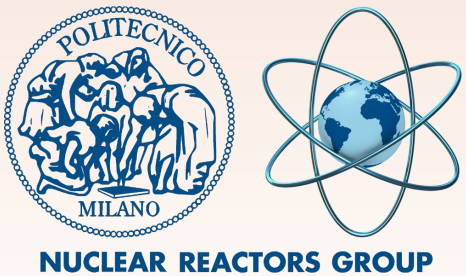
Atelier Sûreté-MSFR
Grenoble, France,
24 – 25 Nov. 2014

Étude préliminaire des conséquences d'un arrêt des pompes

Manuele Aufiero - LPSC/CNRS & Olivier Geoffroy - INOPRO

Simulation performed in the framework of a collaboration between POLIMI and INOPRO within the EVOL Project

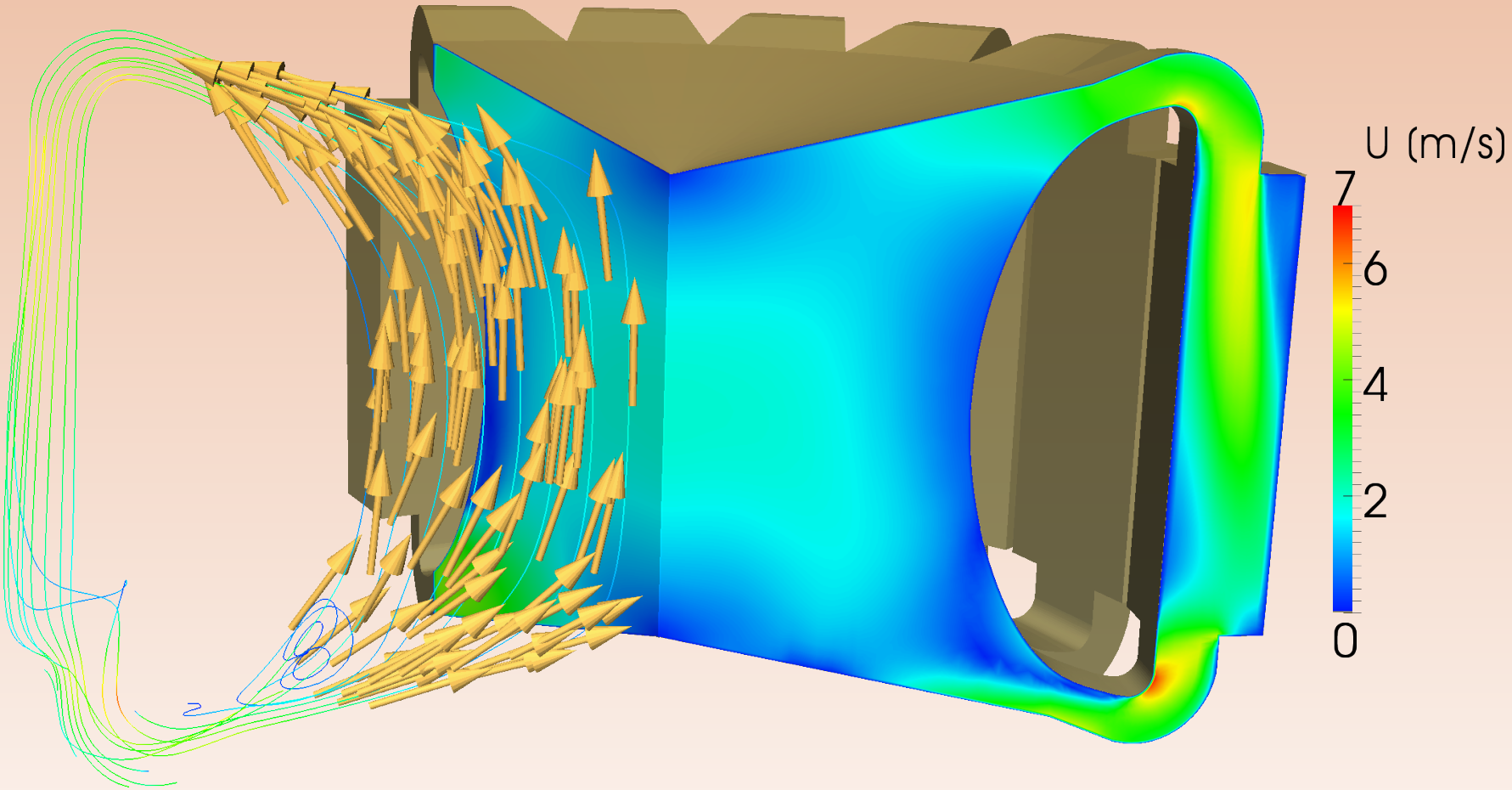


Simulation tools have been developed within the EVOL project for detailed coupled CFD/Neutronic analysis on "real" 3D full-core MSFR geometries.

- Verification, "code-to-code" assessment

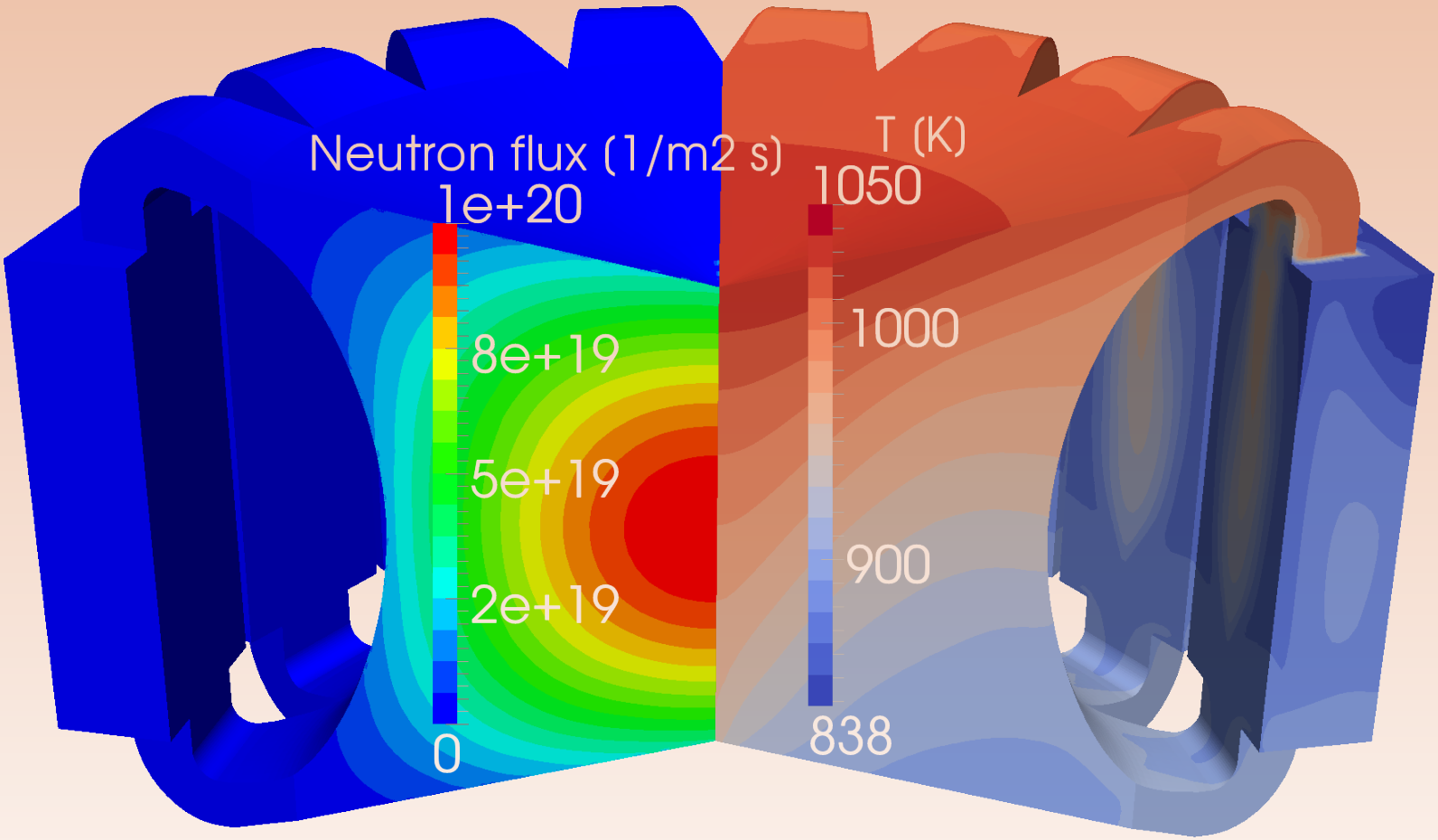
  (see presentations of tomorrow)
- Study of possible accidental scenarios on the optimized MSFR geometry

OpenFOAM solver: coupling neutronics and CFD



Coupled CFD/neutronics calculation for the MSFR: velocity field

OpenFOAM solver: coupling neutronics and CFD



Coupled CFD/neutronics calculation for the MSFR: ϕ & T

Accidental scenarios – examples

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Reactivity insertion – accidental Uranium release.

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Single pump failure.

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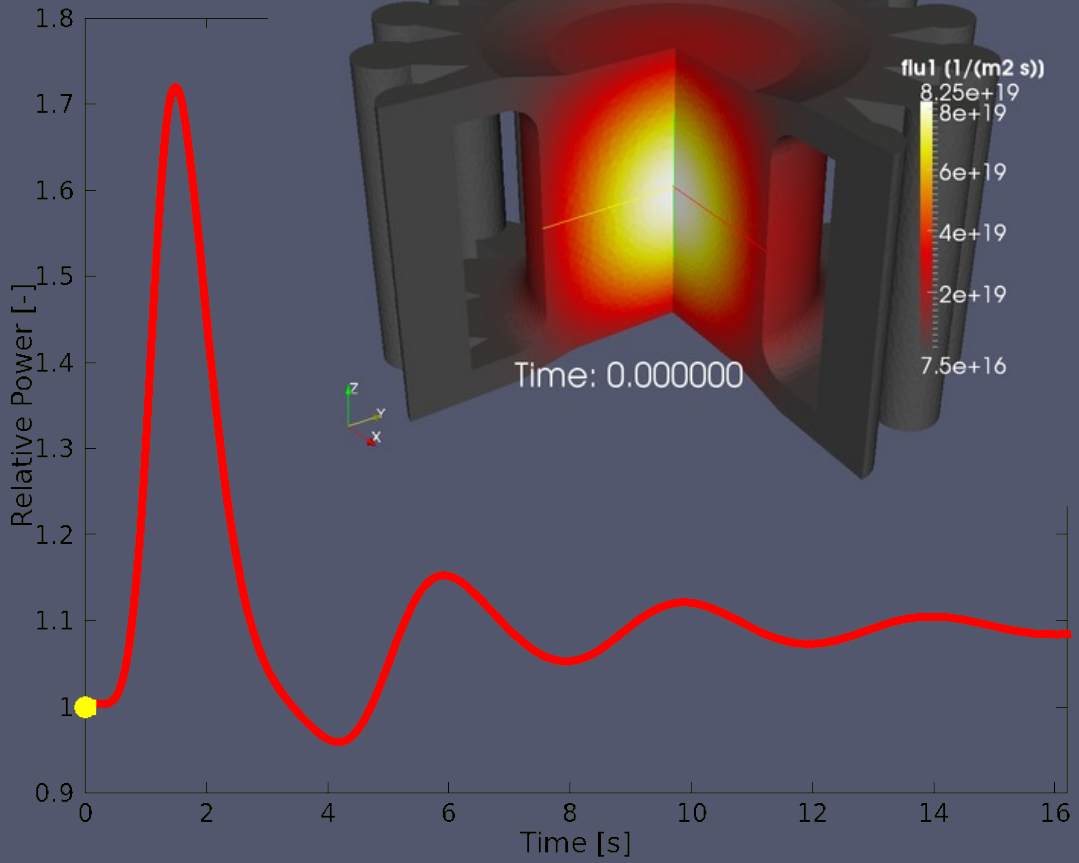
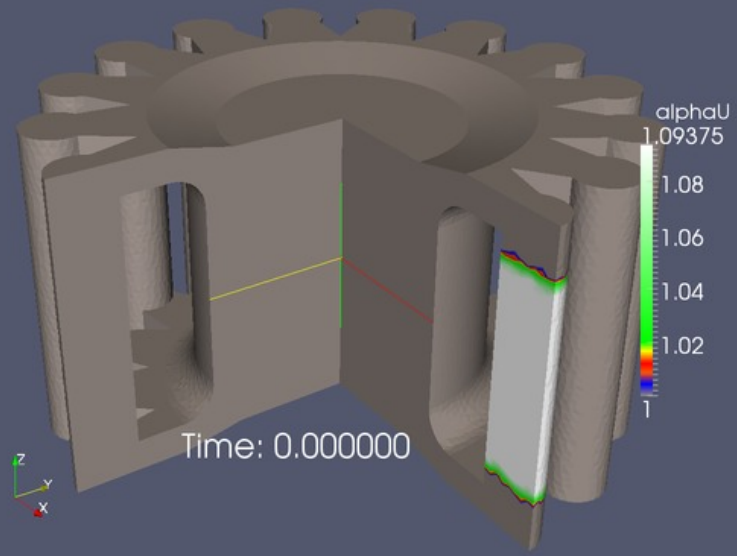
Accidental release of $\sim$ 15 kg of ^{233}U in one of the external loops





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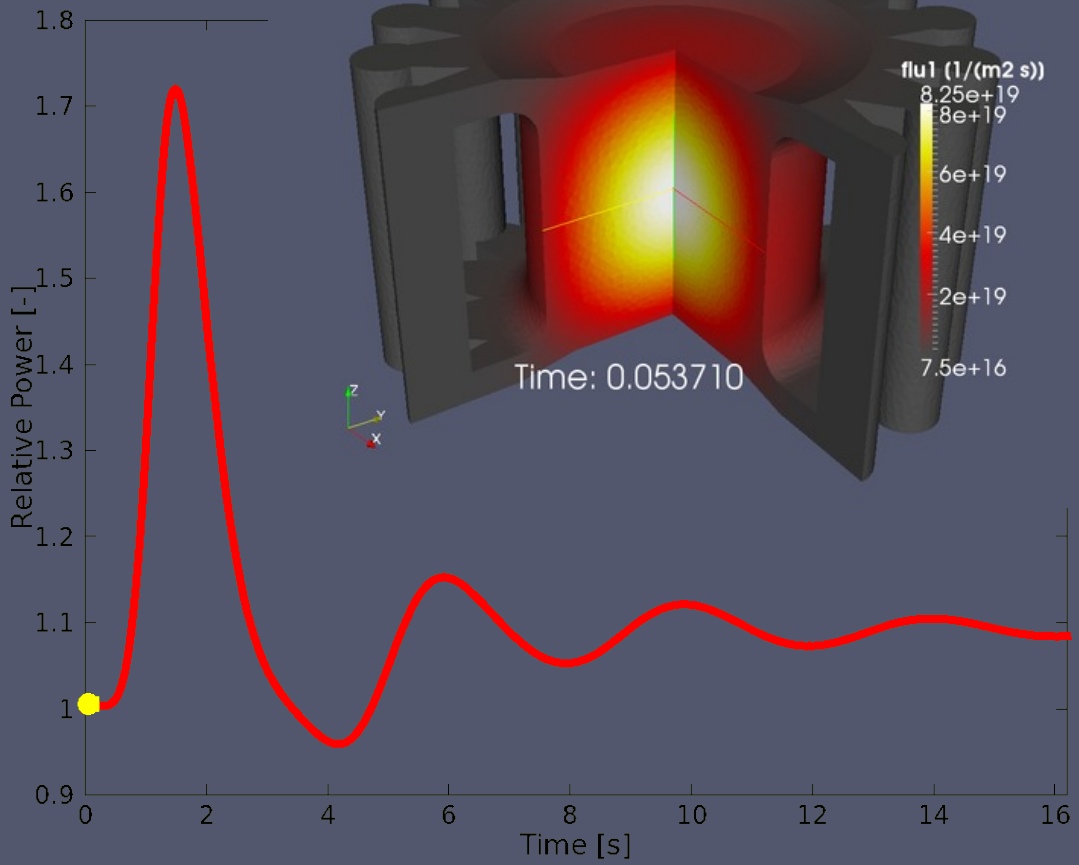

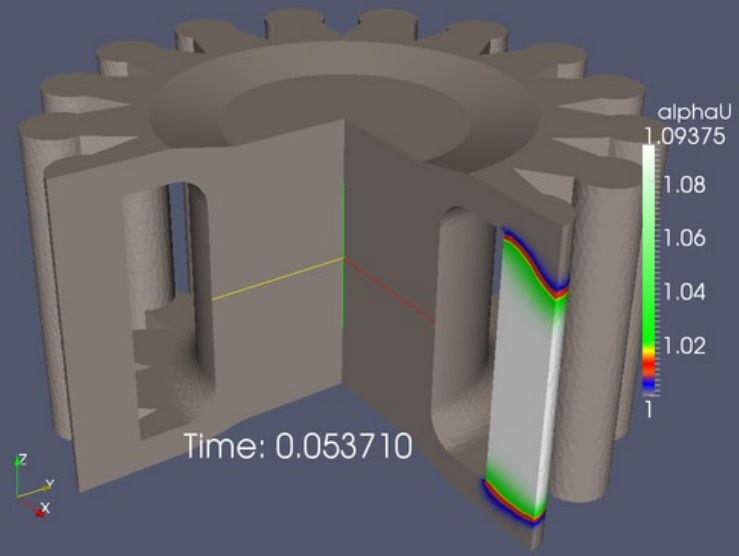

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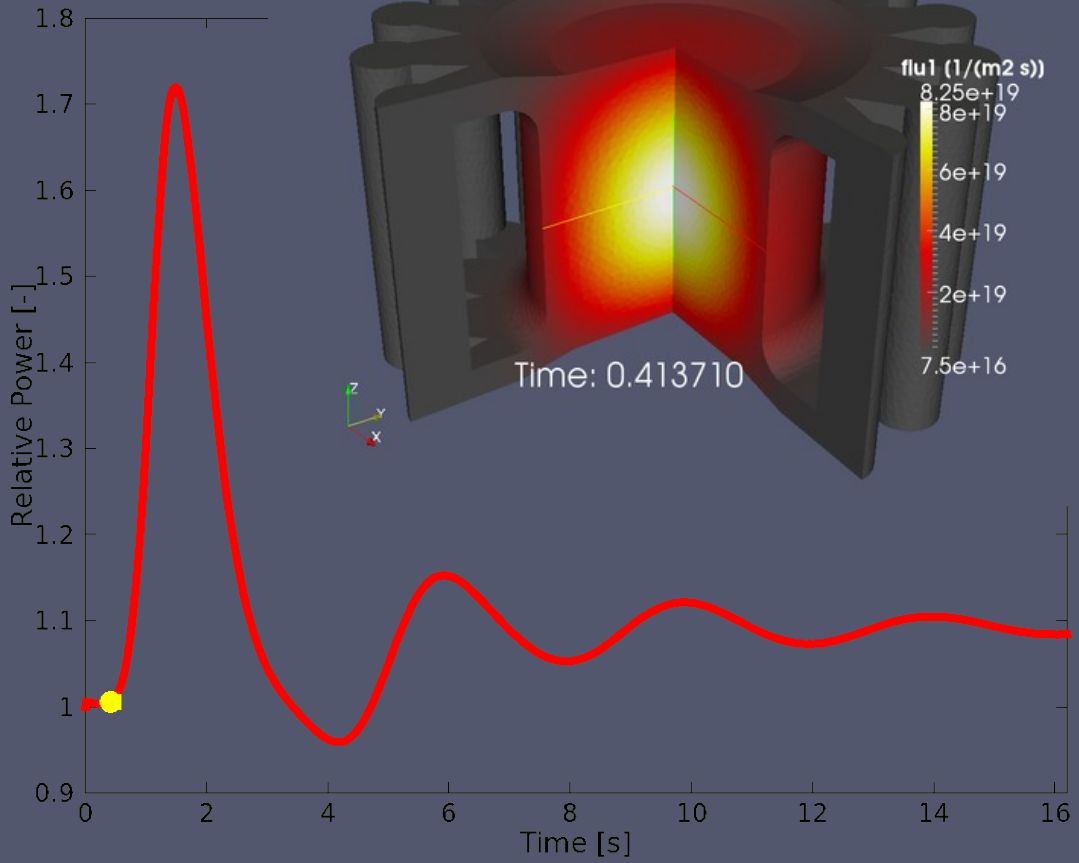

