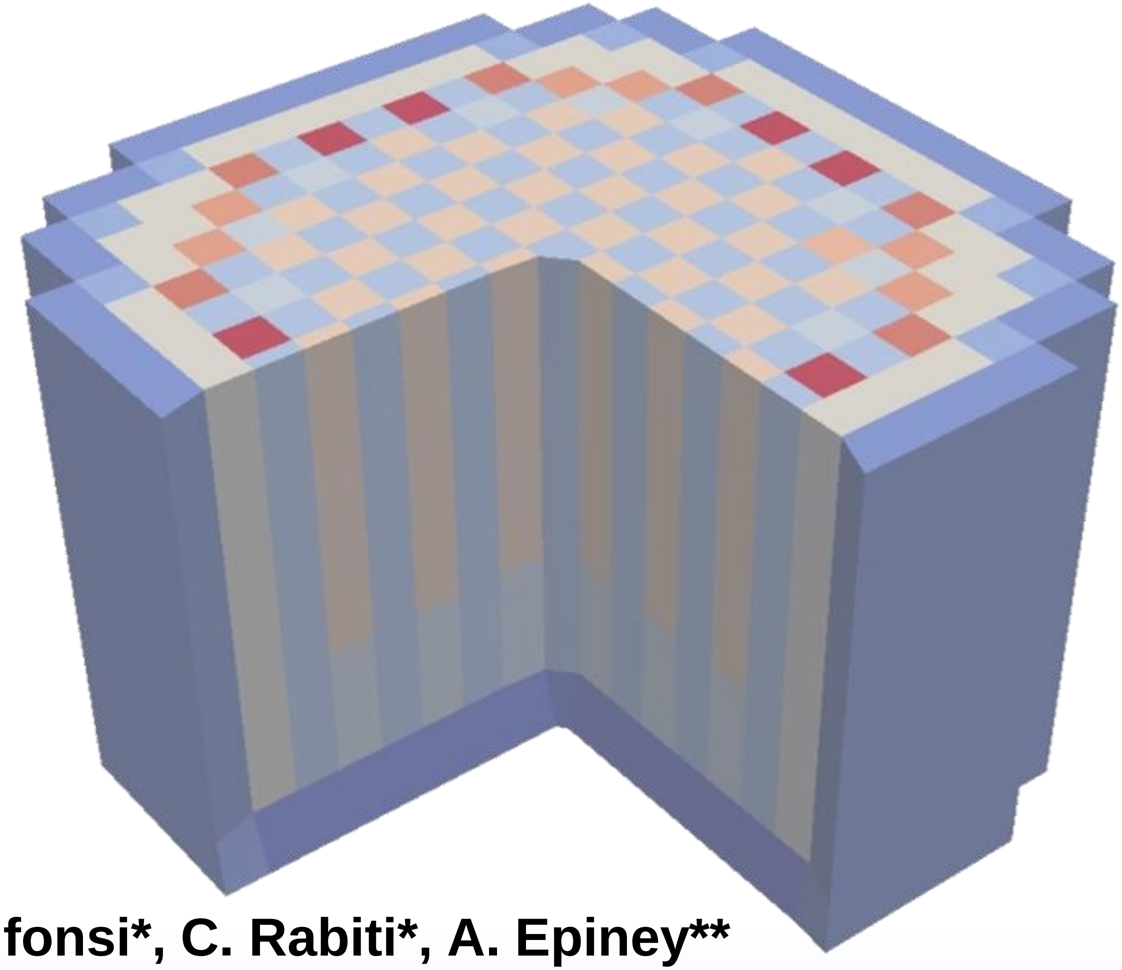
Capabilities of PHISICS/RELAP5-3D



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International RELAP5-3D User group meeting, Idaho Falls, Sept. 10-11, 2014

Overview

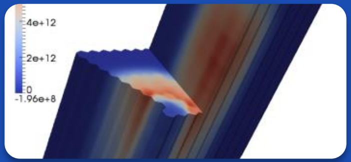
- PHISICS-RELAP5-3D overview
  - Solvers
  - Cross Sections

- What can PHISICS/RELAP5-3D suite do?
  - Steady
  - Time dependent
  - Fuel Cycle
  - and more

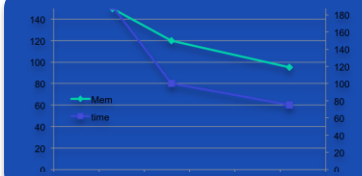
- Conclusions

Software purpose

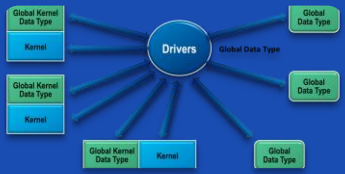
Parallel and **H**ighly **I**nnovative **S**imulation for the **I**NL **C**ode **S**ystem (PHISICS) principal purposes are:



Provide state of the art simulation capability to reactor designers, especially for advanced reactors such as Generation IV systems



Provide an optimal trade off between needed computational resources and accuracy



Simplify the independent development of modules by different teams and future maintenance

Modules

INSTANT

Intelligent Nodal and Semi-structured Treatment for Advanced Neutron Transport

MIXER

MRTAU

Multi-Reactor Transmutation Analysis Utility

CRITICALITY

TIME INTEGRATOR

RELAP5-3D coupling

Shuffling module

INSTANT

- **INSTANT is the transport/diffusion nodal solver**
- **Solution is based on the second order formulation of the transport equation projected on the angular spherical harmonics**

Capability Summary	
Energy	Unlimited
Spatial Order	33
Angular Order	33 (it is also the order of the angular scattering supported)
MESHES	Cartesian 2/3D, Hex 2/3D, Triangular, Wedges
Adjoint	Fundamental, Source (no generalized source)

