Development progress and methodology of FANCSEE fuel cycle code

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Contents

Introduction

- FANCSEE is a **standalone** advanced fuel cycle simulation code originally developed at KTH, Sweden

- Written in C and C++ for Linux

Idea behind FANCSEE

- Fuel cycle simulation code
- GUI controlled
- User-friendly
- For simple and complex scenarios
- Short runtime
- For students, researchers, policymakers

Main features

Reactor libraries:

- PWR, BWR, LFR, HTGR, SFR
- Calculated with Serpent 2, processed in MATLAB
- Burnup matrix exponential solved with Chebyshev Rational Approximation Method (CRAM)

Output:

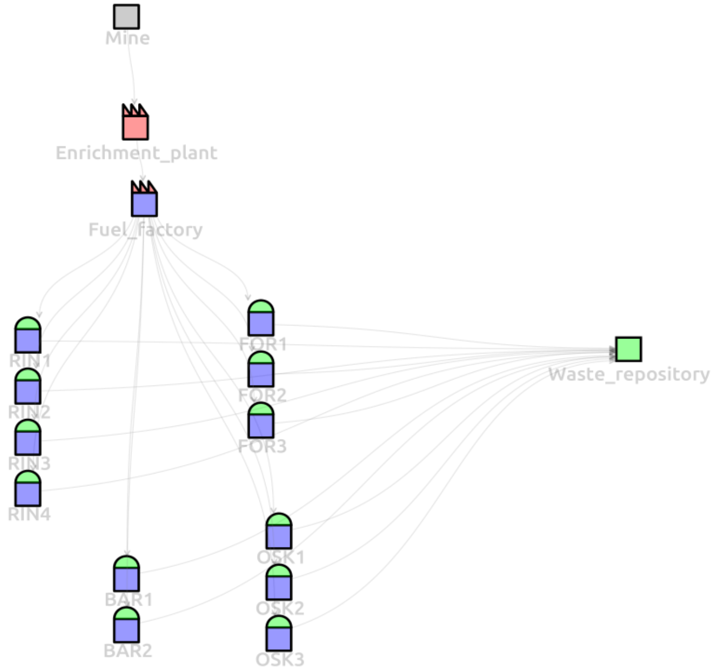
- Tracking of up to 1307 different nuclides
- Plotting of results for each facility and nuclide
  - Nuclide mass
  - Inhaled or ingested toxicity
  - Radioactivity
- Results can be plotted directly or exported to MATLAB

Scenarios

Scenarios are simulated through setting up **facilities** with discrete **functions** and **parameters**.

The possible facilities are:

- Uranium Mines
- Enrichment Plants
- Reprocessing Plants
- Fuel Factories
- Reactors
- Waste Repositories



Facility parameters

- Mine, Enrichment Plant, Fuel Factory and Reprocessing Plant can have a processing capacity limit (in kg/day)
- Reprocessing Plant parameters
  - Reprocessing order
    - First In First Out (FIFO) or Last In First Out (LIFO)
  - Reprocessing limit – number of times a fuel batch can be reprocessed
  - Minimum cooling time before reprocessing [years]
  - Maximum viable age for reprocessing [years]

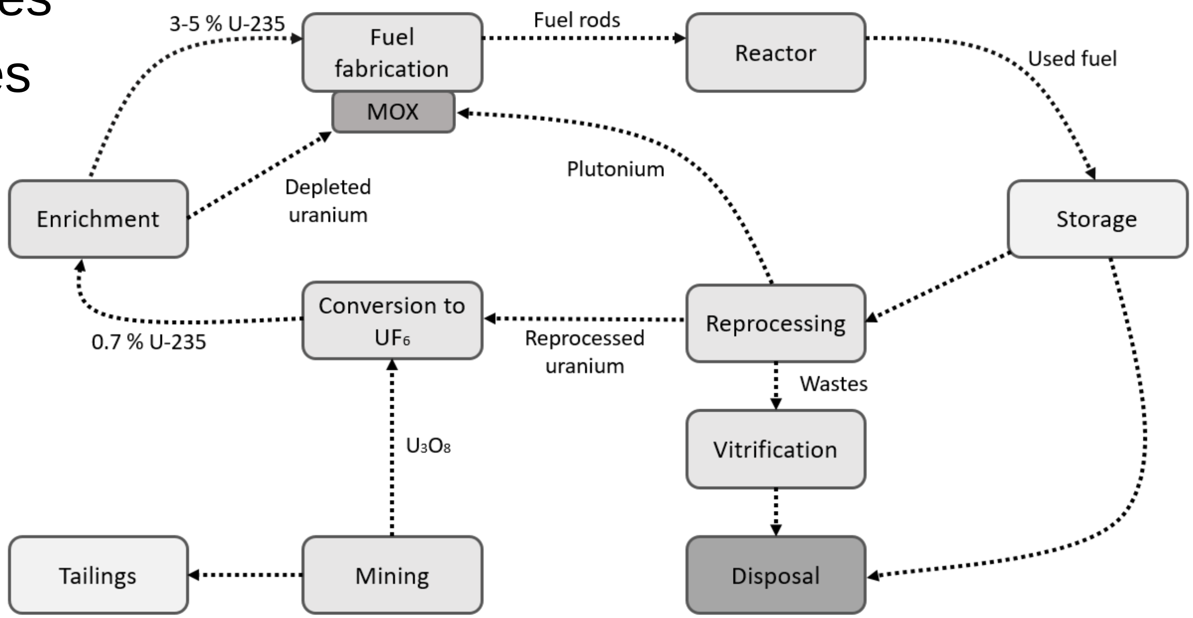
Reactor parameters

- Power
- Fuel mass (heavy metals mass only)
- Fuel type
- Reactor type
- Number of fuel batches
- Fuel cycle time
- Refueling time
- (Pu) Enrichment