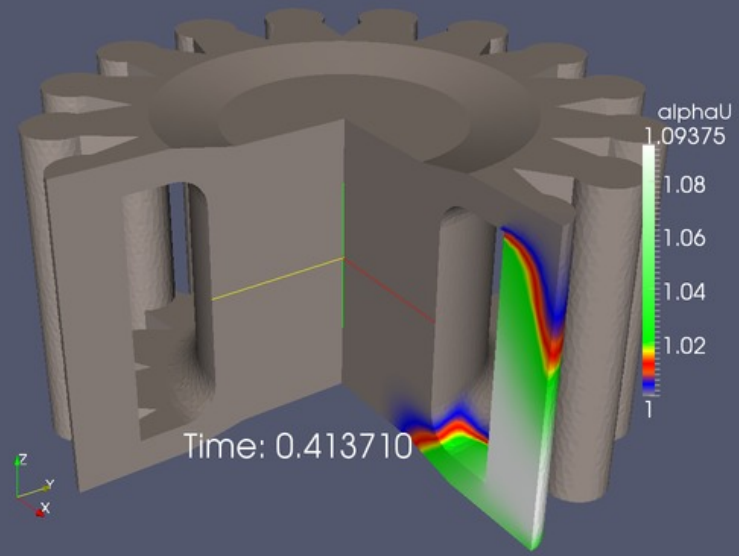

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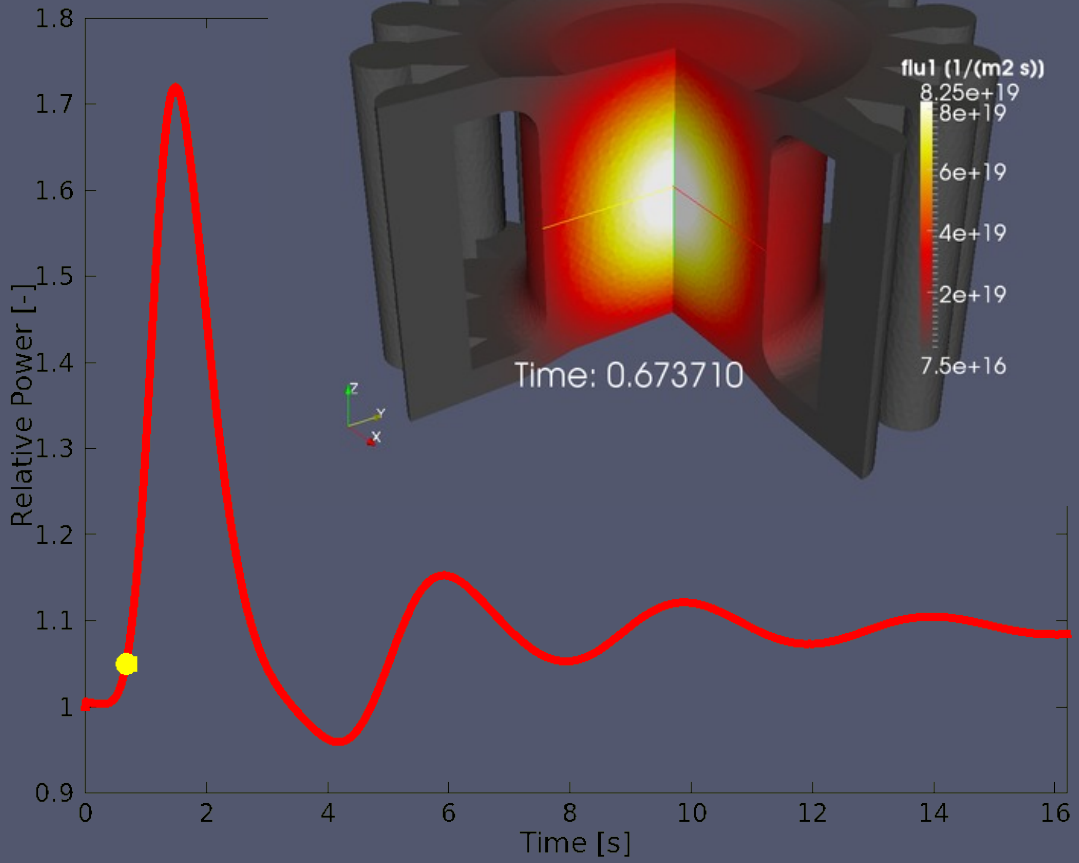

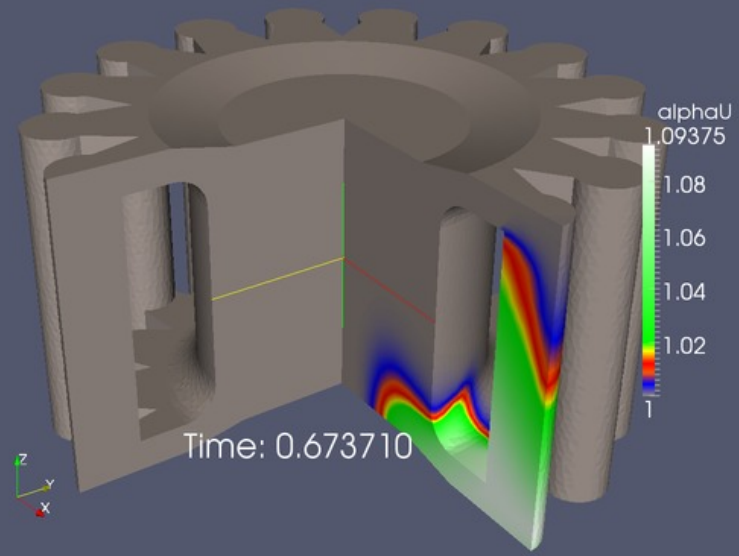

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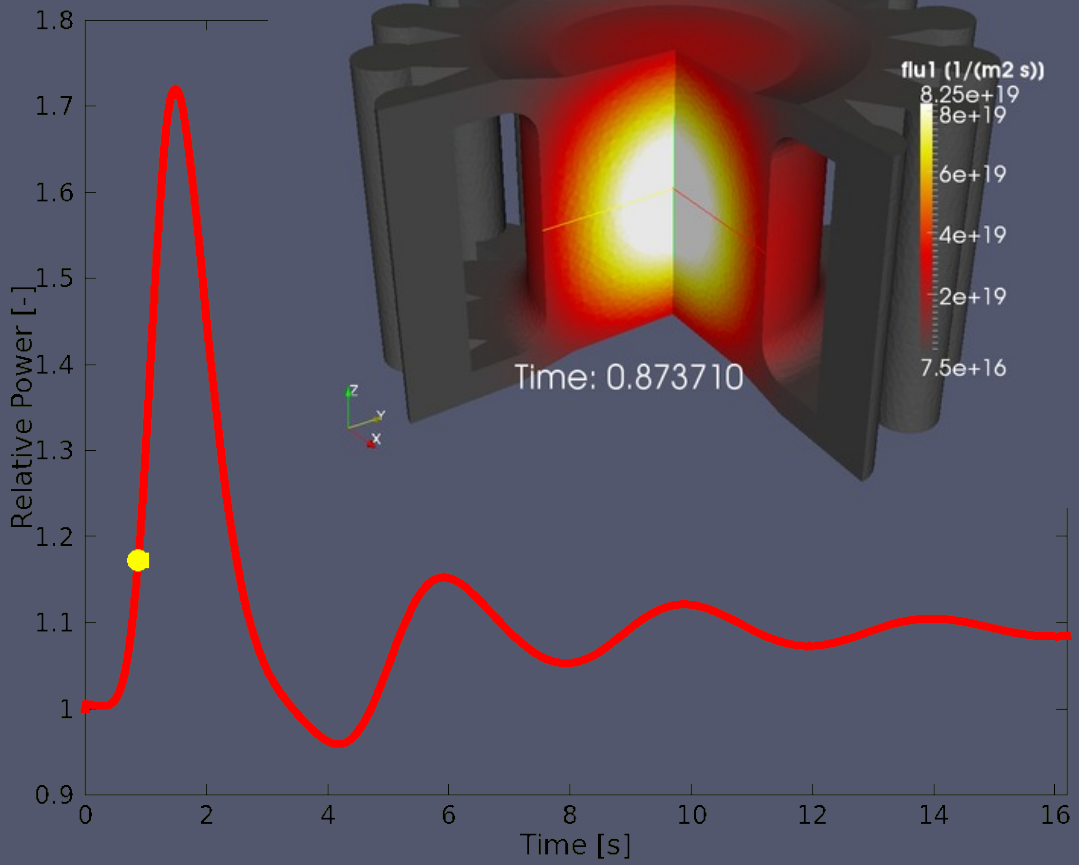

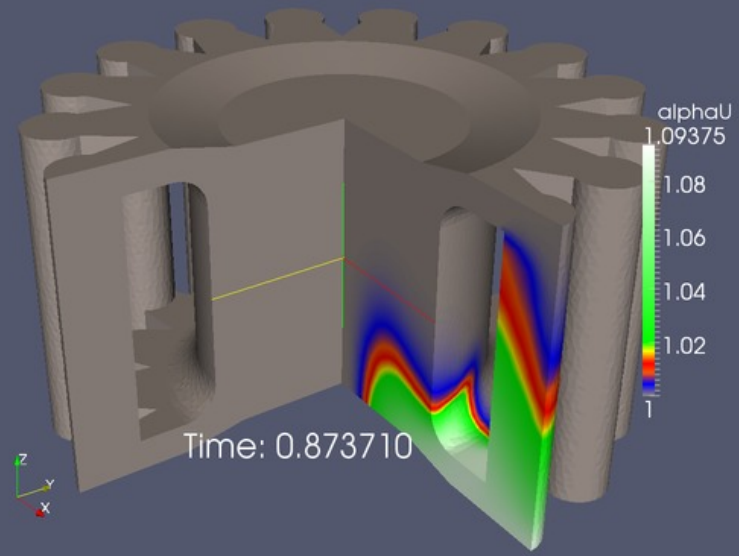

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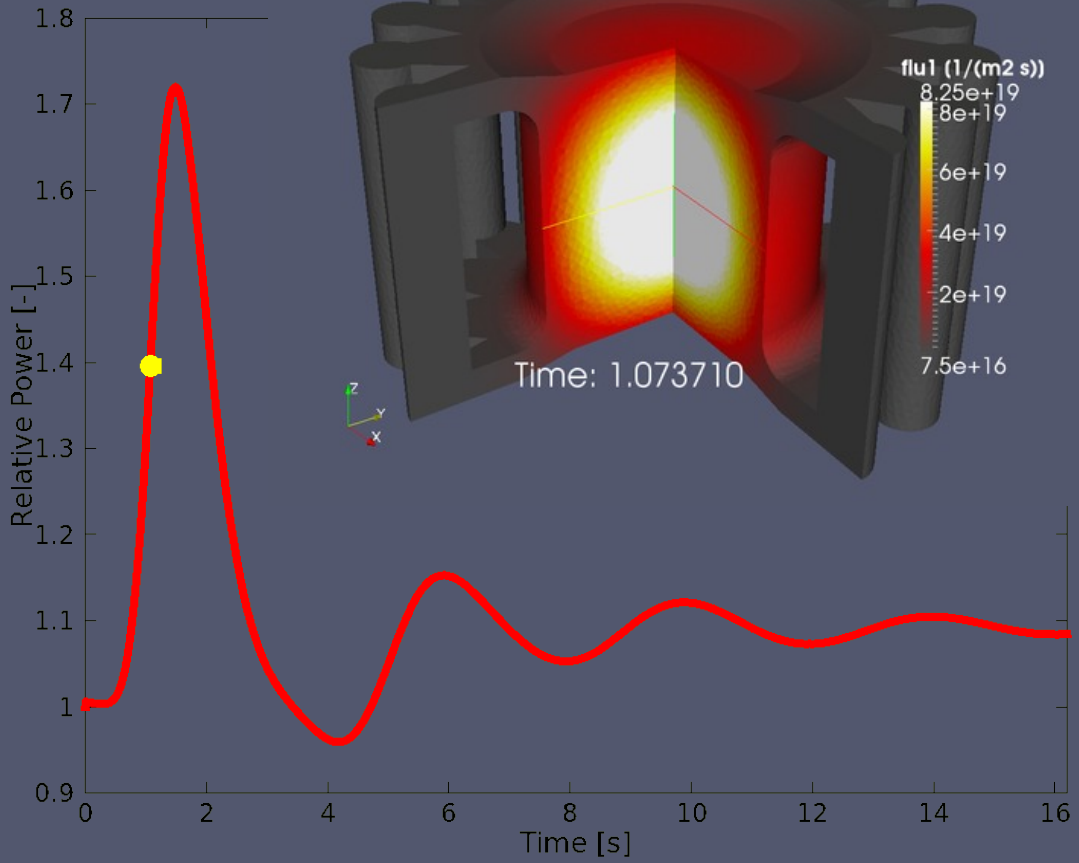

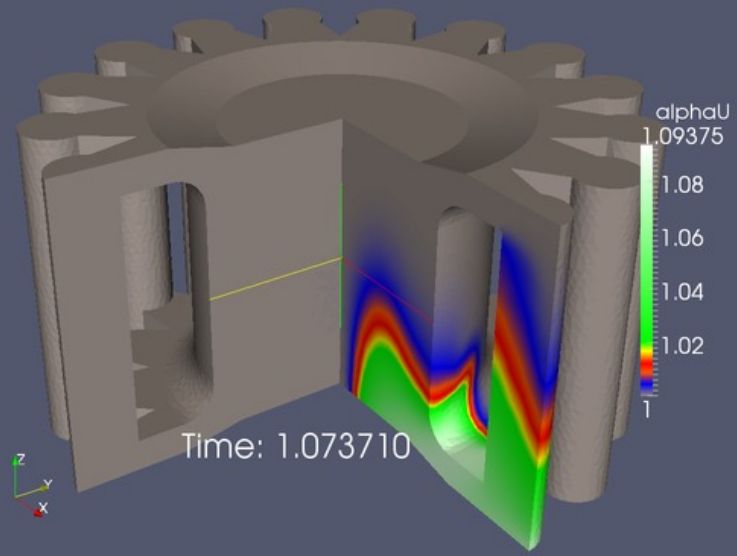

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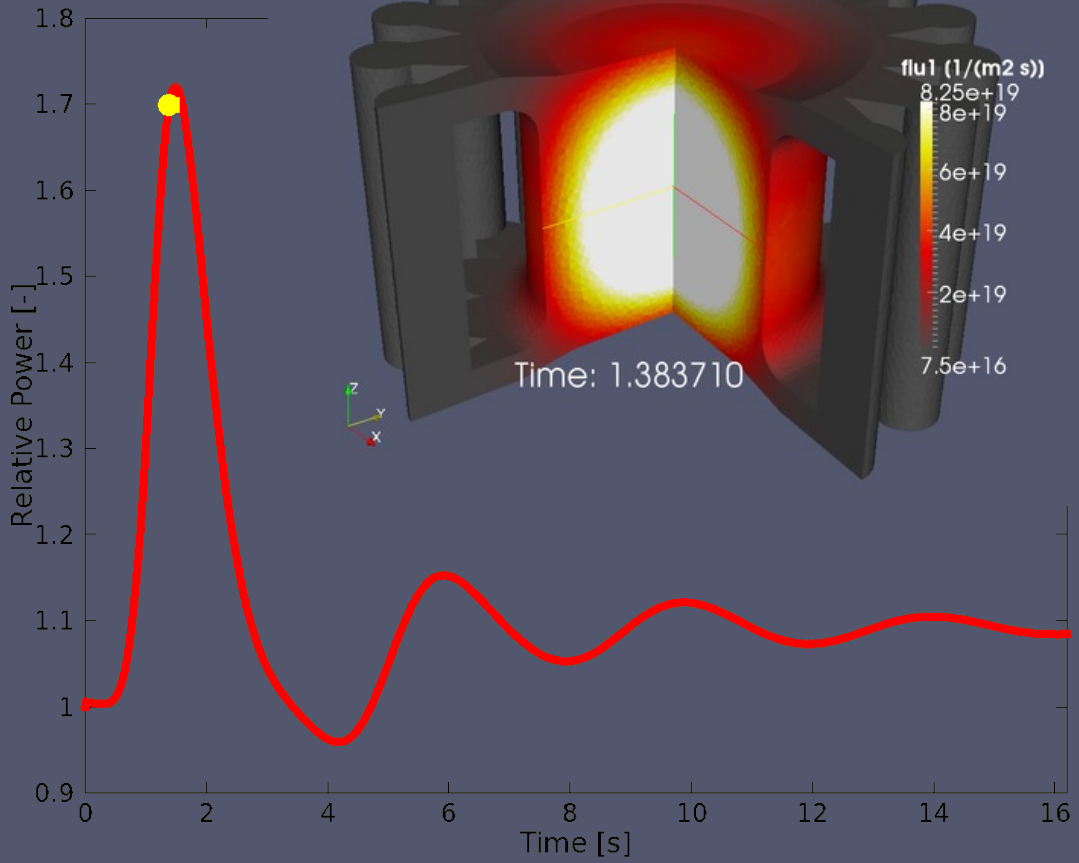

