DE LA RECHERCHE À L'INDUSTRIE

Full Burnup Credit conservatisms in PWR-UOx industrial applications, due to the correction and penalty factors derived from the French experiments using the JEFF3.1.1 evaluation

Coralie CARMOUZE, Cécile RIFFARD, Alain SANTAMARINA

CEA, DEN, CAD, DER, SPRC – *Saint Paul-lez-Durance, France*

Gabriele GRASSI

AREVA-NC, BU RECYCLAGE – *Paris, France*

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CONTENT

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- The full BUC method
  - Calculation route and new features
  - Different steps and assumptions
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- Conclusion and prospect

Context (1/2)

Concept of Burnup Credit (BUC)

Taking credit for the reduction of the reactivity of nuclear spent fuel due to their burnup is referred to as **"Burnup Credit" (BUC).**

Allowing reactivity credit for spent nuclear fuels offers many economic incentives.

Background : Increasing ^{235}U enrichments

Applications : Transport, Storage

Historical

No BUC:

Fresh fuel inventory in criticality calculation

↔ **no depletion calculation**

BUC « Actinide-Only »:

- **Depletion calculation** with nominal values of the irradiated parameters;
- **Only actinides** composed the fuel inventory in **criticality calculations**: :
- ^{235}U, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu;
- **UNIFORM** axial burn-up ⇨ 50-least irradiated-centimeters of the fuel assembly

NO BUC

1980

Current status in France : « Actinide-Only » for PWR-UOx fuel at La Hague reprocessing facility

BUC Actinide-Only

2003

Full BUC method

2013: Validation of the implementation of the Full French BUC approach by the German Safety Authorities (BFs) for the TN24E transport cask

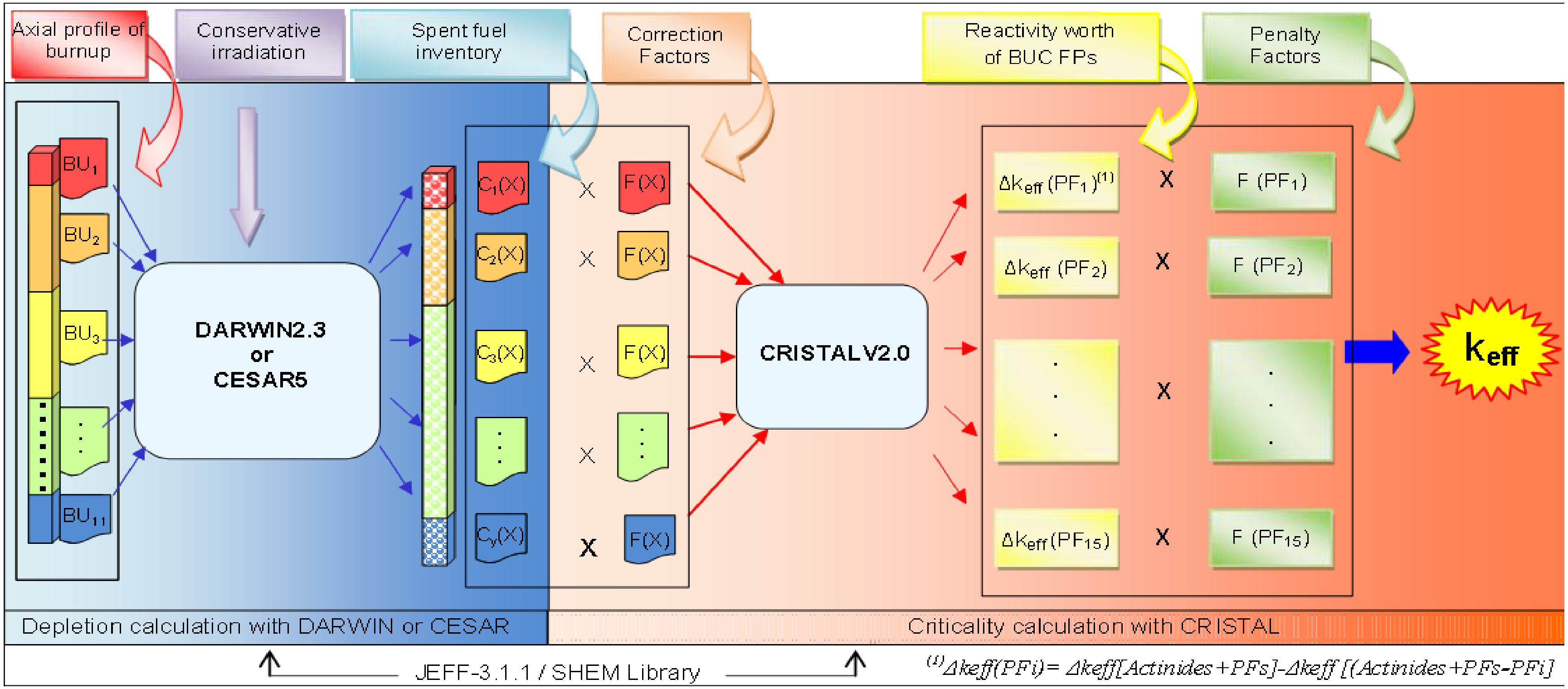
Context (2/2)