Scenario types

FANCSEE can calculate

- Open cycles
- Partially closed cycles
- Fully closed cycles
- Decay of isotopes



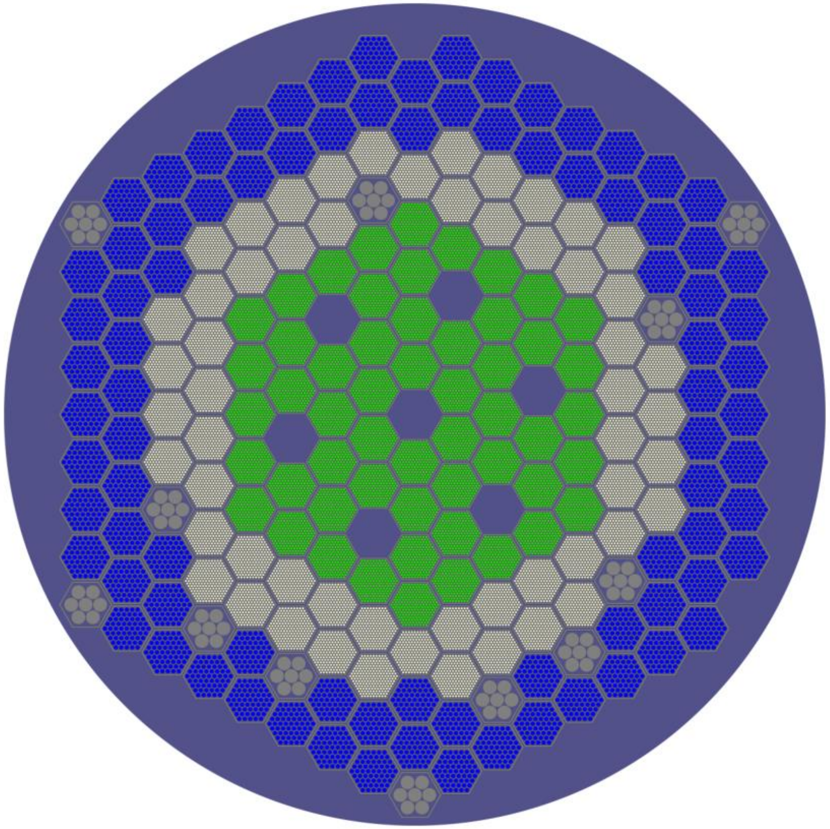
French fuel cycle

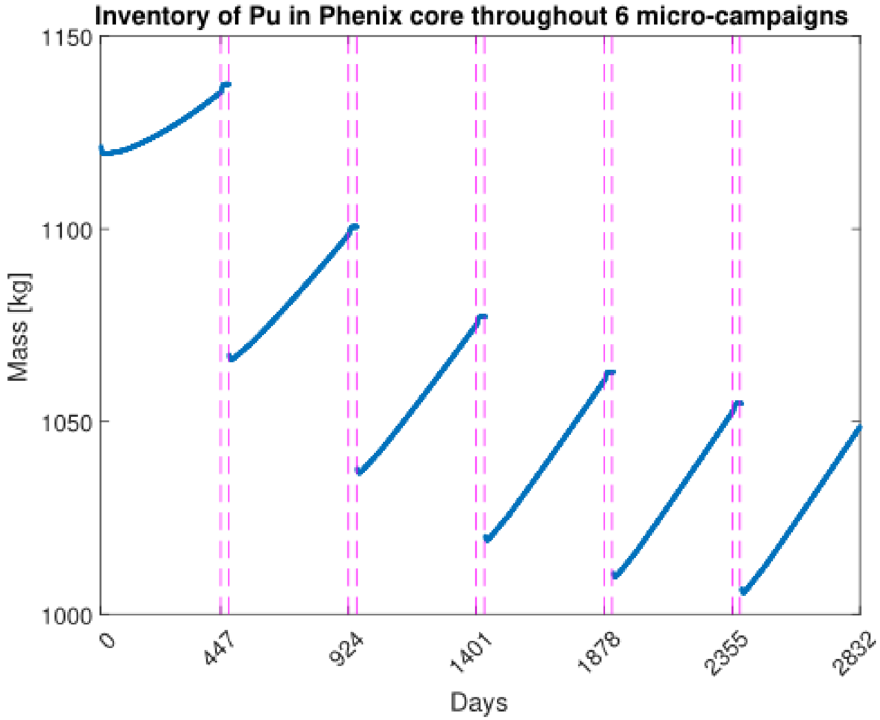
Results section

- Core designs were implemented by students of KTH
  - Y. Hrabar (KTH)
  - C. Ding (KTH, Tsinghua University)
  - J. Zou (KTH, Tsinghua University)
  - A. Bidakowski (KTH, Uppsala University)
- Results from Master's thesis of Y. Hrabar

  Development, benchmarking and validation of the Advanced Nuclear Fuel Cycle Simulator – FANCSEE and advanced use of Monte Carlo methods in nuclear reactor calculations, CentraleSupelec - University Paris-Saclay 2019

