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Incorporating GPT into the sub-step method for coupled MC codes

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Outline

- Introduction
- Objective of the current research
- Method/Algorithm
- Test case
- Results
  - Comparison with Serpent
  - Performance of various schemes
  - Convergence studies
- Summary and future work

Introduction

- **Many coupling schemes are used in MC codes**
- **Serpent has many options too**
  - Explicit, Predictor-Corrector (with ND averaging or RR averaging), substep, higher-order substep (with multiple interpolation/extrapolation options), stochastic iterative methods.
- **Different methods target specific problem:**
  - Stochastic iterative methods for multi-regional problems for addressing numerical instabilities.
  - Substep methods for problems with rapid variation in reaction rates
  - In reality, most users probably use either the predictor or predictor-corrector methods

Objective

- Universally applicable method
  - No stability issues
  - Captures time-variation of cross sections and fluxes
- Computationally efficient
- This study is only a proof of principal
  - Further studies are needed to demonstrate efficiency

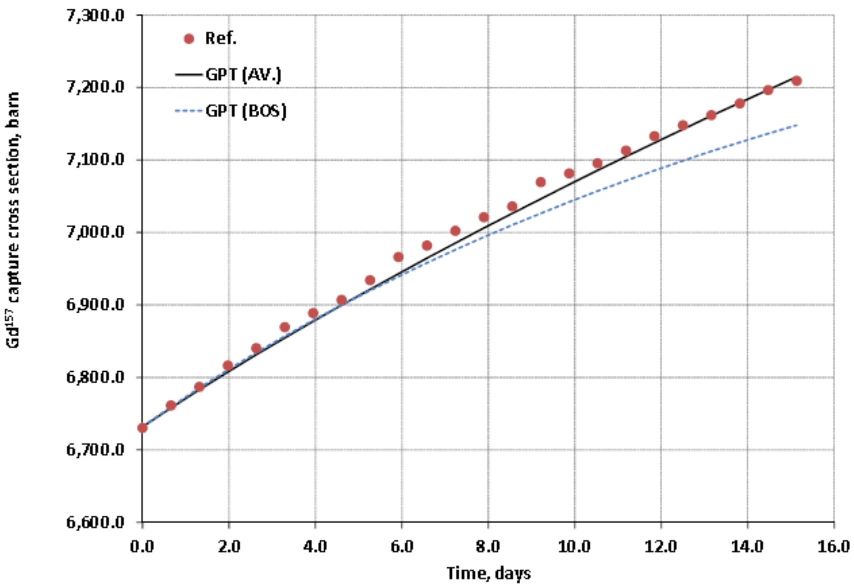
The idea

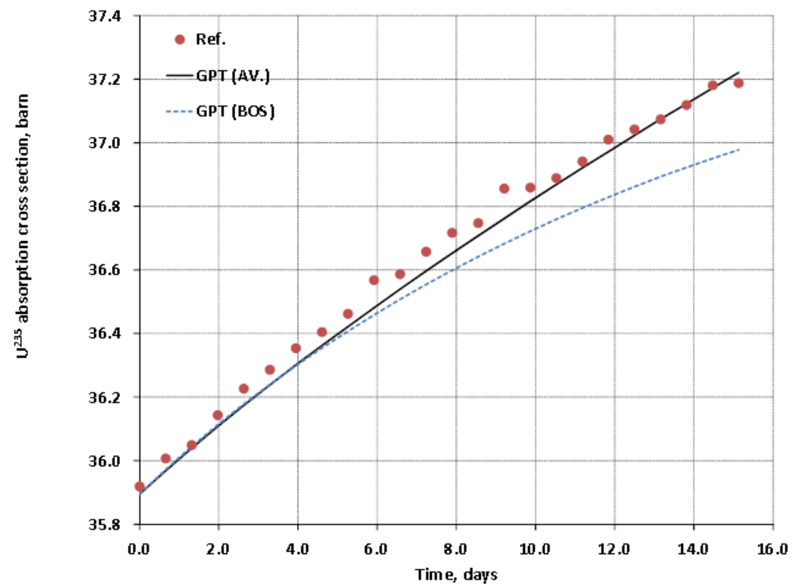
- **Cross section values are function of concentrations**
  - Example: Gd depletes → softer spectrum → increases Gd cross sect.
- **Also means that** the change in Gd concentration will change the cross section of U^{235}.
- **In a mixture of M nuclides**, a perturbation in any nuclide density may significantly affect the cross sections of all other nuclides
- Solution: a collision history-based approach was implemented in Serpent (M. Aufiero et al.)
  - Allows computing the perturbation effects of any quantity
    - Used here to obtain the sensitivity coefficients: $S_i^j = \frac{\partial\sigma^j/\sigma^j}{\partial N_i/N_i}$

