High conversion Th-U^{233} fuel assembly for current generation of PWRs

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OUTLINE

- Objectives
- Codes
- IAEA benchmark
- Fuel assembly design optimization
- Results
- Summary

OBJECTIVES

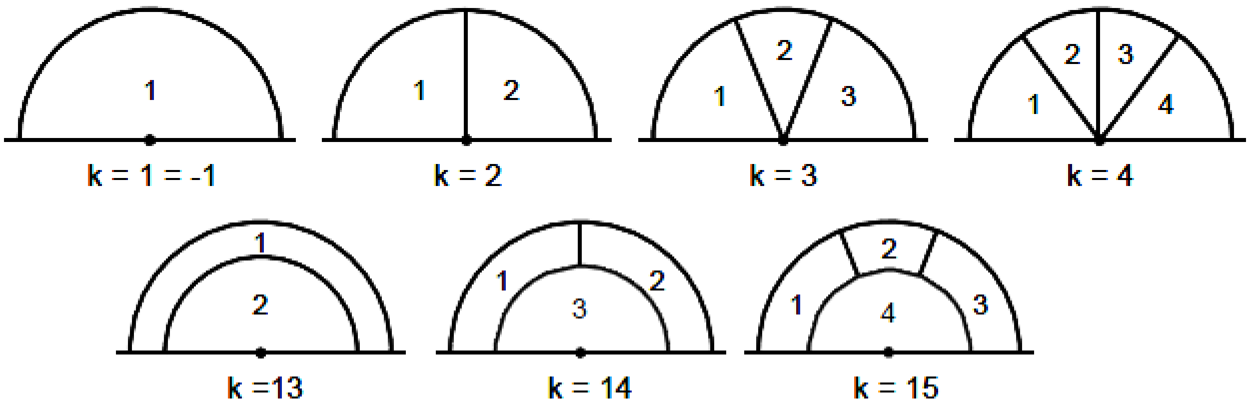
- To improve utilization of natural resource in current PWRs
- Via the use of high conversion Th-U^{233} fuel cycle
  - Heterogeneous seed-blanket fuel assembly design
  - In closed fuel cycle
- The assembly should be retrofittable into a PWR core
  - Typical 17x17 PWR lattice
  - Standard operating conditions
  - Without affecting the safety

CODES

- HELIOS
  - Lattice transport code
  - Collision probabilities with current coupling
  - Used as a production code in the study
- SERPENT
  - Used for:
    - Benchmarking purposes
    - Evaluation of spent fuel characteristics

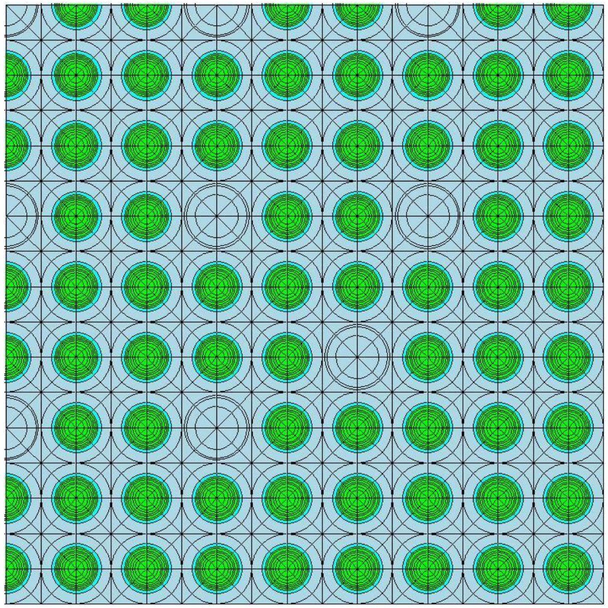
IAEA Th BENCHMARK
Helios vs. Serpent

- To verify Helios capabilities for the Th based fuel analysis
- To find optimal setup options for Helios
  - Resonance categories, current coupling, discretization
  - No clear recommendation from developer



