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FUEL RELIABILITY IMPROVEMENTS

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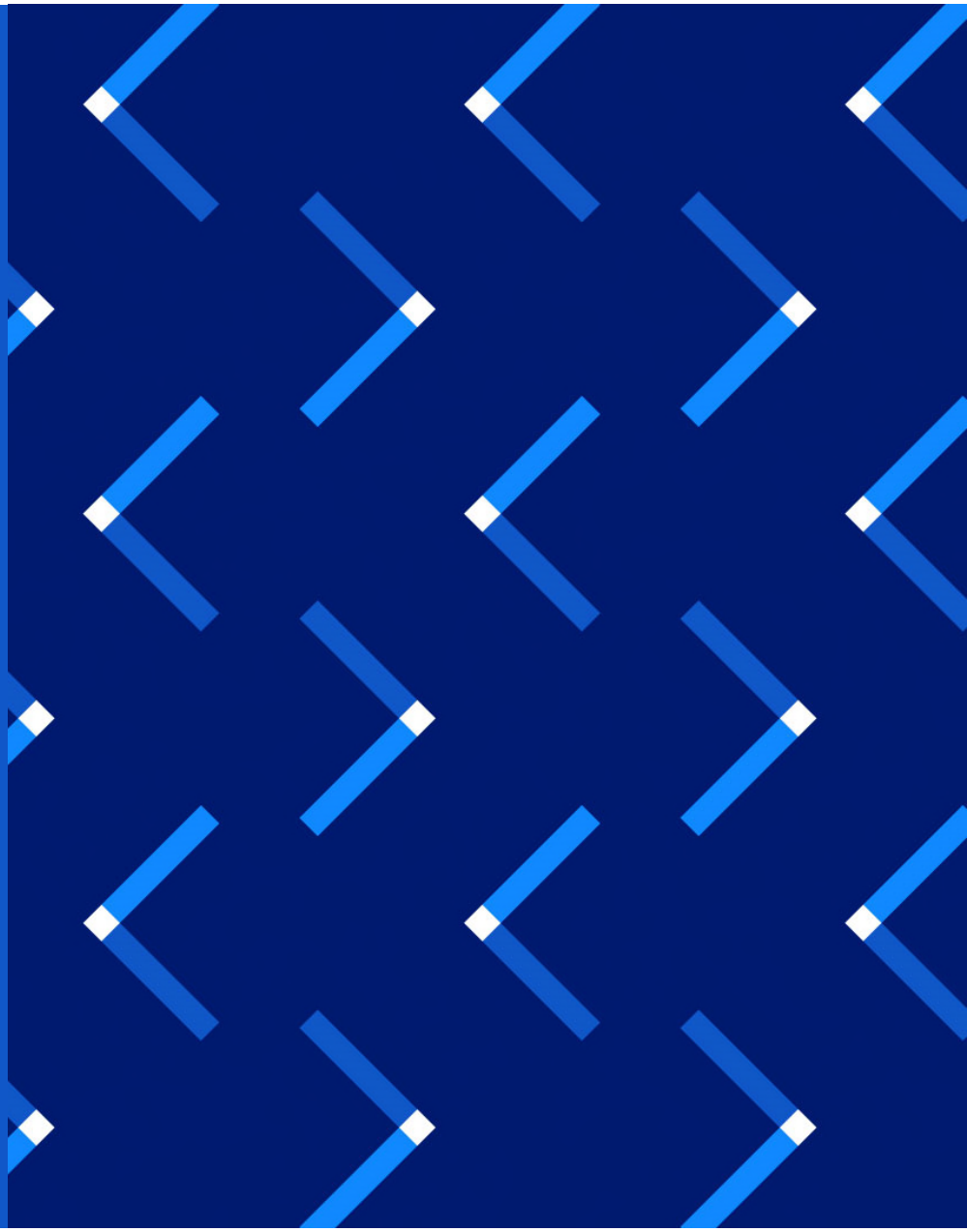

