Neutronic analysis of Th-^{233}U self sustainable BWR fuel cycle with BGCore and Serpent Codes

by

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Outline

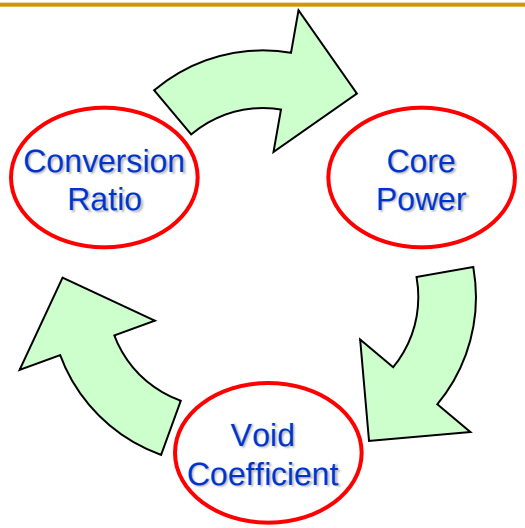
- Th-^{233}U fuel cycle
- BWR Seed-Blanket assembly
- Computational tools
  - *BGCore system*
  - *Serpent*
- Results: Code-to-Code comparison
  - *Nutronic parameters (k_{inf}, FIR, nuclide densities)*
  - *Computational efficiency (CPU time, memory)*
- Summary and conclusions

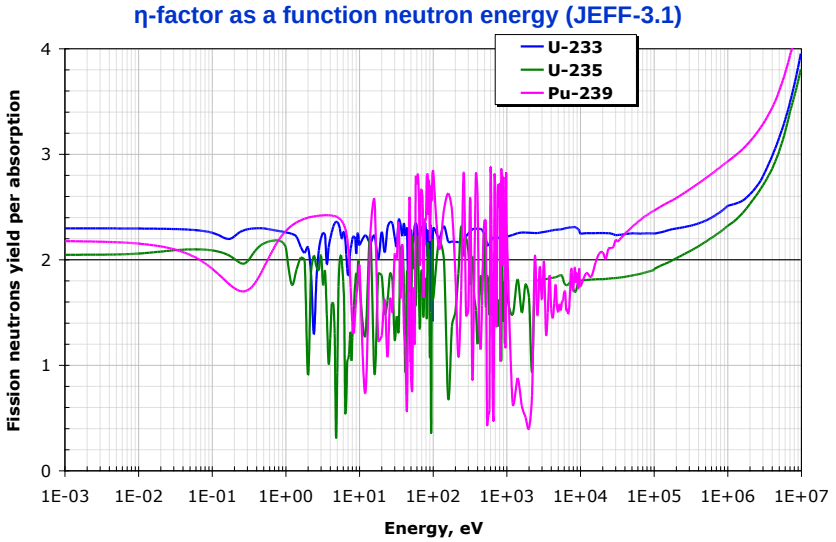
Introduction to Th-^{233}U fuel cycle

- **Self-sustainable fuel cycle:**
  - ThO_2-$^{233}UO_2$ Fuel with continuous recycling of ^{233}U
  - Standard ABWR balance of plant
  - Heterogeneous reactor assembly structure
  - Modifications should not compromise reactor safety

- **Evaluated parameters:**
  - K-inf vs. time
  - Fissile Inventory Ratio - $$FIR \equiv \frac{\text{Fissile mass at time } t}{\text{Initial fissile mass loading}}$$

