China Experimental Fast Reactor (CEFR): transient simulation of the control rod drop tests with Serpent

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Content

- A quick overview of CEFR
- Description of the CR drop experiments
- Computational methodology
- Results

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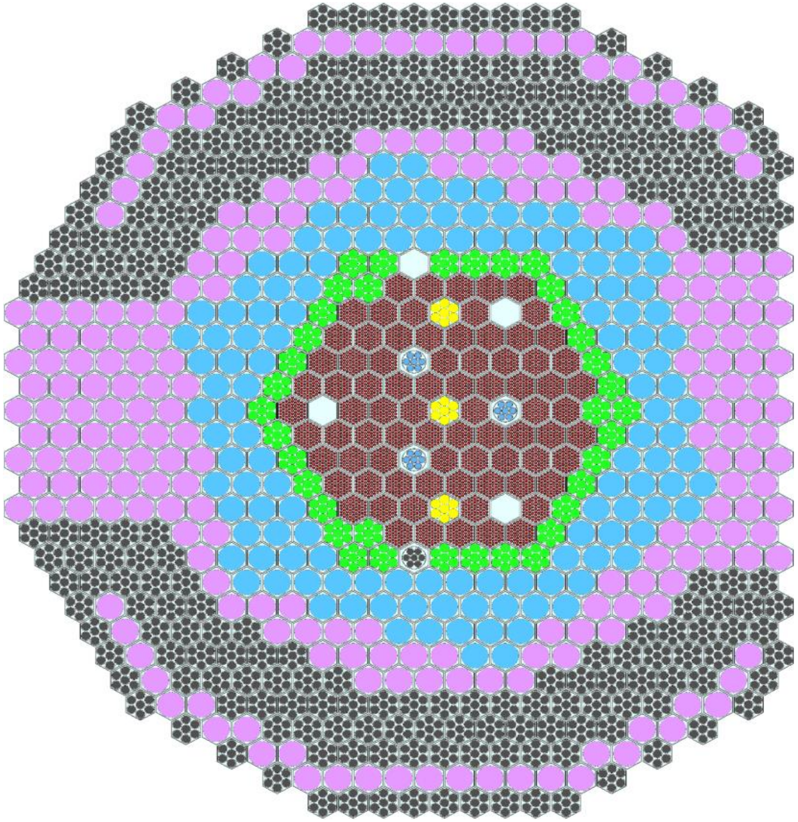
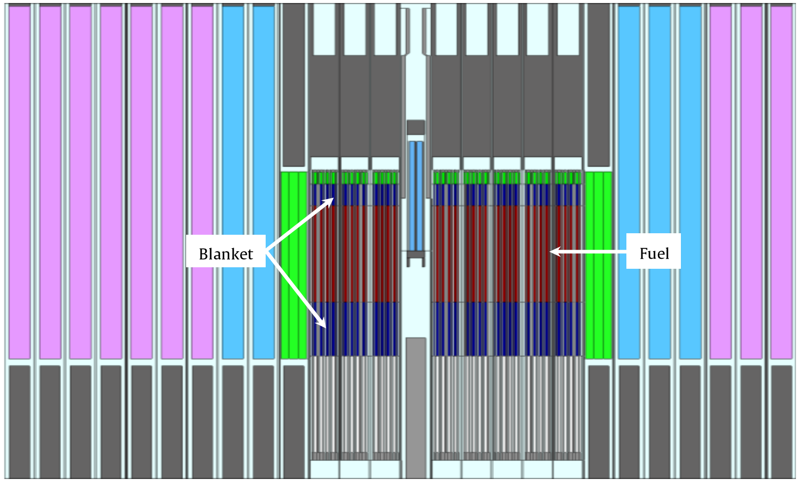
CEFR overview

- CEFR - China Experimental Fast Reactor
- Located at CIAE near Beijing
- First SFR operated in China
- $65MW_{th}$ pool-type SFR
- 79 fuel sub-assemblies
- 64.4 wt% enriched UO2 fuel