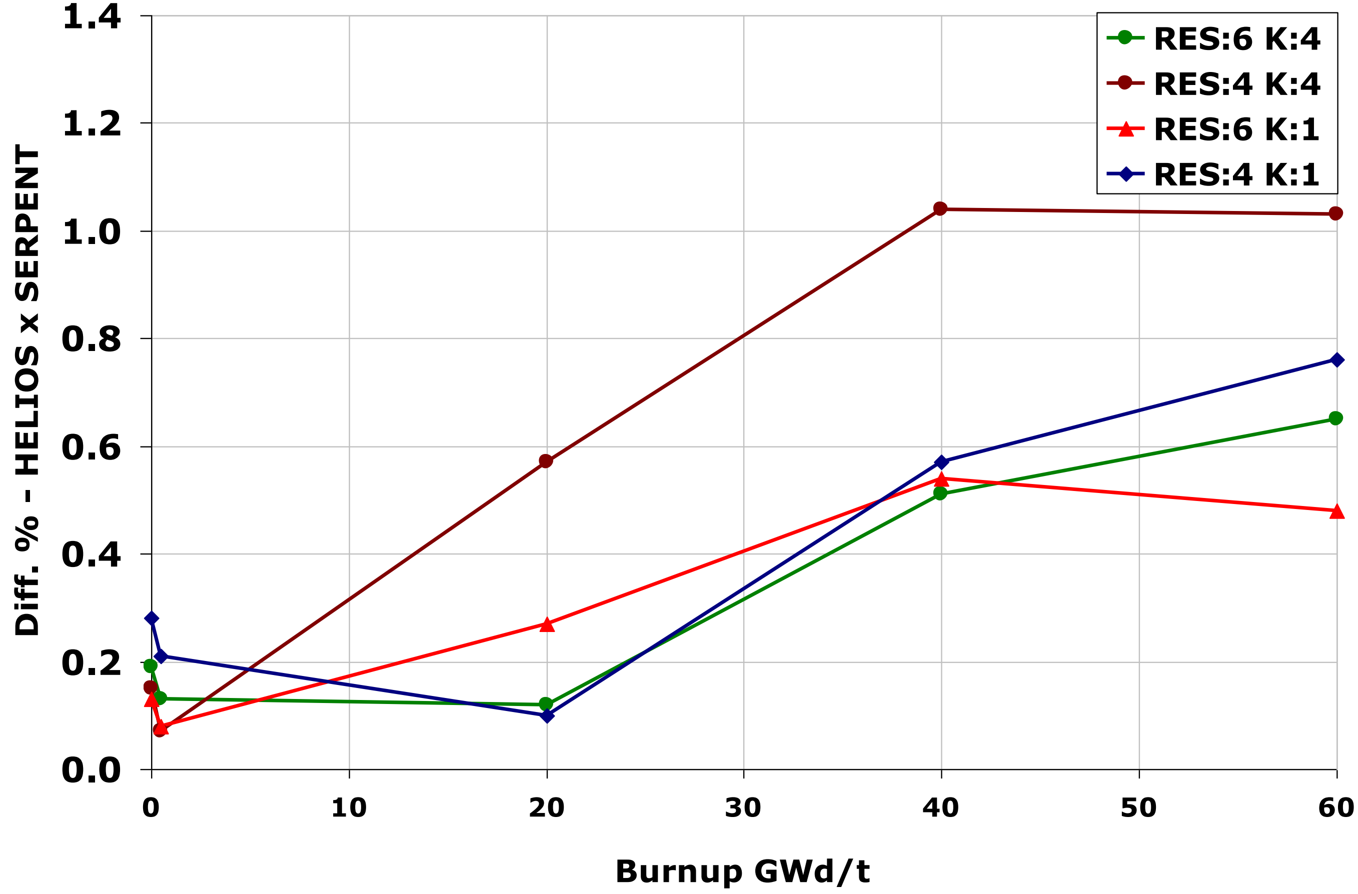
IAEA BENCHMARK

- Fuel assembly parameters
- Th-Pu fuel
- 17x17 PWR fuel assembly lattice
- 25 water hole positions
- Power density of 37.7 MW/t

