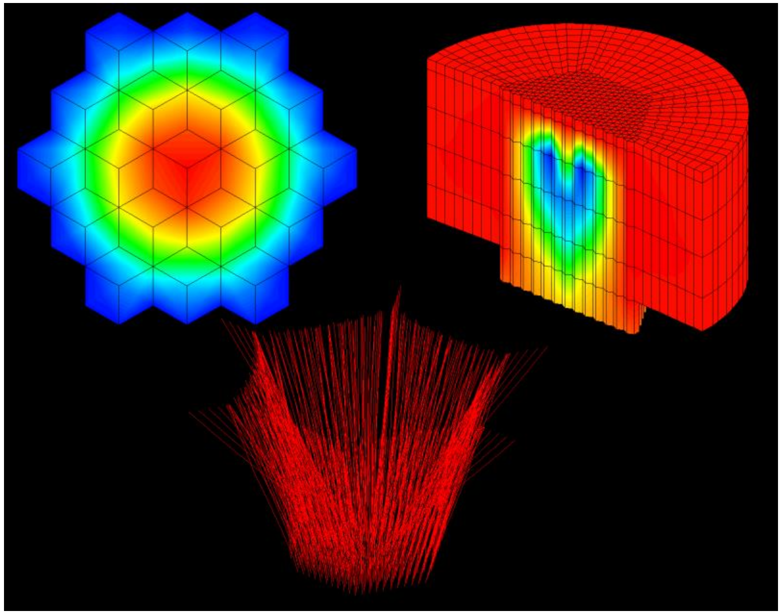
DE LA RECHERCHE À L'INDUSTRIE

SIMULATIONS OF SFR NEUTRONIC TRANSIENTS FOR CHOSEN MECHANICAL SCENARIOS.



CLUB CAST3M 2015

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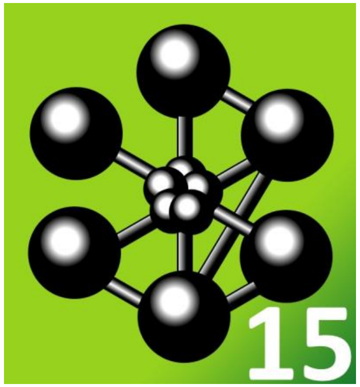
INTRODUCTION

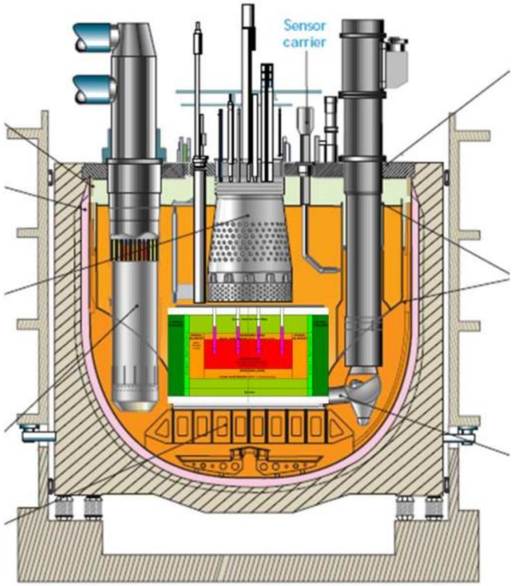
- The aspects studied during my internship in CEA Saclay will be presented.

- 2 major topics are involved:
  - Methodology for coupling of mechanical and neutronic simulations (deformed geometry).
  - Selected mechanical excitation scenarios applied to the test fast core model and corresponding neutron responses.



- Mechanical part → Cast3M,
  neutronic calculation → Cast3M Neutronic Tool
  (by Cyril PATRICOT)

PURPOSE OF THE STUDY



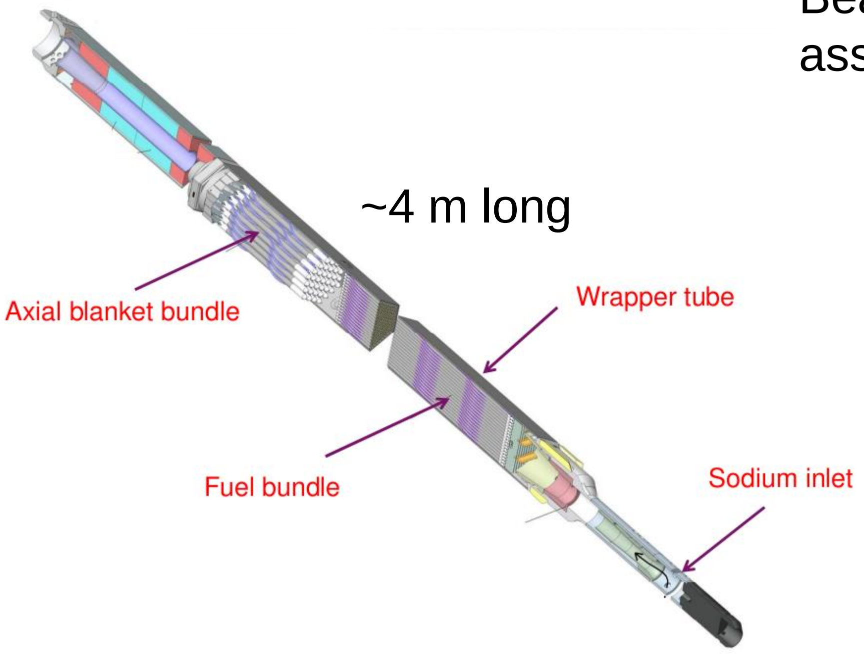
- Sodium-cooled Fast Reactor is an example of nuclear system operating on neutron flux spectrum and belonging to Gen4 designs.
- Compact cores are relatively sensitive to geometrical deformations, that is why tools for neutronic-mechanical coopling are important.
- Our attention is focused on the reactor core model which undergoes various mechanical scenarios of short timescale (<1 s).