GPT-based sub-step algorithm

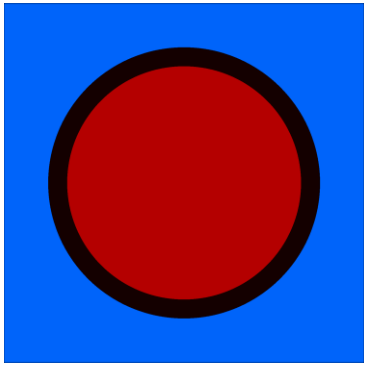
- In order to find the time-dependent cross section
  - $\sigma_j(t) = \sigma_j(t_0)\left(1 + \sum_i^M S_i^j(t_0)\frac{N_i(t)-N_i(t_0)}{N_i(t_0)}\right)$
- We can use Lagrange interpolation if $\sigma_j(t)$ was calculated using $S_i^j(t_0)$ obtained at different time-points (i.e. BOS, EOS)
  - $\sigma(t) = \sum_{j=0}^{n} l_j^{(n)}\sigma_j(t_j)$
  - $l_j^{(n)} = \prod_{\substack{i=0 \\ i\neq j}}^{n}\frac{t-t_i}{t_j-t_i}$; polynomial of degree (n)
- Here, we used:
  - **L**inear **I**nterpolation (i.e. n=1): GPT/LI
  - **Q**uadratic **I**nterpolation (i.e. n=2): GPT/QI

Calculated cross sections vs time





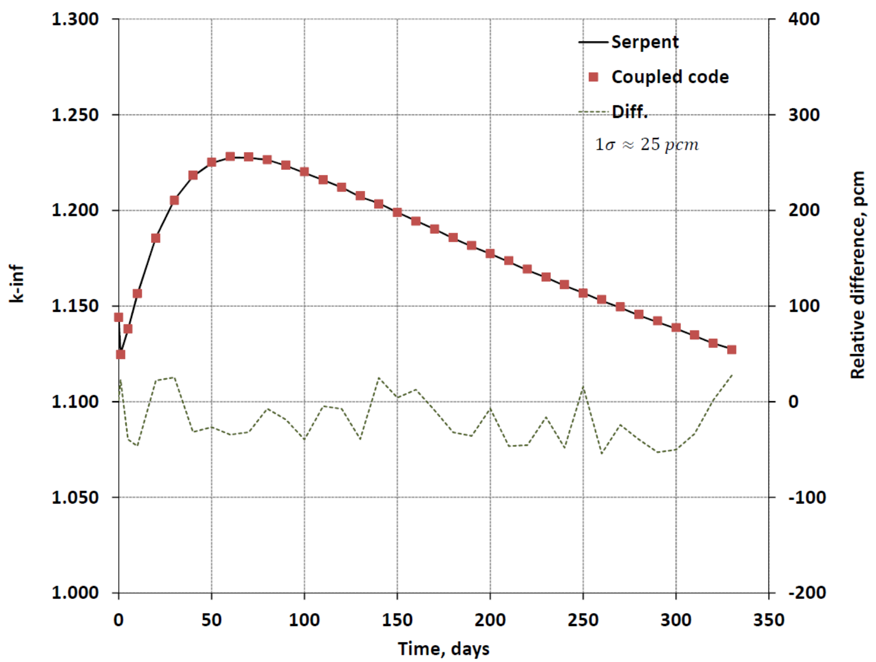
Test case



- Typical PWR unit cell with UO_2 fuel.
  - UO_2 fuel 3.5 ^{w}% mixed with 0.5 ^{w}% of Gd_2O_3
  - Pin was not subdivided
- **Results**:
  - Comparison of coupled system vs. Serpent (“sanity” check)
  - Performance of various schemes:
    - Predictor-Corrector (PC): averaging of reaction rates
    - LE/QI (Isotalo and Aarnio, 2011): sub-step method
      - **L**inear **E**xtrapolation and **Q**uadratic **I**nterpolation
    - GPT/LI and GPT/QI
  - Convergence studies

