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D. Rochman

Nuclear data needs for Spent Fuel Characterization: a review of PSI experience

Consultancy meeting, IAEA, videomeeting, November 2-4, 2020

Summary

- Spent Fuel Characterization: What is at stake ?
- Spent Fuel Characterization: an ongoing national & international effort

- Requirements
- Examples for
  - criticality,
  - decay heat,
  - burnup,
  - neutron/gamma source
  - and isotopic contents

- Only the neutronic aspect will be tackled here

SFC: What is at stake ?

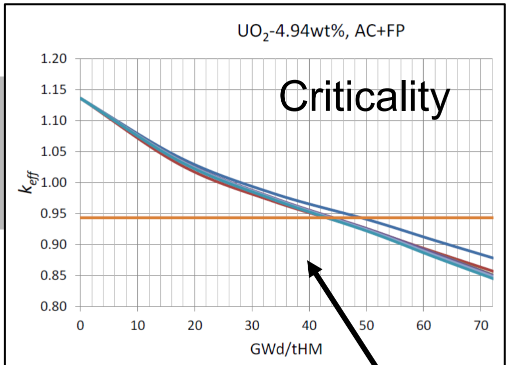
- Safety is the main criteria for Spent Fuel handling during
  - Cask transport,
  - Cask wet/dry storage,
  - Canister deep geological disposal

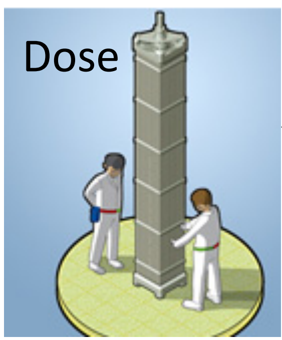
- A precise knowledge of Spent Fuel also affects:
  - The design of interim storage and final repository facility
  - Cask/canister loading
  - Safeguards
  - Cost

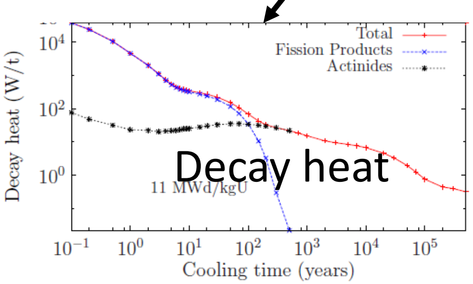
- Precise knowledge of the Spent Fuel means
  - Accountability (counting)
  - Characteristics (part measurements and part calculations)

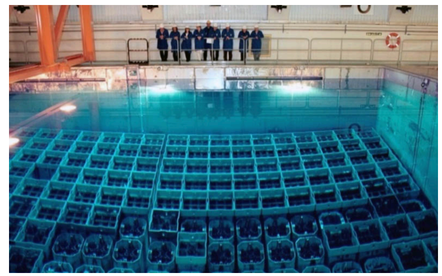
- Safety, design, cost are therefore dependent on calculations, which depend, among other relevant parameters, on nuclear data

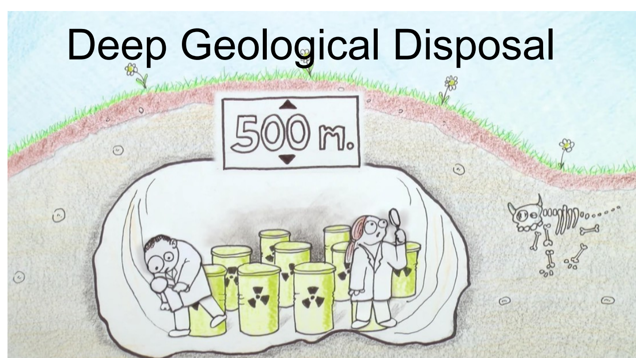
SFC: What is at stake ?