Th-^{233}U methodology





- **Conversion Ratio →**

  hard spectrum

- **Hard spectrum →**

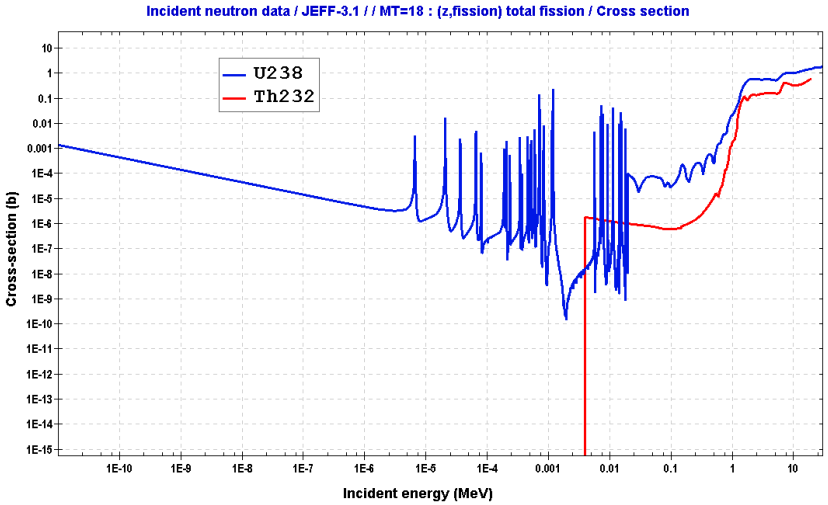
  Void Coefficient >0

- **Void Coefficient >0 →**

  heterogeneous geometry

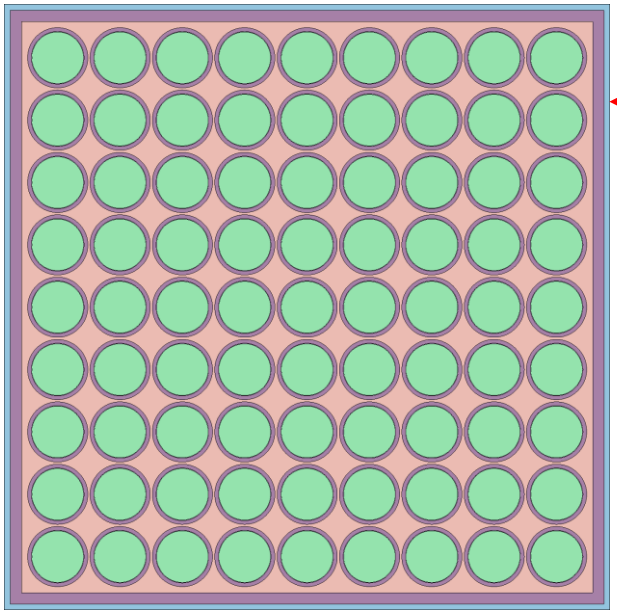
- **Heterogeneous geometry →**

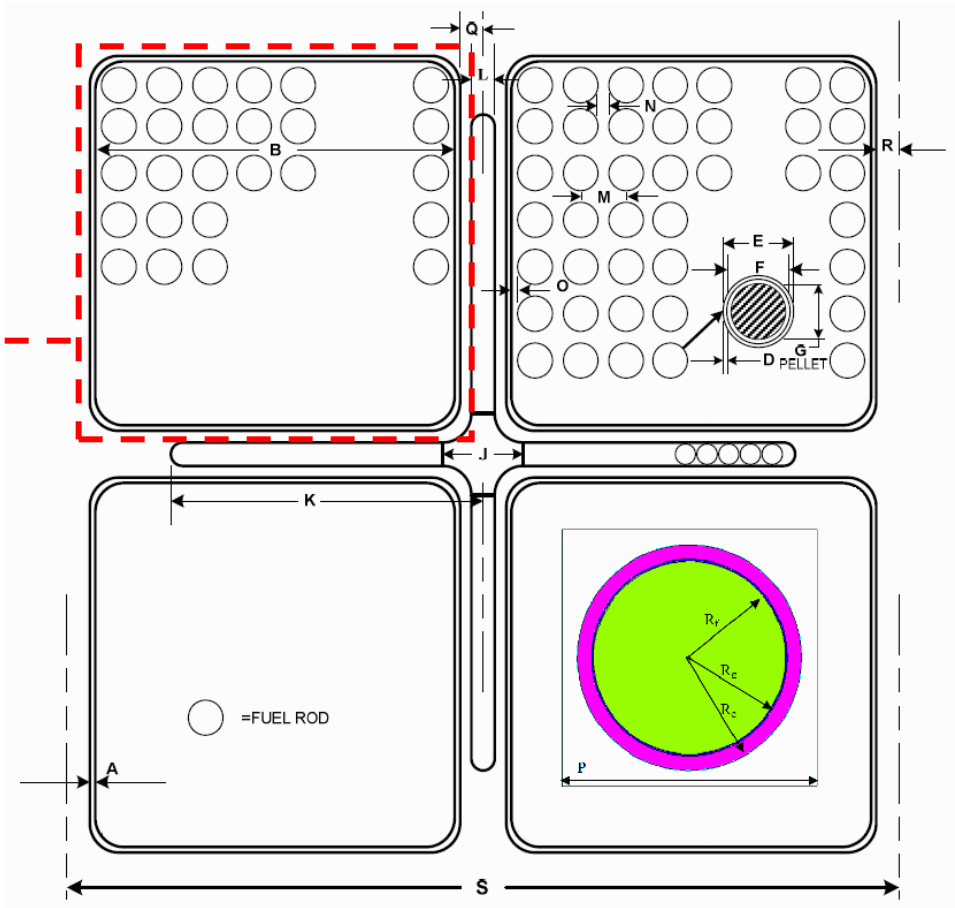
  limits core power density



Th-^{233}U Seed-Blanket BWR assembly

- BWR SB radial configuration
  - 9x9 lattice
  - No water holes



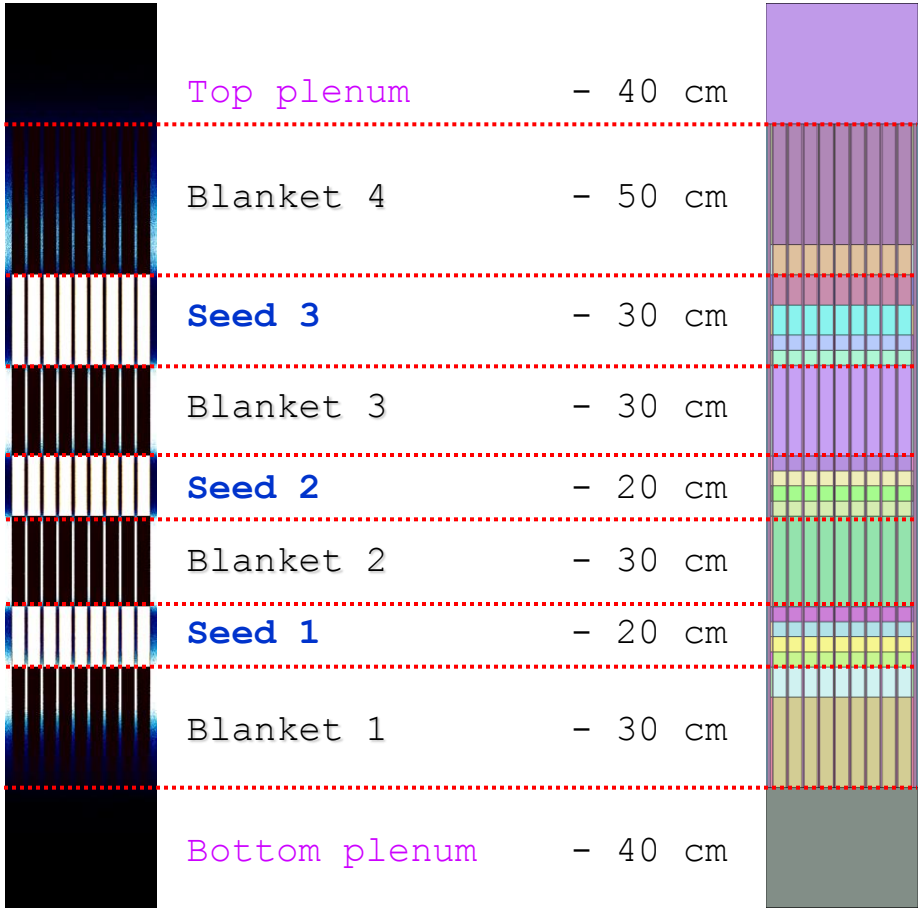


Axial configuration

- 3 axial Seed zones (Th-$^{233}UO_2$)
- 4 axial Blanket zones (ThO_2)
- Dimensions derived from prior analyses