- **2003: New and more rigorous method / reducing the conservatisms → « Full BUC » method**

- ✓ **Depletion calculations** with conservative conditions of irradiation (MOX surrounding, control rods…)
- ✓ **Criticality calculations:**
  - Fuel inventory composed **of 12 ACTINIDES and 15 FISSION PRODUCTS** (absorbing stables and non volatile)
  - Application of Isotopic Correction Factors
  - Definition of a conservative axial burnup profile

- **2009:** Determination of a conservative axial burnup profile
- **2011:** Determination of new correction factors with the recent JEFF3.1.1 / SHEM library
- **2013: Complete Full BUC method and impact evaluation of an industrial case with the latest version of the codes (DARWIN2.3 and CRISTALV2.0) and library (JEFF3.1.1)**

Connexion of a depletion code: DARWIN and a criticality- safety package: CRISTAL



New Version of codes and ND library : (JEFF3.1.1-SHEM / APOLLO2.8.3) DARWIN2.3 or CESAR5.3 / CRISTALV2*.0.dev

** The Criticality Package CRISTALV2 has been developped jointly by **IRSN, CEA and AREVA***

*« Trends of the deterministic route APOLLO2.8/JEFF3.1.1 of CRISTAL V2 Criticality Package » C. Riffard & all **- Topical session Method I***

Which purpose ?

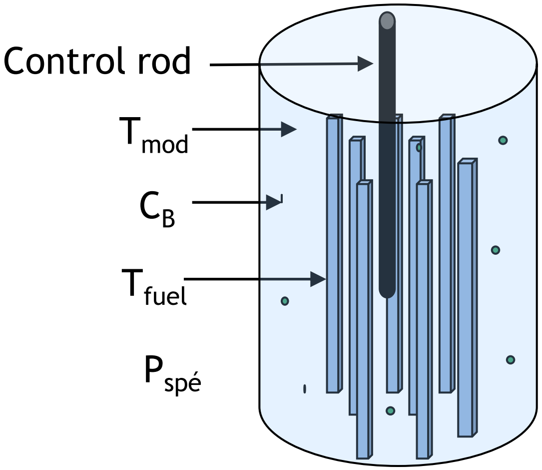
Guaranty the conservativeness of the depleted fuel inventory in the criticality calculations of PWR UOx spent assemblies and **get** a conservative and physically realistic value of the k_{eff} :

→ use conservative irradiation conditions in depletion calculation ;

→ consider calculation biases on BUC isotopes inventory and individual reactivity worth in criticality studies.