Phénix results

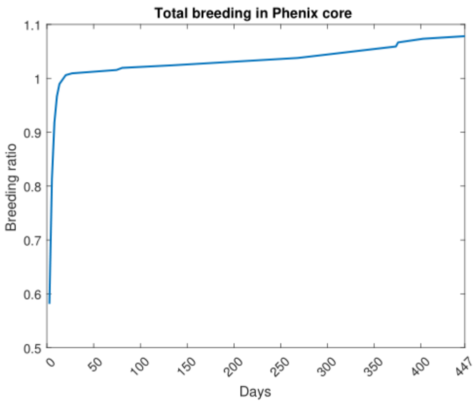


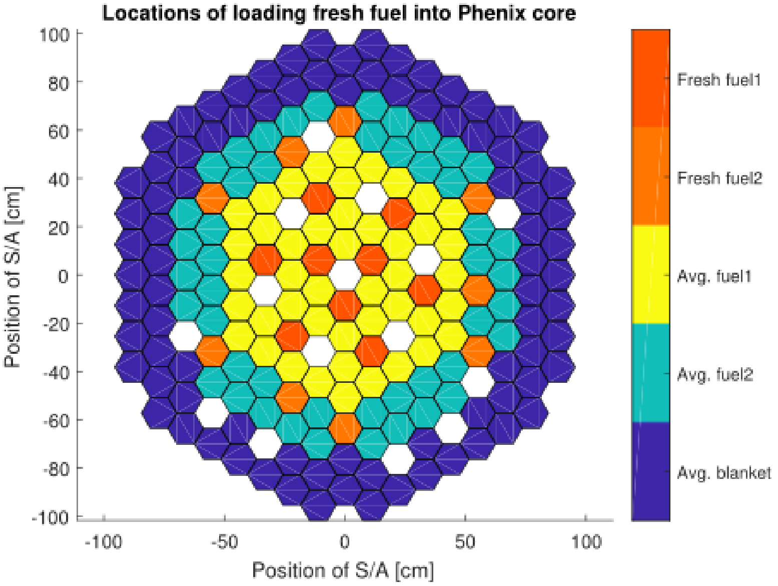


Phénix results

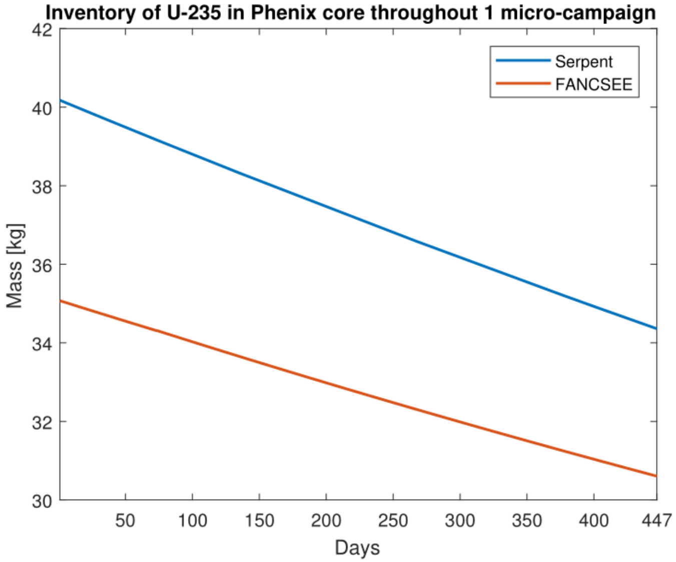
- Core with two regions of different enrichment of plutonium in the form of a $UO_2 - PuO_2$ mixed oxide
- Detailed core and fuel composition implementations
- 5 types of fuel libraries

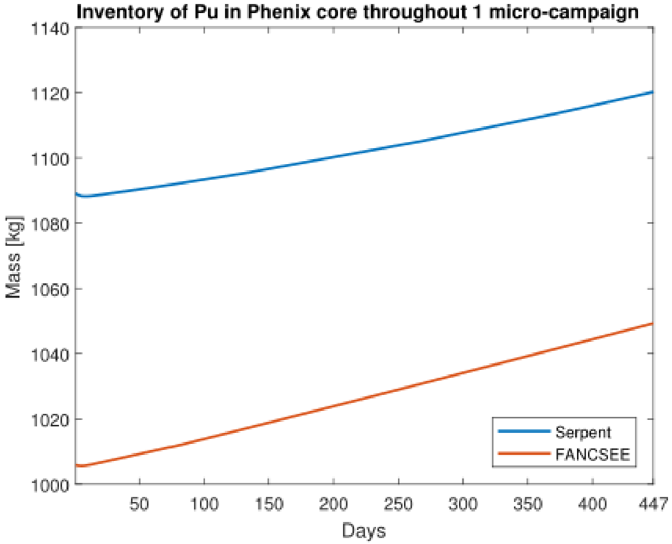
Parameter	563 MW 1974-1993	350 MW 1993-2009
Thermal power [MW]	563	345
Gross electrical power [MW]	250	142
Net electrical power [MW]	233	129
Neutron flux at core centerline (n/cm^2s)	$7 \cdot 10^{15}$	$4.5 \cdot 10^{15}$
Primary sodium core outlet temp. [°C]	560	530
Primary core inlet temp. [°C]	400	385
Secondary sodium SG inlet temp. [°C]	550	525
Superheated steam temp. [°C]	512	490
Turbine HP cylinder steam pressure [bar]	163	140