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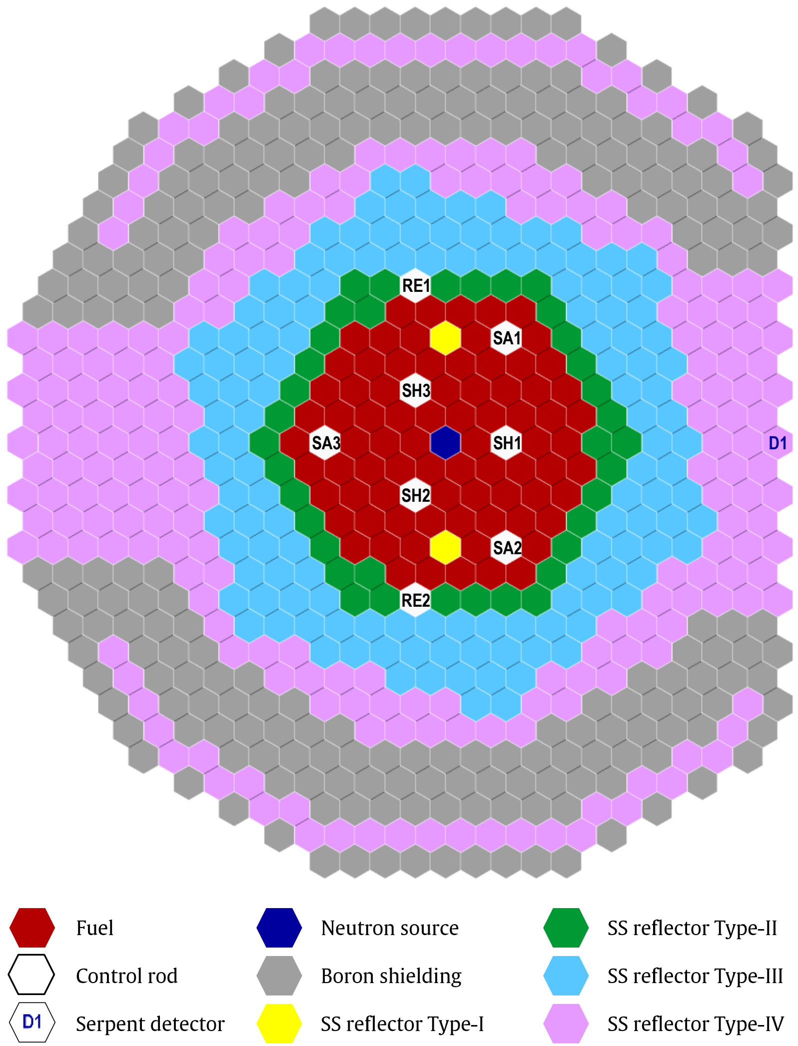
CEFR reactivity control system

- 8 control rods
- 2 regulating CRs (RE1 and RE2)
  - Fine power control
  - natural B10
- 3 shim CRs (SH1, SH2, and SH3)
  - Large reactivity changes
  - 92% enriched B10.
- 3 safety CRs (SA1, SA2, and SA3)
  - Emergency shutdown
  - with 92% enriched B10



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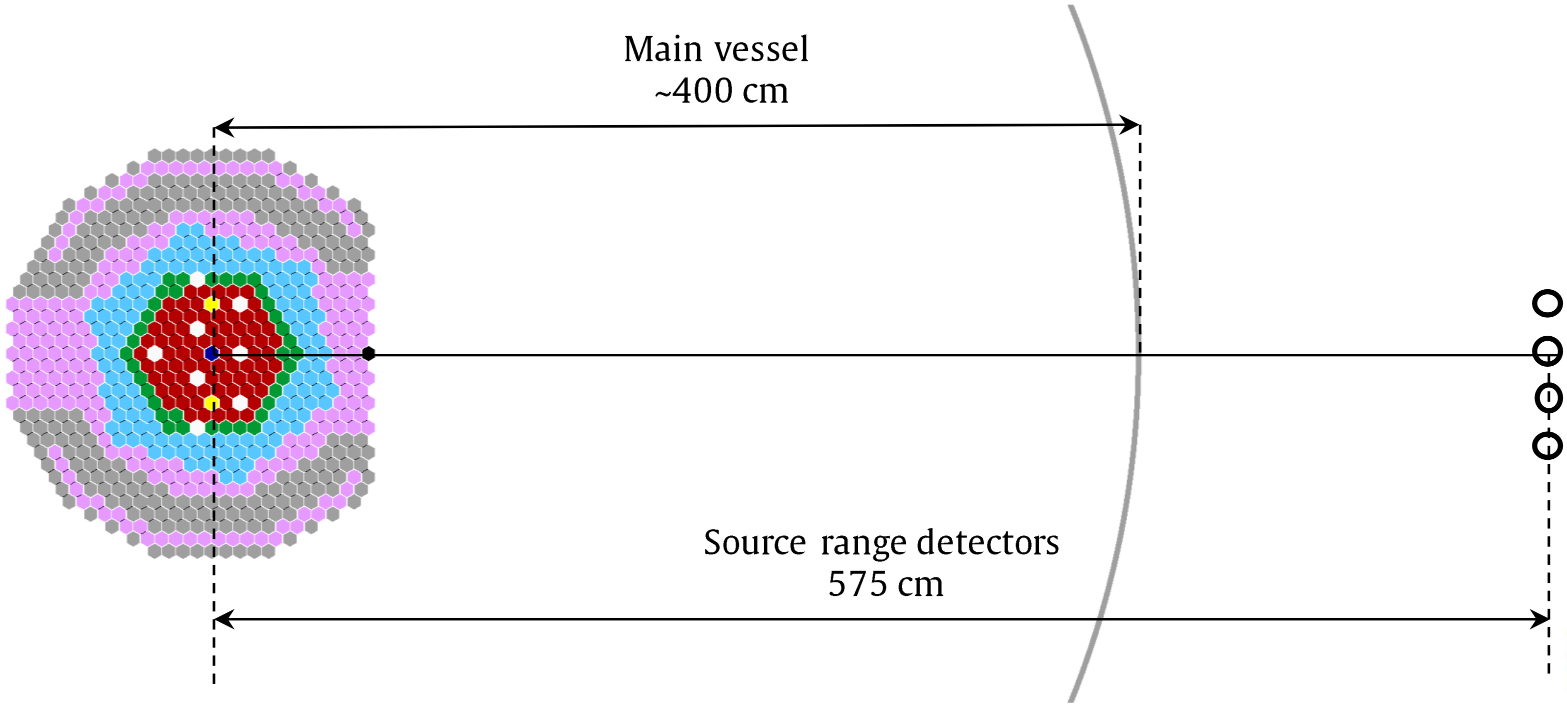
Rod drop test for evaluation of the CR worth