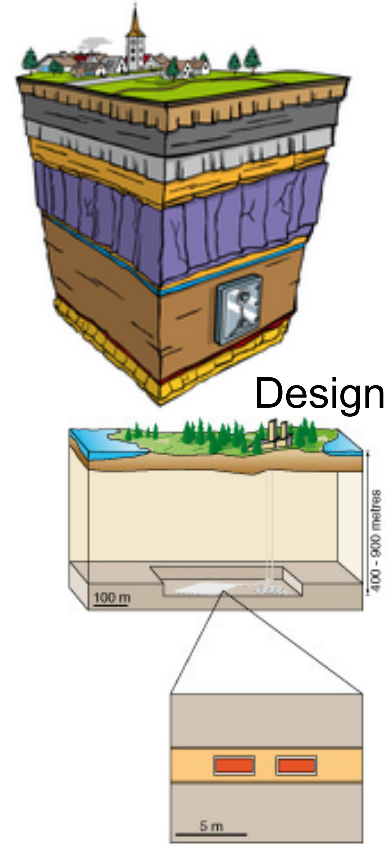


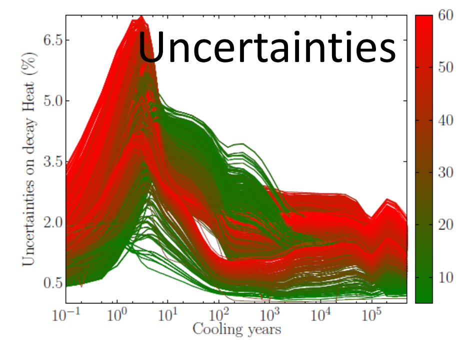












An ongoing national & international effort

- New IAEA CRP: Spent Fuel Characterization (T13018)
- EU EURAD SFC WP8: Spent Fuel Characterisation and Evolution until disposal
- SKB Blind test in prediction of decay power: 25 groups/organizations
- OECD/NEA WPNCS
- National Efforts: US, France, Japan, Russia
- Tools: SCALE, CMS, …
- International standards: (DIN, ISO, JAERI, NRC, ASTM)
- Measurements and compilations: SF-COMPO, ICSBEP, CLAB, HEDL, GE-Morris
- → a lot of efforts, rules, knowledge

SFC: Requirements

- Estimation of code predictions (C/E), biases, errors, uncertainties for
  - Decay heat
  - Criticality
  - Radiation dose
  - Nuclide inventory
  - SF characteristics (BU, enrichment, irradiation life, cooling life)
  - Many quantities are linked

- Nuclear data play a role in all the above
  - The question is: Are the C/E good enough ?
  - Another question is: Are the Δ(C/E) good enough ?
  - Another question is: how much nuclear data affect C/E and Δ(C/E) ?
  - Another question is: are all the Δ(C/E) for the above quantities consistent ?

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Example for criticality for Geological Disposal of spent fuel

around 2022. One of the requirements for the design of the repository is the safety of the installations (encapsulation facility and repository) from the point of view of a possible criticality excursion over a 1'000'000 year lifetime. Criticality, were it to occur, would produce elevated temperatures (several hundred degrees) in the near field, which could affect safety relevant properties and induce groundwater movement.

nagra.

Arbeitsbericht NAB 17-23

Tab. 3-2: Actinides only (AC) burnup credit nuclides.

U-233	U-234	U-235	U-236	U-238	Pu-238
Pu-239	Pu-240	Pu-241	Pu-242	Am-241	Cm-242
Cm-243	Cm-244	Cm-245	Cm-246		

materials *Materials* **2019**, *12*, 494; MDPI

Article

Preliminary Assessment of Criticality Safety Constraints for Swiss Spent Nu in Disposal Canisters

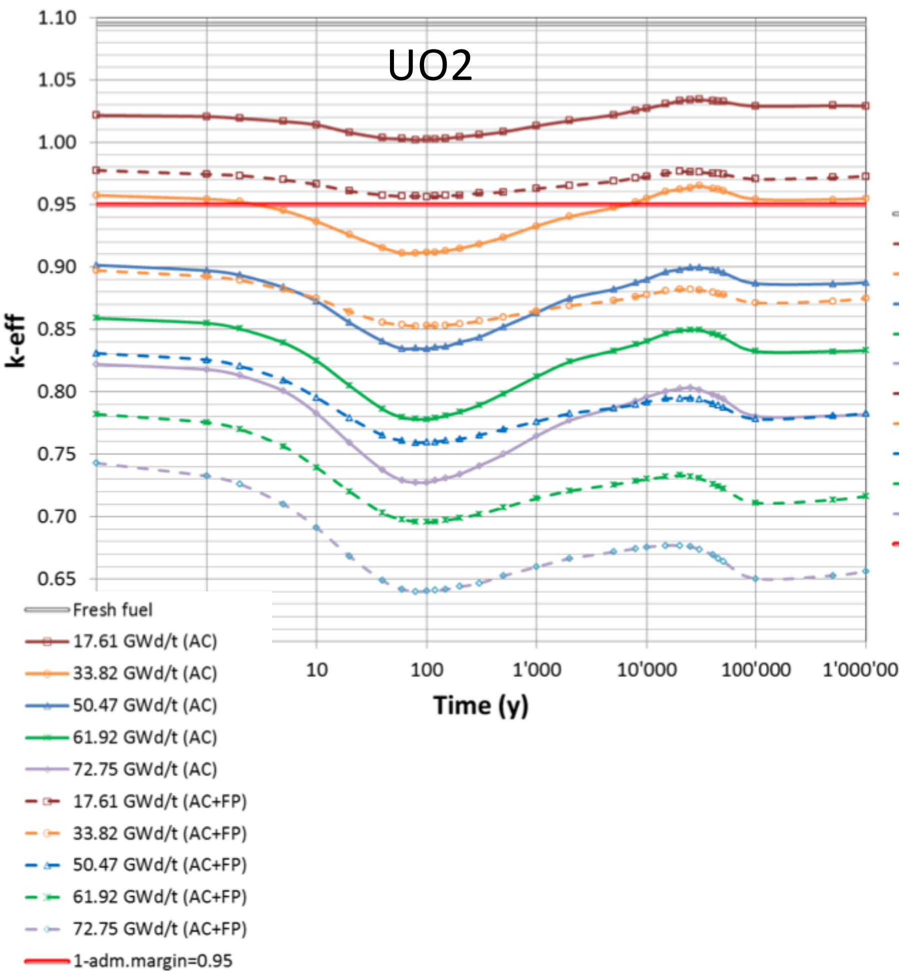
Alexander Vasiliev [1,*], Jose Herrero [1], Marco Pecchia [1], Hakim Ferroukhi [1] and Stefano Caruso [2]

