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FRAMATOME UNIQUE OPERATING EXPERIENCE ON 14FT PRODUCTS

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1st International Conference on LWR Fuel Performance, Modelling and Experimental Support,
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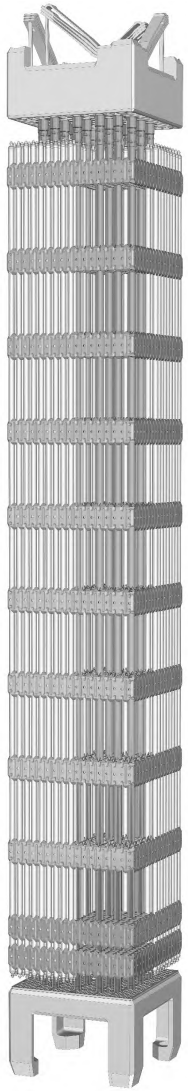
LWR

Mechanical Challenges of 14ft FA designs

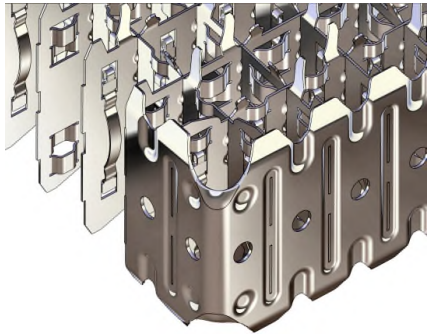


- The 14ft cores are demanding:
  - Large number of fuel assemblies (FA)
  - Longer and more flexible structures
  - Higher hydraulic mass flows and mass flow gradients, resulting in stronger hydraulic forces and fluid structure interaction (FSI) effects
  - Irradiation for 350 to 450 equivalent full power days

- Framatome upgraded its technologies by deploying its best proven components to:
  - Mitigate FA irradiation deformations
  - Reduce RCCA drop times
  - Facilitate handling and reduce outage times
  - Prevent Fretting and Vibration risks → *see dedicated presentation*
  - Prevent debris from reaching fuel rods

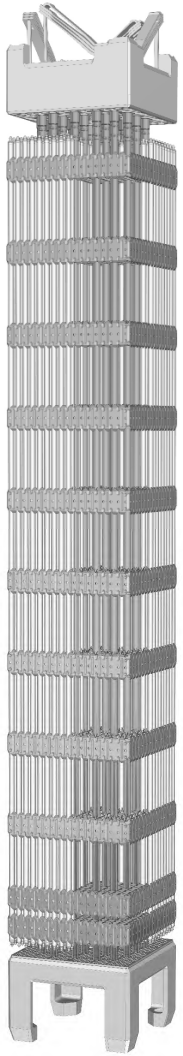
A few FA evolutions

- Deployment of quaternary alloy Q12 material as a structural material
  - High performance with respect to creep
  - Proven reduction of the in-core deformation
  - No drop times issue observed in cycles with only Q12-based designs
- Implementation of MONOBLOC guide tube with optimized Hold Down (HD) spring force
  - Reduction of the in-core deformation by a factor 2
- Improved AFA 3G grid against handling hazard
  - No observation of grid tearing being reported neither for the improved grids nor for adjacent FAs
- Implementation of the “twin grid” concept in the AFA 3G 14 ft designs
  - Full fix for grid-to-rod fretting issue Framatome experienced beginning of the 2000’s in some AFA 2G 17x17 14 ft
- The design change to the Robust FUELGUARD bottom nozzle and HMP grid is on-going

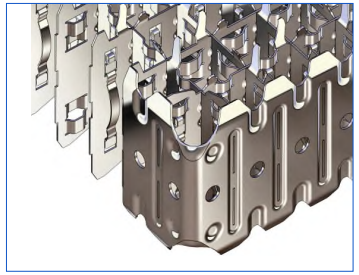


Framatome 14ft historical products

AFA 3GL designs



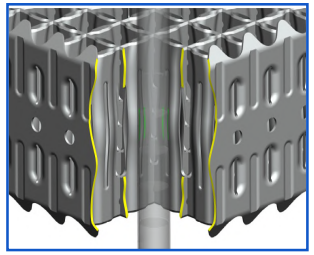
Improved AFA 3G grid



AFA technology	HTP technology
• Improved bimetallic vaned grid with springs & dimples • MONOBLOC guide tube • Lower Twin Grid • TRAPPER debris filter	• Monometallic grid with doublets & curved flow channels • MONOBLOC guide tube • Lower HMP • Robust FUELGUARD
More than 17 000 AFA 3GL FA have been irradiated in 25 PWR reactors	More than 4 000 HTP FA have been irradiated in Siemens long cores reactors

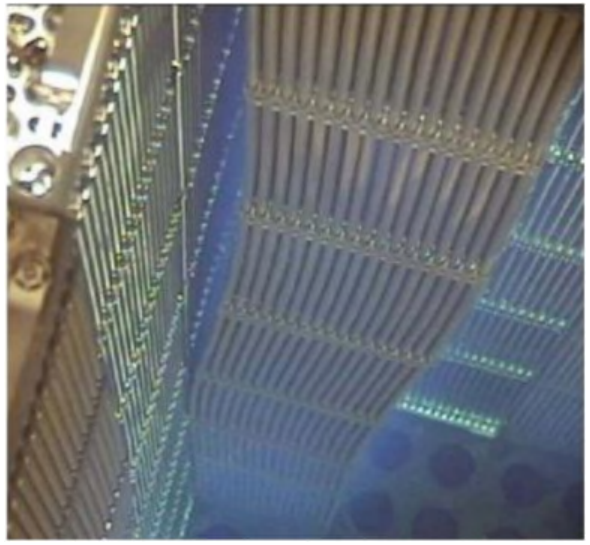
HTP designs

HTP grid



Framatome has been delivering proven long bundle products on PWR over decades

FA bow Challenges



Fuel Assembly (FA) bow is a general phenomenon in PWR

- It occurs during normal operating conditions along the cycles
- Increased FA bow can negatively influence the handling of the fuel during core loading and unloading by potentially leading to large handling loads and time delays during the outage
- Extreme FA bow can be detrimental to core performance and RCCA drop times

- The main challenge is to **anticipate excessive FA bow and/or find remedies:**
  - Thanks to a database of bow measurements at End Of Cycle (EOC)
  - By analyzing the bow distributions which can be regularly observed: repeating typical bow patterns, pattern dependency on shuffling strategy, repeatability of bow directions and amplitudes