- Part of the physical start-up tests performed in 2010
- Isothermal CZP conditions at 245°C
- Real-time reactivity calculation
- Based on the source range detector data



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Our objectives

- Simulation of the CEFR CR drop transients with Serpent
- Evaluation of the integral CR worth (CRW)
- Validation against the measurement data

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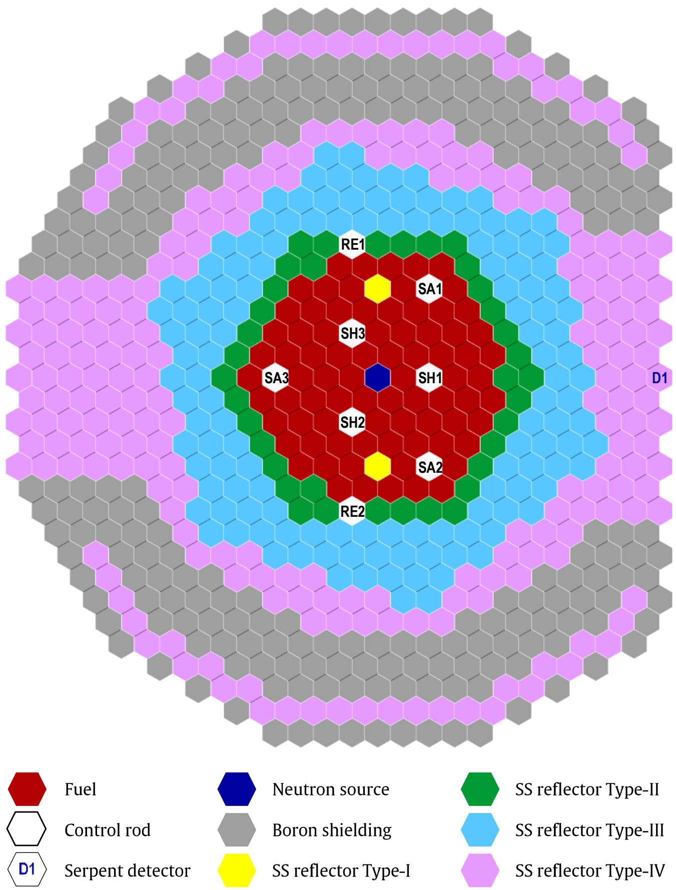
Considered measurements

Dropped CR	Drop duration, sec	Drop speed, cm/sec
RE1	2.5	20.1
RE2	2.5	19.8
SH1	2.0	24.9
SH2	2.0	25.0
SH3	2.0	24.6
SA1	0.5	100.4
SA2	0.5	98.7
SA3	0.5	102.0



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Transient modeling of the CR drop test

- Stage 1: Static simulation to get a source of neutrons and precursors
- Stage 2: Dynamic simulation of the CR drop process
- Initiation of the drop at t=0.5 sec
- Step-wise CR position update via time-dependent geometry transformation
- CRW estimation
  - Static method: based on two eigenvalue Monte Carlo calculations
  - Dynamic method: using dynamic reactivity

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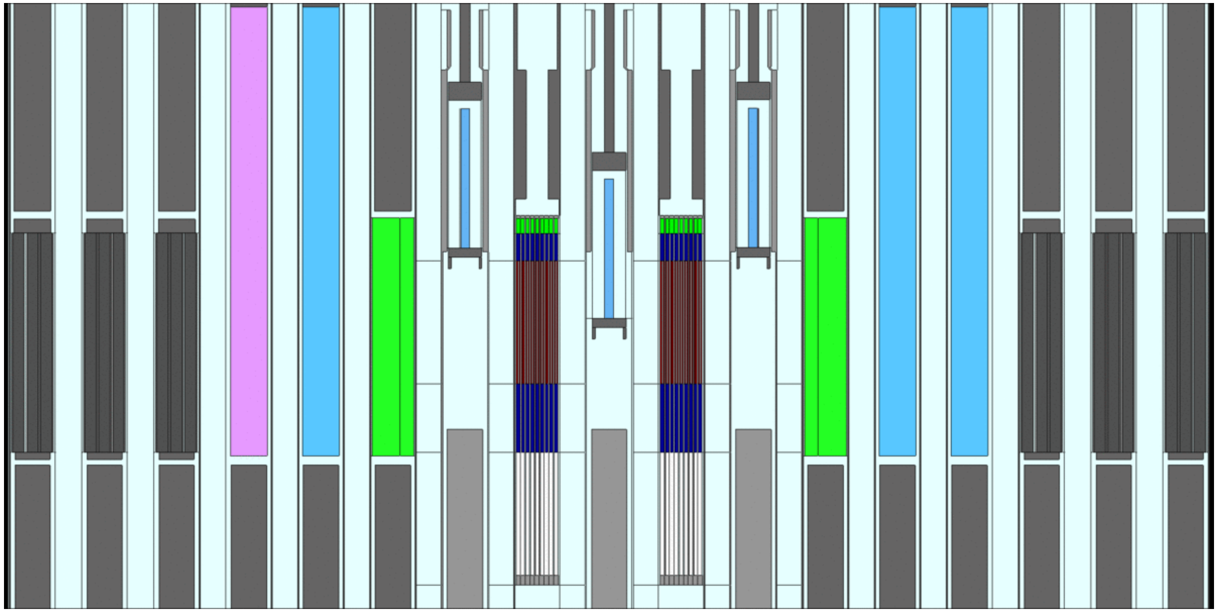
Transient modeling of the CR drop test