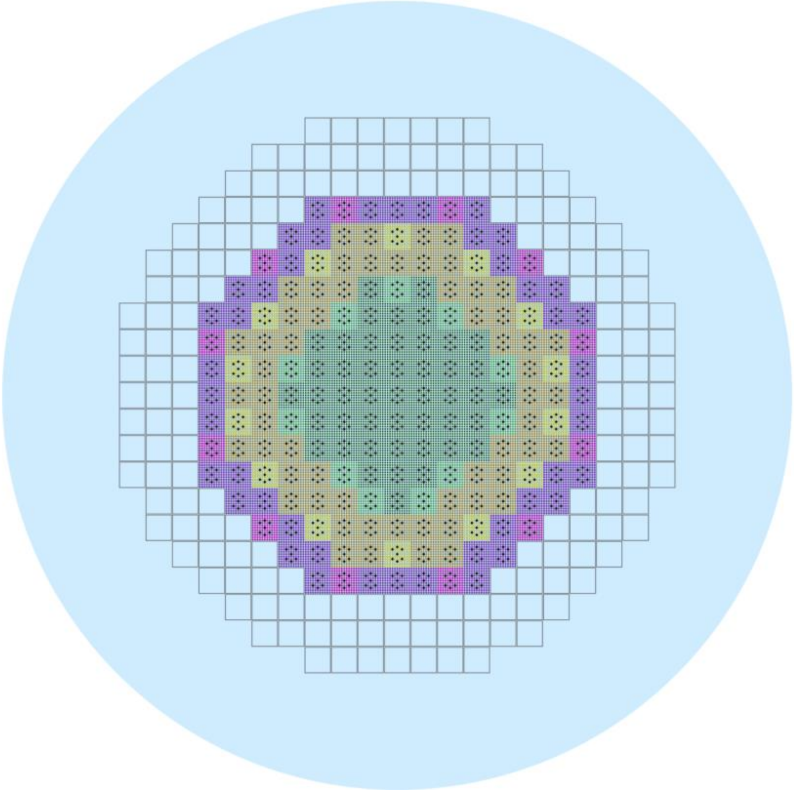
Phénix results comparison

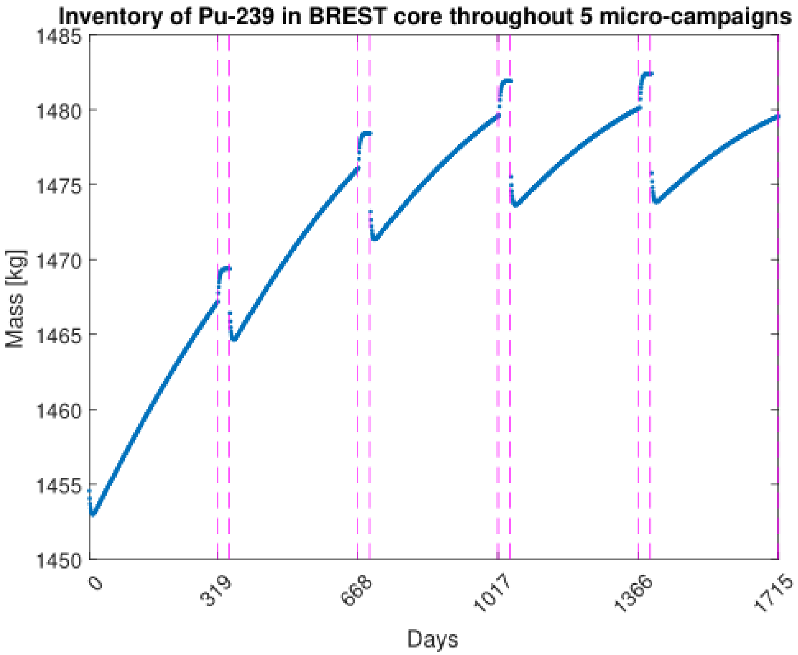




- Initial differences related to lower flexibility of fuel inputs in FANCSEE than Serpent
  - Depleted U enrichment is fixed in FANCSEE
  - Pu vector depends on the rest of the cycle (LWR cycle)
  - No custom first batch definition
- Changes in inventory between codes are in agreement

