Nuclear Data Testing for PWR at JSI

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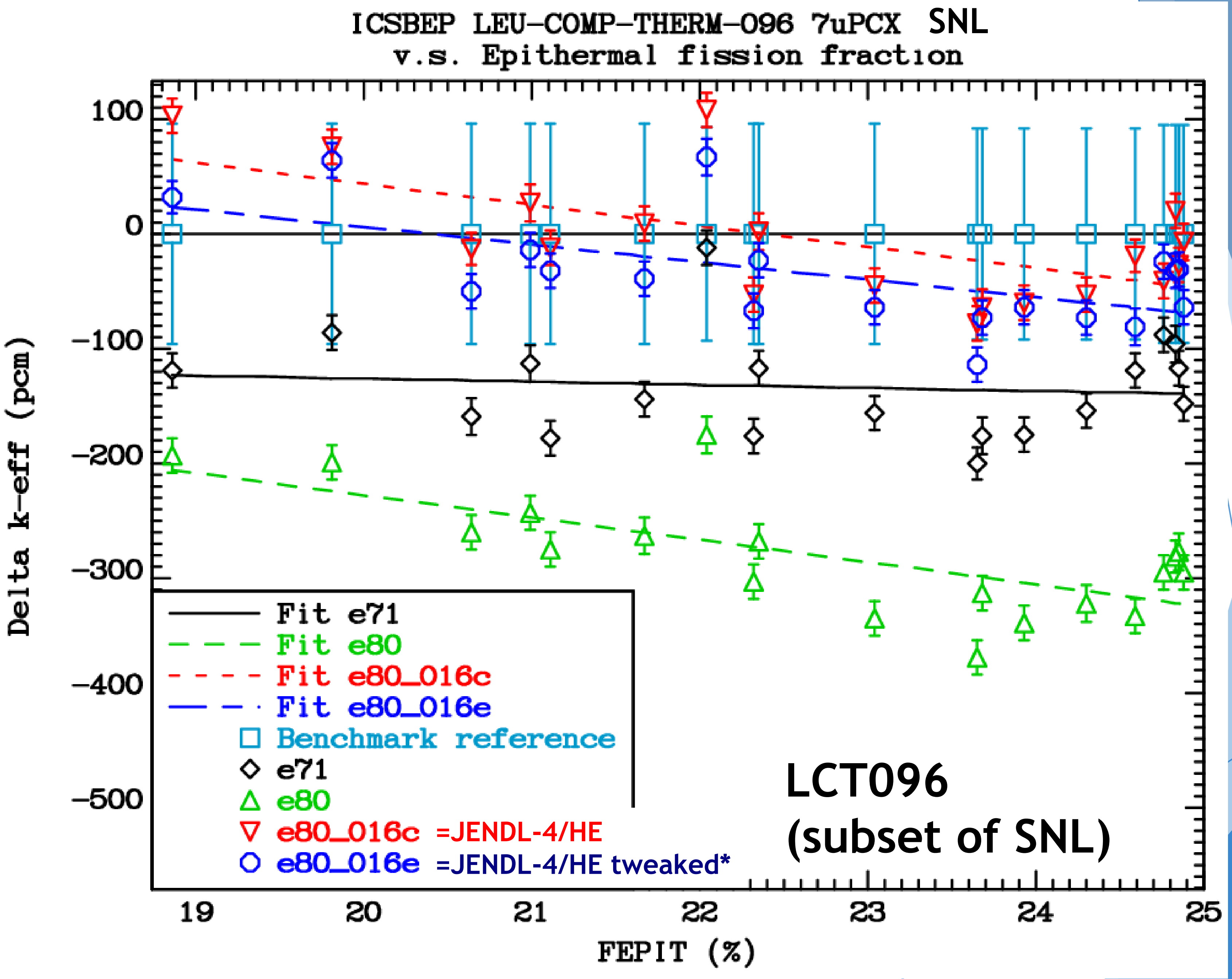
Scope

- Sandia National Laboratory series of benchmakks
  - LCT-078, 079, 080, 096, 097 in ICSBEP
- Reactivity loss with burnup in a pin-cell calculation
  - Westinghouse Vantage-5 fuel for a 16x16 fuel assembly of the Krsko NPP
  - Cross section library intercomparison
- Comparison with measured boron concentrations at different stages in a fuel cycle of the Krsko NPP for 30 cycles of operation
- Oktavian-Cr benchmark

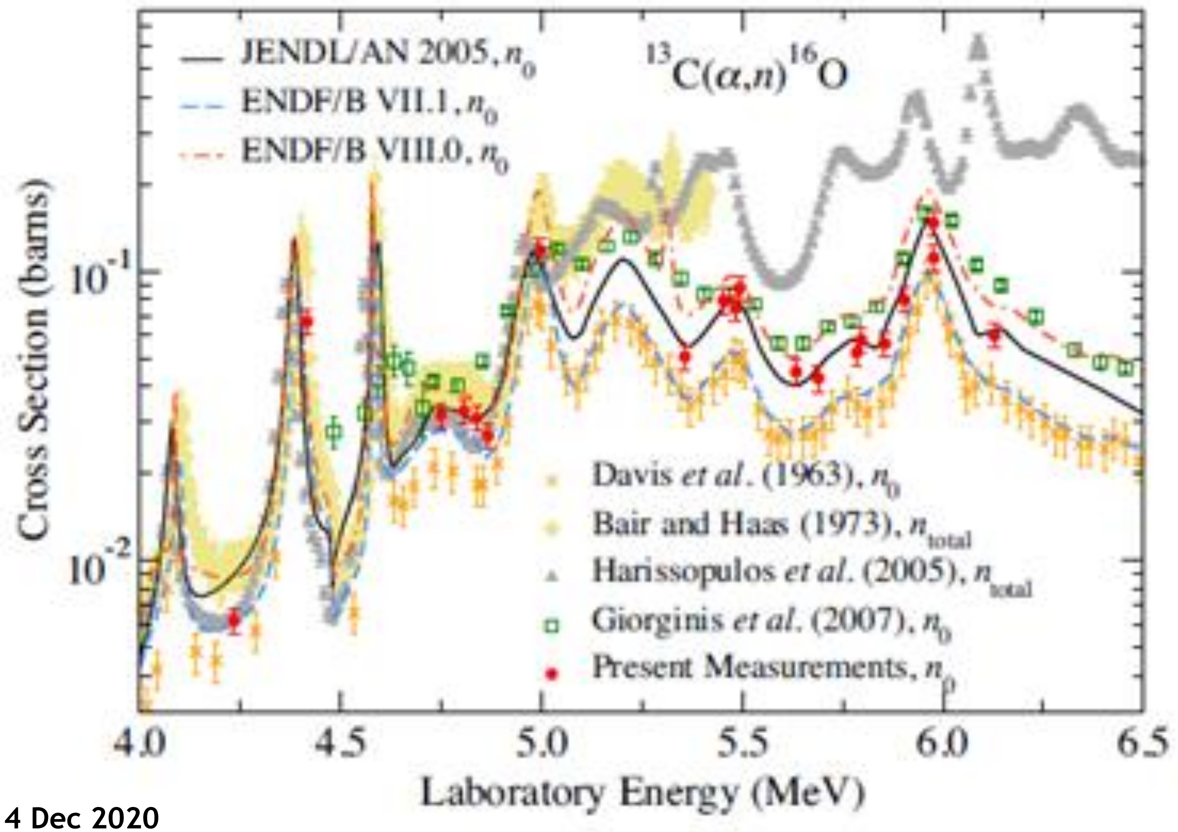
The “SNL” benchmarks series (LCT-078, 079, 080, 096, 097 in ICSBEP)

- In the “SNL” benchmarks series performance with ENDF/B-VIII.0 was degraded by up to 300 pcm compared to ENDF/B-VII.1.
- Swapping U-235 from **ENDF/B-VII.1** was by far insufficient to explain the difference.
- Performance was practically restored swapping O-16 from ENDF/B-VII.1.
- Performance with new O-16 from **JEFF-4T** was similar to ENDF/B-VIII.0.
- From differential data **JENDL-4/HE** which is consistent with JENDL/AN 2005 seems to be the best choice (for the time being).
- Minor tweaks to cross sections in the thermal range in JENDL-4/HE to follow ENDF/B-VIII.0 thermal cross section values.