MRTAU

- **MRTAU module is a Bateman solver**

Isotopic Density Vector

$$\dot{\bar{N}} = \bar{\bar{\Lambda}}\bar{N}$$

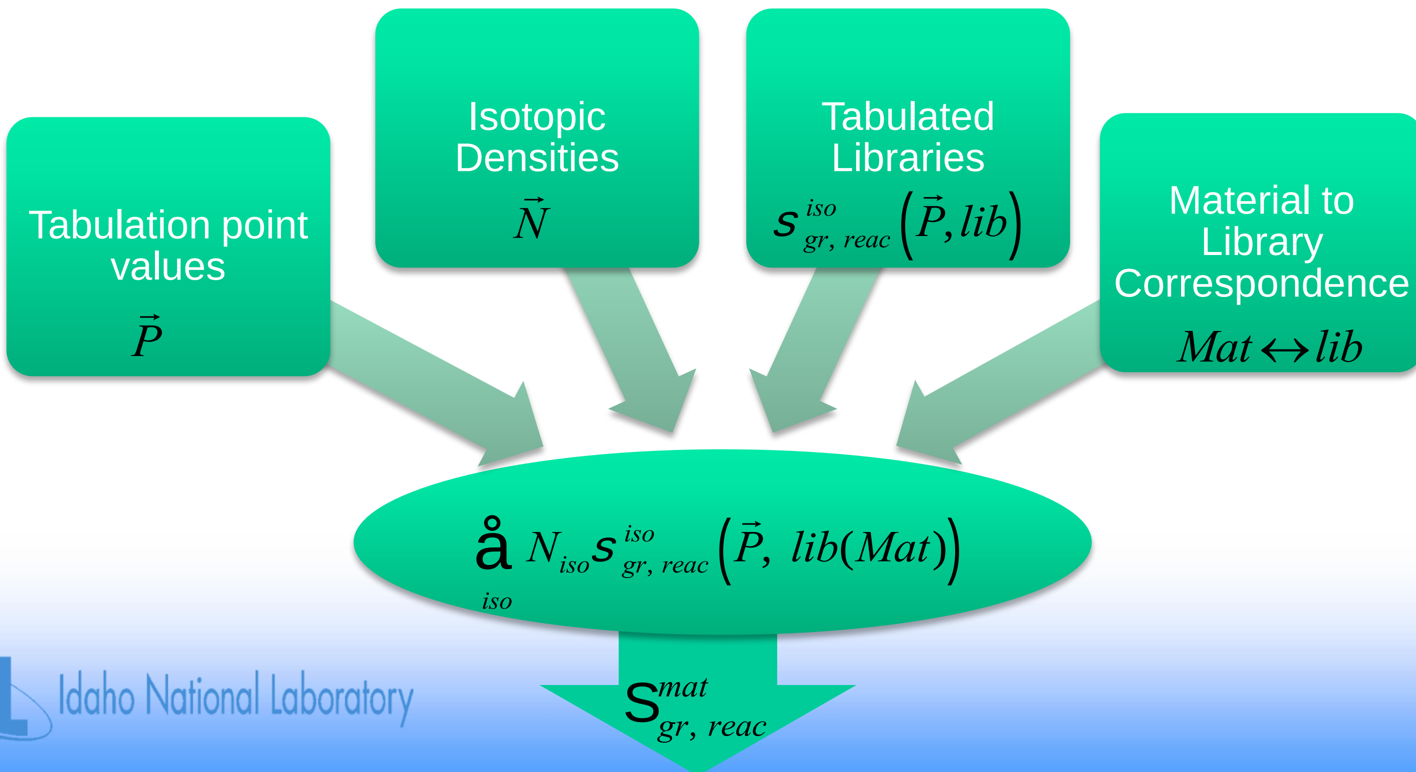
$$\bar{N} = \bar{N}_0 e^{-\bar{\bar{\Lambda}} t}$$

Micro Reaction Rate, Capture, Natural Decay

- **Two algorithms are available for the exponential evaluation:**
  - **C**hebyshev **R**ational **A**pproximation **M**ethod **(CRAM)**
  - **Taylor Series**
- **CRAM has been implemented since its stability allows to treat short and long lived nuclides employing the same methodology**
- **Verified via convergence studies and compared to ORIGEN**

Mixer

- Cross section manipulation is agnostic with respect to the usage of micro, macro, or mixed
- N dimensional linear interpolation among parameters
- Cross sections are tabulated with respect to an arbitrary number of parameters: fuel temperature, coolant temperature, coolant density, control rod (CR) position, boron concentration, etc.



Criticality Search

Given

- Target k_{eff}
- Regions
- Isotopes

Seeks the density matching the target

- If Macro-isotope → Material movement
- If Micro-Isotope → Number density

$$\left.\frac{\partial K}{\partial N}\right|_i = \frac{K_i - K_{i-1}}{N_i - N_{i-1}} \longrightarrow N_{i+1} = \frac{K_{target} - K_i}{\left.\frac{\partial K}{\partial N}\right|_i} + N_i$$

$$K_{target} = K_i + \left.\frac{\partial K}{\partial N}\right|_i (N_{i+1} - N_i)$$

If the isotope density is also a tabulation dimension, It is possible to

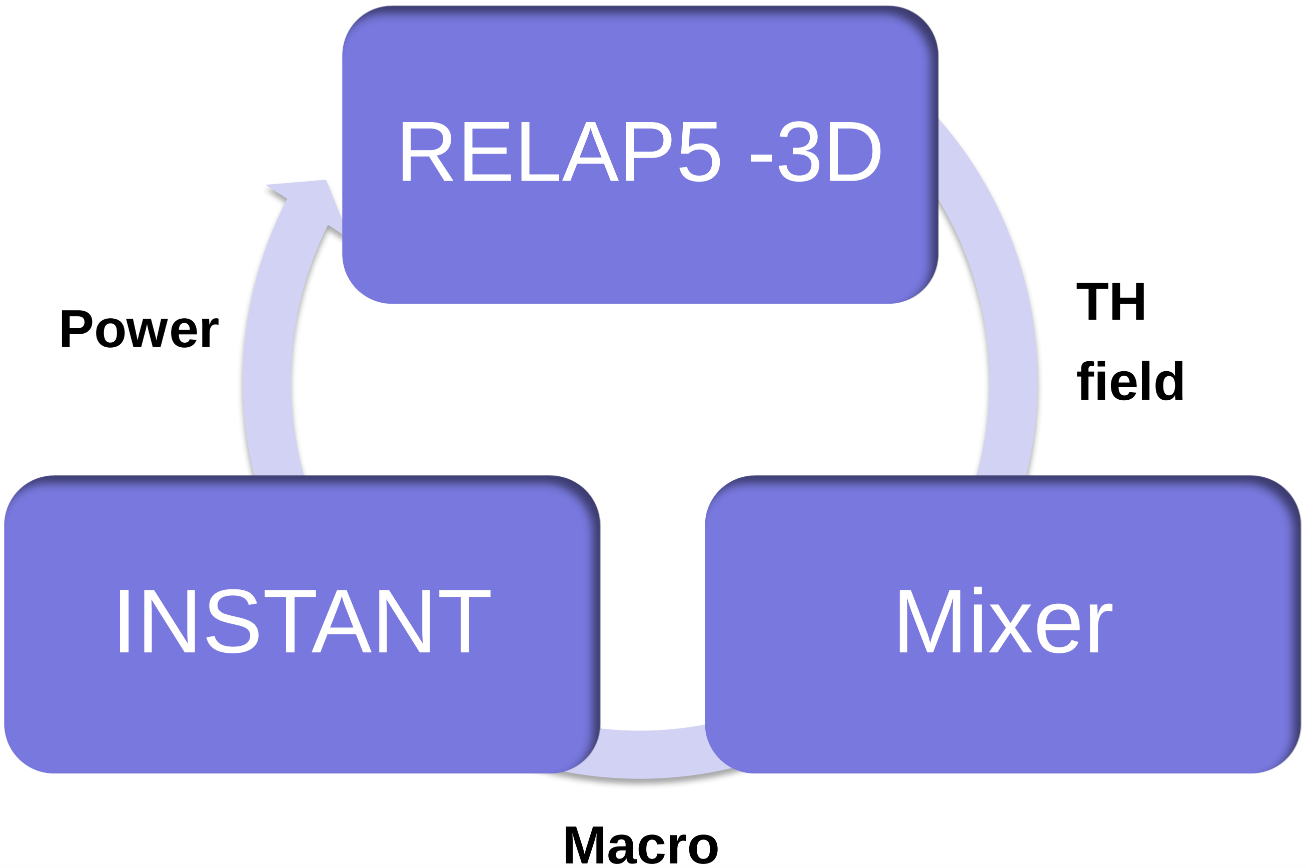
- Compute the new macro by considering only the target isotope (faster mixing)
- Re-compute the mixing for all the isotopes in the material

