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Consistent Code-to-Code Comparison of Pin-cell Depletion Benchmark Suite

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CORE

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VERA depletion benchmark suite

Consistent Code-to-Code Comparison of Pin-cell Depletion Benchmark Suite

VERA depletion benchmark suite

- When verifying the depletion calculation module of reactor analysis codes, the code-to-code comparisons of depletion benchmark calculation results can be one of the viable methods.

- A depletion benchmark suite has been developed based on "The VERA core physics benchmark progression problems*".

*AT. Godfrey, The VERA Core Physics Benchmark Progression Problem Specifications, CASL-U-2012-0131-004, Rev. 4, Oak Ridge National Laboratory, 2014.

VERA depletion benchmark suite

- **The VERA depletion benchmark problems include 10 single fuel pin problems with various fuel temperatures, enrichment of ^{235}U, and burnable poisons.**

Problem	Description	Temperature (K)			Moderator density (g/cm^3)	^{235}U w/o	Power density (w/gU)
		Moderator	Cladding	Fuel			
1A	Pin (3.1w/o)	565	565	565	0.743	3.1	40.0
1B	Pin (3.1w/o)	600	600	600	0.700	3.1	40.0
1C	**Pin (3.1w/o)**	**600**	**600**	**900**	**0.700**	**3.1**	**40.0**
1D	Pin (3.1w/o)	600	600	1200	0.700	3.1	40.0
1E	Pin (IFBA)	600	600	900	0.700	3.1	40.0
1F	Pin (2.1w/o)	600	600	900	0.700	2.1	40.0
1G	Pin (3.6w/o)	600	600	900	0.700	3.6	40.0
1H	Pin (4.6w/o)	600	600	900	0.700	4.6	40.0
1I	**Pin (Gadolinia)**	**600**	**600**	**900**	**0.700**	**1.8**	**40.0**
1J	Pin (3.1w/o)	600	600	600/900/1200	0.700	3.1	40.0

VERA depletion benchmark suite

- **The VERA depletion benchmark suite provides a recommended burnup step and depletion intra-zone for each problems.**
  - **40 burnup steps**

Step	MWD / kgU	Step	MWD / kgU	Step	MWD / kgU	Step	MWD / kgU
1	0.00	11	7.00	21	17.00	31	37.50
2	0.01	12	8.00	22	18.00	32	40.00
3	0.25	13	9.00	23	19.00	33	42.50
4	0.50	14	10.00	24	20.00	34	45.00
5	1.00	15	11.00	25	22.50	35	47.50
6	2.00	16	12.00	26	25.00	36	50.00
7	3.00	17	13.00	27	27.50	37	52.50
8	4.00	18	14.00	28	30.00	38	55.00
9	5.00	19	15.00	29	32.50	39	57.50
10	6.00	20	16.00	30	35.00	40	60.00

  - **3 depletion zones for UO_2 pins and 5 zones for gadolinia pin.**

VERA depletion benchmark suite

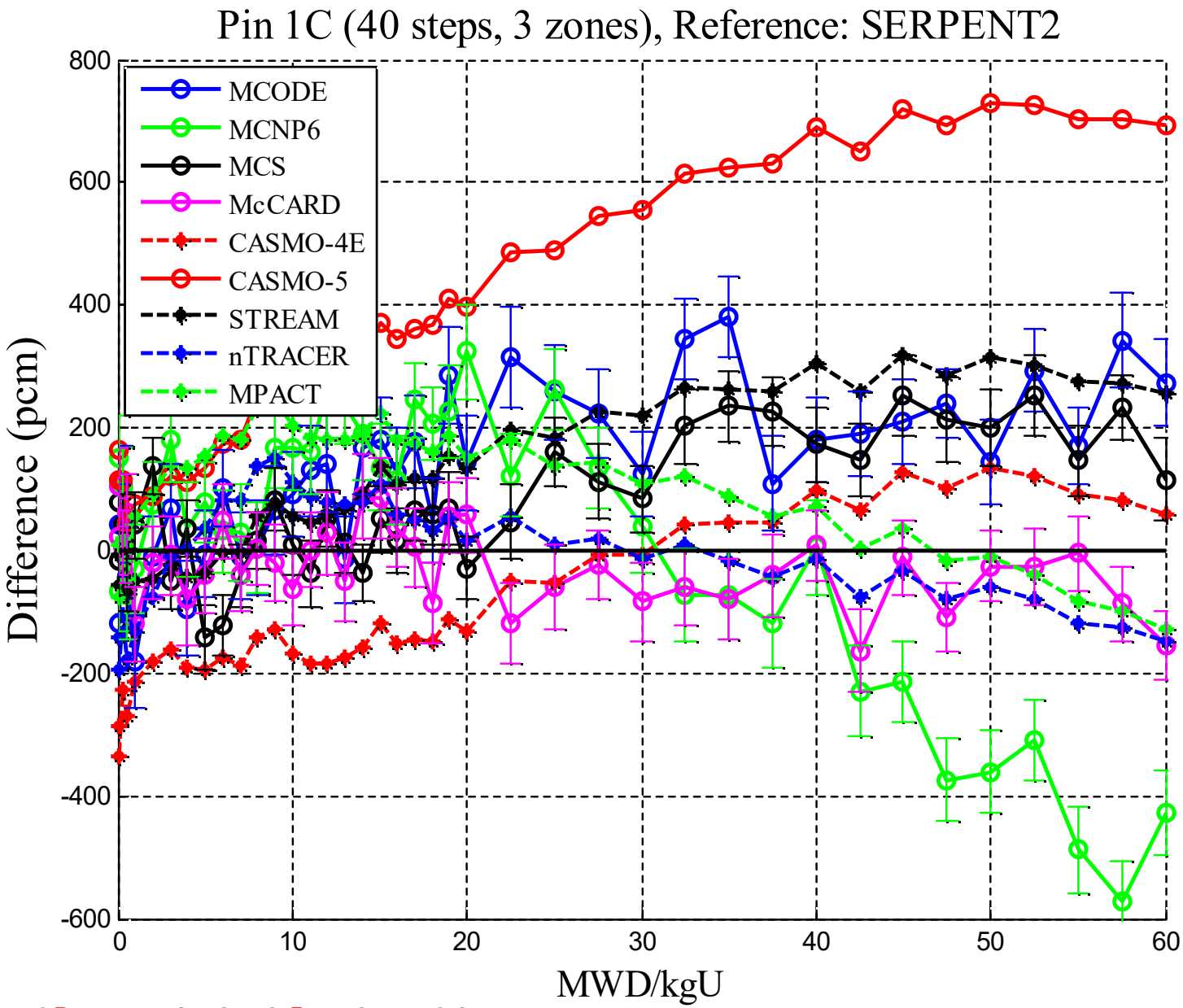
▪ Code-to-Code comparison

• Depletion calculation information.

Code	SERPENT2	MCODE (MCNP5 + ORIGEN2.2)	MCNP6	MCS	CASMO-5	STREAM	McCARD	nTRACER	MPACT
Developer	VTT	MIT	LANL	UNIST	Studsvik	UNIST	SNU	SNU	CASL
Transport	MC	MC	MC	MC	MOC	MOC	MC	MOC	MOC
Energy group	CE	CE	CE	CE	586	72	CE	47	47
XS Library	ENDF/B-VII.0	ENDF/B-VII.0	ENDF/B-VII.0	ENDF/B-VII.0	ENDF/B-VII.1	ENDF/B-VII.0	ENDF/B-VII.0	ENDF/B-VII.0	ENDF/B-VII.0
Kappa data	SERPENT2	ORIGEN2.2	MCNP6	VERA	CASMO-5	VERA	ORIGEN2.2	ENDF/B-VII.0 + (nu-1) 6.1MeV for parasitic γ	ENDF/B-VII.0 + Inhouse
Decay library	ENDF/B-VII	ORIGEN2.2 (ENDF/B-VI)	CINDER90	ORIGEN2.2	ENDF/B-VII + α	ORIGEN2.2	ORIGEN2.2	ORIGEN	ORIGEN-S (ENDF/B-VII.0)
Yield library	ENDF/B-VII	ORIGEN2.2 (ENDF/B-VI)	CINDER90	ENDF/B-349	ENDF/B-VII + α	ENDF/B-349	ENDF/B-349	ORIGEN	ORIGEN-S (ENDF/B-VII.0)
Depletion solver	CRAM	MEM (ORIGEN2.2)	MEM (CINDER90)	CRAM	CRAM	CRAM	MEM	Krylov	MEM (ORIGEN-S)
Predictor-Corrector	Full-PC	Semi-PC	Full-PC	Full-PC	Semi-PC	Full-PC	Semi-PC	Semi-PC	Full-PC
Equilibrium Xe	Possible	Impossible	Impossible	Impossible	Possible	Impossible	Impossible	Possible	Possible
Critical spectrum	Possible	Impossible	Impossible	Impossible	Possible	Possible	Impossible	Possible	Possible
Gd treatment	-	-	-	-	QD	QD	-	QD	Post correction

VERA depletion benchmark suite

- **How can we trust this results?**



Sensitivity study

Consistent Code-to-Code Comparison of Pin-cell Depletion Benchmark Suite

Sensitivity study

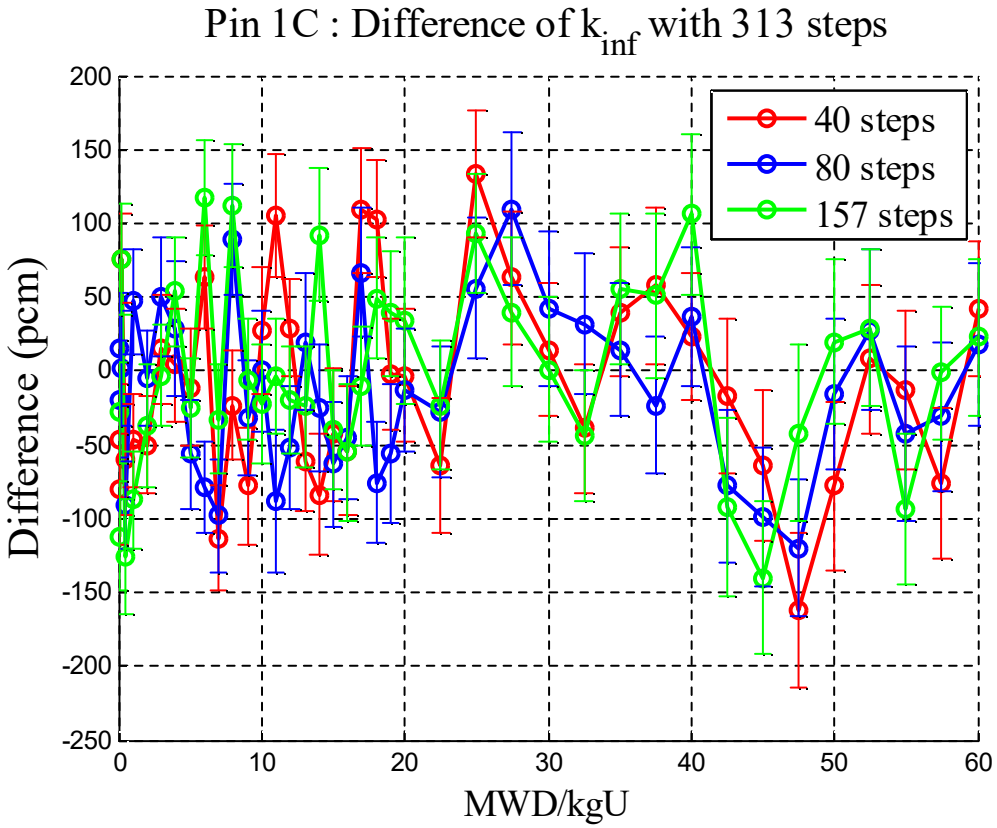
- **Solver-dependent**
  - Burnup interval sensitivity
  - CRAM and MEM
- **Problem-dependent**
  - Depletion intra-zone sensitivity
  - UO_2 and Gadolinia
- **Data-dependent**
  - Q-value sensitivity
  - Kappa from ORIGEN, SERPENT2, and VERA