BREST results

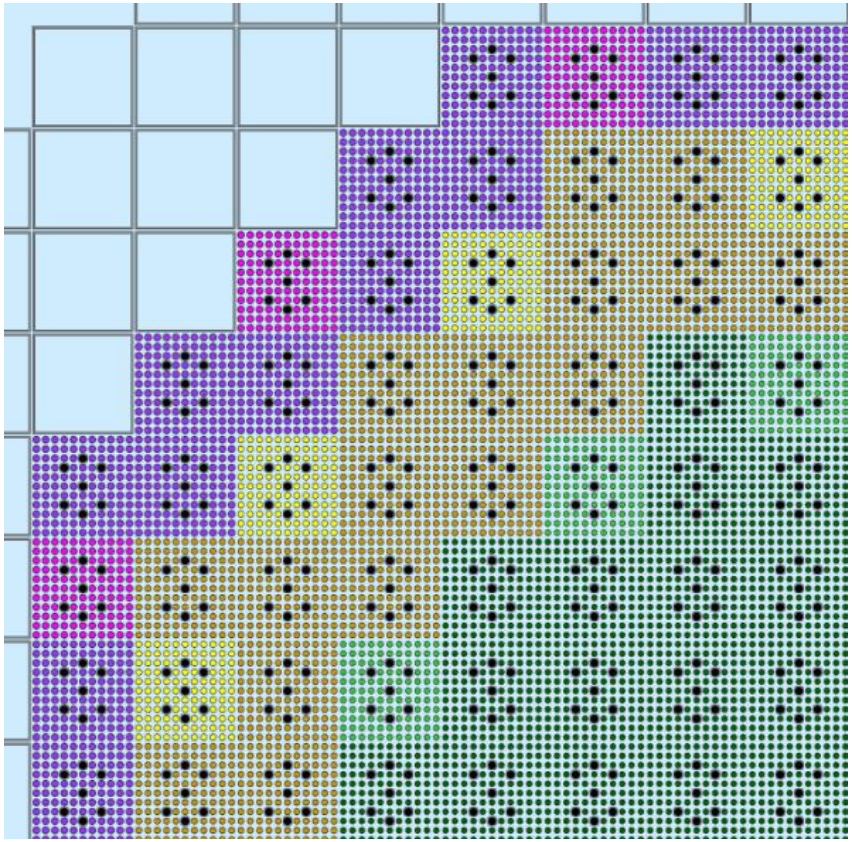




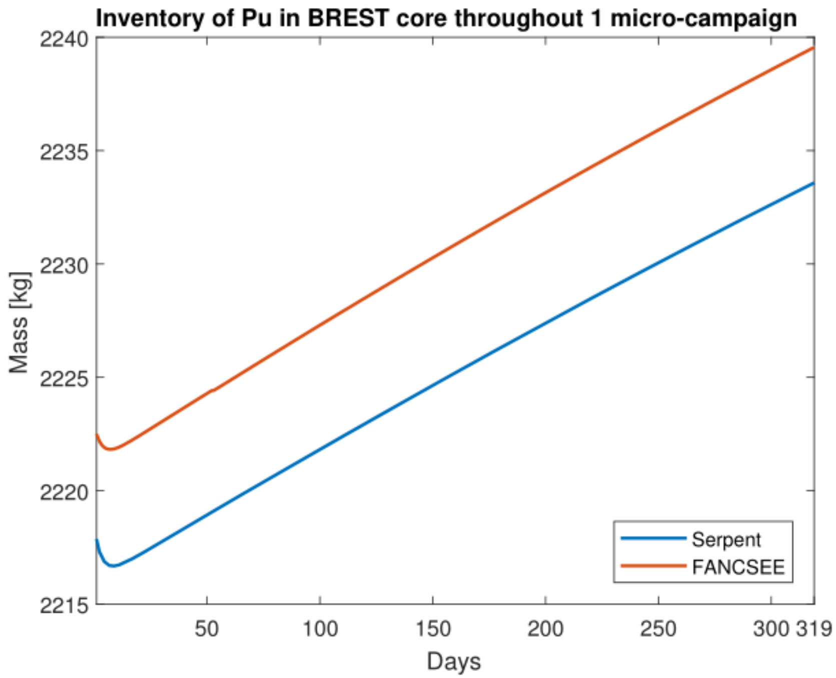
BREST results

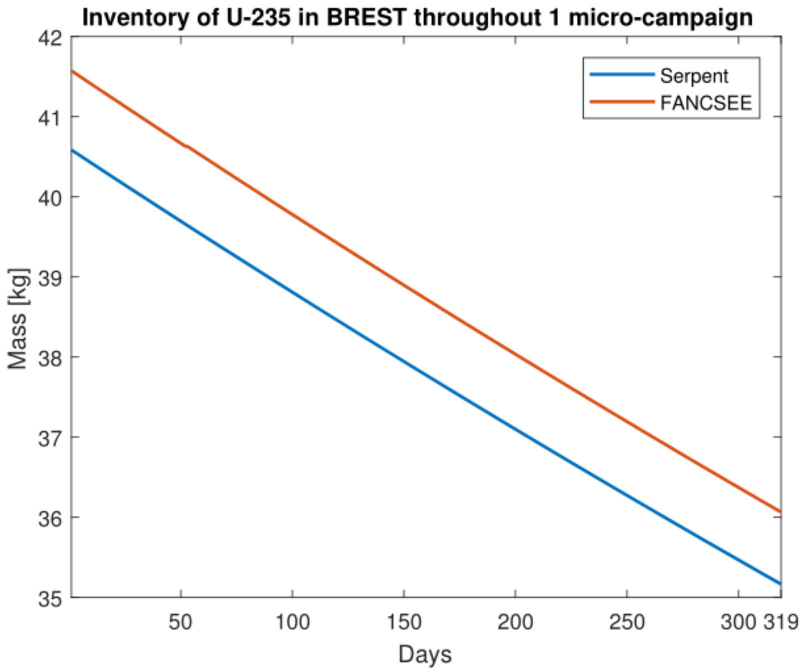
- Detailed model based on documentation from 1997 by *Research and Development Institute of Power Engineering*
- 6 different libraries: initial and average old fuel batches, two enrichment zones, two blanket zones

Parameter	Quantity
Thermal power[MW]	700
Net electrical power [MW]	300
Coolant	lead
Coolant temperature at core inlet [K]	693
Coolant temperature at core outlet [K]	813
Number of steam generators	8
Number of primary pumps	4
Core fuel	UN + PuN
Core fuel load [t]	16.7
Breeding ratio	1.06