PHISICS/RELAP5-3D

- **Since 2011 PHISICS has been integrated with RELAP-5 3D while NESTLE is still the standard option**

- **Several calculation schemes are available:**
  - **Steady state search**
  - **Time dependent TH coupled**
  - **Transient with depletion (from Xenon to full depletion)**
  - **Pre-burning and transient**
  - **Depletion with TH feedback (with criticality search)**
  - **Fuel Cycle with TH feedbacks and Shuffling capability**

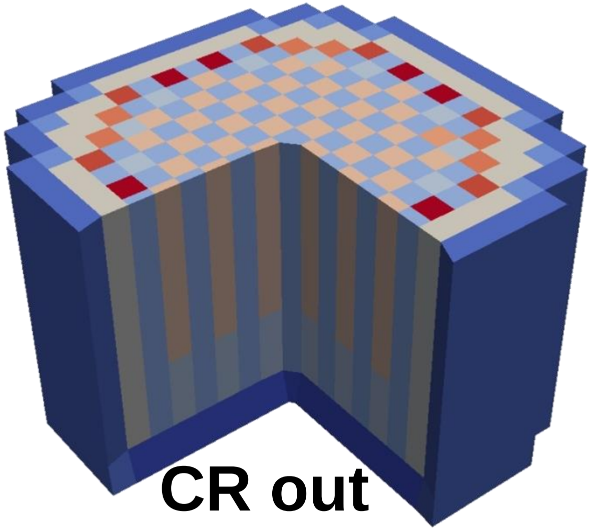
Steady State



Steady State vs. NESTLE

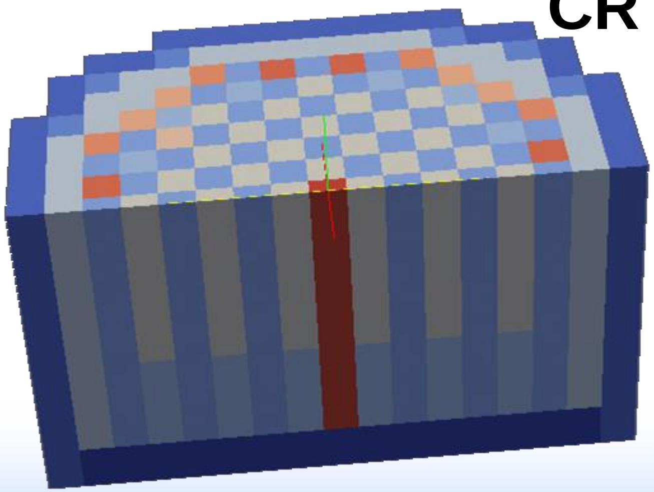
An option to transform the NESTLE input into PHISICS is present

- **11 Materials**
- **36 TH feedback zones**
- **2 Energy groups**
- **Full core model**
- **17x17 radial nodes**
- **13 axial levels**