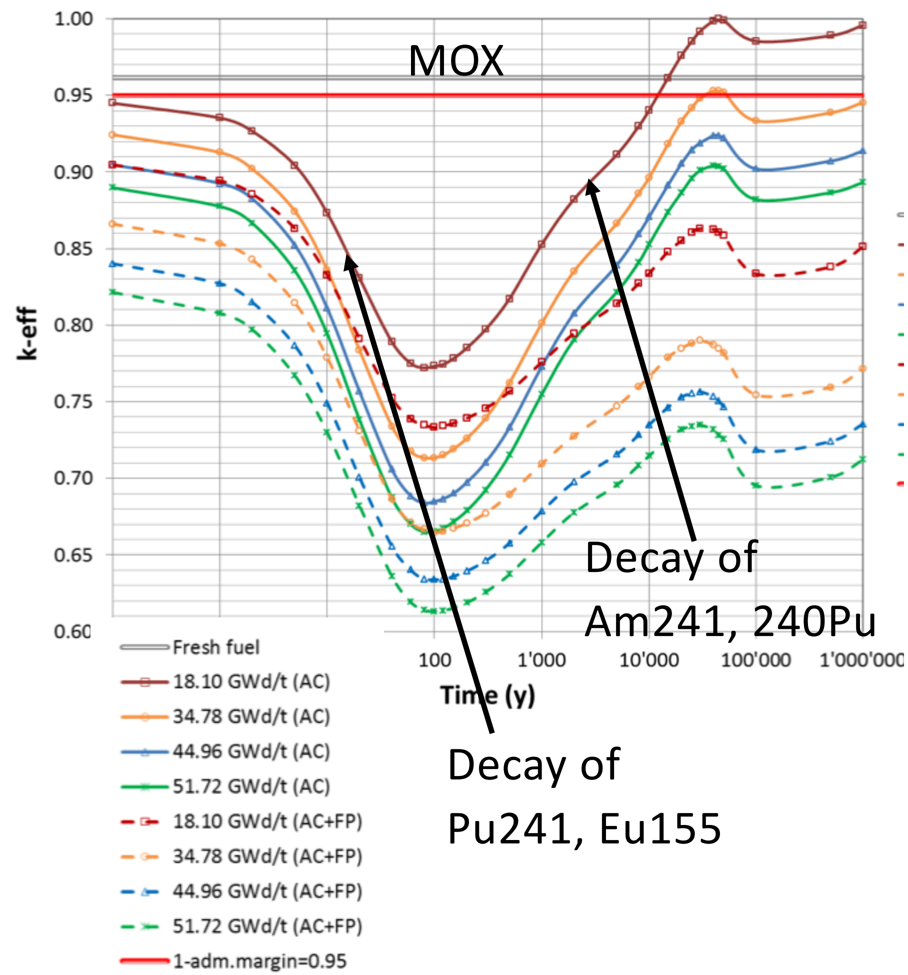
Tab. 3-3: Actinides plus fission products (AC+FP) burnup credit nuclides.

