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Assessment of the neutron noise induced by the stationary fuel assembly vibrations in a light water reactor

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This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 754316.

Introduction – *Neutron noise*

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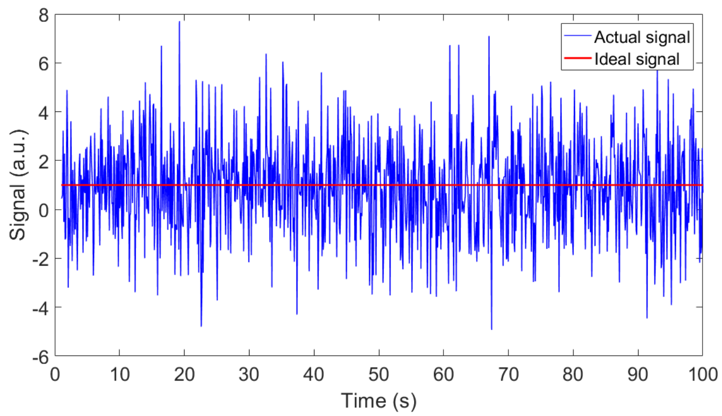
- **“Noise”** is deviation of any time-dependent variable from its mean value

$$X(r,t)=Xo(r,t)+\delta X(r,t)$$



- **Noise always present**; even at steady-state reactor conditions, fluctuations due to e.g. vibrations of mechanical components occur

Introduction – *Neutron noise in some PWRs*

- Systematic increase in the noise levels in SIEMENS pre-Konvoi PWR reactors over several cycles; Impact on the availability of the plant

- Operational problems due to
  - ➢Increased mechanical vibrations of reactor internals, especially **fuel assembly (FA) vibrations**
  - ➢Thermal-hydraulic parameters fluctuations

- **Important to identify and locate anomalies**

CORTEX
Core monitoring techniques and experimental validation and demonstration

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CORTEX
Core monitoring techniques and experimental validation and demonstration

- Conventional codes use nodal methods and assembly-homogenized XSs to model fuel assembly vibrations;
  - ➢*Displacement (sub-mm) smaller than coarse mesh size*
  - ➢*Fixed computational grid*
  - ➢*Difficult to reproduce local intra-nodal perturbations*

Introduction – *Purpose of the study*

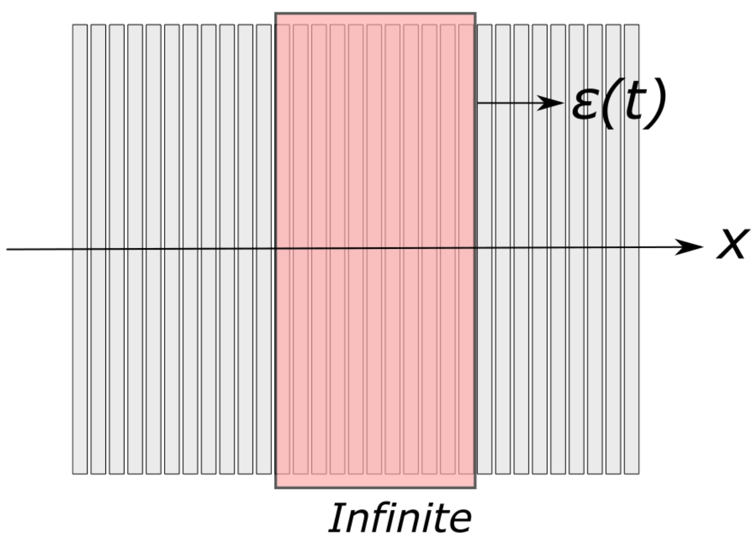
Objectives:

- Perform comparative analysis between nodal-based and pin-based modelling approaches
- Investigate the impact of XS homogenization on the modeling of fuel assembly vibrations