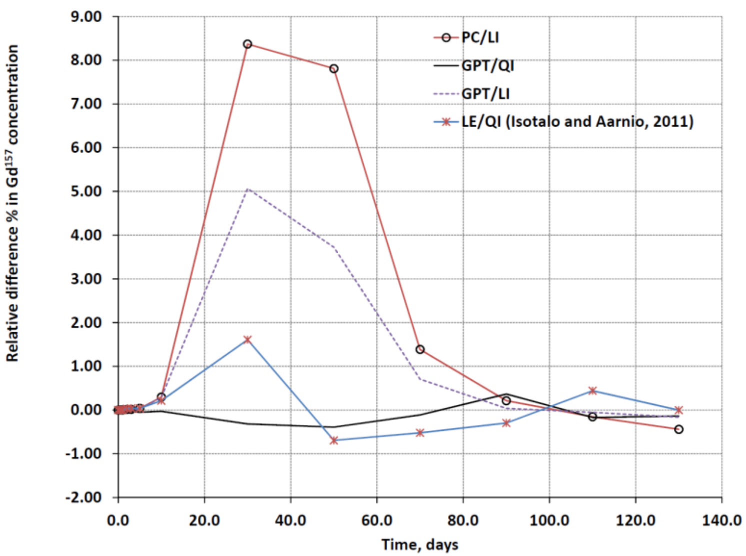
Comparison with Serpent

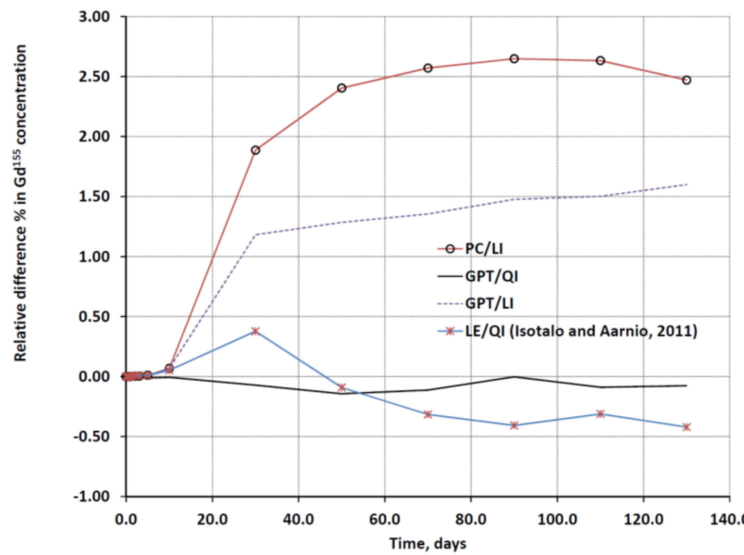
- A wrapper script was developed to couple Serpent with a stand-alone depletion solver
- A benchmark was required to demonstrate the consistency of the results



Performance of various schemes

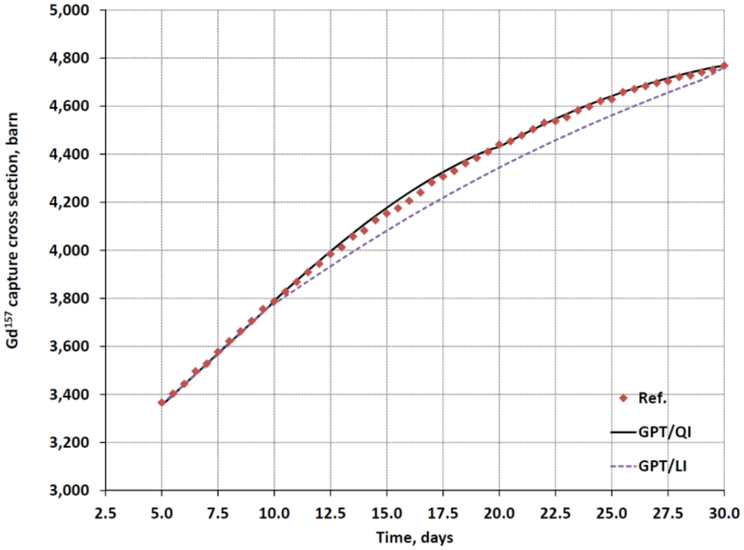
- Gd absorber strongly affects the neutron spectrum and vice-versa.
- Fine Δt are required to capture $\sigma(t)$ of various nuclides
- Reference solution was obtained with PC/LI and $\Delta t = 0.5$ days
- Compared with GPT/LI, GPT/QI, LE/QI and PC/LI with $\Delta t = 20$ days

