Business from technology

Track-length estimator capability in Serpent

Tuomas Viitanen & Jaakko Leppänen

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Introduction

- All reaction rates and their derivatives (like k_{eff}) are in Serpent calculated with *collision estimators* which are, in general, less efficient than *track-length* estimators.
- There are basically two reasons for this choice:
  - The surface crossings are not recorded in the Delta-tracking mode, which complicates resolving of track-lengths.
  - In multi-physics applications it is beneficial to model materials with inhomogeneous temperature and density distributions. This is not possible with track-length estimators.
- Nevertheless, a special implementation of track-length estimators for detectors has been included in Serpent 2.1.18.

Collision and track-length estimators in a nutshell

- Collision estimators are scored only at collision sites (virtual or actual)
  - Scores are defined

$$s_i = w \frac{f_i}{\Sigma_{\mathrm{maj}}(E)} \,, \tag{1}$$

where w is the neutron weight, f_i is the value of the response function and $\Sigma_{\mathrm{maj}}(E)$ is the Delta-tracking majorant cross section.

- Track-length estimators are scored every time a neutron penetrates the region of interest
  - Scores are defined

$$s_i = w f_i l_{\mathrm{t}} \,, \tag{2}$$

where l_{t} is the neutron track-length.

New track-length estimator capability

- Track-length estimators can now be associated with surfaces:
  - With “det <detector_name> dtl <surface>” the detector is scored within surface <surface>.
- Implementation is based on analysing the neutron tracks preceding *each* collision point and checking whether the neutron traveled within <surface> or not.
  - This increases the CPU time requirement, especially if the number of track-length estimators is large.

```
surf 700 sph 0.0 0.0 -5.0 0.5
det MnKP dtl 700 dr 102 manganese
```

Example case: neutron dosimetry in FiR 1 Reactor

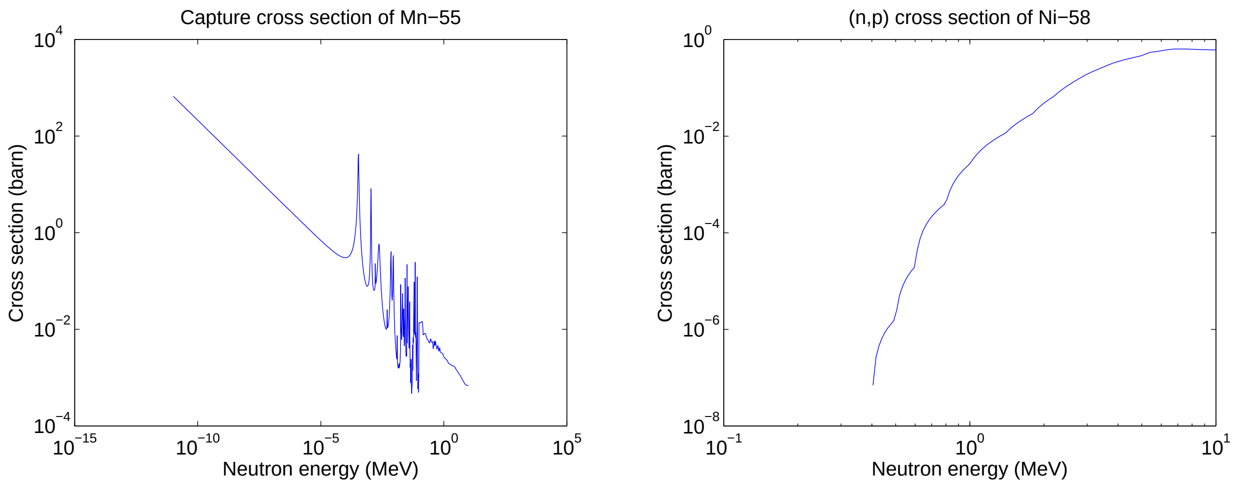
- FiR 1 is a pool-type 250 kW Triga Mk-II research reactor, operated by VTT.
  - U-ZrH metal alloy fuel.
  - Operation started 1962, decomissioning planned 2016.
  - Total energy produced $\sim 500\ \mathrm{MWdth}$.
- A Serpent model of the reactor was validated against dosimetry measurements, results presented at ISRD-2014 [1].