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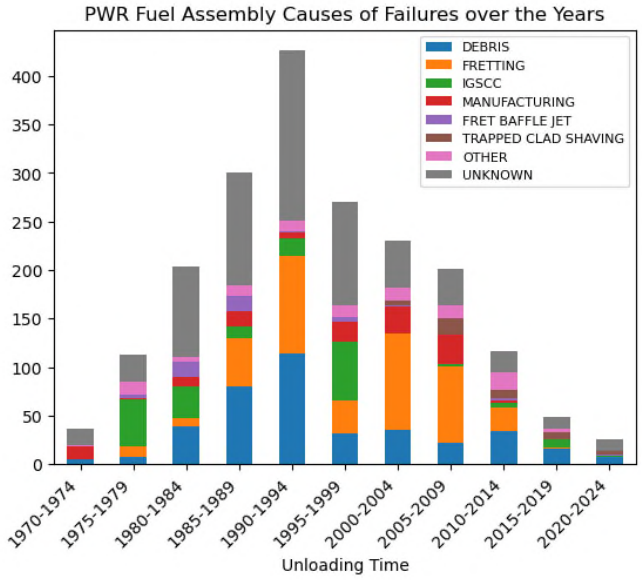
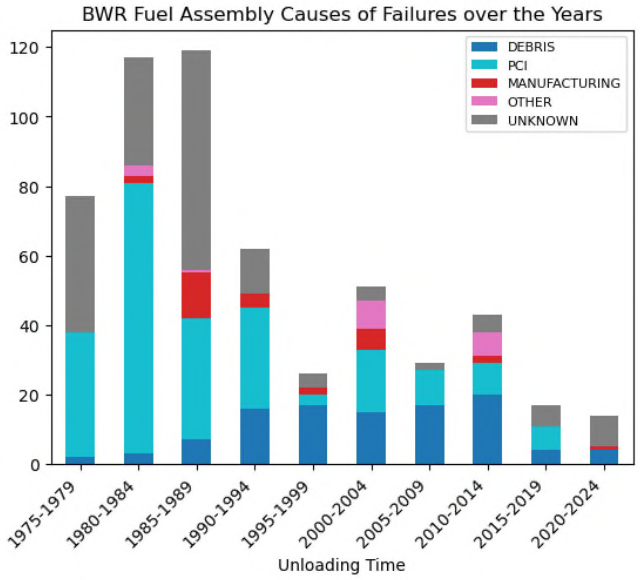
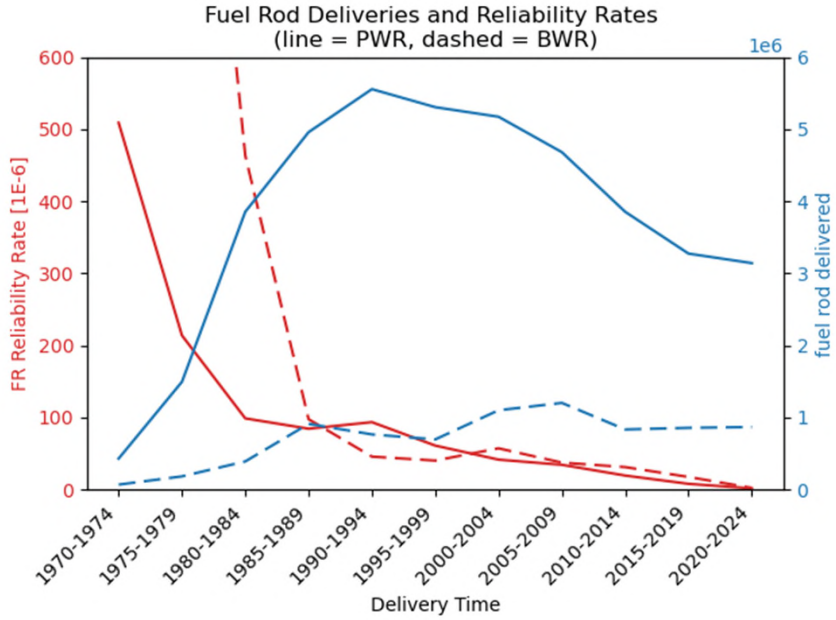
Overview

Reliability Rate Evolution

- In both PWR and BWR, the reliability rates significantly improved since the early days of nuclear
- Historically, the main causes of failures are
  - In PWRs: debris, fretting, stress corrosion cracking, baffle jetting (early times) and manufacturing
  - In BWRs: debris, PCI and manufacturing