Axial configuration

- Variable seed enrichment to manage power peaking
  - 18 burnable zones



Type	$^{233}UO_2$ Fraction [$^{w}/_{o}$]	Zone size [cm]	Moderator density [$^{g}/_{cc}$]
Top Plenum	-	40	0.14421
Blanket 4-b	0	40	0.14421
Blanket 4-a	0	10	0.14457
Seed 3-d	14	10	0.15406
Seed 3-c	13	10	0.17560
Seed 3-b	12	5	0.19586
Seed 3-a	10	5	0.21274
Blanket 3	0	30	0.22372
Seed 2-d	14	5	0.23655
Seed 2-c	15	5	0.26300
Seed 2-b	14	5	0.29318
Seed 2-a	13	5	0.33603
Blanket 2	0	30	0.36729
Seed 1-d	13	5	0.40522
Seed 1-c	13	5	0.49771
Seed 1-b	10	5	0.63108
Seed 1-a	7	5	0.74098
Blanket 1-b	0	10	0.74564
Blanket 1-a	0	30	0.74573
Bottom Plenum	-	40	0.74573

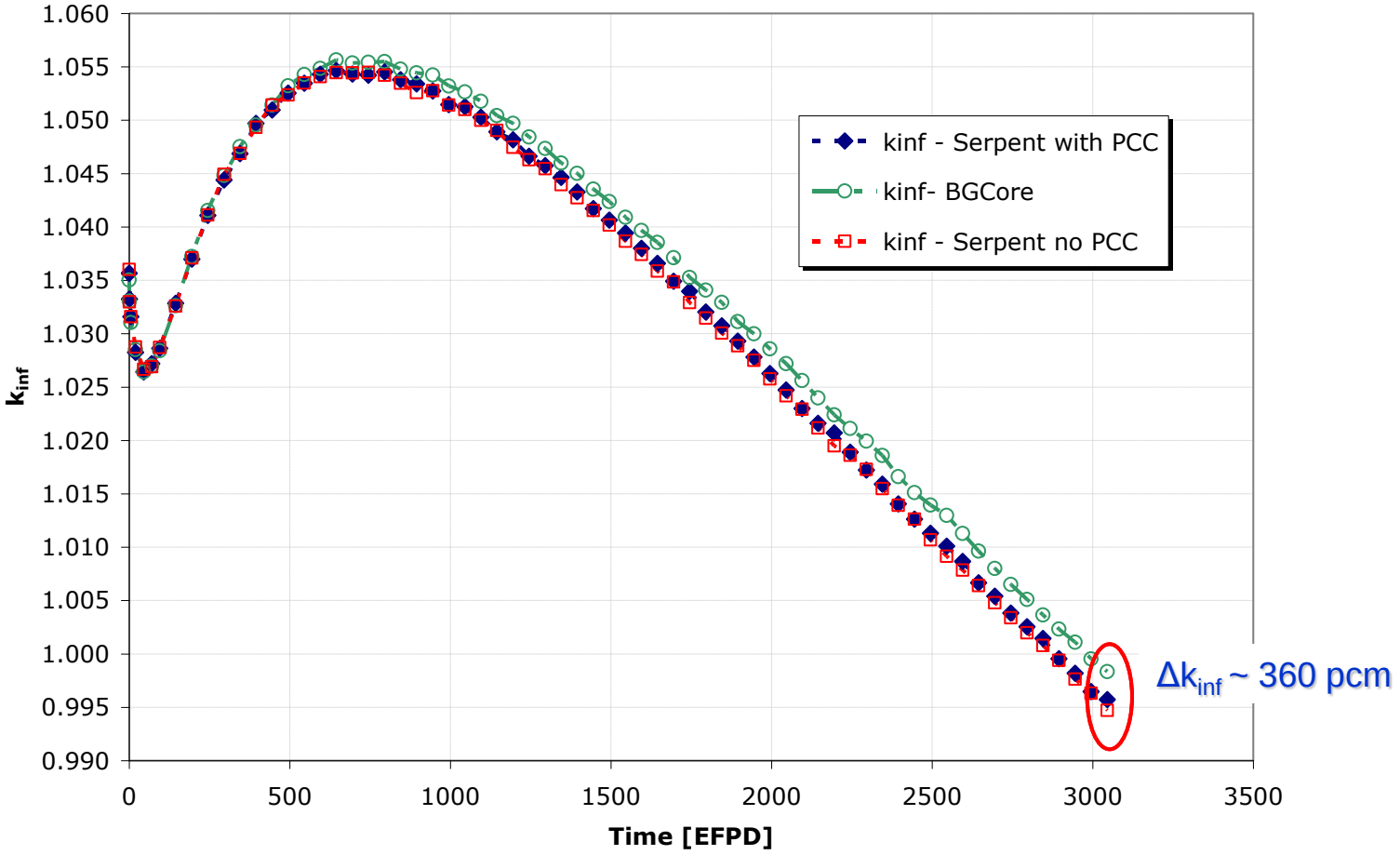
Description of computational tools

- BGCore
  - Neutron transport solution by MCNP
  - Multi-group cross sections for depletion (SARAF)
  - Thermo-hydraulic feedback (THERMO)

- Serpent (ver. 1.1.14)
  - Unique features
    - delta-tracking method
    - uniform energy grid for cross section data
    - depletion using CRAM-method

