CORTEX
Core monitoring techniques and experimental validation and demonstration

On the modelling of fuel assembly vibrations using coarse mesh approaches

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Introduction

- Special emphasis in CORTEX on fuel assembly vibrations
- Neutron noise induced by fuel assembly vibrations often modelled by coarse mesh approaches
- Purpose of this work:

  To investigate whether coarse mesh approaches can reproduce the global behavior of the neutron noise

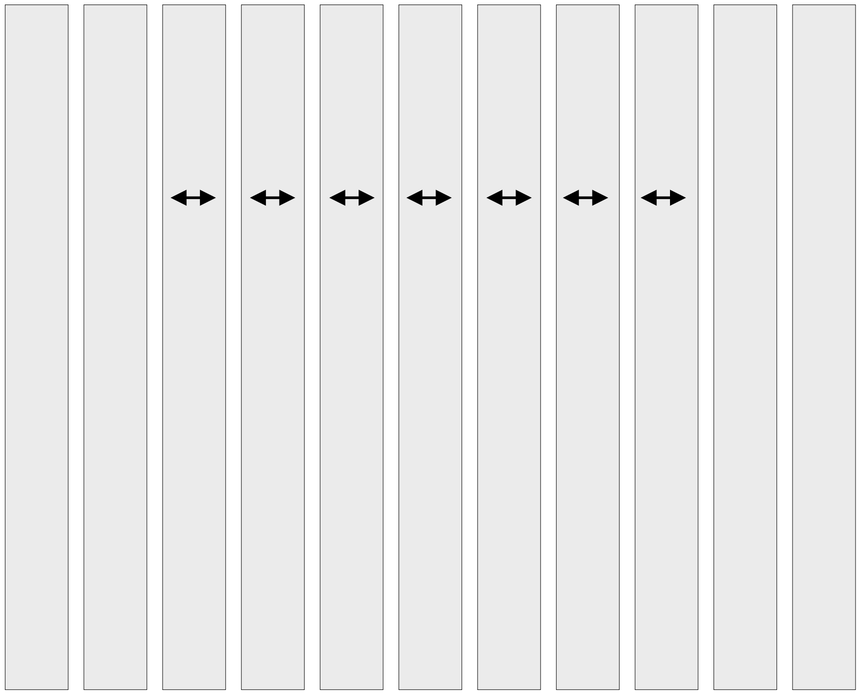
Introduction

- Plan of the presentation:
  - Modelling of fuel assembly vibrations
  - System considered and approximations used
  - Results:
    - Theoretical considerations
    - Heterogeneous systems
    - Homogenized systems
  - Conclusions

Modelling of fuel assembly vibrations

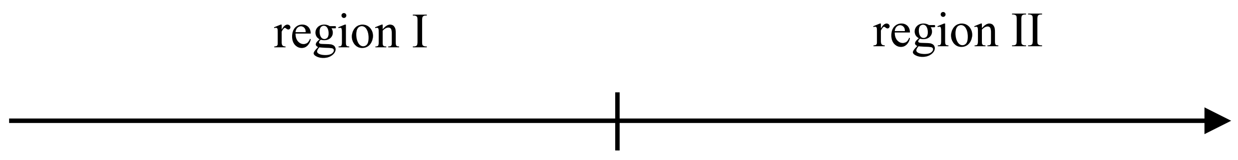
Modelling of fuel assembly vibrations

- Fuel assembly vibrations = displacement of the boundaries between "homogeneous" regions



Modelling of fuel assembly vibrations

- Illustration on a moving interface between two homogeneous regions:



$$b(t) = b_0 + \varepsilon(t) \qquad x$$

➢ Static cross-section representation:

$$\Sigma_{\alpha,0}(x) = \left[1 - \mathrm{H}(x - b_0)\right]\Sigma_{\alpha,I} + \mathrm{H}(x - b_0)\Sigma_{\alpha,II}$$