Note: FR Reliability Rate = Number of FR leak / number of FR delivered

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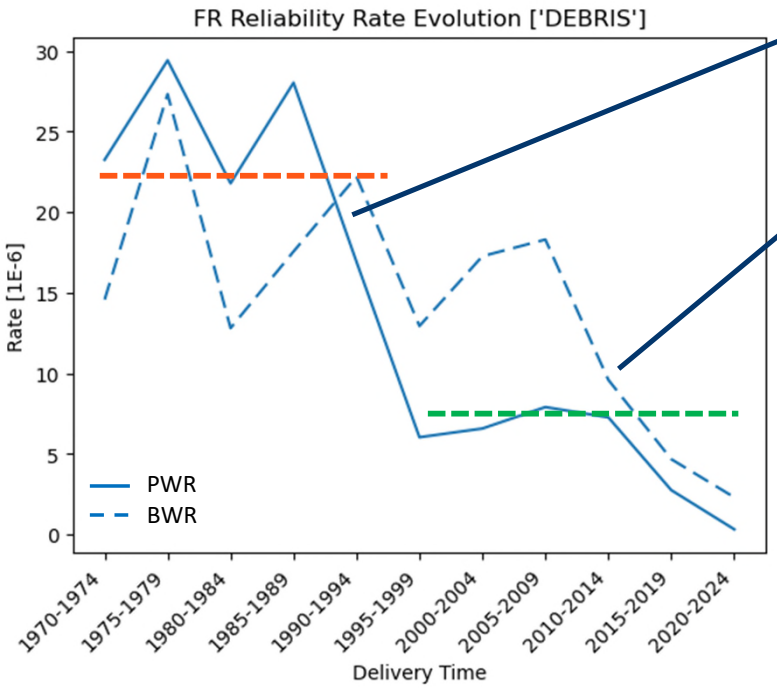
Improvements

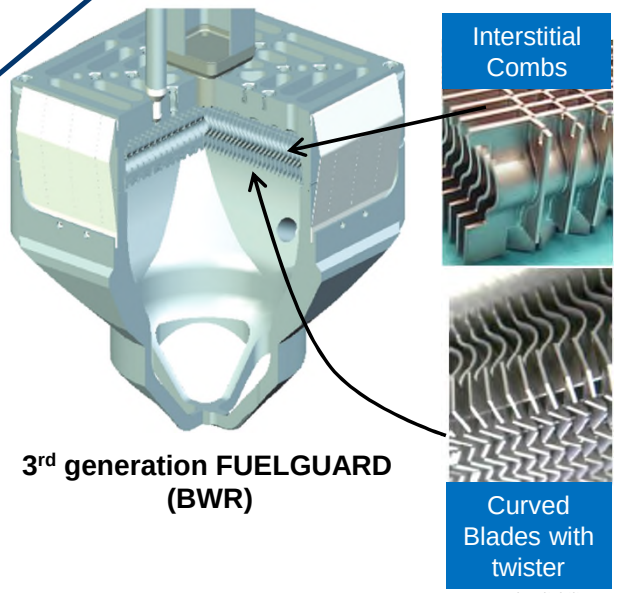
Improvements against Debris

- Improvements against debris fretting
- Filters: various generations and technologies



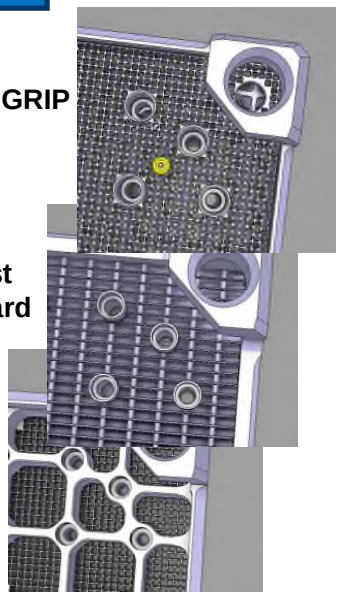
Deployment of filters in bottom nozzles

Filtering technology improvements (esp. in BWR) including upper tie grids



3rd generation FUELGUARD (BWR)