PLAN OF PRESENTATION

OUTLINE

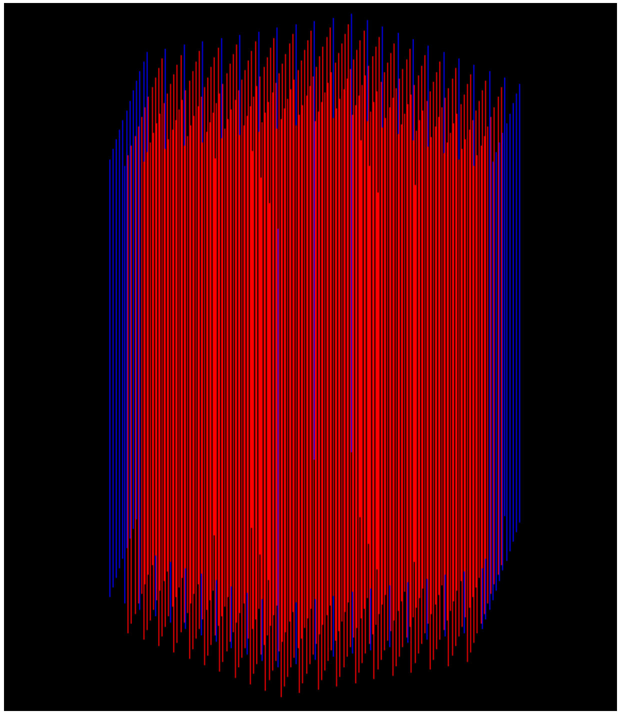
NUMERICAL AND PHYSICAL MODEL

- The considered geometry comprises a beam of assemblies located on the diagrid.
- The core is surrounded by the lateral neutronic protection (PNL) and immersed in sodium coolant (at rest).

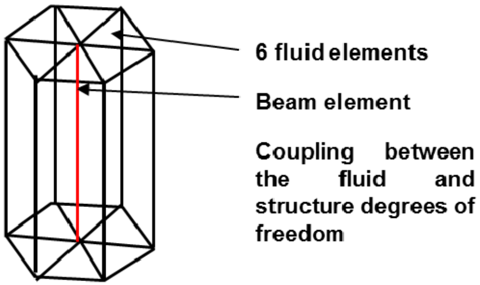


~4 m long

Beam of assemblies

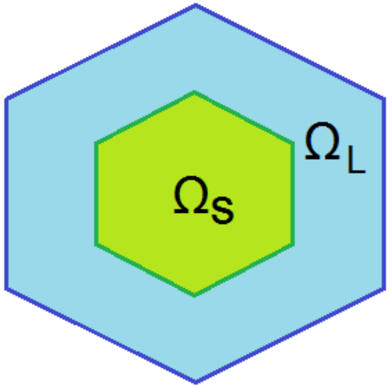


NUMERICAL AND PHYSICAL MODEL (2)



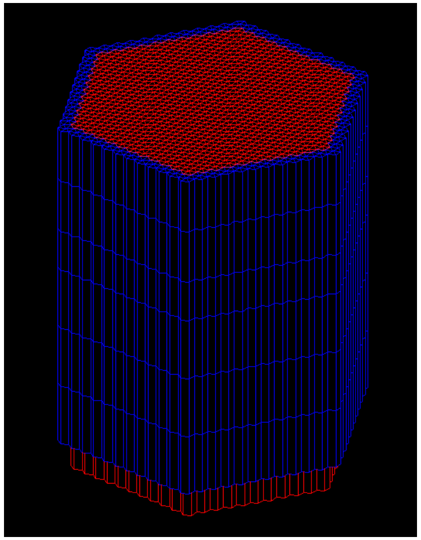
- The system is modeled using finite elements method (FEM).
- Structures are treated as hexagonal bundle of beams that may collide (+impact stiffness).
- The behavior of the structures takes into account behavior of coolant → Fluid-Structure Interaction (FSI).
- Perfect fluid + little displacements → Linear Euler Eqations

$$\rho\ddot{\overrightarrow{X_L}} = -\vec{\nabla}P$$
$$P = -\rho c^2 div\overrightarrow{X_L}$$
$$\dot{\overrightarrow{V_L}}.\vec{n} = \dot{\overrightarrow{V_S}}.\overrightarrow{n}$$

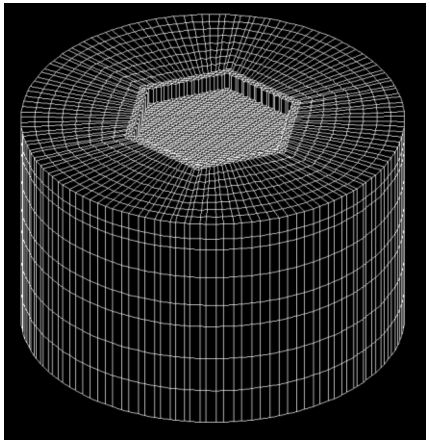


- Dissipation of fluid energy → Rayleigh damping.
- Homogenization of fluid → reduced size of the problem.
- Displacements and rotation only in XY direction.