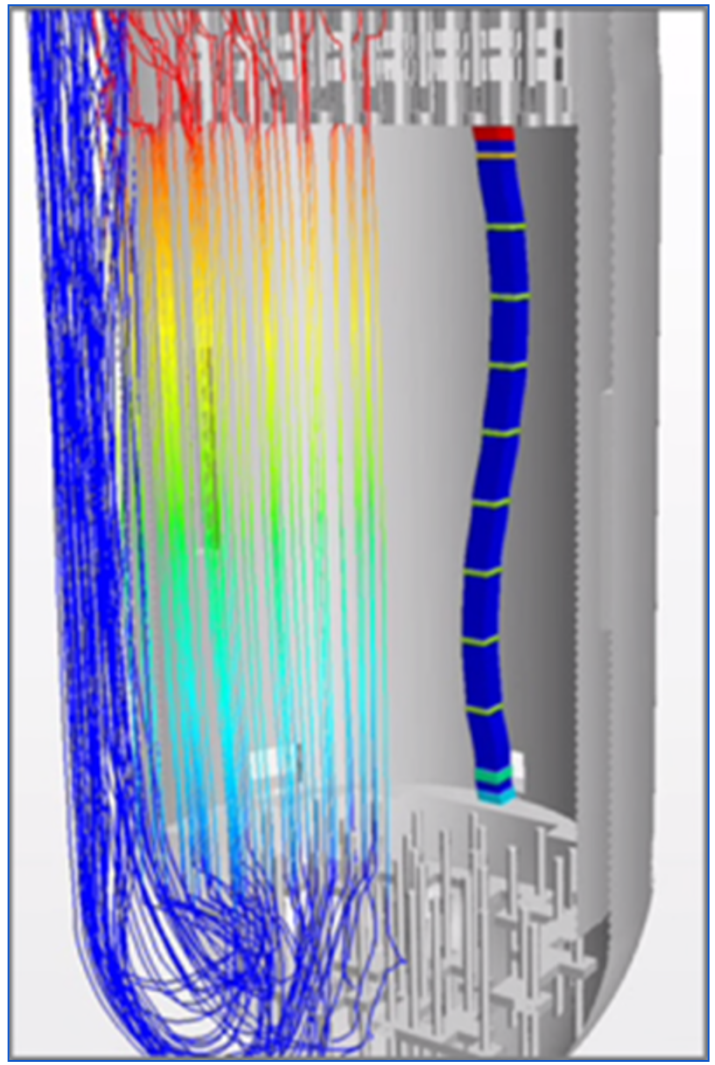
→ A diverse operating experience feedback reinforces Framatome's expertise in addressing FA bow

The FA bow multi-physics phenomenology

- Complex multi-physics
  - Core and vessel thermal-hydraulics
  - FA non-linear mechanical behavior under irradiation and its interaction with neighboring FA/core shroud
  - Neutron physics aspects (e.g., fuel management)

- Coupled phenomena
  - Strong Fluid-Structure Interaction (FSI)
  - Strong flow interaction between core & plena

- Multi-scale aspects
  - FA scale: local effect of the design
  - Core scale: global core effect
  - Reactor scale: primary circuit effect



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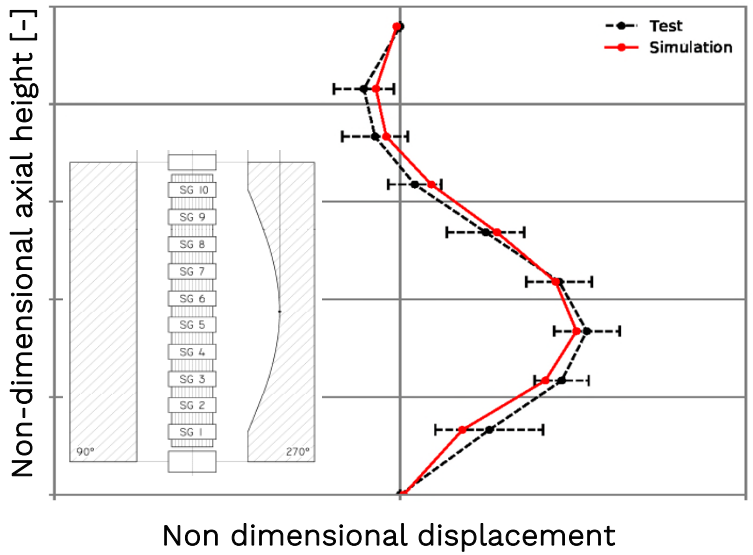
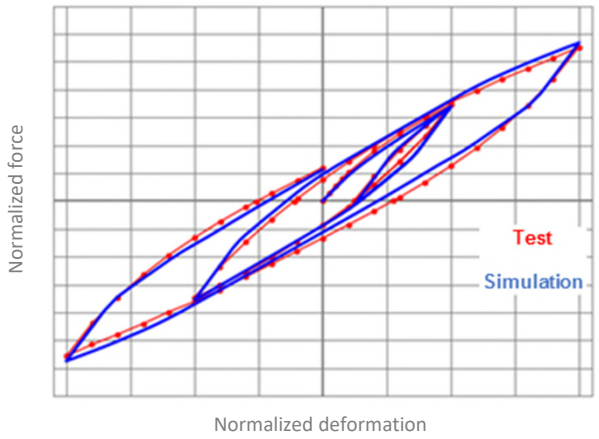
Test facilities & Design tools