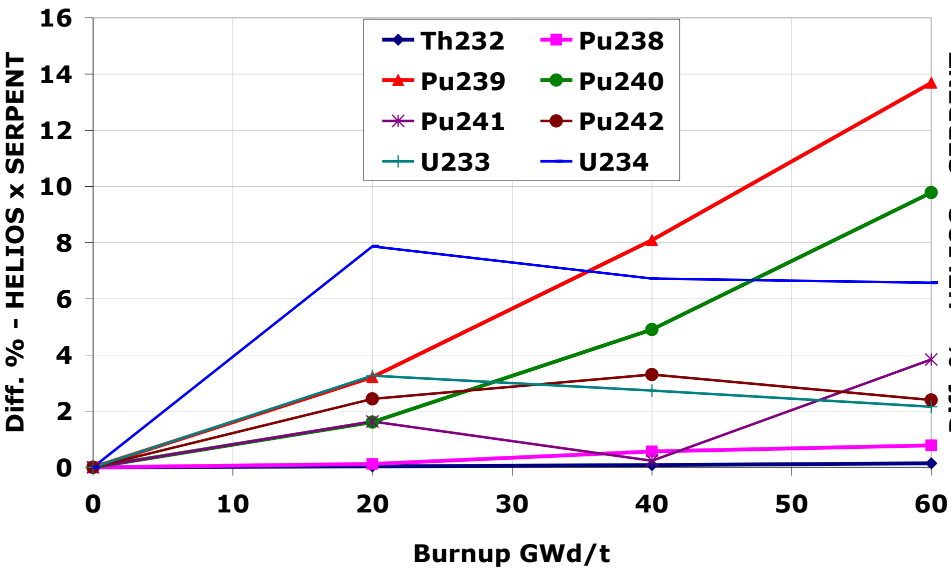


One quarter of fuel assembly

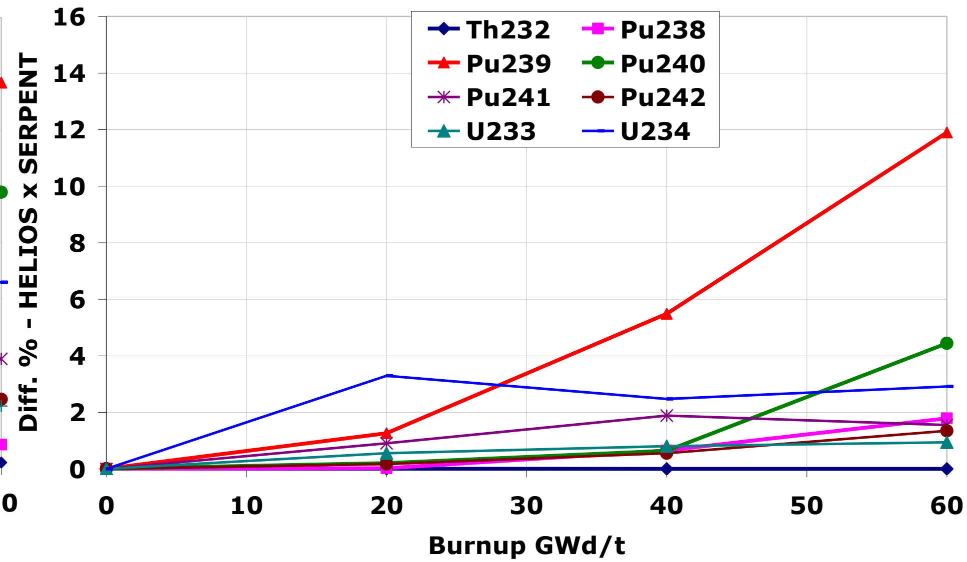
IAEA benchmark results – Kinf
Serpent vs. Helios



IAEA benchmark results – Number densities Serpent vs. Helios



Res:6 K:4



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DRESDEN concept HZDR

IAEA benchmark results – Power map BOL Serpent vs. Helios

W								
1.10%	0.81%							
1.25%	0.85%	1.25%						
W	0.90%	0.87%	W					
0.39%	0.80%	0.85%	0.77%	0.04%				
0.61%	0.71%	0.59%	1.18%	1.18%	W			
W	1.42%	1.50%	W	1.62%	1.24%	0.37%		
0.51%	0.37%	0.51%	0.72%	0.40%	0.62%	1.12%	0.83%	
0.85%	1.56%	0.71%	0.74%	0.79%	0.87%	0.67%	0.80%	0.08%