NUMERICAL AND PHYSICAL MODEL (3)



Meshes of fluid



- Numerical equations derived in (U,P,φ) formulation.
- Introduction of additional variable → symmetrical matrices

$$\ddot{\varphi} = P$$

- The final homogeneous equations governing simulation:

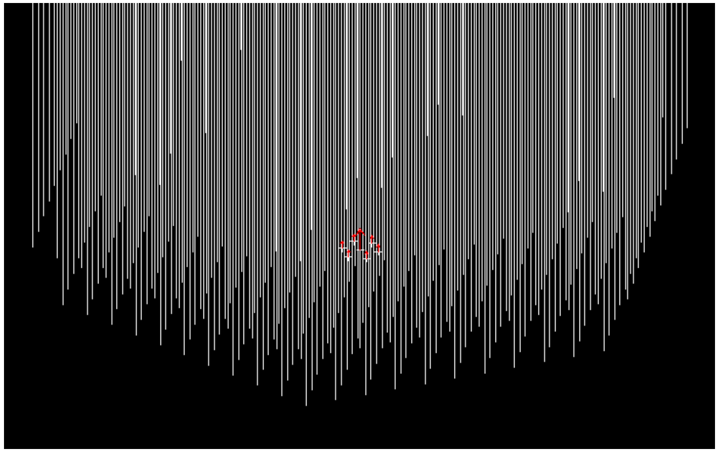
$$\begin{bmatrix} M+M^* & 0 & -C+JC' \\ 0 & 0 & -A(\Omega_L/\Omega_T) \\ -C+JC' & -A(\Omega_L/\Omega_T) & -(1-J)G \end{bmatrix} \begin{bmatrix} \ddot{X}_S \\ \ddot{P} \\ \ddot{\varphi} \end{bmatrix} + \begin{bmatrix} K & 0 & 0 \\ 0 & A(\Omega_L/\Omega_T) & 0 \\ -0 & 0 & 0 \end{bmatrix} \begin{bmatrix} X_S \\ P \\ \varphi \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

- Acceptable computational cost for whole-core simulation (~several hours)

MECHANICAL TEST SCENARIOS

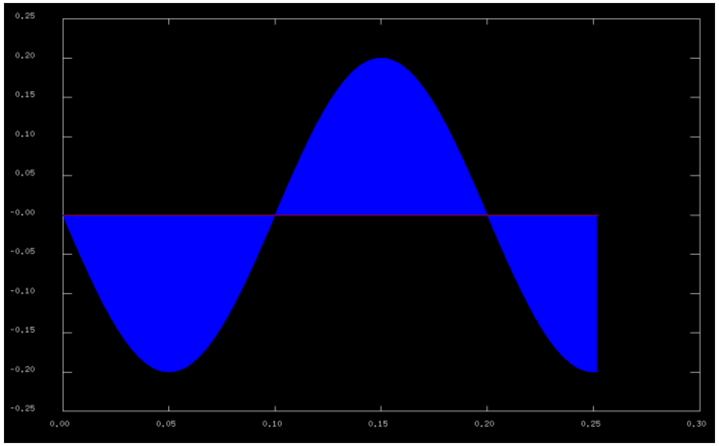
- Injection of 100 L at the bottom of core.

  → Injection time 0.05 s
  → Located at central fuel assembly
  → Simulation time of 0.25 s



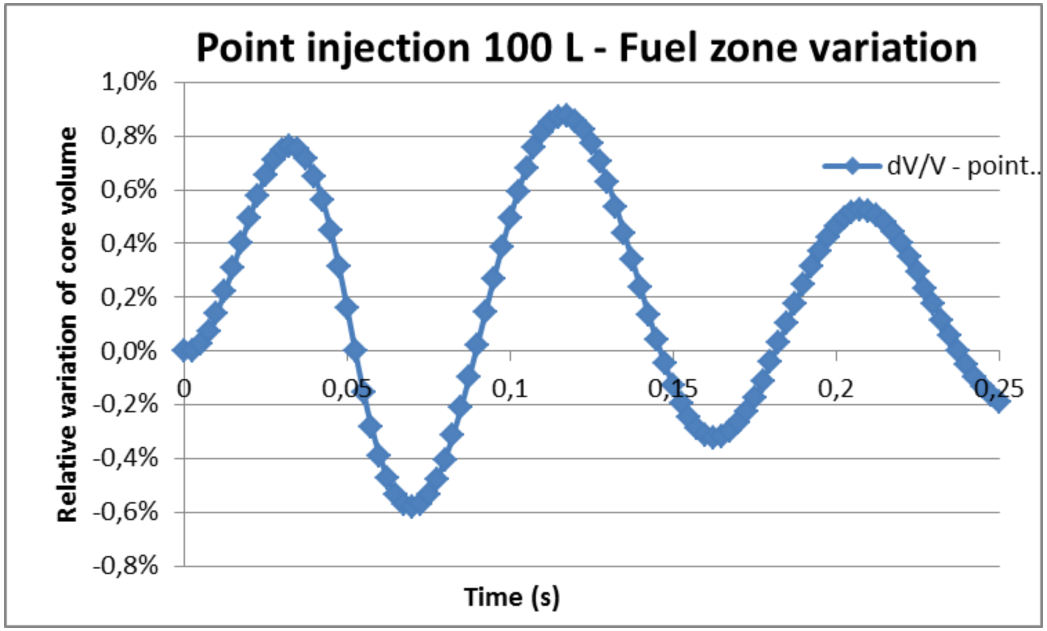
- Weak seismic excitation

  → Frequency of 1 Hz
  → Amplitude around ~1 cm or less
  → Acceleration applied to all elements
  → Simulation time of 0.8 s