BREST results comparison



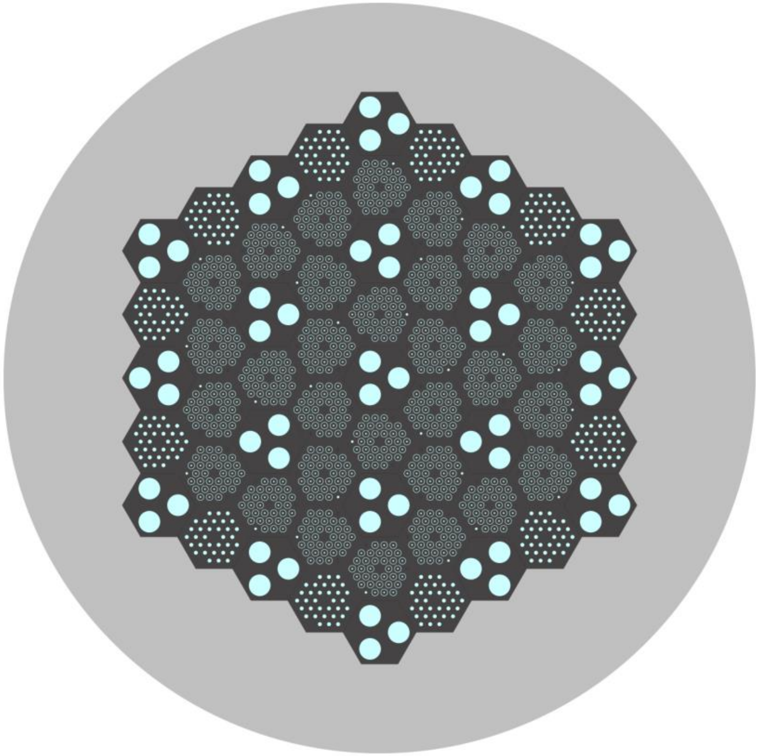


- Conclusions similar as in Phénix
- Changes in inventory between codes are in agreement

HTTR results

- Single batch loading pattern
- Non-homogeneous fuel
- From SERPENT 2 demo files with permission of J. Leppänen

Parameter	Quantity
Thermal power[MW]	300
Average power density [W/cm^3]	2.5
Coolant	helium
Coolant temperature at core inlet [K]	395
Coolant temperature at core outlet [K]	950
Primary coolant pressure [MPa]	4
Core structure	
graphite	
Number of steam generators	8
Number of primary pumps	4
Core fuel	UO_2
Uranium enrichment	3 to 10 wt%
Burnup-up period [EFPD]	660



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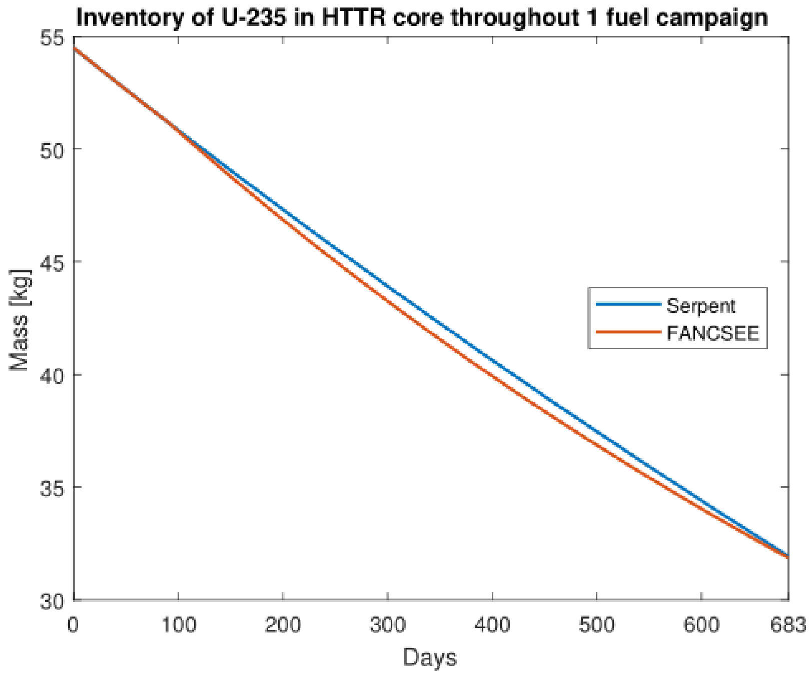
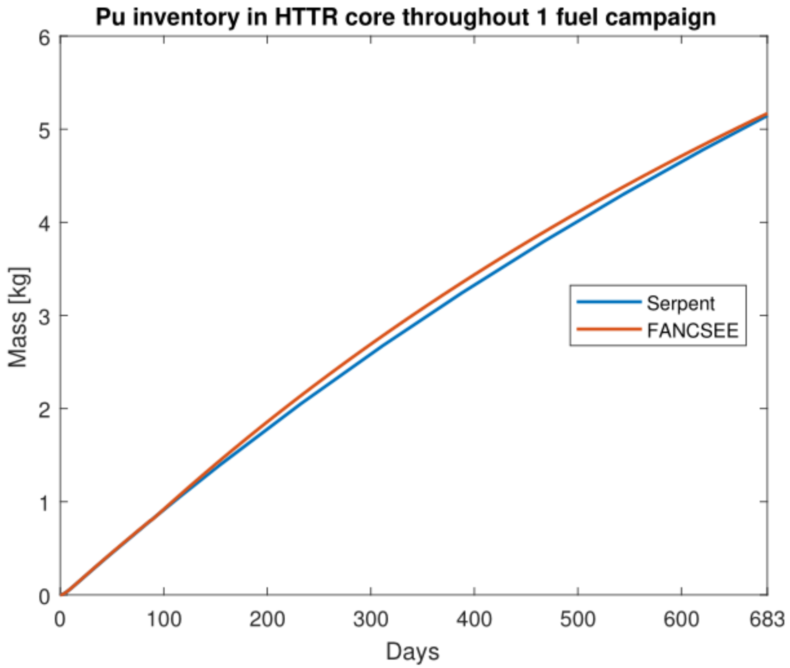