Approaches are based on the ε/d model

Methodology – *Noise analysis approach*

- Collective movement of fuel pins assumed
- Radial movement of FAs along one preferred direction



Methodology – *Noise analysis approach*

<u>ε/d model</u>

For two neighboring regions - regions II and III:

$$\Sigma_{\alpha,g}(x) = [1 - \theta(x-b)]\Sigma_{\alpha,g,II} + \theta(x-b)\Sigma_{\alpha,g,III} \qquad (1)$$

Using $b(x,t) = bo + \varepsilon(t)$ and 1st order Taylor Expansion

$$\Sigma_{\alpha,g}(x) = [1 - \theta(x-b_0)]\Sigma_{\alpha,g,II} + \theta(x-b_0)\Sigma_{\alpha,g,III} + \varepsilon(t)\delta(x-b_0)[\Sigma_{\alpha,g,II} - \Sigma_{\alpha,g,III}] \qquad (2)$$

Since static microscopic XS (when ε(t) = 0) is

$$\Sigma_{\alpha,g,0}(x) = [1 - \theta(x-b_0)]\Sigma_{\alpha,g,II} + \theta(x-b_0)\Sigma_{\alpha,g,III} \qquad (3)$$

Therefore, noise source corresponding to fluctuating boundary between II and III is expressed as

$$\delta\Sigma_{\alpha,g}(x,t) = \varepsilon(t)\delta(x-b_0)[\Sigma_{\alpha,g,II} - \Sigma_{\alpha,g,III}] \qquad (4)$$

Or in frequency-domain as

$$\delta\Sigma_{\alpha,g}(x,\omega) = \varepsilon(\omega)\delta(x-b_0)[\Sigma_{\alpha,g,II} - \Sigma_{\alpha,g,III}] \qquad (5)$$

Methodology – *Noise analysis approach*

ε/d Approach

Fuel assembly level (Nodal)

Pin cell level

Methodology – *Noise analysis approach*

ε/d Approach

Fuel assembly level (Nodal)

Assembly-approximated

Pin cell level

Region I and III: Neighboring FAs
Region II: Vibrating FA

"Noise sources" defined as the difference of the static macroscopic cross sections between Region II and Region I, and Region II and III.

Methodology – *Noise analysis approach*

ε/d Approach

Fuel assembly level (Nodal)

Assembly-approximated

Boundary-localized

Pin cell level

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ε/d Approach

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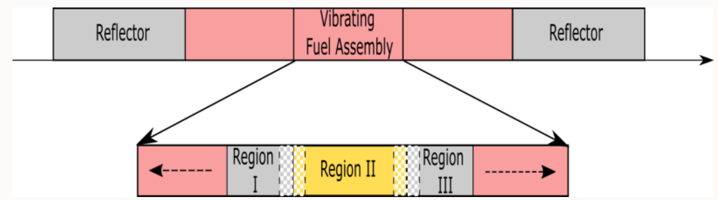
Pin cell level



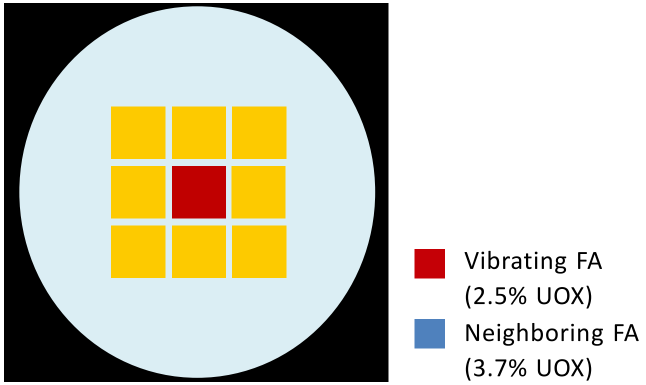
Region I and III: Moderator
Region II: Fuel

"Noise sources" defined as the difference of the static macroscopic cross sections between Region II and Region I, and Region II and III.