➢ Dynamic cross-section representation:

$$\delta\Sigma_{\alpha}(x,t) = -\Delta\Sigma_{\alpha}\mathrm{H}(x - b_0) + \Delta\Sigma_{\alpha}\mathrm{H}\left(x - b_0 - \varepsilon(t)\right)$$

with

$$\Delta\Sigma_{\alpha} = \Sigma_{\alpha,II} - \Sigma_{\alpha,I}$$

Modelling of fuel assembly vibrations

- Illustration on a moving interface between two homogeneous regions:

  For $\varepsilon(t) = d\sin(\omega_0 t)$ and using the model of Rouchon and Sanchez*, one obtains in the frequency domain at the fundamental frequency ω_0 :

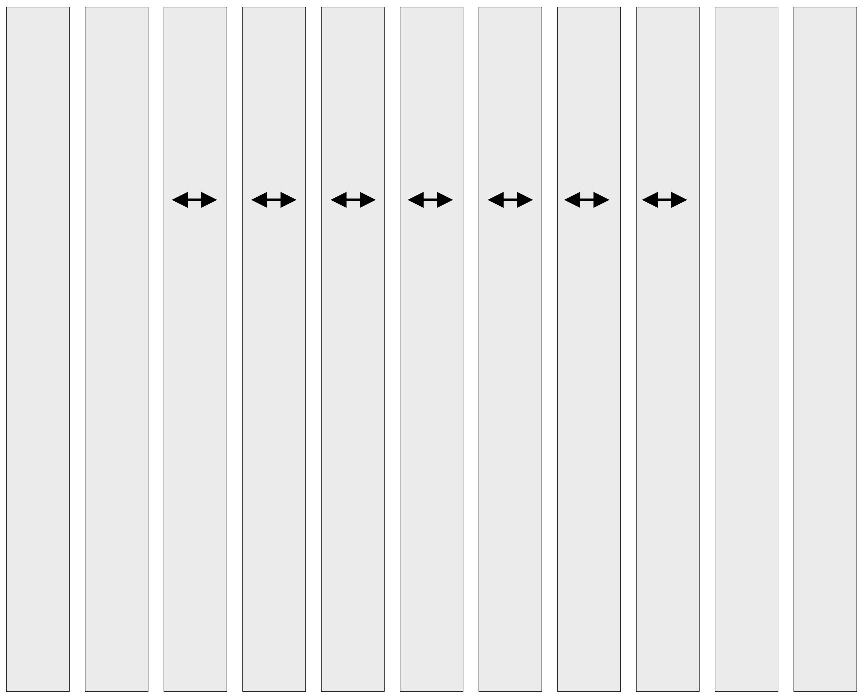
$$\delta\Sigma_\alpha(x,\omega_0) = 2\iota\Delta\Sigma_\alpha \cos\left[\omega_0\tau(x)\right]$$

with $\tau(x) = \frac{1}{\omega_0}\arcsin\left(\frac{x-b_0}{d}\right)$ and for $x \in \left[b_0 - d; b_0 + d\right]$

*Rouchon A. and Sanchez R., "Analysis of vibration-induced neutron noise using one-dimension noise diffusion theory," Proc. Int. Congress on Advances in Nuclear Power Plants (ICAPP2015), Nice, France, May 3-5, 2015 (2015).

Modelling of fuel assembly vibrations

- After homogenization = displacement of only two boundaries between "homogeneous" regions