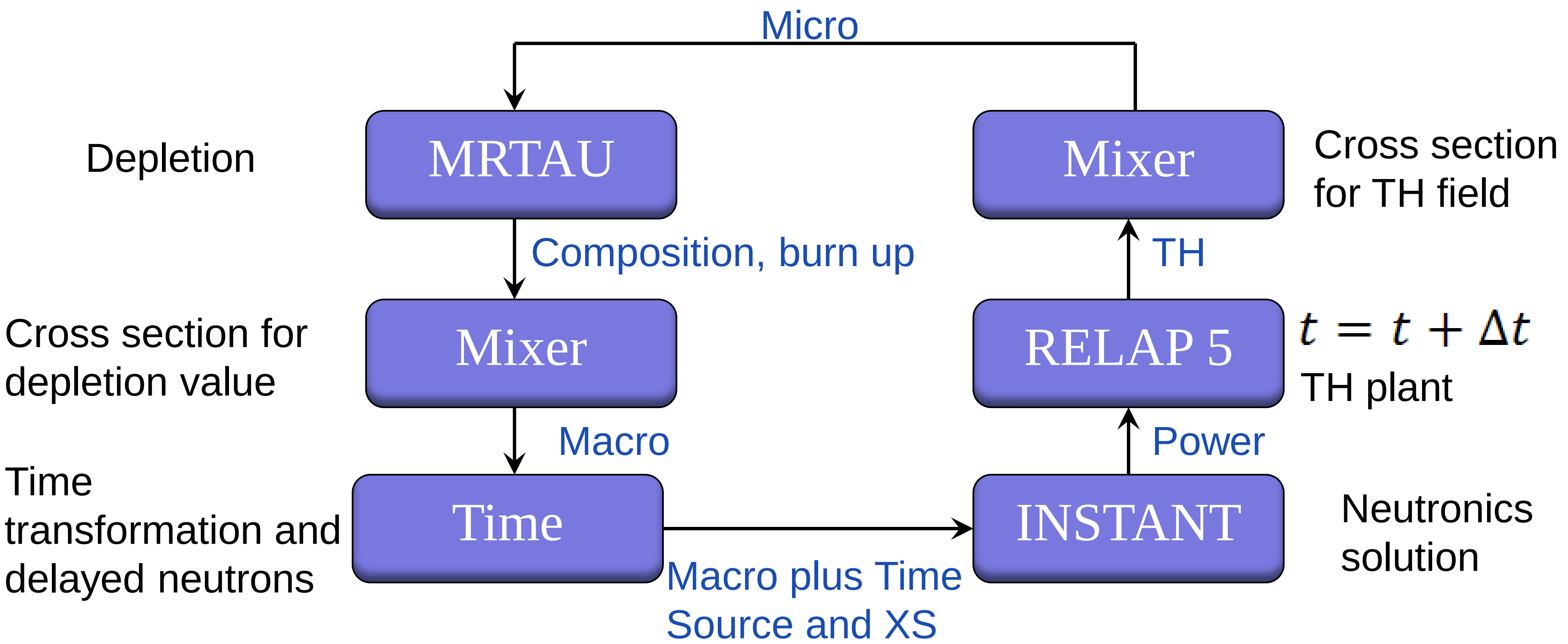
CR out

CR in

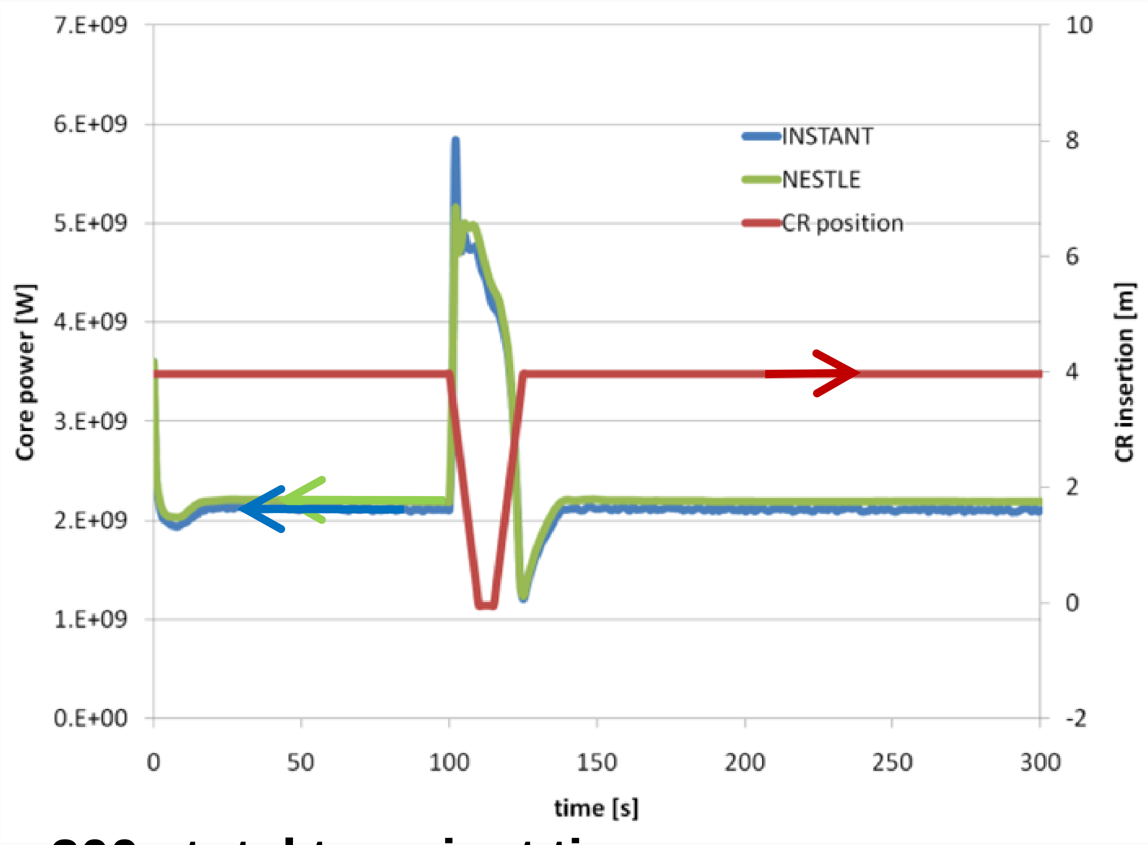


	Keff	
	Initial	Converged
PHISICS	1.01639	1.00348
RELAP	1.01731	1.00483
Delta	0.00092	0.00135