Methodology – *Calculation route*

Step 1: XS generation with SERPENT2

- 2-D core design representative of a LWR; 3x3 fuel assemblies, each containing UOX fueled 17x17 pins surrounded by water
- Vibrating FA has slightly lower enrichment
- 2G cross sections at nodal and pin level



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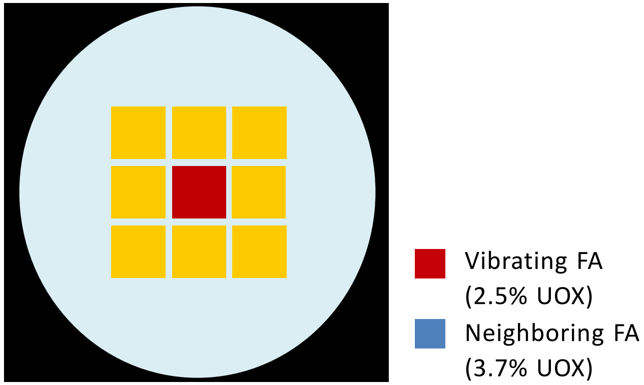


Step 2: Neutron noise calculation with CORESIM

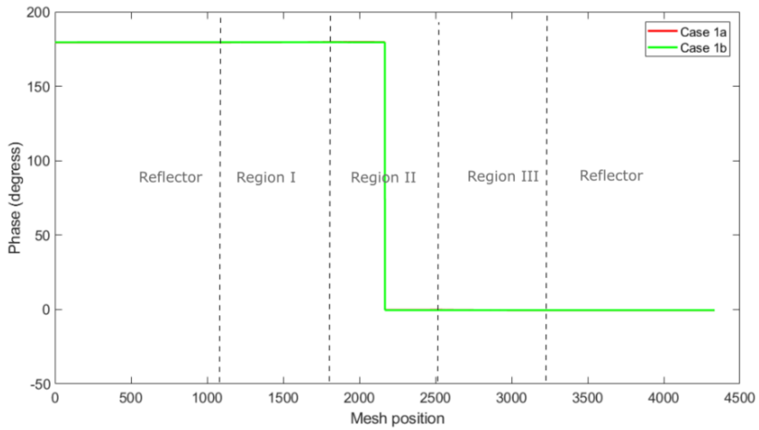
- 2G neutron noise diffusion equations in the frequency domain
- 1-D reactor model of size 130 cm with a fine mesh
- **FA size = *21.42 cm*; Mesh node size = *0.03 cm*; Pin pitch = *1.26 cm;* Frequency = *1 Hz***

