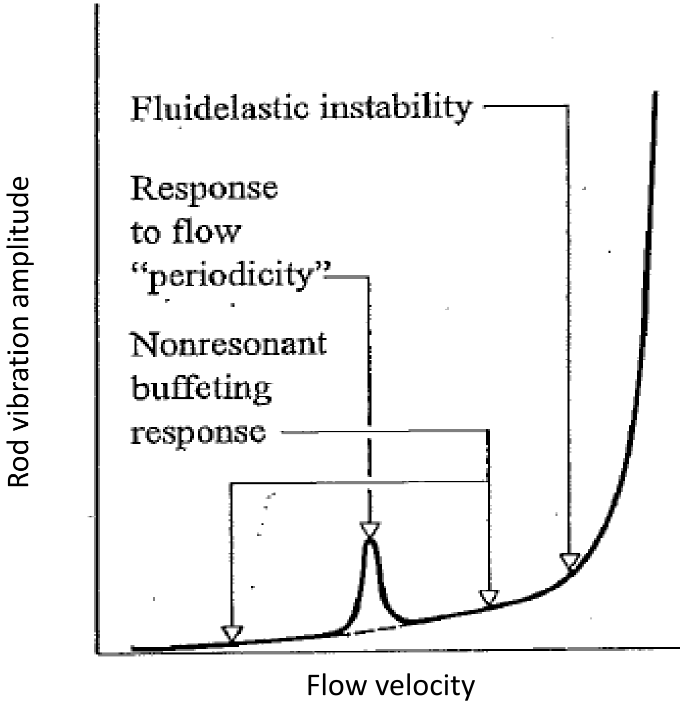
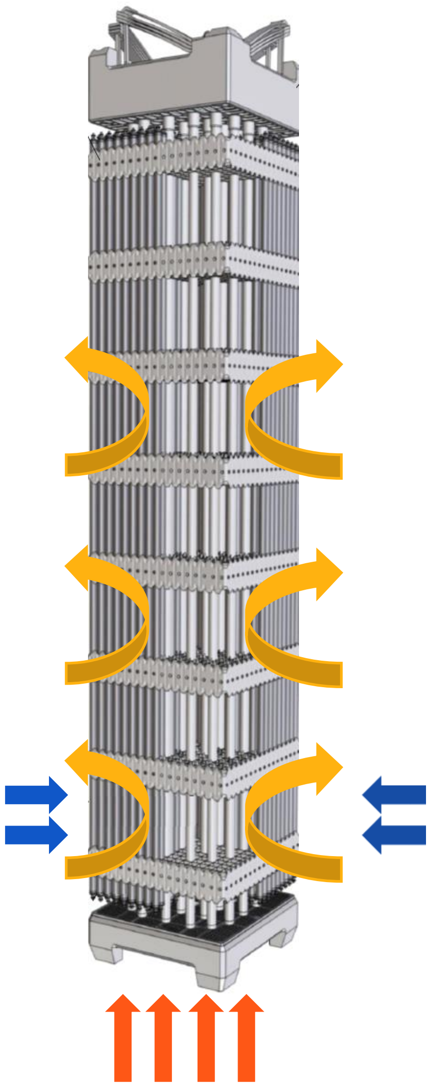
Context (1/2)

- **Grid-to-rod fretting (GtRF) results from the complex multi-physics coupling of:**
  - Highly turbulent flow inherent to the reactor operation
    - Axial flow jets through the Lower Core Plate holes (LCP) + bottom nozzle
    - Turbulence generated by the grid mixing vanes
    - Transverse flow redistribution inside the core
  - Multi-supported fuel rods dynamic response, whose characteristics evolve through time due to irradiation-induced relaxation of the supports
  - Tribological interactions at the interface between the cladding and its supports





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Context (2/2)

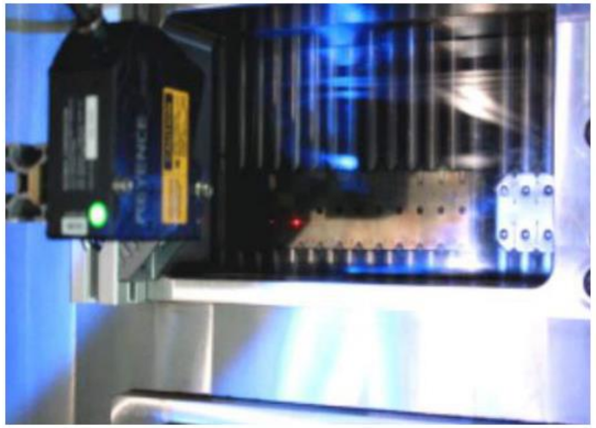
Grid-to-rod fretting in
an PWR 1300 (IAEA, 2010)