U-233	U-234	U-235	U-236	U-238	Np-237	Pu-238	Pu-239
Pu-240	Pu-241	Pu-242	Am-241	Am-242m	Am-243	Cm-242	Cm-243
Cm-244	Cm-245	Cm-246	Mo-95	Tc-99	Ru-101	Rh-103	Ag-109
Cs-133	Nd-143	Nd-145	Sm-147	Sm-149	Sm-150	Sm-151	Sm-152
Eu-151	Eu-153	Gd-155					

Example for criticality for Geological Disposal of spent fuel

- Canister 4 identical assemblies,





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Example for criticality for Geological Disposal of spent fuel

- Canister 4 identical assemblies, 50 000 y, UO2 4.94%, uncertainty on keff
- Using ENDF/B-VII.1 covariance data

Exposure (GWd/t)	σ_{ND}	σ_{OP}	σ_{BU-eff}	σ_{TP}	$\sigma_{T1/2}$	σ_{MC}	$1*\sigma_{tot}$	$2*\sigma_{tot}$
0	0.00367	0.00000	0.00000	0.00010	0.00015	0.00025	0.00368	**0.00737**
17.61	0.00560	0.00100	0.00200	0.00010	0.00015	0.00025	0.00604	**0.01208**
33.82	0.00700	0.00400	0.00200	0.00010	0.00015	0.00025	0.00831	**0.01662**
50.47	0.00834	0.00500	0.00700	0.00010	0.00015	0.00025	0.01199	**0.02397**
61.92	0.00930	0.00500	0.00700	0.00010	0.00015	0.00025	0.01267	**0.02534**
72.75	0.01026	0.00500	0.00700	0.00010	0.00015	0.00025	0.01339	**0.02679**

- Why is that important ? Because spent assemblies have to be more burnt to be loaded in canister (problematic for first and last reactor cycles).

Example for decay heat

Technical Report

TR-10-13

Spent nuclear fuel for disposal in the KBS-3 repository

Svensk Kärnbränslehantering AB

December 2010

6.4 Decay power

The decay power will be calculated for all assemblies before they are selected for encapsulation. A margin is added to the calculated decay power to ensure that the actual decay power conform to the criteria 1,700 W. Based on comparisons between calculated and measured decay powers, the uncertainty in calculated decay power is estimated to 2%, and the current selection of assemblies is made so that the total calculated decay power of the assemblies in a canister does not exceed 1,650 W. The decay power of each assembly, if required, can be measured in conjunction with the delivery to the encapsulation part of the Clink facility.

Swedish Nuclear Fuel and Waste Management Co

Box 250, SE-101 24 Stockholm

Phone +46 8 459 84 00

SKB

Example for decay heat

Strål
säkerhets
myndigheten
Swedish Radiation Safety Authority

Authors: Sophie Grape
Carl Hellesen
Henrik Sjöstrand
Mattias Lantz
Staffan

heat in the fuel assemblies. It is stated, with a reference, that the uncertainty has been estimated to about 2 %. We would like to know what confidence level that has been used for this estimate of that uncertainty. The 2 % uncertainty is somewhat contradicted by the fact that the uncertainty of the radionuclide inventory is calculated with a 12/20 percent uncertainty for fission products/actinides in /SKBdoc 1221579/ (see comments on that document).

Technical Note

2015:51

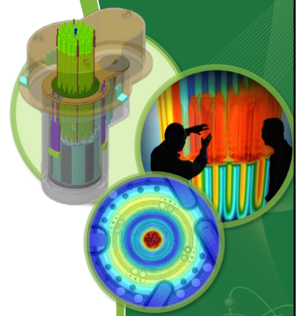
Initial State of Spent Nuclear Fuel

Main Review Phase

Report number: 2015:51 ISSN: 2000-0456
Available at www.stralsakerhetsmyndigheten.se

Example for decay heat

Decay Heat Uncertainty due to Modeling and Nuclear Data Uncertainties



Germina Ilas
Henrik Liljenfeldt

Oak Ridge National Laboratory

SCALE Users' Group Workshop 2017

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Nuclear Engineering and Design 319 (2017) 176–184

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journal homepage: www.elsevier.com/locate/nucengdes

ELSEVIER

Decay heat uncertainty for BWR used fuel due to modeling and nuclear data uncertainties ☆