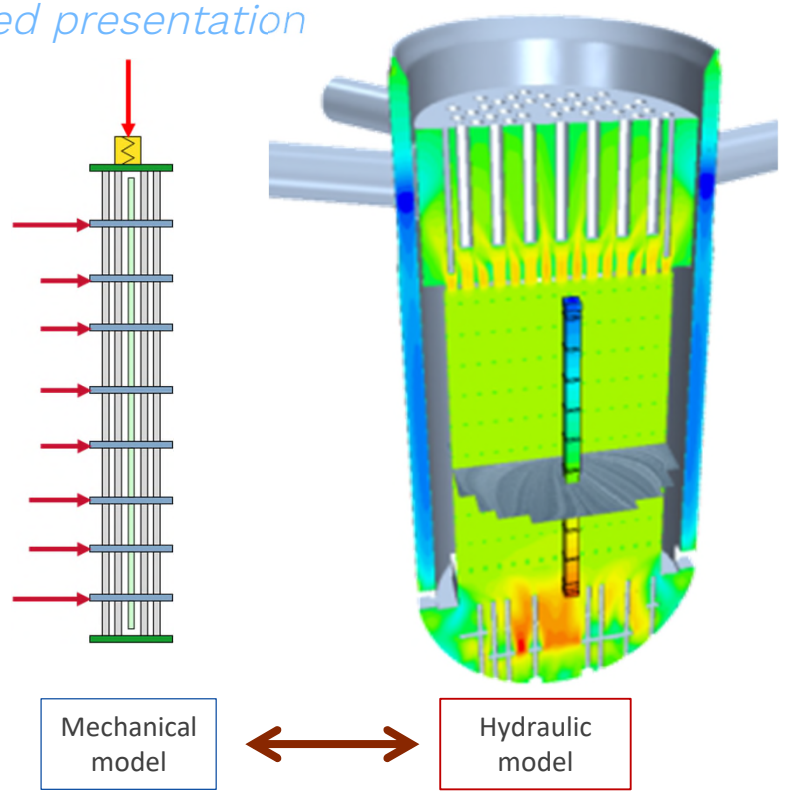
- Framatome **tested full scale FA mockups** to characterize its lateral response to
  - Controlled transverse excitations and
  - Under axial flow to investigate fluid structure interactions
- The scale 1 Peter loop test facility has been used to characterize 14ft FA under diverse deformed boundary conditions to cover a wide range of deformation





- Framatome developed **numerical tools to design robust FA** with respect to the complex FA bow methodology

→ *See dedicated presentation*



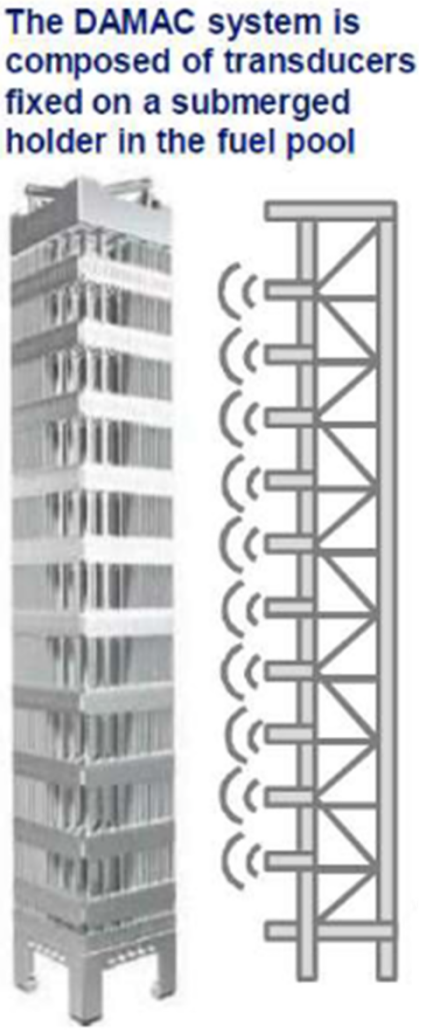
FA bow measurement device

- In France, since the 2000s, a specific measurement tool so-called DAMAC has been developed to measure FA bow based on ultrasonic measurements of the deflections (or lateral deformations) at the level of the grids

- These measurements are carried out in the spent fuel pool during the refueling outages

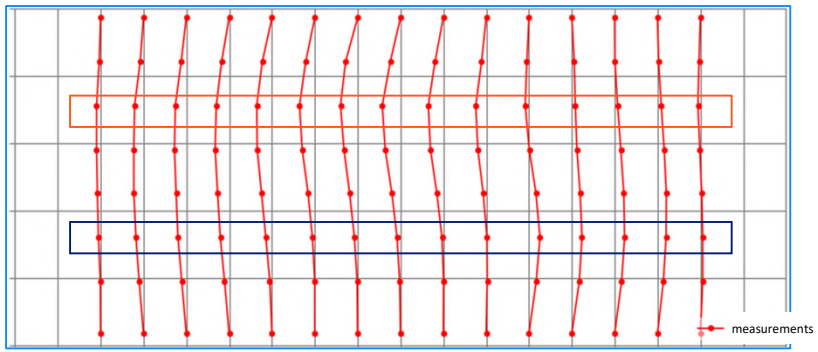
- One measurement for each direction at each mixing grid level:
  - 4100 measurements for a complete 1450 MW PWR core (205 FAs)
  - with limited impact on the outage schedule

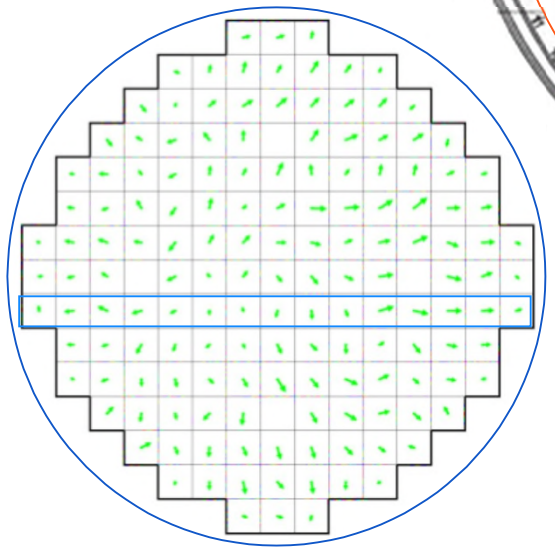
- Today, about ten reactors (900 MWe, 1300 MWe, and 1450 MWe, and 1600 MWe) perform DAMAC measurements during the refueling outages