Time Dependent



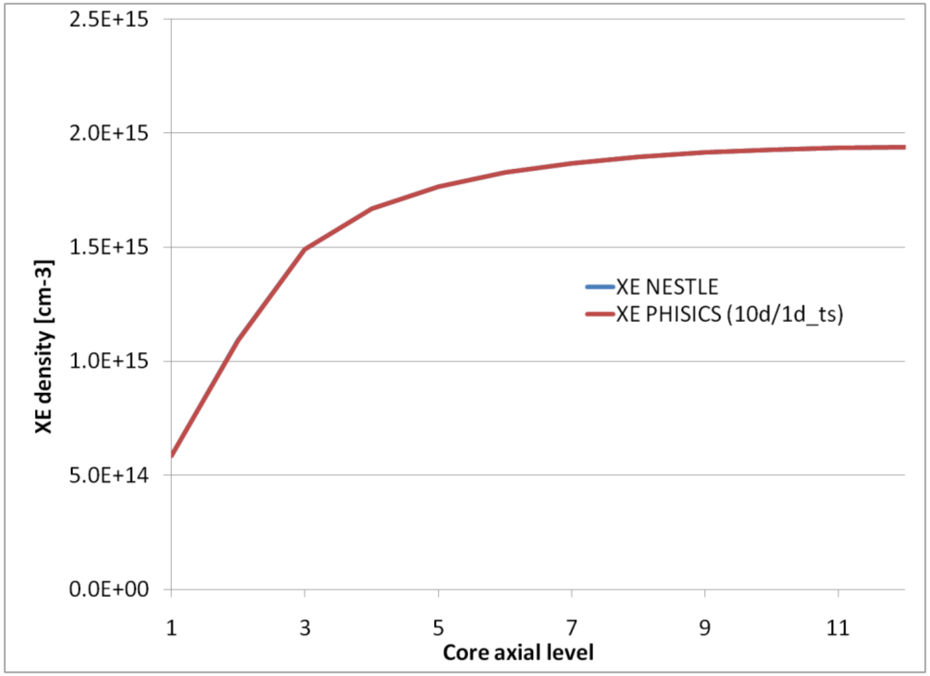
Time Dependent: CR movement

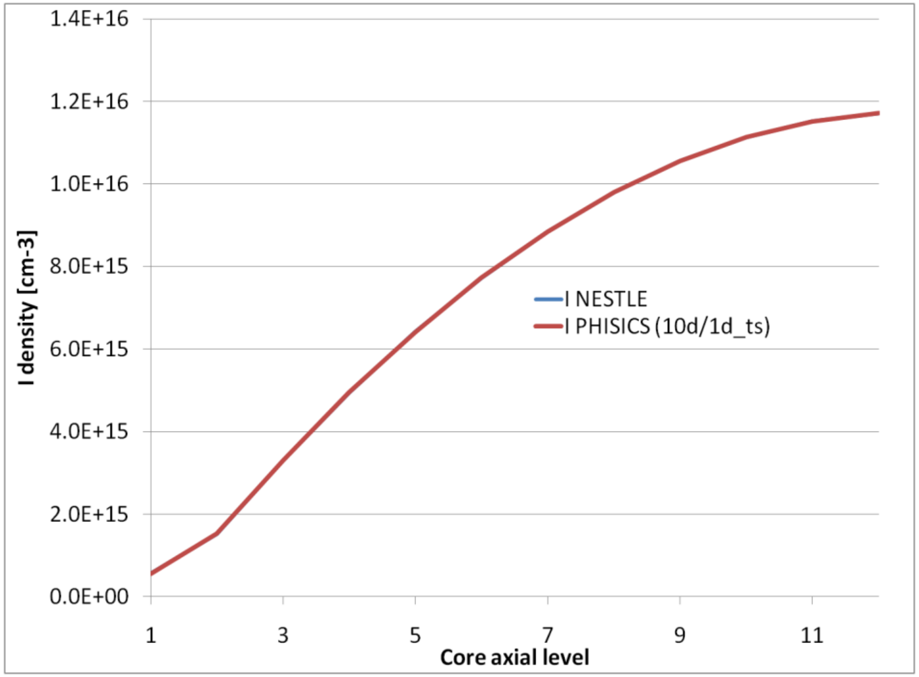


- **Stability satisfied in the initial phase of the simulation**
- **Peak in reasonable agreement with REALP5-3D NESTLE (integral power deposition differences negligible)**
- **After CR reinsertion power is re-stabilized at initial value**

- **300s total transient time**
- **CR movement: withdrawn from 100s to 110s, reinserted from 115s to 125s**

Time Dependent: SCRAM (pre-burning)





- **Same PWR core as previous example**
- **Initial xenon/iodine distribution computed by NESTLE (asymptotic) and PHISCS (10 days pre-burning, 1 day time step) using initial condition TH field.**

Full agreement

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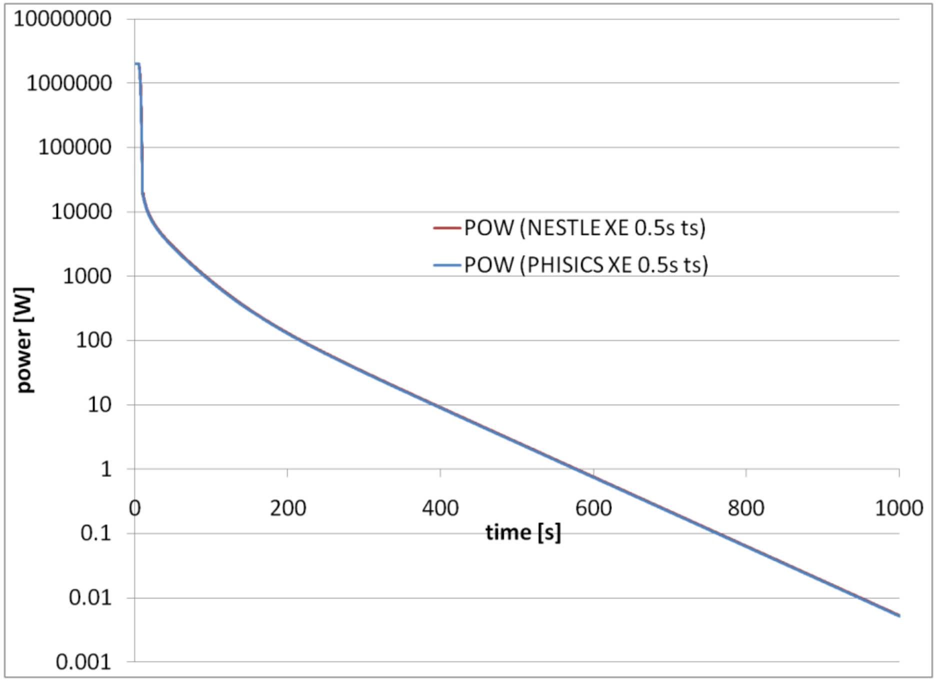
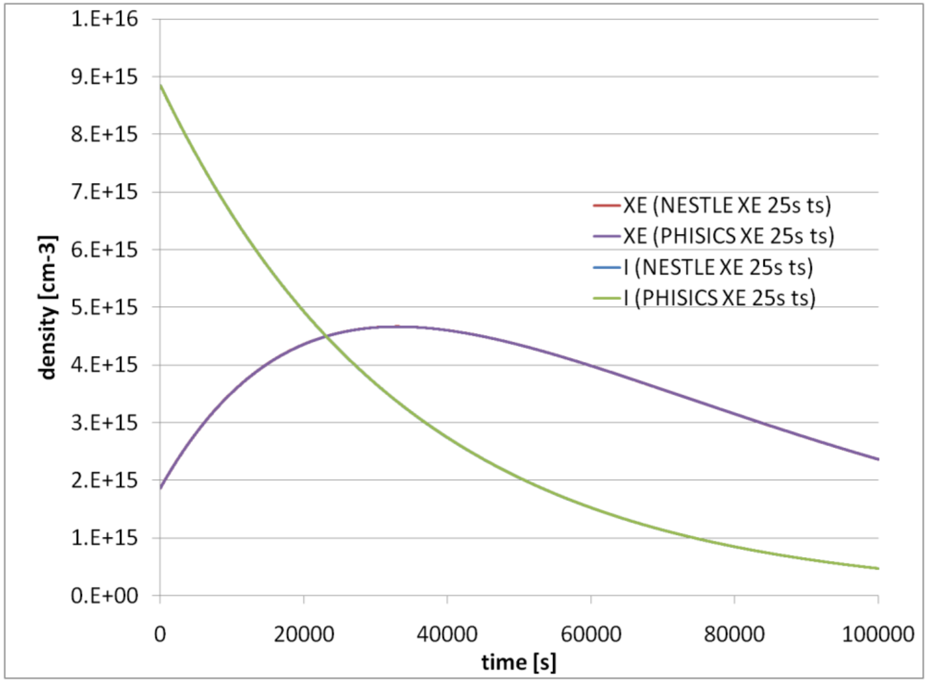
SCRAM with xenon





- **100`000s total transient time**
- **null transient until 5s than SCRAM**
- **SCRAM by control rod insertion**