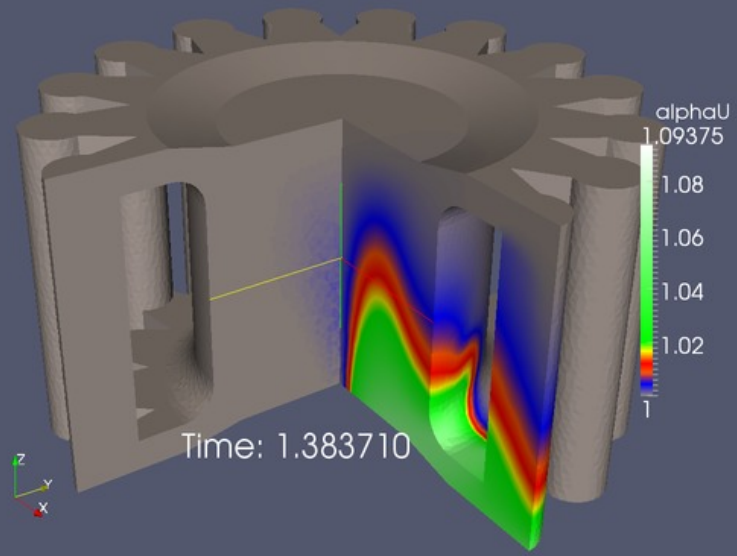

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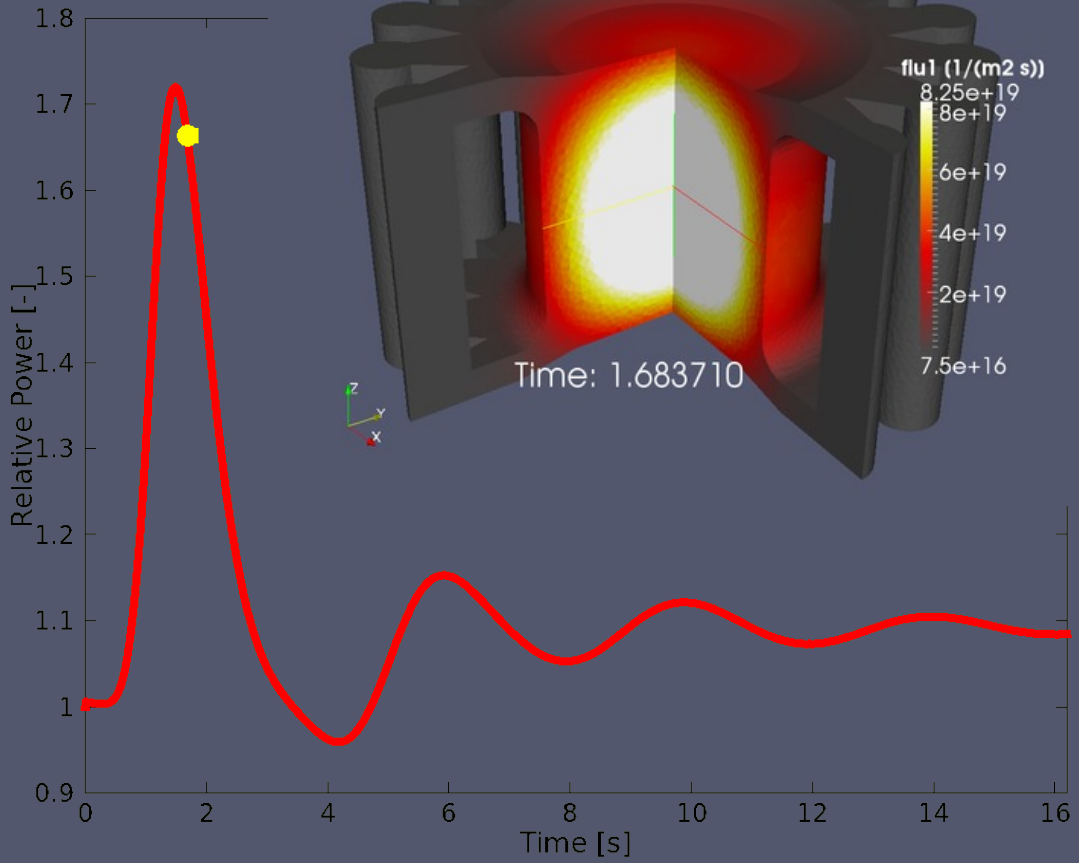

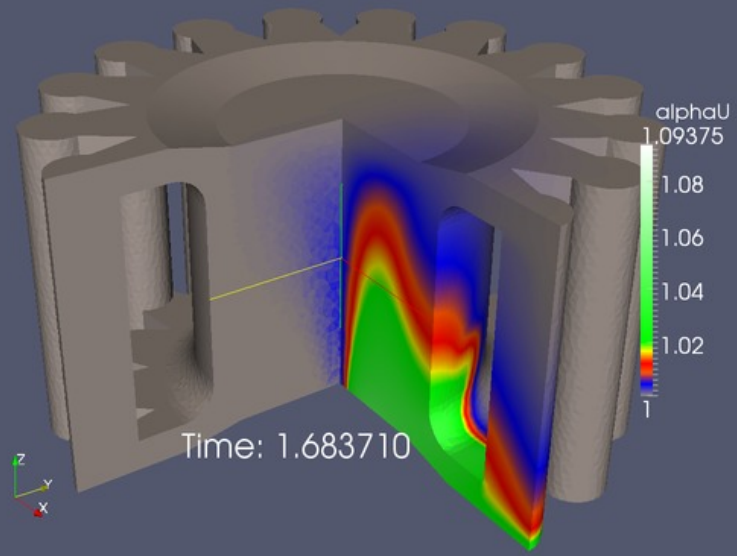

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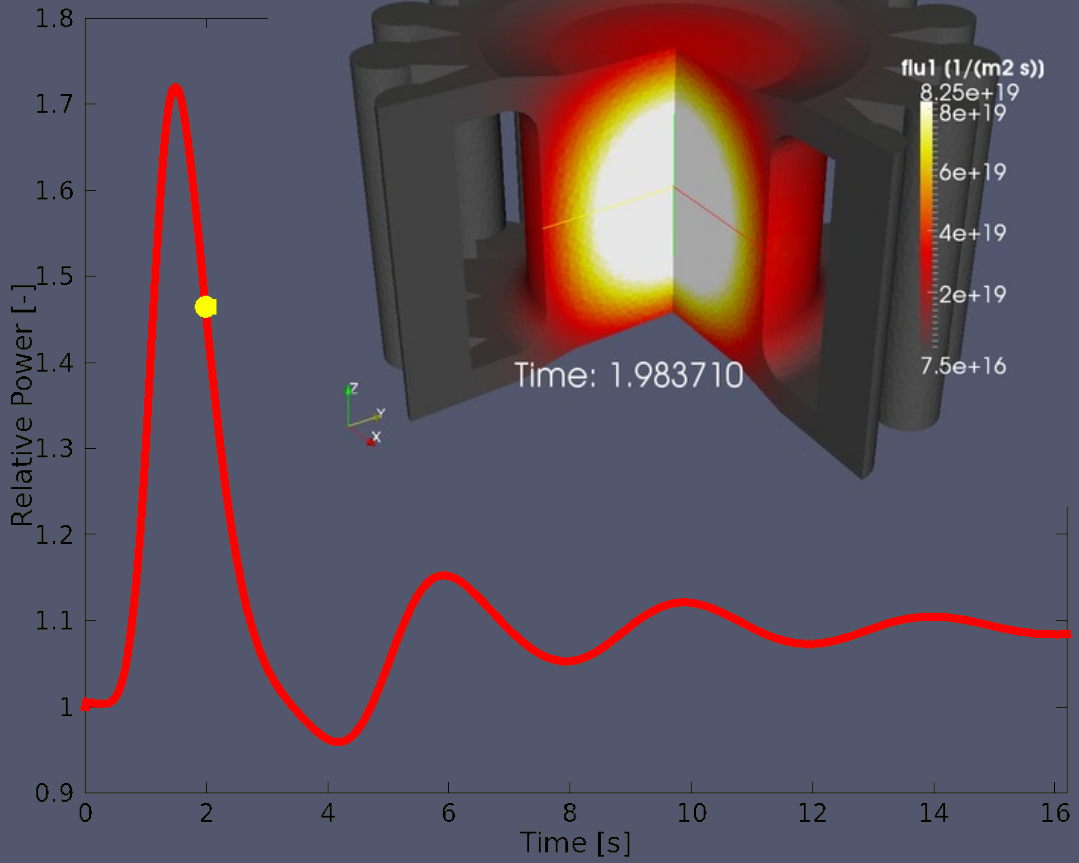

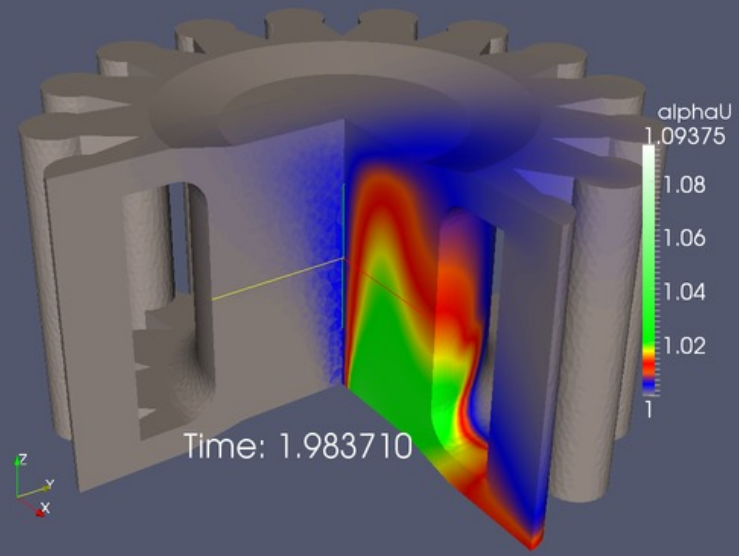

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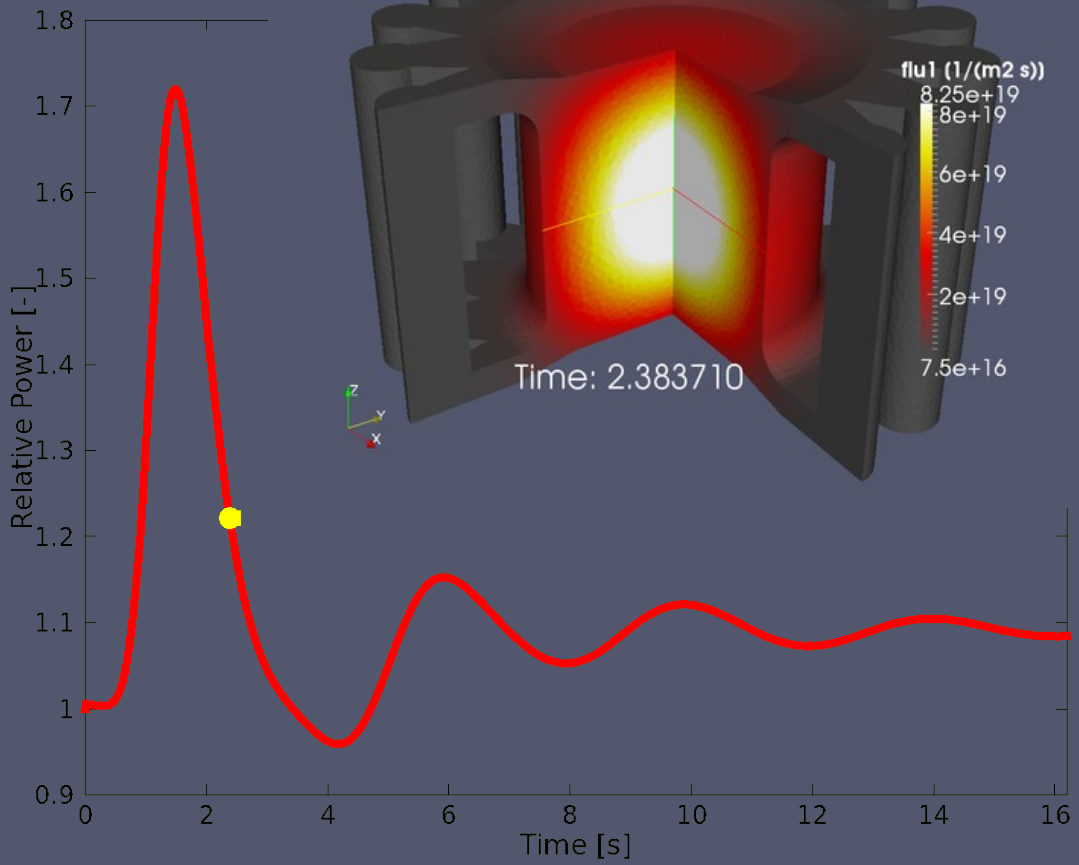

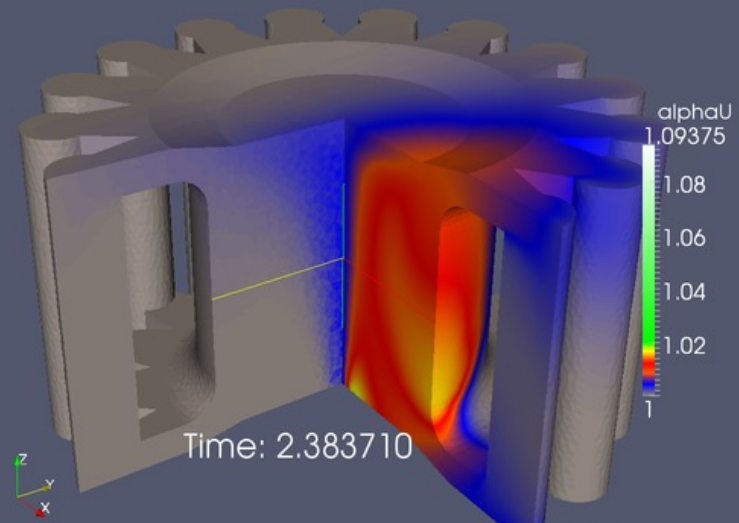

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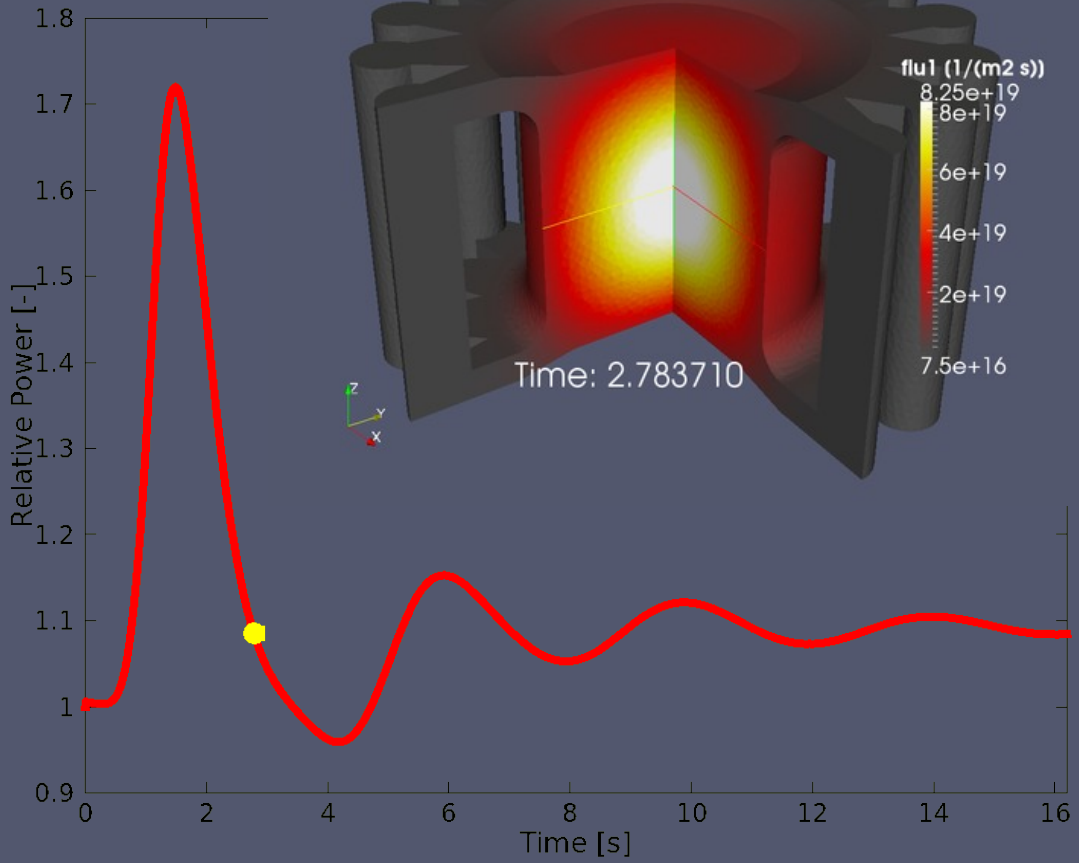

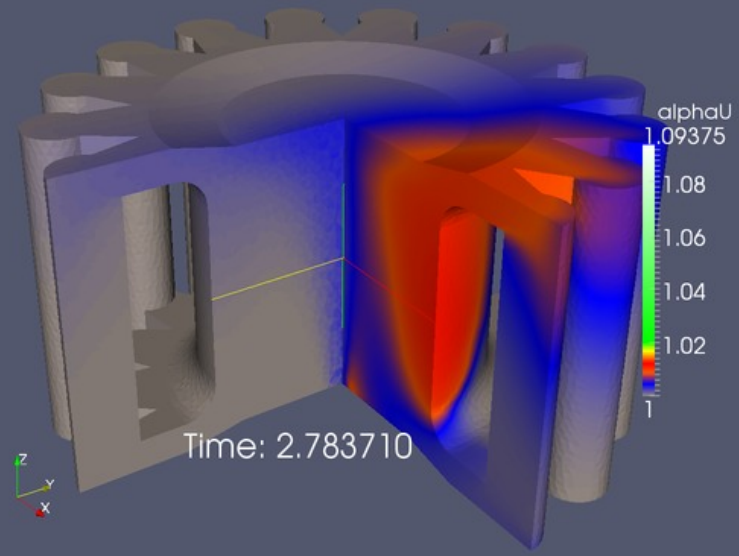

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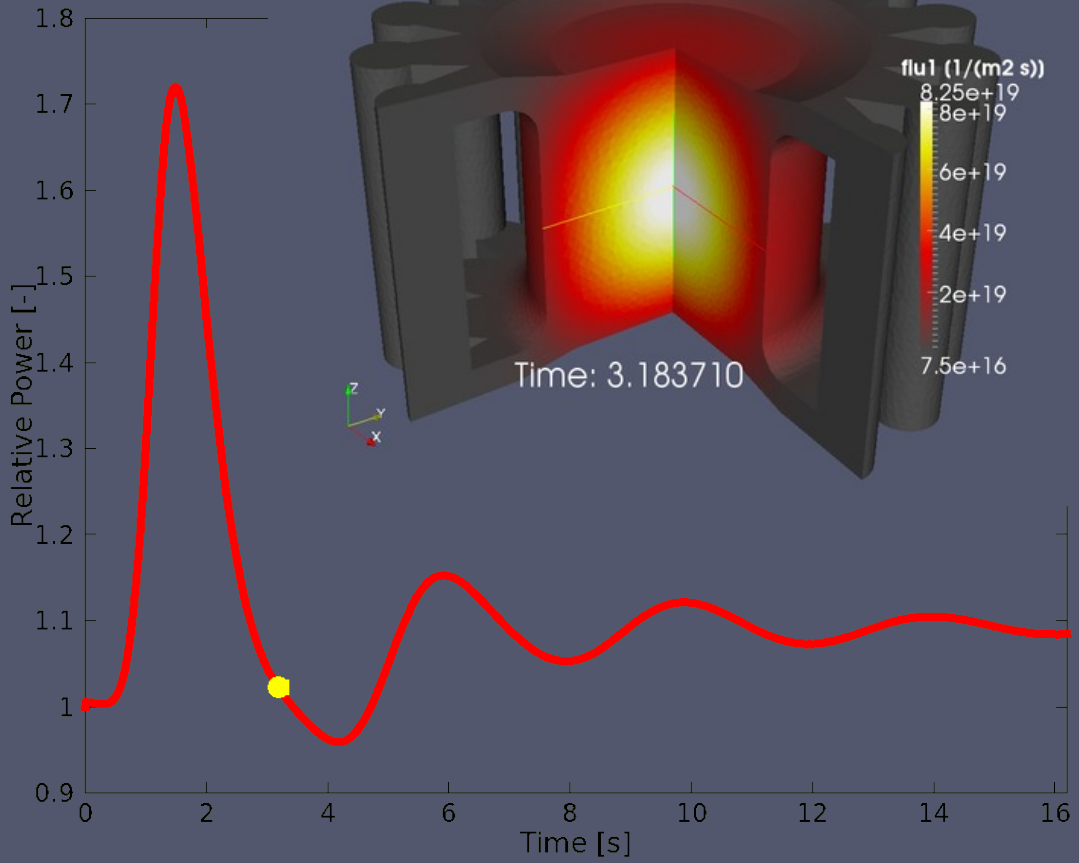