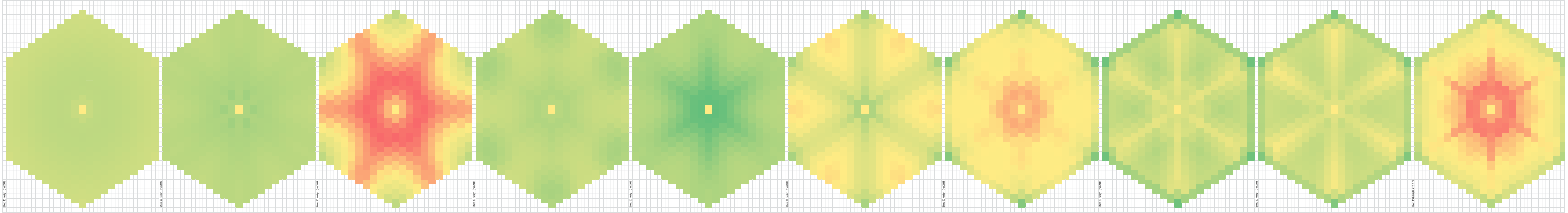


MECHANICAL RESULTS: LIQUID INJECTION

- Variation of fuel volume



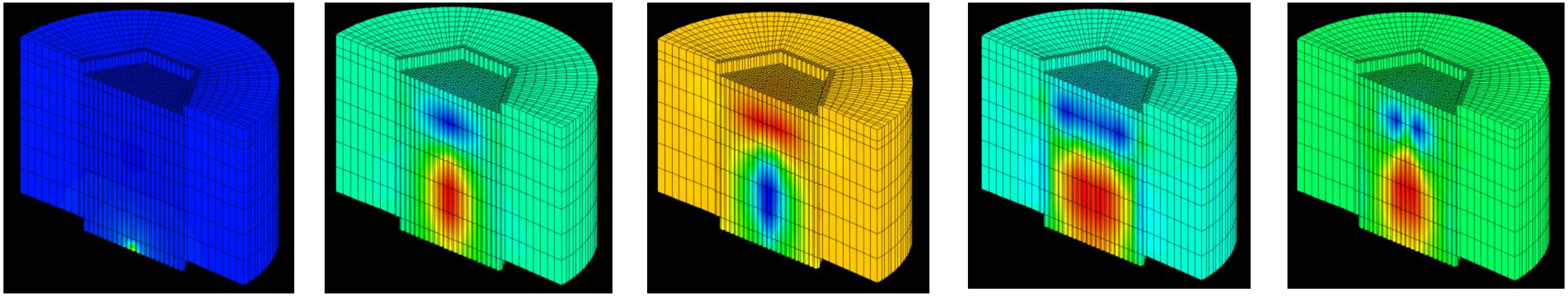
- Radial displacements of assemblies (compression – red, departure – green)



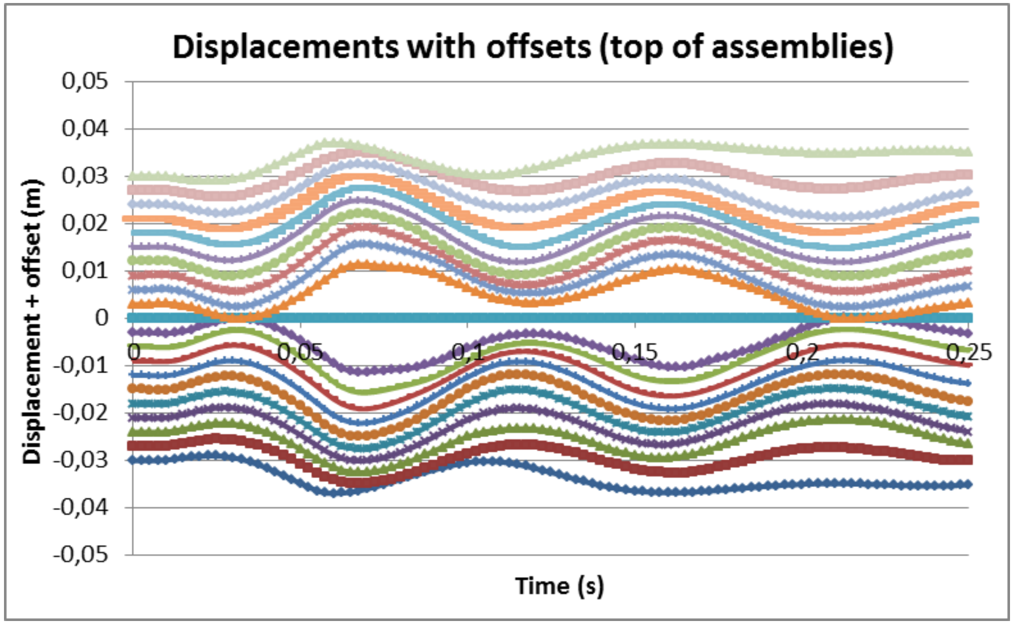
Time steps of 0.025s →

MECHANICAL REULTS: LIQUID INJECTION (2)