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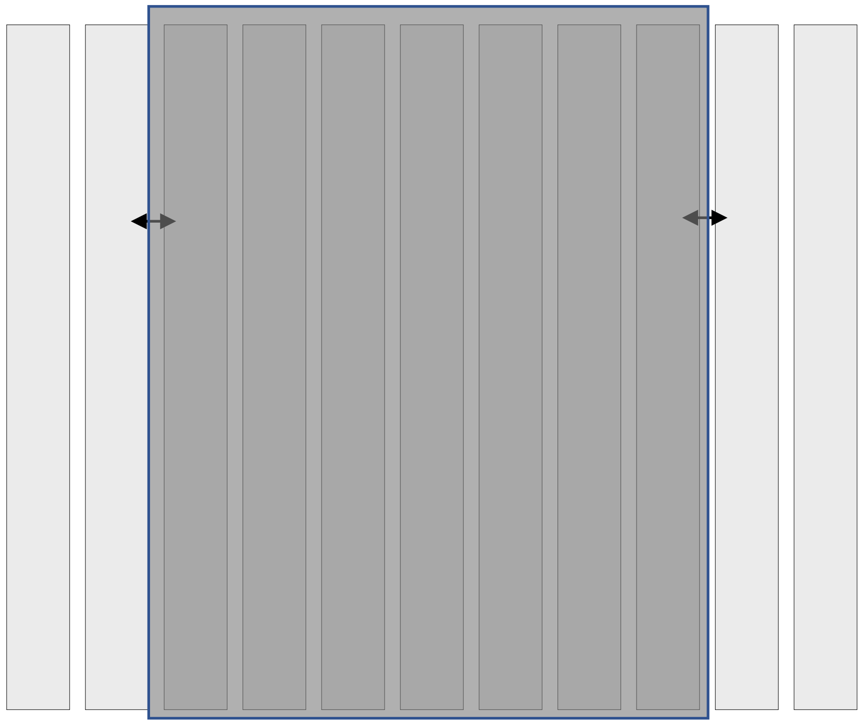


Modelling of fuel assembly vibrations

- Illustration on a moving interface between two homogeneous regions:

  Approximated treatment relying on the ε/d model of Pazsit* giving at the fundamental frequency ω_0:

$$\delta\Sigma_\alpha\left(x,\omega_0\right)=\mathcal{F}\left\{\varepsilon\left(t\right)\right\}_{\omega_0}\delta\left(x-b_0\right)\Delta\Sigma_\alpha$$

*Jonsson A., Tran H.N., Dykin V. and Pázsit I., "Analytical investigation of the properties of neutron noise induced by vibrating absorber and control rods," Kerntechnik, 77 (5), pp. 371-380 (2012).

System considered and approximations used

System considered and approximations used

- 1-D PWR model of 361.25 cm
- 15 fuel assemblies, each containing 17 fuel pins
- Core surrounded by reflector
- Two-group diffusion theory
- Frequency domain
- Linear theory
- No thermal-hydraulic feedback
- Effect of the noise source estimated numerically using CORE SIM
- Fine mesh of 0.00125 cm used throughout the entire work

Results

Results – theoretical considerations

- In two-group theory, neutron noise given as:

$$\begin{bmatrix}\delta\phi_1(x,\omega)\\ \delta\phi_2(x,\omega)\end{bmatrix}=\begin{bmatrix}\int_V\left[G_{1\to1}(x,x',\omega)S_1(x',\omega)+G_{2\to1}(x,x',\omega)S_2(x',\omega)\right]dx'\\ \int_V\left[G_{1\to2}(x,x',\omega)S_1(x',\omega)+G_{2\to2}(x,x',\omega)S_2(x',\omega)\right]dx'\end{bmatrix}$$

with

$$\begin{bmatrix}S_1(x',\omega)\\ S_2(x',\omega)\end{bmatrix}=\Phi_r(x')\delta\Sigma_r(x',\omega)+\Phi_a(x')\begin{bmatrix}\delta\Sigma_{a,1}(x',\omega)\\ \delta\Sigma_{a,2}(x',\omega)\end{bmatrix}+\Phi_f(x',\omega)\begin{bmatrix}\delta\nu\Sigma_{f,1}(x',\omega)\\ \delta\nu\Sigma_{f,2}(x',\omega)\end{bmatrix}$$

➢ In the ε/d model, 2 noise sources S_1 and S_2 entirely defining the problem for each vibrating boundary