Conservative irradiation conditions – conclusion from early studies

Irradiation parameters	Conservative values
Fuel temperature	873 K
Moderator temperature	598 K
Boron Concentration	600 ppm
Specific power	40 W/g
Environment of the UOx assembly	Complete MOx environment (8 assemblies)
Control rods	Full axial insertion B_4C material
Control rods insertion	Throughout all the irradiation

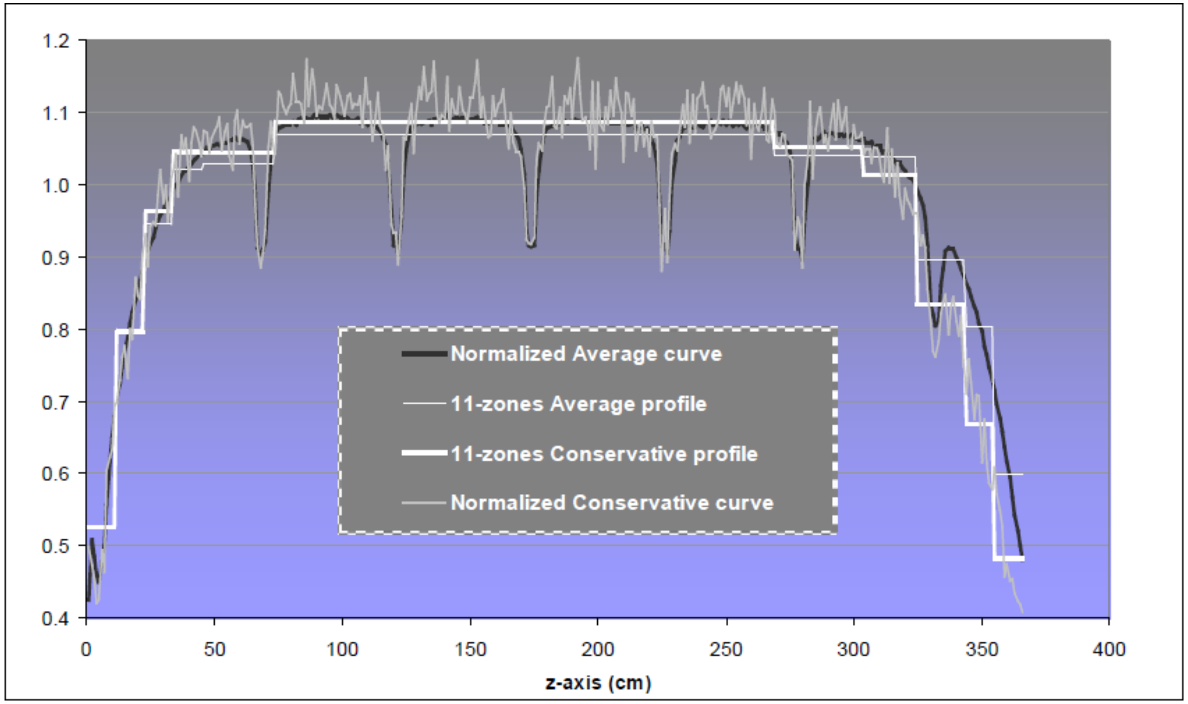


Penalizing burnup profile

Use of a mean uniform burnup profile for BU > 30 GWd/t → **not physical**

- Determination of an **axial burnup profile** for PWR-UOx fuel based on the French database of axial burn-up measurements - covering :

  ⇨ Average **burnup** ranging between **20-50 GWd/t**



Simplified 11-zones model

Two set of correction factors

Guaranty the conservativeness of the depleted fuel inventory

Underestimate absorbing isotopes – **Overestimate** fissile isotopes

1. Isotopic Correction Factors (ICFs)

Applied on the concentrations of the BUC isotopes

Before the criticality calculation

2. Reactivity worth Correction Factors

Applied on the calculated reactivity worth of the BUC isotopes

After the criticality calculation

Specific BUC experimental program

Post Irradiation Experiments for the validation of spent fuel inventory calculation