Max. error – 1.62 %

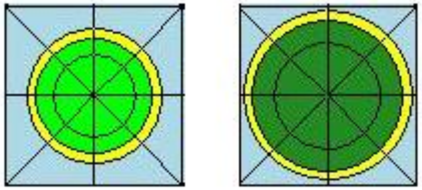
Average error – 0.75 %

Res:6 K:1

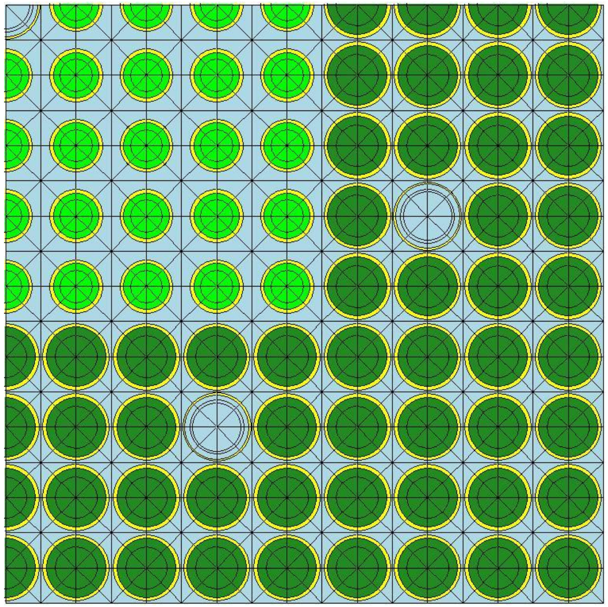
FUEL ASSEMBLY DESIGN OPTIMIZATION

Seed-Blanket fuel assembly design

- Th-U^{233} Fuel
- Typical 17x17 PWR lattice
- 80 seed and 200 blanket pins
- 9 guide tubes
- Seed pin radius – 0.4095 cm
- Blanket pin radius – 0.5300 cm (Enlarged)
- Power density 70 W/cm^3
  - High peaking in seed



Seed Blanket



One quarter of 17x17 SB fuel assembly

FUEL ASSEMBLY DESIGN OPTIMIZATION

Methodology

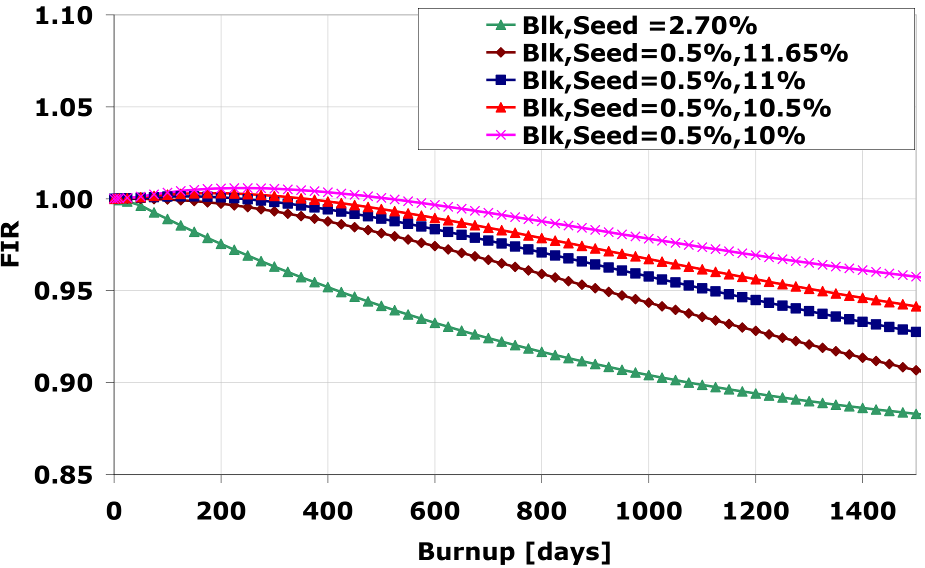
- 2D fuel assembly level
- Non Linear Reactivity Model
  - For estimation of k-eff and fuel cycle length
- To calculate
  - Fissile inventory ratio (FIR)
  - Fuel cycle length
  - Keff core
  - Local pin-by-pin power distribution
  - Activity of discharged fuel
- Constrains
  - 3 batches, 18 month fuel cycle
  - Keff > 1 during the fuel cycle