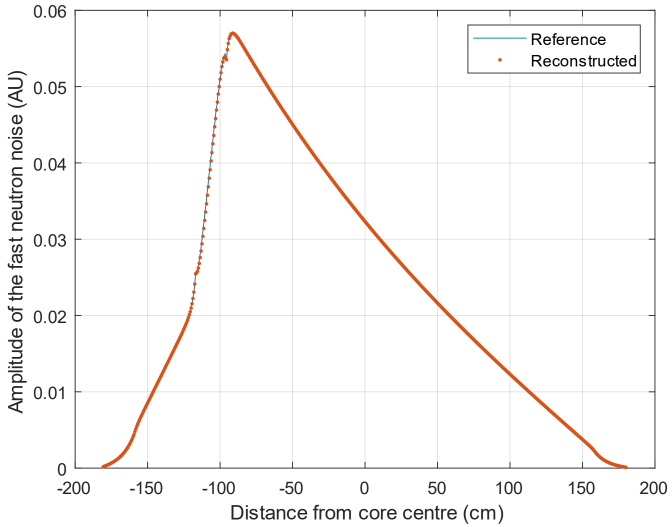
Results – theoretical considerations

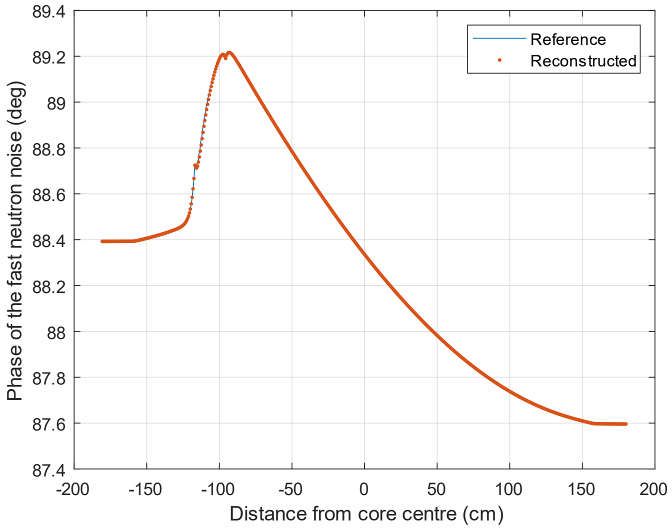
- After spatial homogenization, problem only requiring 4 noise sources

➢4 conditions necessary

Results for heterogeneous systems

- Normalization to the actual solution at the two locations of the introduced noise sources, for both the fast and the thermal group:





➢ Very good agreement for the fast neutron noise

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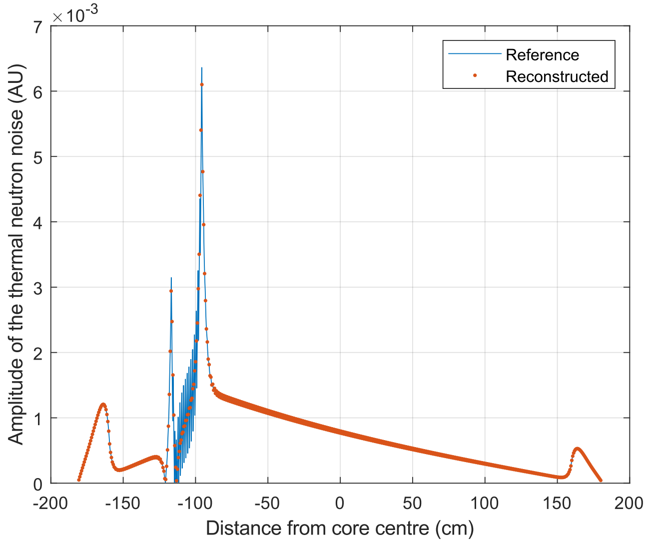
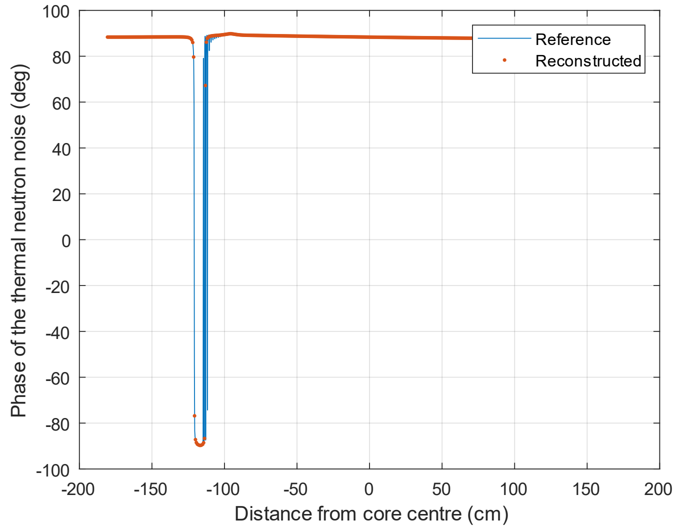