- Pressure variation in system

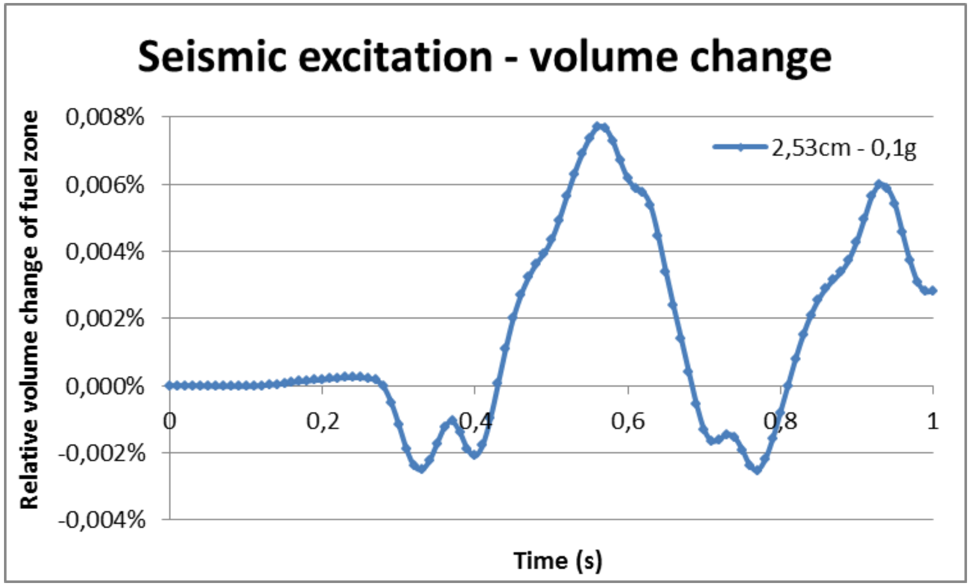


- Displacement of assemblies at the top

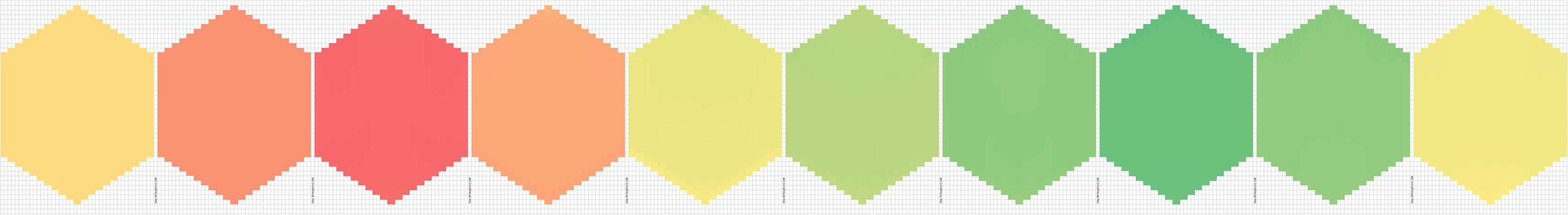


MECHANICAL REULTS: SEISMIC EXCITATION

- Variation of fuel volume



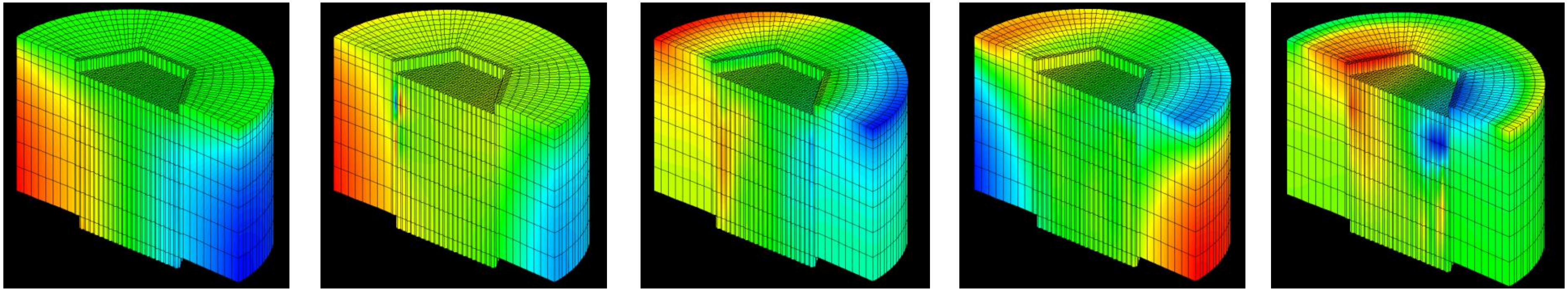
- Horizontal displacement of assemblies (left – red, right – green)



Time steps of 0.1s →

MECHANICAL REULTS: SEISMIC EXCITATION (2)

- Pressure variation in system



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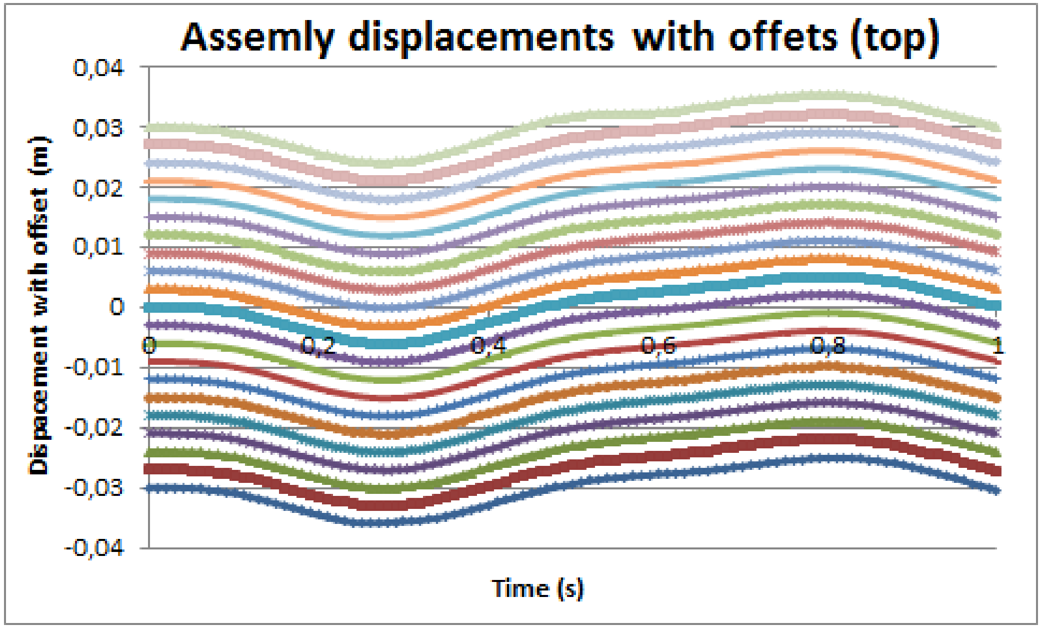