CrossMark

Germina Ilas *, Henrik Liljenfeldt

Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN 37831-6172, USA

Conclusion

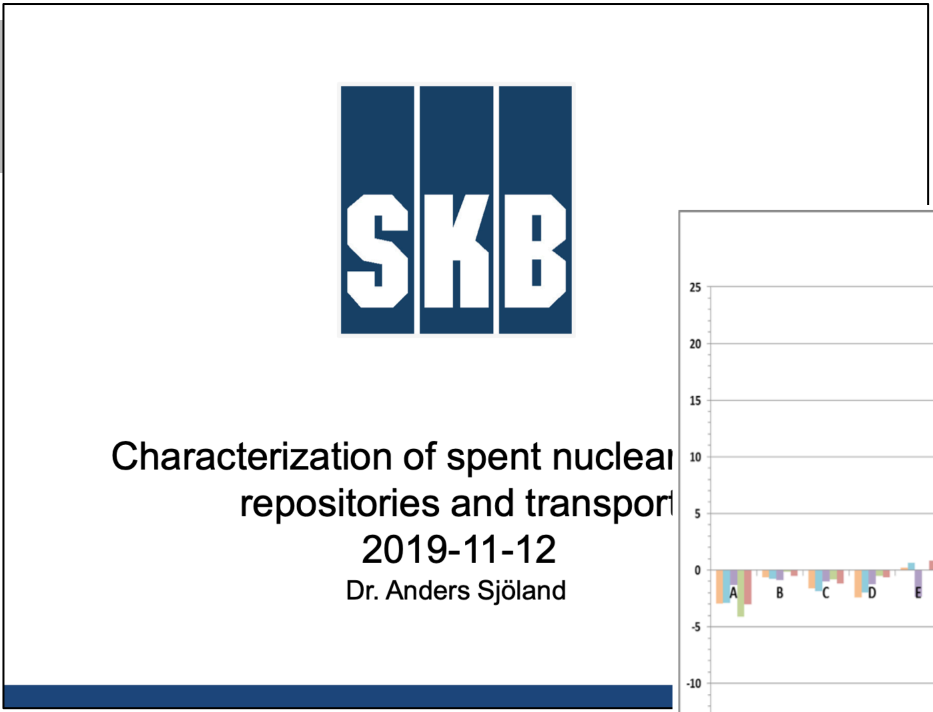
- SCALE/ORIGEN has well-established, well-validated capabilities for spent fuel M&S, including evaluation of uncertainties in calculated decay heat due to both modeling and nuclear data uncertainties
- Calculated decay heat agrees well with measurement data for PWR and BWR
  - average C/E is 1.002 (σ =0.012) for PWR and 0.997 (σ =0.024) for BWR
- Uncertainty in calculated decay heat
  - dominated by uncertainty in cross-section data (σ= 0.9%) and operating data (σ= 0.8%)
  - small effect of uncertainty in fuel data (σ= 0.2%) and fission yield data (σ= 0.3%)
- Decay heat uncertainty values are driven by uncertainty in isotopic masses of a handful of important decay heat contributors
- Uncertainty in calculated decay heat (separate effects) is comparable to measurement uncertainty (σ= 0.9%) for this assembly
- Quantifying uncertainty can provide useful information and inform decisions on design and operation of spent fuel storage facilities, particularly in regimes where measurement data are not available or are not practical to obtain.

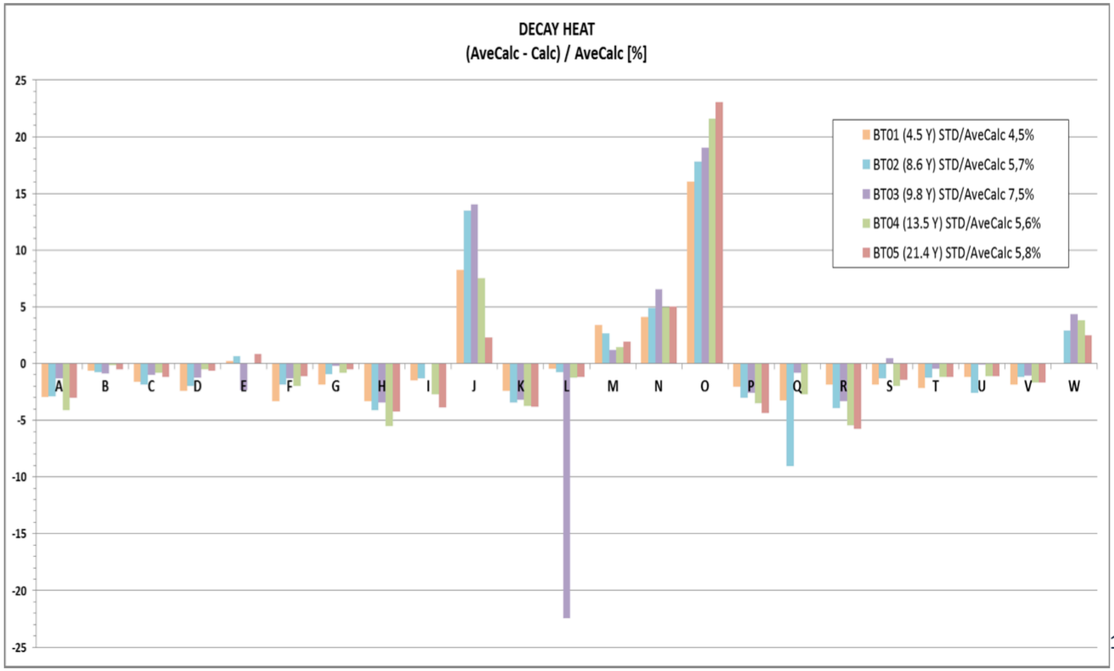
20 Decay heat uncertainty due to nuclear and modeling data uncertainties SCALE Users Group Workshop, September 28, 2017