ICSBEP LEU-COMP-THERM-096 7uPCX SNL
v.s. Epithermal fission fraction
Delta k-eff (pcm)
100
0
−100
−200
−300
−400
−500
19
20
21
22
23
24
25
FEPIT (%)
Fit e71
Fit e80
Fit e80_016c
Fit e80_016e
Benchmark reference
e71
e80
e80_016c =JENDL-4/HE
e80_016e =JENDL-4/HE tweaked*
LCT096
(subset of SNL)

O-16 Alternative Evaluation (differential)

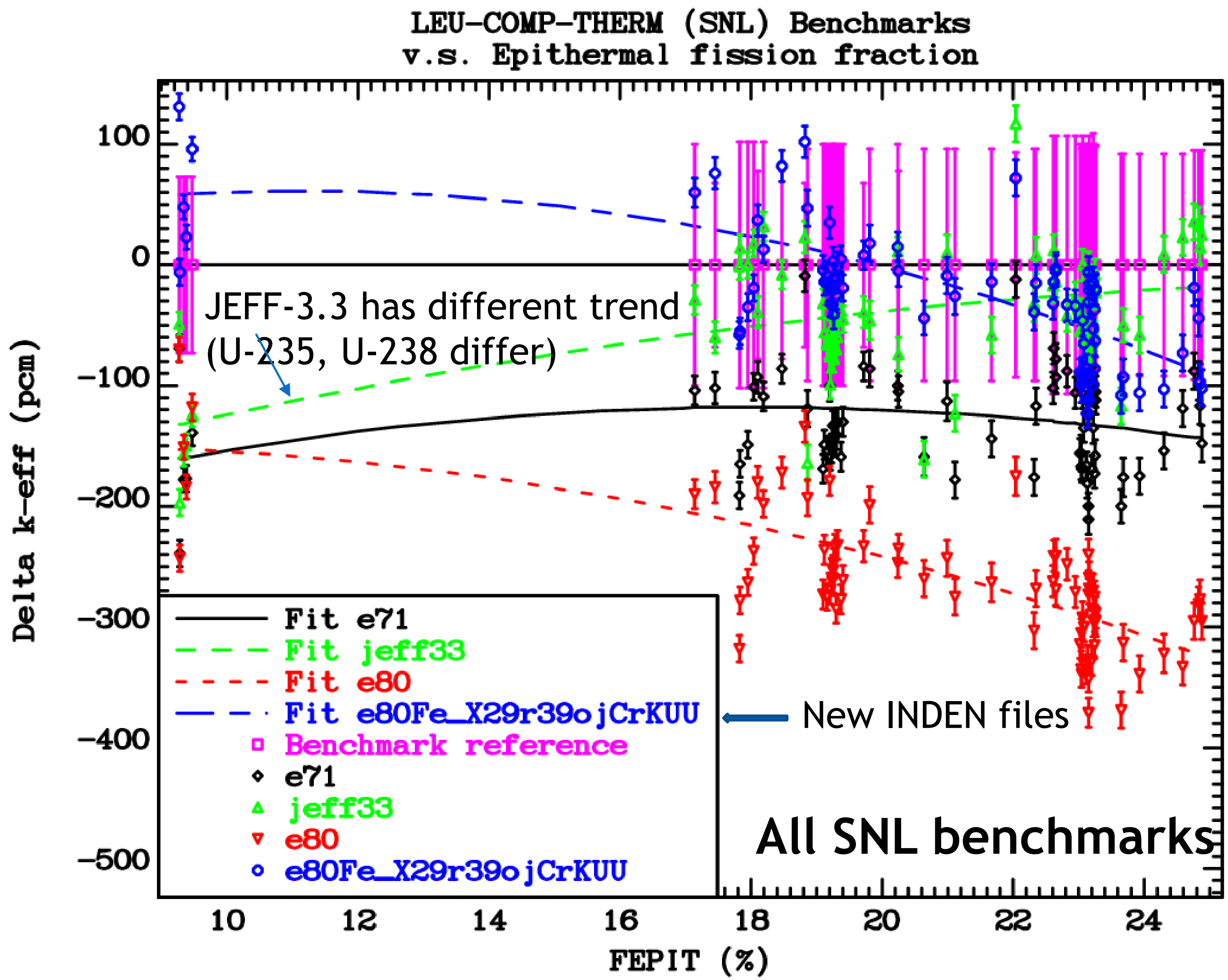
- There is still a lot of controversy regarding the O-16 evaluation, particularly the O-16(n,α) cross section; new data and corresponding R-matrix analysis are needed
- New data by Febbraro et al, Phys. Rev. Lett **125** (2020) 062501



inverse reaction to (n,α_0)

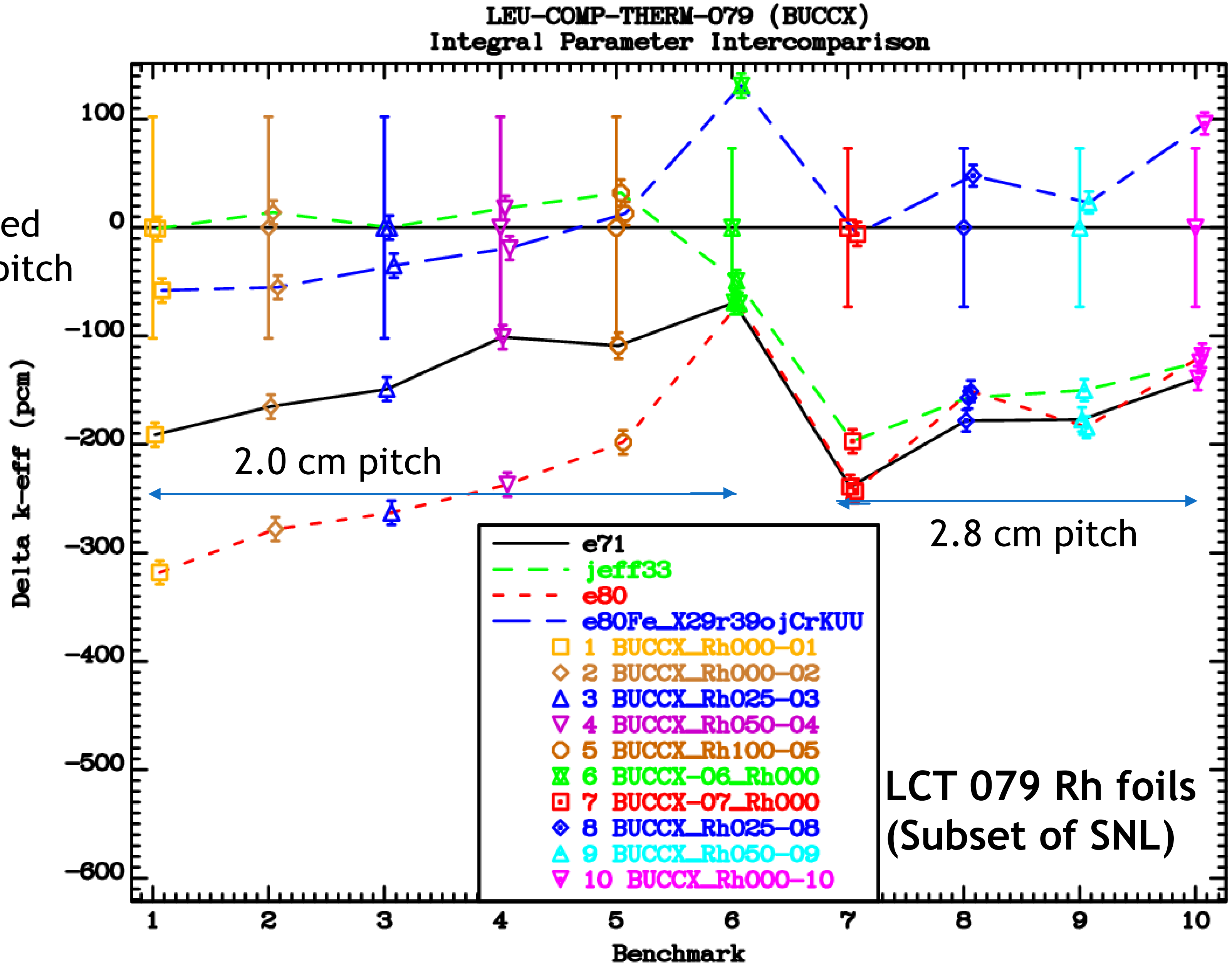
JENDL/AN 2005 best !
ENDF/B-VIII.0 too high
ENDF/B-VII.1 low

JEFF-33 = ENDF/B-VII.1


LEU-COMP-THERM (SNL) Benchmarks
v.s. Epithermal fission fraction
Delta k-eff (pcm)
FEPIT (%)
100
0
−100
−200
−300
−400
−500
10
12
14
16
18
20
22
24
JEFF-3.3 has different trend
(U-235, U-238 differ)
Fit e71
Fit jeff33
Fit e80
Fit e80Fe_X29r39ojCrKUU
Benchmark reference
e71
jeff33
e80
e80Fe_X29r39ojCrKUU
New INDEN files
All SNL benchmarks