OUTLINE

I. Mechanical calculation

  I.1. Numerical and physical model

  I.2. Mechanical test scenarios

II. Neutronic simulation

  II.1. Description of diffusion neutron solver

  II.2. Results - power evolution in system

III. Summary and prospects for the upcomming studies

CAST3M NEUTRONIC TOOL

- Neutron transport simplified to multigroup diffusion equation (Fick’s law)

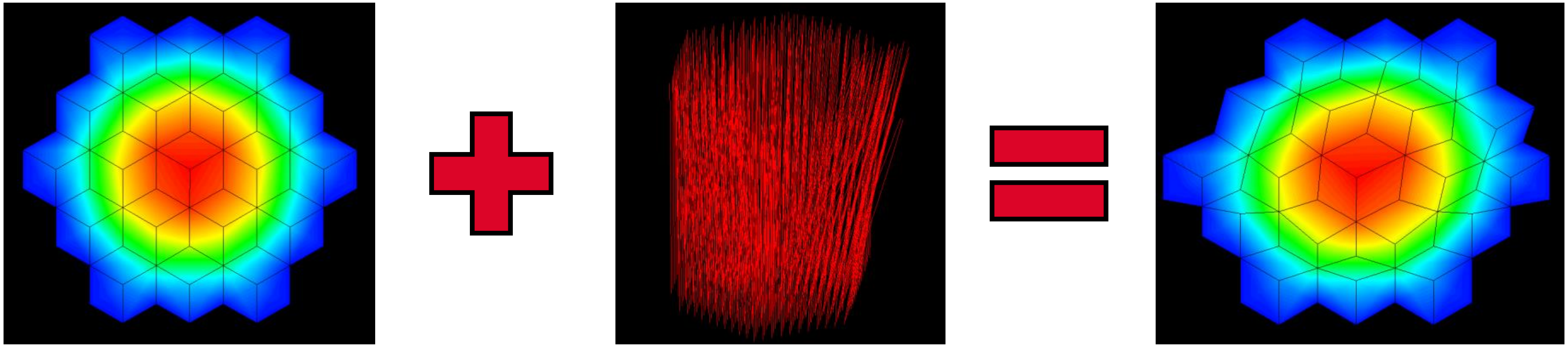
$$\overbrace{-\frac{1}{V^g}\frac{\partial\phi^g(x)}{\partial t}}^{\text{Time evolution}} = \overbrace{\nabla\big(D^g(x)\nabla\phi^g(x)\big)}^{\text{Transport/ diffusion}} - \overbrace{\sigma^g_{disp}(x)\phi^g(x)}^{\text{removal}} +$$

$$\underbrace{\sum_{g'\neq g}\sigma_s^{g'\to g}(x)\phi^{g'}(x)}_{\text{Transfer/arrival}} + \underbrace{\chi_p^g(x)(1-\beta)\sum_{g'}\nu\sigma_f^{g'}(x)\phi^{g'}(x)}_{\text{Fission production}} + \underbrace{\sum_l \chi_l^g\lambda_l C_i^l}_{\text{Delayed neutrons}}.$$

- Equation above for each energy group of neutrons
- \+ Set of equations for precursor concentrations

CAST3M NEUTRONIC TOOL (2)

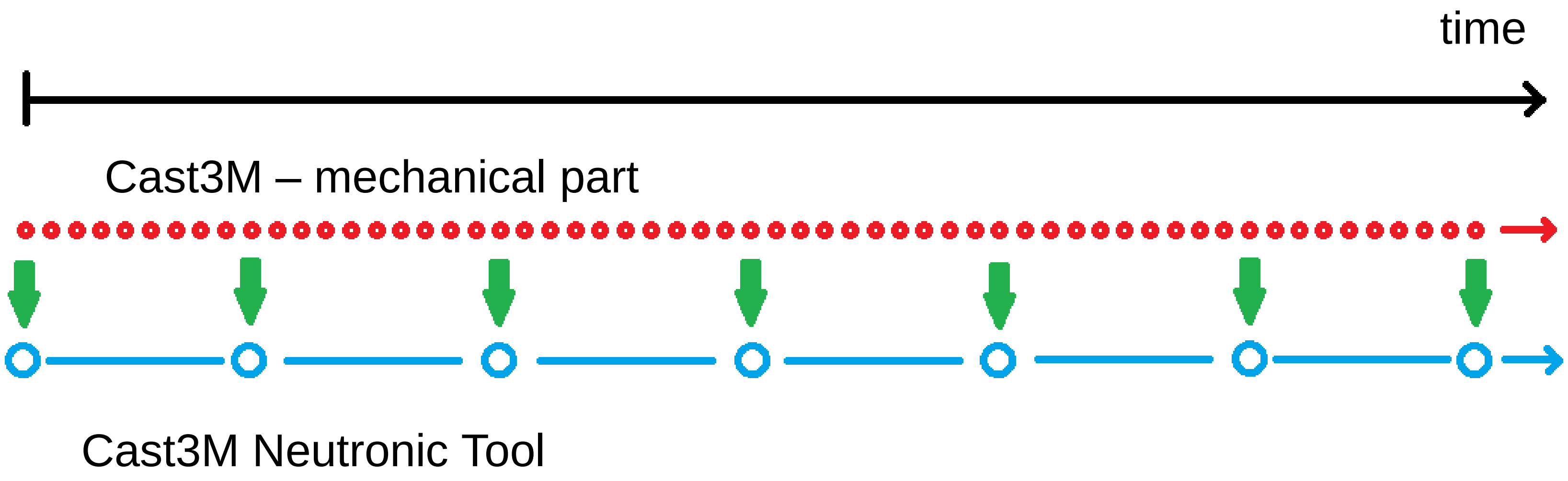
- The novelty of the CNT concerns direct treatment of geometry displacements