Oscillations experiments in the MINERVE reactor for the validation of the FPs reactivity worth

1- Isotopic correction factors:

The estimation of the penalized bias and of the resulting correction factors is based on two components:

1- The calculation biases : calculation-experiment comparison (**C/E-1**)

⇒ **ICFs derived from the DARWIN2.3/JEFF3.1.1 experimental validation** based on a rigorous selection of 22 well characterized samples
BU ∈ [15 -60 GWj/t] ; Ei ^{235}U ∈ [3.1 - 4.5%]

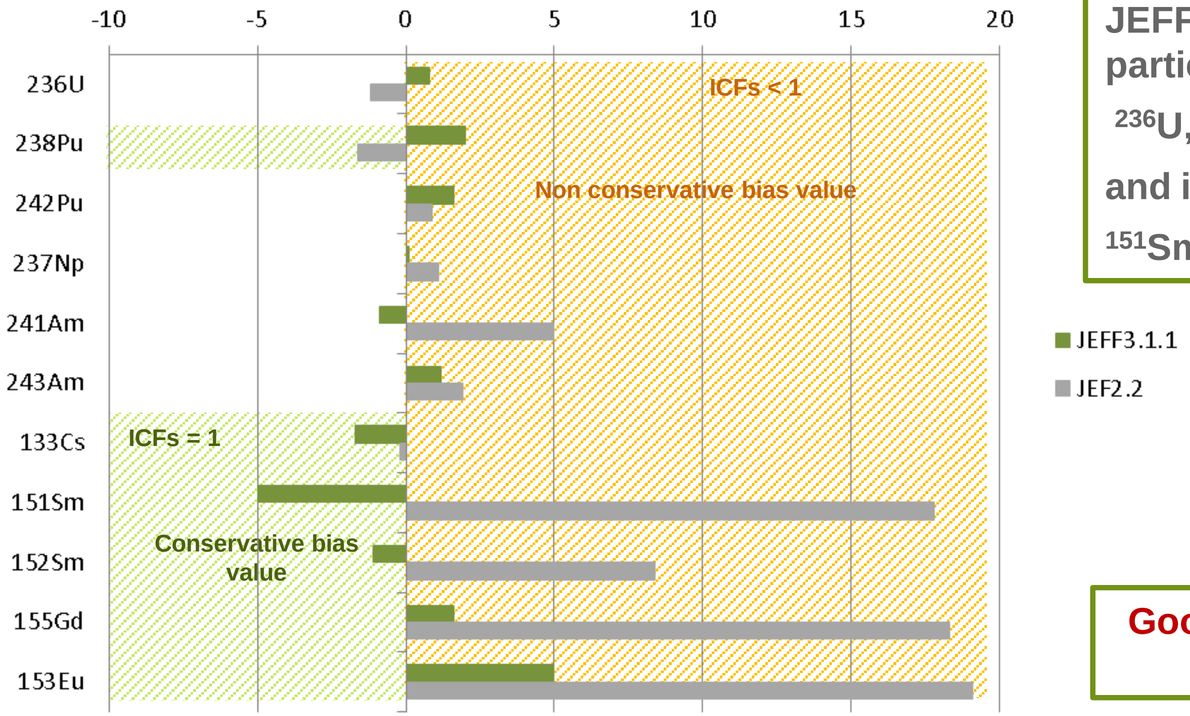
2- The experimental uncertainties : the bias is penalized by the one-sided 95% confidence interval

⇒ *Penalized bias for fissile isotopes* $\Delta = (C\text{-}E)/E - 1.65\sigma$

⇒ *Penalized bias for absorber isotopes* $\Delta = (C\text{-}E)/E + 1.65\sigma$

Fissile isotopes are corrected by a factor > 1
Absorbing isotopes are corrected by a factor < 1
Overestimated fissile isotopes and underestimated absorber isotopes are not corrected

Comparison of penalized bias values with previous JEF2 evaluation



Penalized bias value at 30 GWd/t
(C/E-1) ± 1.65σ (%)