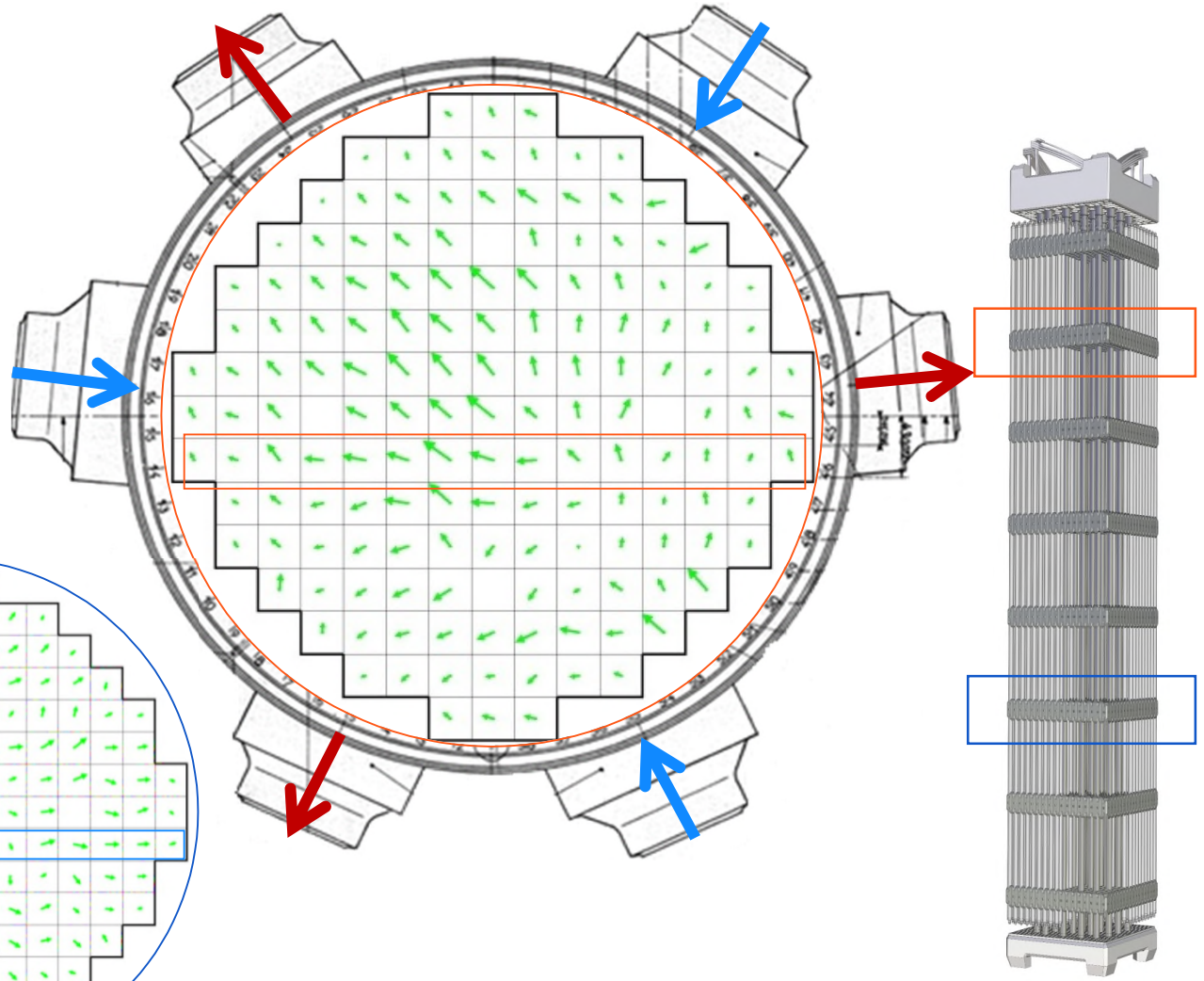


900 MW Operating Experience Feedback

- The 900 MWe – corresponding to 12ft FA designs – may feature very different FA bow orientations
- Core-wise “diagonal” orientation can be observed
- Level of deformations are stable and lower than in the case of 14ft FA cores
- These measurements contribute to extending Framatome’s knowledge on FA bow.