PWR bottom nozzle designs

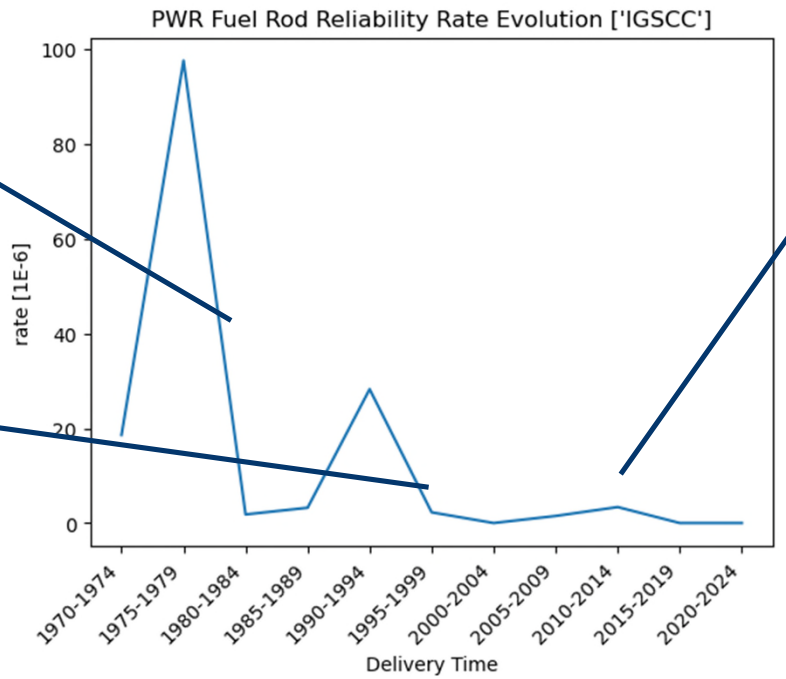


Improvements against IGSCC

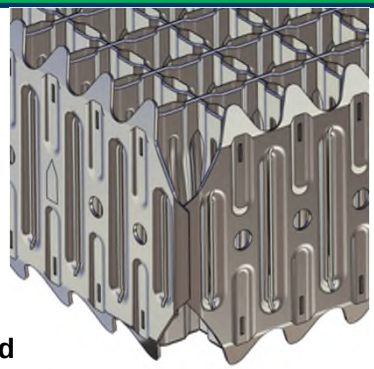
- Stress Corrosion Cracking in lower end spacer grids → rod support degradation in the most sensitive location
- Significant gains in reliability of the Alloy 718 components allowed
  - Delaying leak appearance time
  - Improving the component reliability

Phase out of first FA designs (failures occurred mostly in 1st cycle)

Improvement then phase out of bimetallic spacer designs in KWU reactors (most failures occurred in 2nd cycle)



Remaining failures mostly in 3rd year of operation or more. Material improvements and lastly HMP spacer deployment allow eradication of the issue



HMP™ End Grid

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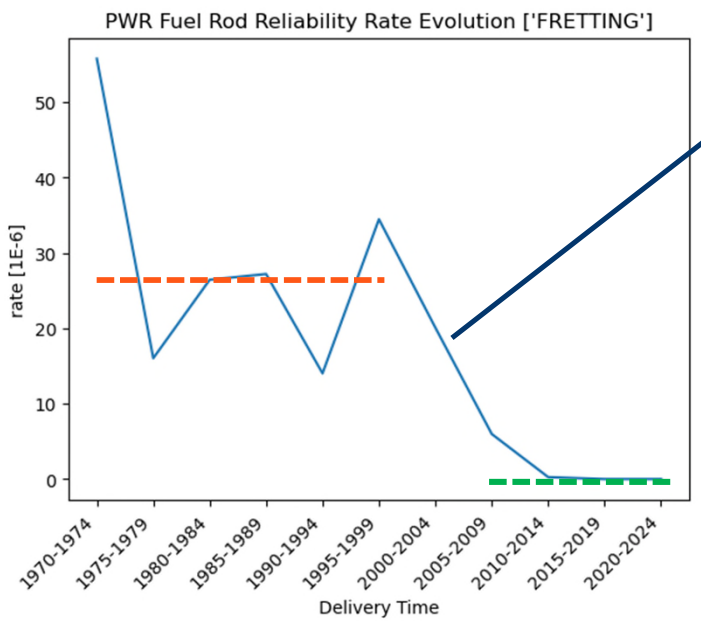
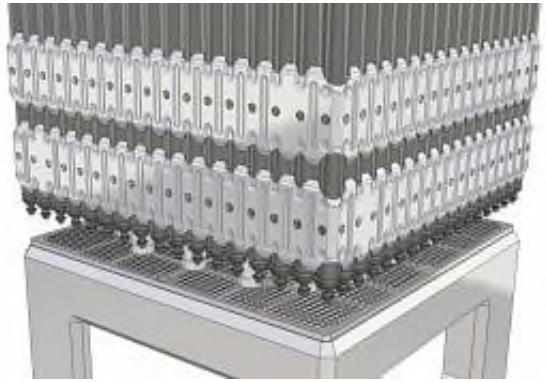
Improvements against Grid to Rod Fretting