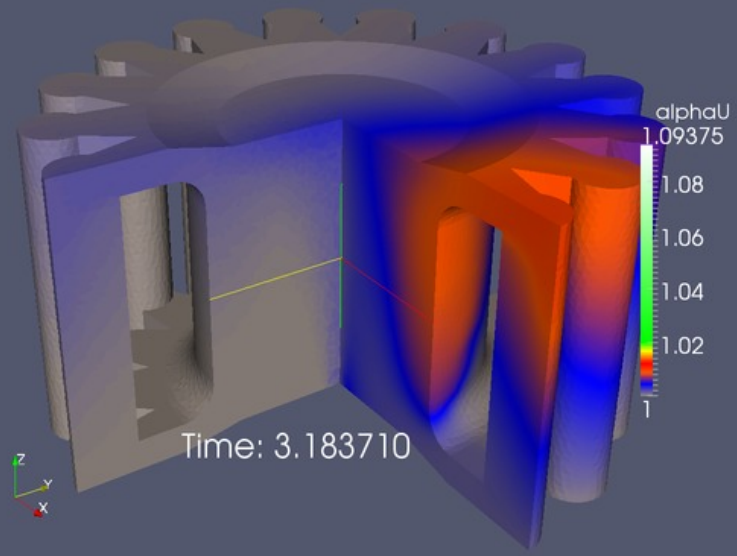

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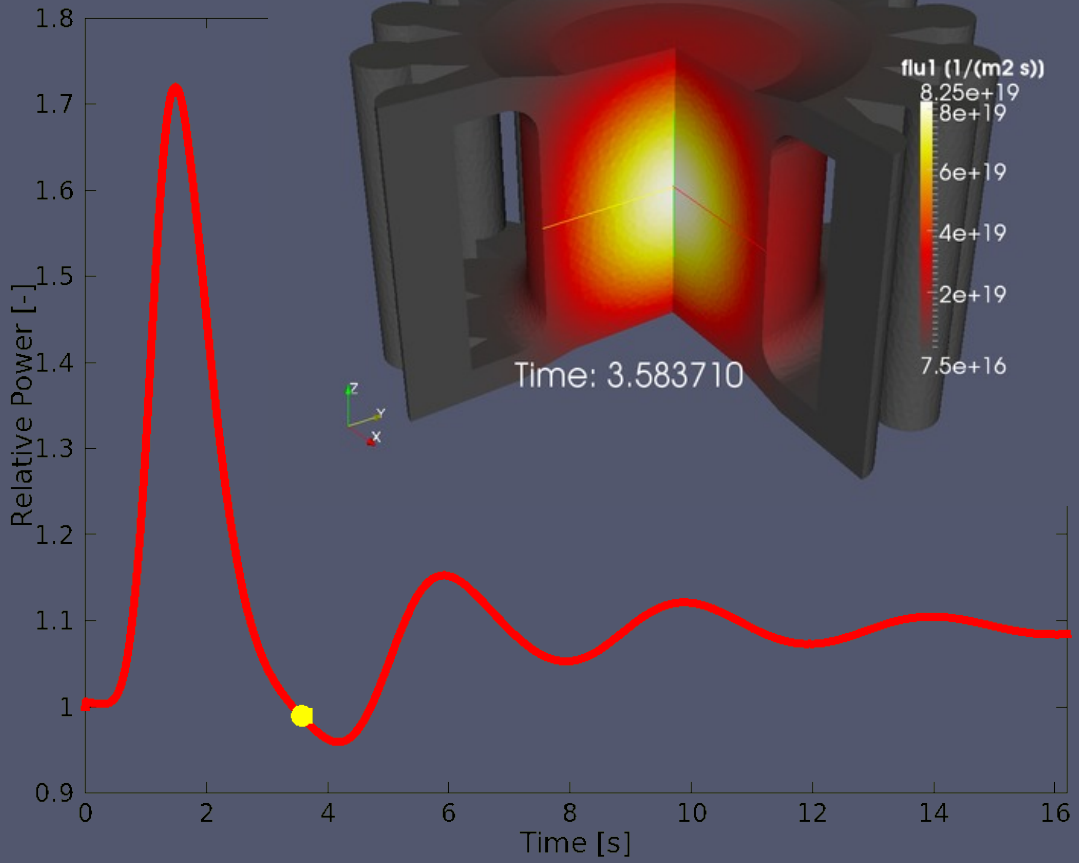

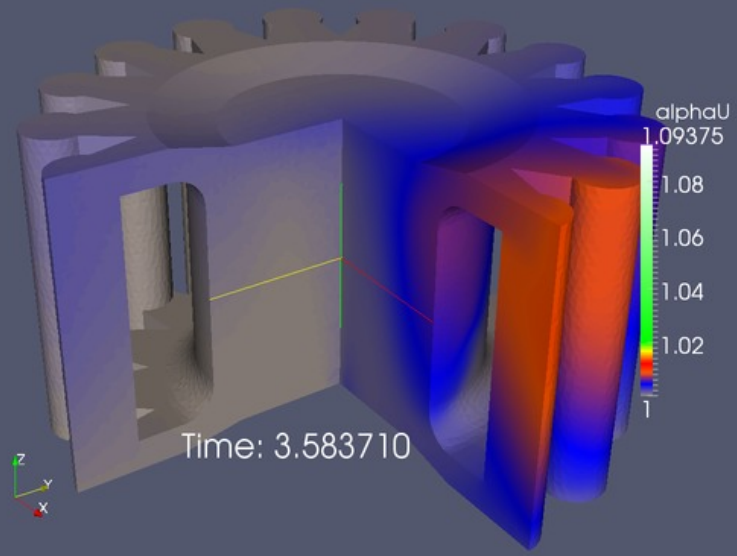

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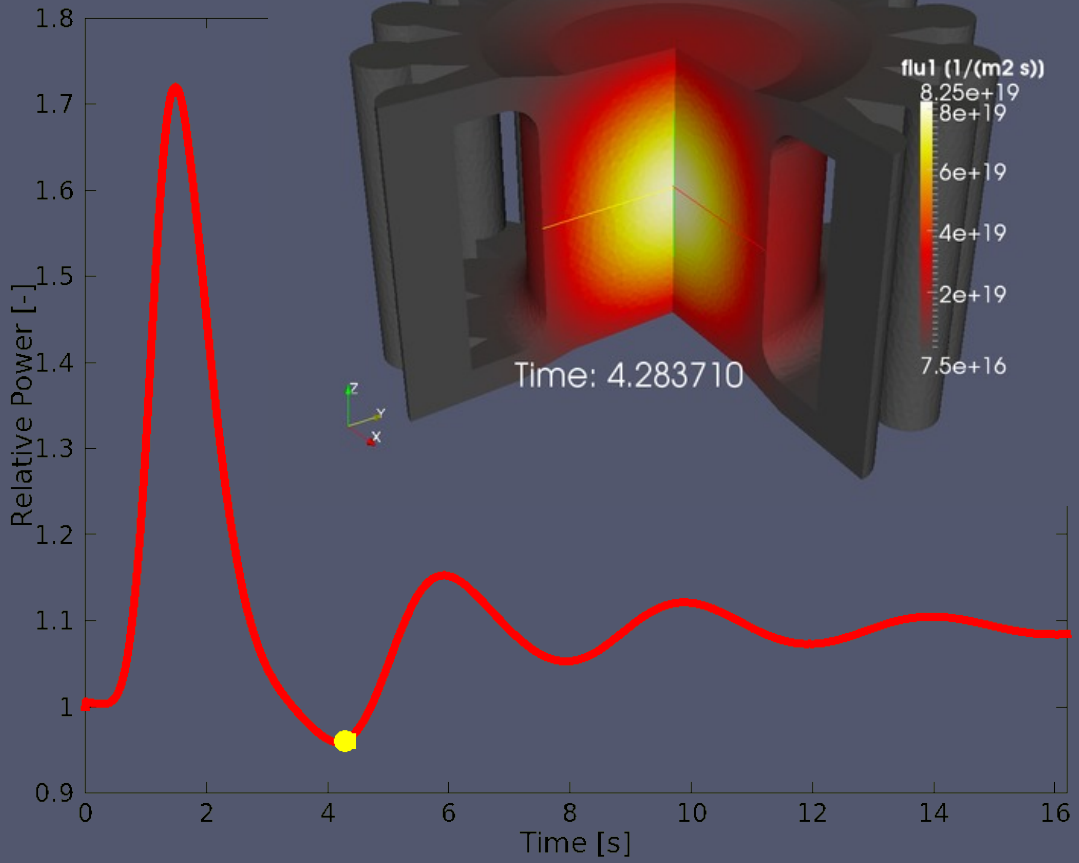

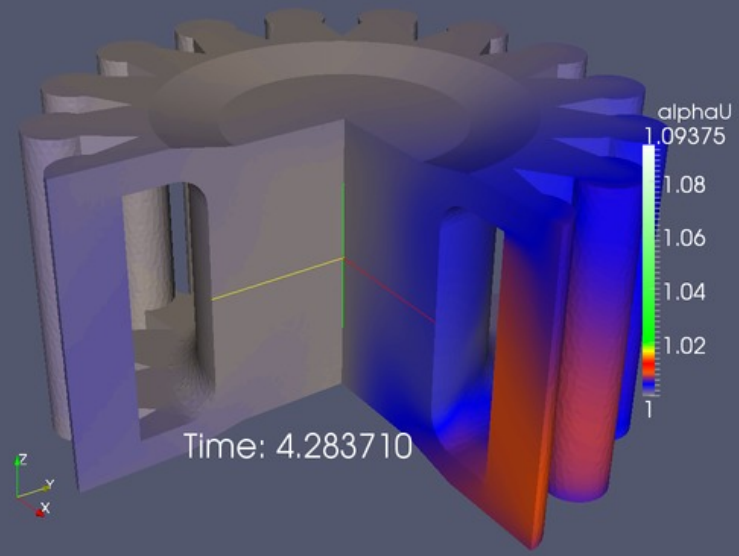

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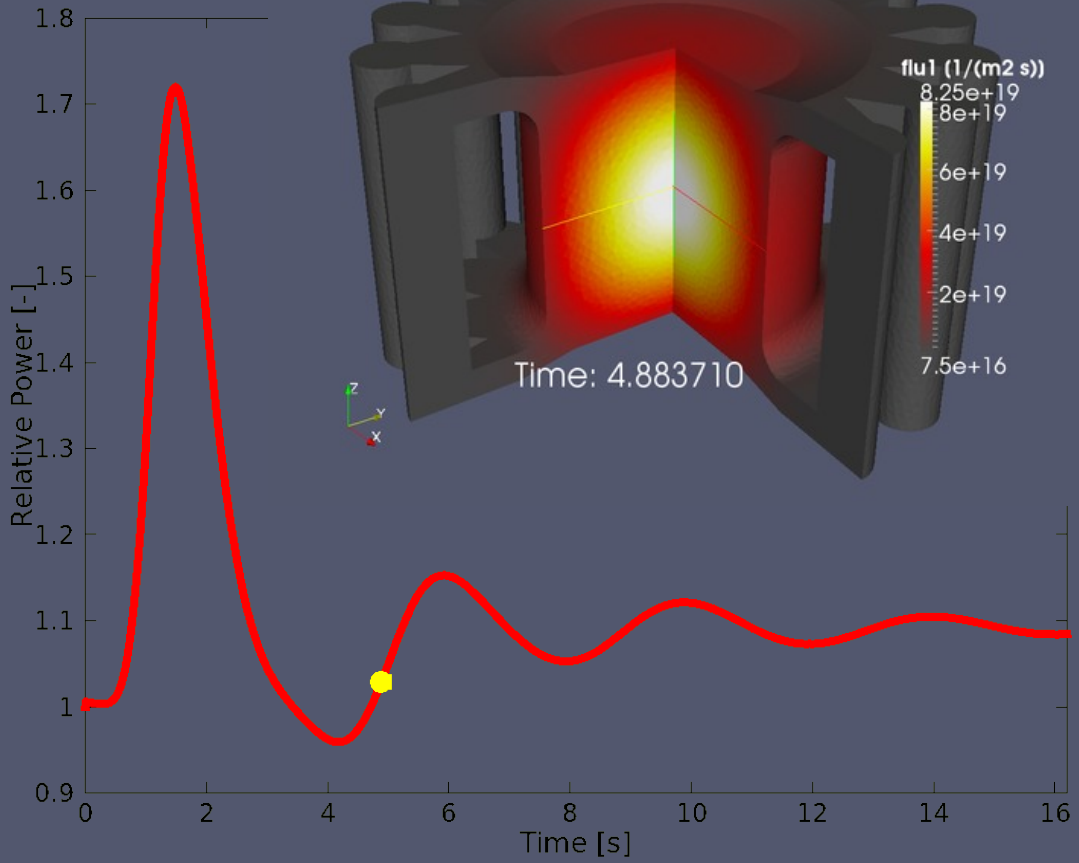

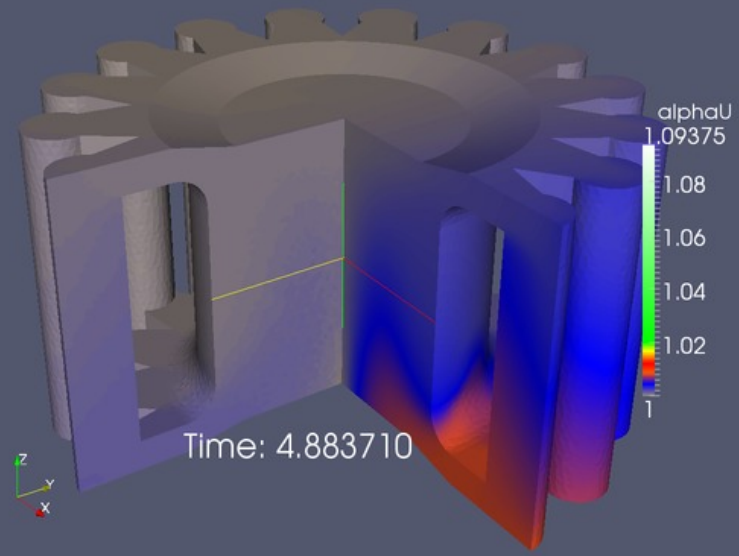

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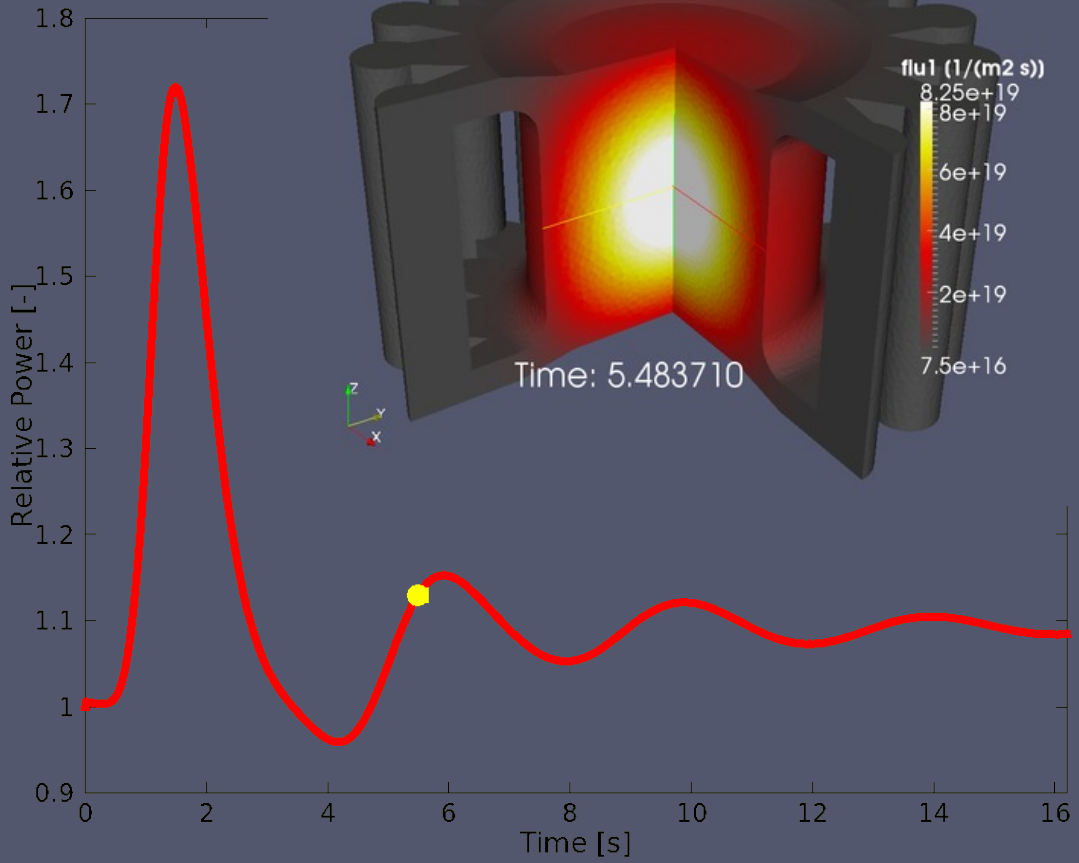