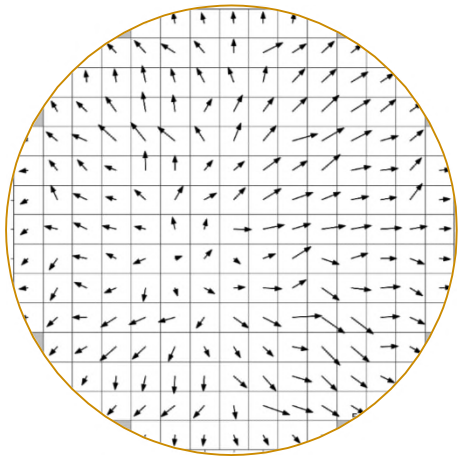


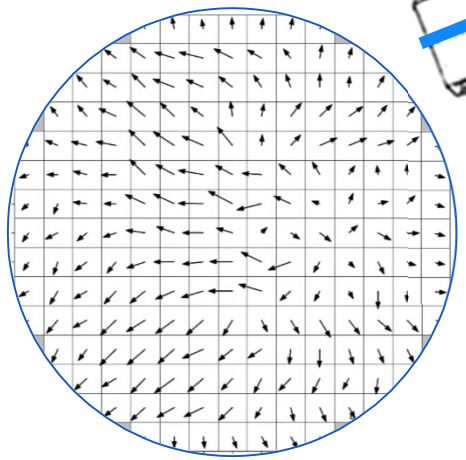


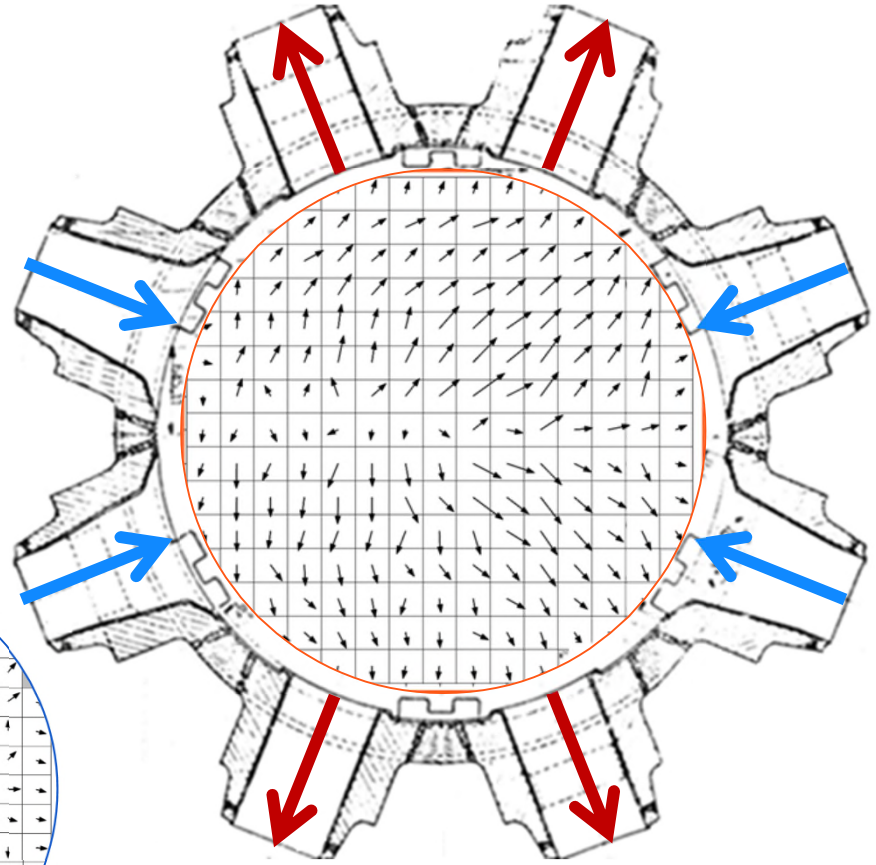


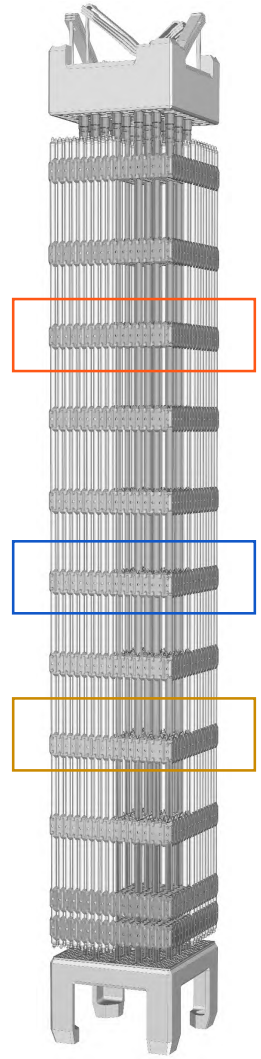
1300 MW Operating Experience Feedback (1/2)

- FA bow deformation is specific to a core design
- The orientation is mainly driven by the hydraulic characteristics of the core
  - number and location of the cold and hot legs
  - Core inlet mass flow rate
  - Core outlet mass flow distribution
- Past operating experience features the occurrence of S-shaped deformation









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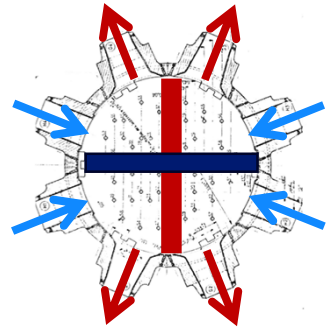
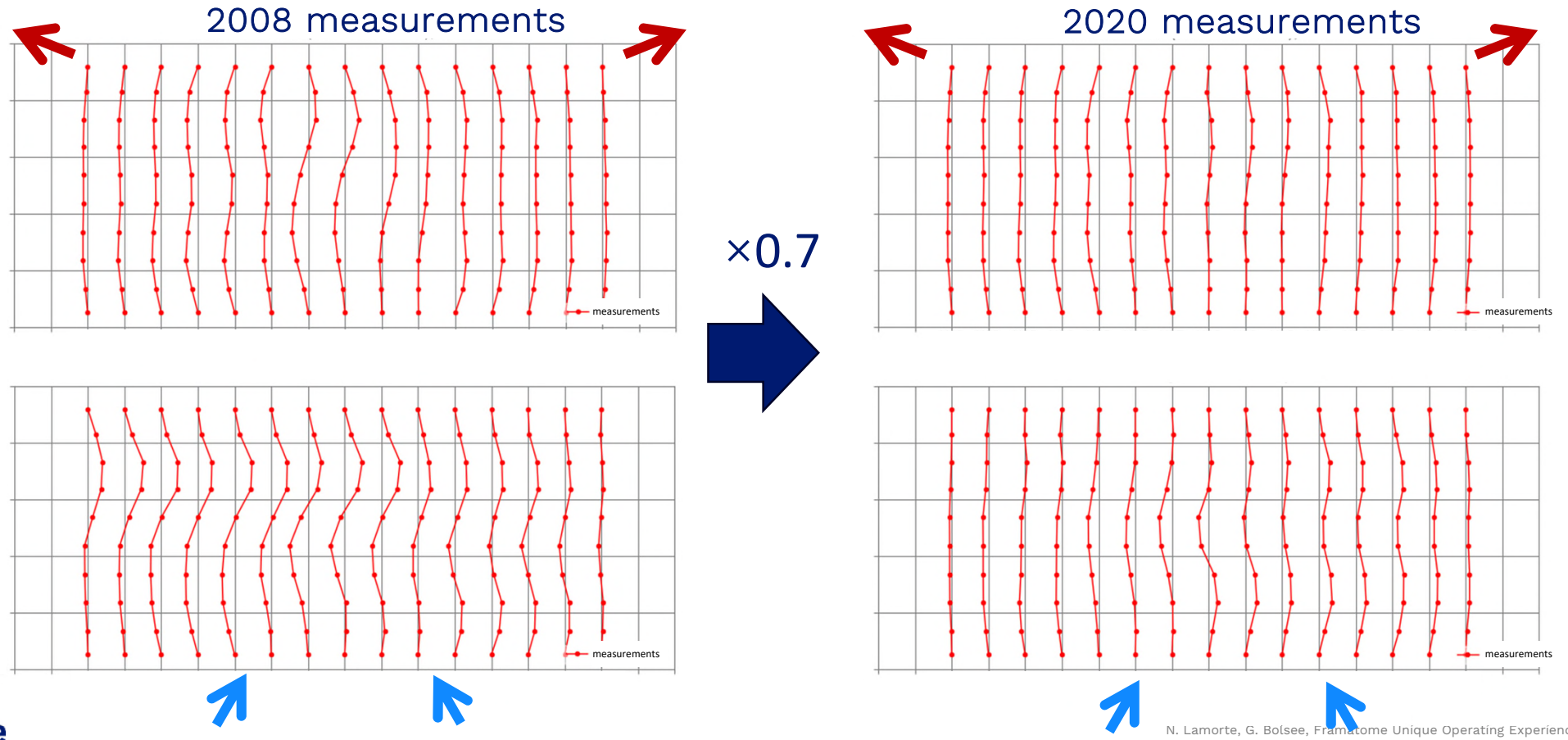
1300 MW Operating Experience Feedback (2/2)

- Thanks to the improved AFA3G designs, deformation levels have improved significantly,
- Improvements are observed where the deformation is the highest: in the long rows of the core