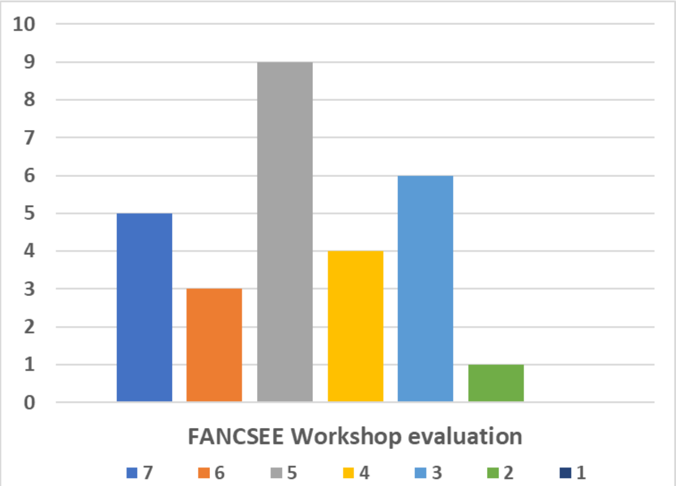
- Results between SERPENT and FANCSEE were in good agreement
- Simpler fuel scheme – single-batch loading pattern – prevents initial results disagreemens

Summer school 2019

- Afternoon exercise done 17/6/2019 in Oskarshamn, Sweden
  - Part of „Elements of the Back-end of the Nuclear Fuel Cycle” course
  - Organized together with KTH and W. Gudowski
  - Led by B. Chmielarz and Y. Hrabar
- Students belonged to nuclear engineering courses from US, Sweden, France and China
- Goals :
  - Familiarize students with different types of fuel cycles
  - Visualize long-term SNF repository requirements by calculating the scenario of Sweden

Summer school 2019 analysis

- Only a few teams have finished the exercise
  - Only the most tech-savvy students were ahead of time
- Unforeseen technical difficulties eat up time
  - Old hardware (32-bit systems)
  - Laptops without USB-A ports
  - Students unfamiliar with Linux or VMs
- The most mixed results out of all classes given
  - Liked and disliked by equally many
  - 4.8/7(28 evaluations)



Excellent ↔ Poor

Project status

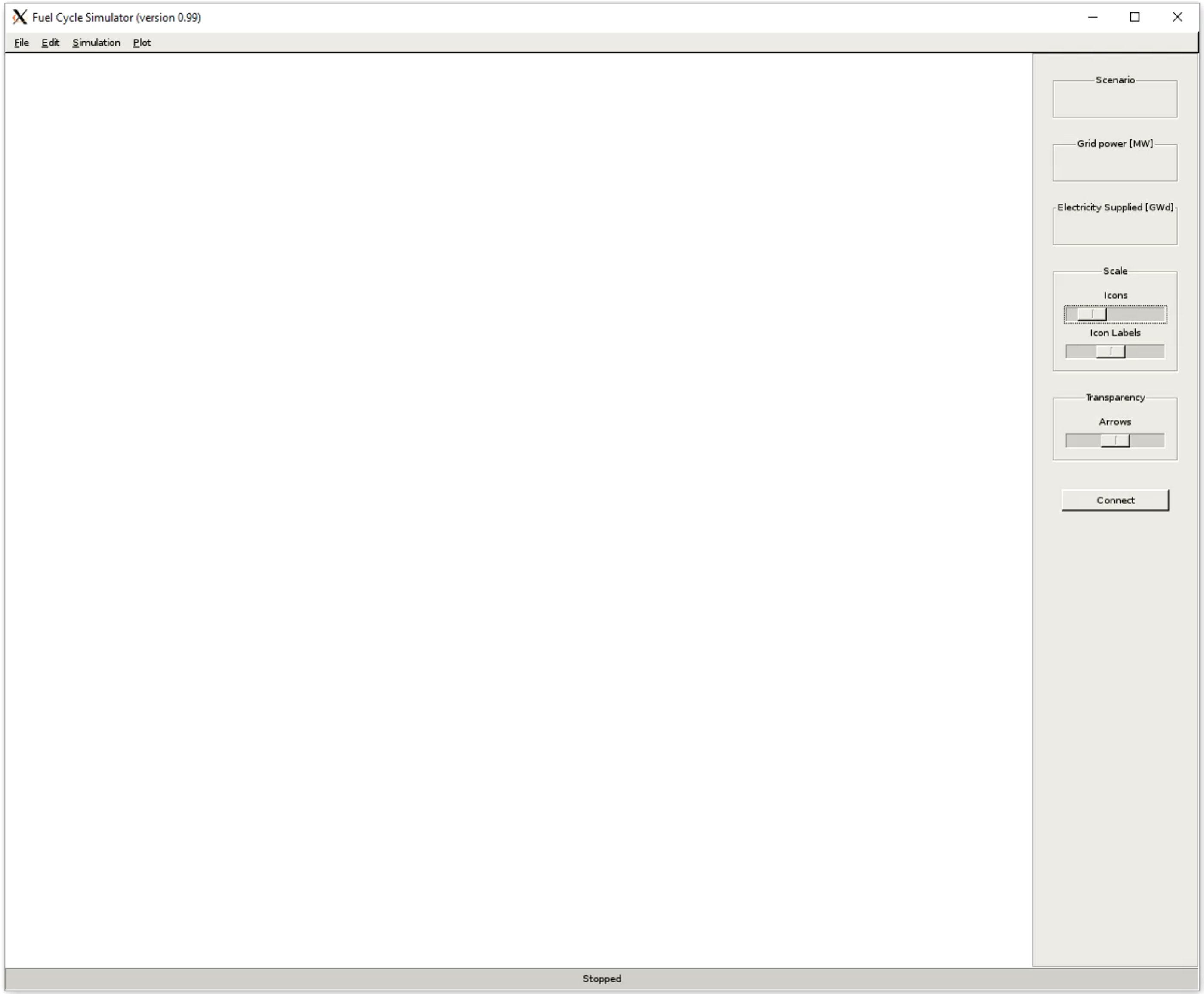
- Supervisor of the project (W. Gudowski) retired from KTH
- Lead developer (B. Chmielarz) works for a different organization
  - Movement of competences and ownership required to continue development
- Looking for a PhD student at NCBJ, Poland