Results: Nutronic parameters

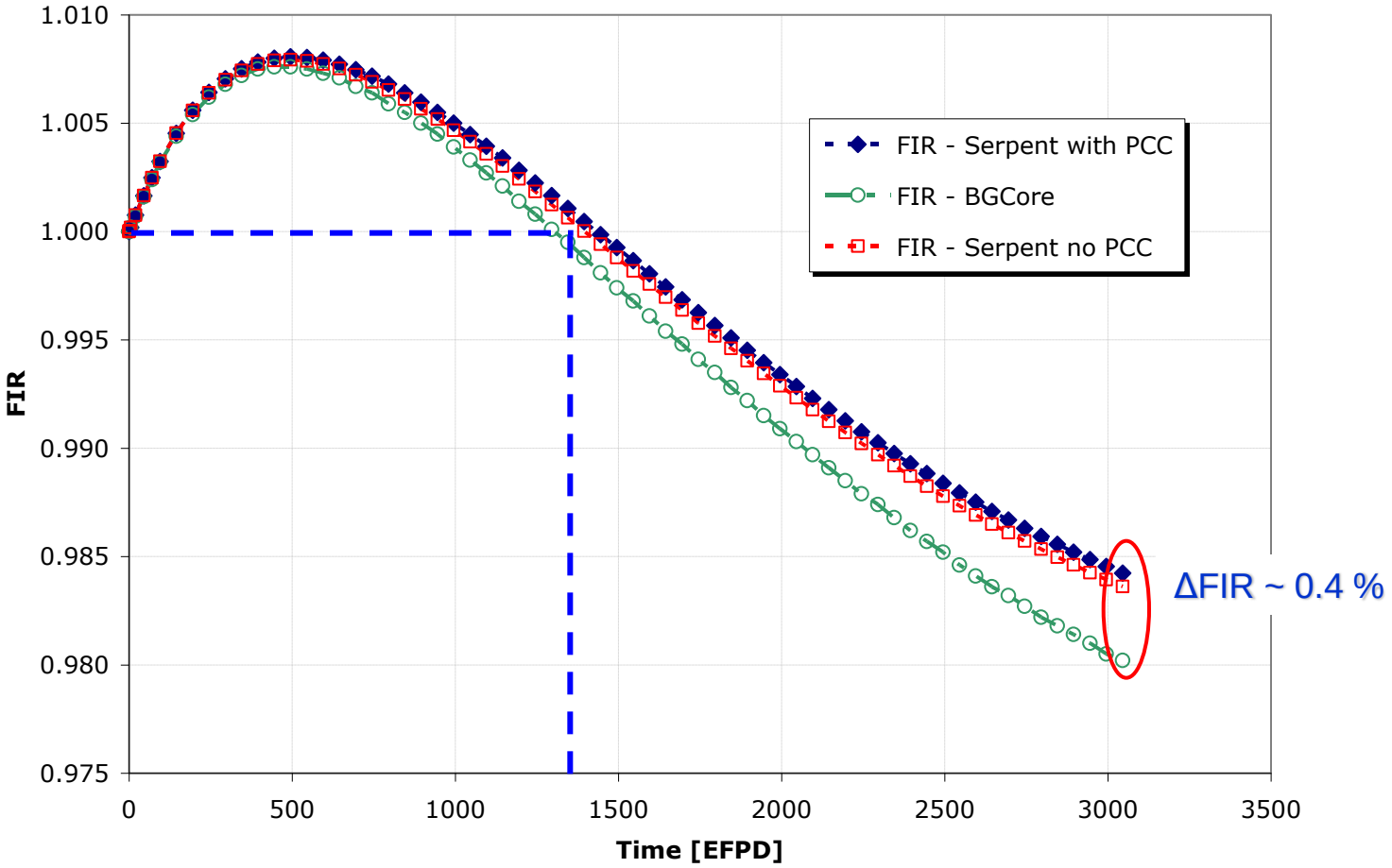
- Neutron multiplication factor - k_{inf}