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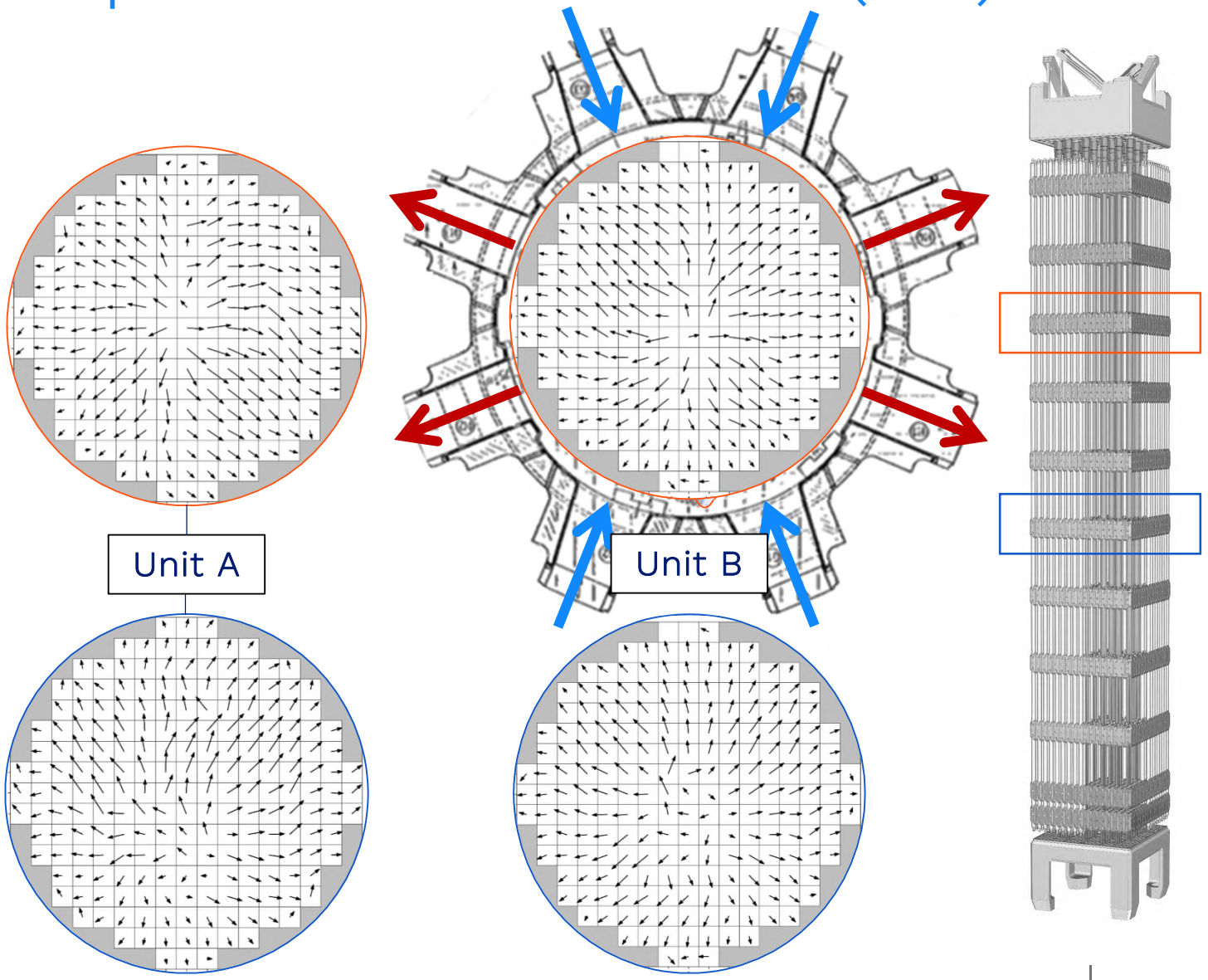
1450 MW Operating Experience Feedback (1/2)

- In the four 1450 MW units, FA bow have been measured exhaustively for the past 10 years
- FA bow pattern are similar in terms of orientation between the 4 different units
- Compared to 1300 MW core, the FA deformation is radial and consists of C- and W- shapes
- Difference exists between, yet the overall deformation are similar



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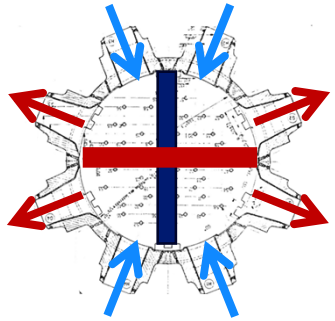
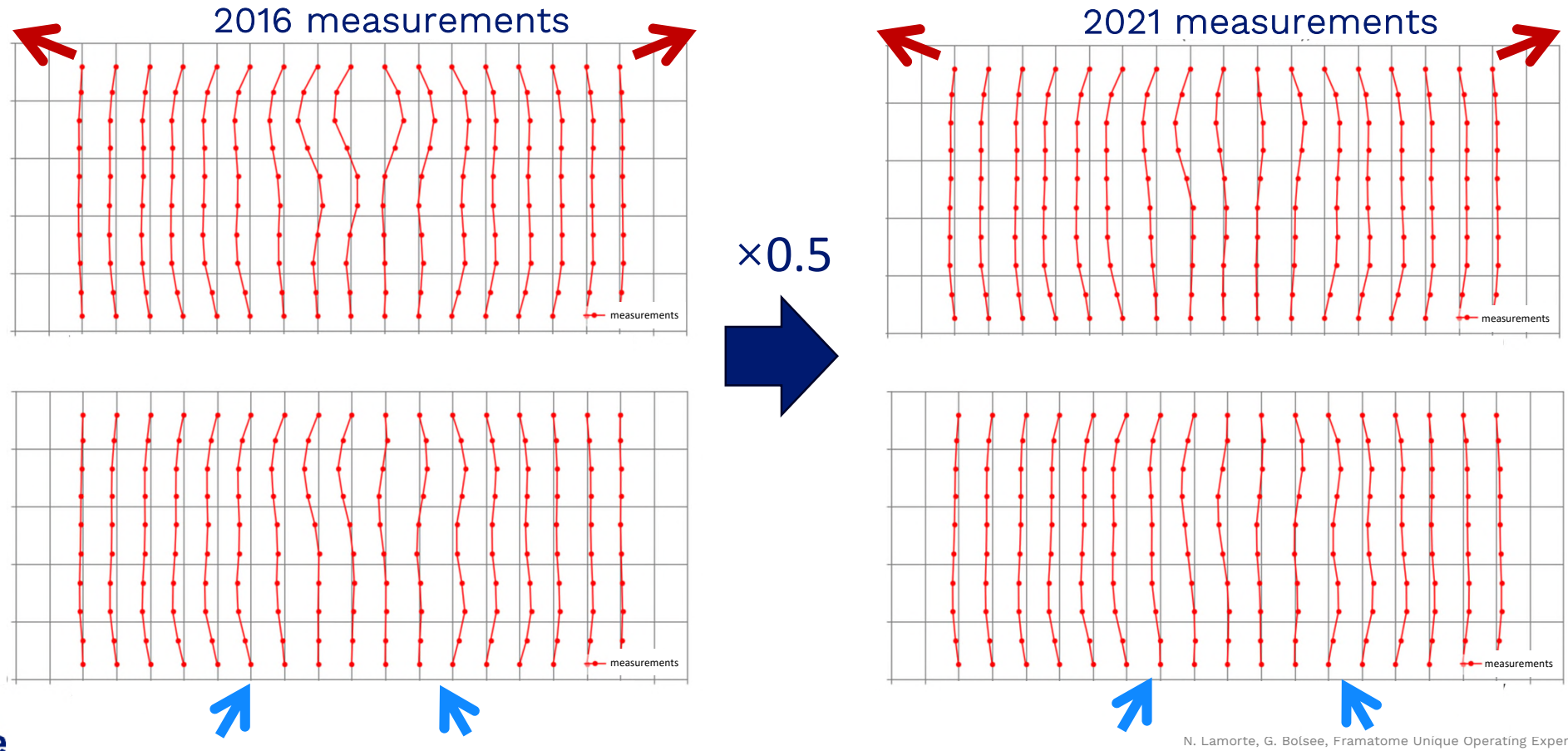
1450 MW Operating Experience Feedback (2/2)