Serpent Model of FiR 1

- Originally developed for calculating rod-wise inventories.
- Each fuel rod is divided into three axial burnup zones.
- Burnup calculation from 1962 to end of 2010.
  - All changes in the fuel loading taken into account.
  - Extremely complex power history approximated with yearly average steps.
- No T-H feedback, fuel at 400 K and coolant at 294 K constant temperature.
- Funny coincidence: k_{eff} of the current reactor model was within $\pm$ 90 pcm from exact criticality.

Neutron dosimetry with Mn and Ni

- 9+9 Mn and Ni samples were irradiated and the activation was modeled with Serpent 2.
  - 8+8 in different positions of the Lazy Susan irraditation ring
  - 1+1 in the central thimble
  - Responses: ^{58}Ni(n,p)^{58}Co (fast) and ^{55}Mn(n,γ)^{56}Mn (thermal)
- Capability to use dosimetry ACE cross sections was added in Serpent 2.1.18.



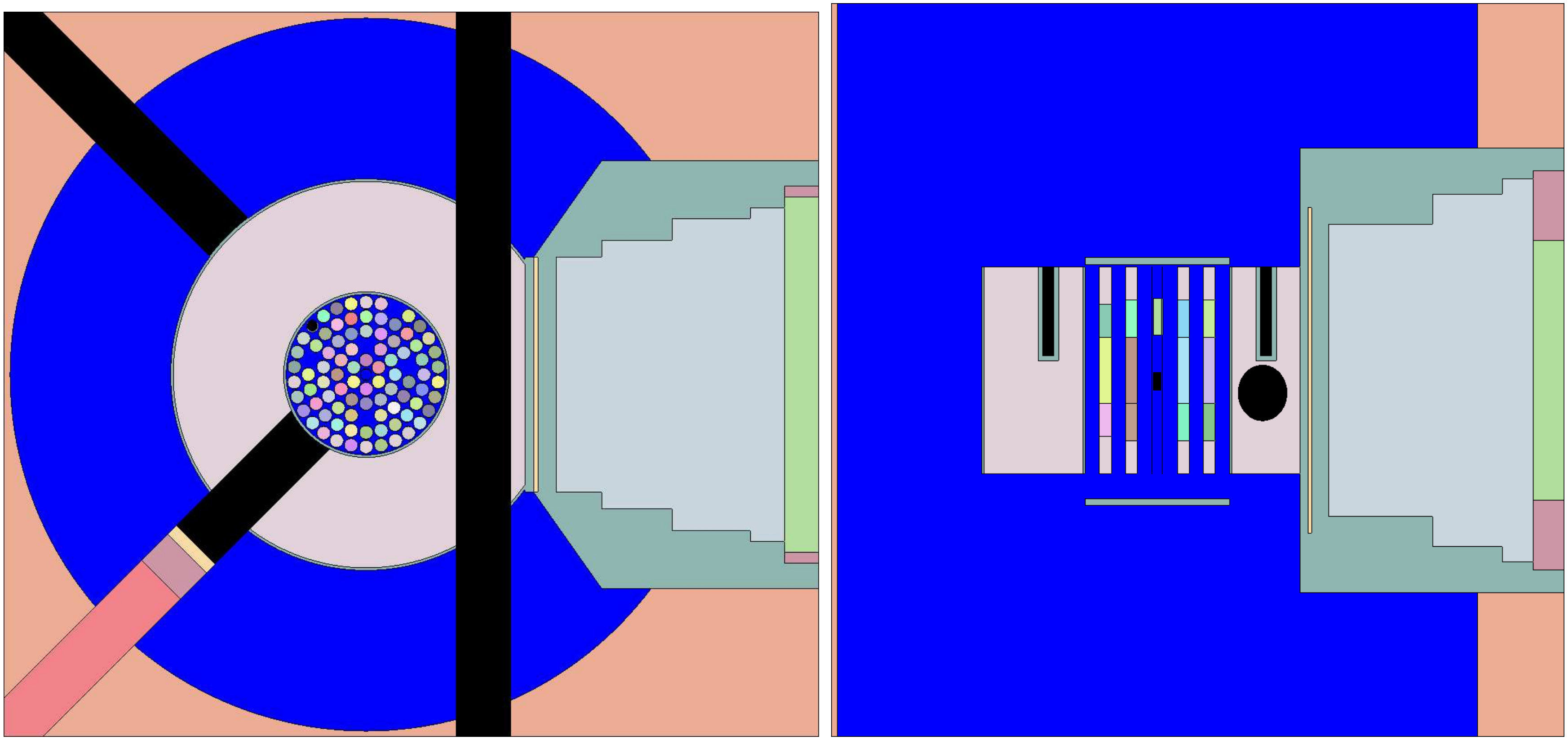


Figure 1: Serpent geometry plots of of FiR 1, top-down view (left) and side view (right).

