IAEA
International Atomic Energy Agency

Joint ICTP-IAEA Workshop on Reactor Physics, Thermal Hydraulics and Plant Design Engineering of Small Modular Reactors

13th April 2026 – 17th April 2026

Benchmark for MSRs modelling

15th April 2026

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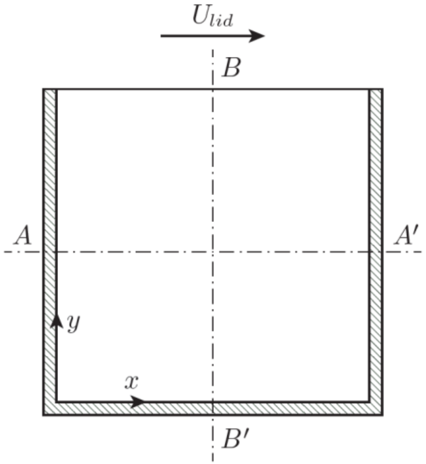
The CNRS benchmark

- **Simple problem,** but still representative of MSFR
- Divided into **phases and steps**
- **Coupling** between various physical phenomena **gradually introduced**
- Phenomena complex to model as turbulence or Doppler feedback are absent

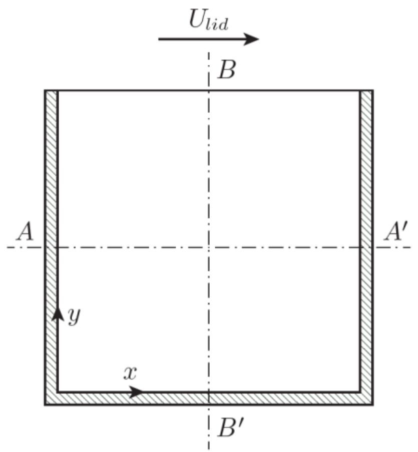


for more info: Tiberga et al. (2020), https://doi.org/10.1016/j.anucene.2020.107428

The CNRS benchmark

Main characteristics:

- LiF-BeF2-UF4 salt
- Prescribed nuclear data (condensed into 6 groups)
- No Doppler feedback, only density
- Incompressible laminar flow
- Boussinesq approximation for buoyancy
- Simple 2D geometry: square cavity
- Constant thermodynamic properties
- No model prescribed for neutronics



Boundary conditions:

- Homogeneous bare reactor ⇒ standard vacuum + hom. Neumann for precursors
- No-slip, zero velocity at each walls except lid: U_{lid}
- Adiabatic walls, volumetric heat transfer coefficient γ imposed: $q''' = \gamma(900 - T)$

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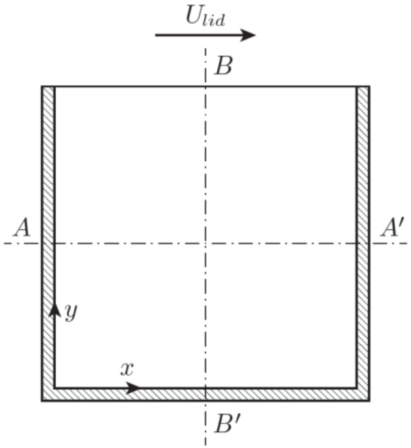

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Benchmark – mesh creation

Step 0 – Mesh creation

Let's create the mesh through the blockMesh utility

Goal: Create a 2D square mesh

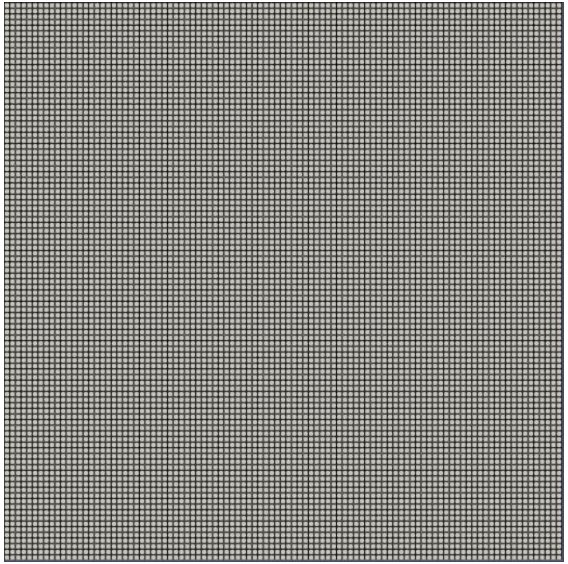
Input:

Number of divisions

for the square sides

Ouput:

Simulation mesh



Benchmark – Phase 0

Step 0.1 – Velocity field

Study solution of steady-state incompressible flow

Goal: test capability to get a correct velocity field

Input:

$U_{lid} = 0.5$ m/s

Ouput:

Velocity components along centrelines

Benchmark – Phase 0

Step 0.1 – Velocity field

Study solution of steady-state incompressible flow

Goal: test capability to get a correct velocity field

Code	ρ (pcm)
CNRS-SP_1	411.3
CNRS-SP_3	353.7
PoliMi	421.2
PSI	411.7
TUD-S_2	482.6
TUD-S_6	578.1

Input:

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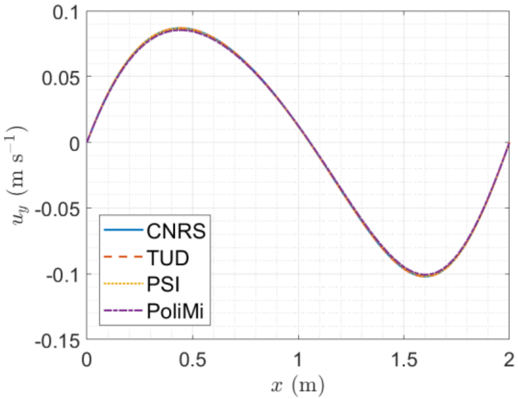

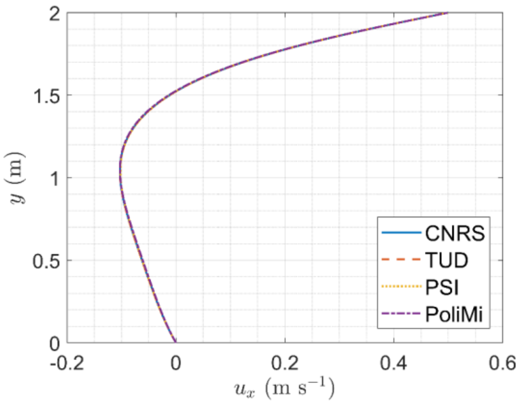

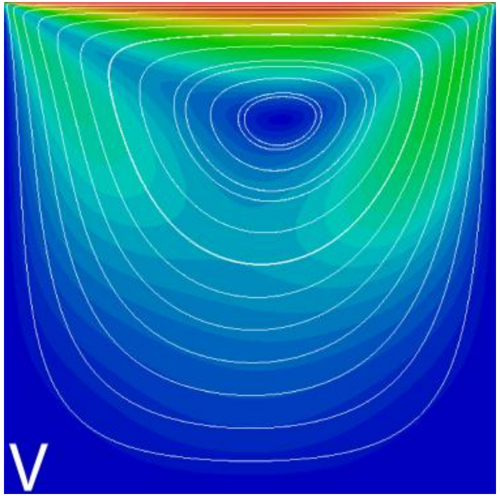

Benchmark – Phase 0

Step 0.2 – Neutronics

Study neutronics criticality eigenvalue problem with isothermal and static fuel

Goal: verify the neutronics solutions of the codes in simple, static-fuel

Input:

$T = 900\ K$

$P = 1\ GW$

Ouput:

Fission rate density $\int \Sigma\_f\ \Phi dE$

Reactivity ρ

Benchmark – Phase 0

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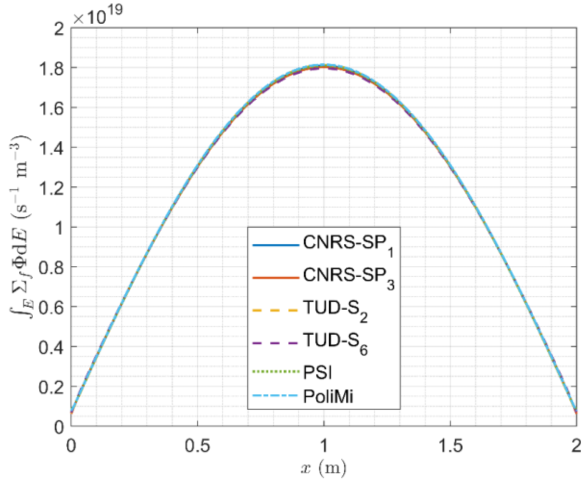


Benchmark – Phase 0

Step 0.3 – Temperature field

Study passive scalar transport

Goal: verify the capability to correctly transport passive scalars

Input:

Frozen velocity field from 0.1

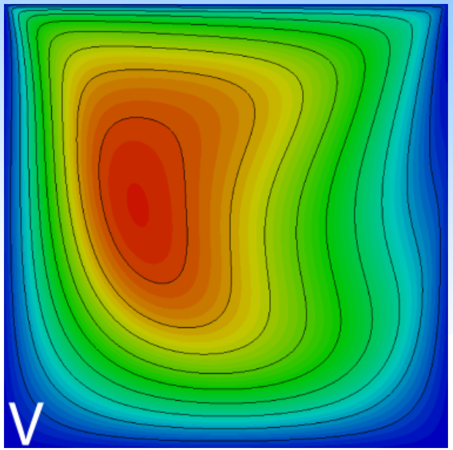
Frozen fission power from 0.2

$$\gamma = 10^6 \frac{\mathrm{W}}{\mathrm{m^2 K}}$$

Ouput:

Temperature along centrelines

Benchmark – Phase 0



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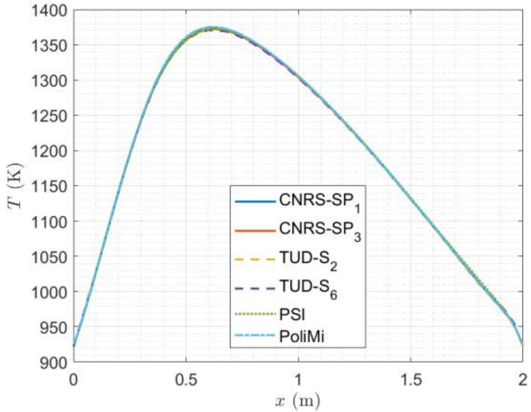

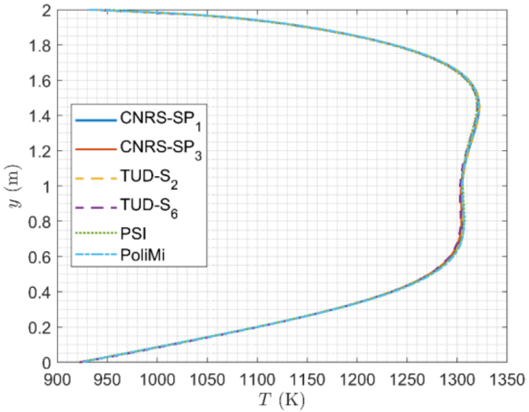

Benchmark – Phase 1

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Step 1.1 – Circulating fuel

Study the criticality problem in presence of circulating fuel

Goal: correct evaluation of the effects of the fluid flow on neutronics

Input:

Frozen velocity field from 0.1

$\mathrm{T} = 900\ \mathrm{K}$

$\mathrm{P} = 1\ \mathrm{GW}$

Ouput:

Delayed neutron source along centrelines

Reactivity change from step 0.2

Benchmark – Phase 1

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Input:

Frozen velocity field from 0.1

$T = 900$ K

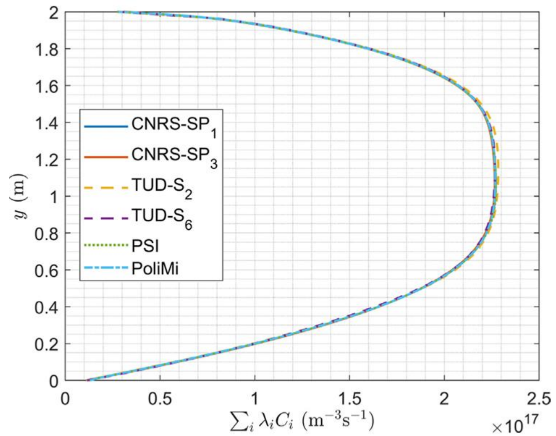
$P = 1$ GW

Ouput:

Delayed neutron source along centrelines

Reactivity change from step 0.2

Code	$\rho - \rho_{s_{0.2}}$ (pcm)
CNRS-SP_1	−62.5
CNRS-SP_3	−62.6
PoliMi	−62.0
PSI	−63.0
TUD-S_2	−62.0
TUD-S_6	−60.7



Benchmark – Phase 1

Step 1.2 – Power coupling

Study the coupling between neutronics and temperature field

Goal: analyse flux deformation by temperature and flux effect on temperature

Input:

Frozen velocity field from 0.1

$\mathrm{P} = 1\ \mathrm{GW}$

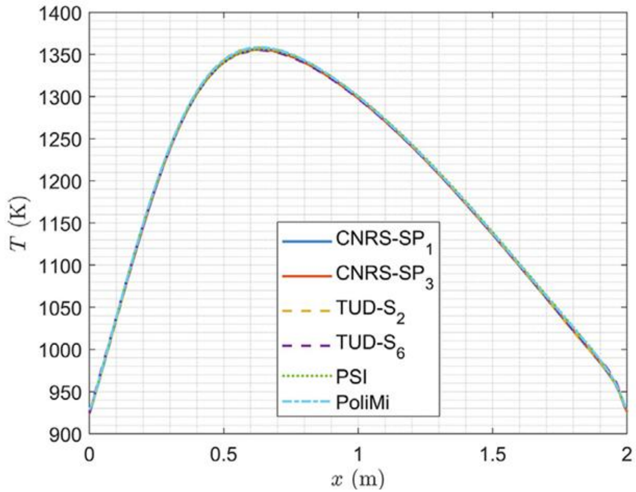
$\gamma = 10^6 \frac{\mathrm{W}}{\mathrm{m^2 K}}$

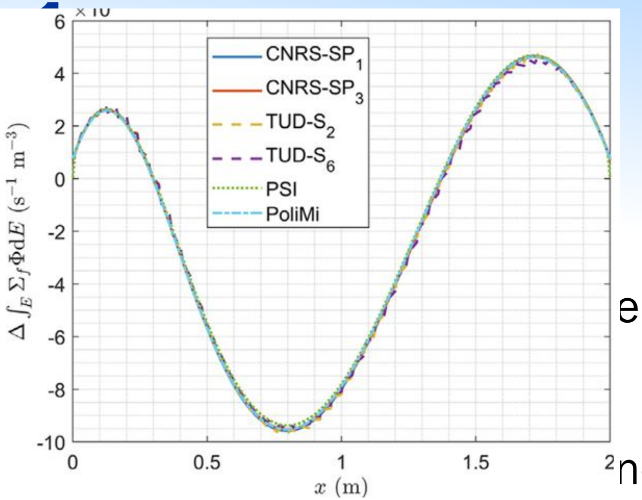
Ouput:

Temperature along centrelines

Reactivity change from step 1.1

Fission rate density profile change from step 0.2





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nes

$$P = 1\ \text{GW}$$

$$\gamma = 10^6 \frac{\text{W}}{\text{m}^2\text{K}}$$

Reactivity change from step 1.1

Fission rate density profile change from step 0.2

Code	$\rho - \rho_{s_{1.1}}$ (pcm)
CNRS-SP_1	−1152.0
CNRS-SP_3	−1152.7
PoliMi	−1161.0
PSI	−1154.8
TUD-S_2	−1145.2
TUD-S_6	−1122.0

Benchmark – Phase 1

Step 1.3 – Buoyancy

Study the effect of density induced movement

Goal: analyse velocity field induced by fission heat and reactivity introduction by precursors movement

Input:

$U_{lid} = 0\ \mathrm{m/s}$

$P = 1\ \mathrm{GW}$

$\gamma = 10^6 \frac{\mathrm{W}}{\mathrm{m^2 K}}$

Ouput:

Velocity along centrelines

Temperature field along centrelines

Delayed neutron source along centrelines

Reactivity change from step 0.2

Benchmark – Phase 1

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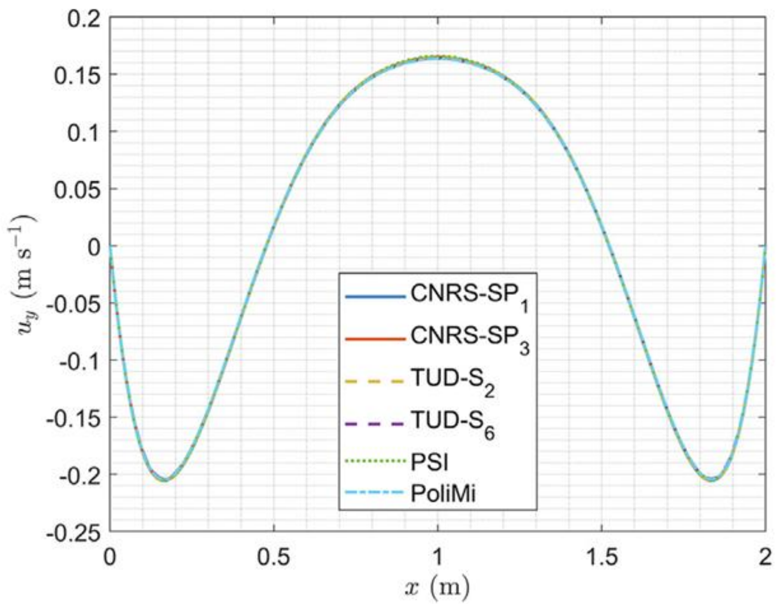