Full agreement

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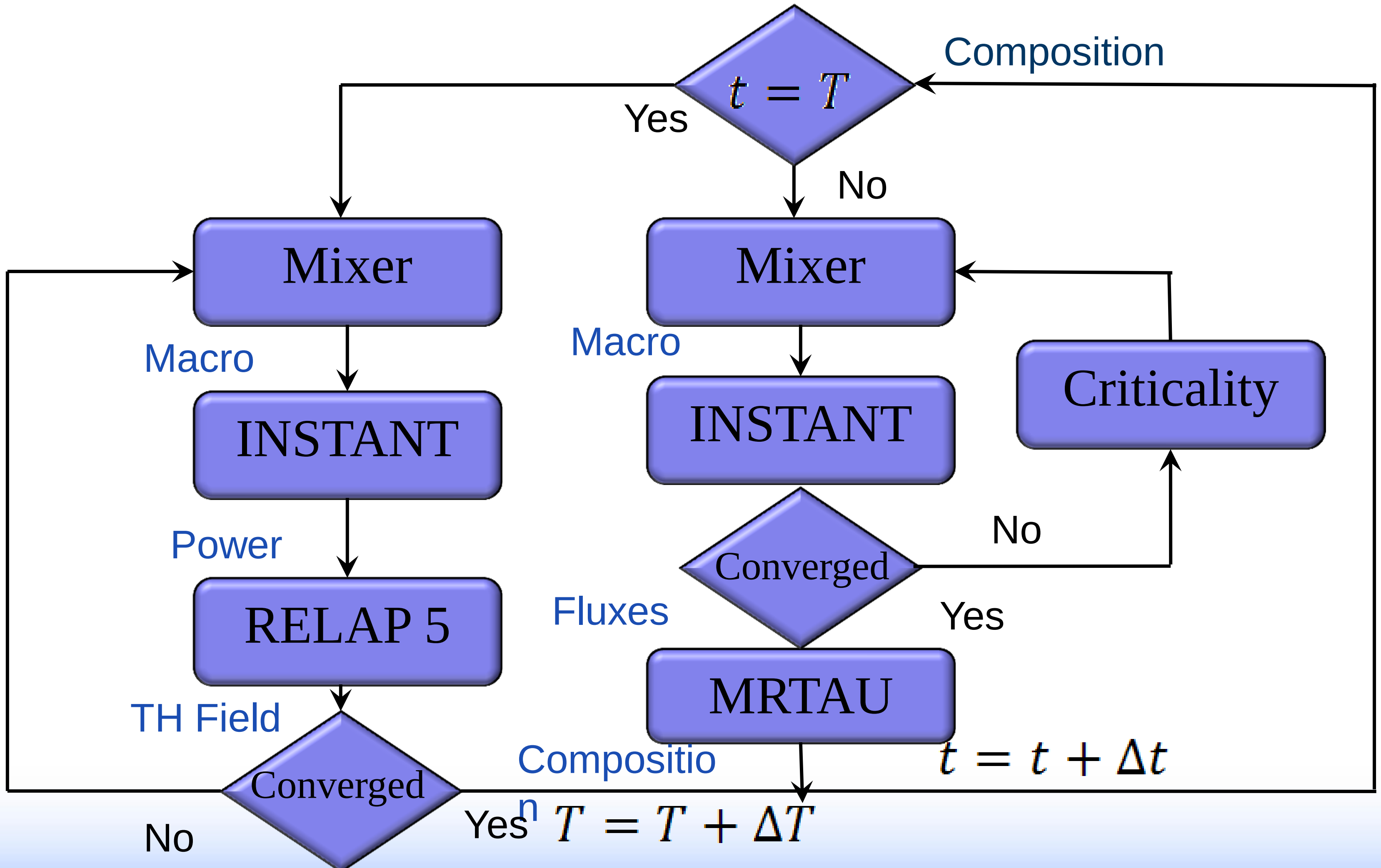
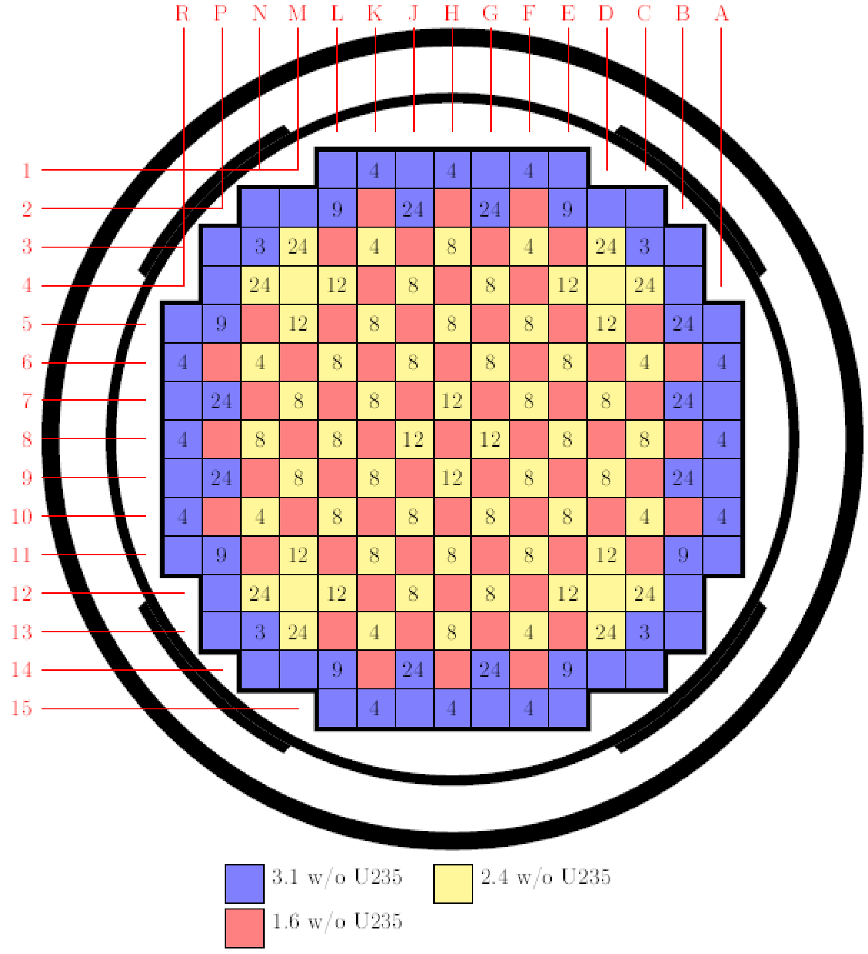
Depletion Evolution Scheme:



Depletion Time Evolution example

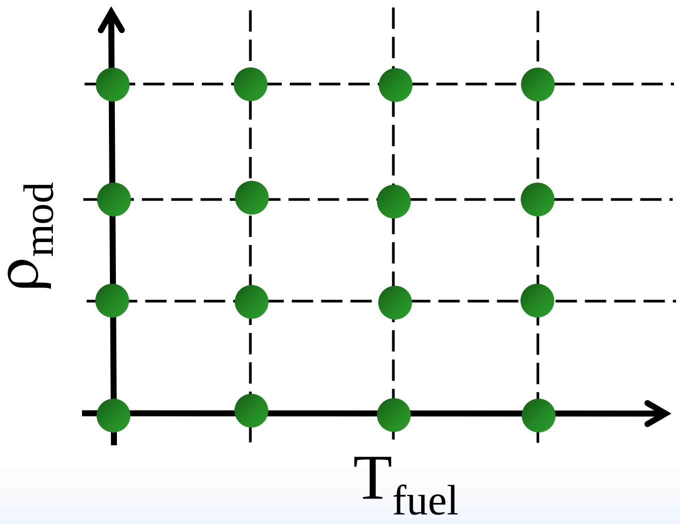
- Full core **coupled thermal-hydraulics/depletion** benchmark
- Real **plant data** available
- 15x15 assemblies
- 17 different assembly types
  - 3 different enrichments
  - burnable absorber
  - control rods
- Benchmark goals follow core data for:
  - First two cycles in normal operation
  - Assembly shuffling between cycles