Dropped CR	Drop duration, sec	Drop speed, cm/sec	Simulated time interval, sec	Position update, sec
RE1	2.5	20.1	7	0.1
RE2	2.5	19.8	7	0.1
SH1	2.0	24.9	7	0.1
SH2	2.0	25.0	7	0.1
SH3	2.0	24.6	7	0.1
SA1	0.5	100.4	5	0.05
SA2	0.5	98.7	5	0.05
SA3	0.5	102.0	5	0.05



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Calculation of dynamic reactivity by two methods

- Inverse point kinetics (IPK):

$$\rho_{IPK}(t) = \frac{\Lambda}{n(t)}\frac{dn(t)}{dt} + \beta - \frac{n(0)}{n(t)}\sum_{i=1}^{nd}\beta_i\, e^{-\lambda_i t} - \frac{1}{n(t)}\sum_{i=1}^{nd}\lambda_i\beta_i\, e^{-\lambda_i t}\int_0^t e^{\lambda_i\tau} n(\tau)d\tau$$

- Instant neutron balance (NB):

$$keff_{NB}(t) = \frac{gain}{loss} = \frac{P(t)}{C(t) + F(t) + L(t) - S(t)}$$

$$\rho_{NB}(t) = \frac{keff_{NB}(t) - 1}{keff_{NB}(t)}$$

- ***IPK -*** can be solved both globally or locally
- ***NB*** - can be solved locally only

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Results

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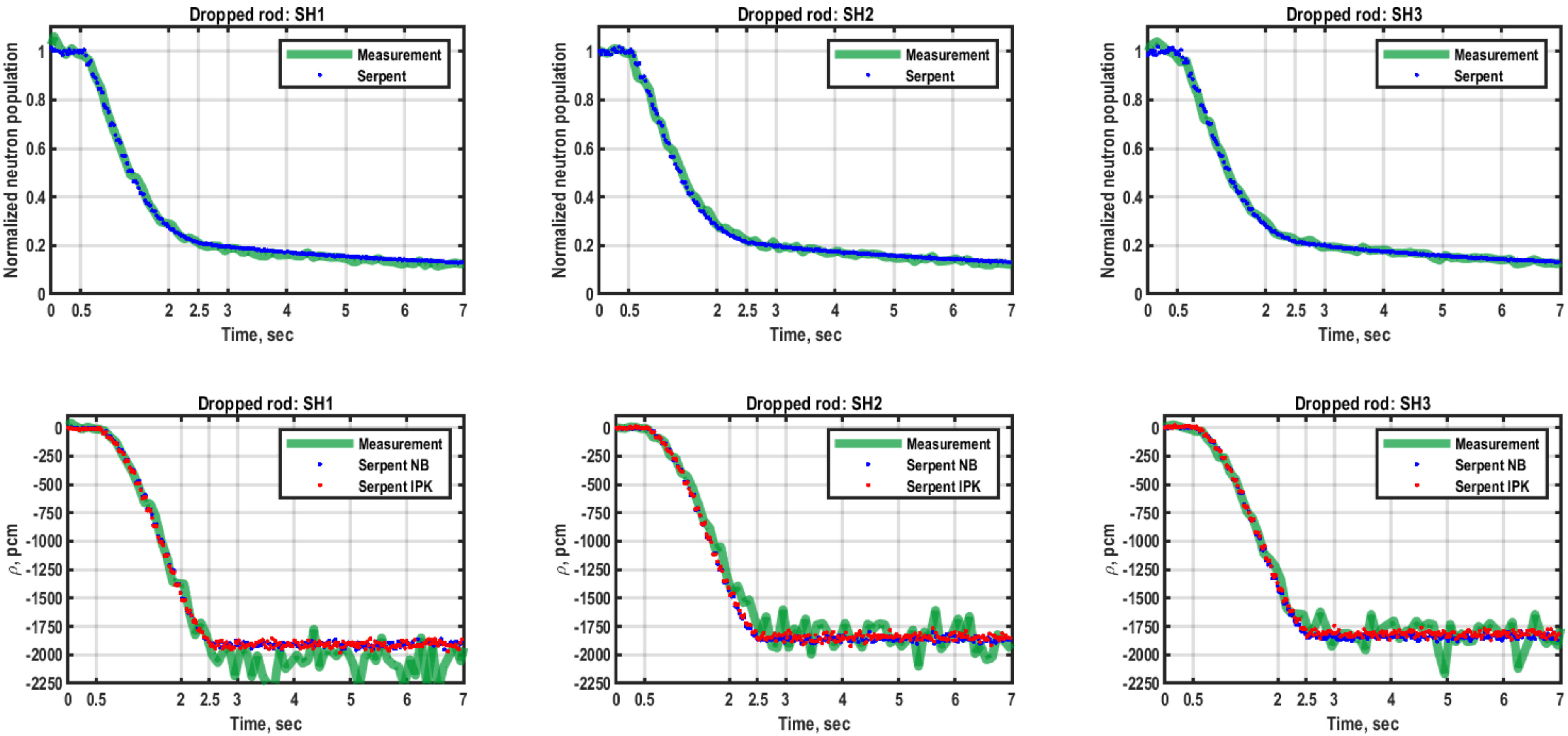
Neutron population and reactivity: Shim rods