Sensitivity study

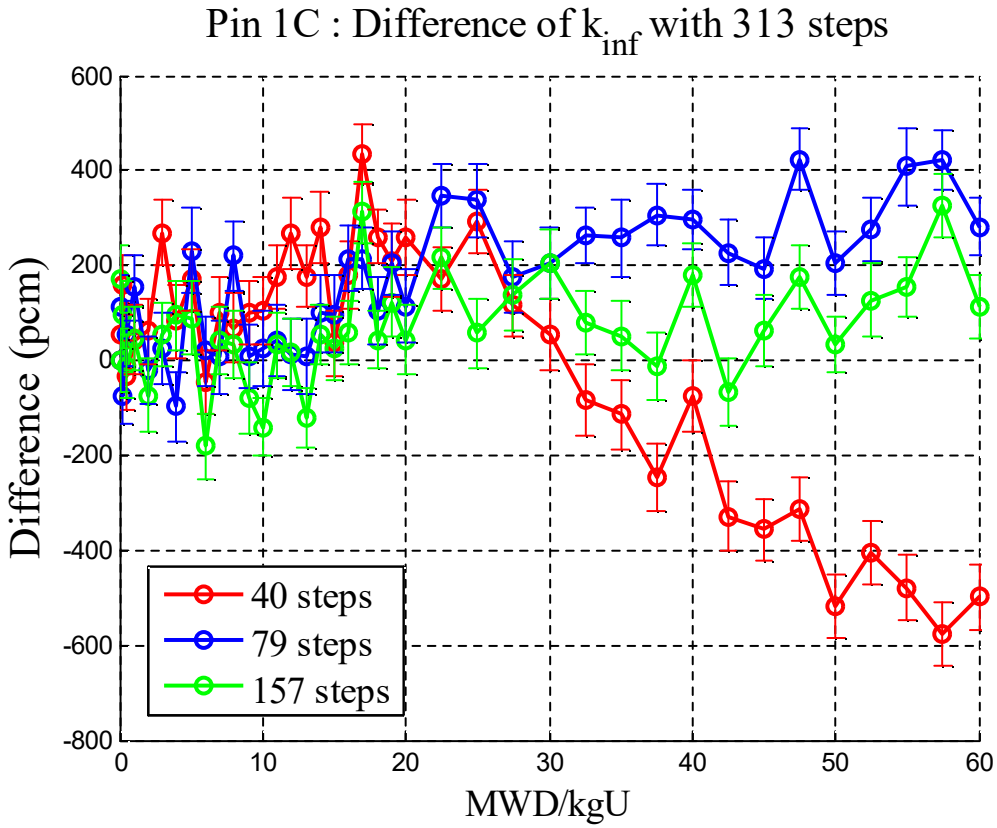
- **Burnup interval sensitivity**
  - Test was performed using
    - SERPENT2 : CRAM
    - MCNP6 : MEM w/o sub-step
  - For the case: 1C, 1I.
  - Monte Carlo histories,
    - Pin: 20,000 history/cycle, 20 inactive cycle, 80 active cycle
  - Depletion intra-zone,
    - UO_2: 3 zones
    - Gadolinia: 5 zones
  - Based on 40 burnup points, splitting intervals,
    - 40 intervals
    - 79 intervals
    - 157 intervals
    - 313 intervals

Sensitivity study

- **Burnup interval sensitivity**
  - **Difference of multiplication factor from 313 steps using SERPENT2 and MCNP6 for problem 1C.**



SERPENT2



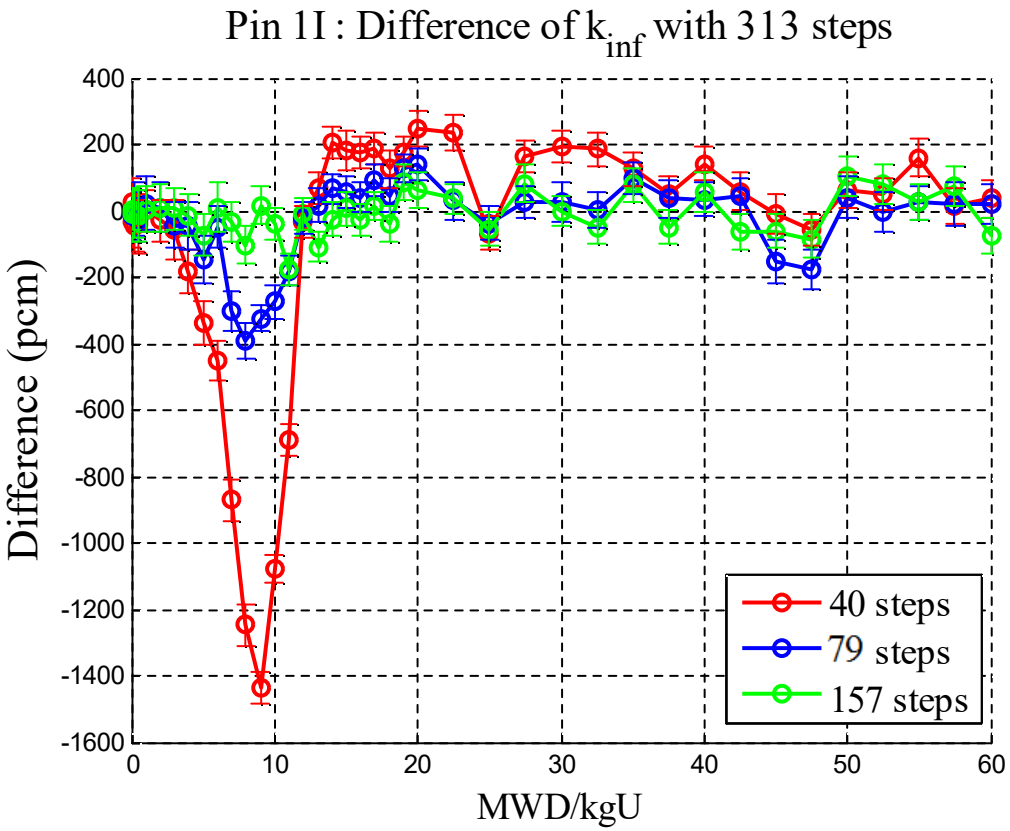
MCNP6

*For normal UO_2 pin problem, 40 burnup intervals is sufficient by using CRAM. However, it is insufficient by using MEM.

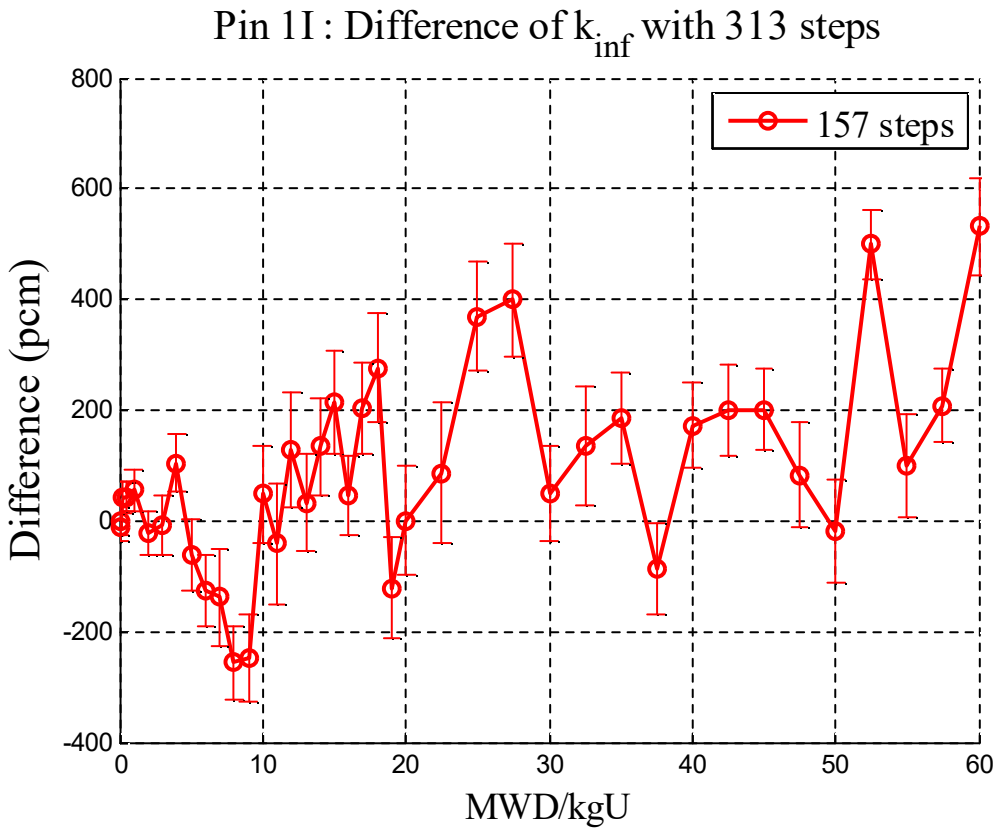
Sensitivity study

Burnup interval sensitivity

- Difference of multiplication factor from 313 steps using SERPENT2 and MCNP6 for problem 1I.



SERPENT2



MCNP6

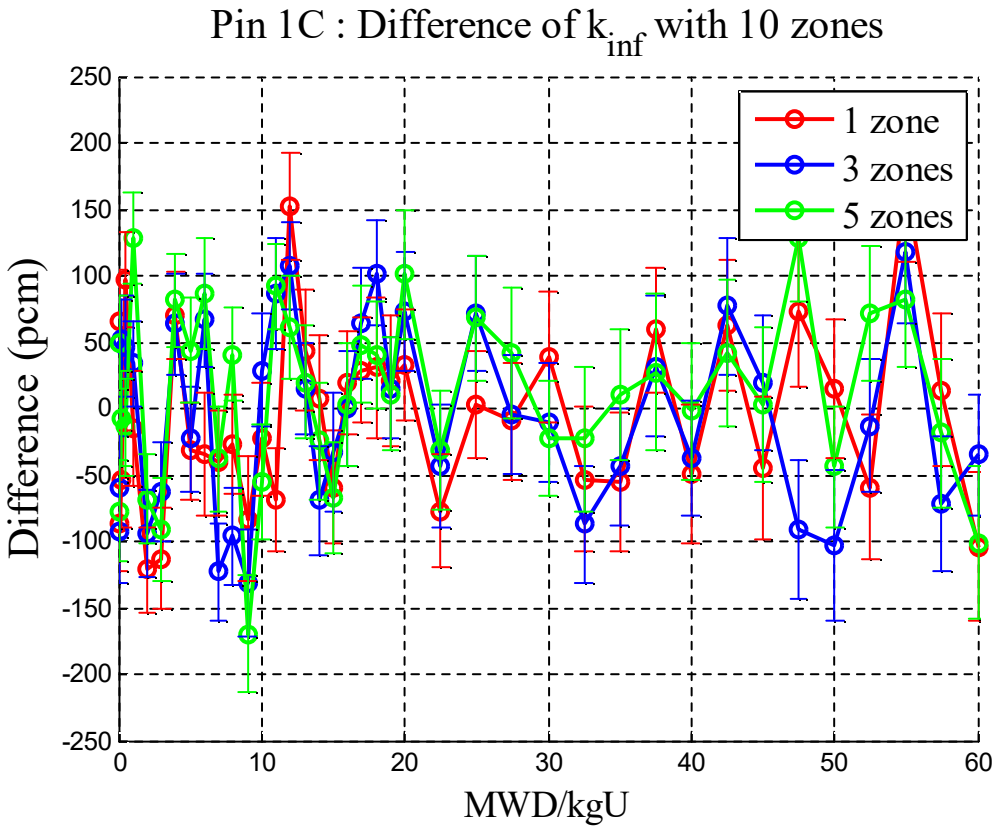
*For normal UO_2 pin problem, 157 burnup intervals is sufficient by using CRAM. However, it is insufficient by using MEM.