OAK RIDGE National Laboratory

Example for decay heat

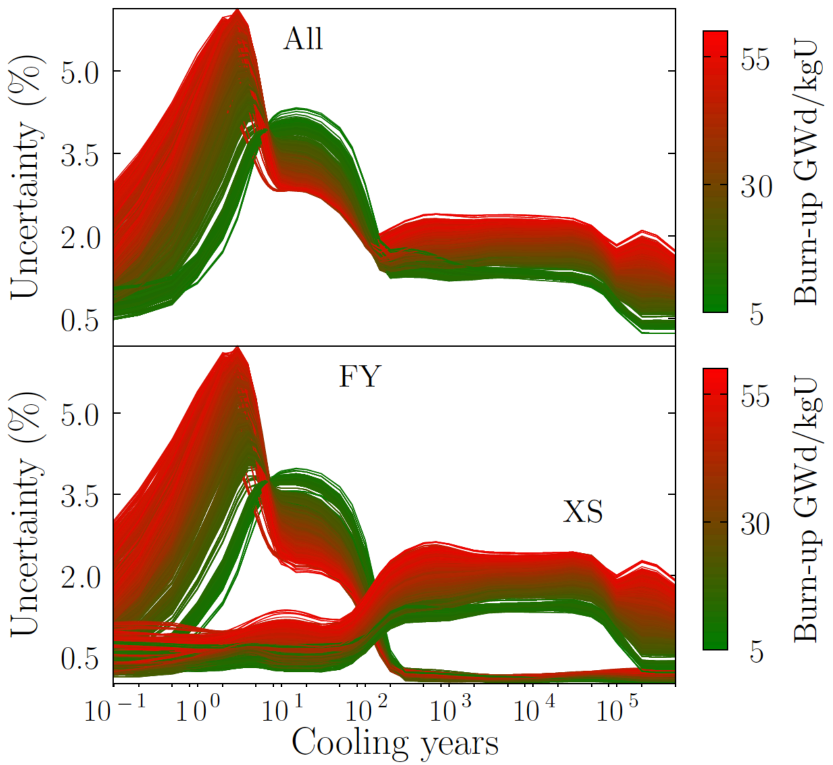
- Are the previous biases confirmed by the new “blind DH benchmark” ?