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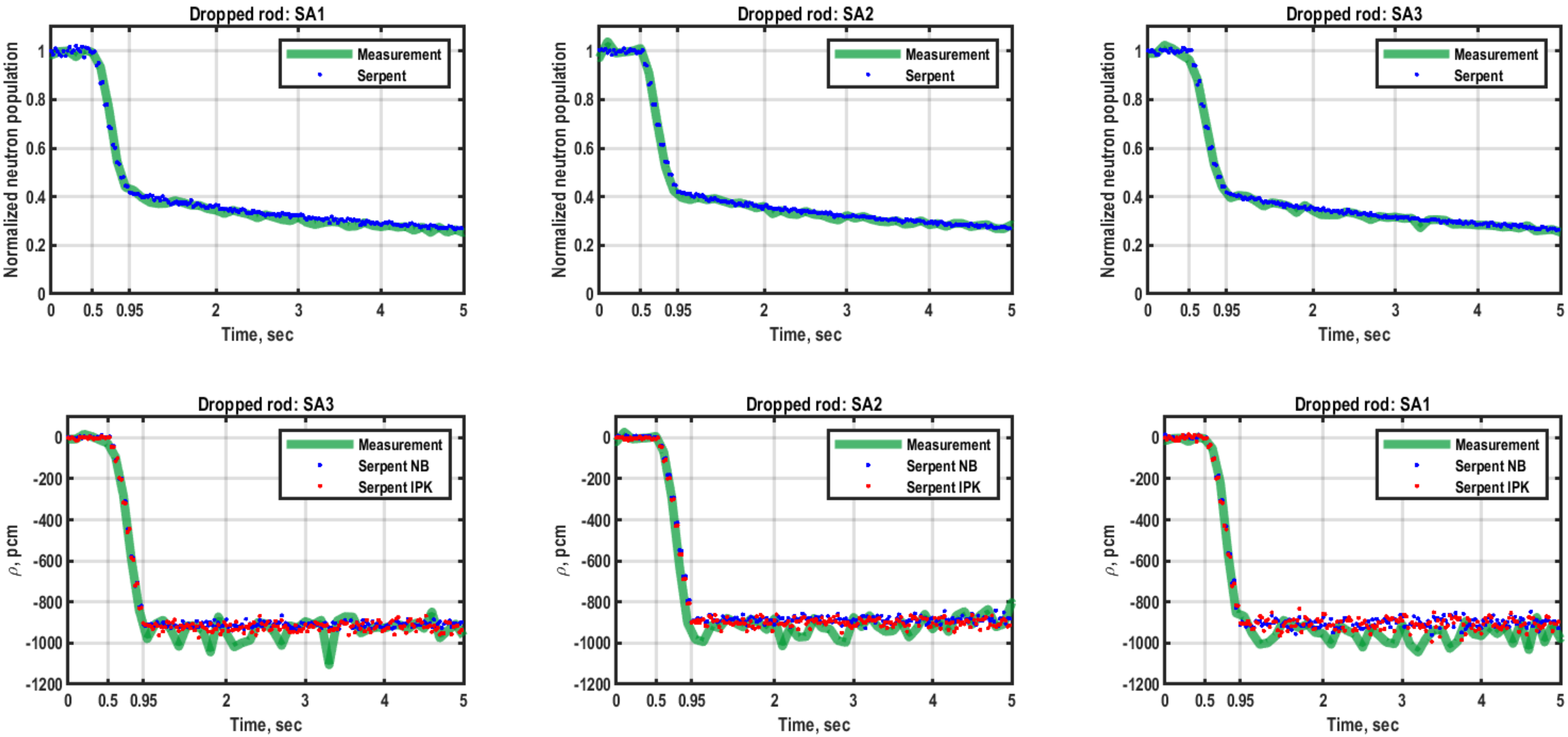
Neutron population and reactivity: Safety rods