FUEL ASSEMBLY DESIGN OPTIMIZATION

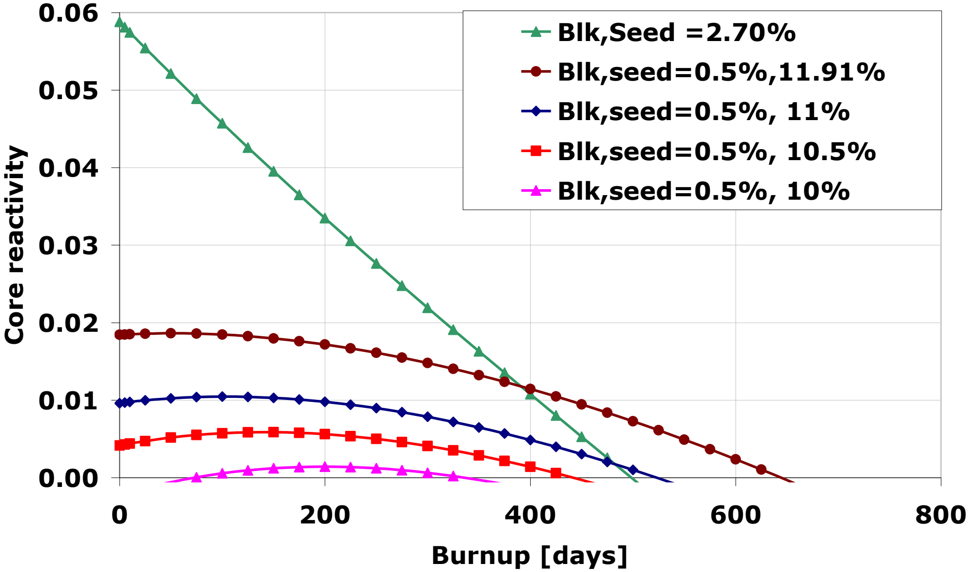
Strategy

- Start with the equal seed and blanket enrichment
    - Adjust the enrichment to achieve the desired fuel cycle length
- Decrease enrichment in blanket while keeping the total U^{233} amount
- Decrease enrichment in seed while keeping the enrichment in blanket

RESULTS obtained by Helios



Fissile inventory ratio



Core reactivity

For optimized fuel assembly:

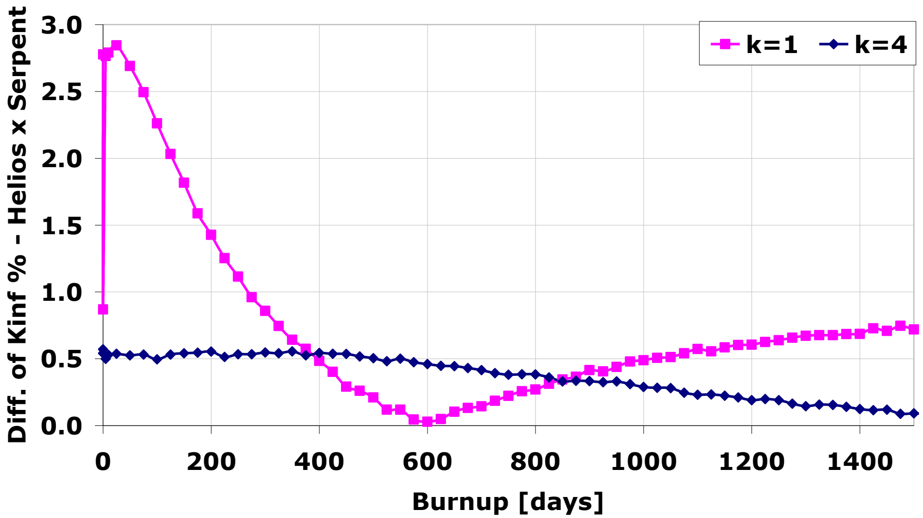
- FIR = 0.95
- Fuel cycle length = 440 EFPD