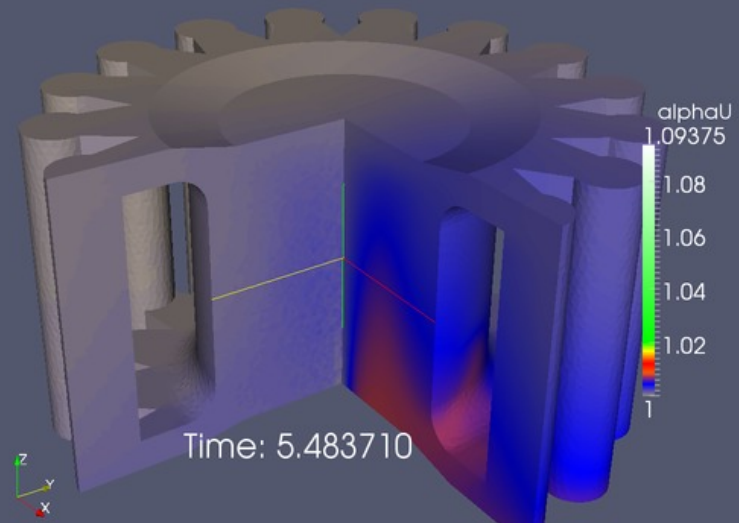

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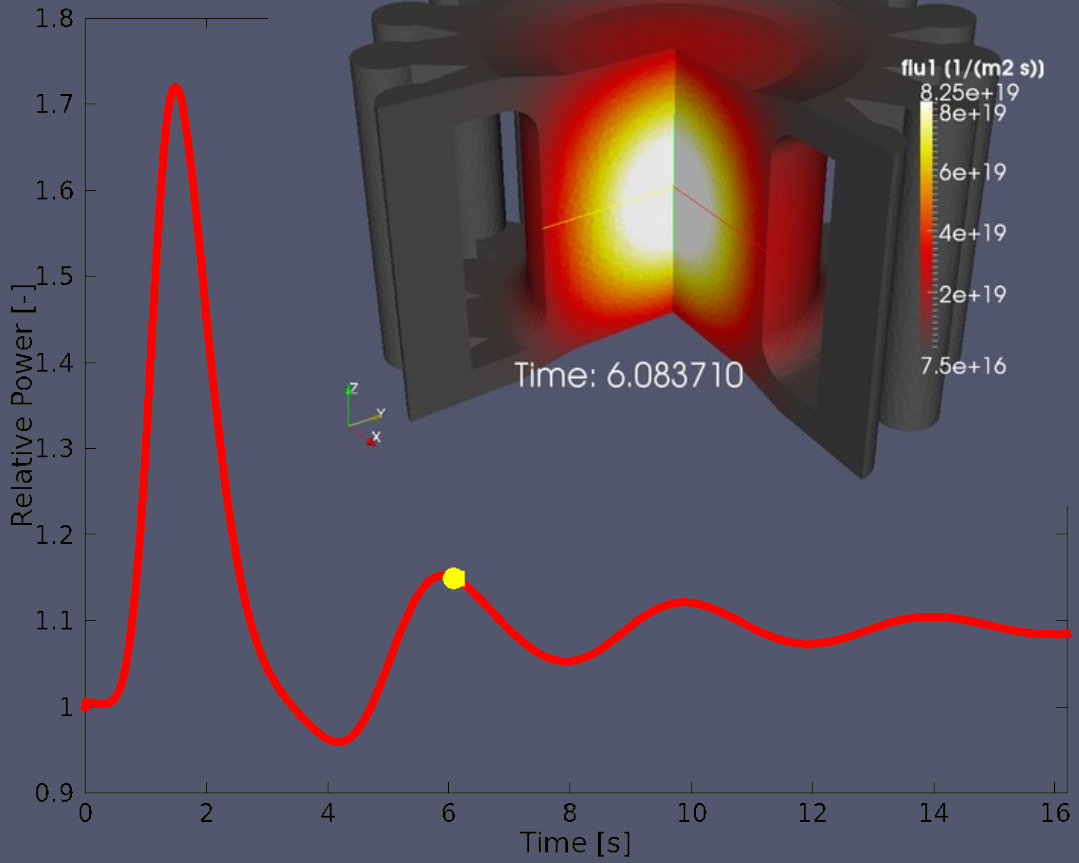
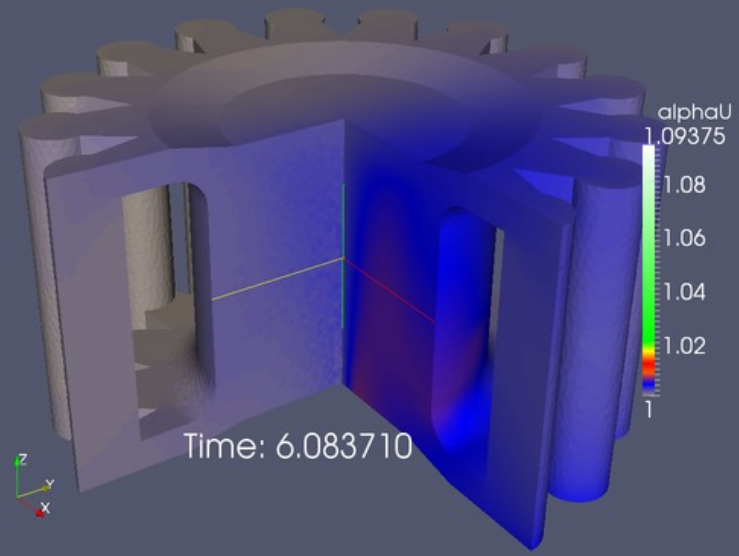




Accidental scenarios – examples

Reactivity insertion – accidental Uranium release.

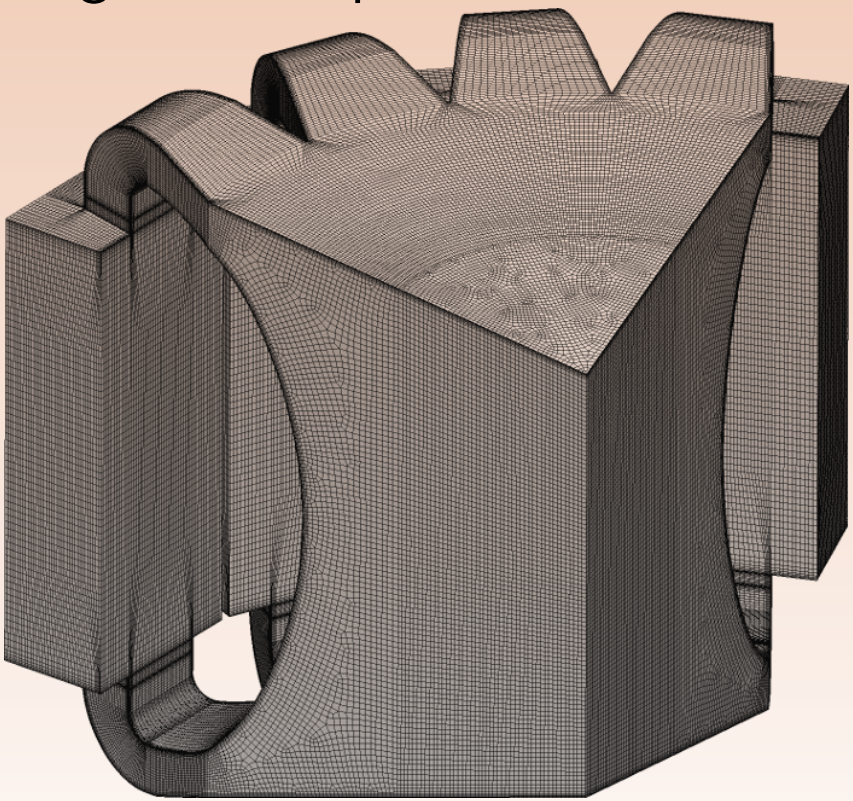
Single pump failure.

Loss of flow.

Single pump failure (one out of 16)

Accidental scenario

Unprotected pump blockage at $t = 0$ (e.g., bearing failure) after long reactor operation



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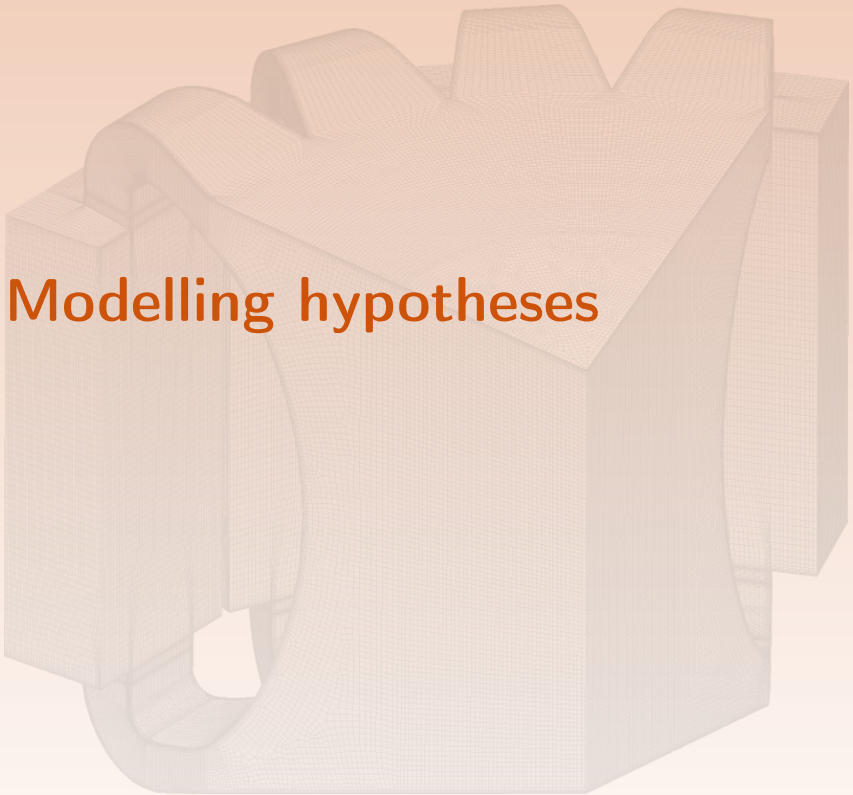

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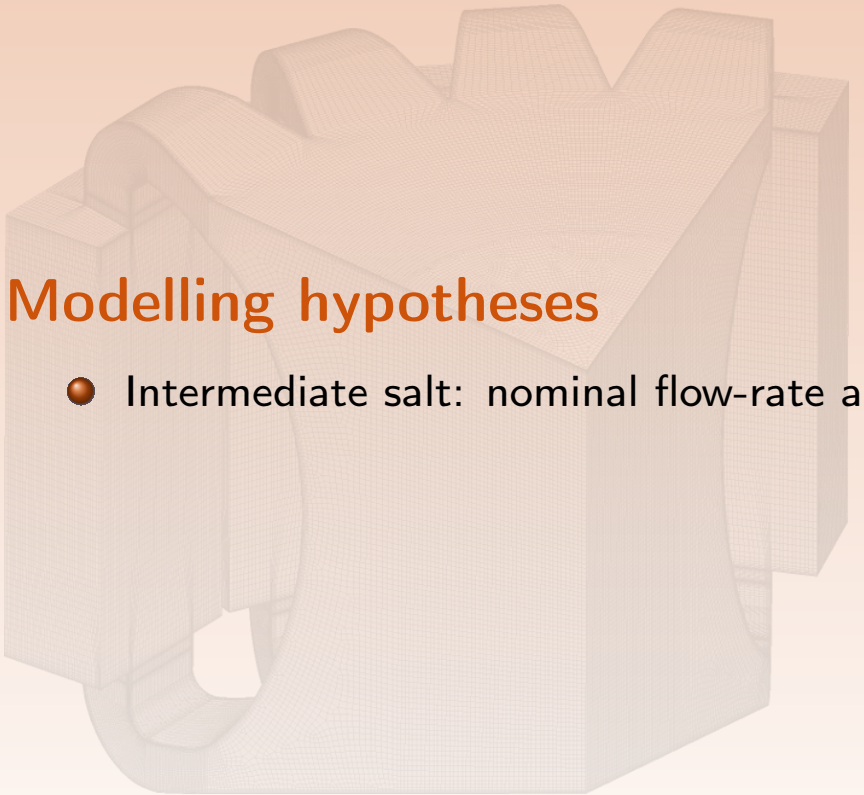

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- Intermediate salt: nominal flow-rate and inlet temperature **(500°C)**

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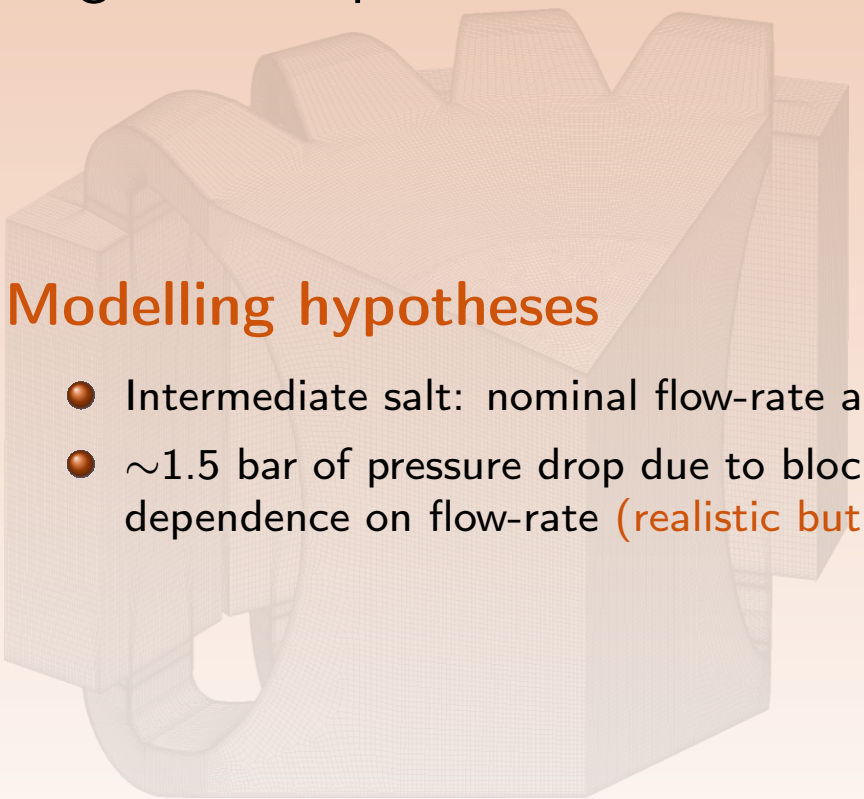

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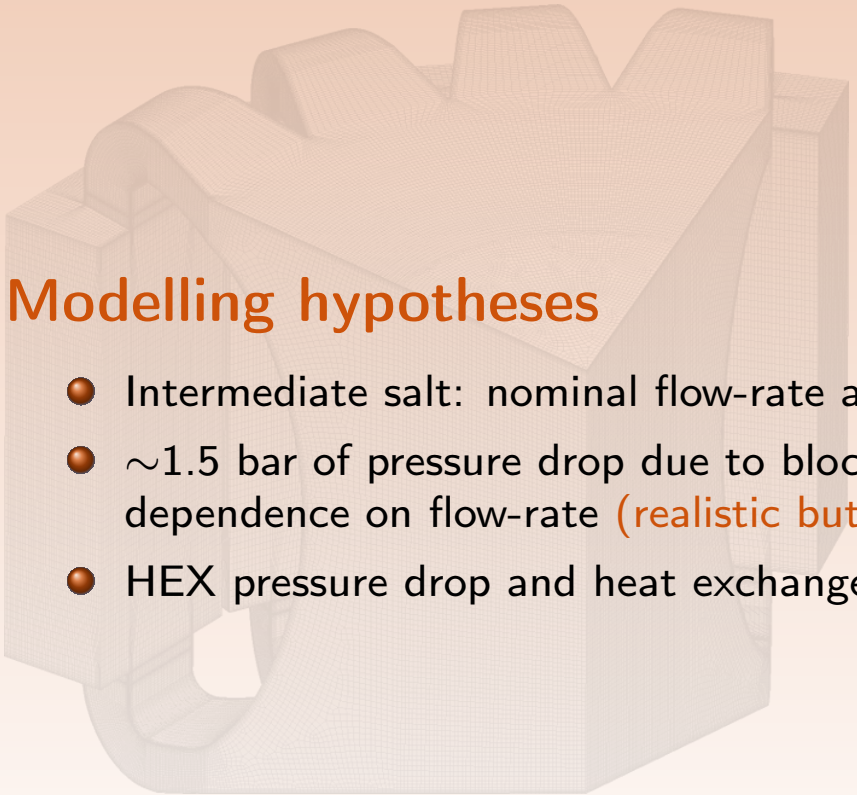

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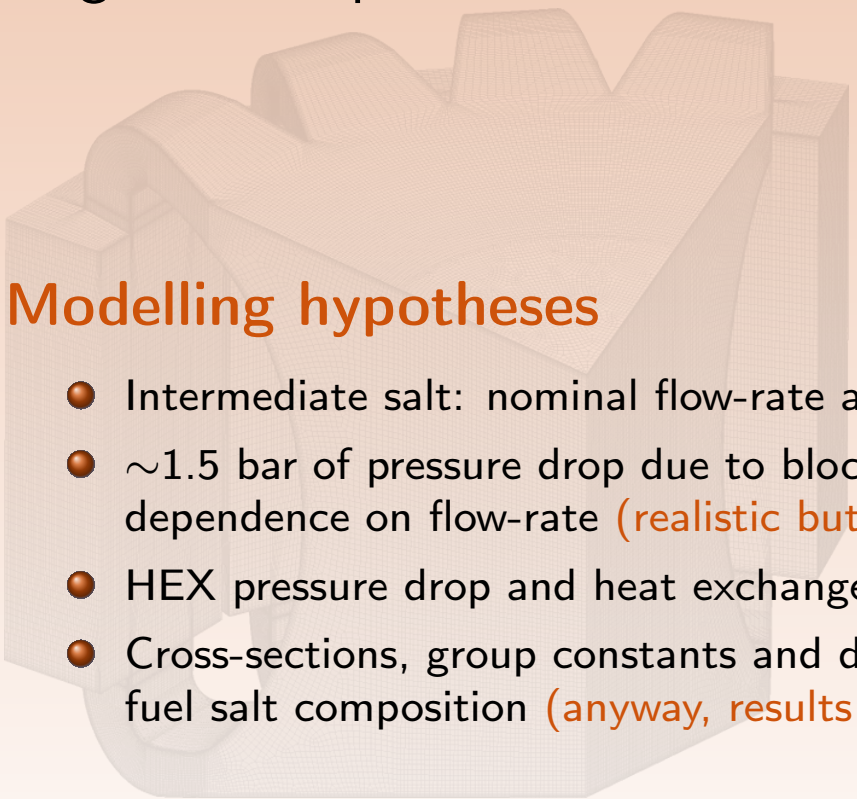