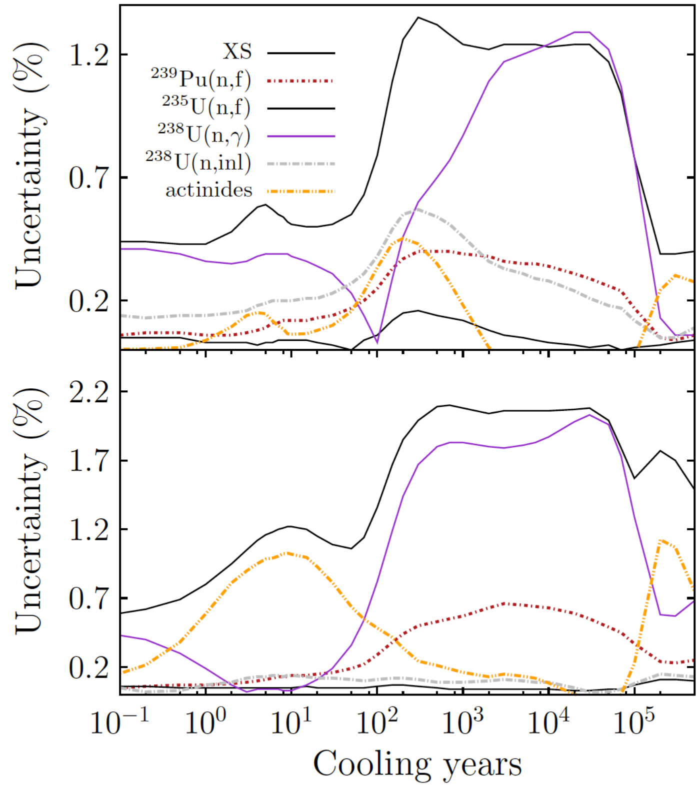




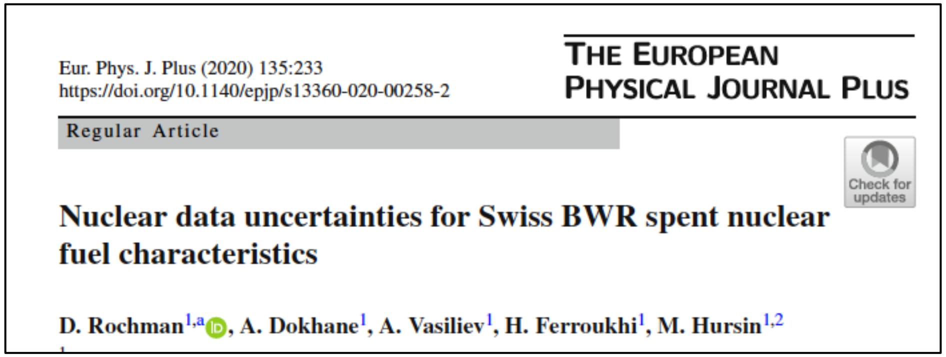
- There is a higher bias in these recent (blind) results compared to previously reported values (underestimation of 3-5 %)

Example for decay heat (BWR)





- ENDF/B-VII.1 covariances
- Full core BWR model: uncertainties are 2 % minimum

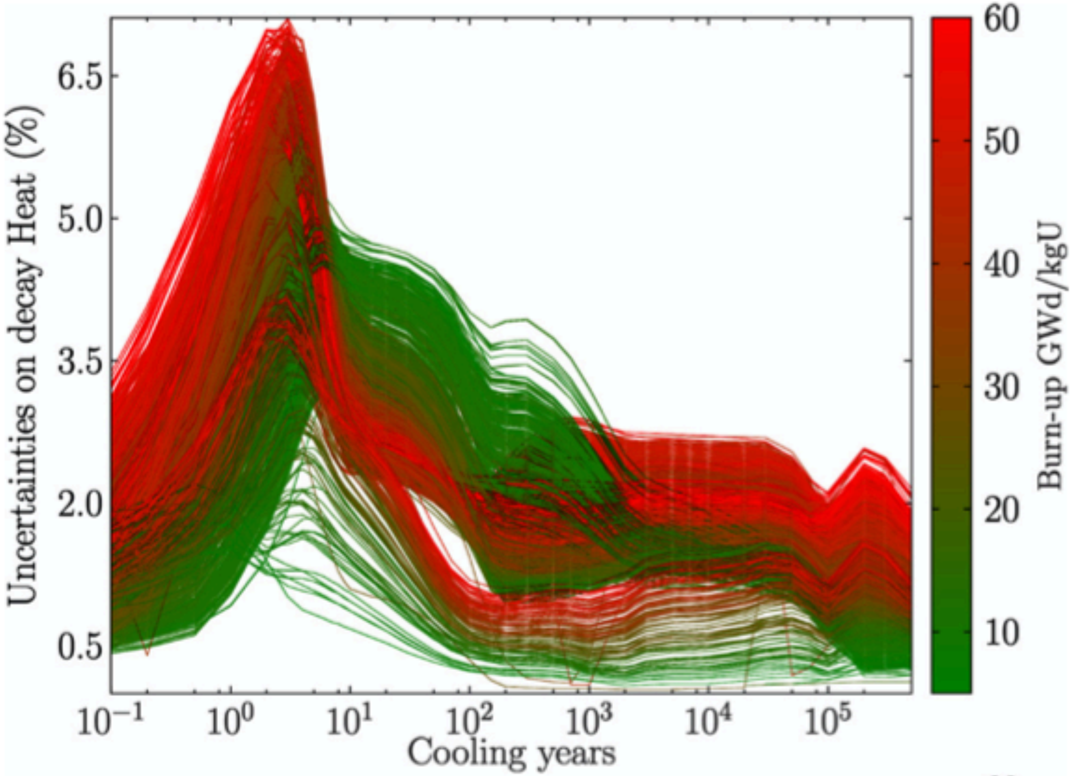

Eur. Phys. J. Plus (2020) 135:233
https://doi.org/10.1140/epjp/s13360-020-00258-2
THE EUROPEAN PHYSICAL JOURNAL PLUS
Regular Article