Results – *Case 1: Nodal calculations*

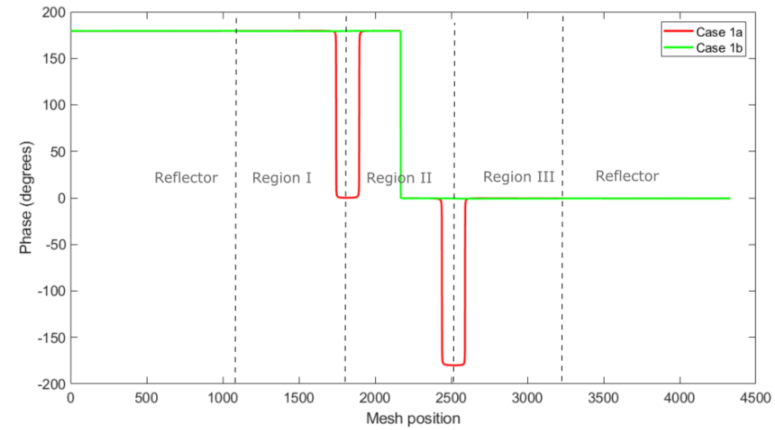
Case 1a (Red): Boundary-localized nodal

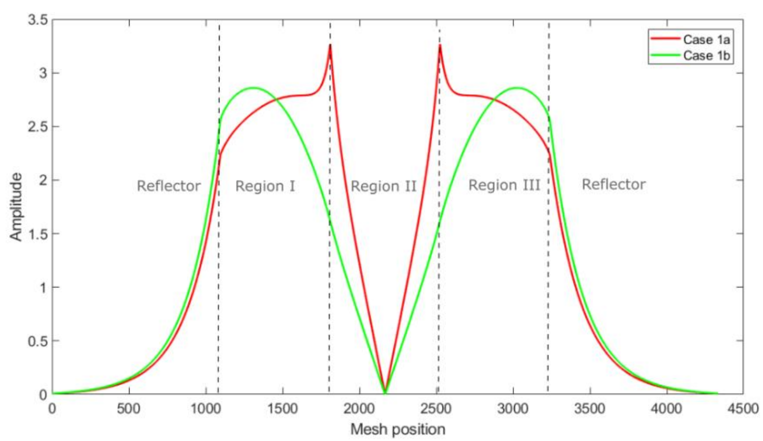
Case 1b (Green): Assembly-approximated nodal