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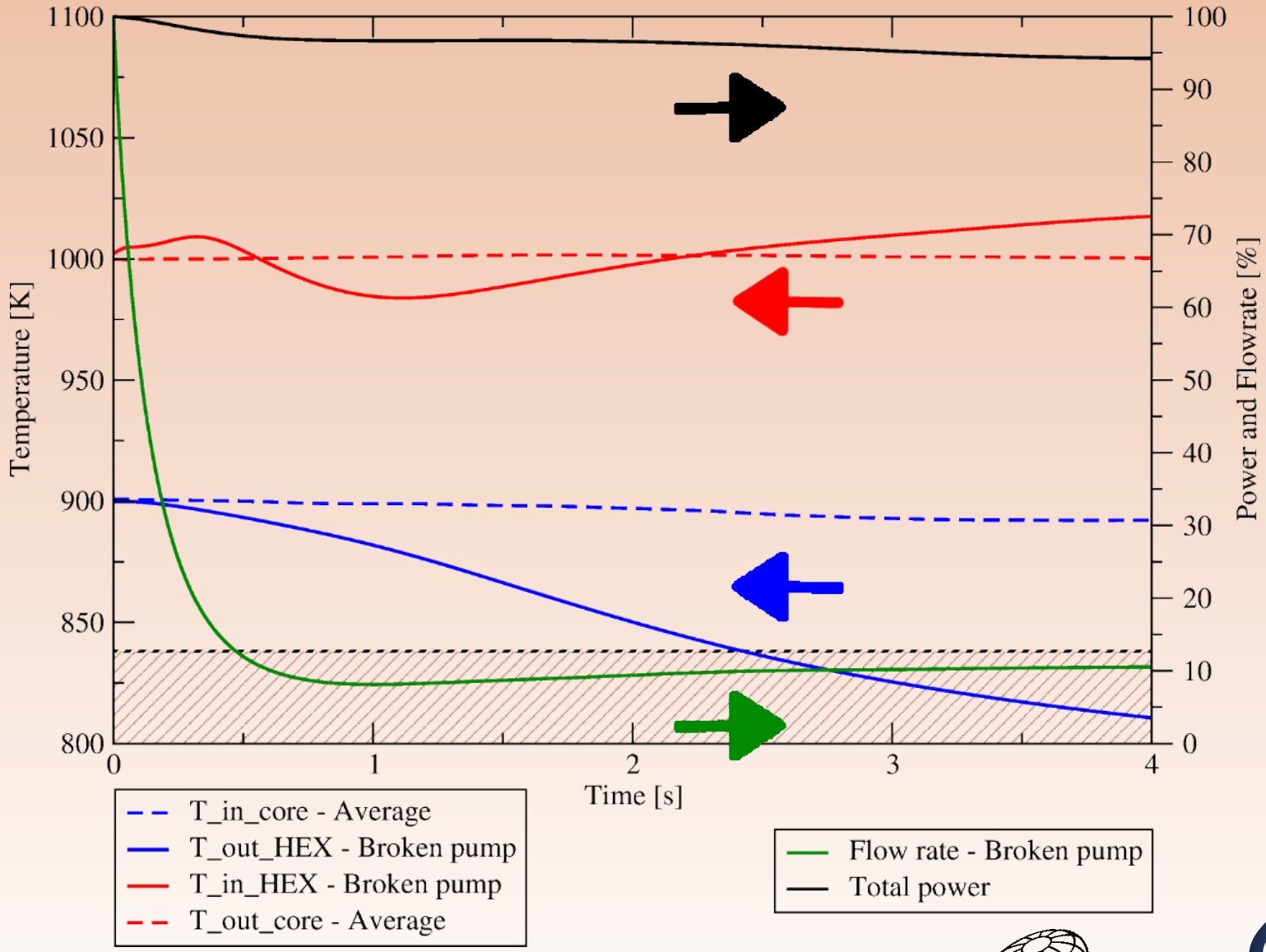
- HEX pressure drop and heat exchange coefficient as function of the flow-rate
- Cross-sections, group constants and decay heat curves relative to equilibrium fuel salt composition (anyway, results are not too sensitive)

Single pump failure – **What happens?**



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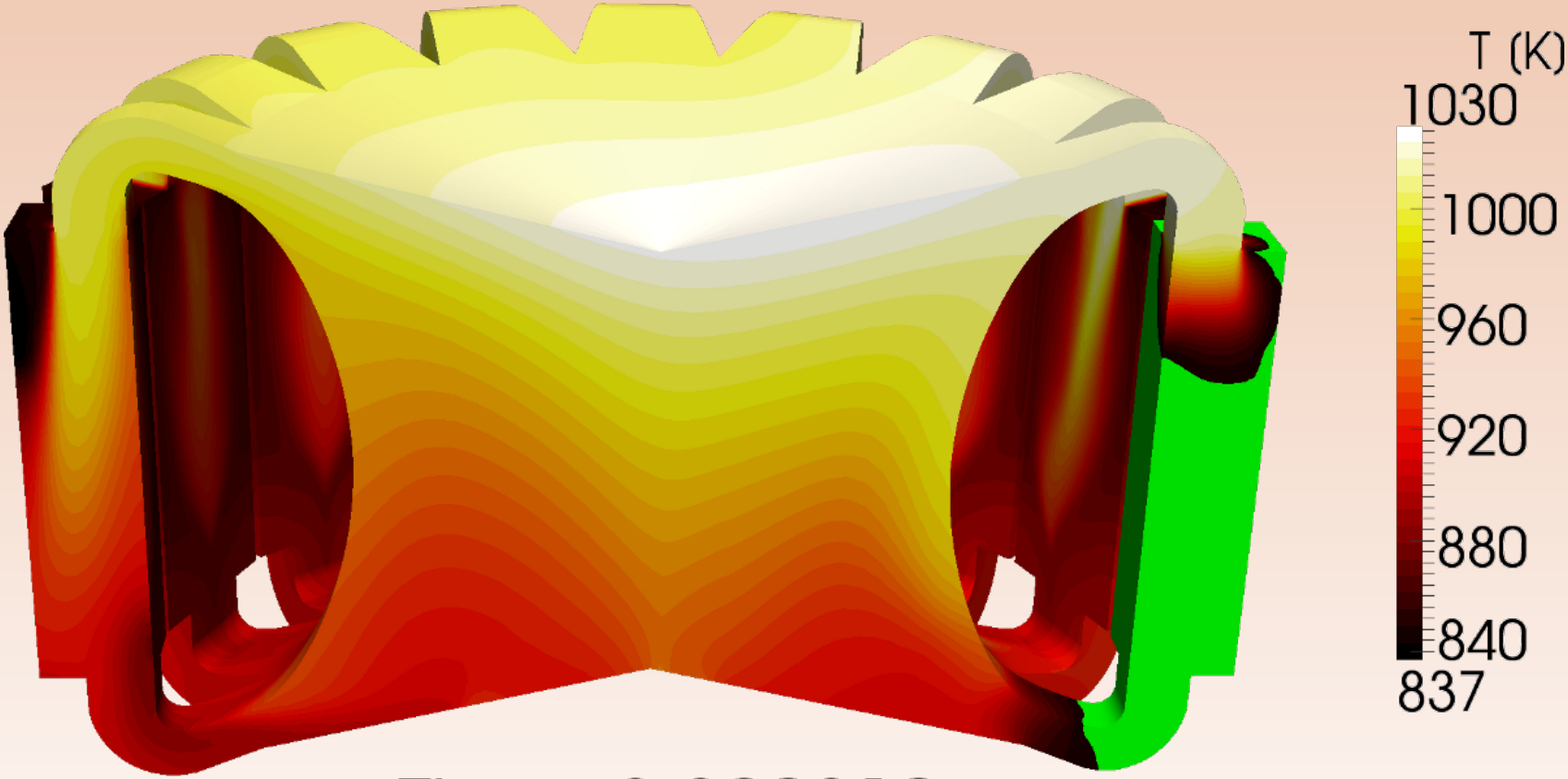

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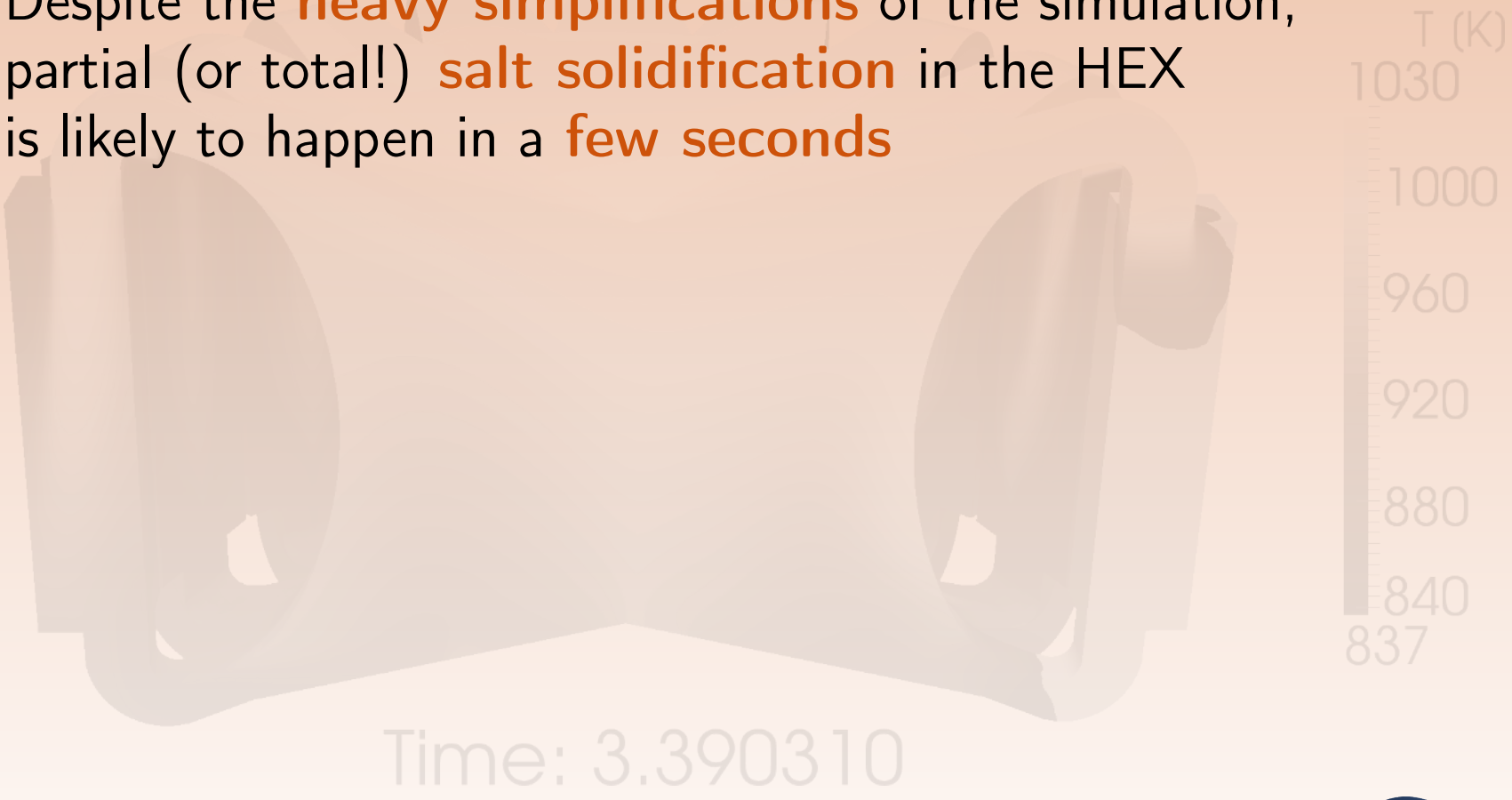
Despite the **heavy simplifications** of the simulation,
partial (or total!) **salt solidification** in the HEX
is likely to happen in a **few seconds**



Single pump failure – **What happens?**

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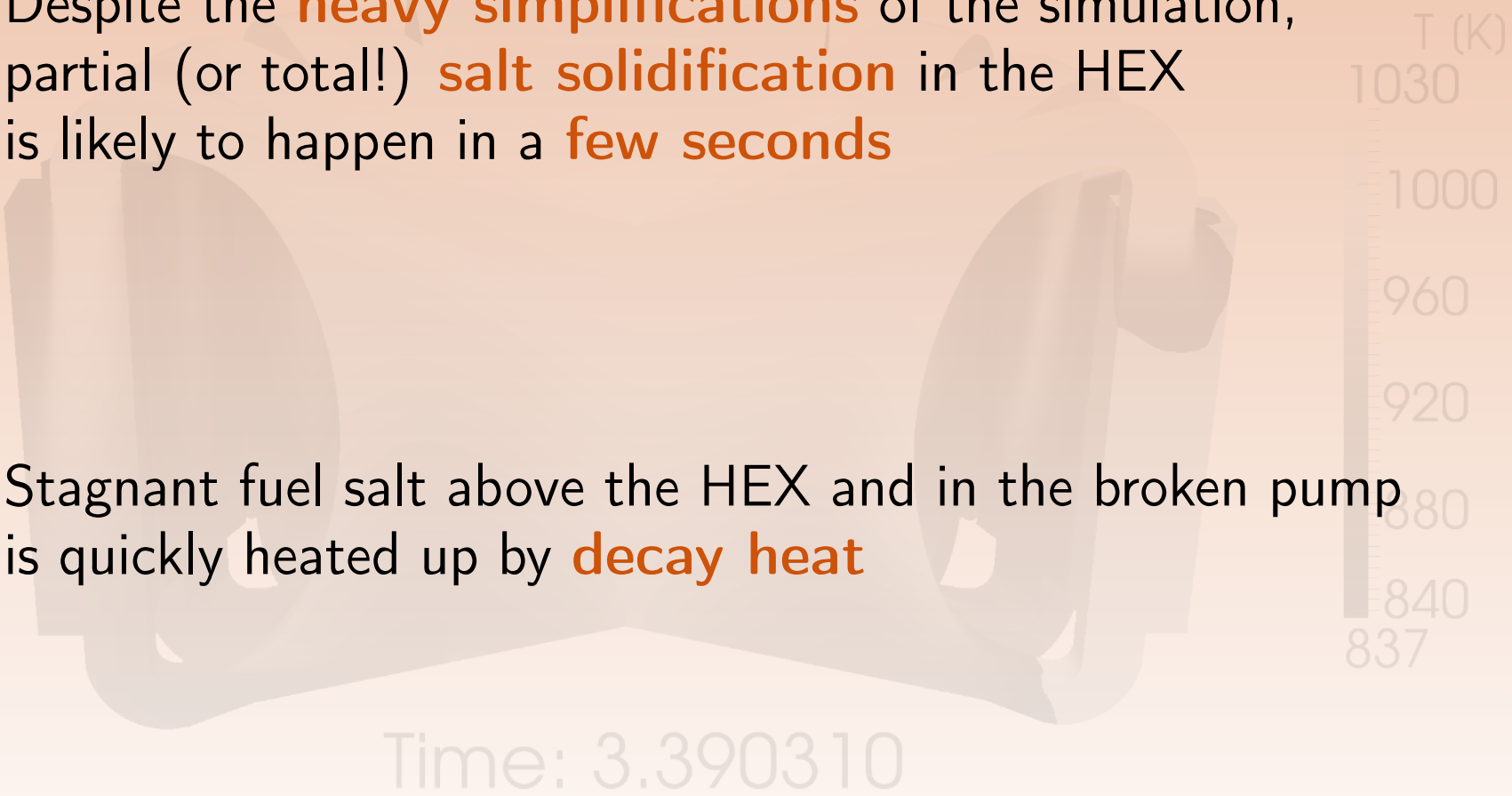
Stagnant fuel salt above the HEX and in the broken pump
is quickly heated up by **decay heat**



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- Exponential pump coast down, $\tau = 1$ or 15 s (small to medium inertial flywheel)

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- Nominal intermediate salt inlet temperature **(500°C)**

Loss of flow

Accidental scenario

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Modelling hypotheses

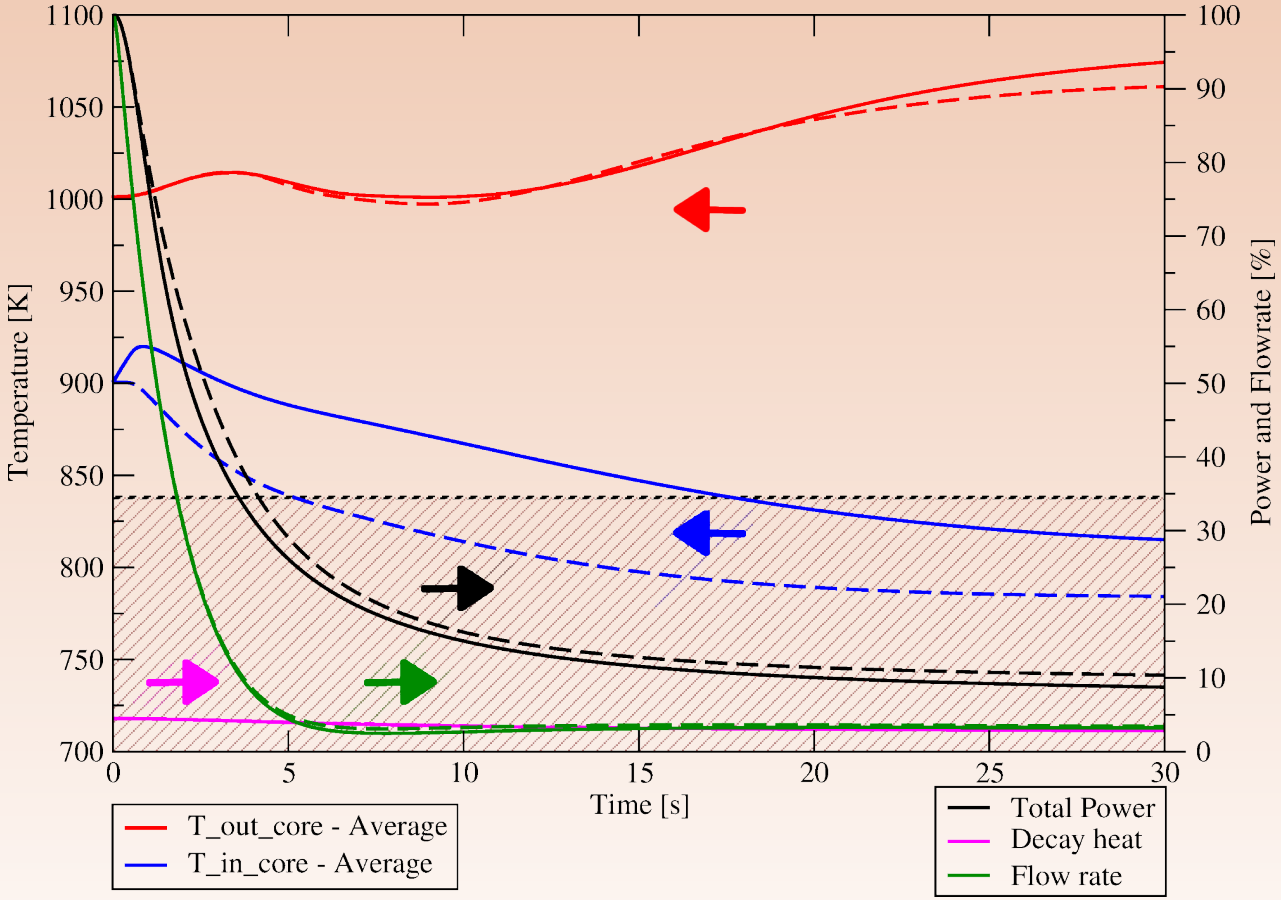
- Exponential pump coast down, $\tau = 1$ or 15 s
  (small to medium inertial flywheel)
- Nominal intermediate salt inlet temperature **(500°C)**
- Unprotected scenario: nominal intermediate salt flow rate
  "Mitigated" scenario: fast reduction of intermediate salt flow rate to **10 %**