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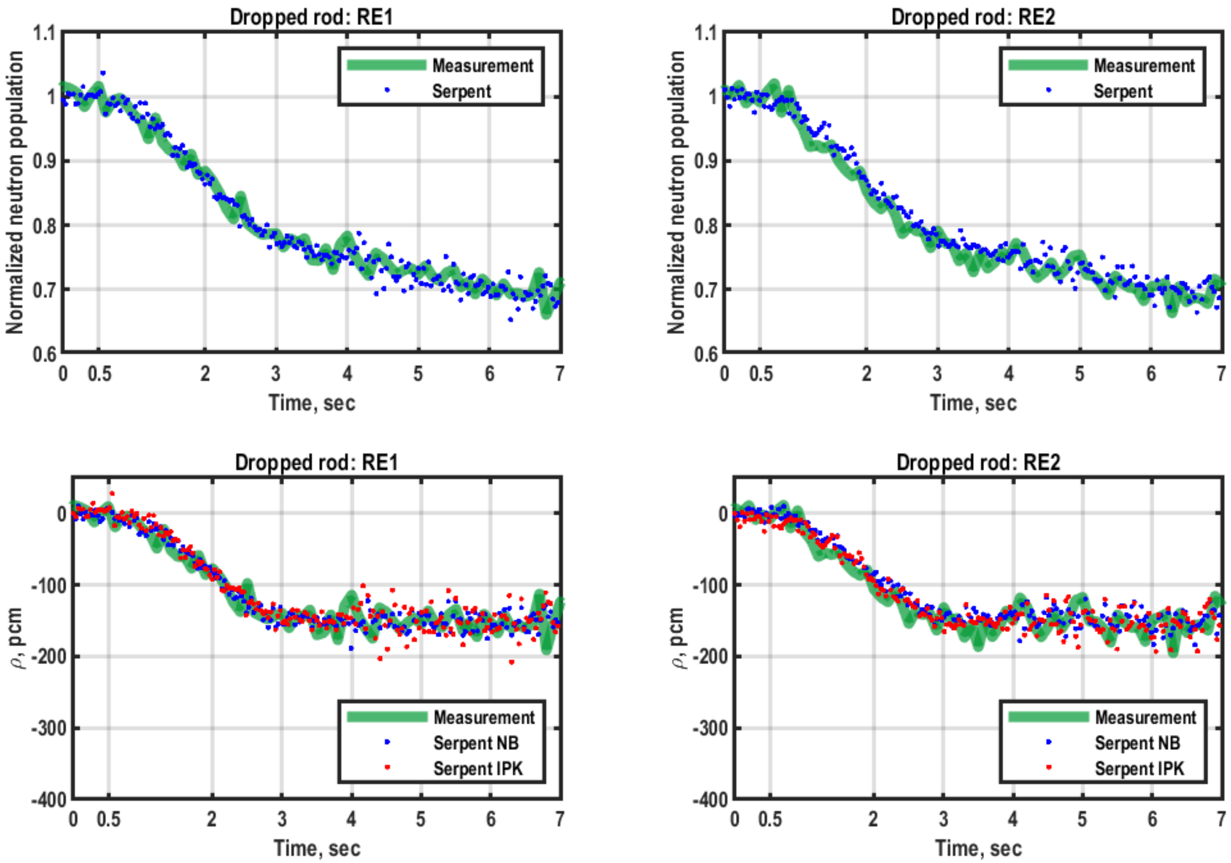
Neutron population and reactivity: Regulating rods