*KUU=INDEN:
- Offset eliminated
- No trend with pitch

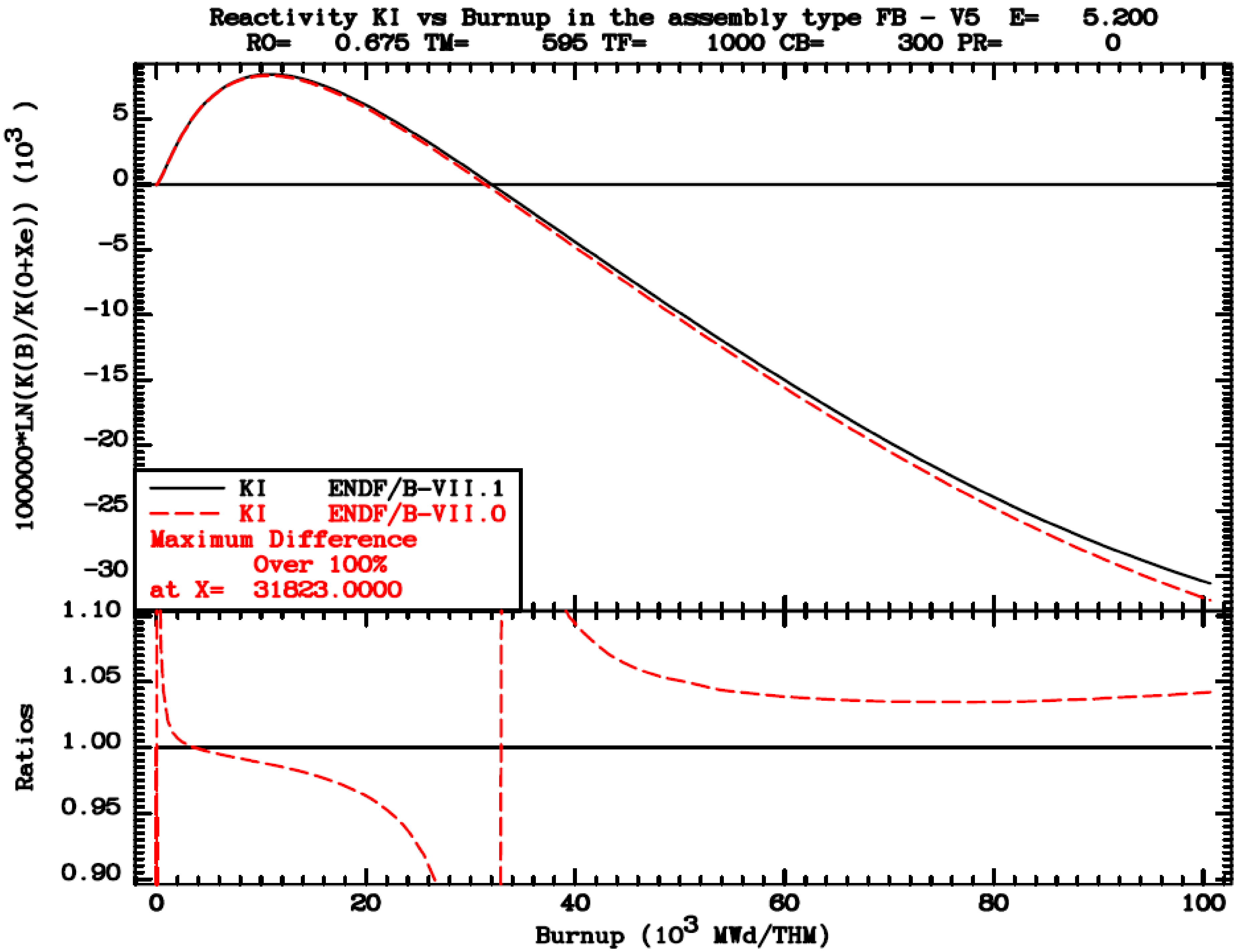
JEFF-3.3
- Trend with pitch

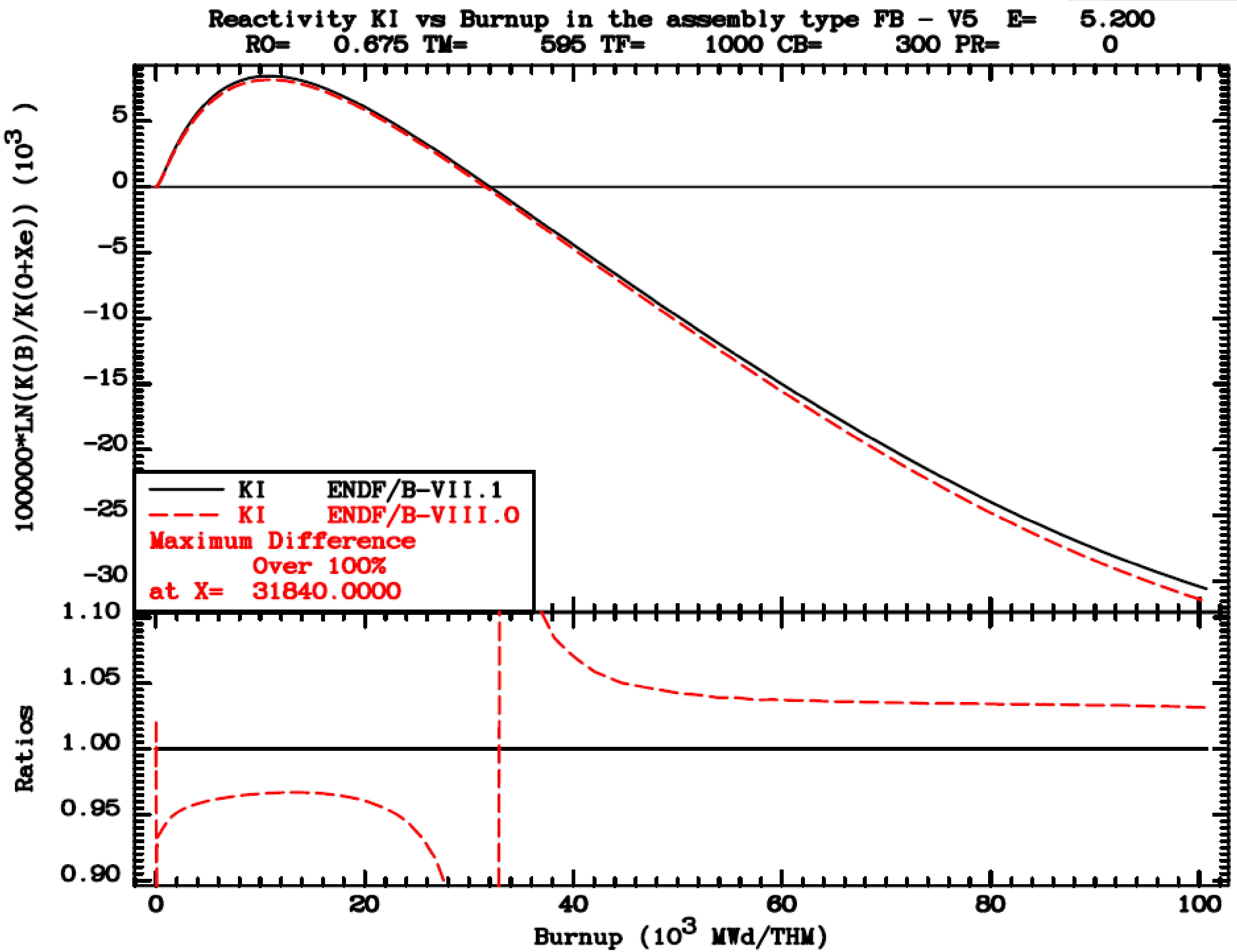


LWR Pin-Cell Burnup

- Example: pin-cell of Westinghouse Vantage fuel, 5.2 w/o enrichment, full power.
- WIMSD-5B calculation in 69 energy groups
  - 1D transport, but equal for all libraries → valid comparison
- With ENDF/B-VIII.0 there is some reactivity **loss** at high burnup compared to ENDF/B-VII.1
- With ENDF/B-VII.1 there was reactivity **gain** compared to ENDF/B-VII.0
- → ENDF/B-VIII.0 is similar to ENDF/B-VII.0 in terms of reactivity

(Detailed plots of inventory of all burnable materials available in the Supplementary document: Note: ENDF/B-VIII.0 explicitly includes Eu156,157, which **increases Gd** production but **no dramatic change of reactivity**)