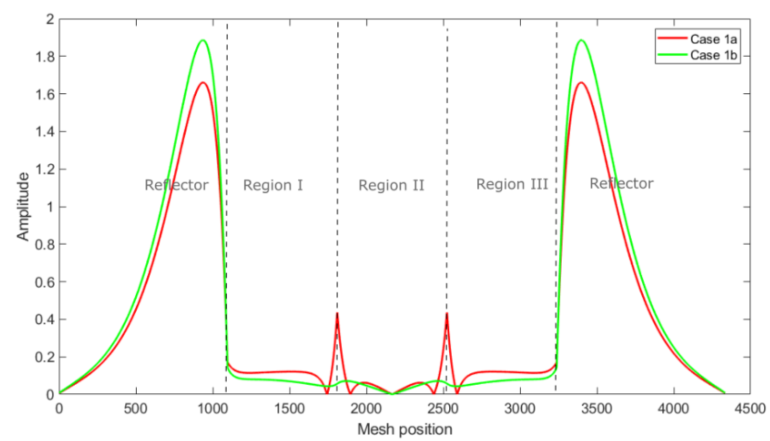
Fast group



Thermal group







Note: Both fast and thermal noise sources are introduced

Dashed lines represent the interfaces in the core

Results – *Case 1: Nodal calculations*

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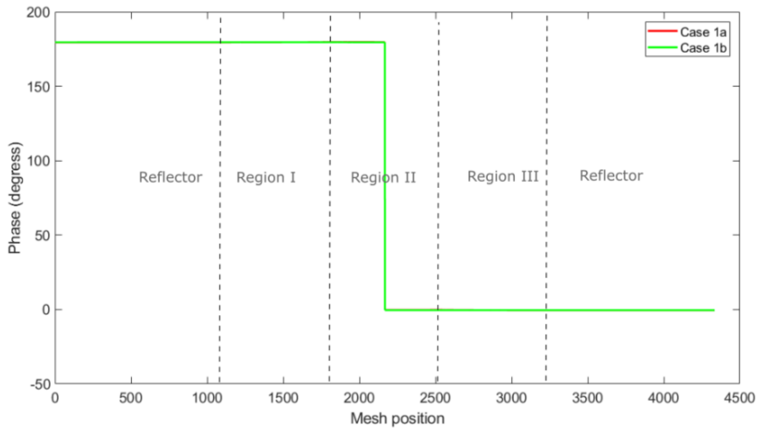
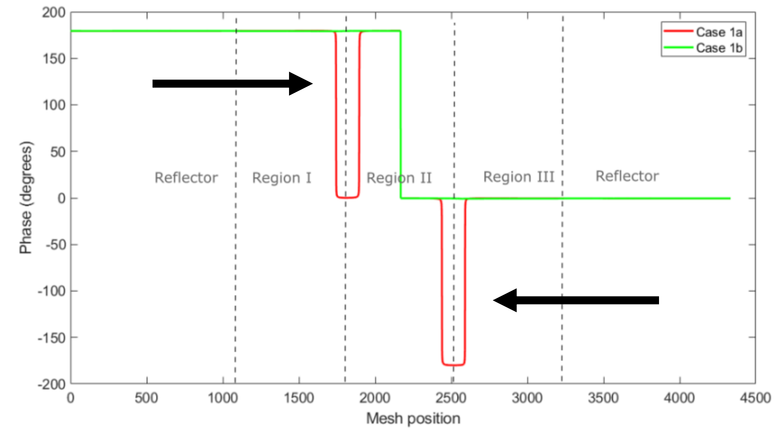
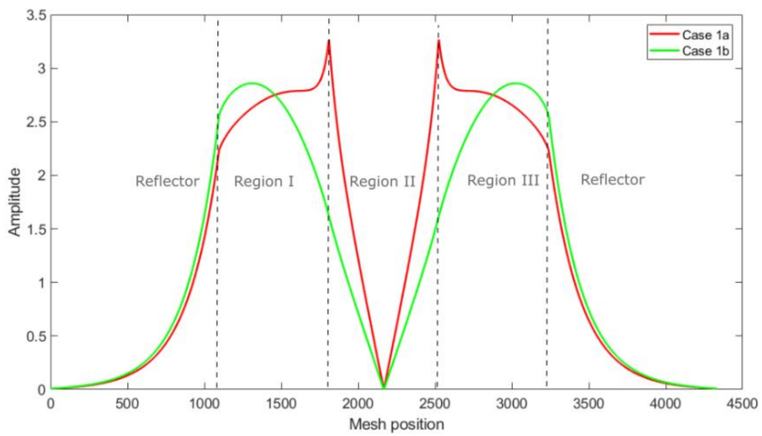
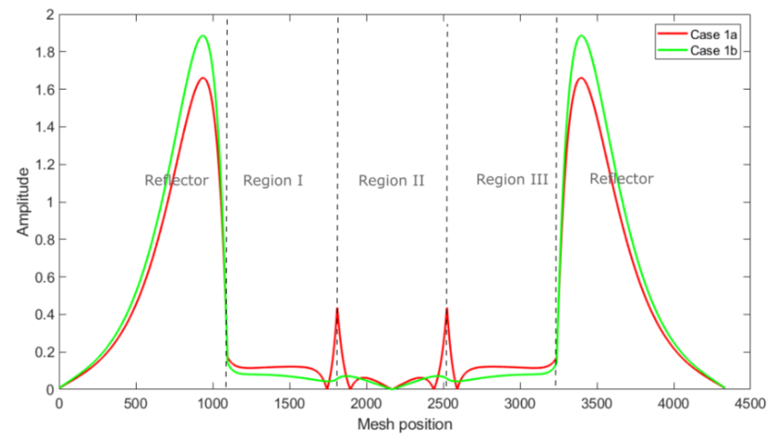
Fast group