Acknowledgements

- Part of this project has been funded within the European Project “Brilliant”, Grant Agreement: 662167

Thank you for your attention!

Questions?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Plot
Scenario
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Electricity Supplied [GWd]
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Transparency
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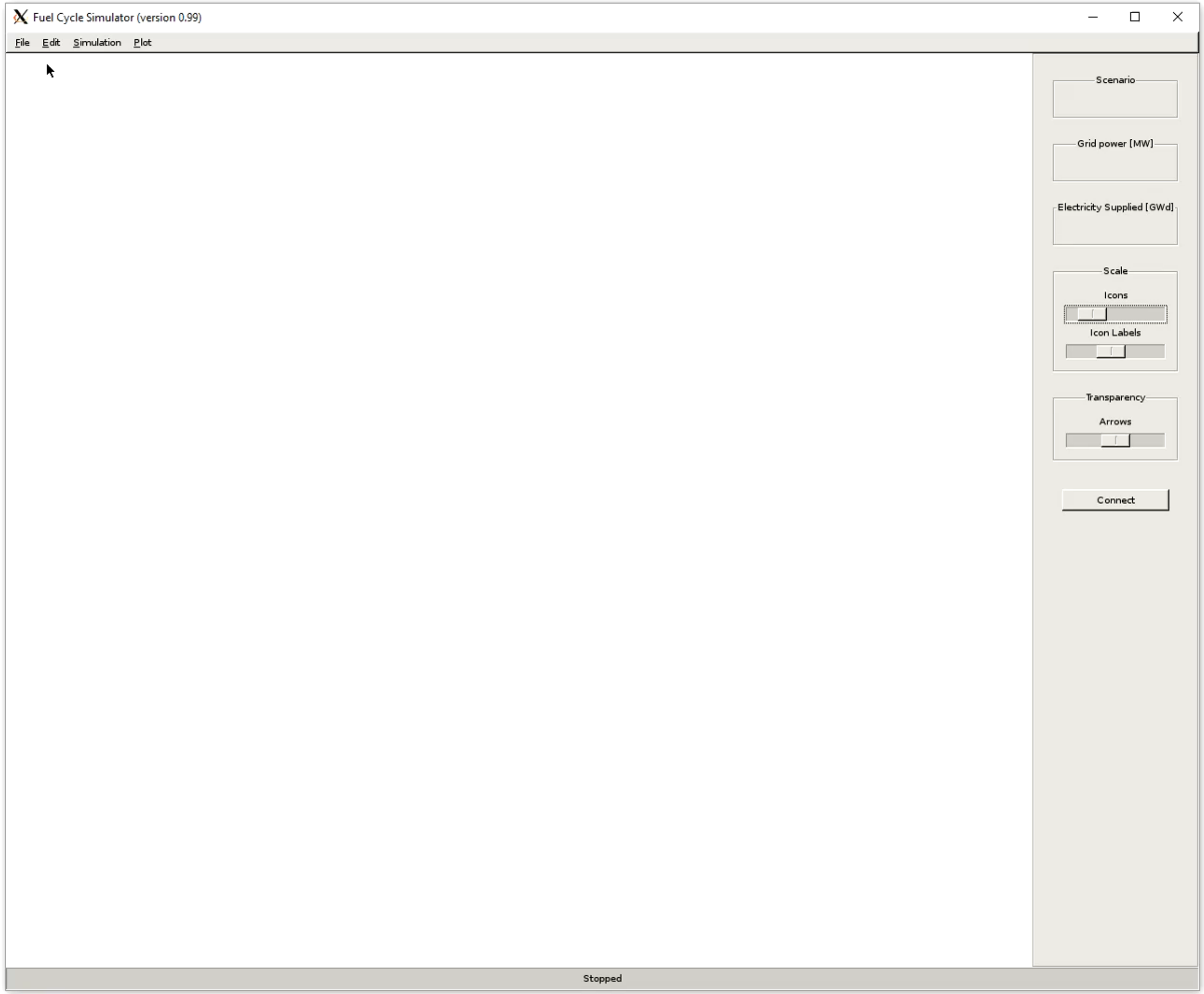
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