- **Although current industry trends indicate that the number of GtRF-induced failures has decreased over the last decade, it remains a strong concern for fuel vendors, utilities, and regulators worldwide**
  - Ever-present turbulence-induced excitation should be overcome by appropriate design of the rod support
  - Adequate design of the fuel assembly architecture should also prevent resonant response (e.g. SIE)

- **Leveraging its extensive experience in nuclear fuel design, Framatome has developed a set of solutions to address GtRF and ensure the highest level of performance of its products**

Experimental protocols (1/2)

PETER loop testing hall



Laser measurement in PETER test facility

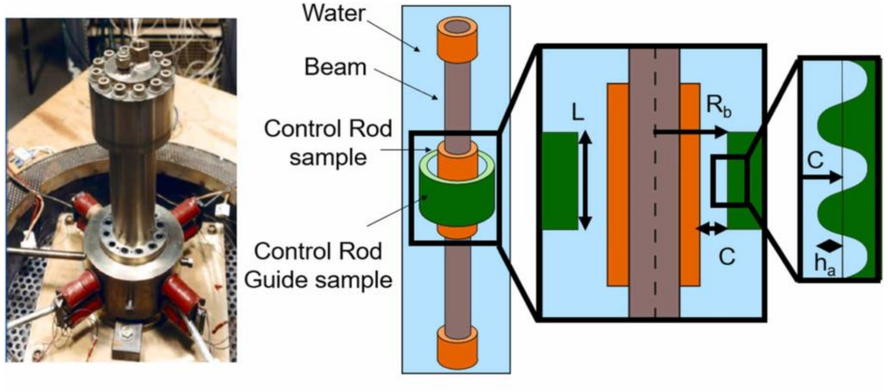
- **Framatome leverages several full-scale hydraulic loops to characterize the GtRF robustness of its products under representative conditions**
  - PETER Loop flexible set-up allows for a variety of configurations (e.g. axial flow sweep, crossflows) and measurements (e.g. rod vibrations, fuel assembly motion, flow fields…)
  - HERMES-T and HERMES-P (operated by CEA) allow respectively for bi-assembly testing and life & wear test in representative operation thermal-hydraulic conditions
  - Testing is done on representative FA mock-ups prepared specifically to achieve penalizing configuration (e.g. damping and/or rod support)

→ Supports direct demonstration of resistance to GtRF

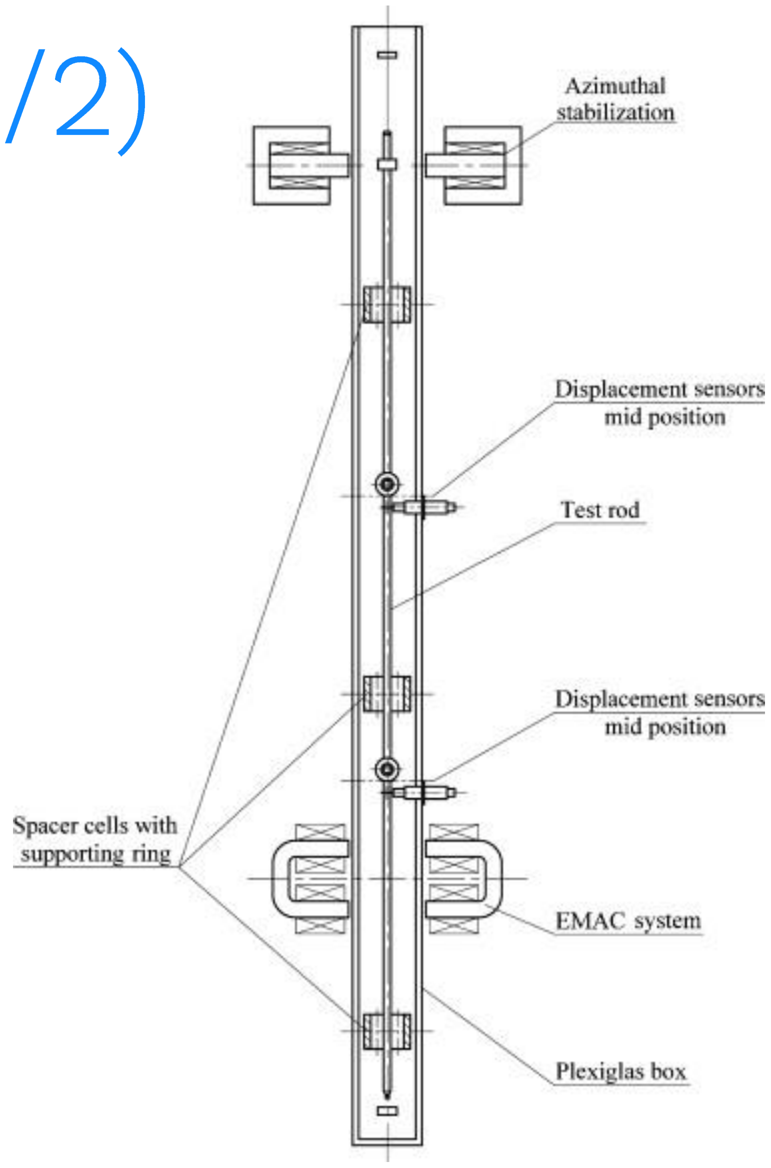
→ Provides reference experimental datasets to support model V&V