Thermal group







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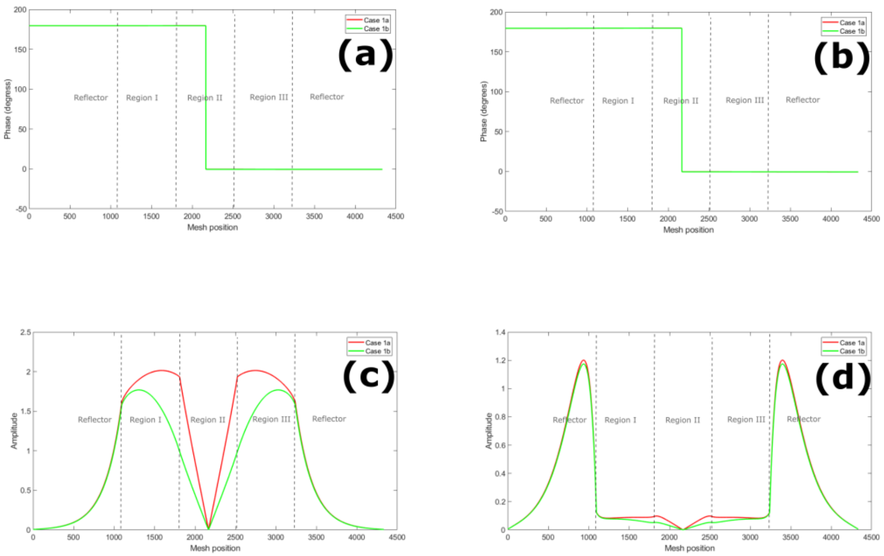
Fast group | **Thermal group**



(a-d): Only fast noise sources introduced

Results – *Case 1: Nodal calculations*

Case 1a (Red): Boundary-localized nodal
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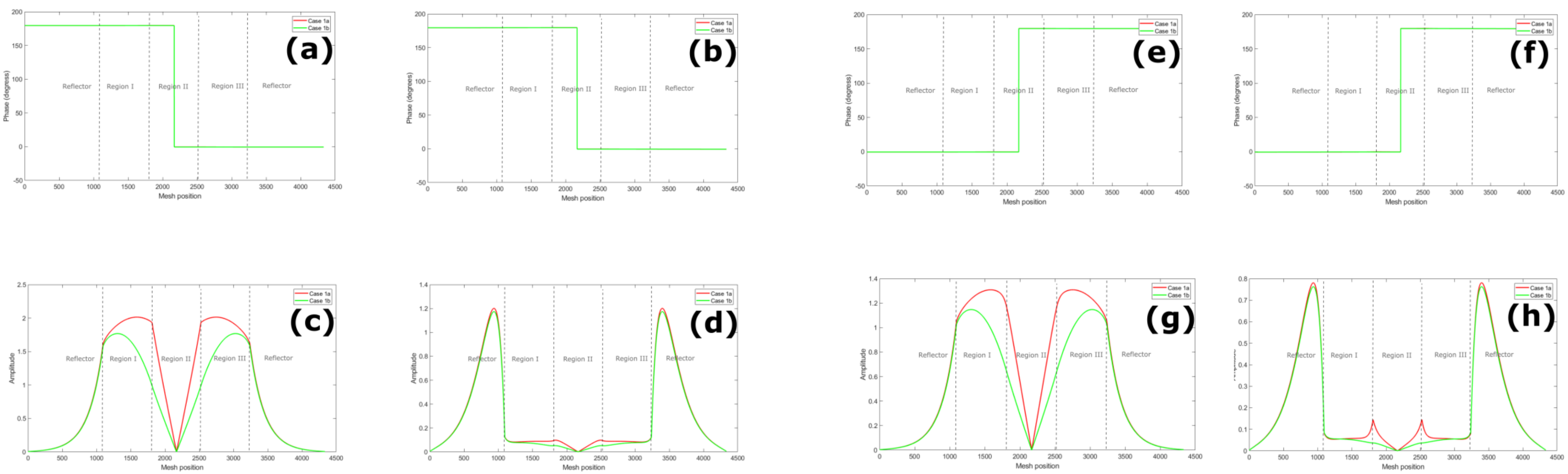
Fast group | **Thermal group** | **Fast group** | **Thermal group**

