Calculating the inventory of FiR 1 Triga Mk II with Serpent 1.1.16

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2nd International Serpent User Group Meeting , Madrid

September 19th, 2012

Outline

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Introduction: FiR 1

- Finland’s first nuclear reactor.
- Triga Mk-II
- Started in 1962 at 100 kW, upgraded to 250 kW in 1967
- Used in BNCT cancer treatments, isotope production and education.
- About to be decomissioned (according to current knowledge).

Introduction: motivation

- The nuclide inventory of FiR 1 Triga Mk-II reactor was needed for safety, security and final disposal analyses.
  - Average-rod calculations with ORIGEN (+ a representative spectrum from MCNP)
  - Detailed, rod-wise calculation with Serpent

Shuffle-property of Serpent

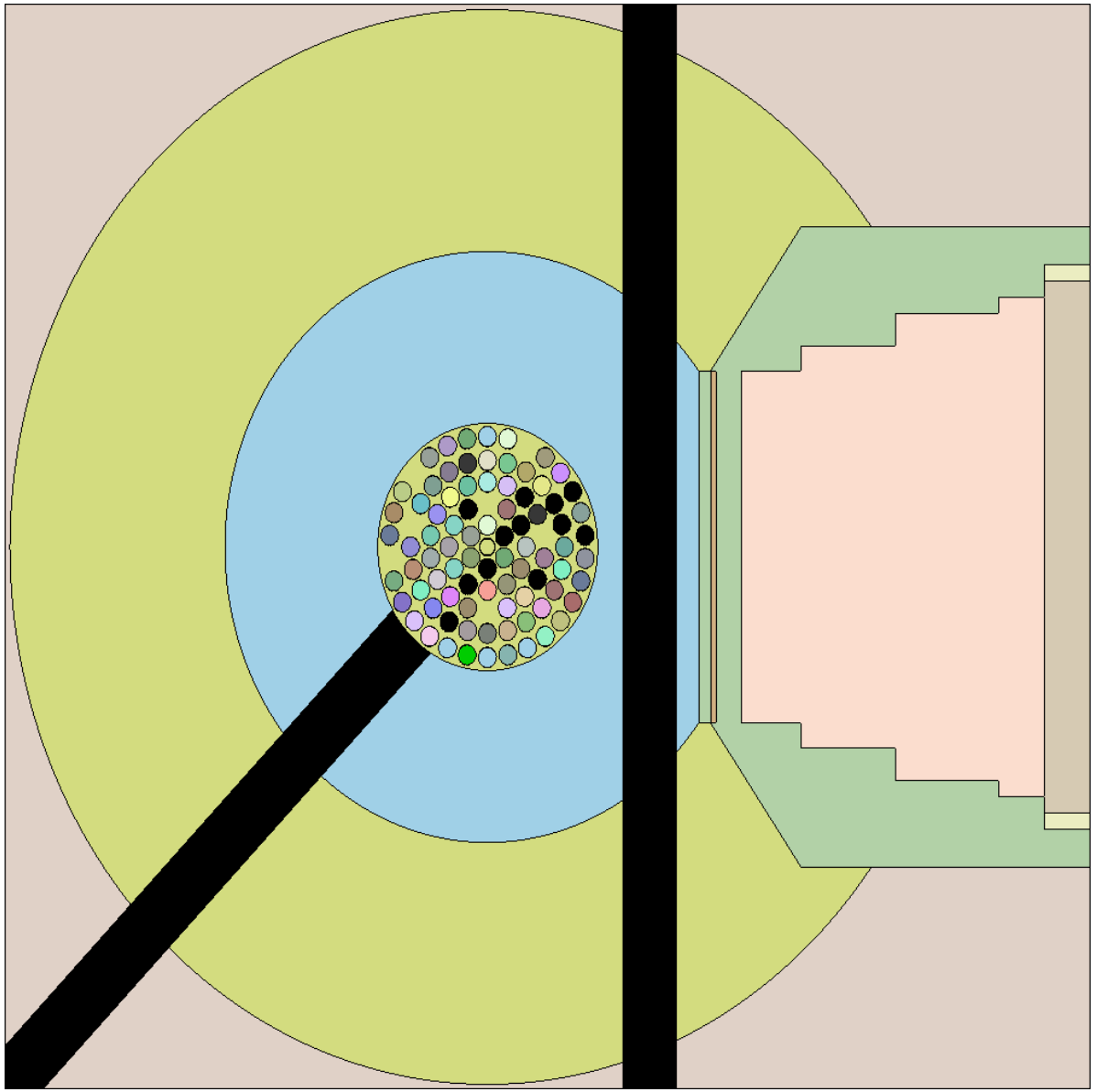
- An undocumented property in Serpent versions 1.1.17 $\rightarrow$
  - Because of a bug, not to be used before version 1.1.18 !
  - Still not very thoroughly tested...
- Slightly different implementation in Serpent 2
- Makes it possible to interchange two universes in a geometry within a burnup calculation.
  - Modelling of changes in the fuel loading

```
set power 250000
dep daystep 6.276480
shuffle 8002 2552
dep daystep 113.723520
```

Geometry model

- VTT has three kinds of Triga fuel rods:
  - Al-clad rods with 8 w-% Uranium
  - SS-clad rods with 8.5 w-% Uranium
  - SS-clad rods with 12 w-% Uranium
- Each fuel rod was divided into 3 burnup regions in axial direction for calculation.
- Geometry of the core, (epi-)thermal column and two out of three beam tubes were modelled in high detail.