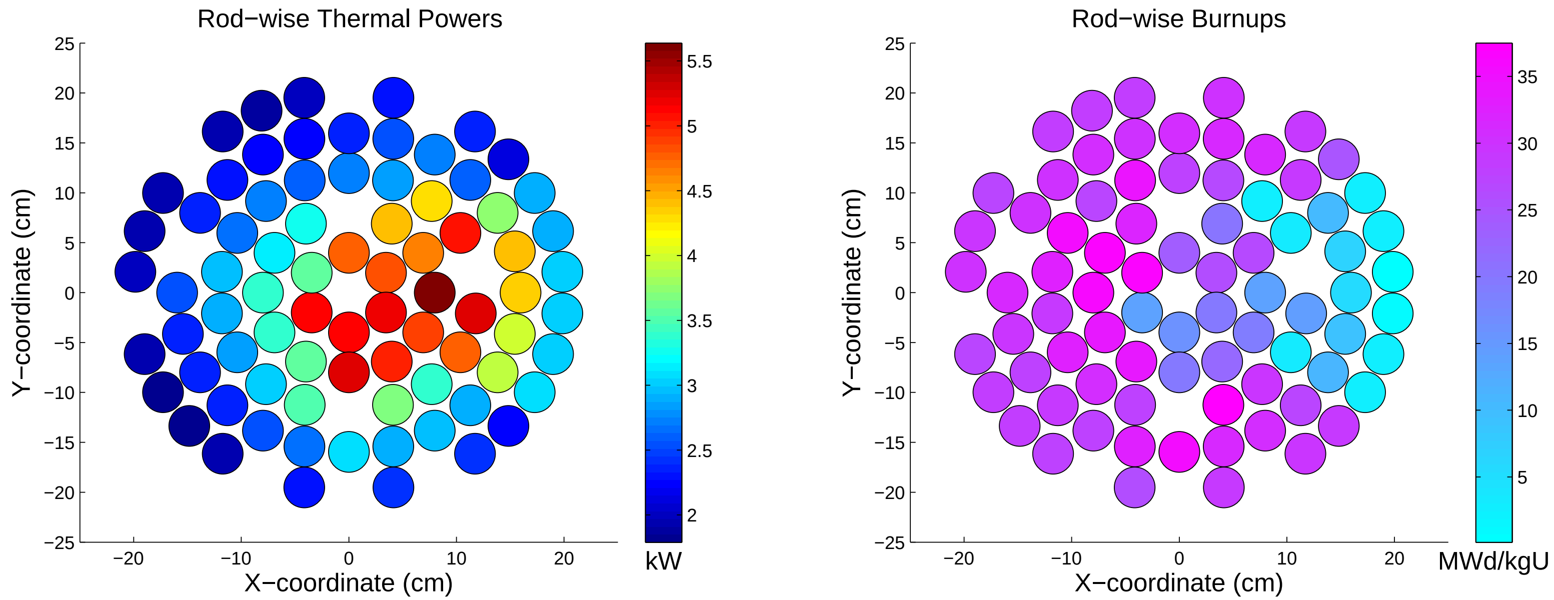


Figure 2: Asymmetry of the fuel loading can be recognized in the power- and burnup distributions.

Serpent calculations

- The dosimeter irradiations were modeled using JEFF-3.1.1 cross sections for neutron transport and IRDF-2002 cross sections for dosimetry.
- 400 million active neutron histories were run in each calculation.
- Calculation times were about 14 h when using 12 OpenMP threads on an Intel Xeon workstation running at 3.47 GHz.
- The efficiency of reaction rate estimators is measured using Figures-of-Merit (FOM), defined

$$FOM = \frac{1}{\sigma^2 t}\,, \tag{3}$$

where t is the calculation time and σ is the standard deviation of the estimator.

Collision vs. Track-length Estimators