Sensitivity study

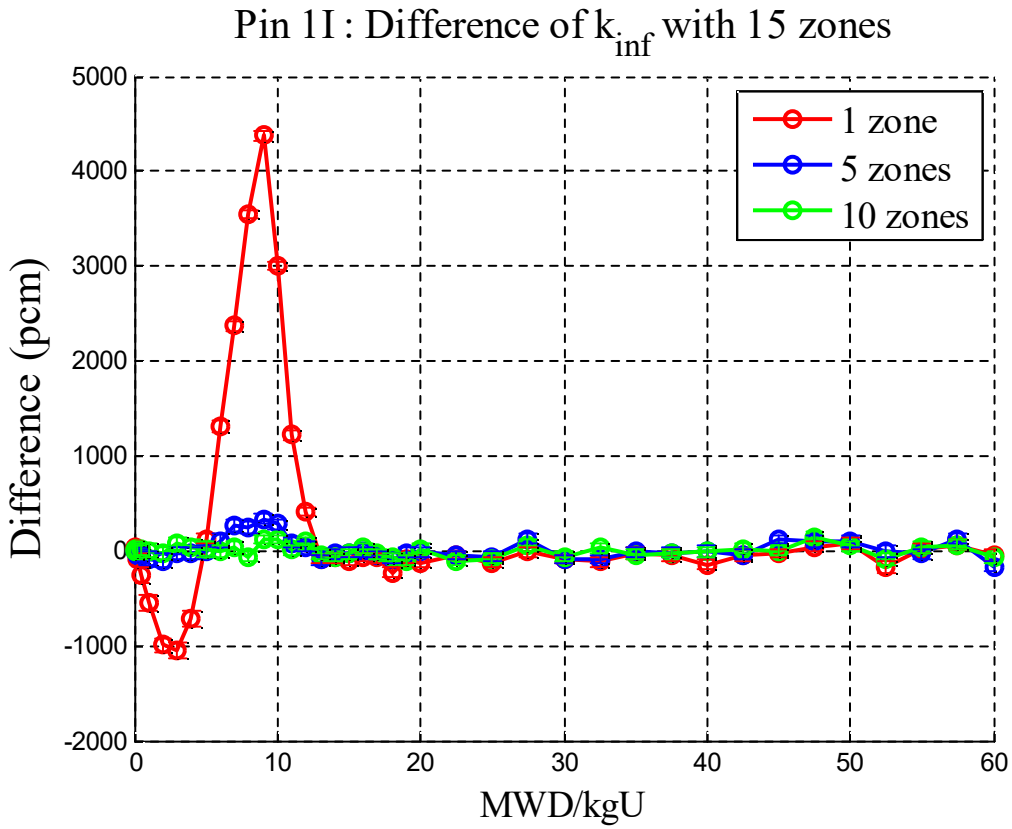
- **Depletion intra-zone sensitivity**
  - Test was performed using
    - SERPENT2
  - For the case: 1C, 1I
  - Monte Carlo histories,
    - Pin: 20,000 history/cycle, 20 inactive cycle, 80 active cycle
  - Burnup intervals,
    - 1C: 40 burnup intervals
    - 1I: 157 burnup intervals
  - Depletion intra-zone test cases,
    - 1C: 1/3/5/10 zones
    - 1I: 1/5/10/15 zones

Sensitivity study

- **Depletion intra-zone sensitivity**
  - **Multiplication factor of Problem 1C and 1I.**



Problem 1C



Problem 1I

*For normal UO_2 pin problem, 1 depletion intra-zone is sufficient.
For normal gad pin problem, 10 depletion intra-zones are required to obtain converged solution.

Sensitivity study

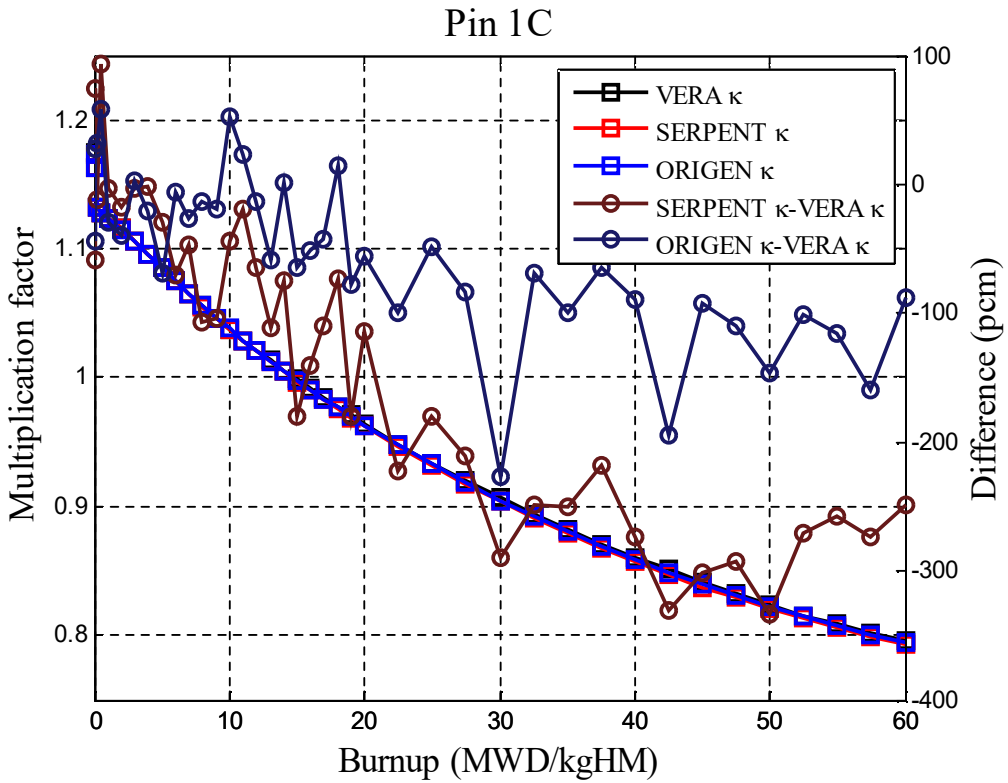
Q-value sensitivity

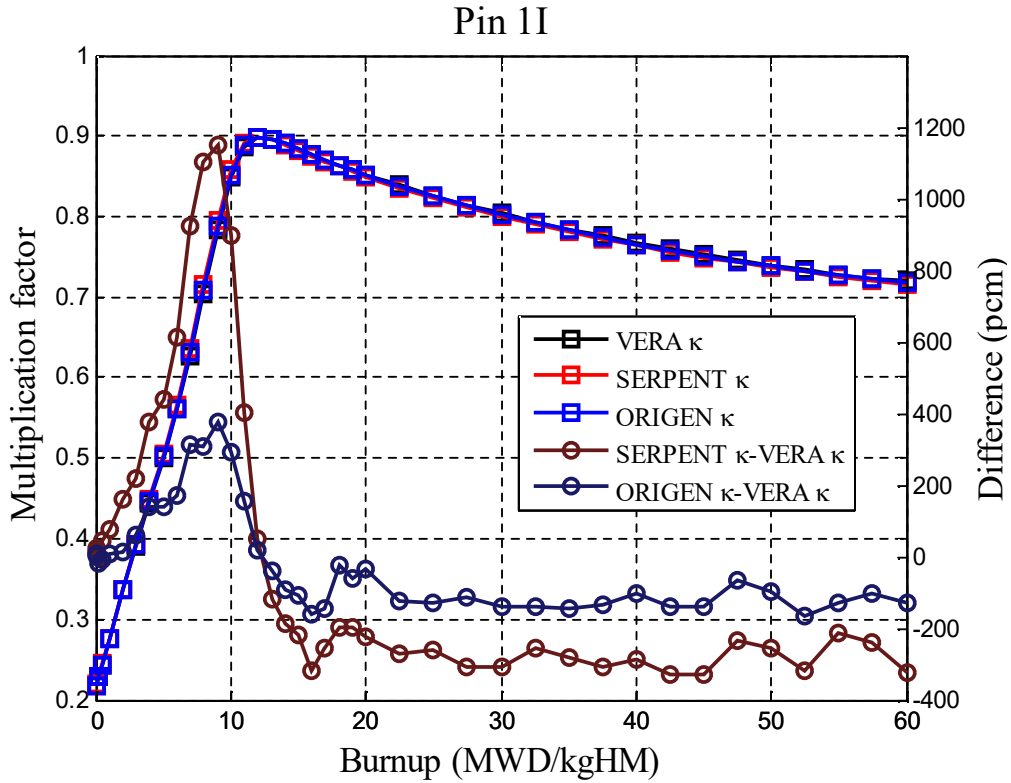
- Test was performed using SERPENT2.
- For case, 1C and 1I.
- Q value from VERA, ORIGEN2.2, and SERPENT2.