➢ Very good agreement for the thermal neutron noise

Results for heterogeneous systems

- 4 noise sources sufficient to reproduce the actual neutron noise
- Same level of accuracy obtained when replacing 2 of the 4 necessary conditions by a normalization to the same reactivity effect, evaluated:
  - Either using the spatial dependence of the actual solution, e.g., for the thermal group:

$$\delta\rho_{2,\delta\phi}\left(\omega\right)=\frac{1}{A_0 G_0\left(\omega\right)}\int_V \frac{1}{v_2}\phi_{2,0}^{+}\left(x\right)\delta\phi_2^{\text{reconstructed}}\left(x,\omega\right)dx=\frac{1}{A_0 G_0\left(\omega\right)}\int_V \frac{1}{v_2}\phi_{2,0}^{+}\left(x\right)\delta\phi_2^{\text{reference}}\left(x,\omega\right)dx$$

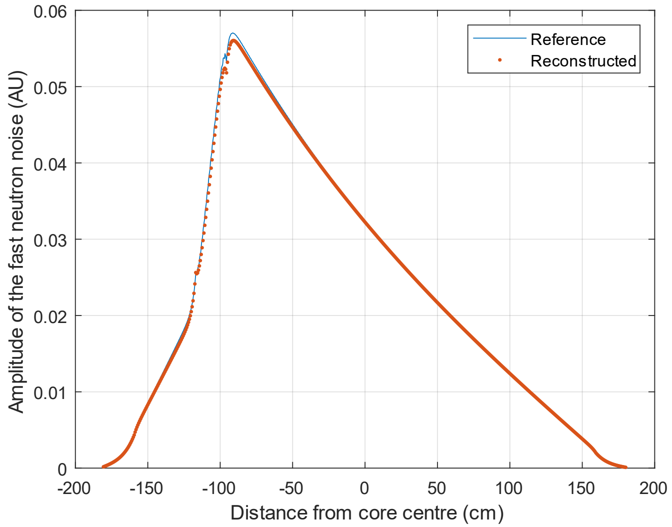
  - Or using the perturbations of the cross-sections directly (preferable), e.g., for the thermal group:

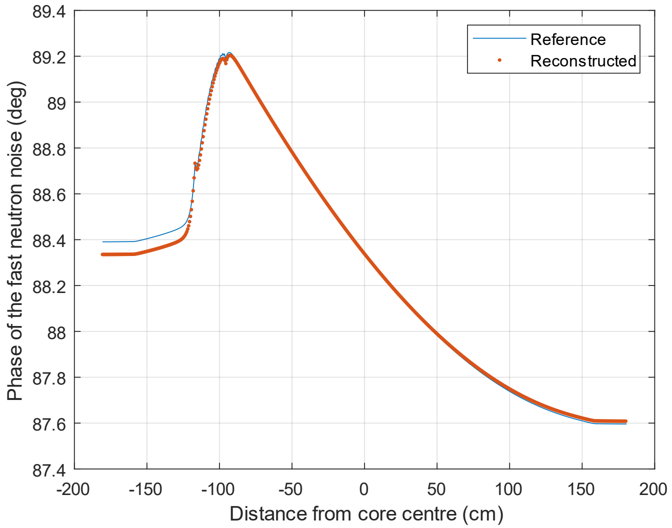
$$\delta\rho_{2,\delta\Sigma}\left(\omega\right)=\frac{1}{F_0}\int_V\left\{\delta\Sigma_r^{\text{reconstructed}}\left(x,\omega\right)\phi_{2,0}^{+}\left(x\right)\phi_{1,0}\left(x\right)-\delta\Sigma_{a,2}^{\text{reconstructed}}\left(x,\omega\right)\phi_{2,0}^{+}\left(x\right)\phi_{2,0}\left(x\right)\right\}dx$$