* PCC – Predictor Corrector algorithm in Serpent

Results: Nutronic parameters

- Fissile Inventory Ration - FIR

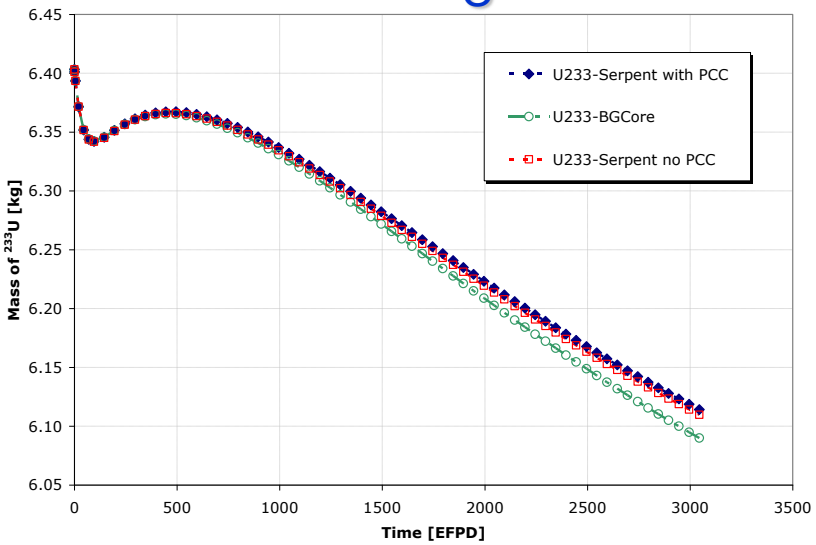


* PCC – Predictor Corrector isotope estimation in Serpent

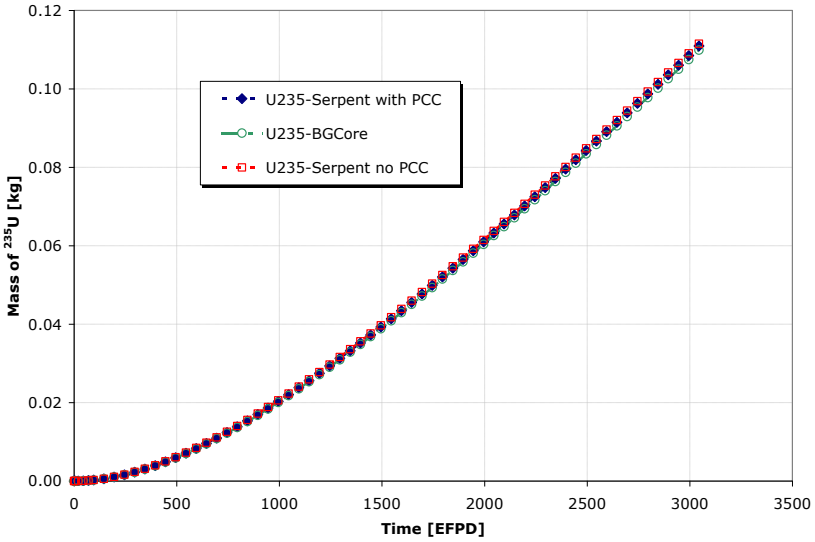
Results: Nutronic parameters

- Mass of ^{235}U
- Mass of ^{233}Pa
- Mass of ^{233}U
  - Under investigation

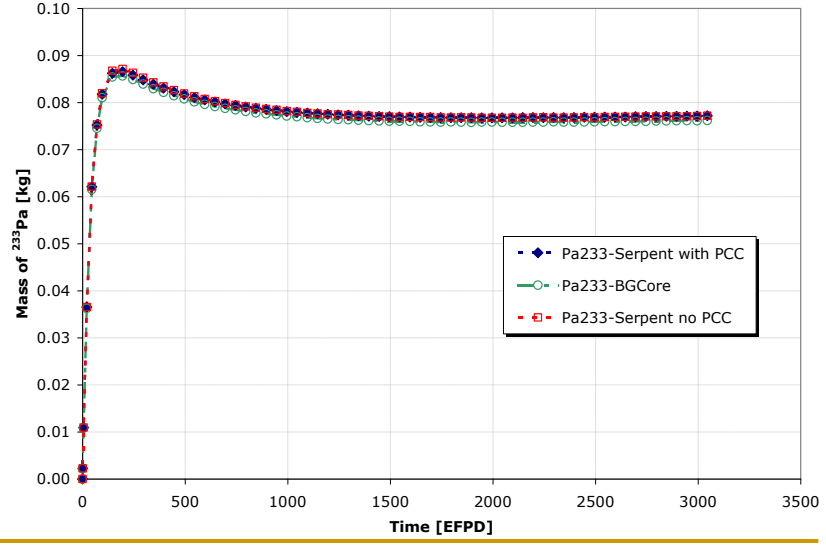
^{233}U



^{235}U



^{233}Pa



Remarks on computational efficiency

- Total Execution time
  - **Machine Configuration**
    - **SUN Intel(R) Xeon X2270**
    - **16 CPU's 2933 MHz**
    - **24 GB RAM memory**

* PCC – Predictor Corrector algorithm in Serpent

3CPU - Serpent with PCC Exe. Time [min]	3CPU - Serpent no PCC Exe. Time [min]	Speed-Up factor
1771.19	1113.92	**1.59**

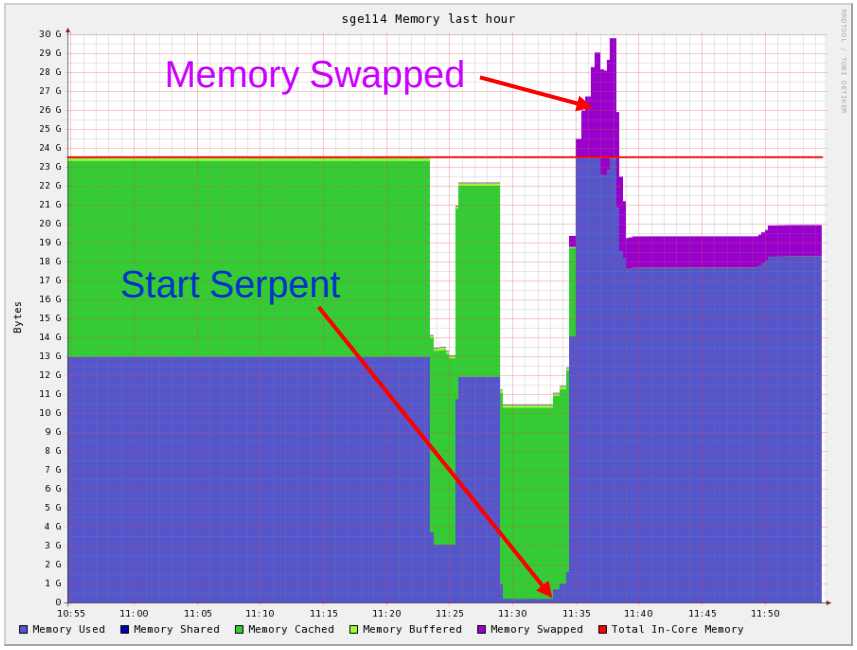
3CPU - BGCore no PCC Exe. Time [min]	3CPU - Serpent no PCC Exe. Time [min]	Speed-Up factor
6431.80	1113.92	**5.77**

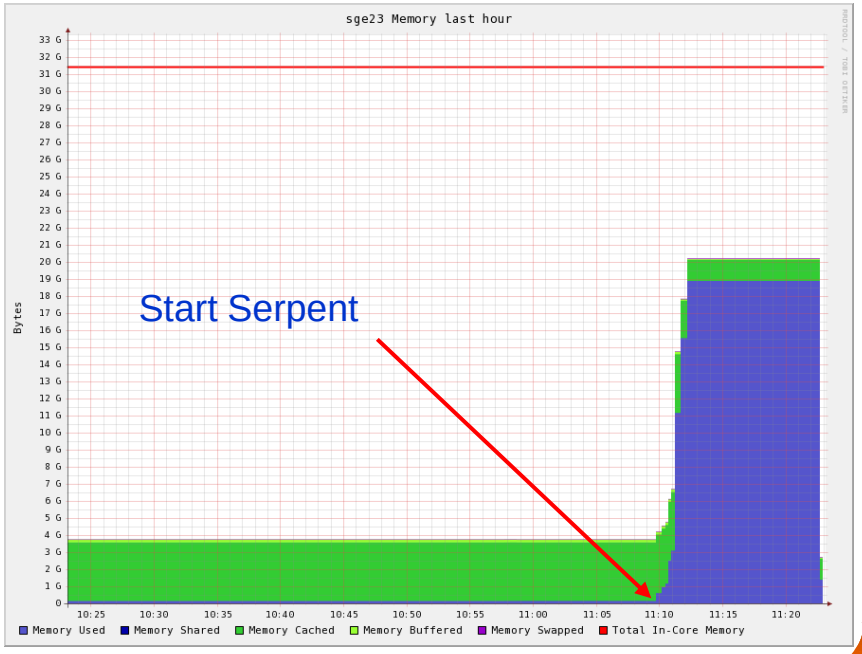
16CPU - BGCore no PCC Exe. Time [min]	3CPU - Serpent no PCC Exe. Time [min]	Speed-Up factor
2508.60	1113.92	**2.25**