Isotope	Q-value (MeV)			Difference with VERA (%)	
	VERA	ORIGEN2.2	SERPENT2	ORIGEN2.2	SERPENT2
922350	202.3400	202.3375	202.2700	-0.001	-0.035
922380	212.6004	212.6030	206.7723	0.001	-2.741
932390	213.8699	213.8674	198.3858	-0.001	-7.240
942360	205.9501	205.9511	203.6065	0.000	-1.138
942370	206.0499			-100.000	-100.000
942380	210.1799	210.1779		-0.001	-100.000
942390	214.2768	211.1087	207.6202	-1.479	-3.107
942400	214.1801	214.1822		0.001	-100.000
942410	216.8446	213.6371	210.8946	-1.479	-2.744
942420	216.9800	216.9789	210.4769	-0.001	-2.997
942430			208.8272	0.000	100.000
942440	212.9998			-100.000	-100.000
952410	217.4200	217.4198	210.8737	0.000	-3.011
952420	215.3834	213.8606	208.8272	-0.707	-3.044
952421	222.2877	215.8425	208.8272	-2.899	-6.055

Sensitivity study

- **Q-value sensitivity**
  - **SERPENT2 test results**





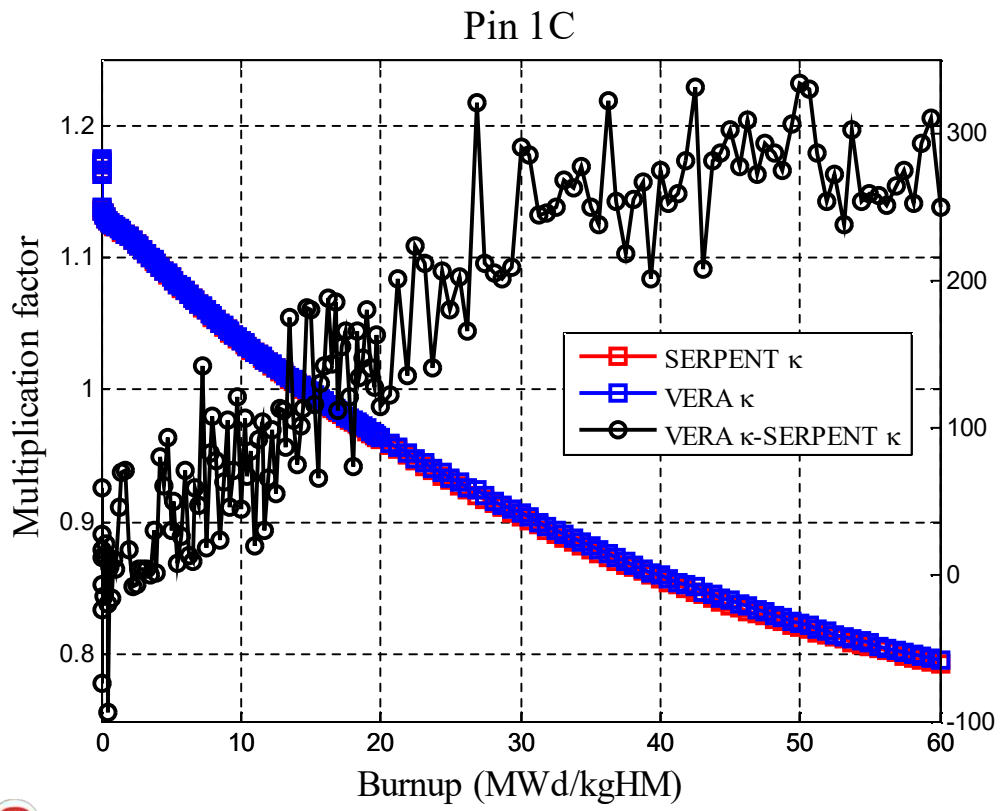
*Q-value from VERA is larger than that from ORIGEN2.2 and SERPENT2,
So, flux level can be lower and the fuel is burned slower.

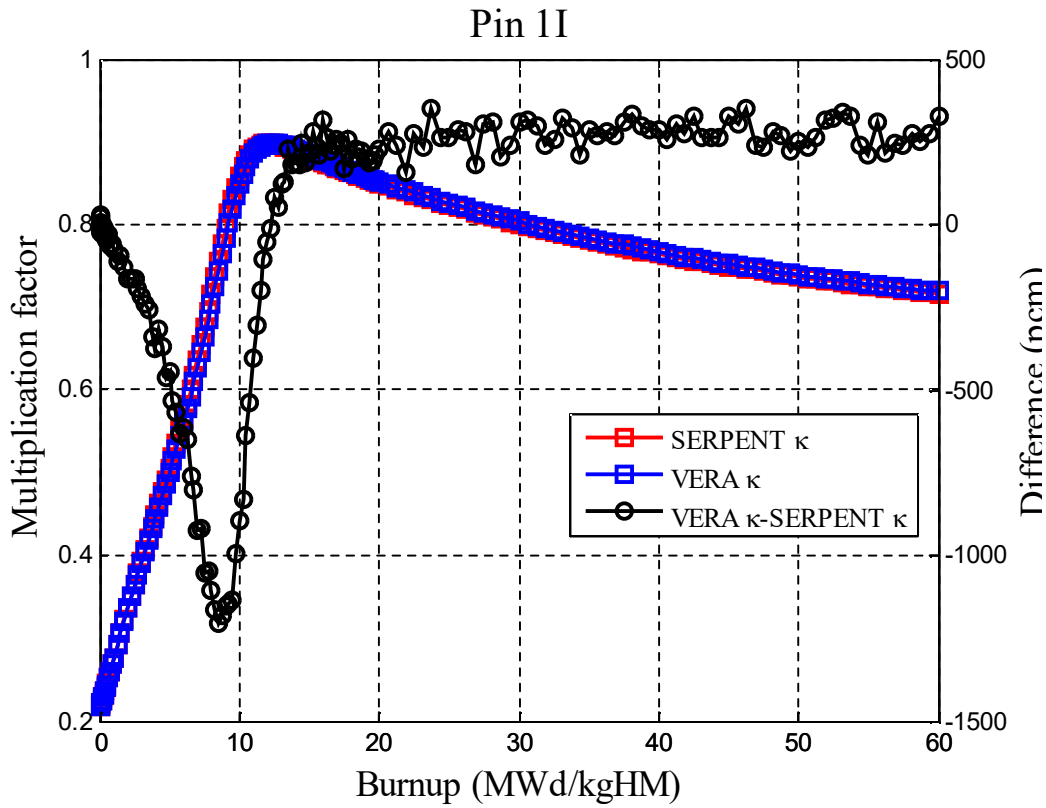
Comparison method

Consistent Code-to-Code Comparison of Pin-cell Depletion Benchmark Suite

Comparison method

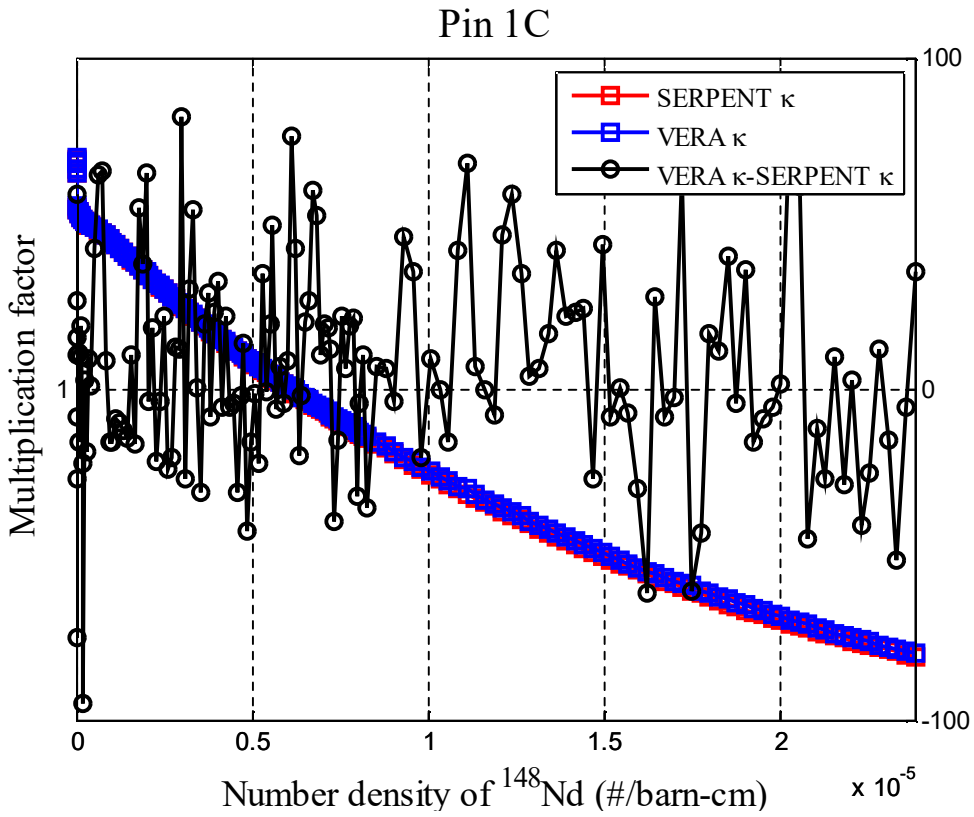
- **Compare with Burnup**
  - **Code: SERPENT2**
  - **The k_{inf} depletion calculation result with various kappa value (VERA, SERPENT kappa) by using SERPENT2.**
  - **When the difference is compare in terms of burnup (x-axis), the difference from different kappa is remarkable.**