JEFF-3.1.1 based predictions are particularly improved for minor actinides:

^{236}U, ^{237}Np, ^{238}Pu, ^{242}Pu, ^{243}Am, ^{241}Am

and important BUC FPs:

^{151}Sm, ^{152}Sm, ^{153}Eu, ^{155}Gd

Good confidence for spent fuel criticality application

Reference
C. RIFFARD, A. SANTAMARINA, J.F THRO, « Correction Factors applied to isotopic concentrations in Burnup Credit of PWR LEU applications with the recent JEFF-3.1.1 / SHEM Library » , Proc of Int Conf ICNC, 19 - 22 September 2011, Edinburgh Conference Centre

2- Reactivity worth correction factors

Experimental validation of the FPs reactivity worth in representative spectrum for PWR UOx applications :

Trends due to ND in JEFF-3.1.1 evaluation

The estimation of the penalized bias and of the resulting correction factors is based on two components**:**

1- The calculation biases : calculation-experiment comparisons (**C/E-1**)
Give by the rigorous interpretation of fission product oscillations experiments

Reference : A. Gruel, P. Leconte, D. Bernard, P. Archier, G. Noguère, **"Interpretation of Fission Product Oscillations in the MINERVE reactor, from Thermal to Epithermal Spectra"**, Nuclear Science & Engineering.

The calculation biases are well quantified and give accurate informations on nuclear data

2- The total uncertainties (measurements and technological)

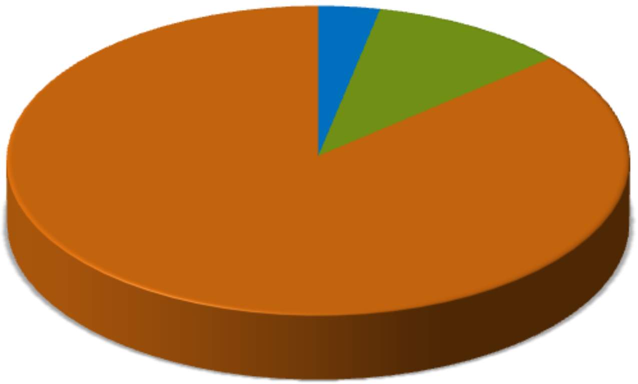
✓ *45 GWd/t BU and a 1 year CT*

Isotopic Correction Factors ⇨ **7% Δkeff**

Total penalty: 1600 pcm

FPs reactivity worth Correction Factors ⇨ **3% Δkeff**

FPs	Impact on the keff in a transport cask (pcm)
MO95	8
TC99	46
RU101	20
RH103	139
AG109	11
CS133	67
ND143	24
ND145	17
SM147	38
SM149	61
SM150	5
SM151	25
SM152	23
EU153	0
GD155	8
Total penalty	500 pcm