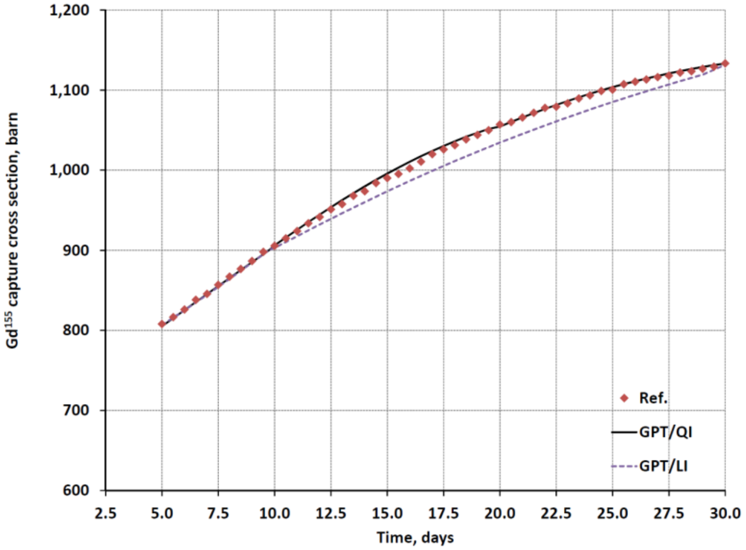




Time-dependent cross sections

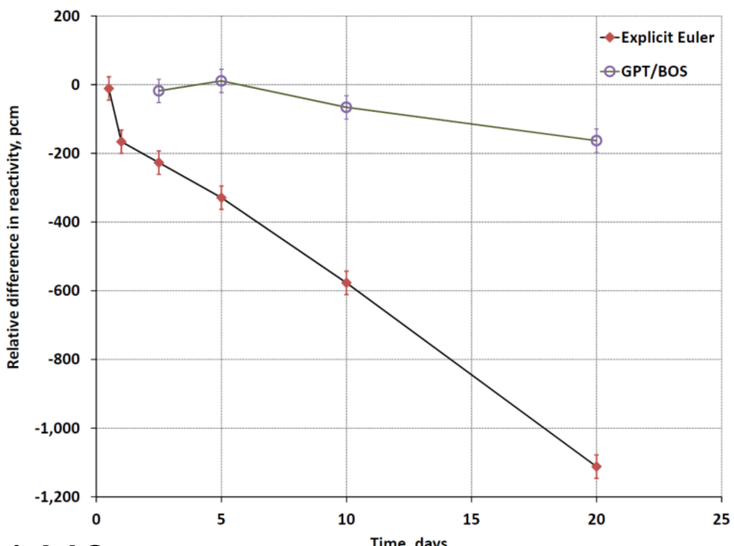
- Two time-steps are presented, i.e. 5-10 d and 10-30 d.
- Transport solution is obtained only in discrete points, i.e. 5, 10, 30d



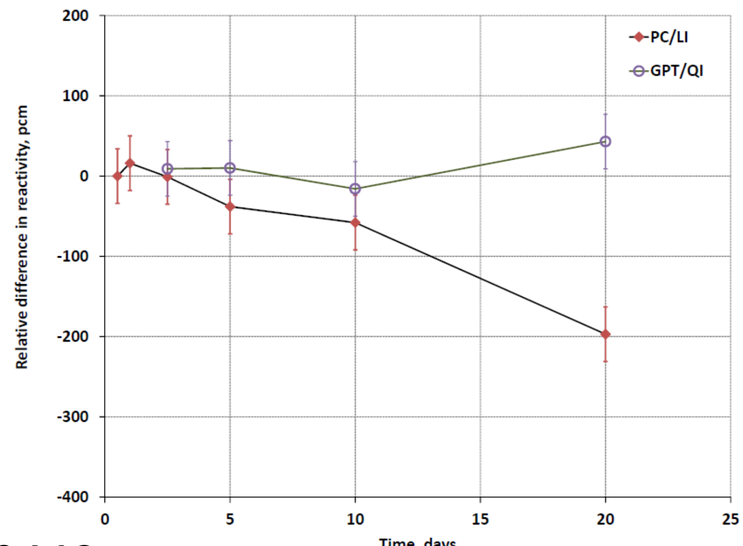


Convergence study

- Analyses were repeated for different time step lengths
  - 0.5, 1, 2.5, 5, 10 and 20 days (high statistics)
  - Reference solution: PC/LI (0.5 days)
  - Speed-up factor of 20



1 MC per step



2 MC per step

Summary

- Coupling procedure is important
- Previous studies identified stability issues
- Alternative methods were developed, but
  - Require many iterations to be accurate
- This study proposes an iteration-free method
  - Sensitivity coefficients are calculated using GPT in Serpent
  - Allow to predicting accurate time variation of cross sections
  - Combined with sub-step approach
- The results are extremely promising

Future …

- In multi-regional problems, the variation of flux has to be taken into consideration using the same approach
- The method is expected to be a useful tool in which non-iterative techniques give rise to spatial oscillations that lead to instabilities.

- **Thank you for your attention**. Questions or suggestions ?