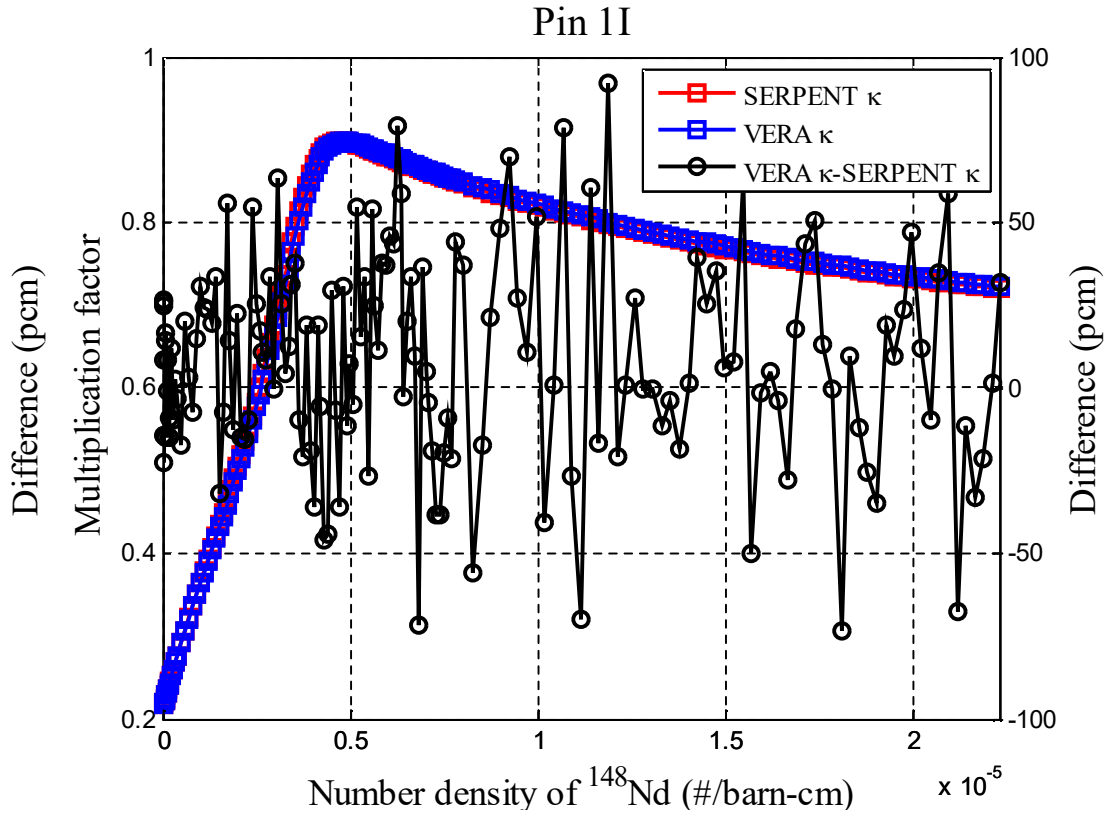




Comparison method

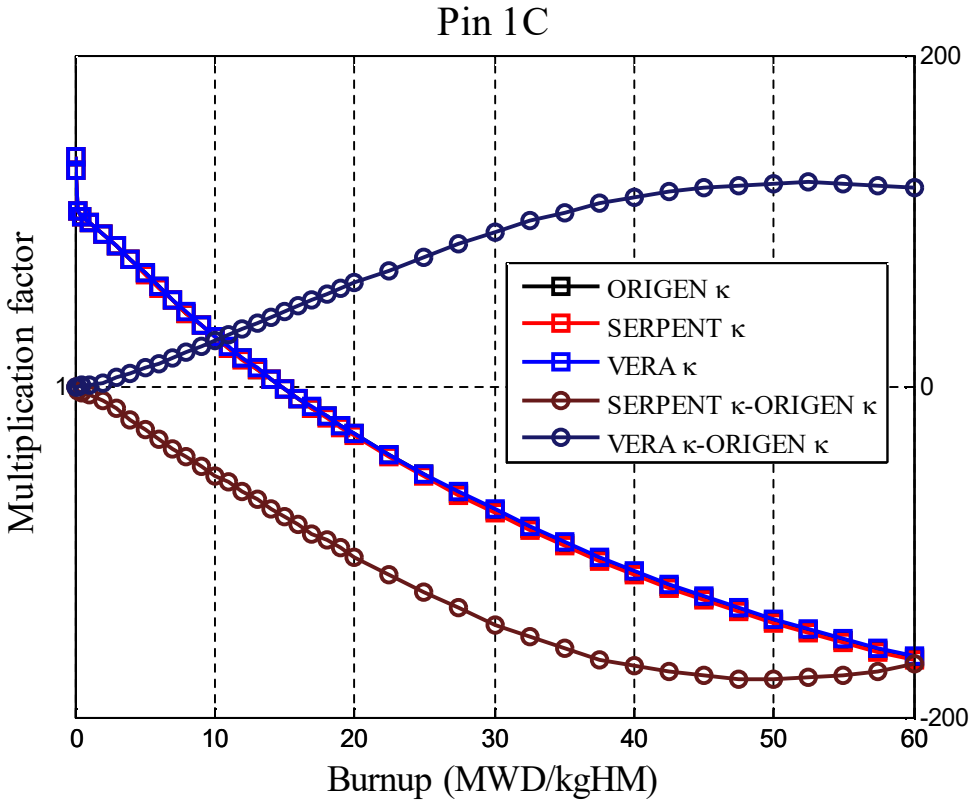
- **Compare with N.D. of ^{148}Nd**
  - **Code: SERPENT2**
  - **When the k_{inf} were comparing with number density of specific isotope (^{148}Nd), it was covered that the difference from different kappa value.**

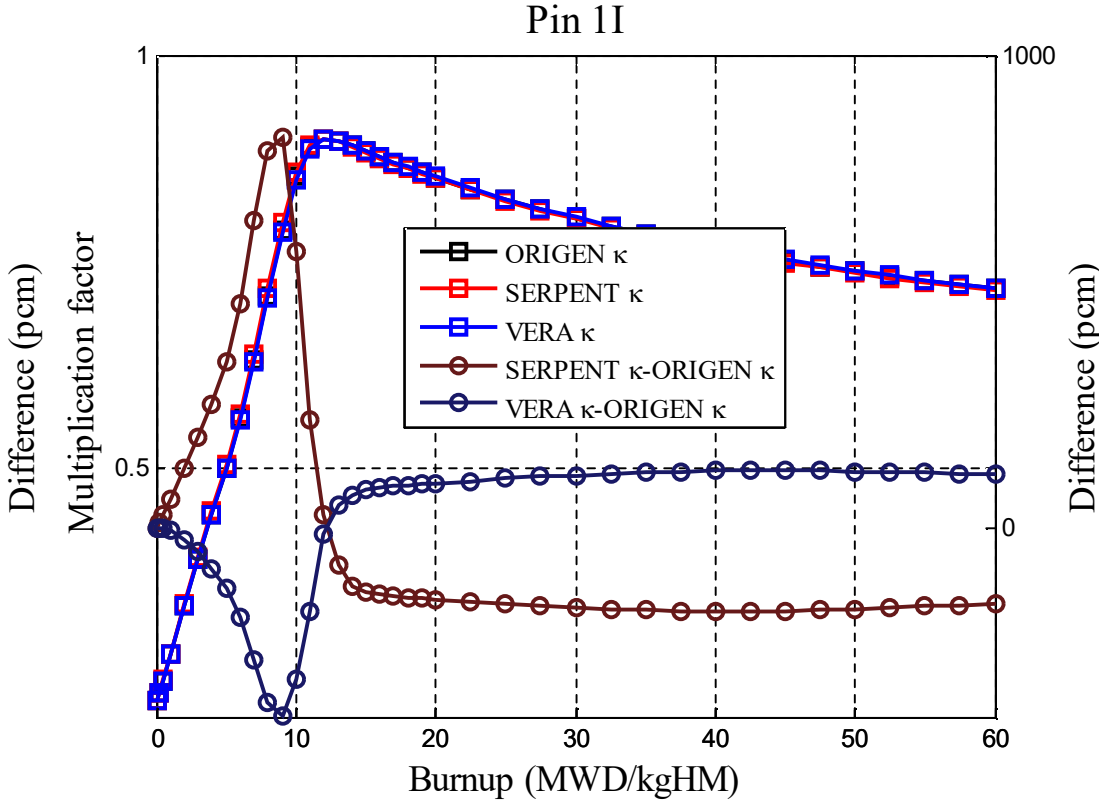




Comparison method

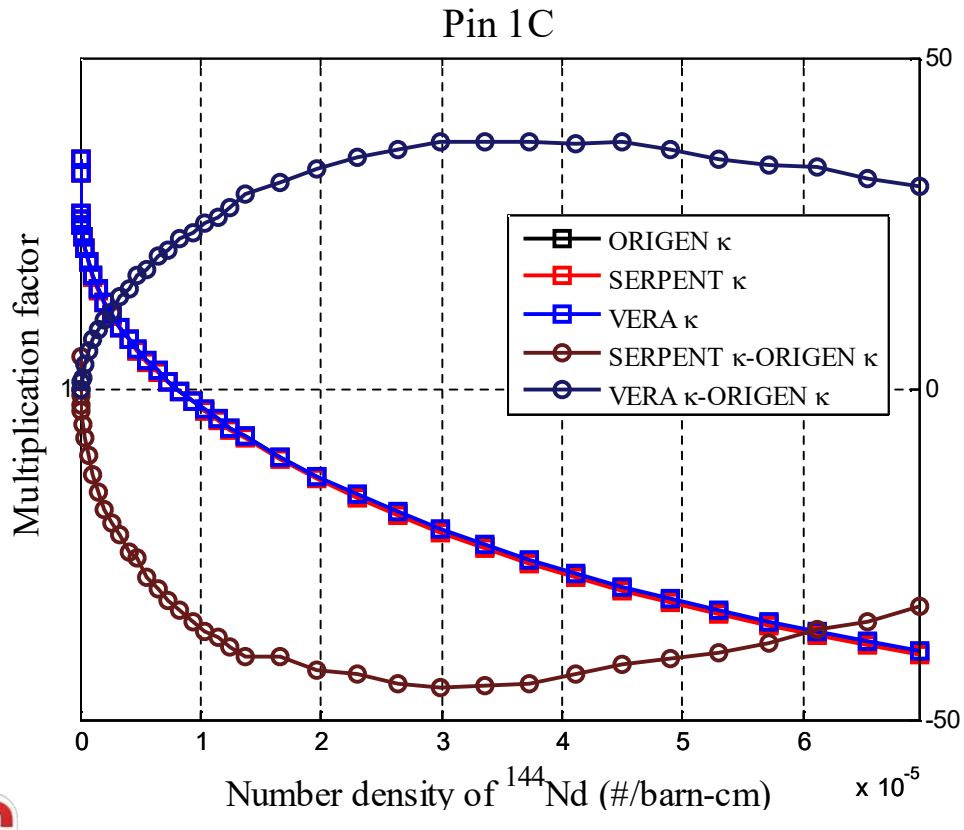
- **Compare with Burnup**
  - **Code: STREAM**
  - **In order to clearly show the difference without statistical error, previous comparison procedure was performed again by using STREAM (UNIST in-house MOC code) with SERPENT, VERA, and ORIGEN kappa value.**