- The benefit of the improved AFA3GL designs is confirmed in 1450 MW cores
- Improvements are observed where the deformation is the highest: in the long rows of the core



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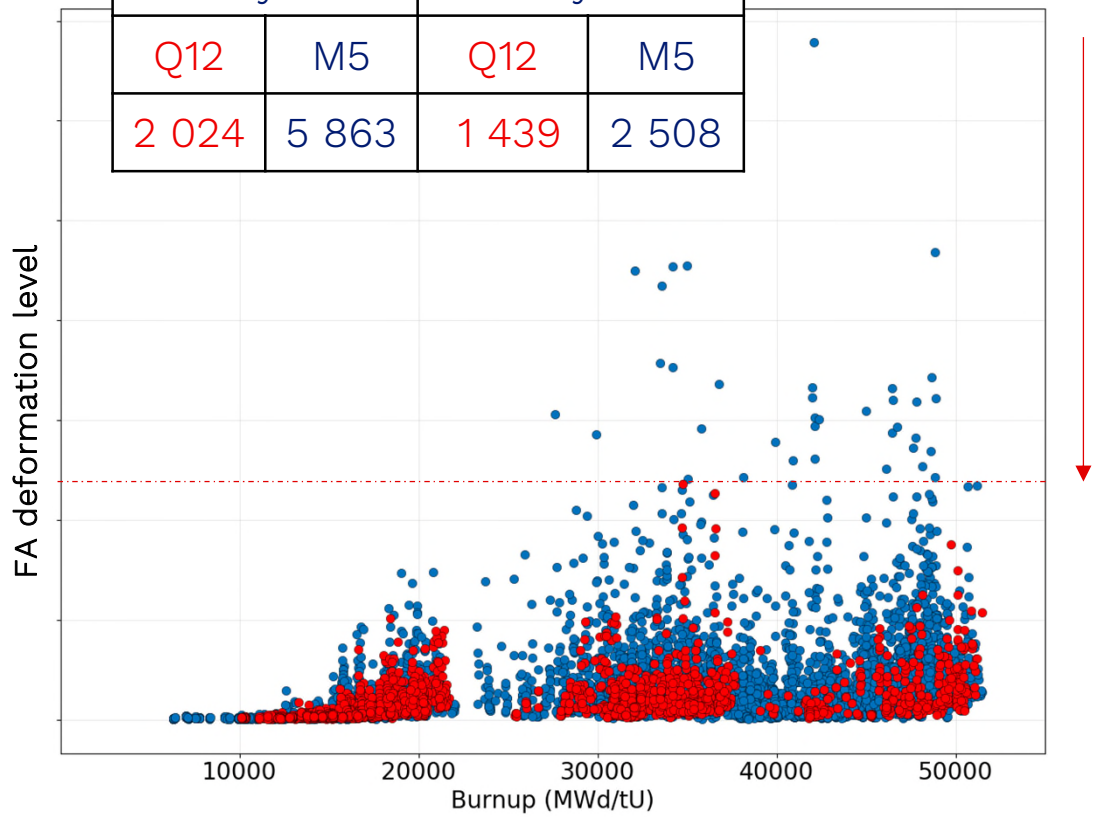
14ft AFA 3G technology FA bow OE

- More than 11 000 measurements of 14ft FA have been obtained in the past 20 years for the latest AFA 3GL FA designs with improved grids.
- The measurements cover a wide range of core designs and FA burnups up to 53 GWd/tU
- This extensive operating experience confirms the benefit of the latest FA design improvements in particular the introduction of Q12 as a structural material

Measured AFA 3GL FA designs with improved grids			
N4 46 cycles		1300 MWe 24 cycles	
Q12	M5	Q12	M5
2 024	5 863	1 439	2 508