Geometry model



Control rod model

- Operation history of control rods is very complex
  - An approximation is required
- Most of the burnup is gained in full power conditions
  - Pulse rod and SHIM I fully withdrawn.
  - Positions of SHIM II and REG vary a lot
    $\rightarrow$ approximated with halfway inserted rods.

Irradiation history model

- FiR 1 has been used on daily basis for many (about 40) years
  - Reactor started in the morning, run for 7-8 hours and shutdown in the afternoon.
- Even if the history data was easily accessible, accurate modelling of the history would require at least 15000 burnup steps.
- Rough approximation:
  - Irradiation history model is based on yearly power productions
  - First, a very long full power step is taken until the yearly burnup is achieved
  - The rest of the year is modelled with a zero power decay step.

FiR model in numbers

- A rather large model:
  - 49 years of operational history
  - 42 changes in fuel loading
  - 91 depletion steps and 92 decay steps.
  - 309 burnable material zones
  - 5680 lines of (mostly automatically generated) input
  - 13.4 GB of memory required in serial mode

Selected results: inventory

- Serpent and ORIGEN inventories are in good agreement for most long-lived nuclides.
- Agreement is worse on short-lived nuclides due to different history models.
- Also concentrations of transuranic elements vary significantly.

Table 1: Comparison of compositions for total inventory.

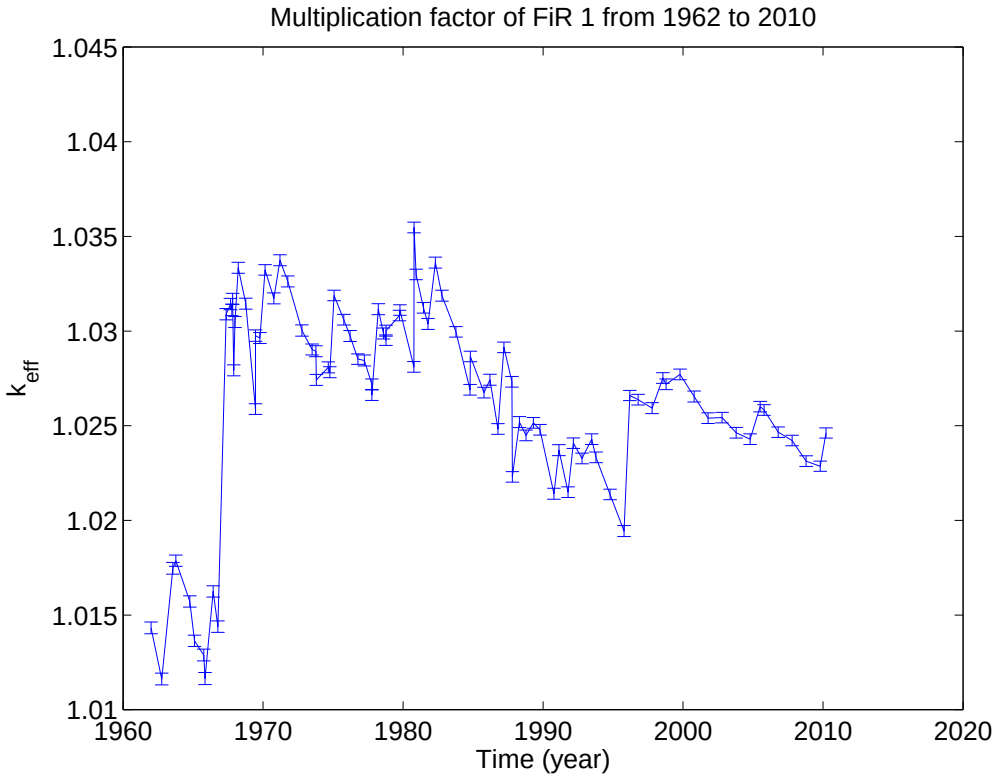
Nuclide	$T_{1/2}$	Difference Serpent-ORIGEN-S
$^{3}\mathrm{H}$	12 y	-11 %
$^{129}\mathrm{I}$	1.5×10^{7} y	45 %
$^{137}\mathrm{Cs}$	30 y	0.3 %
$^{134}\mathrm{Cs}$	2 y	-18 %
$^{235}\mathrm{U}$	7×10^{8} y	1.3 %
$^{238}\mathrm{U}$	4×10^{9} y	1.8 %
$^{239}\mathrm{Pu}$	2.4×10^{4} y	158 %
$^{241}\mathrm{Pu}$	14 y	683 %