- The CNT has been validated with static Monte Carlo simulations using TRIPOLI4 and for keff differences up to several hundreds pcm.
- Comparable simulations for full-core models were done using APOLLO3
- Set of parametric studies suggest generally correct behavior of result

CAST3M NEUTRONIC TOOL (3)

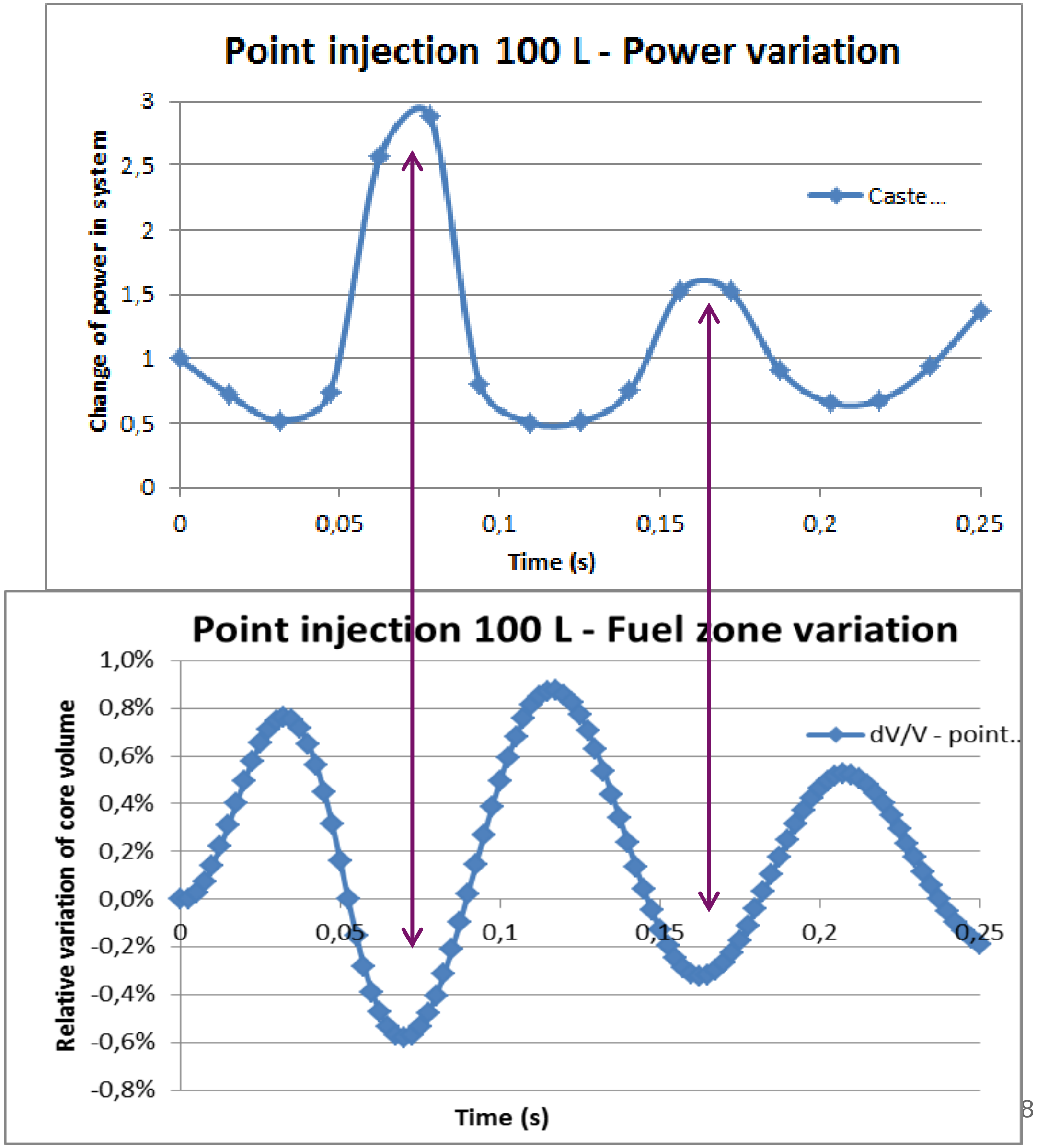
- One way coupling with mechanical simulation



- End-of-step displacements are transfered to neutron diffusion calculations
- Parametric study helped to optimize the length of time step for CNT

NEUTRON DIFFUSION RESULTS – FLUID INJECTION

- Power evolution during neutronic transient...
- ... strongy correlated with variation of active volume