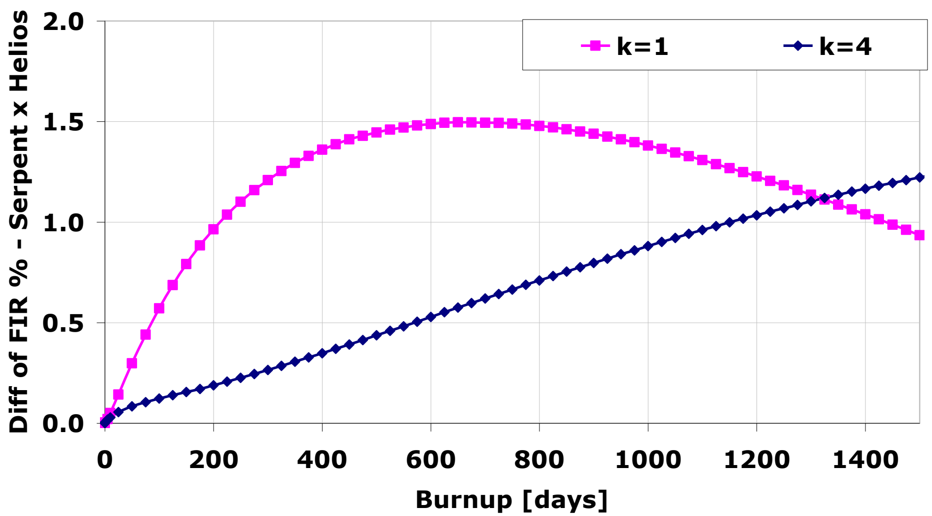
RESULTS obtained by Helios

Power map

W								
1.43	2.77							
1.35	2.69	2.69						
1.37	2.74	2.77	2.85					
1.49	2.99	3.04	3.13	3.32				
0.18	0.37	0.38	0.40	0.40	0.41			
0.20	0.40	0.41	W	0.42	0.41	0.41		
0.20	0.41	0.42	0.43	0.42	0.41	0.41	0.41	
0.20	0.41	0.41	0.42	0.42	0.41	0.41	0.41	0.41

RESULTS confirmation with SERPENT





Difference of Kinf

Difference of FIR

RESULTS confirmation with SERPENT

Differences in power map

W								
0.61%	0.60%							
0.63%	0.42%	0.63%						
0.69%	0.70%	0.52%	0.77%					
0.40%	0.69%	0.45%	0.73%	0.05%				
0.36%	0.36%	0.54%	0.19%	0.77%	0.80%			
0.07%	0.08%	0.53%	W	0.53%	0.60%	0.47%		
0.14%	0.57%	**0.88%**	0.27%	0.78%	0.62%	0.74%	0.45%	
0.38%	0.35%	0.12%	0.07%	0.56%	0.83%	0.76%	0.50%	0.50%