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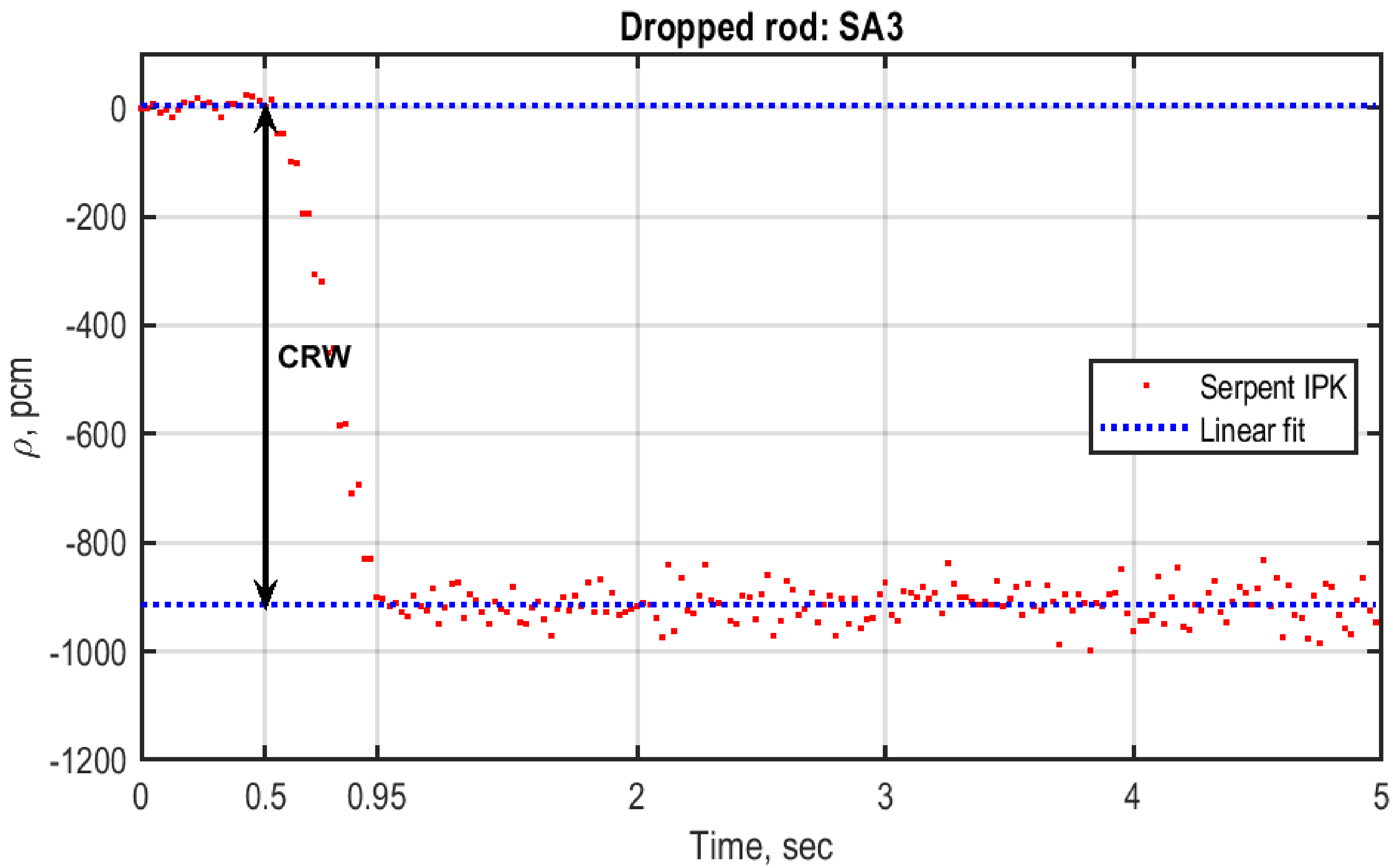
Visualization of the CRW evaluation approach



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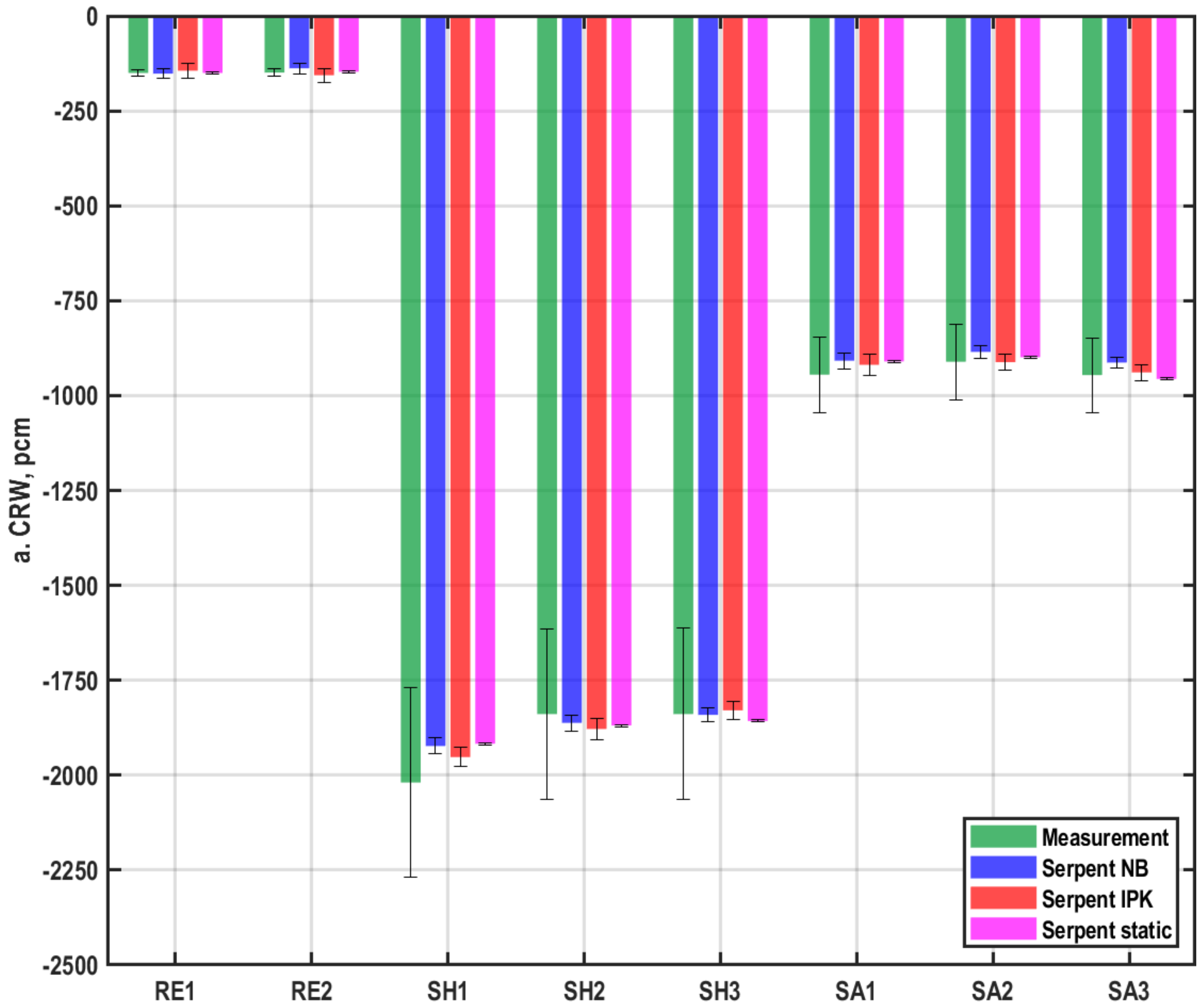
Measured and calculated CRWs (values)