Depletion Time Evolution example

Cross section library generated with HELIOS

- **~200 burned isotopes**
- **64 different materials**
  - Assembly types, reflector, spacers, etc..
- **4 tabulation dimensions**
  - Burn-up (3 points)
  - Fuel temperature (3 points)
  - Moderator density (4 points)
  - Boron concentration (3 pints)
- **All cross points considered**
  - 108 tabulation points



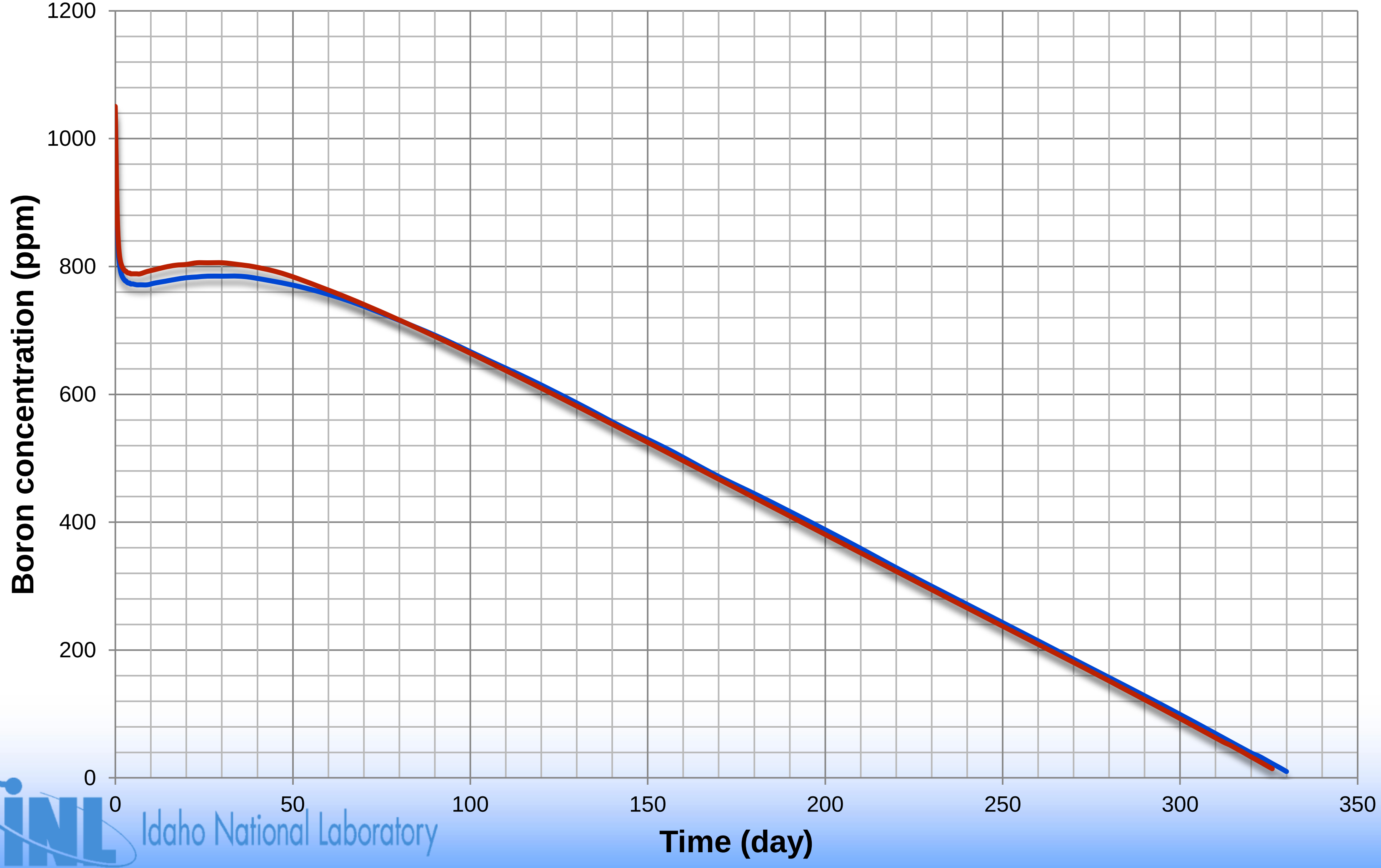
Depletion Time Evolution example

HZP results

Nominal conditions (isothermal)	
Calculated Critical boron (ppm)	1172.186
Boron Worth (pcm/ppm)	-11.2726
Expected Boron Worth(pcm/ppm)	-11.24
Boron Worth relative error (%)	0.29