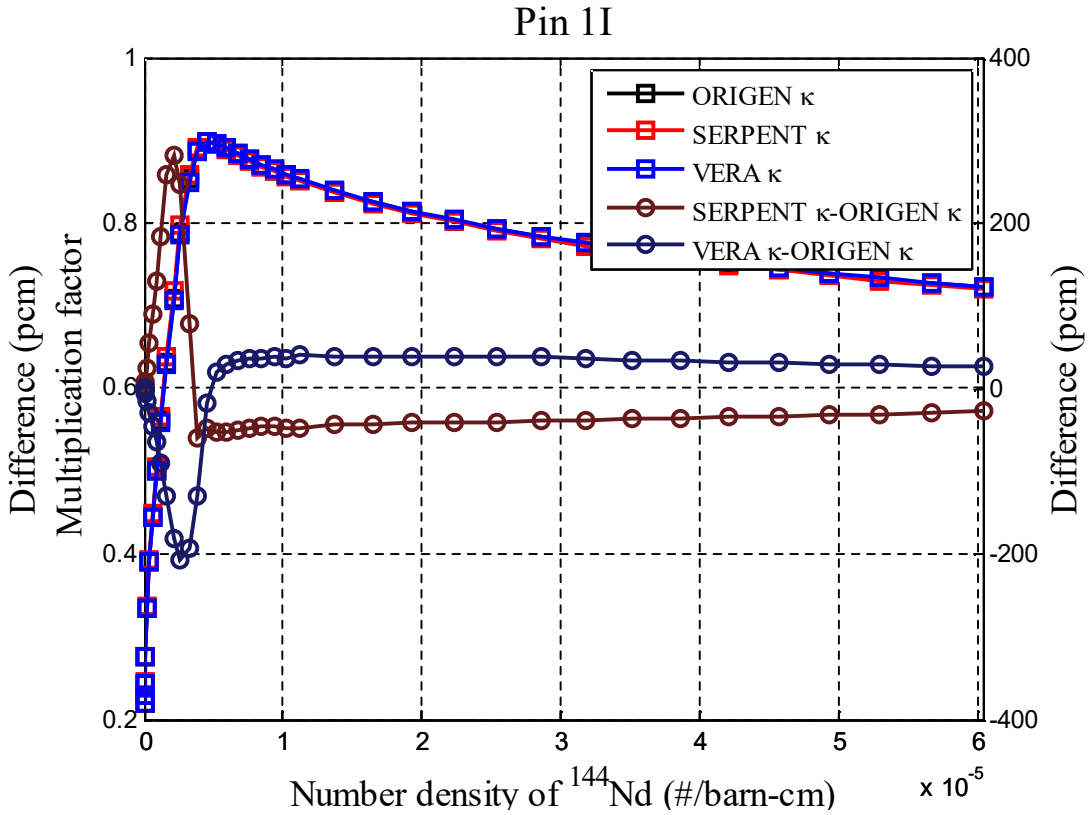




Comparison method

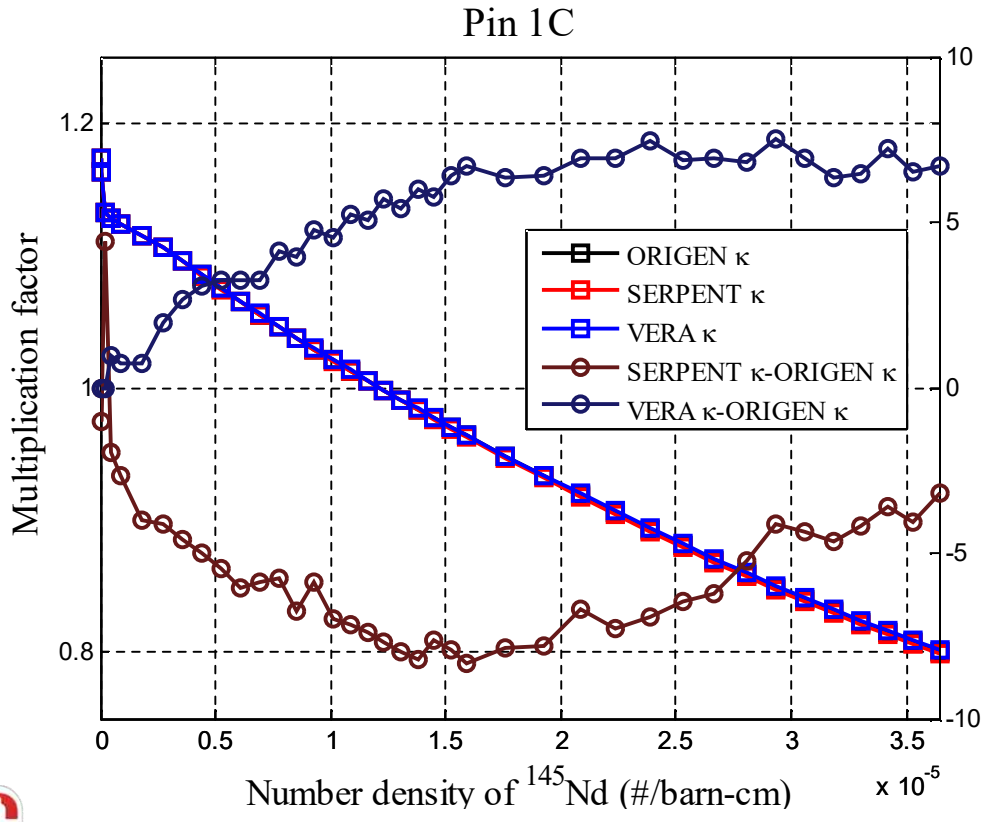
- **Compare with N.D. of ^{144}Nd**
  - **Code: STREAM**
  - **The number density of ^{144}Nd was used as x-axis instead of burnup for comparison.**
  - **Then -400~800pcm difference of k_{inf} were reduced to -200~300pcm.**

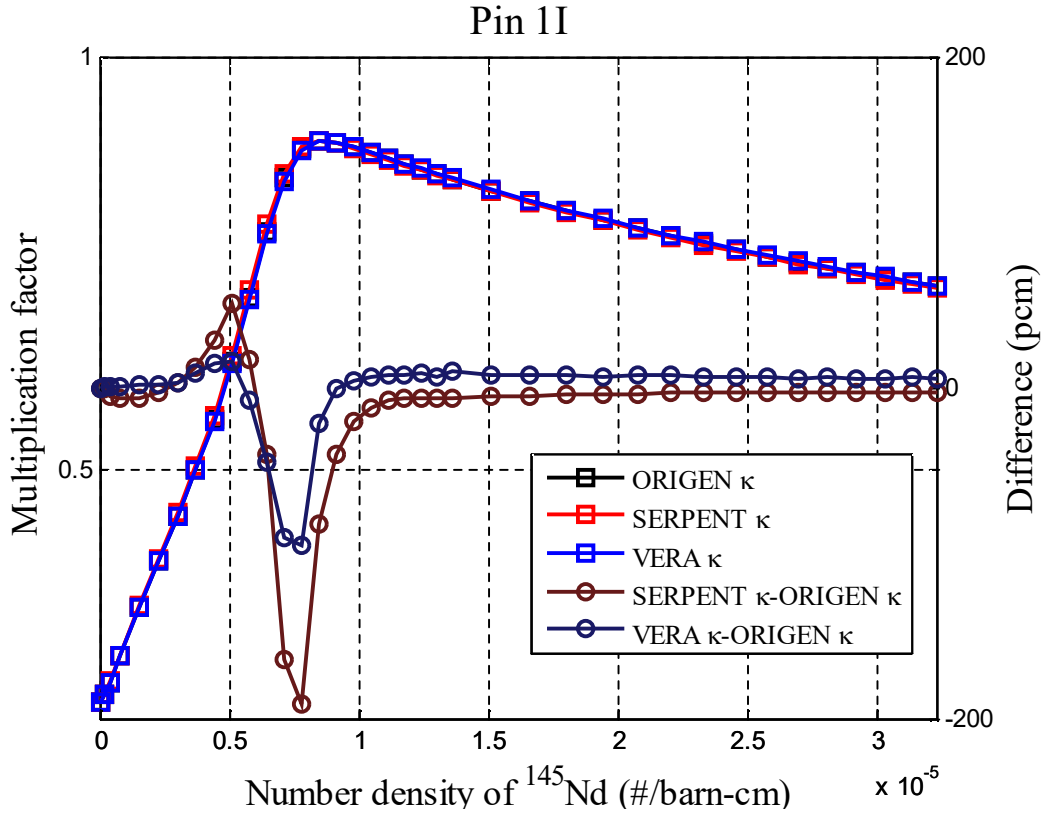




Comparison method

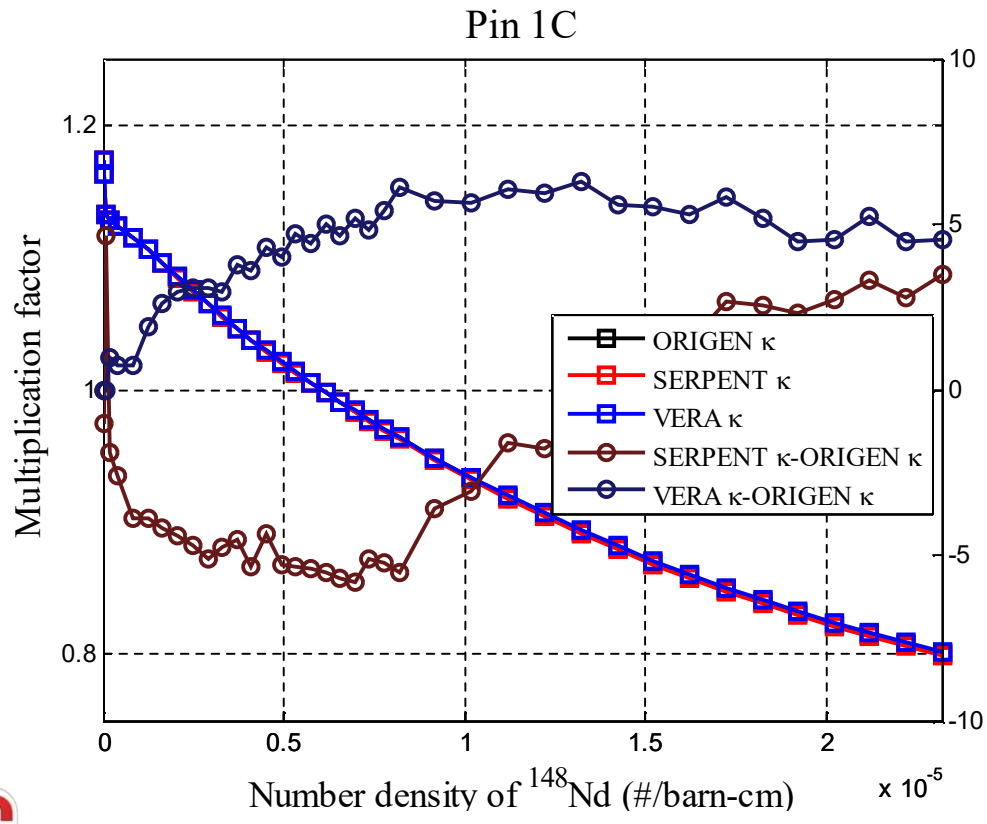
- **Compare with N.D. of ^{145}Nd**
  - **Code: STREAM**
  - **The number density of ^{145}Nd was used as x-axis instead of burnup for comparison.**
  - **Then -400~800pcm difference of k_{inf} were reduced to -200~100pcm.**