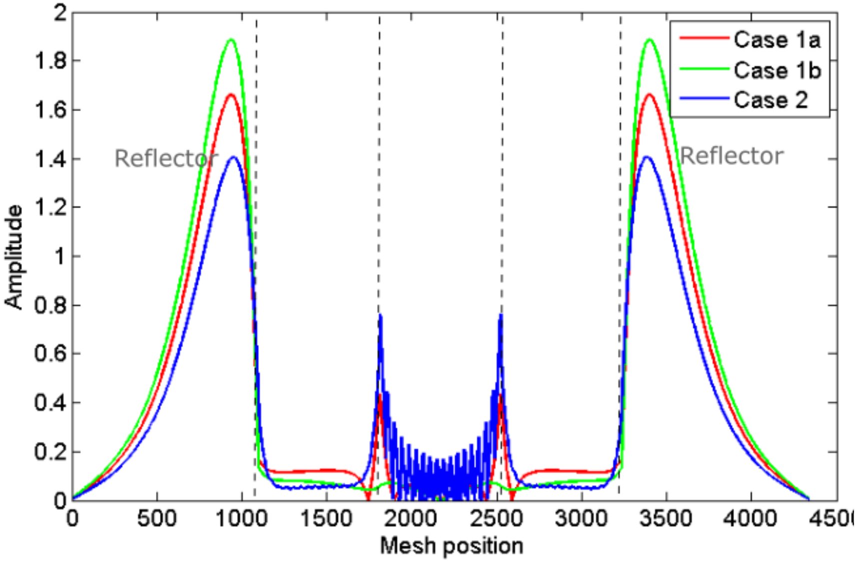


(a-d): Only fast noise sources introduced
(e-h): Only thermal noise sources introduced

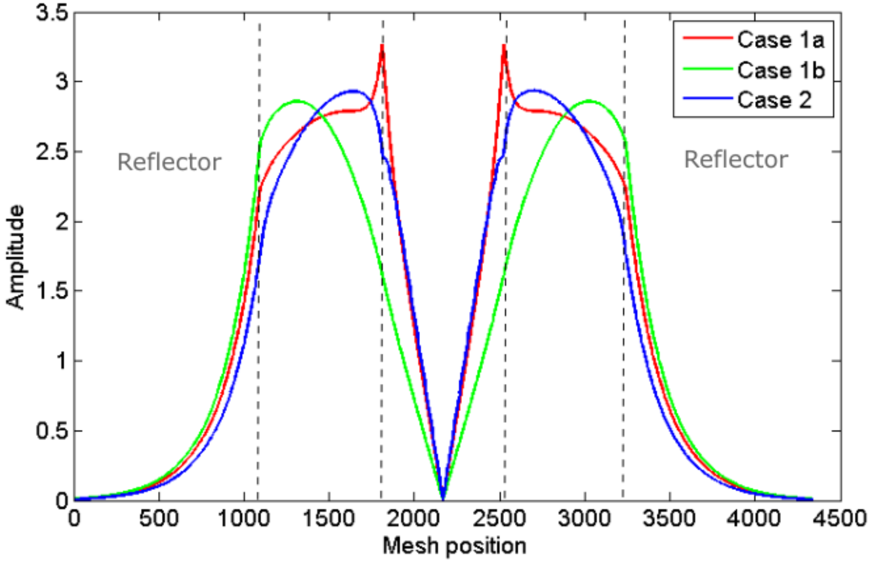
Results – *Comparison b/w nodal and pin-level calculations*

Case 1a (Red): Boundary-localized nodal
Case 1b (Green): Assembly-approximated nodal
Case 2 (Blue): Pin-level

Fast group



Thermal group



Note: Both fast and thermal noise sources are introduced

Conclusions

- Simple 1D CORESIM-based model of neutron noise sources resulting from FA vibrations presented; Impact of cross section homogenization on FA vibrations studied
- Nodal codes can faithfully represent the collective and coherent movement of the fuel pins of a FA
- Both nodal approaches lead to essentially identical results sufficiently away from the perturbation; Close to the perturbation, the two approaches provide rather different response
- 'Boundary-localized' nodal approach should be preferred as it appears to capture local noise information (as a pin-wise approach would do), without requiring an ultra-fine mesh

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