Ouput:

Velocity along centrelines

Temperature field along centrelines

Delayed neutron source along centrelines

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Benchmark – Phase 1

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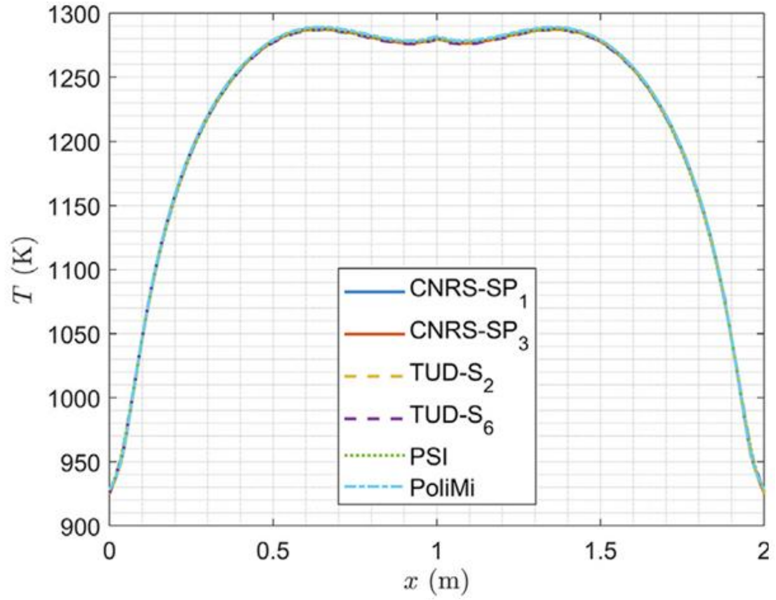

Ouput:

Velocity along centrelines

Temperature field along centrelines

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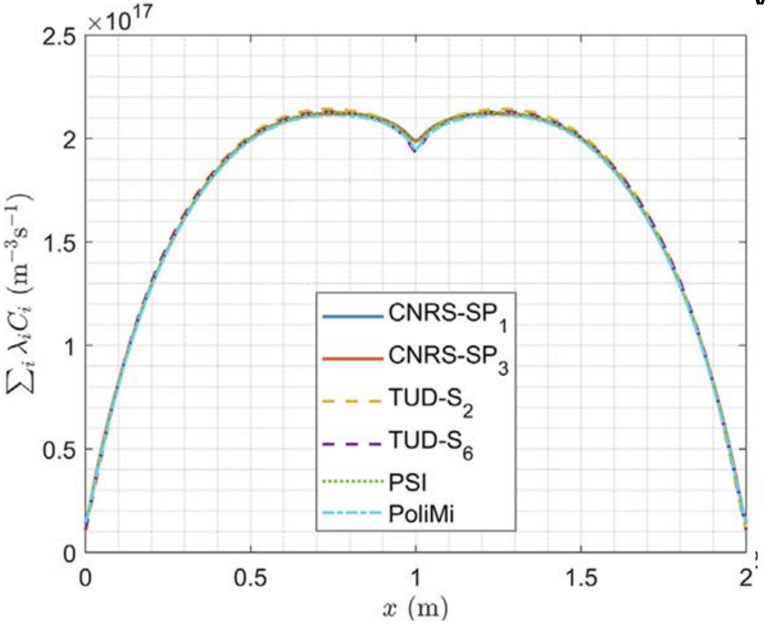

Ouput:

Velocity along centrelines

Temperature field along centrelines

Delayed neutron source along centrelines

Reactivity change from step 0.2

Benchmark – Phase 1

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$$\gamma = 10^6 \frac{W}{m^2 K}$$

Code	$\rho - \rho_{s_{0.2}}$ (pcm)
CNRS-SP_1	−1220.5
CNRS-SP_3	−1220.7
PoliMi	−1227.0
PSI	−1219.6
TUD-S_2	−1208.5
TUD-S_6	−1184.4

Reactivity change from step 0.2

Benchmark – Phase 1

Step 1.4 – Full coupling

Study representative of realistic reactor simulations in terms of physical phenomena