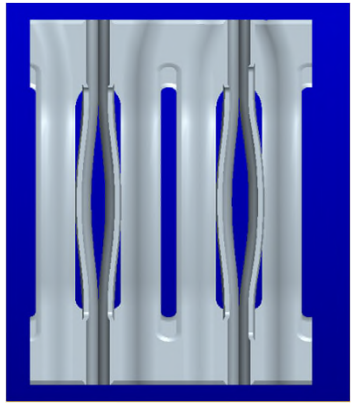
- Improvements against grid to rod fretting (not linked to SCC)
  - Reinforcement at flow entrance
  - Smoothening of rod to grid contacts



Phase out of MarkB / MarkBW
Deployment of HTP / HMP design and AFA 3G twin-grid technology



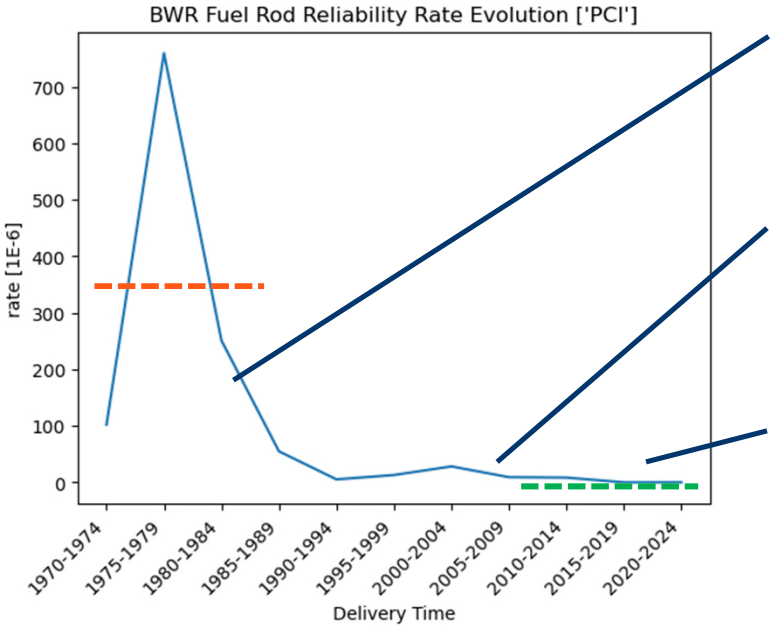
AFA 3G twin-grids



Line contact designs: HTP / HMP

Improvements against PCI

- Because of reactor operation specificities, pellet cladding interaction failure mechanism is much more prevalent in BWRs
- Improvements against PCI were made possible by a combination of design and fabrication improvements as well as reactor operation rules optimization



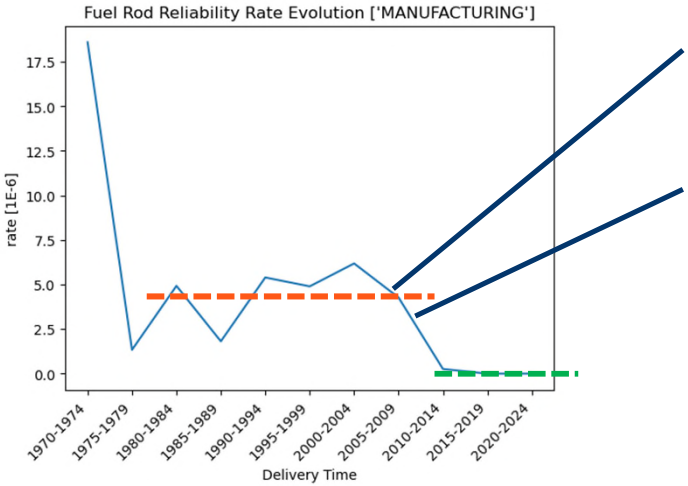
Pellet and fuel rod design optimization
+ BWR operation guidelines