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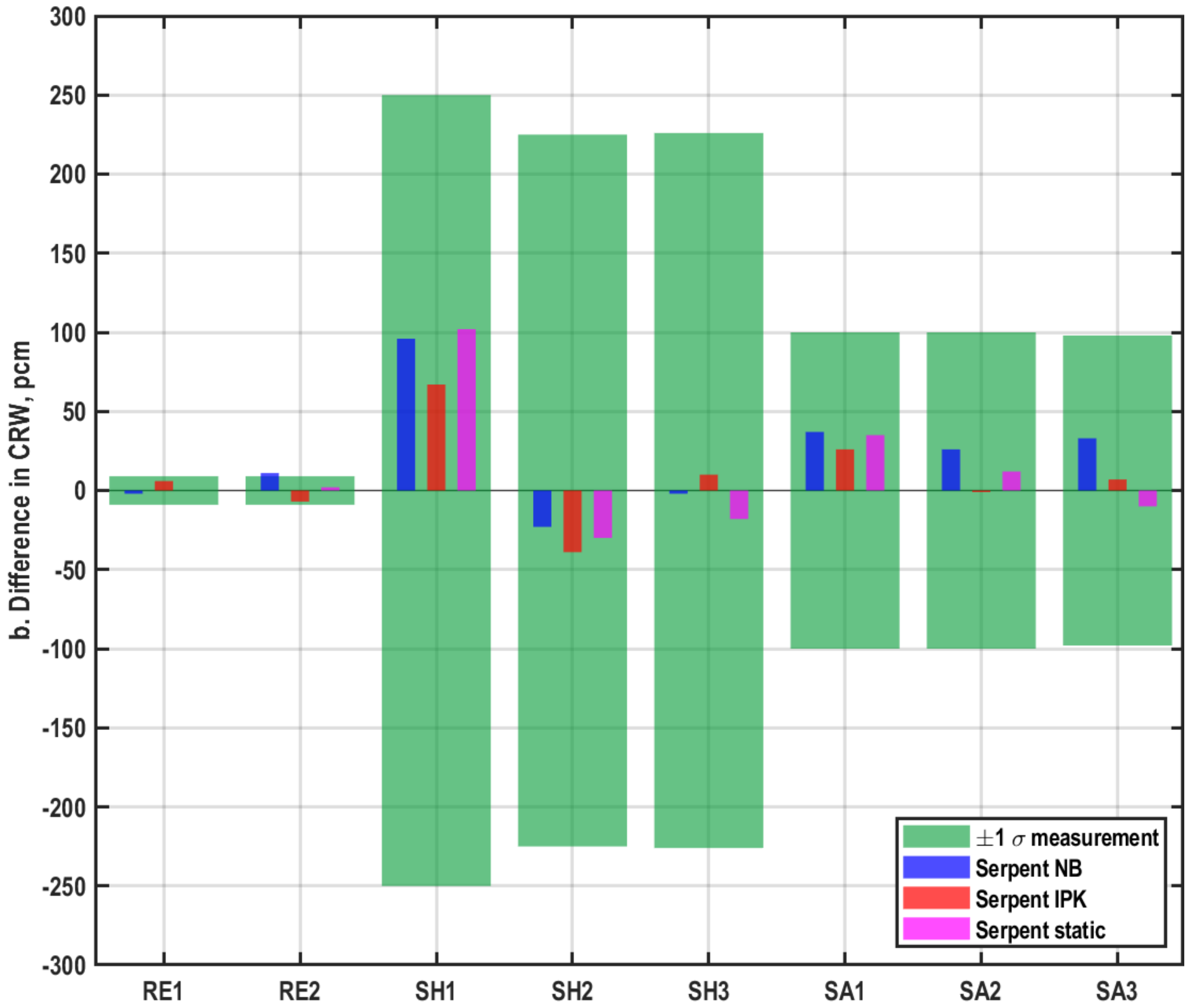
Measured and calculated CRWs (differences)



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Summary

- Serpent was successfully tested vs the real-life fast reactor experiments

- CRW C/E values agree well within the measurement uncertainty

- NB and IPK results are in an excellent agreement
  - Can be seen as complementary approaches
  - However, NB cannot be applied locally (e.g. detector simulation)

- Strong potential to produce hi-fi references solutions in transient analyses

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Thank you for your attention!

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