Experimental protocols (2/2)

- **In addition, Framatome has developed in-house analytical test set-ups for product optimization**
  - Leveraging the expertise of its Technical Centers in Karlstein, Richland and Le Creusot
  - Multi-parameter testing allowing for multiple configurations with respect to excitation & rod support condition
  - Includes tests in representative PWR conditions



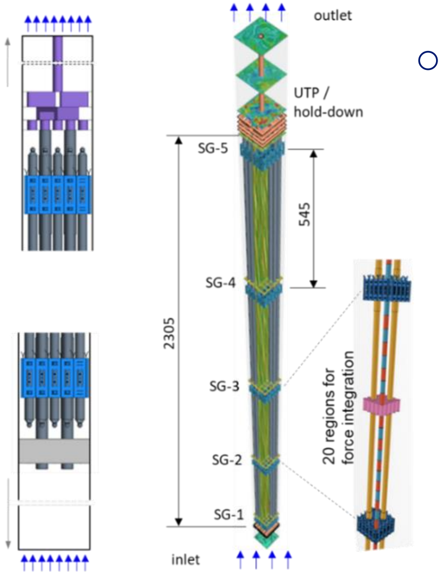
Aurore test bench



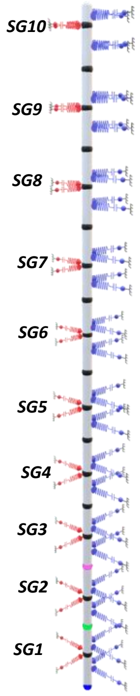
Single rod fretting test in Karlstein Prototyping Lab

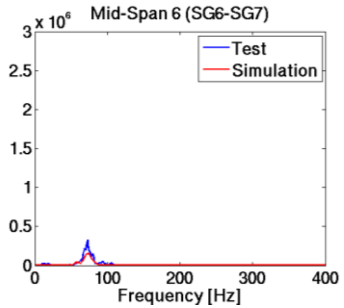
Modeling (1/2)

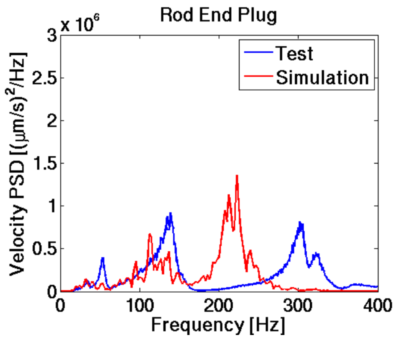
- **To complement the tests Framatome has developed a set of advanced modeling tools using state-of-the-art simulation techniques to gain insight about GtRF phenomenology**