Memory Limitation

Serpent Execution with 4 CPU

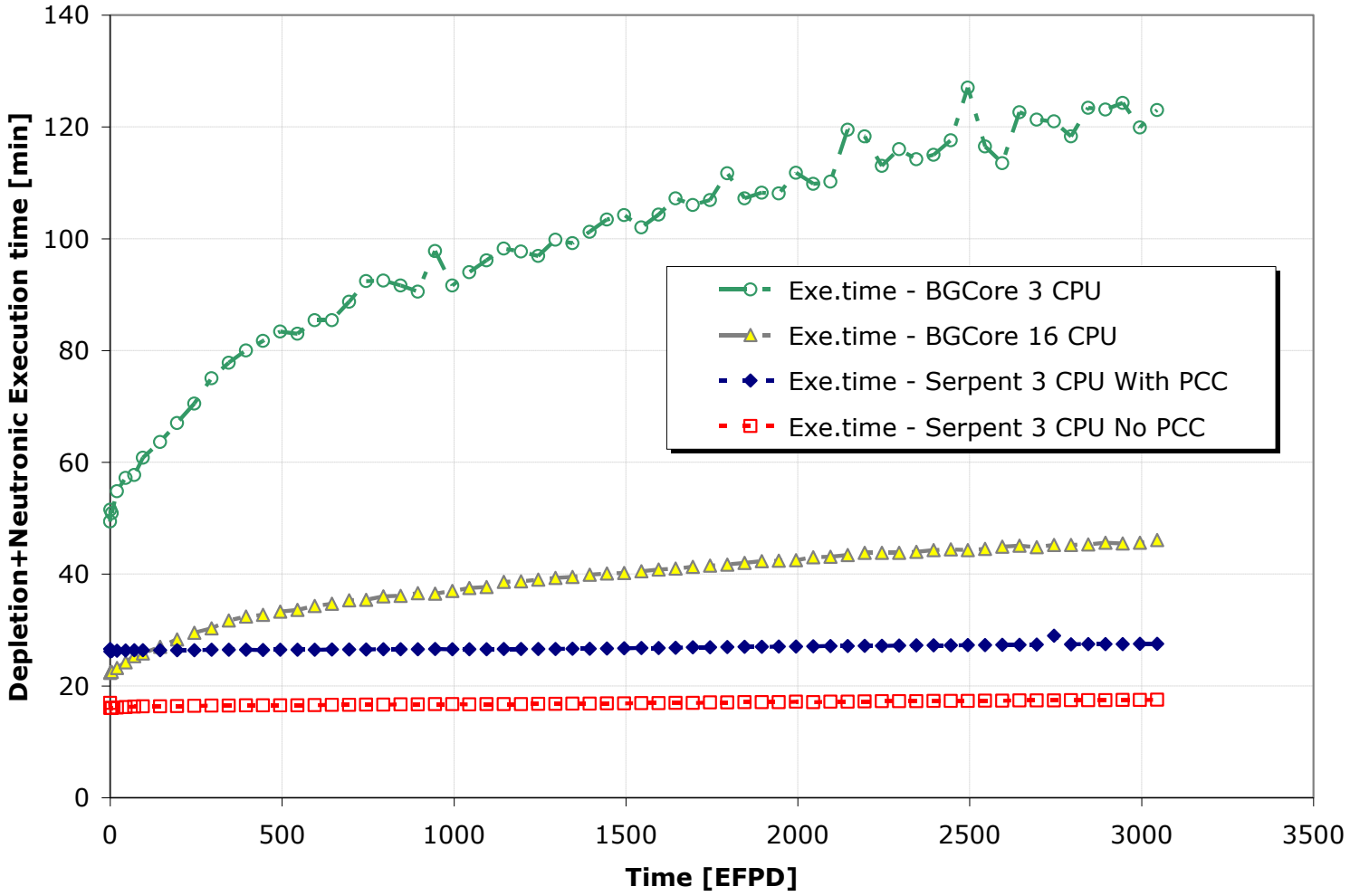
- **Machine Configuration**
  - **SUN Intel(R) Xeon X2270**
  - **16 CPU's 2933 MHz**
  - **24 GB RAM memory**
- **Machine Configuring**
  - **SUN AMD Opteron 2218**
  - **4 CPU's 2613 MHz**
  - **32 GB RAM memory**





CPU time

- Depletion + Transport Execution time



CPU time

- Total Execution time
  - **Machine Configuring**
    - **SUN AMD Opteron 2218**
    - **4 CPU's 2613 MHz**
    - **32 GB RAM memory**

1CPU - BGCore Exe. Time [min]	1CPU - Serpent Exe. Time [min]	Speed-Up factor
28940.30	3812.40	**7.59**

4CPU - Serpent Exe. Time [min]	1CPU - Serpent Exe. Time [min]	Speed-Up factor
1013.93	3812.40	**3.76**

Summary and Conclusions

- **Good agreement in neutronic parameters between Serpent and BGcore**
  - Up to 360 pcm in multiplication factor (at EOL)
  - Up to 0.4% in Fissile Inventory Ratio (at EOL)
  - Minor discrepancy in ^{233}U concentration (under investigation)