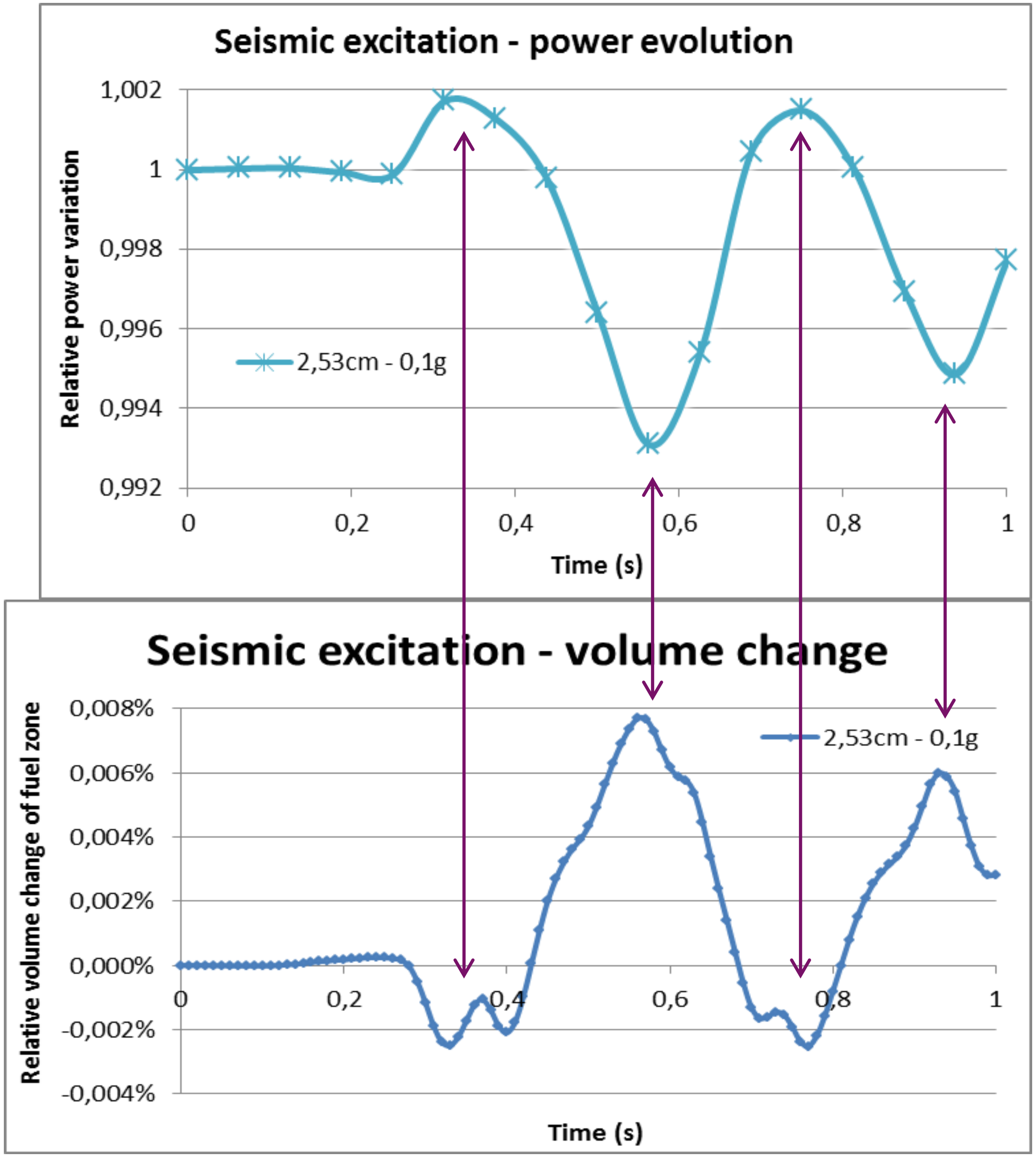


Point injection 100 L - Power variation

Point injection 100 L - Fuel zone variation

NEUTRON DIFFUSION RESULTS – SEISMIC EXCITATION

- Power evolution during neutronic transient...



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I. **Mechanical calculation**

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  II.2. Results - power evolution in system

III. **Summary and prospects for the upcomming studies**

SUMMARY

- Structure mechanics models were used together with neutronic models in Cast3M.

- New methodology for neutron-mecanics linking for Sodium Fast Reactors was established, validated and tested.

- Cast3M Neutronic Tool stands as a general tool for a large variety of mechanical excitations and short scenarios.

- CNT is useful for current and upcomming safety assessments concerning Gen4 systems and framework of ASTRID Project.

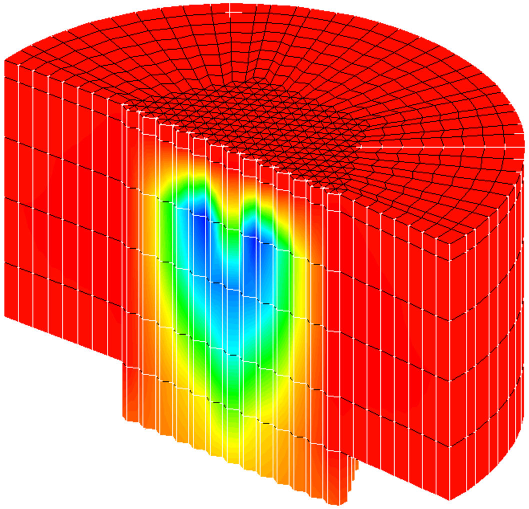
- Code is currently intensively applied to model various scenarious for better understanding of core behavior

PROSPECTS FOR FUTURE DEVELOPMENT

- FSI:
  - Taking into account steady state movement of the fluid
  - Applying turbulent flow models for the liquid sodium

- Structure mechanics:
  - Adding verical (Z) degree of freedom to mechanical model of solid

- Neutronics
  - Improving neutron diffusion model



Thank you for attention