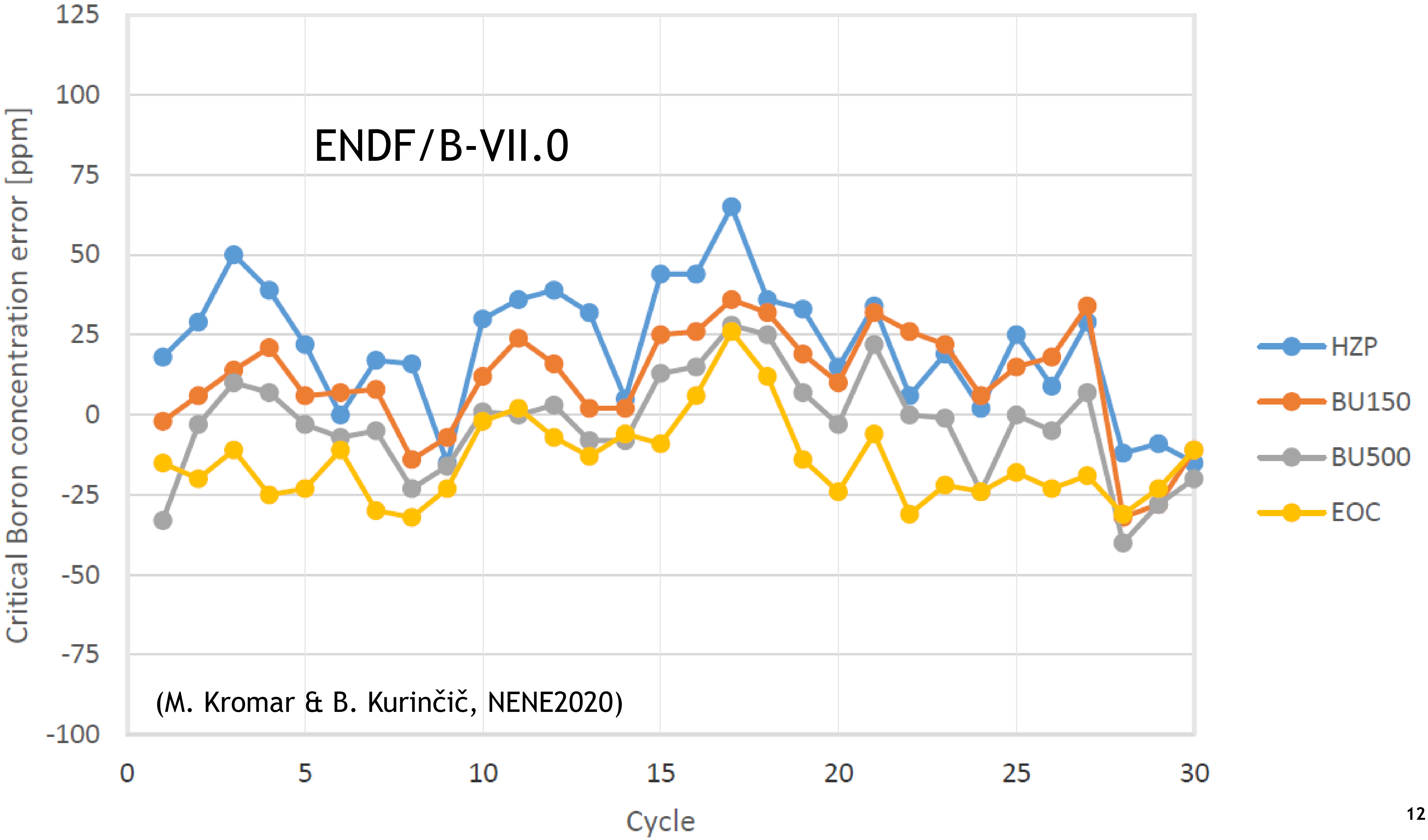

Reactivity KI vs Burnup in the assembly type FB - V5 E= 5.200
RO= 0.675 TM= 595 TF= 1000 CB= 300 PR= 0
100000*LN(K(B)/K(0+Xe)) (10^3)
5
0
-5
-10
-15
-20
-25
-30
KI ENDF/B-VII.1
KI ENDF/B-VII.0
Maximum Difference
Over 100%
at X= 31823.0000
1.10
1.05
1.00
0.95
0.90
Ratios
0
20
40
60
80
100
Burnup (10^3 MWd/THM)

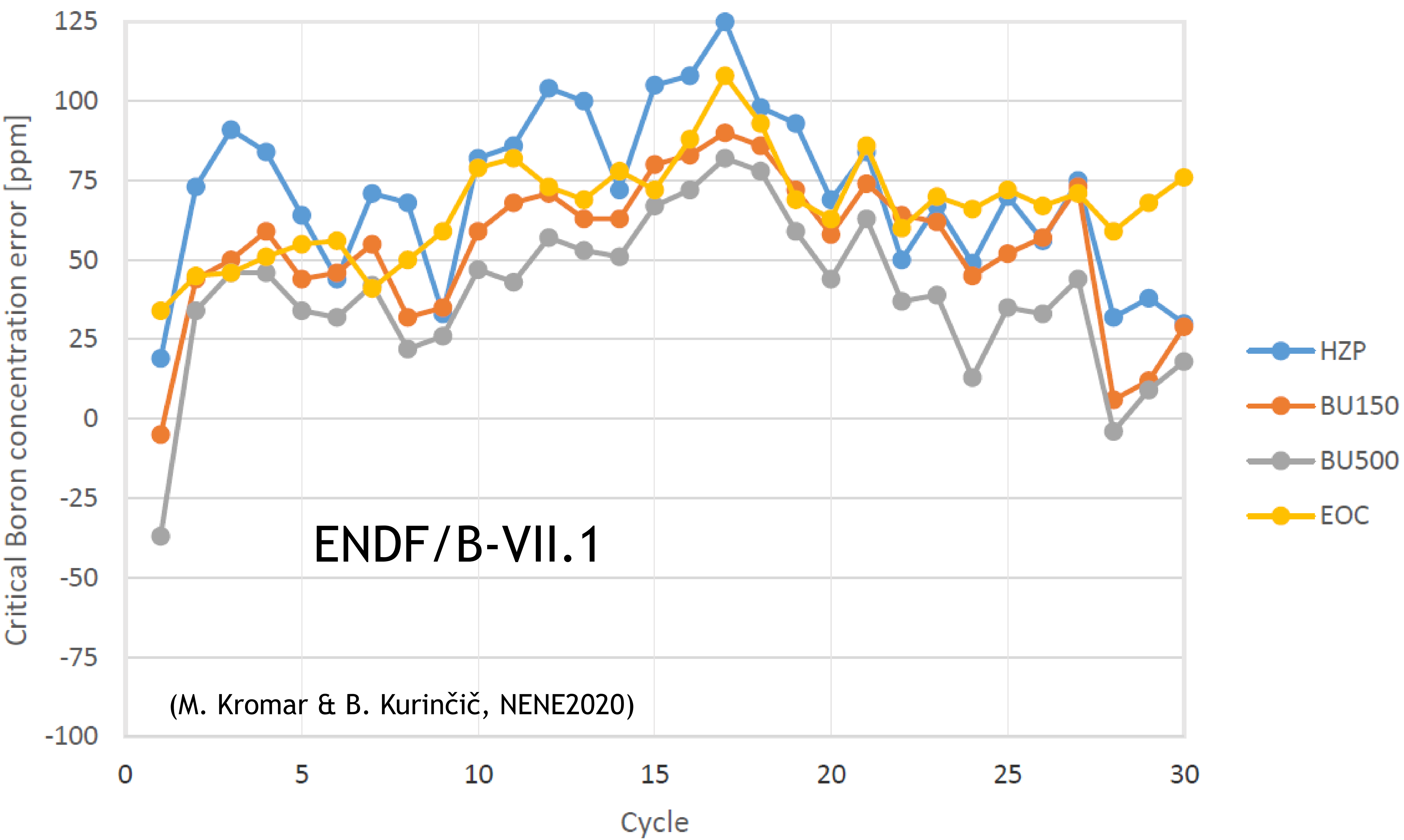

Reactivity KI vs Burnup in the assembly type FB - V5 E= 5.200
RO= 0.675 TM= 595 TF= 1000 CB= 300 PR= 0
100000*LN(K(B)/K(0+Xe)) (10^3)
Ratios
Burnup (10^3 MWd/THM)
KI ENDF/B-VII.1
KI ENDF/B-VIII.0
Maximum Difference
Over 100%
at X= 31840.0000