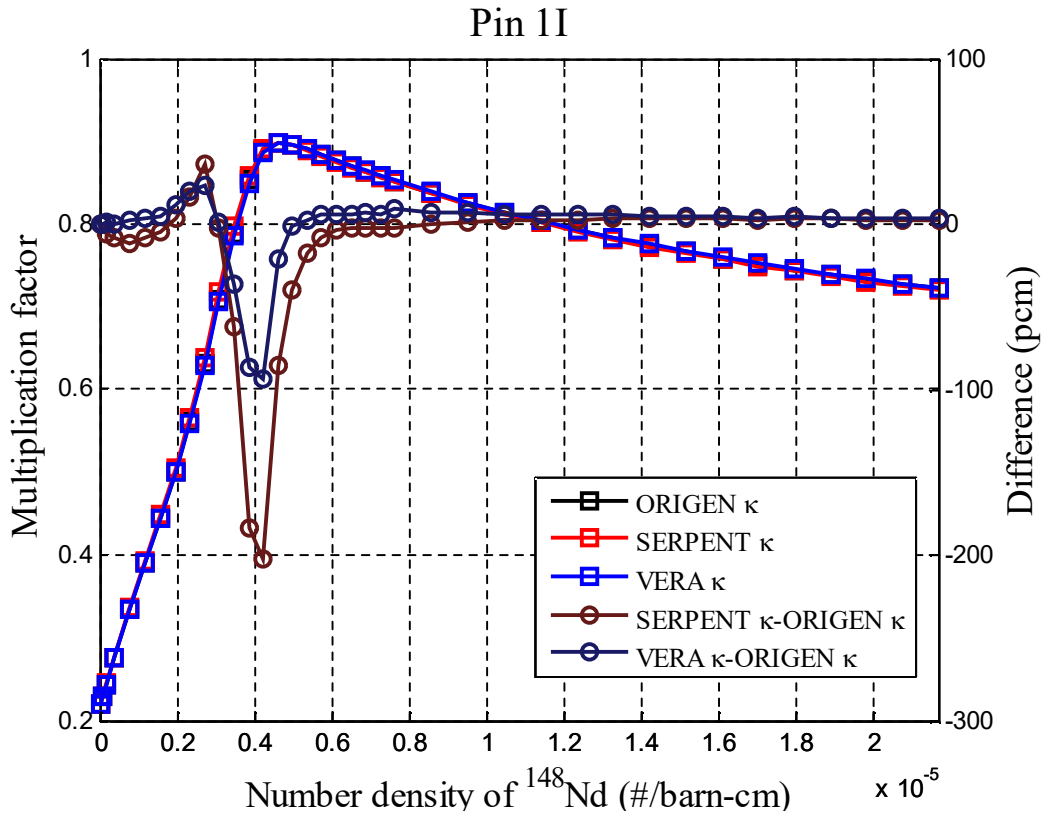




Comparison method

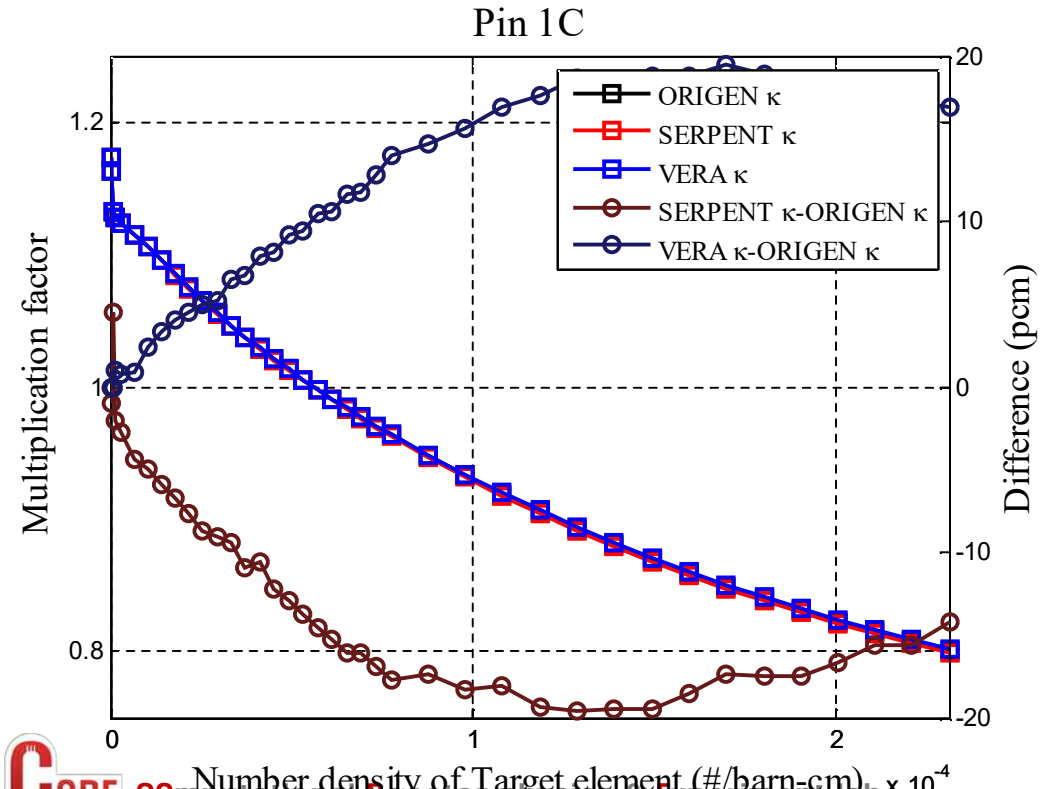
- **Compare with N.D. of ^{148}Nd**
  - **Code: STREAM**
  - **The number density of ^{148}Nd was used as x-axis instead of burnup for comparison.**
  - **Then -400~800pcm difference of k_{inf} were reduced to -200~50pcm.**

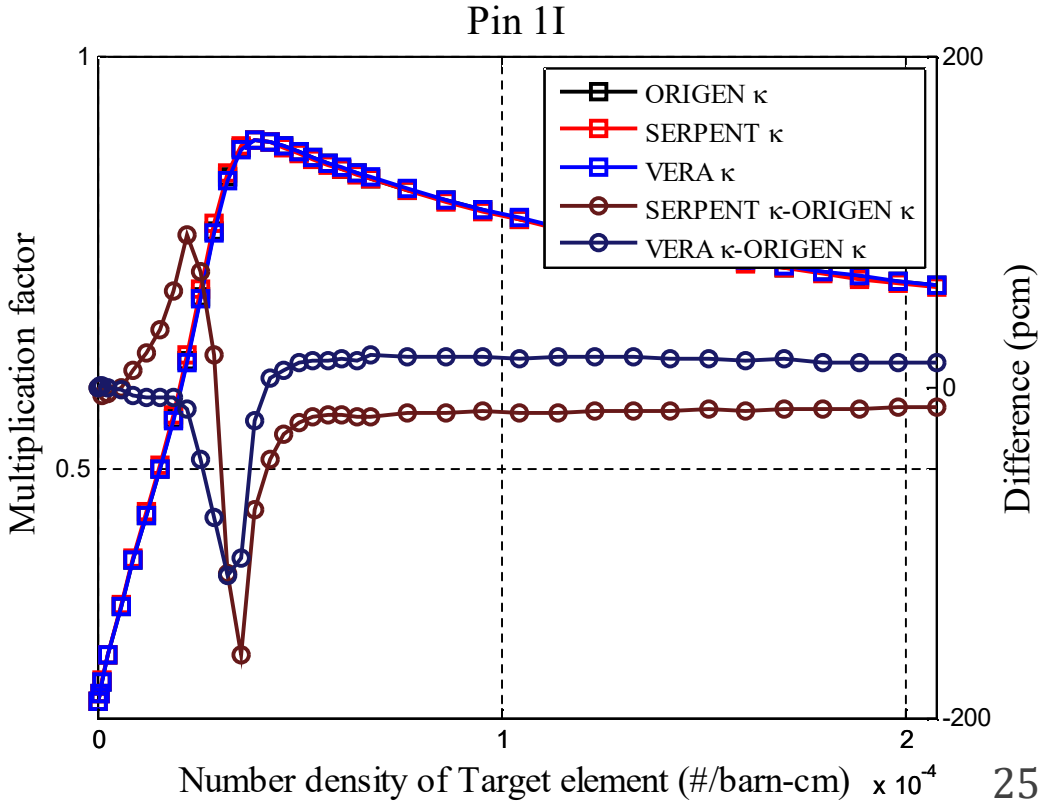




Comparison method

- **Compare with Nd (neodymium) element**
  - **Code: STREAM**
  - **In order to compare the results by computer code with the experiment data, the number density of Nd element was used as x-axis instead of burnup for comparison.**
  - **Then -400~800 pcm difference of k_{inf} were reduced to -100~100pcm.**



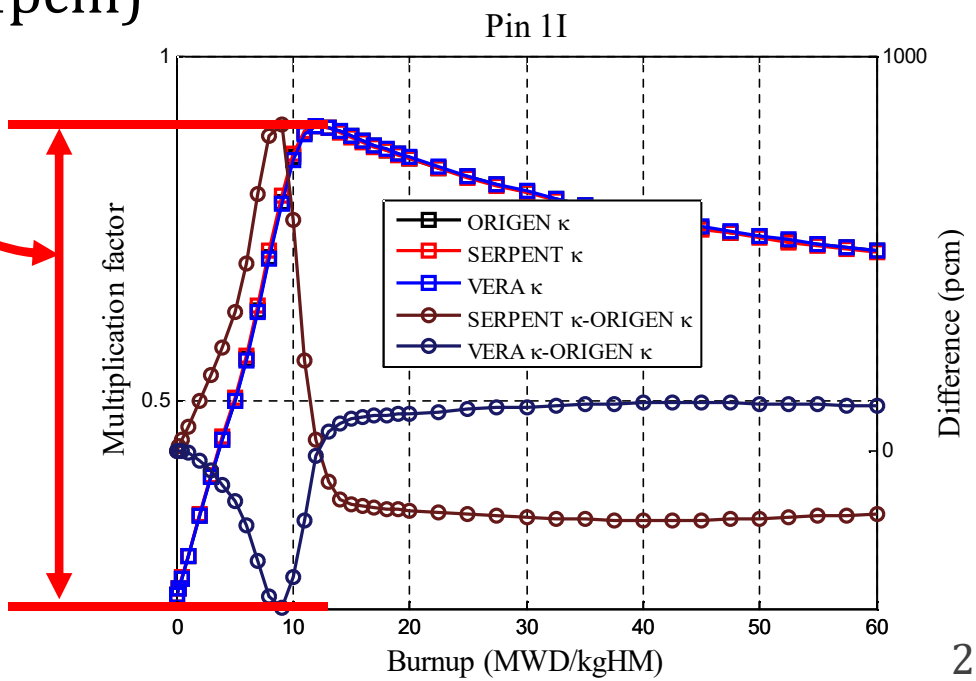


Comparison method

- **Best options of isotope and element for 1C and 1I problem.**

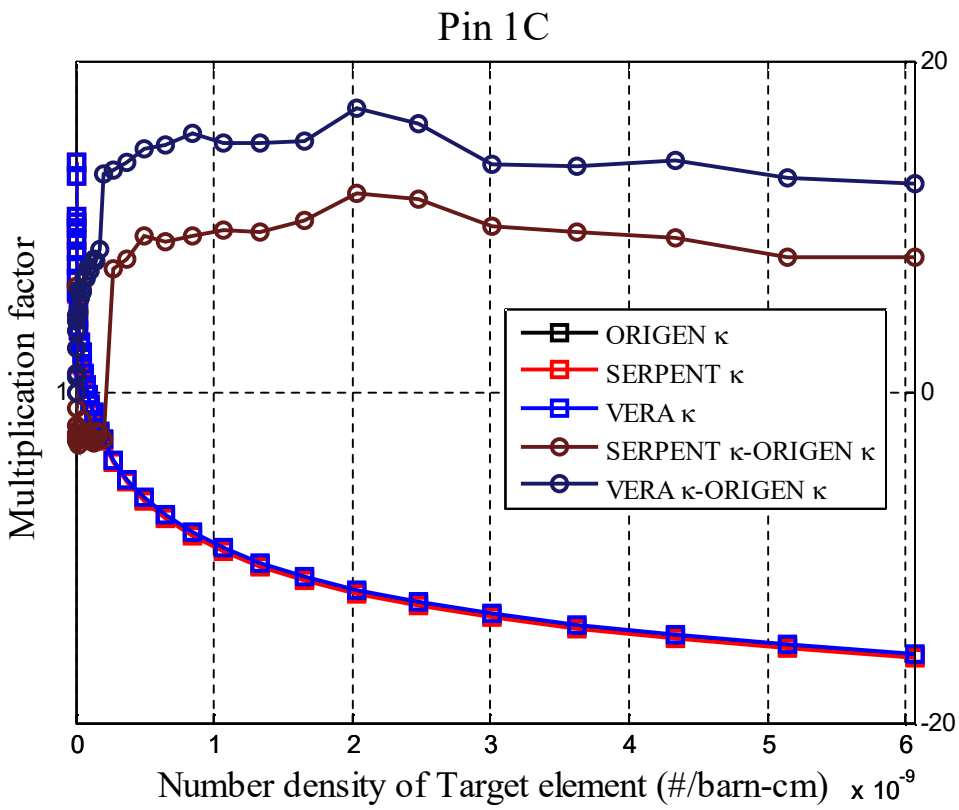
	1C	1I
Isotope	^{148}Nd (12pcm)	^{166}Er (131pcm)
Element	Iodine (8pcm)	Erbium (131pcm)

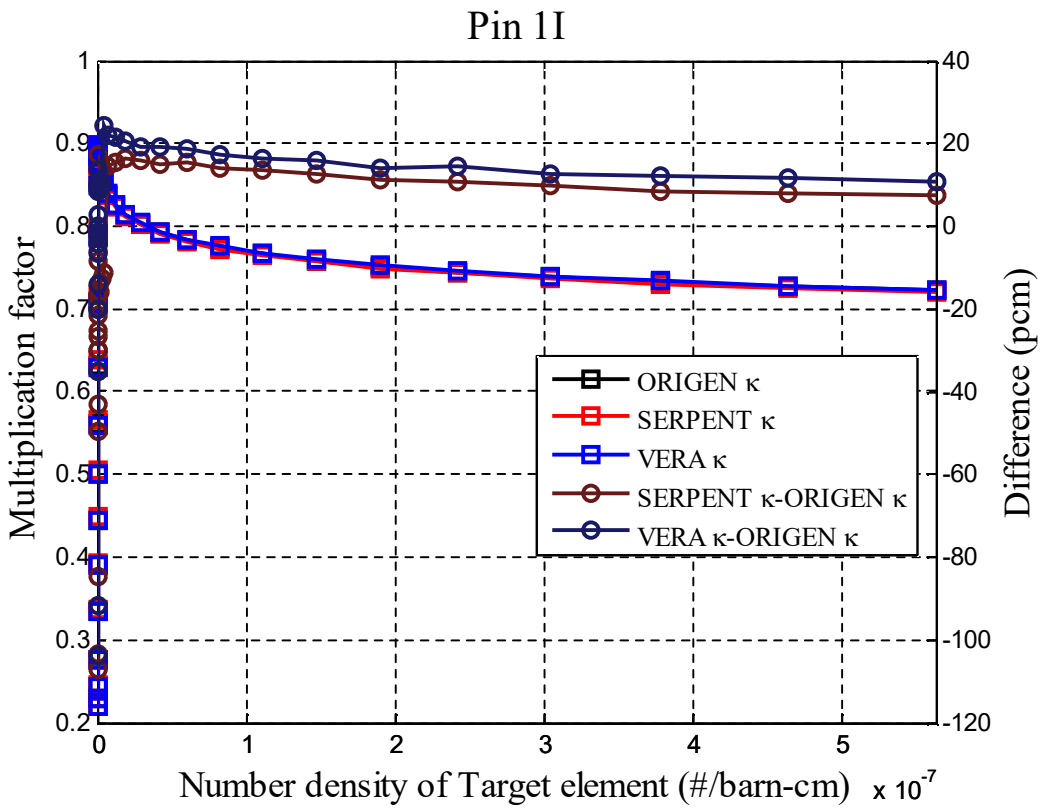
*It means the maximum difference of k_{inf}.