$$=\frac{1}{F_0}\int_V\left\{\delta\Sigma_r^{\text{reference}}\left(x,\omega\right)\phi_{2,0}^{+}\left(x\right)\phi_{1,0}\left(x\right)-\delta\Sigma_{a,2}^{\text{reference}}\left(x,\omega\right)\phi_{2,0}^{+}\left(x\right)\phi_{2,0}\left(x\right)\right\}dx$$

Results for homogenized systems

- Normalization to the actual solution at the two locations of the introduced noise sources, for the fast/thermal groups, respectively:





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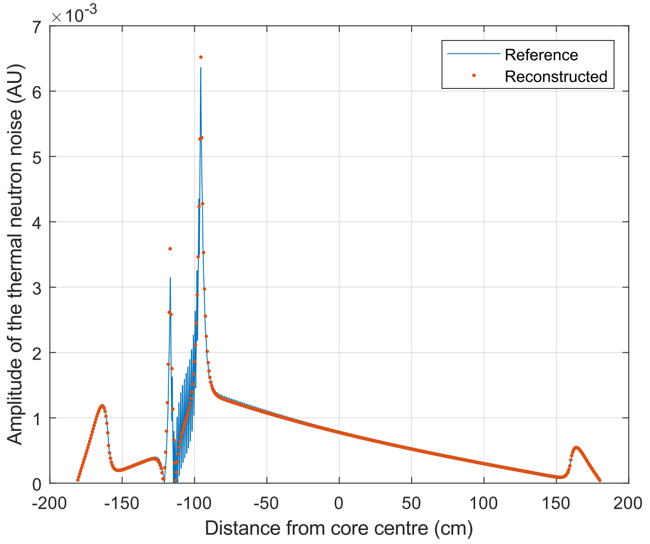

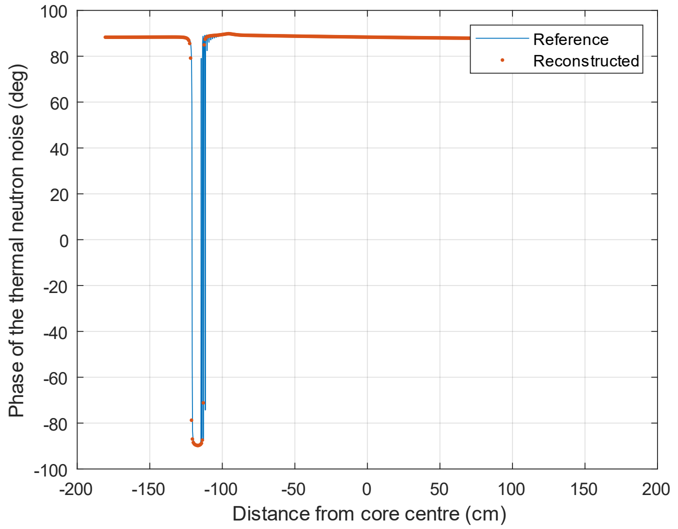

➢ Very good agreement for the thermal neutron noise

Conclusions

Conclusions

- Neutron noise successfully reproduced at the global scales after assembly homogenization, using only 4 noise sources and using the ε/d model

➢ Truly remarkable results

(but noise source weights to be estimated)

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