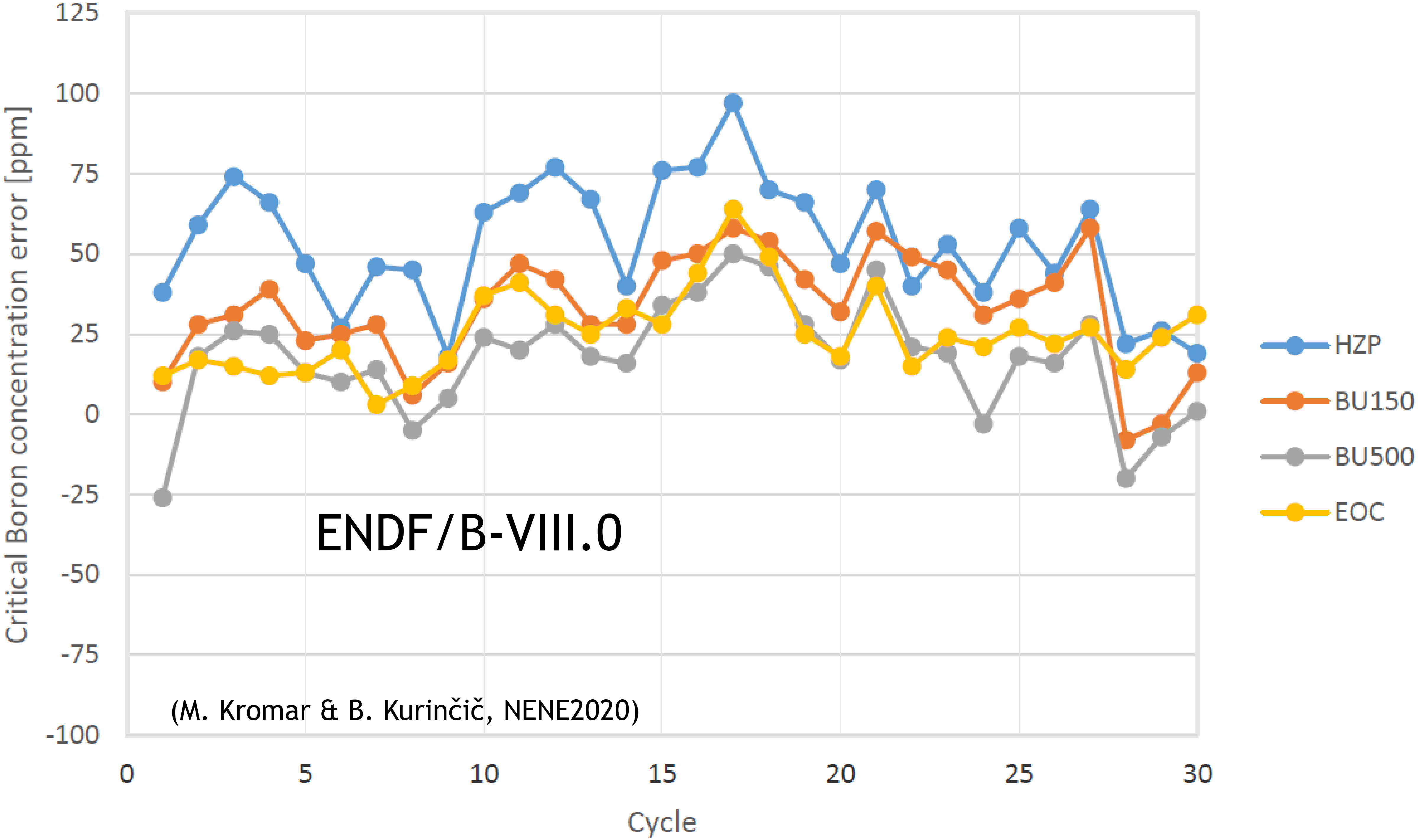
Krsko NPP (Westinghouse 2-loop PWR)

- CORD-2 design calculations (JSI) with different libraries.
  - Enrichment 2.1% - 4.9%, burnable pyrex rods, low-leakage loading pattern, integral burnable absorbers, power uprate from 600 MWe to 700 MWe, cycle length from 12 months to 18 months.
- Differences between measured and calculated boron concentrations at different burnup stages.
- 30 cycles of operation.

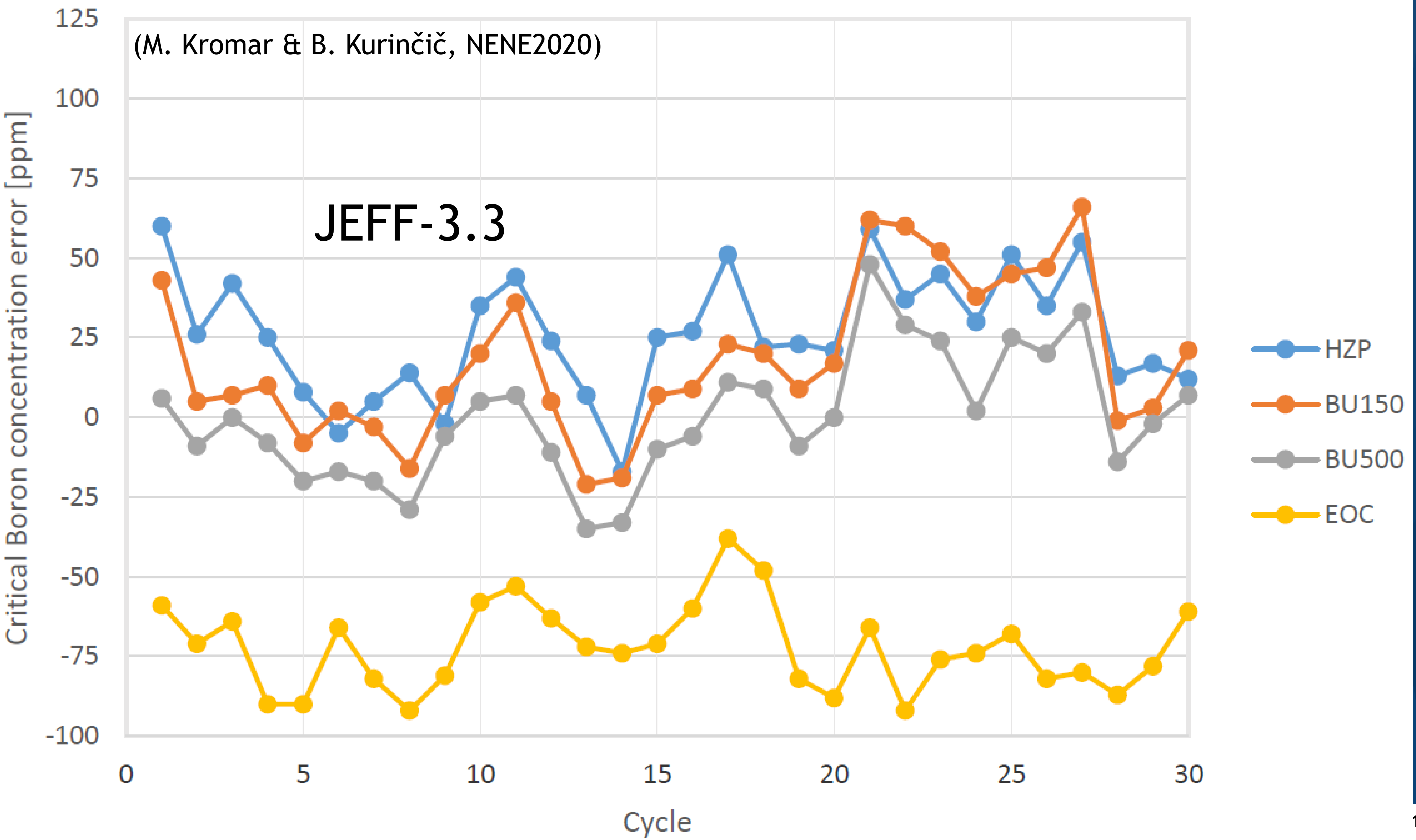
- Results presented by M. Kromar & B. Kurinčič, NENE2020, Portorož, September 2020.


ENDF/B-VII.0
(M. Kromar & B. Kurinčič, NENE2020)
Critical Boron concentration error [ppm]
Cycle
HZP
BU150
BU500
EOC
125
100
75
50
25
0
-25
-50
-75
-100
0
5
10
15
20
25
30


125
100
75
50
25
0
-25
-50
-75
-100
Critical Boron concentration error [ppm]
0
5
10
15
20
25
30
Cycle
HZP
BU150
BU500
EOC
ENDF/B-VII.1
(M. Kromar & B. Kurinčič, NENE2020)



Critical Boron concentration error [ppm]
125
100
75
50
25
0
-25
-50
-75
-100
0
5
10
15
20
25
30
Cycle
HZP
BU150
BU500
EOC
ENDF/B-VIII.0
(M. Kromar & B. Kurinčič, NENE2020)



(M. Kromar & B. Kurinčič, NENE2020)
JEFF-3.3
Critical Boron concentration error [ppm]
125
100
75
50
25
0
-25
-50
-75
-100
0
5
10
15
20
25
30
Cycle
HZP
BU150
BU500
EOC