Pellet manufacturing / inspection improvements, Fe-liner cladding
+ BWR operational restrictions

Cr_2O_3 doped fuel

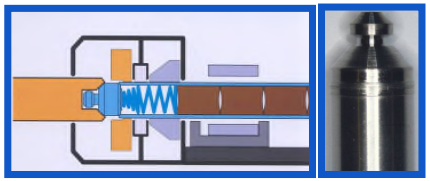
Improvements in Manufacturing

- Upset Shape Welding – A Best Practice Process
  - Removing seal weld
  - Eliminating risk of contamination of melting zone
  - Over 20.000.000 welds 100% leak proof in service!



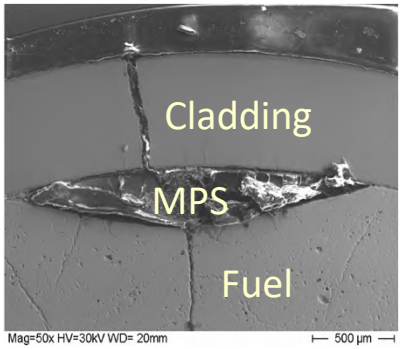
FMEZ standards reinforcement

USW deployment

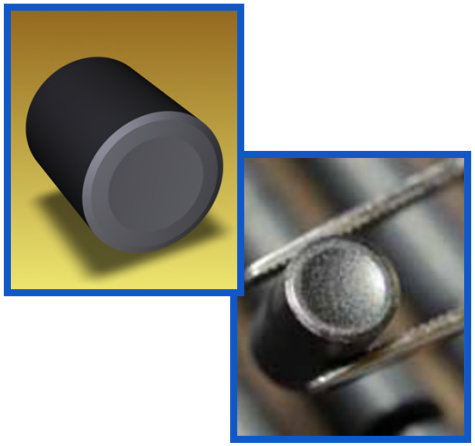


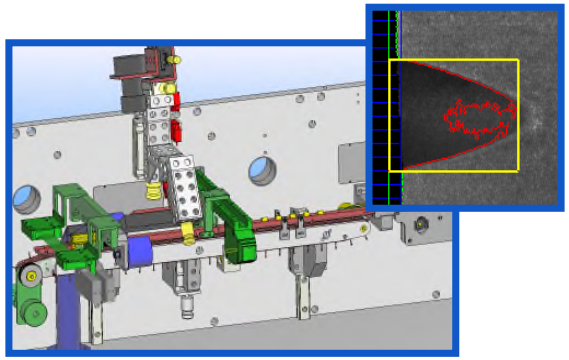
Framatome processes brings additional robustness & reliability

Improvements in Manufacturing



- Chamfered Pellet Design
  - Chamfer reduces propensity to chipping by mechanical impact on the circumferential surface
  - More central pellet-pellet contact preventing chipping by mech. impact at the end face
- Automatic pellet inspection system (APIS) in place in our fuel fabrication facilities