Depletion Time Evolution example

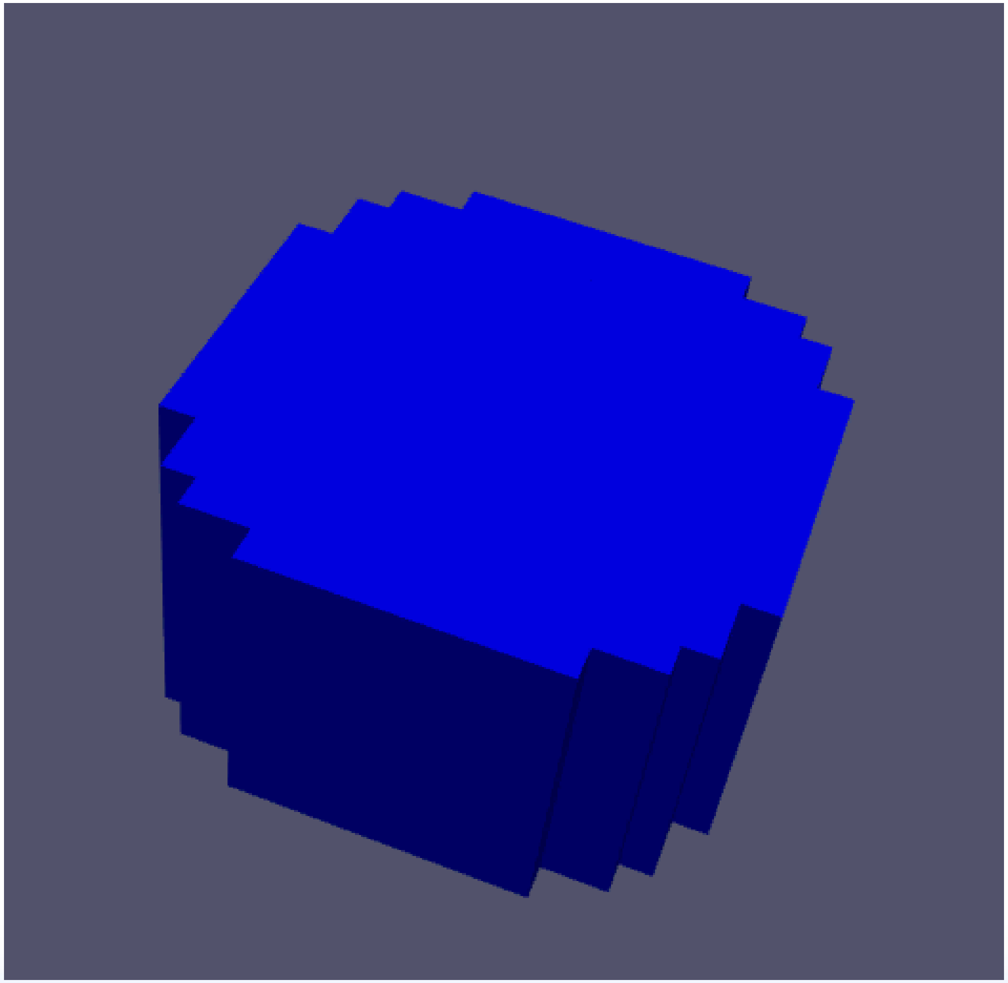
HFP results



HFP results – Fuel evolution

PU239

XE135



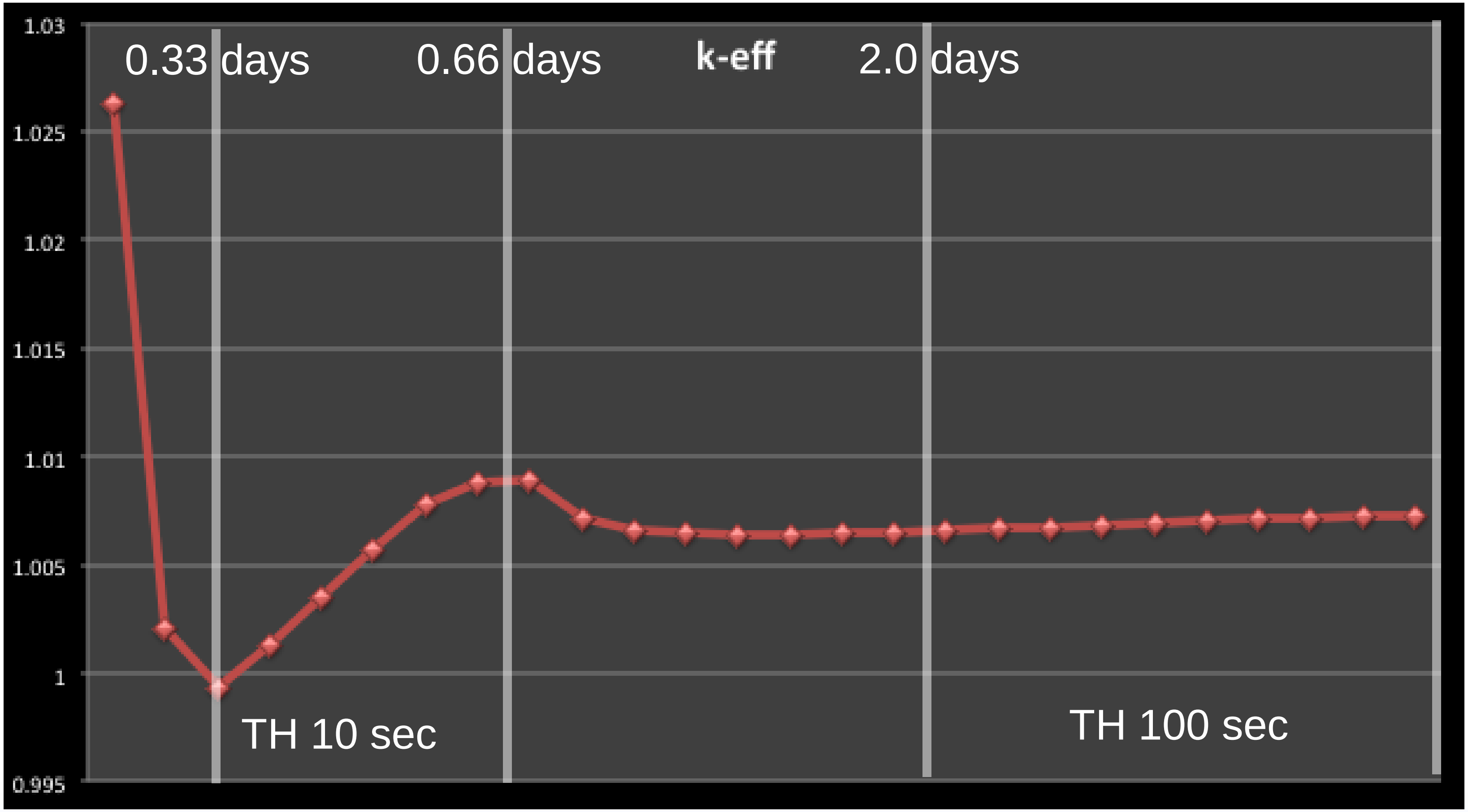
PU240

PU241

Load Following – PWR

- Load following demo case (PWR)
- Neutronics:
    - 15x15 assemblies
    - ~ 9000 kinetic zones
    - 9 different assembly types
        - 3 different enrichments:
        - burnable absorber
        - control rods
- TH:
    - Thermal-Hydraulic model for reactor core only
    - 1 Core channel/assembly
- Control Logic:
    - CR movement to follow a load pattern

Load Following – Steady + Dpl



Improvements and Bug Fix

- **IMPROVEMENTS:**
  - PHISICS Criticality search for all RELAP5/PHISICS schemes
  - Memory parallelization of Cross section Libraries. Reduced memory requirements
  - Broadcasting of all data information (Parallel) => Improved I/O performance in multi-processor calculations
  - General Cleaning of PHISICS/RELAP5-3D interface
  - Improved error handling for the coupled suite
- **FIXES:**
  - Fully testing of all calculation schemes, fixing associated bugs
  - Memory Leaks in PHISICS/RELAP5-3D interface

Conclusions

- PHISICS + RELAP5 3D can be considered an all plant system code
- The integration of the two codes makes the suite able to be used for most the reactor simulation needs: from Fuel Cycle to Safety Analysis
- The missing component is the lattice code
- The new capabilities challenge the availability of data to fully validate the codes

PHISICS and RELAP5-3D are moving toward becoming a full nuclear reactor design and analysis tool.

Info

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- **Main developers: A. Alfonsi, J. Cogliati, A. Epiney, Y. Wang**
- **PHISICS is available (executable) free of charge for universities for non commercial use**
- **PHISICS is available (source) free of charge for universities under a cooperation agreement for non commercial use**
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