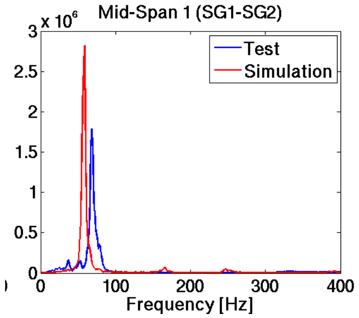


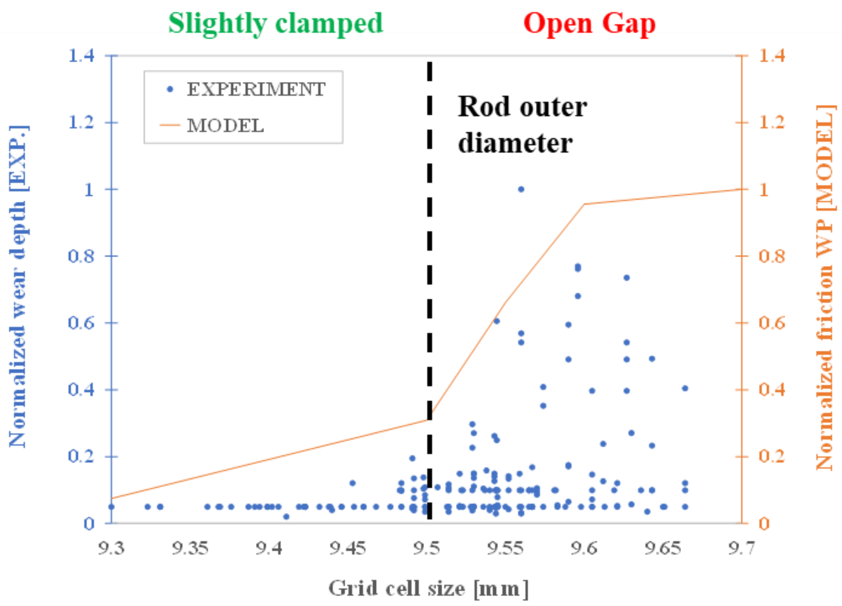
- Unsteady CFD is used to predict turbulent loads acting on the fuel structures
- Non-linear finite element simulations are run to evaluate fuel rod vibration amplitudes and assess the fretting wear risk based on appropriate metrics











Proven prediction capability for a wide range of configurations

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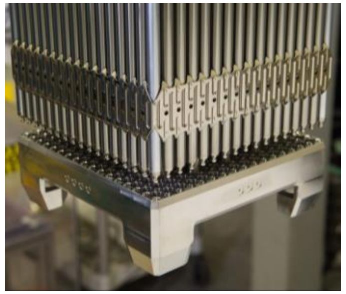
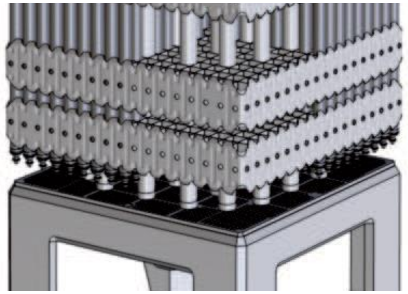
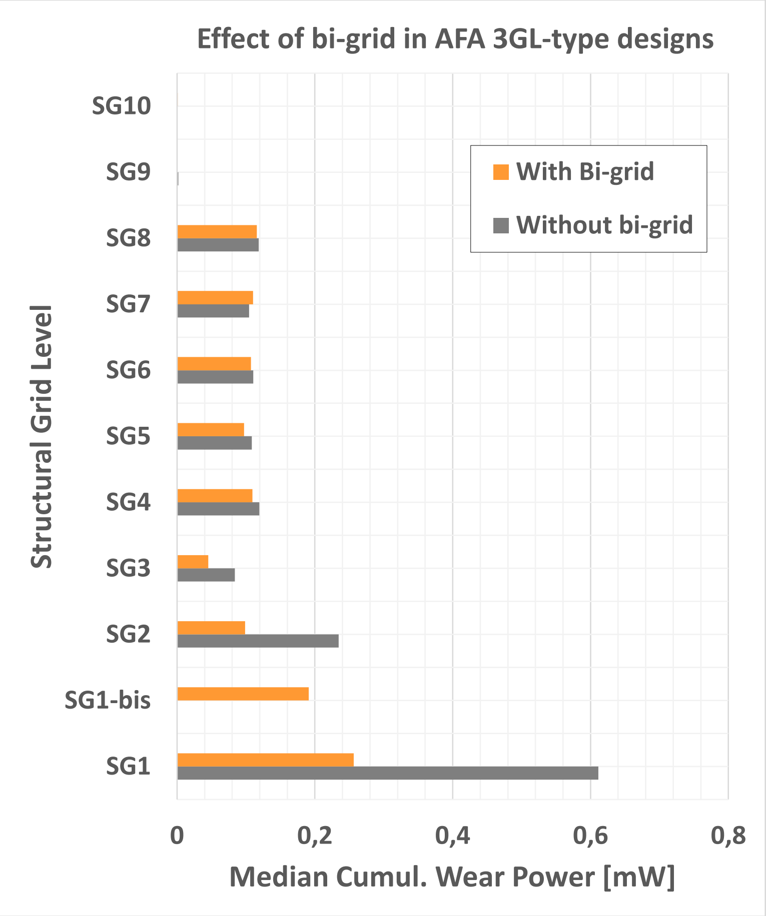
Modeling (2/2)

- **Showcasing model prediction capability : example of AFA 3G lower bi-grid**
  - The configuration known as 'bi-grid' was used to mitigate severe fretting damage in some French reactors in the early 2000's