Krsko NPP – summary of results

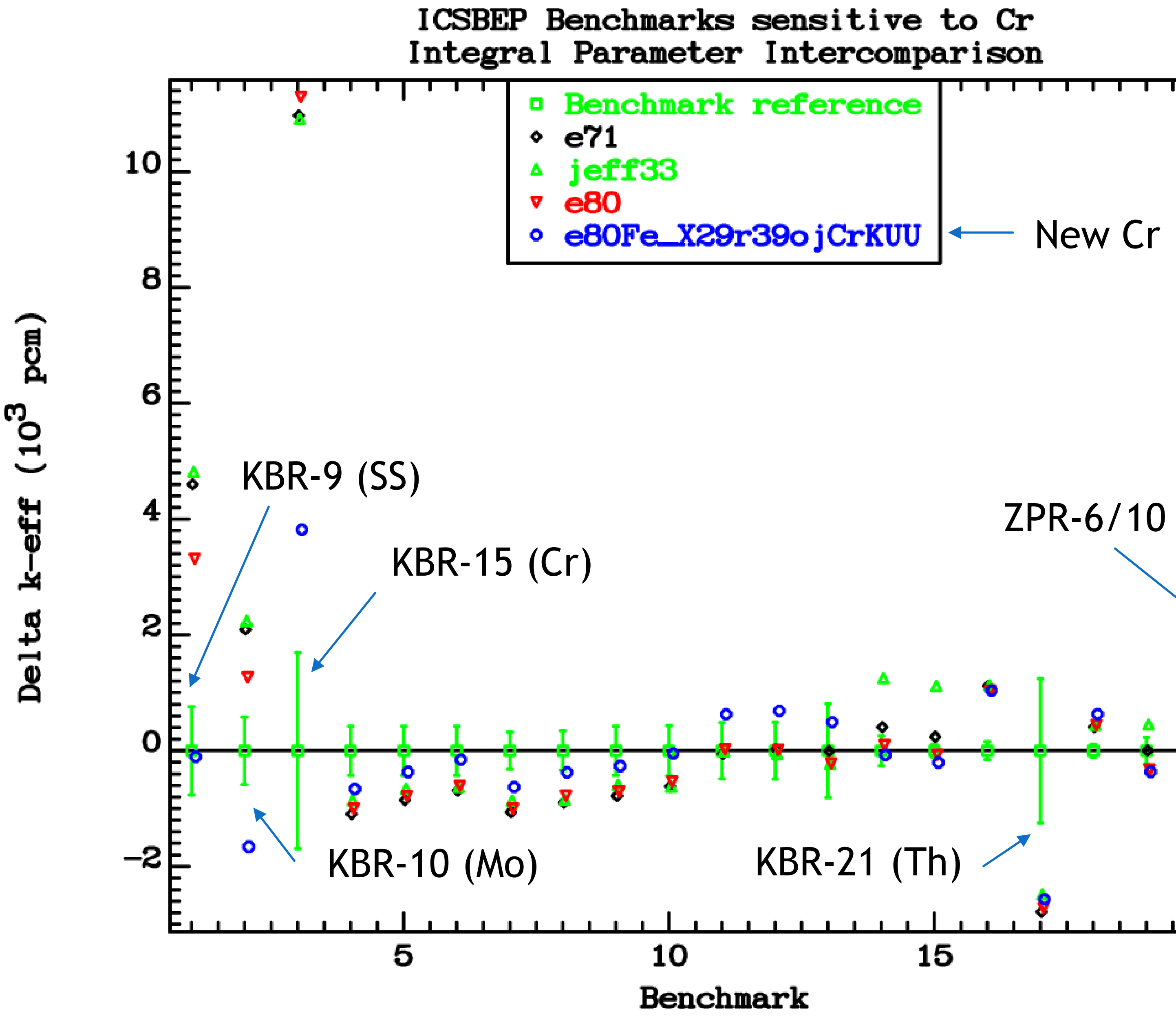
- There is some bias in each of the libraries.
- The difference HZP – BU150, BU500 is the power and xenon defect, which can be model-dependent.
- The difference BU500 – EOC determines cycle length prediction:
  - ENDF/B-VII.0 and ENDF/B-VIII.0 look good and flat,
  - ENDF/B-VII.1 shows some drift in reactivity,
  - JEFF-3.3 differs strongly (problems with JEFF-3.3 Pu-239 evaluation have been reported in works by other authors).

Conclusions

- Doubts were raised at the previous CSEWG Meeting about reactivity trends with enrichment and burnup.
- Reactivity loss with burnup was compared for a pin-cell of a real reactor with different releases of ENDF/B data.
- Critical boron concentrations at different burnup steps were compared to measured data for 30 cycles of operation.
- **ENDF/B-VIII.0** behavior is similar to ENDF/B-VII.0, but different from ENDF/B-VII.1 (pin-cell and PWR).

Chromium isotopes - Criticality

- Cr-isotope new evaluations were performed (ORNL-BNL-IAEA collaboration).
- Very few benchmarks are available.
- In the ICSBEP Handbook there are KBR-15 (HEU-COMP-INTER-005 k_∞) and ZPR-6/10 (PU-MET-INTER-002) with strong sensitivity to Cr – both are big outliers (**11%** and 2% in *k*, respectively)
- Oktavian-Cr is a 14 MeV experiment measuring leakage from a chromium sphere – not in SINBAD.
  - A new model was developed by Bor Kos at JSI.



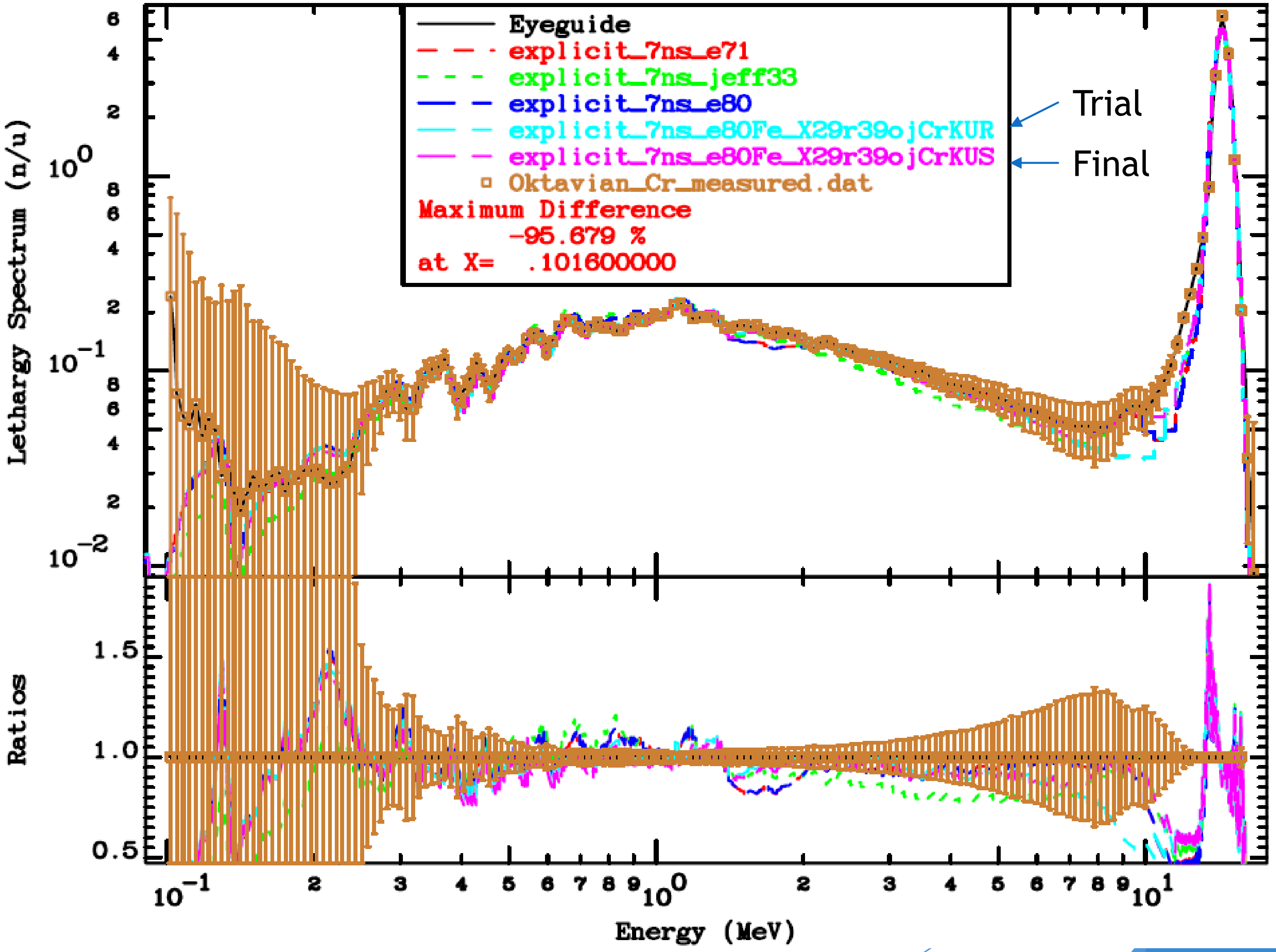
ICSBEP Benchmarks sensitive to Cr
Integral Parameter Intercomparison
Benchmark reference
e71
jeff33
e80
e80Fe_X29r39ojCrKUU
New Cr
KBR-9 (SS)
KBR-15 (Cr)
KBR-10 (Mo)
KBR-21 (Th)
ZPR-6/10
Delta k-eff (10^3 pcm)
Benchmark