Goal: correct evaluation of the full coupled effects

Input:

$U_{lid} = 0 \div 0.5$ m/s

$P = 0 \div 1$ GW

$$\gamma = 10^6 \frac{W}{m^2 K}$$

Ouput:

Reactivity change from step 0.2 as function of P and U_{lid}

Benchmark – Phase 2 (bonus)

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Step 2.1 – Forced convection transient

Study generic transient response of the coupled system

Goal: study how the oscillation in heat transfer coefficient influences power production

Input:

Steady state solution of step 1.4

$$\gamma = \gamma_{\text{ref}}[1 - 0.1 \sin(\text{f} \cdot \text{t})]$$

$$\text{f} = [0.0125; 0.025; 0.05; 0.1; 0.2; 0.4; 0.8] \text{ Hz}$$

Ouput:

Power gain and power shift as function of the perturbation frequency

$$Gain = \frac{(P_{max} - P_{avg})/P_{avg}}{(\gamma_{max} - \gamma_{avg})/\gamma_{avg}}$$

Benchmark – Phase 2 (bonus)

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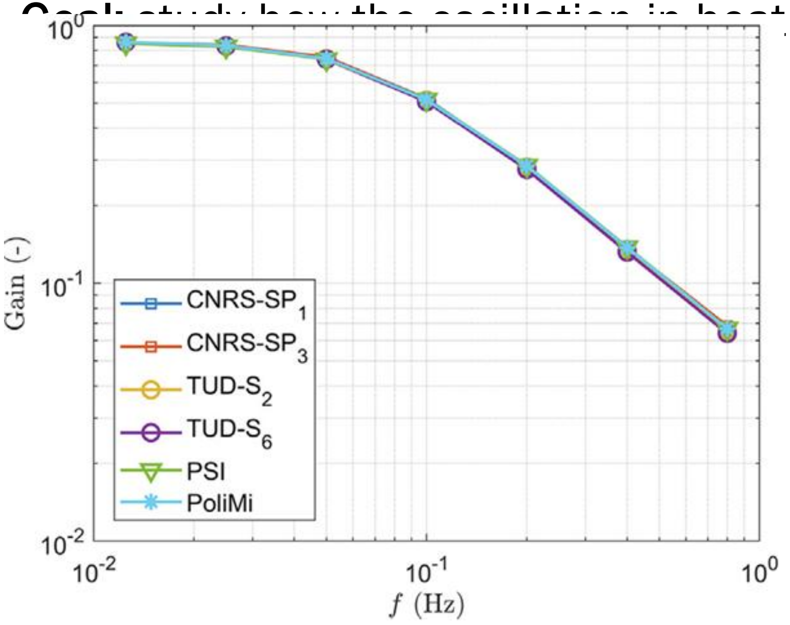

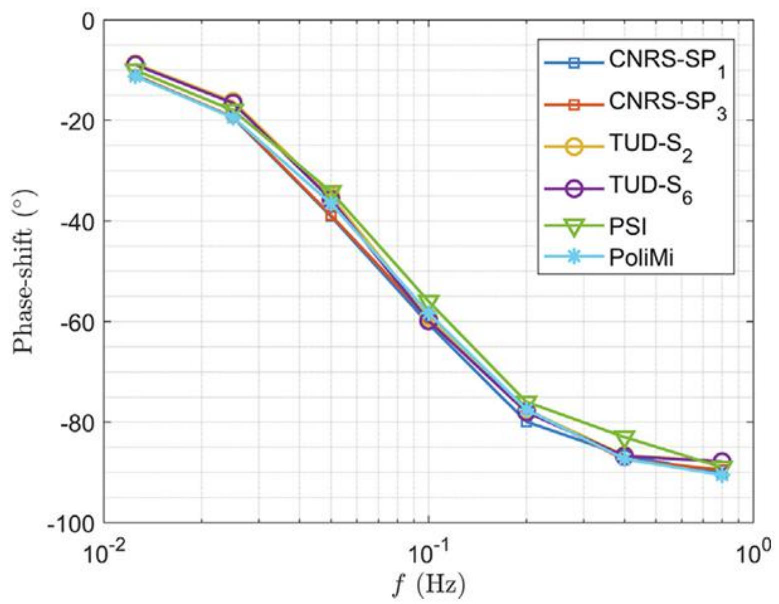

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$$Gain = \frac{(P_{max} - P_{avg})/P_{avg}}{(\gamma_{max} - \gamma_{avg})/\gamma_{avg}}$$

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