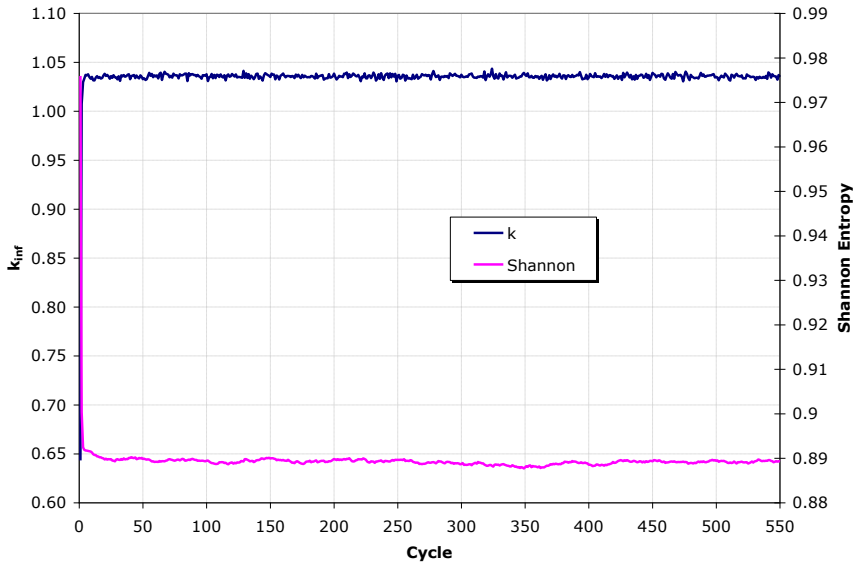
- **Calculation performance**
  - Serpent is ~ ×7 faster than BGCore
    - 1CPU – 7.6
    - 3CPU – 5.8
  - Memory allocation restricts Serpent performance
    - Bottleneck - Initial data preparation
    - At least 1 additional CPU is lost

Thank you

Statistical Accuracy - k-eigenvalue

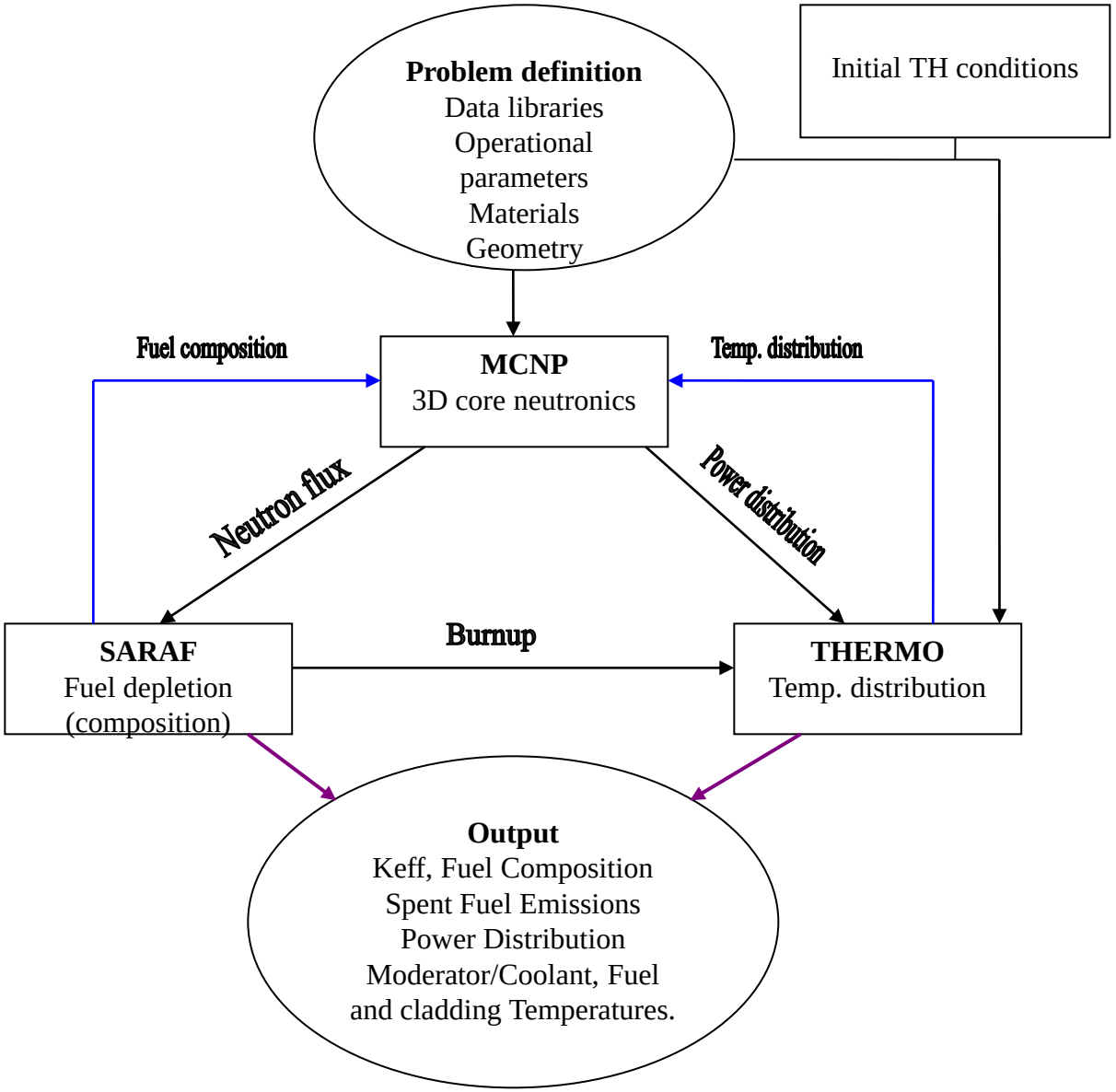
- 100,000 - Source neutrons
- 50 - Inactive cycles
- 100 - Active cycles
- 1.0 - Initial guess for k-eigenvalue