No.	ICSBEP Label	Short name	Common name	Comment
1	HEU-COMP-INTER-005	hci005-009	KBR-09(SS)	k_inf
2	HEU-COMP-INTER-005	hci005-010	KBR-10(Mo)	k_inf
3	HEU-COMP-INTER-005	hci005-015	KBR-15(Cr)	k_inf
4	HEU-COMP-THERM-011	hct011-001	RRC-KI-21x21-001	Cr ; Chromium ; SS_clad
5	HEU-COMP-THERM-011	hct011-002	RRC-KI-21x21-002	Cr ; Chromium ; SS_clad
6	HEU-COMP-THERM-011	hct011-003	RRC-KI-21x21-003	Cr ; Chromium ; SS_clad
7	HEU-COMP-THERM-012	hct012-001	RRC-KI-18x18-001	Cr ; Chromium ; SS_clad
8	HEU-COMP-THERM-012	hct012-002	RRC-KI-18x18-002	Cr ; Chromium ; SS_clad
9	HEU-COMP-THERM-013	hct013-001	RRC-KI-14x14-001	Cr ; Chromium ; SS_clad
10	HEU-COMP-THERM-013	hct013-002	RRC-KI-14x14-002	Cr ; Chromium ; SS_clad
11	HEU-COMP-THERM-014	hct014-001	RRC-KI-10x10-001	Cr ; Chromium ; SS_clad
12	HEU-COMP-THERM-014	hct014-002	RRC-KI-10x10-002	Cr ; Chromium ; SS_clad
13	HEU-COMP-THERM-022	hct022-001	SPERT-III	Cr ; Chromium ; SS_clad
14	HEU-MET-INTER-001	hmi001	ZPR-9/34	SS_refl. Fe Cr
15	HEU-MET-INTER-001	hmi001d	ZPR-9/34	%6 %7 SS_refl. Fe Cr
16	HEU-MET-THERM-016	hmt016	LACEF/Ni-Cr-Mo-Gd	Ni ; Cr ; Mo ; Gd ; Poly
17	IEU-COMP-THERM-005	ict005	KBR-21	
18	LEU-SOL-THERM-012	lst012-001	TRACY-203c	
19	MIX-COMP-FAST-001	mcf001	ZPR-6/7	Cr
20	MIX-MET-FAST-008	mmf008-003	ZEBRA-8C/2	
21	PU-MET-INTER-002	pmi002	ZPR-6/10	Fe, Cr SS_refl. ; Iron

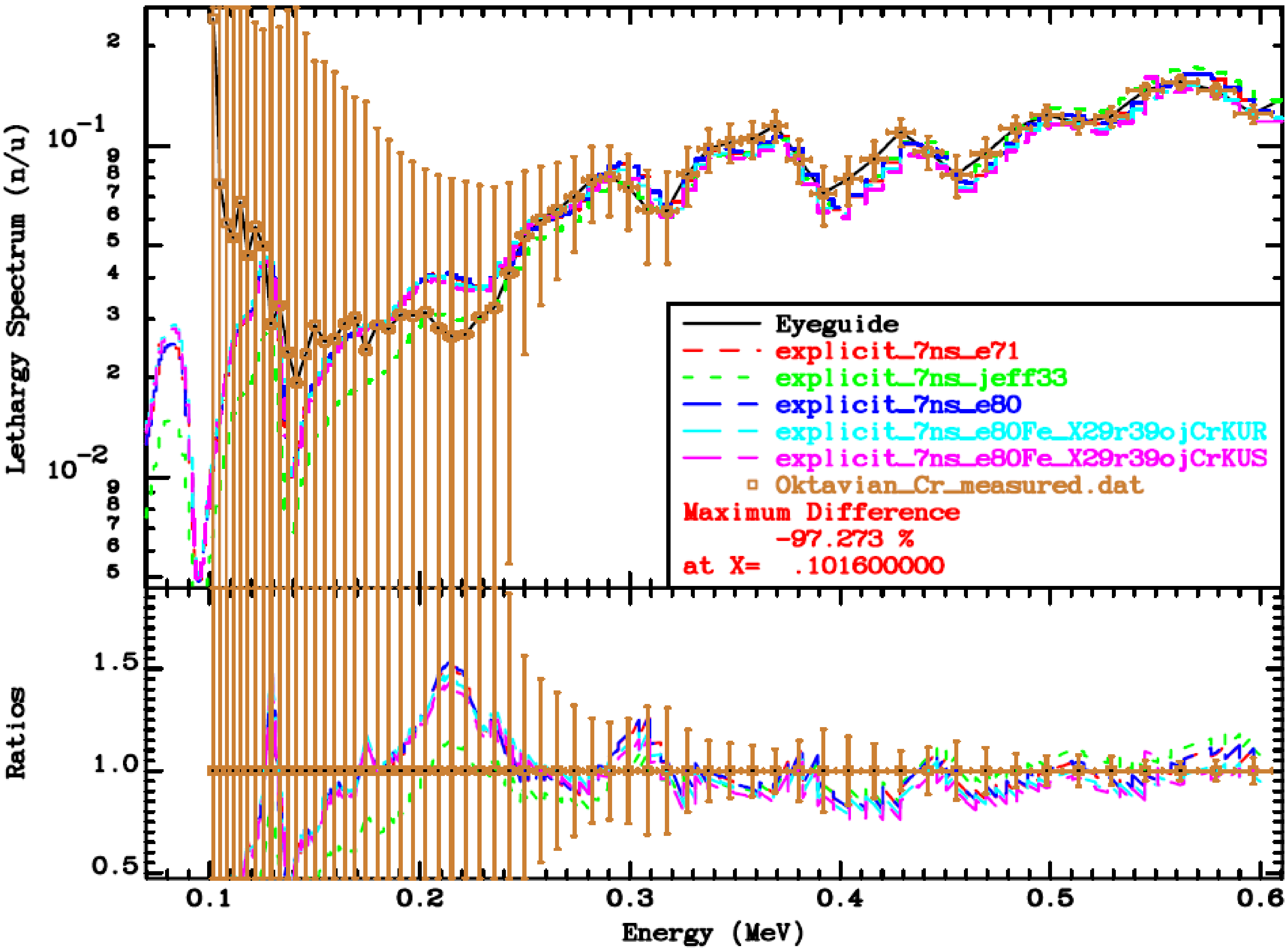
Chromium isotopes – 14 MeV Leakage

- Oktavian-Cr is **not** in SINBAD. New model was developed by B.Kos (JSI) based on previous work by A. Milocco with explicitly modelled source:
  - Analysis in time-domain is crucial – subsequent conversion into the energy domain.
  - Resolution-broadening is needed to reproduce the elastic peak (asymmetric resolution function?).
  - New evaluations of Cr isotopes perform well for 14 MeV benchmarks.

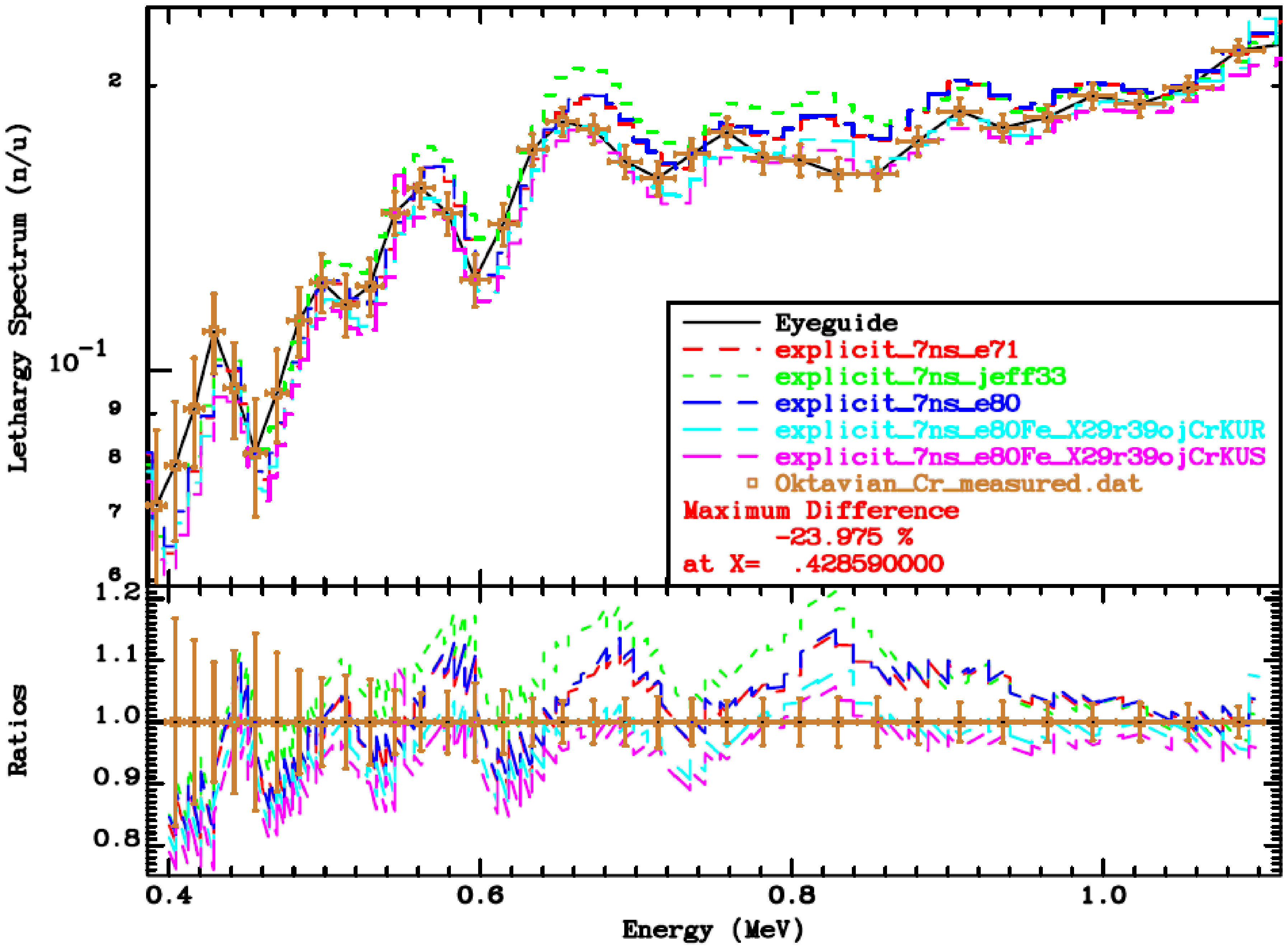
Oktavian Chromium benchmark, neutron leakage