Max. error – 0.88 %
Average error – 0.52 %

PRODUCTION OF U^{233}

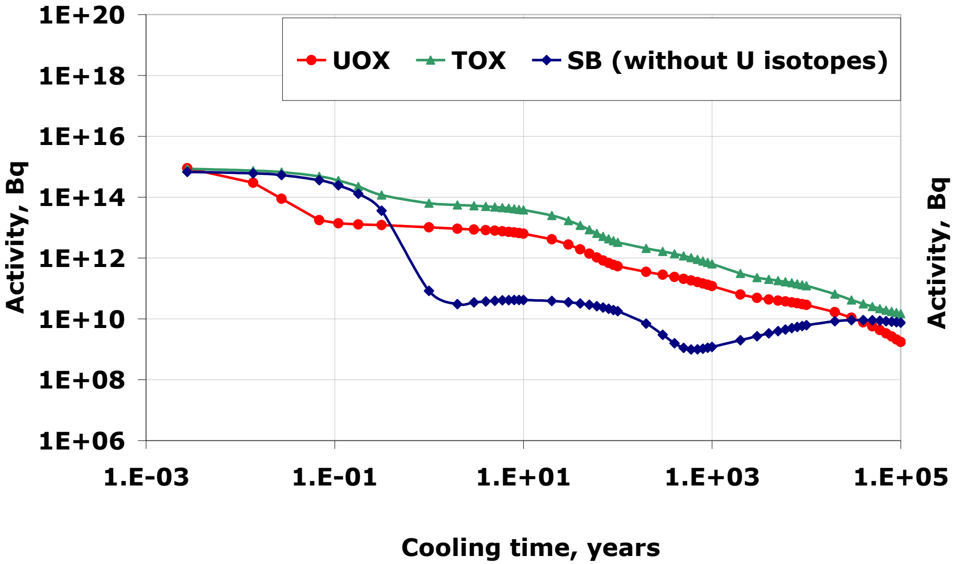
- Creation of U^{233} is necessary
  - Initial
  - Makeup (FIR<1)
- How to create U^{233}:
  - UO_2-ThO_2
  - PuO_2-ThO_2 (TOX)

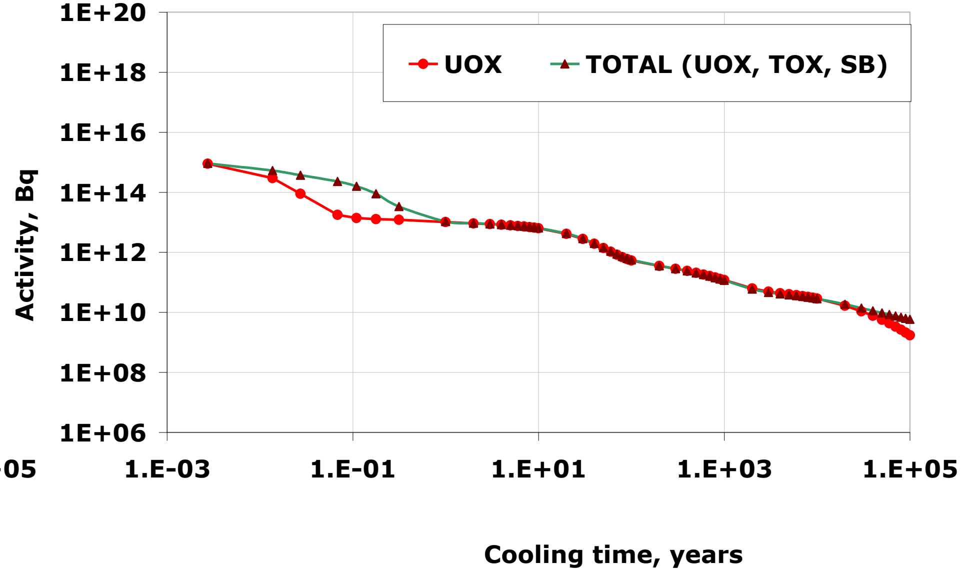
- How many UOX and TOX cores are needed at equilibrium:

ENERGY BALANCE

UOX 1 + TOX 0.13 + SB 0.88 * 0.7 = 1.75

ACTINIDES ACTIVITY IN DISCHARGED FUEL





- Calculated by Serpent
- Depletion till 1350 EFPD
- Decay till 10^5 years

CONCLUSION

- Helios verifications
  - Results in good agreement with Serpent
- For optimized Th-U233 assembly:
  - FIR of about 0.95 can be achieved
  - Generation of U^{233} in TOX core was considered
  - 75% increase in NU utilization
  - No decrease in the discharged fuel activity
- Future work:
  - Detailed T-H analysis
  - Demonstration of sufficient shutdown margins
  - Confirmation of 2D results via full core calculations

Thank you for your attention!