Loss of flow – **What happens?**

Low flywheel inertia: $\tau = 1$ s

Solid lines: fast reduction of intermediate salt flow rate

Dashed lines: unprotected scenario

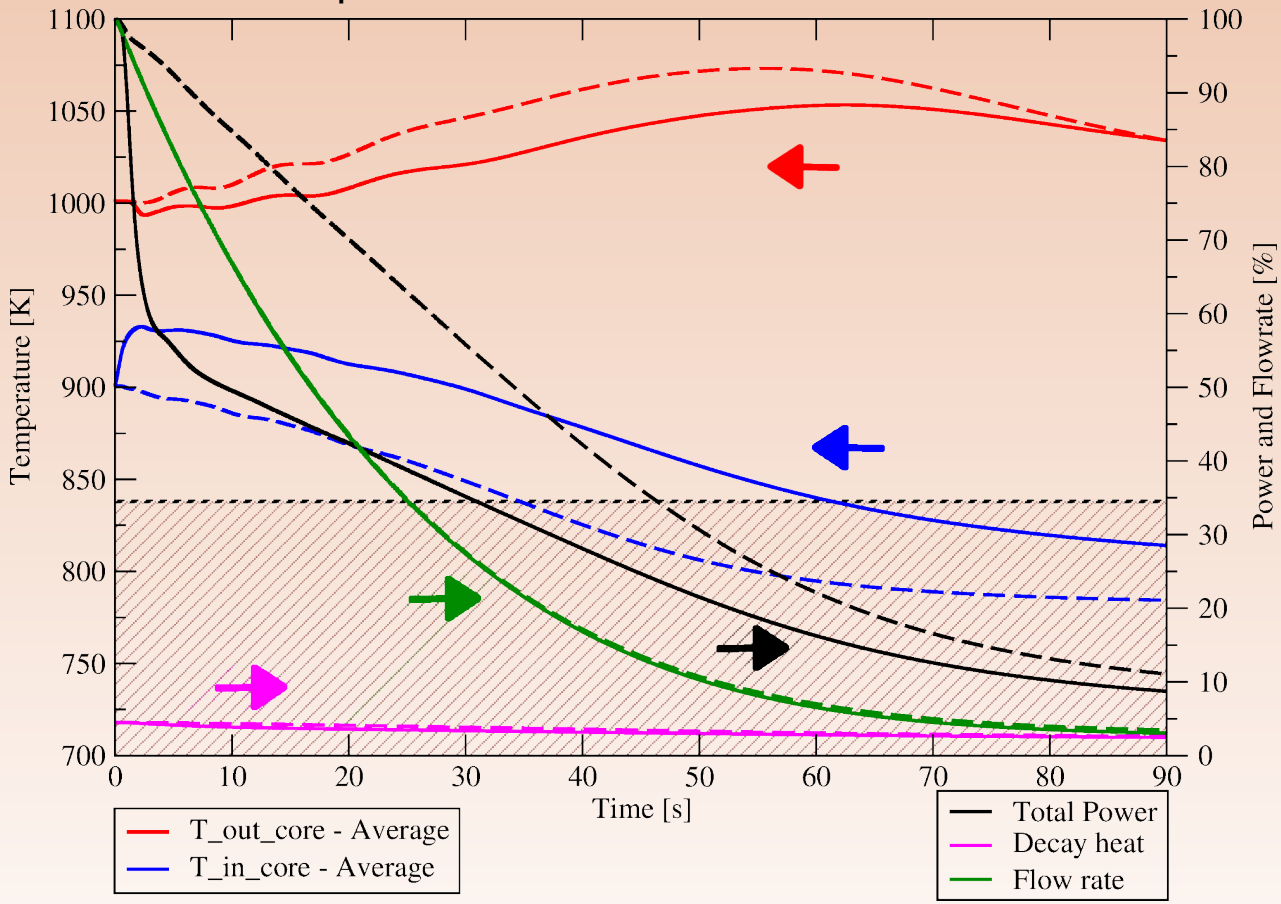


Loss of flow – **What happens?**

Medium flywheel inertia: $\tau = 15$ s

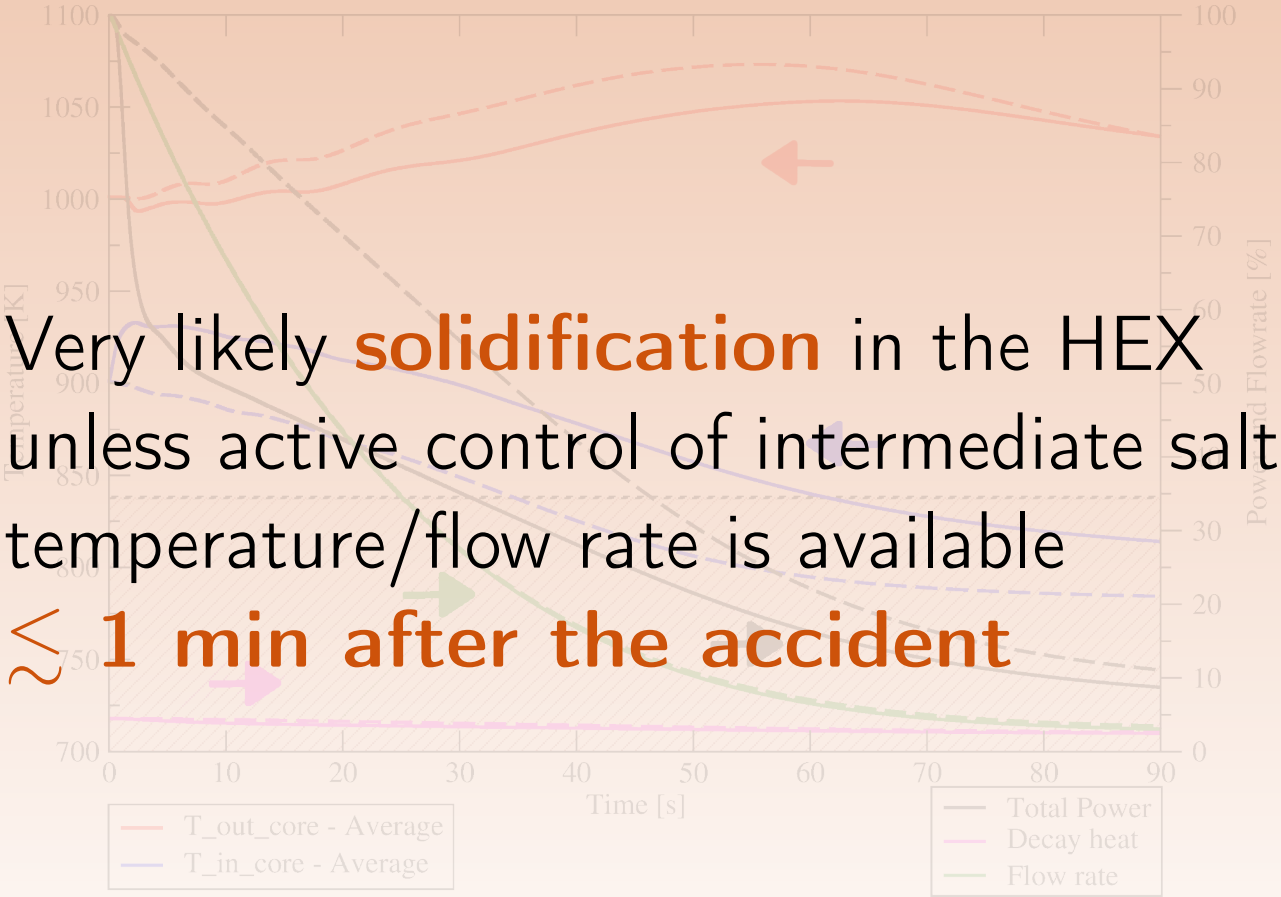
Solid lines: fast reduction of intermediate salt flow rate

Dashed lines: unprotected scenario



Loss of flow – **What happens?**

Medium flywheel inertia: $\tau = 15$ s
Solid lines: fast reduction of intermediate salt flow rate
Dashed lines: unprotected scenario



Very likely **solidification** in the HEX unless active control of intermediate salt temperature/flow rate is available

$\lesssim$ **1 min after the accident**

Mitigation of pump failure – some possible solution

- prevent salt solidification

Mitigation of pump failure – some possible solution

- prevent salt solidification
- limit salt solidification

Mitigation of pump failure – some possible solution

- prevent salt solidification
- limit salt solidification
- endure salt solidification

Mitigation of pump failure – some possible solution

- prevent salt solidification
  - Increase of intermediate salt temperature — Intermediate salt inlet temperature: $\gtrsim 565°C$
- limit salt solidification
  - \+ Solidification is avoided "by design" until intermediate salt temperature is kept above freezing point
  - – Higher HEX volume is required
  - ? Problems at steam generator side(?)
- endure salt solidification

Mitigation of pump failure – some possible solution

- prevent salt solidification
  - Increase of intermediate salt temperature
  - 2 pumps – 1 HEX module
- limit salt solidification
- endure salt solidification

Coupling 2 pumps (in parallel) for a single HEX

\+ Solidification is avoided if enough flow rate is ensured (i.e. $\gtrsim$ 20-30%)

– Ineffective against common cause failure

Mitigation of pump failure – some possible solution

- prevent salt solidification
  - Increase of intermediate salt temperature
  - 2 pumps – 1 HEX module
- limit salt solidification
  - Ad hoc HEX design
- endure salt solidification

E.g., tube within tube
Frozen salt at tube walls acts as thermal barrier and prevents further solidification

\+ Molten passage area is ensured INSIDE the HEX

– Higher HEX volume is required

? Never tested(?)

Mitigation of pump failure – some possible solution

- prevent salt solidification
  - Increase of intermediate salt temperature
  - 2 pumps – 1 HEX module
- limit salt solidification
  - Ad hoc HEX design
  - Large "by-pass" area
- endure salt solidification

A significant fraction of the fuel stream flows in a "by-pass" area

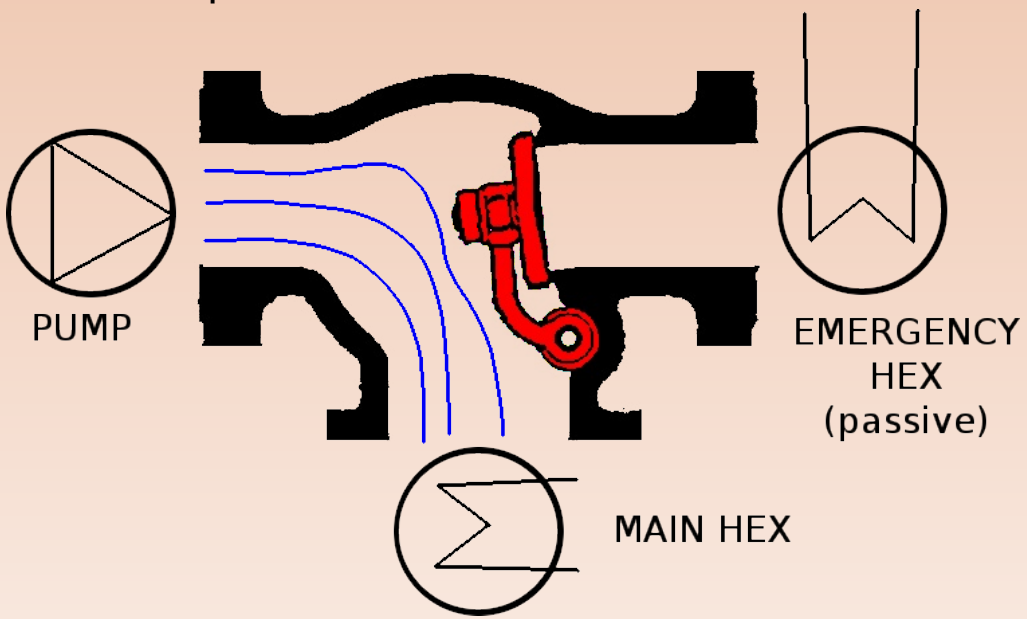
\+ Molten passage area is ensured OUTSIDE the HEX

– Loss in efficiency

Mitigation of pump failure – some possible solution

- prevent salt solidification
  - Increase of intermediate salt temperature
  - 2 pumps – 1 HEX module
- limit salt solidification
  - Ad hoc HEX design
  - Large "by-pass" area
- endure salt solidification
  - Passively actuated valve & HEX

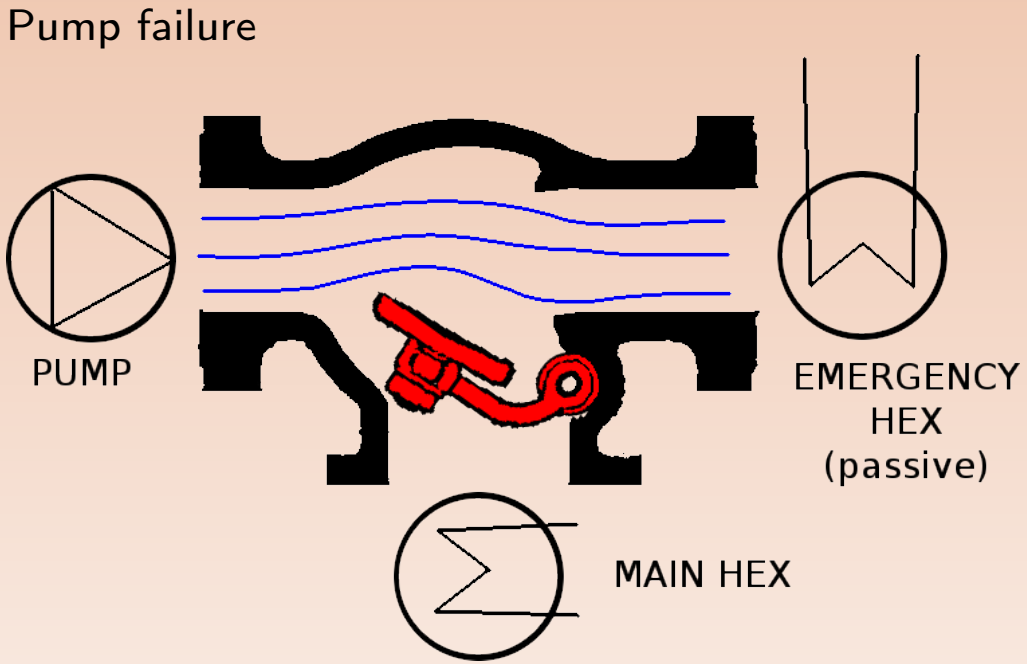
Nominal operation



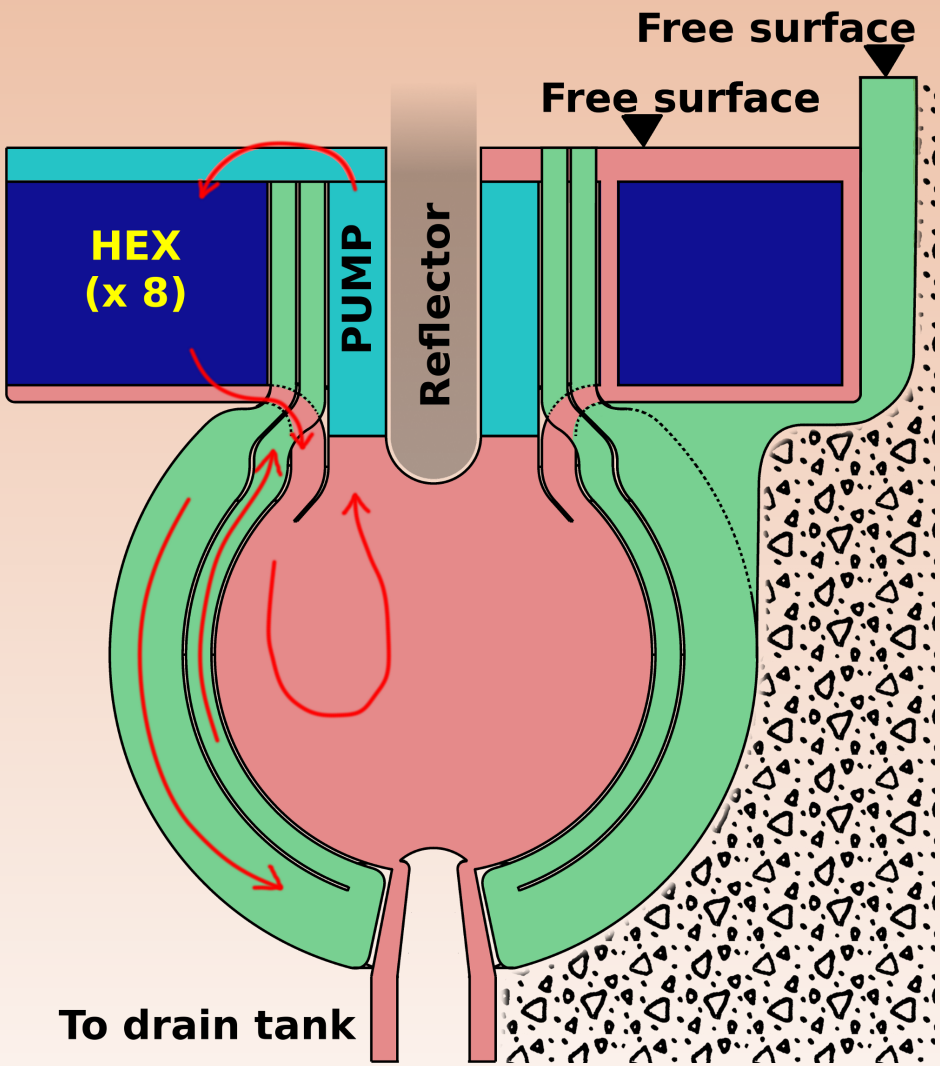
In nominal operation "by-pass" is closed by pressure difference

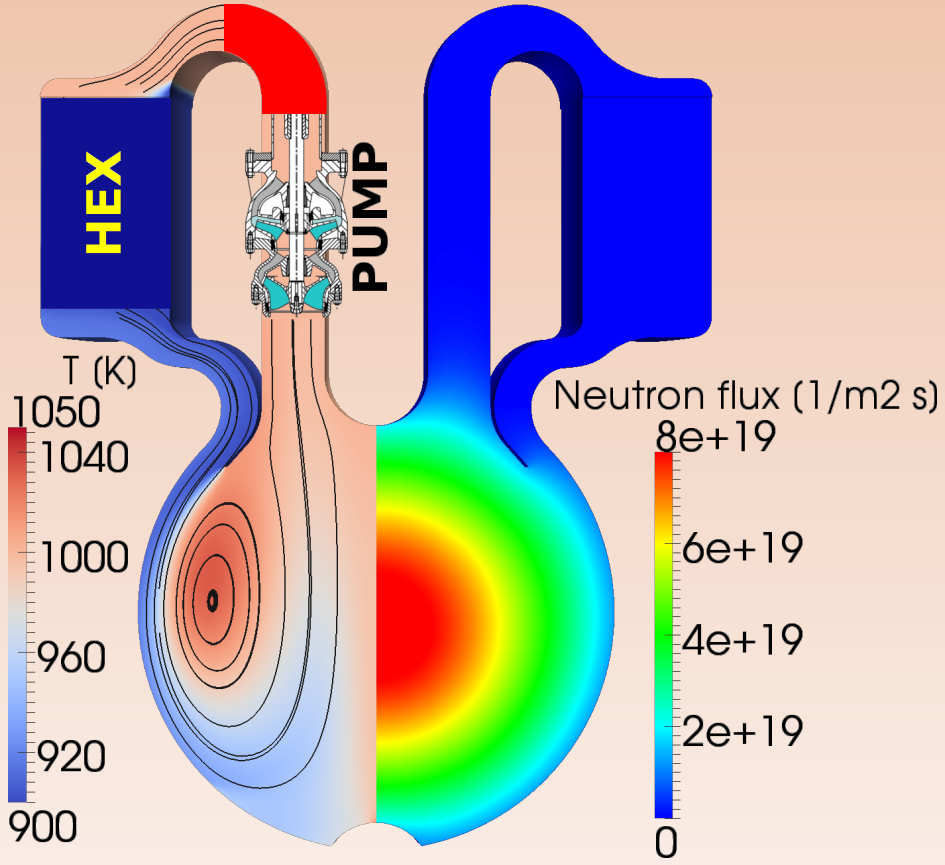
Mitigation of pump failure – some possible solution