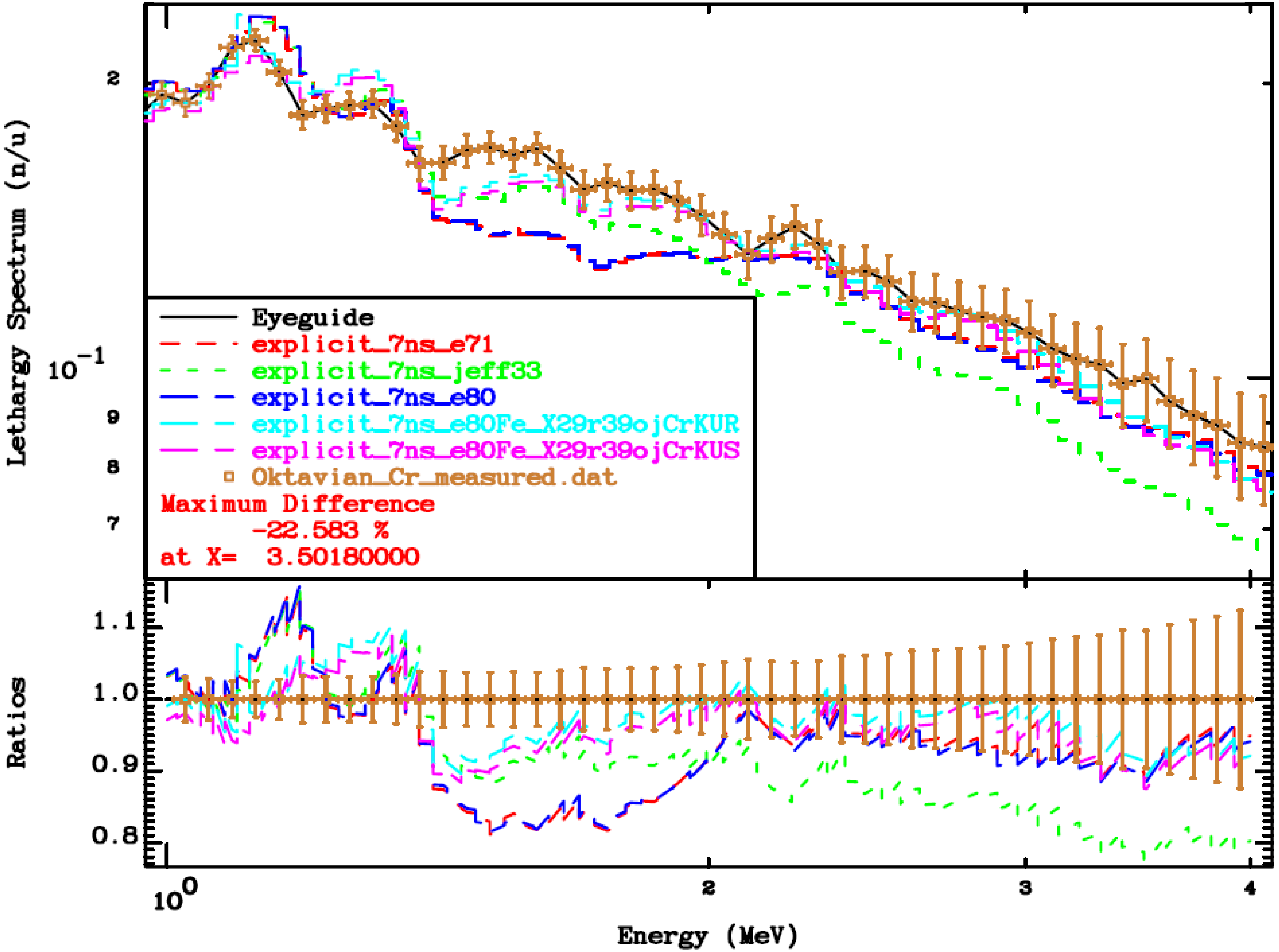
Oktavian Chromium benchmark, neutron leakage



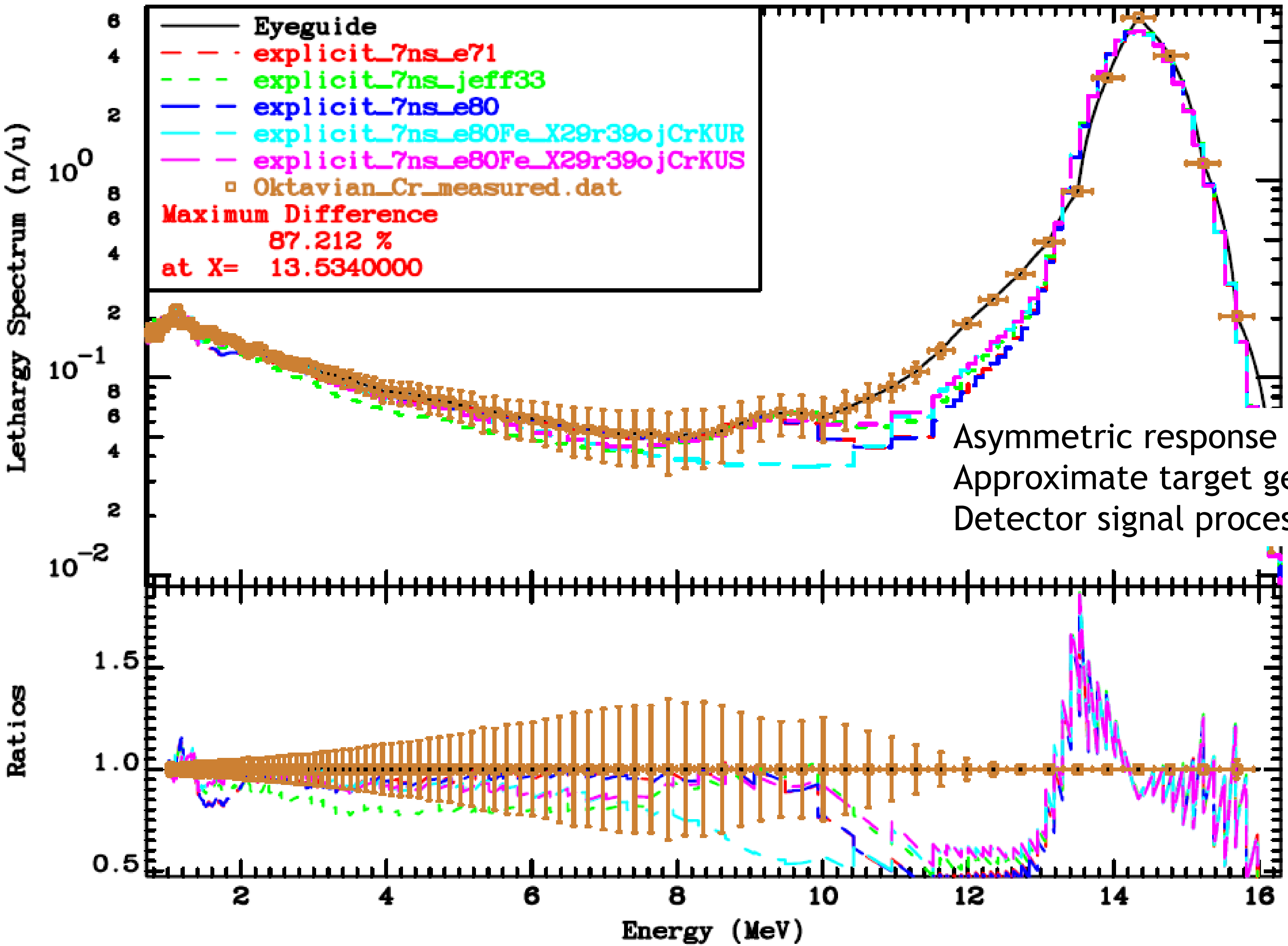
Oktavian Chromium benchmark, neutron leakage



Oktavian Chromium benchmark, neutron leakage



Oktavian Chromium benchmark, neutron leakage



Asymmetric response function
Approximate target geometry
Detector signal processing

Supplement

Plots of the evolution of burnable nuclide concentrations in a pin-cell defined in Slide 8.

Supplement

Plots of the evolution of burnable nuclide concentrations in a pin-cell defined in Slide 8.