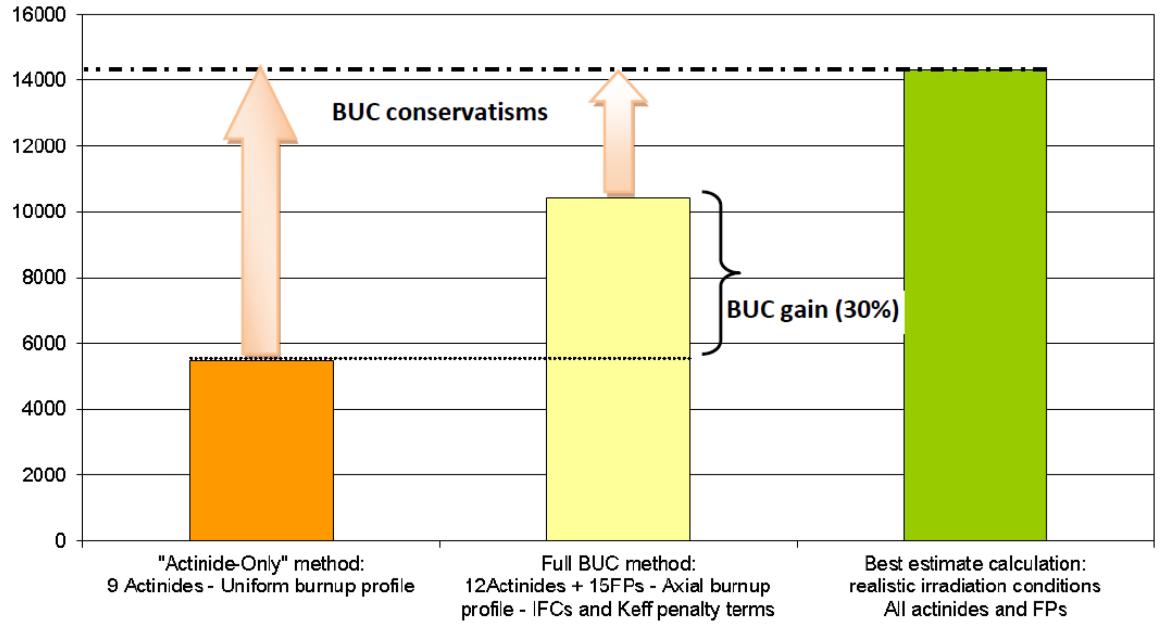


Slight impact in regards to the other conservatisms

Application
Burnup credit gain estimation

Transport cask configuration loaded with 21 irradiated fuel assemblies (4.5%wt) (BUC OCDE benchmark phase II &III)

BU	CT	BUC [k_{eff}(fresh fuel) - k_{eff}(BUCi)] BUC "Actinide-Only"	Full BUC	Best-estimate BUC
15 GWd/t	1 year	5300	9900	14000
	5 years	5500	10400	14300
45 GWd/t	1 years	17400	22000	35300
	5 years	18700	24100	37000
% Best-estimate BUC		**≈40-50%**	**≈60-70%**	**100%**



Full BUC approach: 70% of the best-estimate BUC

vs.

40% in the current actinide-only method

Significant reduction of the conservatisms due to more physically and reresentative assumptions

≈30% gain in BUC-margins

"Full Burnup Credit conservatisms in PWR-UOx industrial applications, due to the correction and penalty factors derived from the French experiments using the JEFF3.1.1 evaluation"

Conclusion and prospect

Full BUC approach

✓ Benefit from the improvement of JEFF3.1.1 prediction in all the step of the process and from the good confidence of latest version of the codes (DARWIN2.3 and CRISTAL V2.0)

✓ Benefit from the quality and the accurate interpretation of a ten years work specific French BUC program

✓ Use of realistic and physically demonstrated hypotheses

Implementation on a transport cask

✓ Confirm the interest of its implementation in criticality studies for transport
→ 30% BUC-margins due to more realistic assumptions

✓ Highlights the impact of the conservatisms in particular of the corrections factors
→ represent only 10% of the full BUC
→ integrate the bias linked to the fuel inventory and the biases on the reactivity worth due to ND
→ contribute to the expansion of the spent fuel inventory composition (minor actinides & FPs)
→ constitute one of the key of the methodology quality

✓ The other conservatisms impact could be reduced for specific applications

Prospect

Improve the way to take account of the reactivity worth of BUC nuclides in criticality studies by using the Integrate Experiment Methodology*

*"Feedback on nuclear data from Burnup Credit Fission Products Oscillations in the MINERVE reactor" A.Chambon &all – **Topical session: Method I**

THANK YOU FOR YOUR ATTENTION !