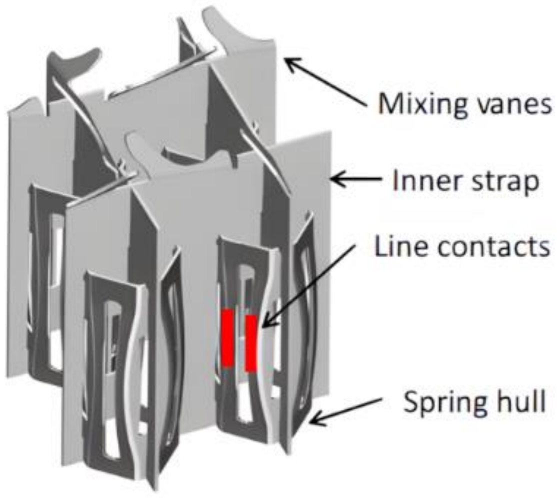




- **Simulation and results:**
  - Comparative simulations of two identical designs except for the introduction of a strengthening grid → excitations taken from previous CFD simulations / supporting conditions were updated.
  - Good agreement with the main trends observed from the operating experience and full-scale life and wear tests: the bi-grid mitigates the fretting severity (assessed as wear power)
  - Lowermost grid remains the most penalizing region for fretting

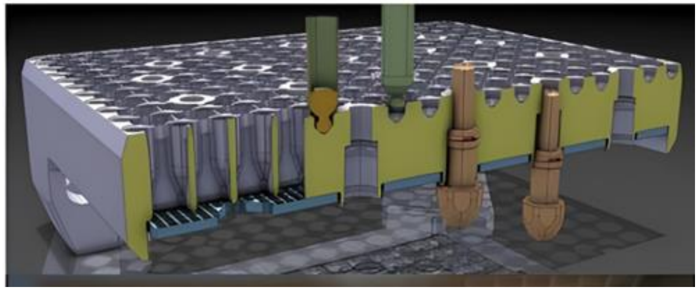
Product optimization

- **Leveraging these advanced methodologies has been key to develop hardware designs which have demonstrated high resistance to GtRF**
- **The unique 'line contact' type of rod support offered by HTP and GAIA designs has been operated successfully in a wide range of reactors, worldwide**
  - More than 17,000 FAs in 50+ reactors, operated up to 70GWd/tU
  - Thanks to self-accommodation at the cladding / grid spring interface

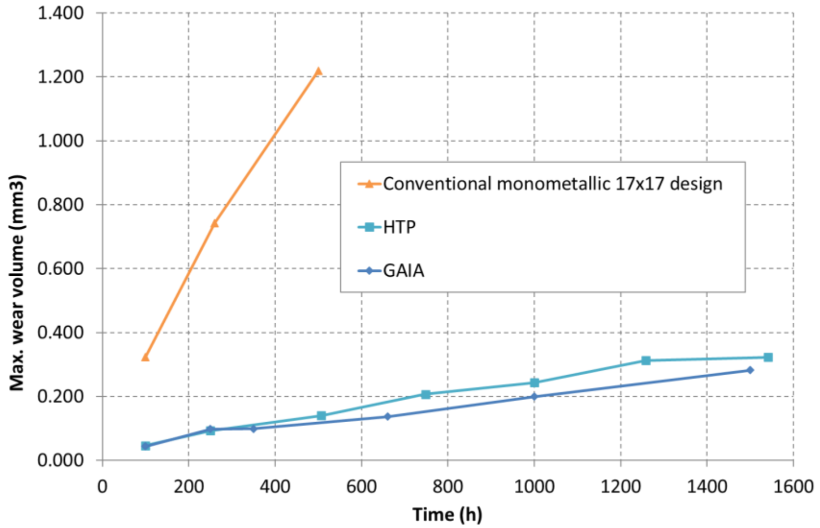


Detail of GAIA mixing grid design

- **Bottom nozzle optimization, resulting in a uniform distribution of inlet flow, and in a reduction of turbulent excitation, has also been proven feasible.**



GAIA Bottom Nozzle



Wear test results for various grid designs

Conclusions

- **Resistance to grid-to-Rod Fretting wear is an essential feature of mature fuel assembly designs**
- **Framatome has an extensive experience regarding GtRF robustness, leveraging:**
    - Testing facilities, both full-scale and analytical
    - State-of-the-art modeling tools accounting for the complex multi-physics interaction between hydraulics, non-linear vibrations, and tribology
- **These advanced methodologies have been used to develop hardware designs whose excellent performance has been proven in a wide range of operating conditions**
- **These solutions will be leveraged to support VVER-440 and 1000 fuel design development.**

Thank you