Comparison method

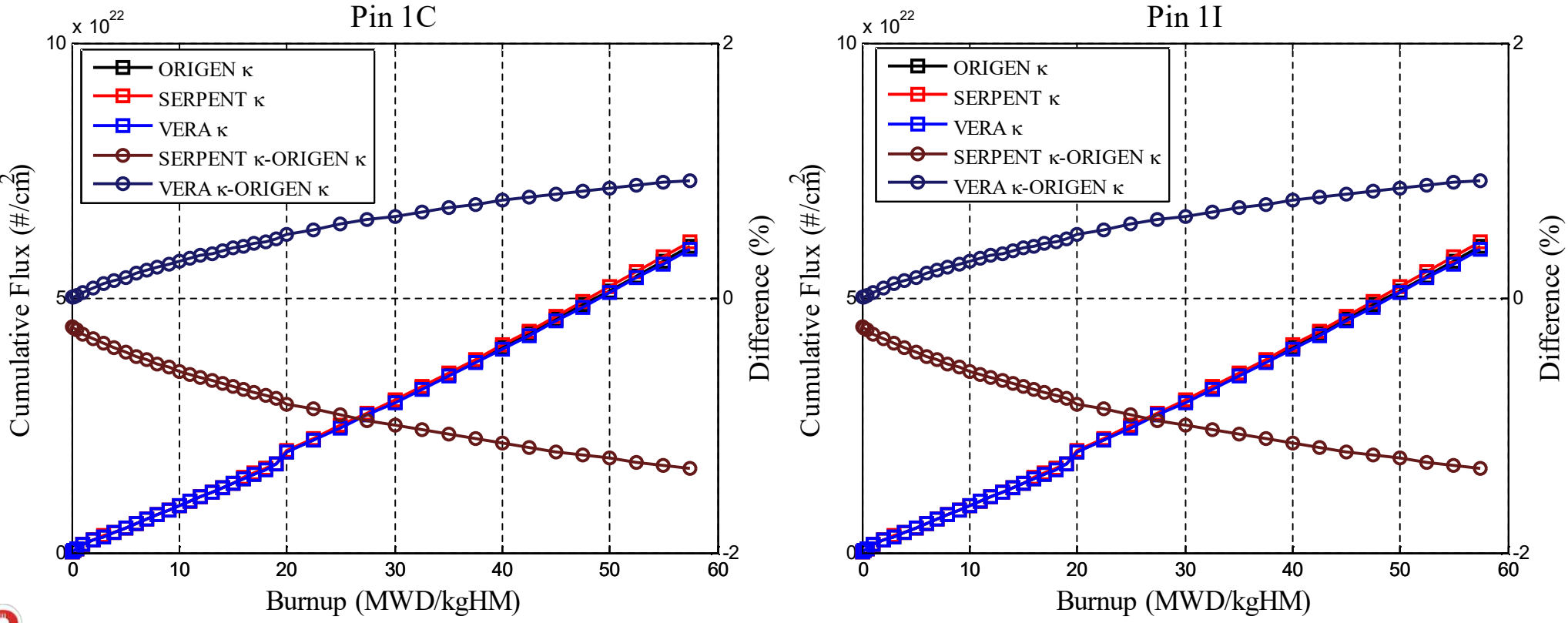
- **Compare with Er (erbium) element**
  - **Code: STREAM**





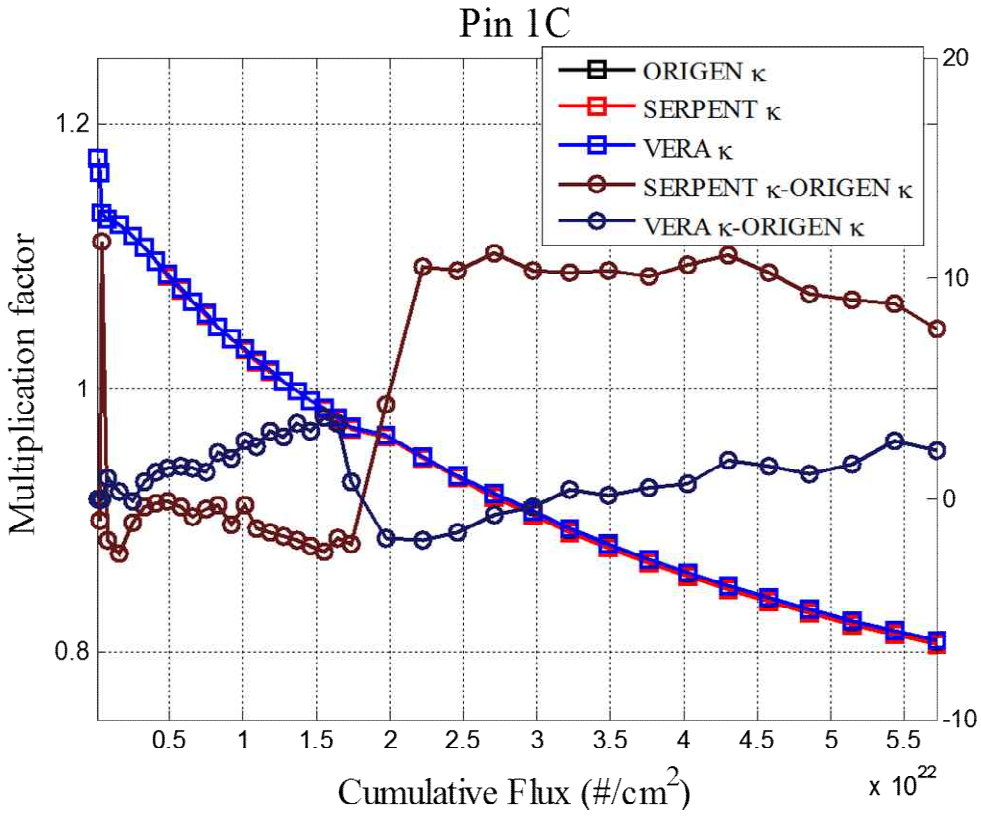
Comparison method

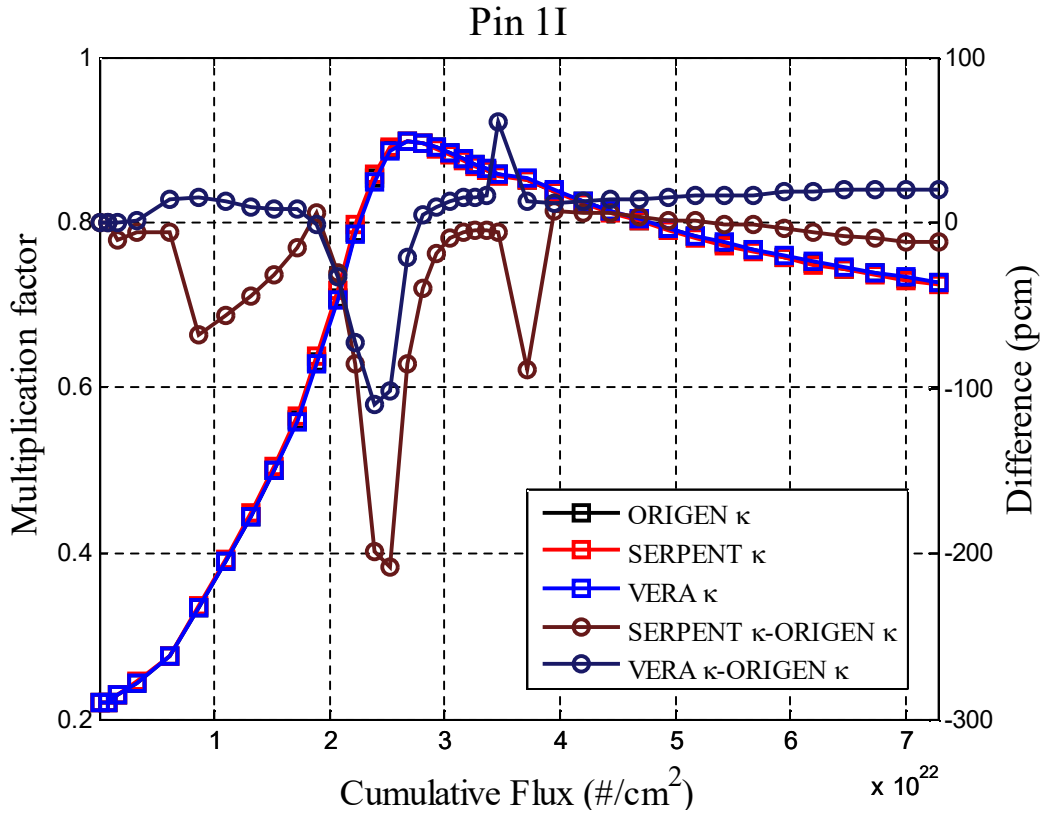
- **Compare with cumulative flux**
  - **Code: STREAM**
  - **The cumulative flux will be used as x-axis instead of burnup for comparison.**
  - **Plot the cumulative flux along the depletion burnup steps.**



Comparison method

- **Depletion comparison using Cumulative flux**
  - **Code: STREAM**
  - **If the cumulative flux was used as the amount of depletion, then -400 ~800pcm difference of k_{inf} were reduced to -200~20pcm.**





Conclusions

Consistent Code-to-Code Comparison of Pin-cell Depletion Benchmark Suite

Conclusions

- VERA depletion benchmark suite was calculated using SERPENT2 with various set of kappa value.
- Optimum depletion calculation options are determined through the sensitivity study of the burnup interval and the number of depletion intra-zones
- Difference of kappa value is main reason occurring difference of multiplication factor in code-to-code comparison.
- By using number density of specific isotope and element or accumulative flux as a criteria of comparison, the discrepancy of k_{inf} is reduced remarkably in code-to-code comparison.


UNIST CORE