- prevent salt solidification
  - Increase of intermediate salt temperature
  - 2 pumps – 1 HEX module
- limit salt solidification
  - Ad hoc HEX design
  - Large "by-pass" area
- endure salt solidification
  - Passively actuated valve & HEX



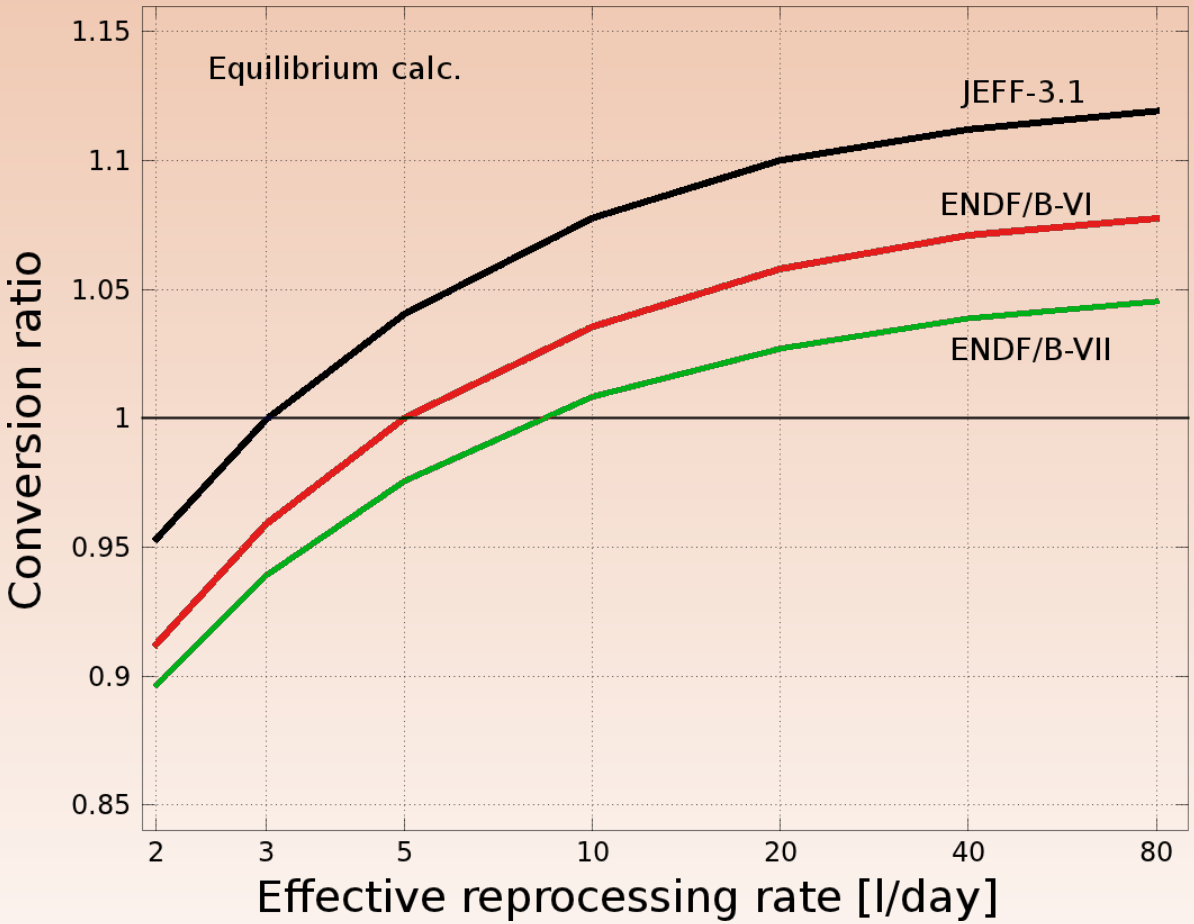
After pump failure, "by-pass" towards emergency HEX opens


Free surface
Free surface
HEX
(x 8)
PUMP
Reflector
To drain tank

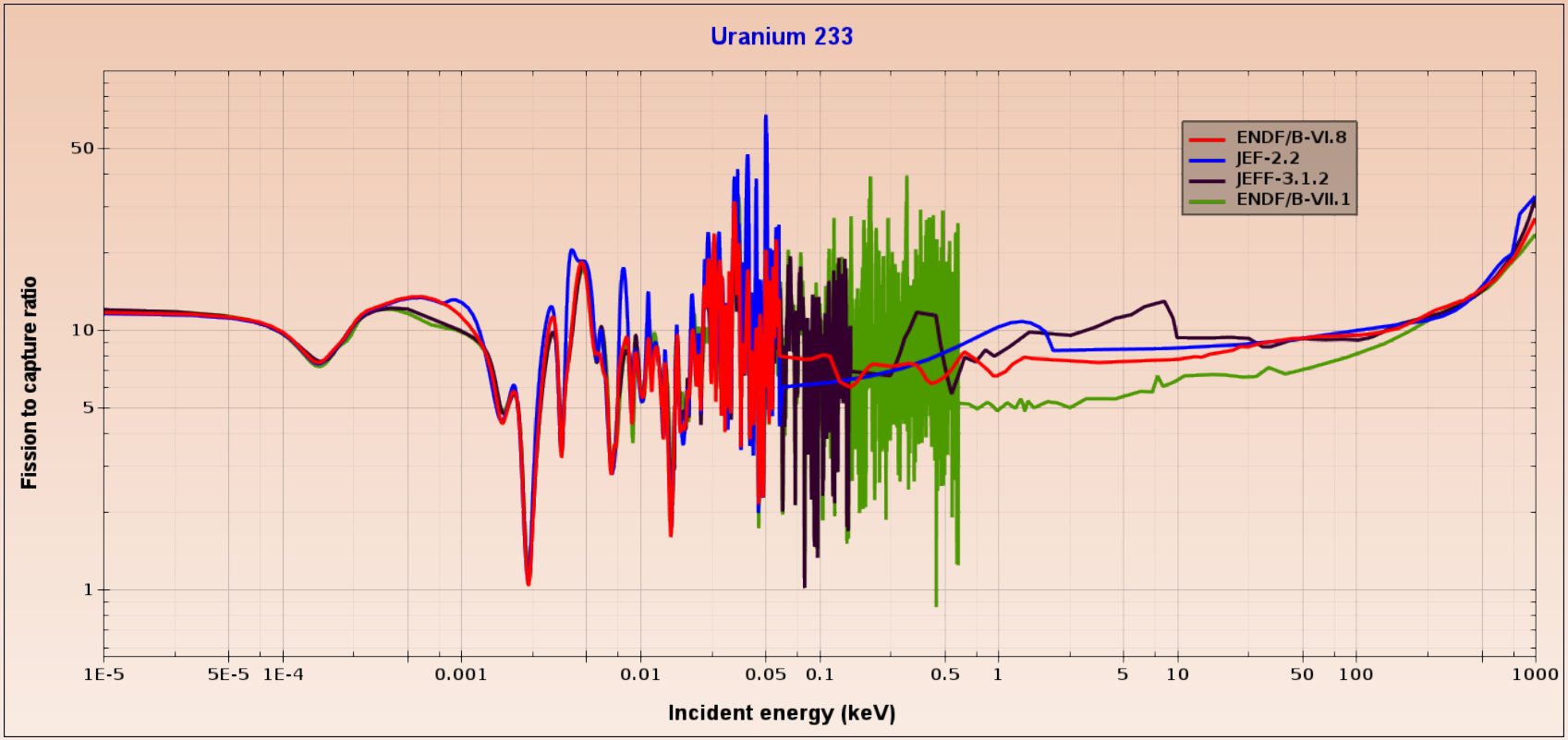

HEX
PUMP
T (K)
1050
1040
1000
960
920
900
Neutron flux (1/m2 s)
8e+19
6e+19
4e+19
2e+19
0

JEFF vs ENDF: equilibrium CR

From JEFF-3.1 to ENDF/B-VII, break-even reprocessing rate prediction doubles.

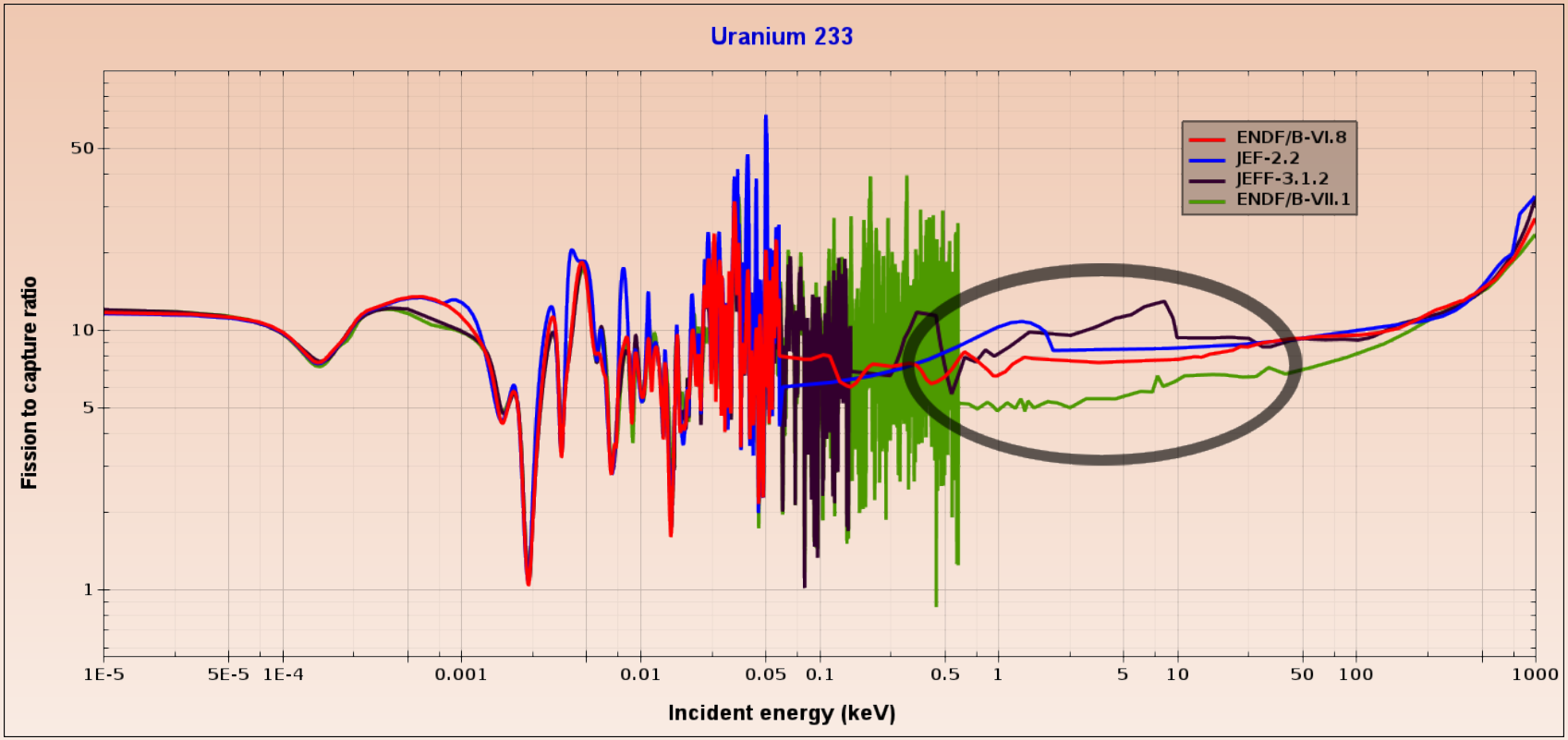


^{233}U Fission to capture ratio



Good agreement between the libraries almost everywhere...

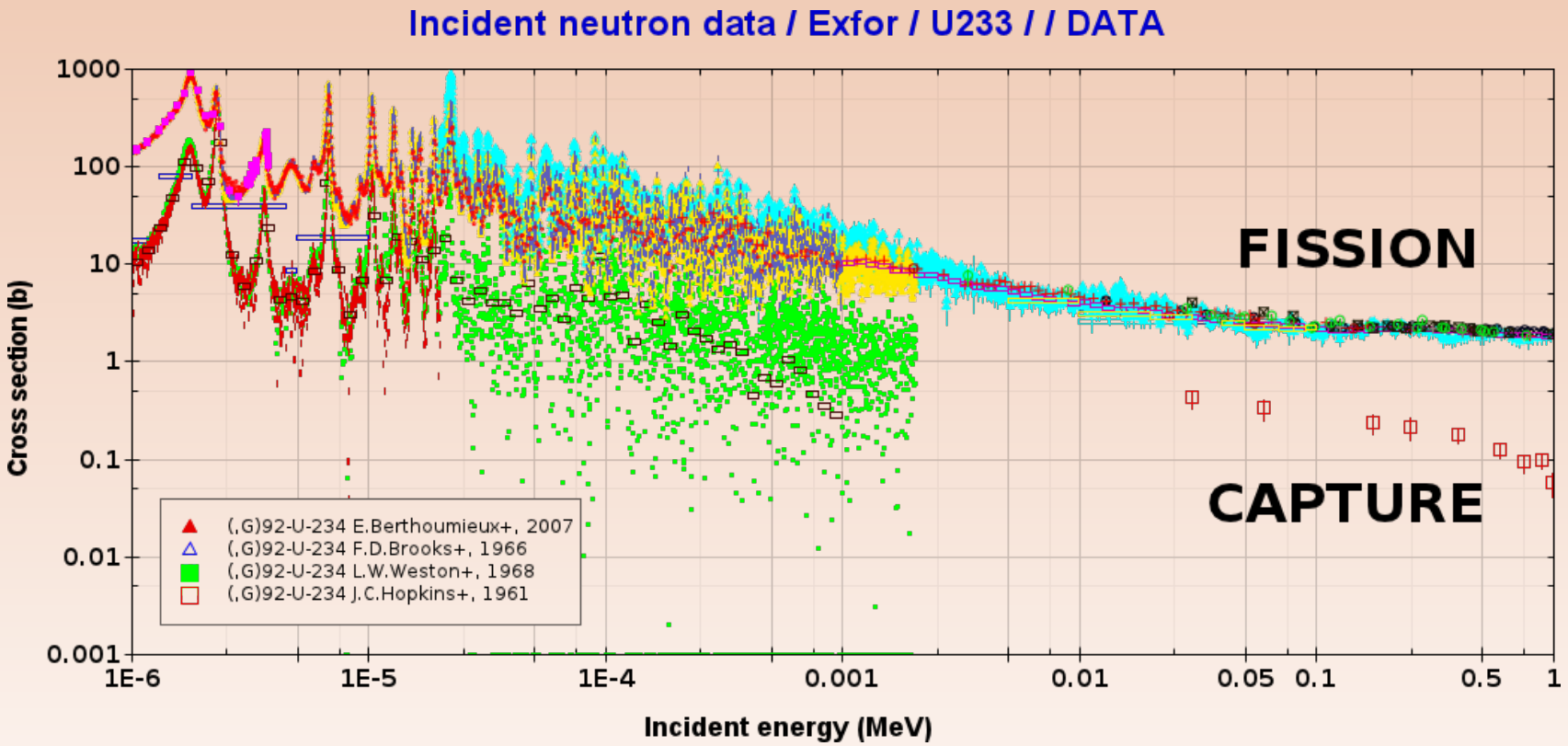
^{233}U Fission to capture ratio



...NOT in the MSFR energy spectrum region.

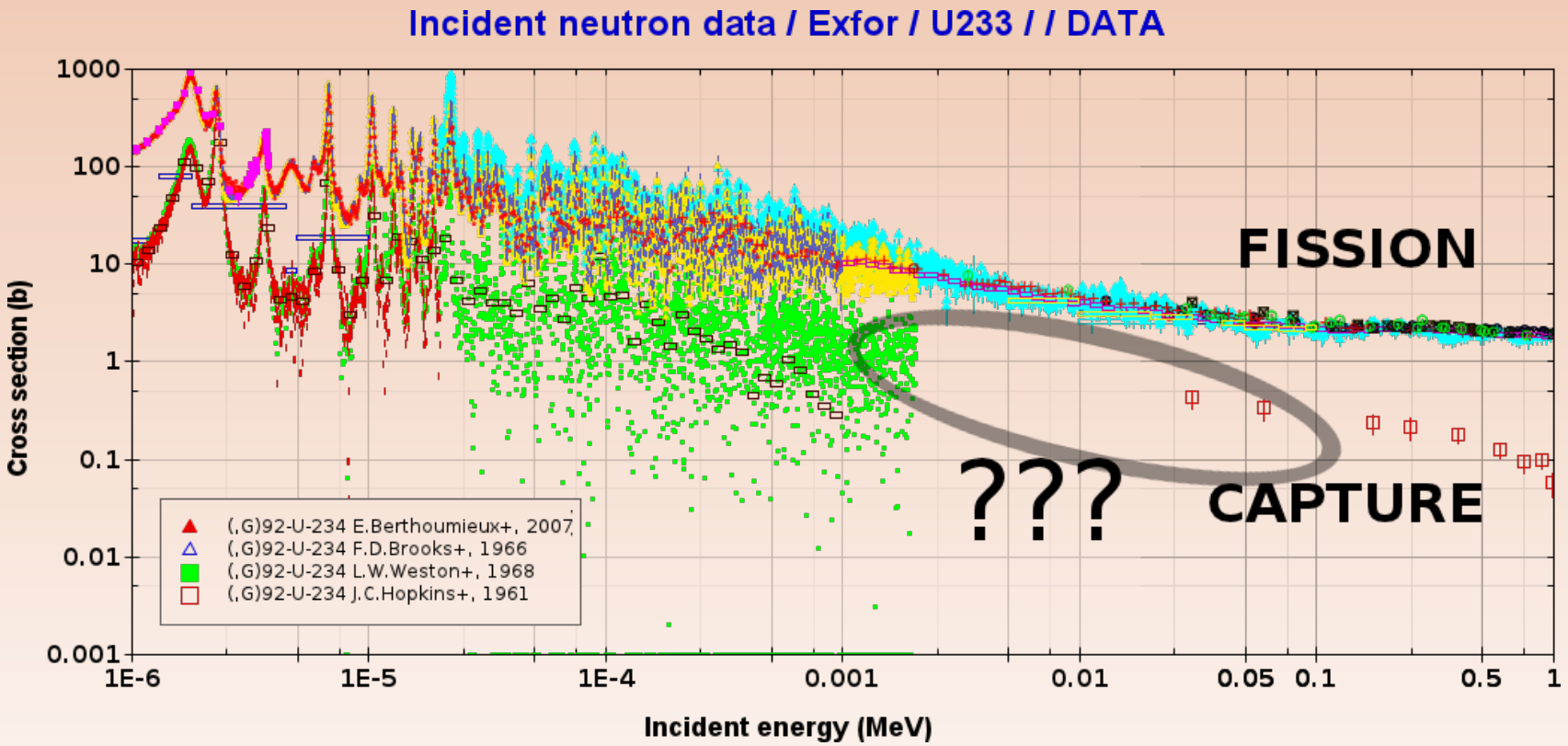
^{233}U Fission to capture ratio

Simple research on the EXFOR database...



^{233}U Fission to capture ratio

Simple research on the EXFOR database... **something missing?**



THANK YOU FOR THE ATTENTION

Vue sur l'agglomération Grenobloise depuis le sommet du Moucherotte (Bertrand93)

QUESTIONS? SUGGESTIONS? NEW IDEAS?