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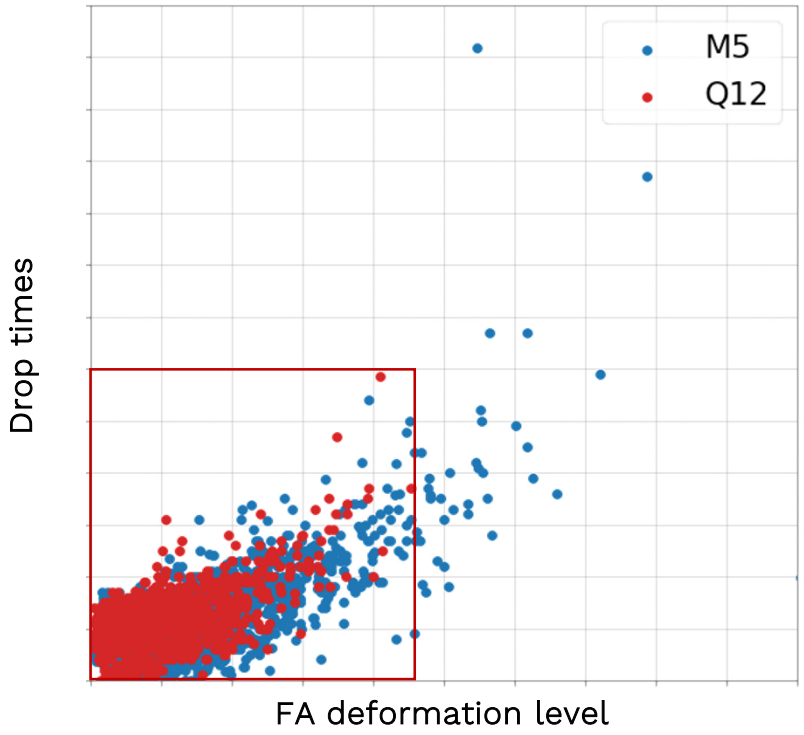
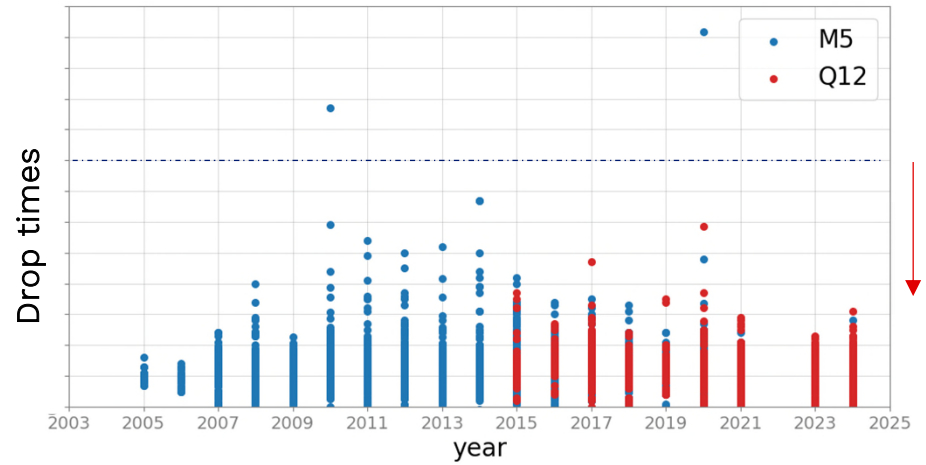
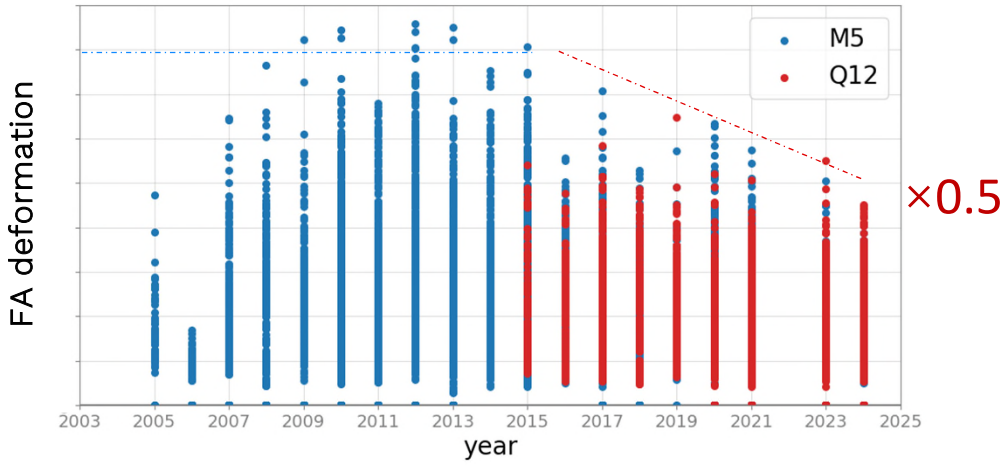
Deformation and drop times

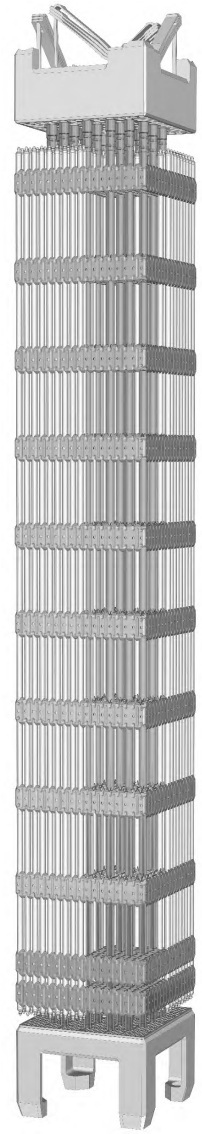
No drop time issue observed in the since the generalization of the latest AFA 3GL designs

→ The benefit on lateral deformation correlates well with the drop times









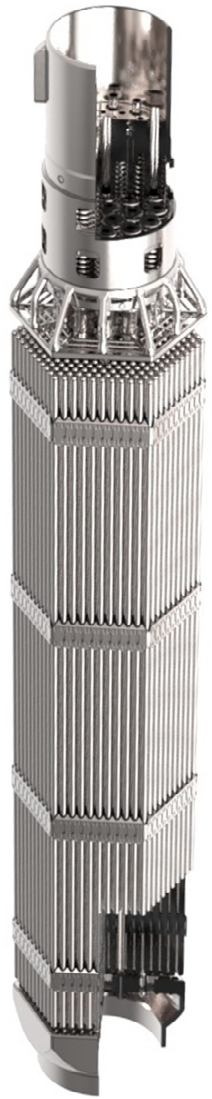
Conclusions & Perspectives

- Framatome built largest experience of long bundles with more than 21 000 FAs irradiated in long cores reactors
- During decades, Framatome upgraded its technologies learning from experience and deploying best proven materials, components, and features
- In parallel, Framatome has developed a bow prediction methodology validated on the key operating experience in 14ft FA cores
- This methodology - also used to identify solutions to increase FA straightness - supports the latest versions of Framatome 14ft designs : GAIA and VVER-1000 fuel assembly designs → *See dedicated presentation*

Framatome's strategy: Support our clients by providing robust and reliable products developed thanks to long term experience in a variety of core designs and advanced codes & methods

GAIA 14ft

VVER



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Thank you

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