Table 1: Performance comparison between collision and track-length estimators for representative estimators.

		Center		Lazy Susan 1	
	Calc. Time	σ	FOM	σ	FOM
	h	%	1/s	%	1/s
Mn, Collision	13.9	1.0	0.2 / 1.0	2.1	0.045 / 1.0
Mn, Track-length	14.1	0.4	1.39 / 6.8	0.7	0.378 / 8.3
Ni, Collision	13.7	2.1	0.05 / 1.0	9.5	0.002 / 1.0
Ni, Track-length	14.0	0.7	0.36 / 7.8	3.4	0.017 / 7.5

Using track-length estimators reduces calculation times by a factor of 6.8–8.3!

Activation results: Nickel

Central Thimble: 4.32E-13 1/s (calculated) vs. 4.78E-13 (measured), difference -9.63 %

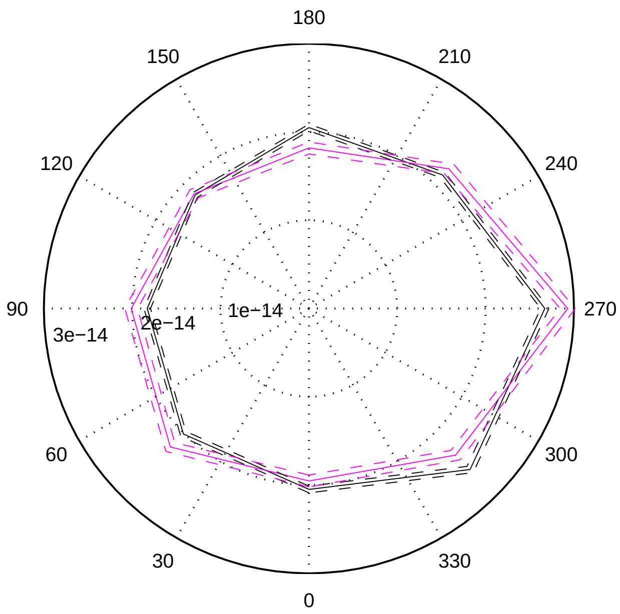


Figure 3: Measured (black) and calculated (magenta) reaction rates (1/s) in the Lazy Susan irradiation ring (left) and corresponding relative differences in % (right).