Commissariat à l’énergie atomique et aux énergies alternatives
Centre de Cadarache | 13108 Saint Paul lez Durance
T. +33 (0)4 42 25 31 30 | F. +33 (0)4 42 25 48 49

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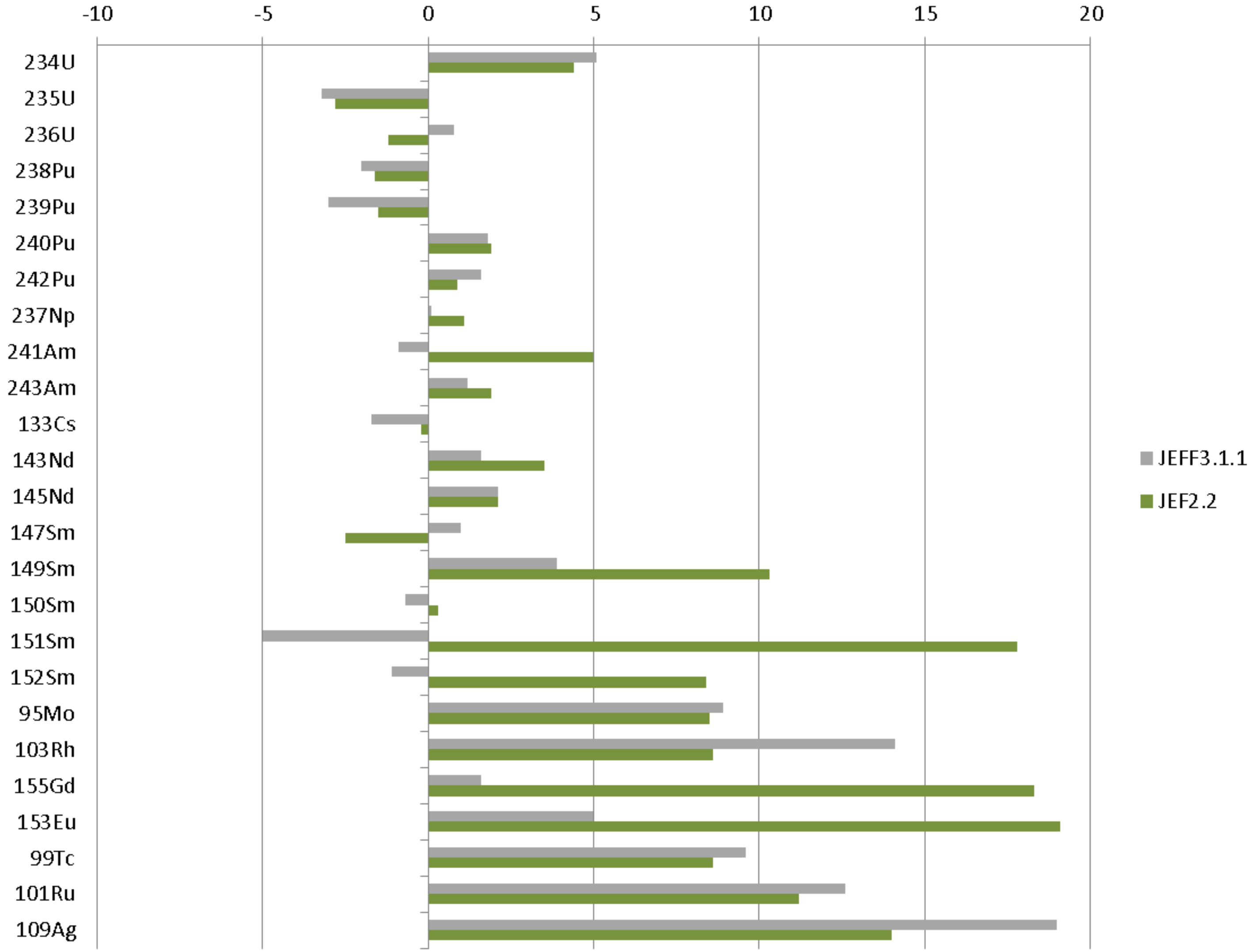

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133Cs
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150Sm
151Sm
152Sm
95Mo
103Rh
155Gd
153Eu
99Tc
101Ru
109Ag
JEFF3.1.1
JEF2.2