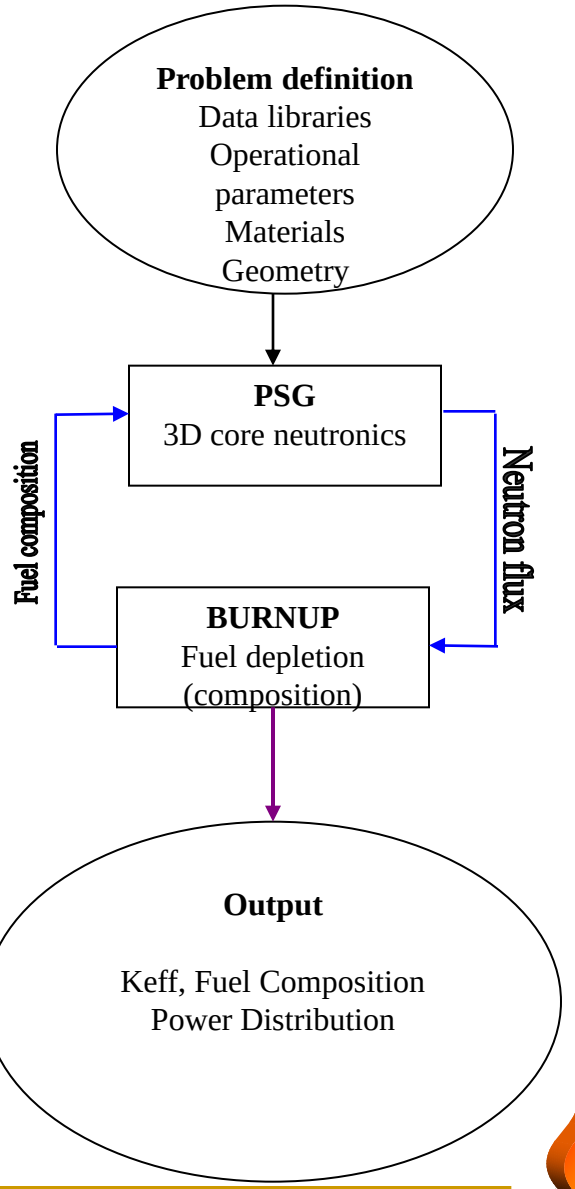
```
set pop 100000 100 50 1.0  - Serpent
kcode 100000 1.0 50 150    - MCNP
```

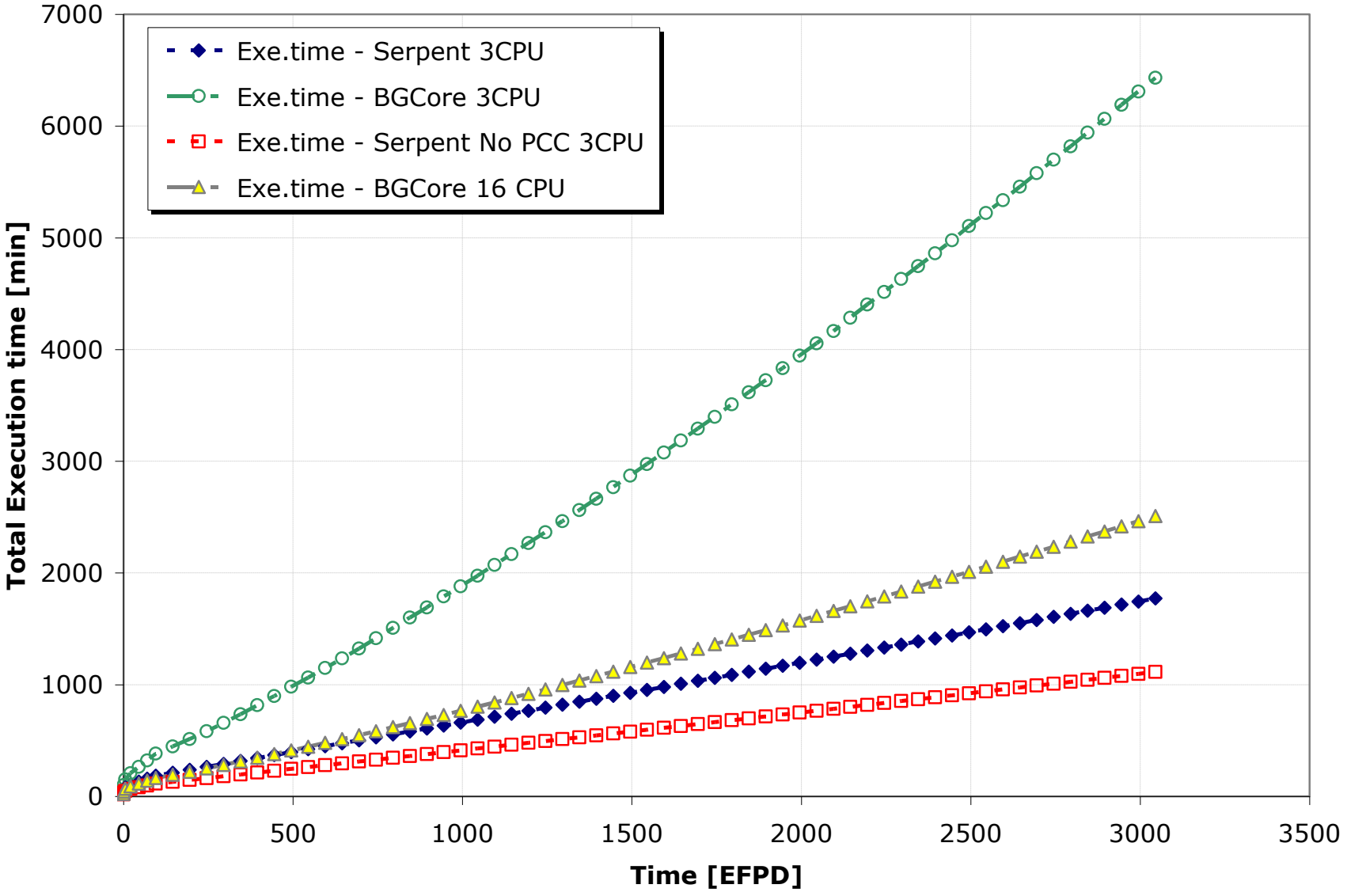


BGCore system

Serpent






Exe.time - Serpent 3CPU
Exe.time - BGCore 3CPU
Exe.time - Serpent No PCC 3CPU
Exe.time - BGCore 16 CPU
Total Execution time [min]
Time [EFPD]
0
1000
2000
3000
4000
5000
6000
7000
0
500
1000
1500
2000
2500
3000
3500