Activation results: Manganese

Central Thimble: 7.38E-11 1/s (calculated) vs. 8.13E-11 (measured), difference -9.20 %

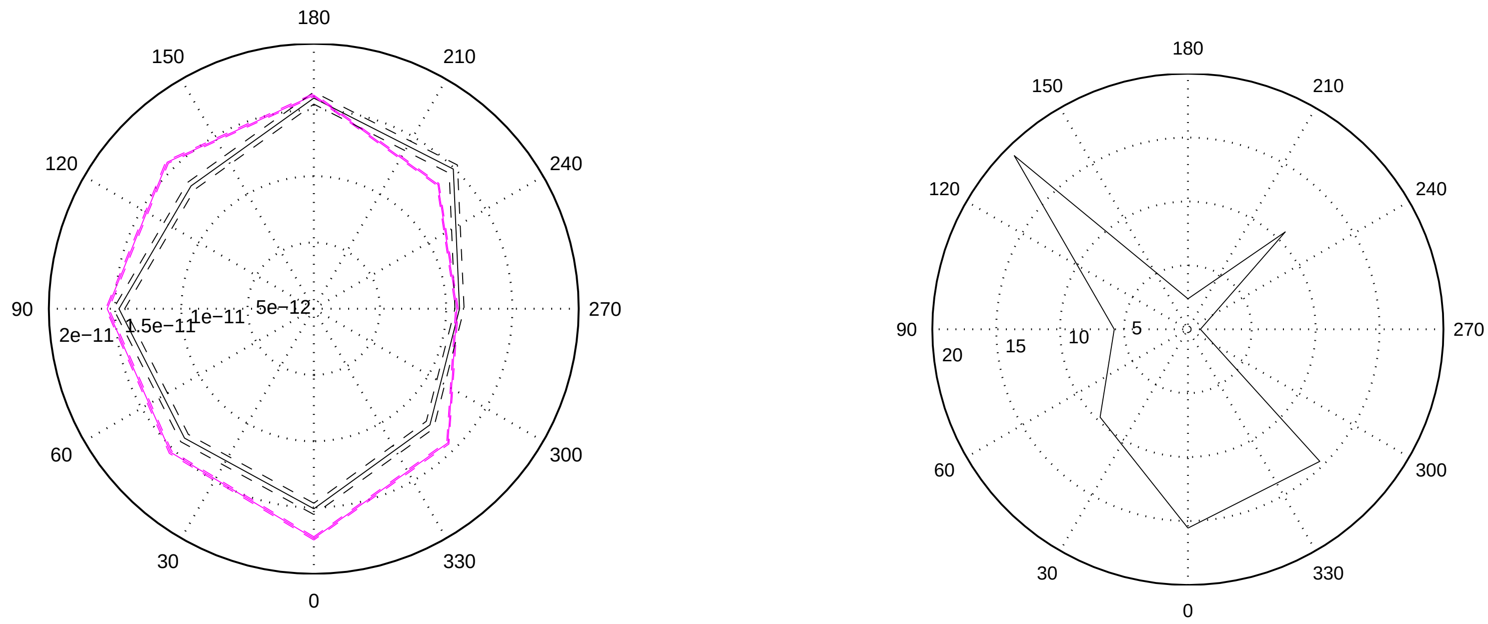


Figure 4: Measured (black) and calculated (magenta) reaction rates (1/s) in the Lazy Susan irradiation ring (left) and corresponding relative differences in % (right).

Summary and Conclusions

- The new track-length estimator capability may save significant amounts of CPU time in some cases.
  - Factors between 6.8–8.3 in Triga dosimetry modelling.
- Dosimetry cross sections can now be used also with Serpent 2.
- (Off-topic:) The differences between the calculated and measured reaction rates were below 12 % for the fast response (Ni) and below 20 % for the thermal response (Mn).

Thank you for your attention!

Questions?

tuomas.viitanen@vtt.fi
http://montecarlo.vtt.fi

References

[1] Viitanen, T. and Leppänen, J. "Validating the Serpent Model of FiR 1 Triga Mk-II Reactor by Means of Reactor Dosimetry." In proc. 15th ISRD, Aix en Provence, France, May. 18-23, (2014).