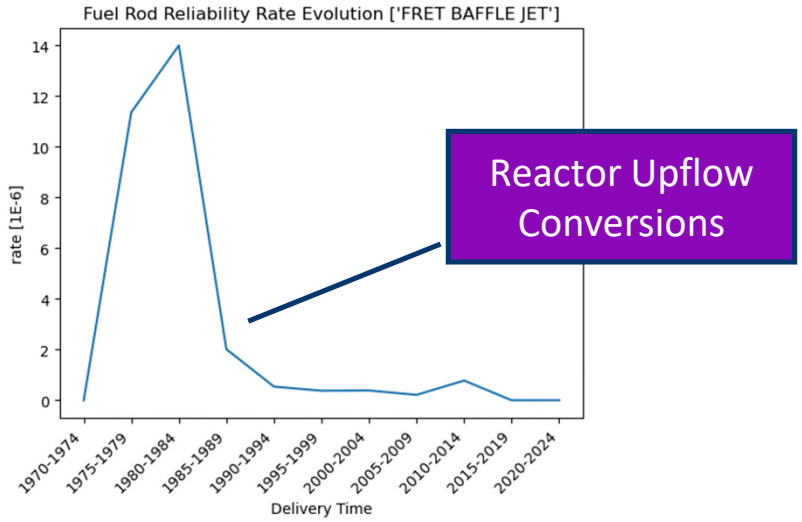


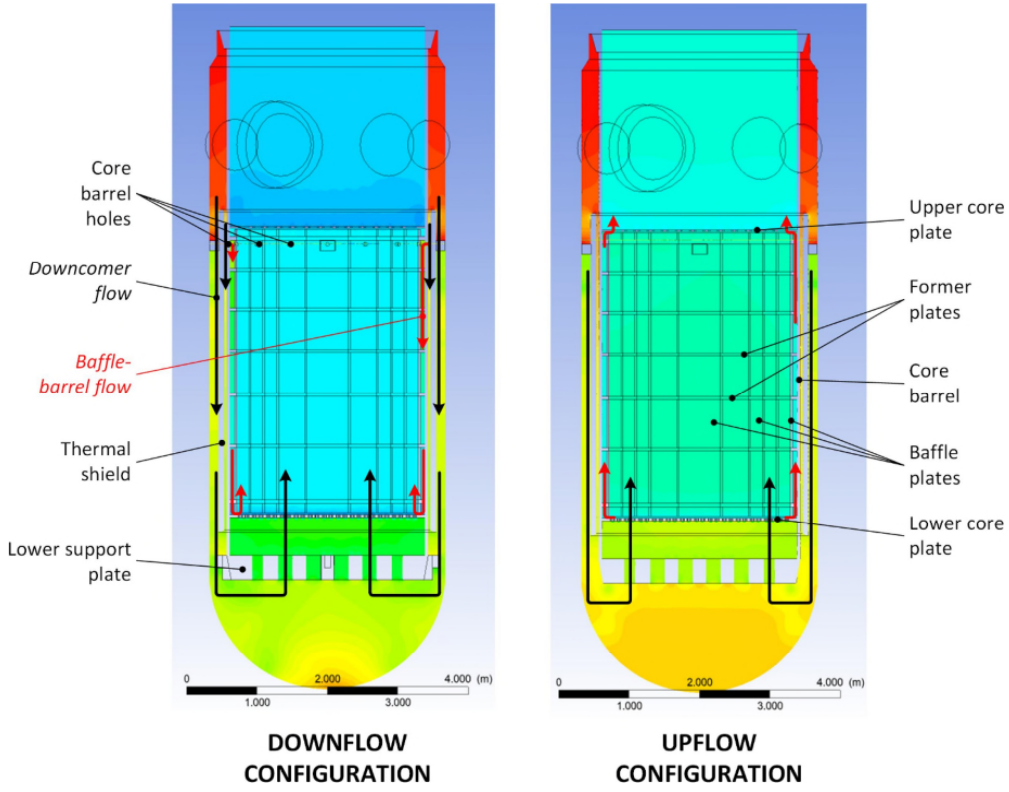


Framatome best practice components & manufacturing

Improvements against Baffle Jet Fretting

- Improvements against baffle jet fretting
  - Upflow conversion of the affected reactors was the main source of improvement
  - Nevertheless, for specific designs of reactors, Framatome proposes reinforced / armored fuel assemblies for the sensitive core locations





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Conclusion

Conclusion

- Over the decades the Framatome fuel reliability rate improved by a factor of ~1000
- Framatome, as a fuel supplier, and the Utilities both contributed to this significant achievement
- Remaining source of fuel failures are intrinsic to
  - The residual risks associated with certain fuel assembly designs and manufacturing constraints
  - The hardly avoidable presence of foreign materials in the reactors that causes debris fretting
- Additive manufacturing is expected to further improve the debris catching capabilities of the fuel assembly entry groups
  - Specific presentation on this topic

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Thank you