Selected results: reactor physics

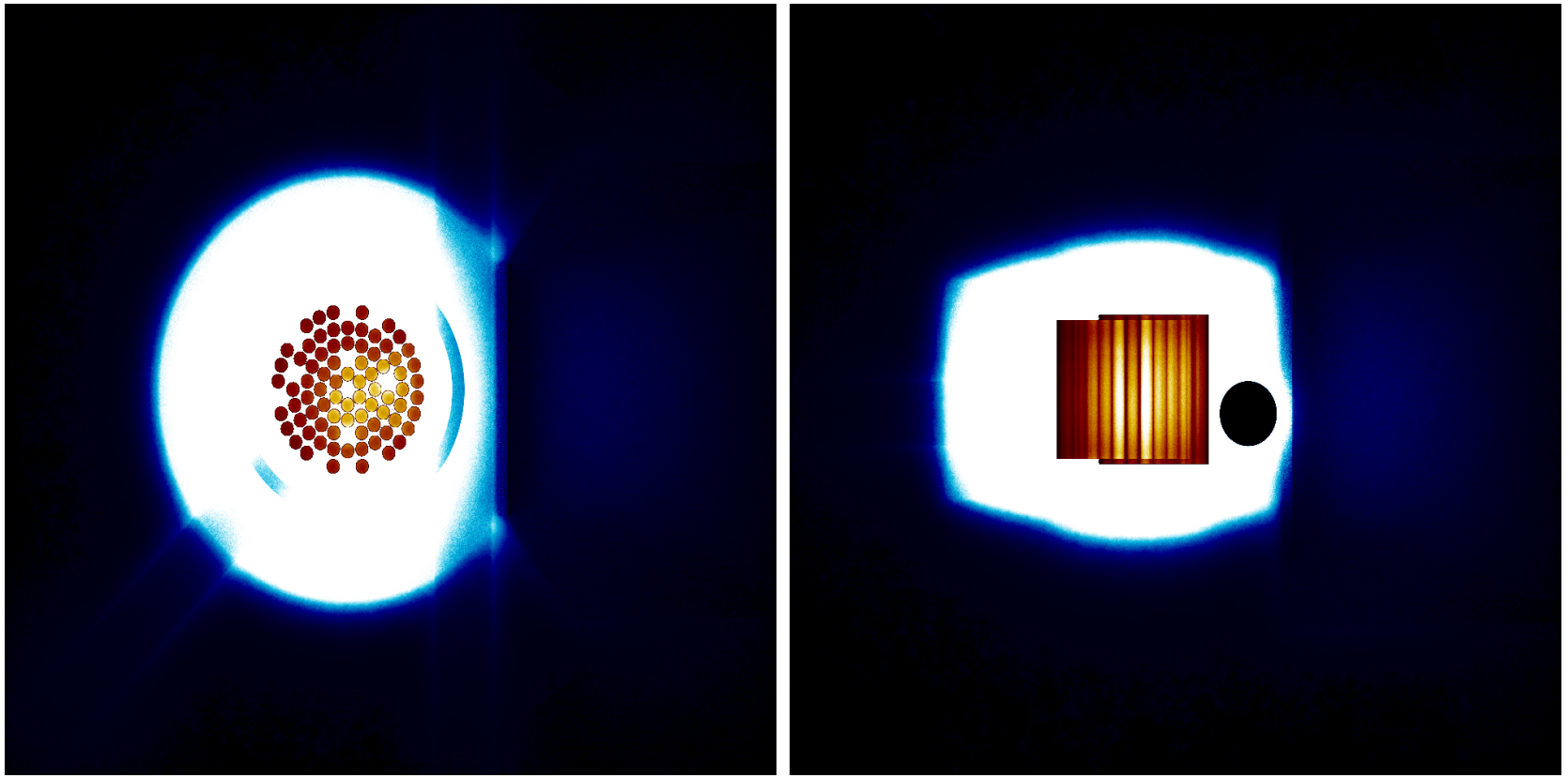
- What comes to reactor physical measures, the model seems to be far from perfect.
- Calculated excess reactivity of the current configuration is about 2700 pcm larger than measured.
  - According to calculations, the reactor would almost reach criticality with only pulse rod withdrawn...
- Ni activation analyses do not agree with Serpent results, either.
- However, the multiplication factor is quite stable and $k_{\mathrm{eff}} > 1$ at all times.

  $\rightarrow$ The model is not fully hopeless.

Multiplication factor with SHIM II and REG halfway inserted



Mesh plots



Summary

- The differences in inventory results were something to expect: two programs with very different methods, two nuclear data libraries, two results.
  - Regardless, the *magnitudes* of compositions were in agreement for all important long-lived nuclides!
- The complex model should be double-checked for errors.
- **Thanks to the new shuffling property, Serpent is well-capable of modeling the fuel depletion in research reactors.**

References

[1] Visuri, P., “Triga reaktorin tehon korottaminen yli 250 kW:n — Tekninen tarkastelu”, Reaktorilaboratorio, VTT, in Finnish, (1975).

[2] Gulf General Atomic, “Specifications: Individual Triga Fuel Elements”, FiR 1-4th_fuel_shipment_technical_description.pdf

[3] Serpent website, http://montecarlo.vtt.fi