Check for updates

Nuclear data uncertainties for Swiss BWR spent nuclear fuel characteristics

D. Rochman[1,a], A. Dokhane[1], A. Vasiliev[1], H. Ferroukhi[1], M. Hursin[1,2]

Example for decay heat (PWR + BWR)



- ENDF/B-VII.1 covariances
- Full core PWR model: uncertainties are 2 % minimum

EPJ Nuclear Sci. Technol. **4**, 6 (2018)

https://doi.org/10.1051/epjn/2018005

EPJ Nuclear Sciences & Technologies

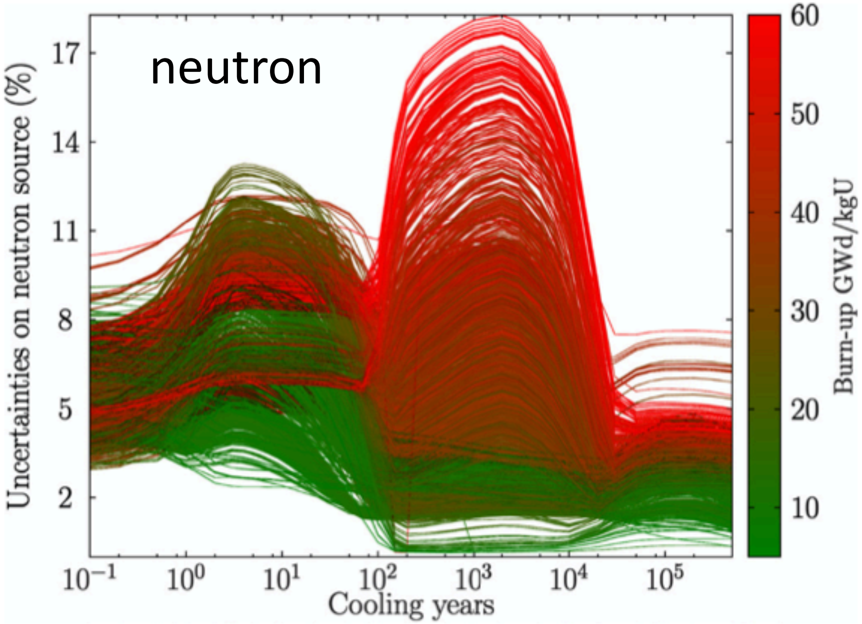
Available online at: https://www.epj-n.org

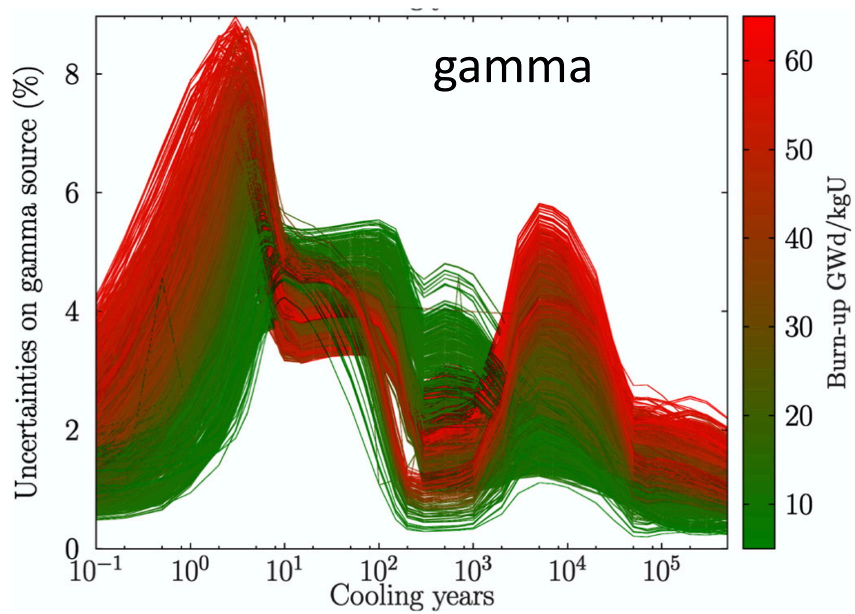
REGULAR ARTICLE OPEN ACCESS

Uncertainties for Swiss LWR spent nuclear fuels due to nuclear data

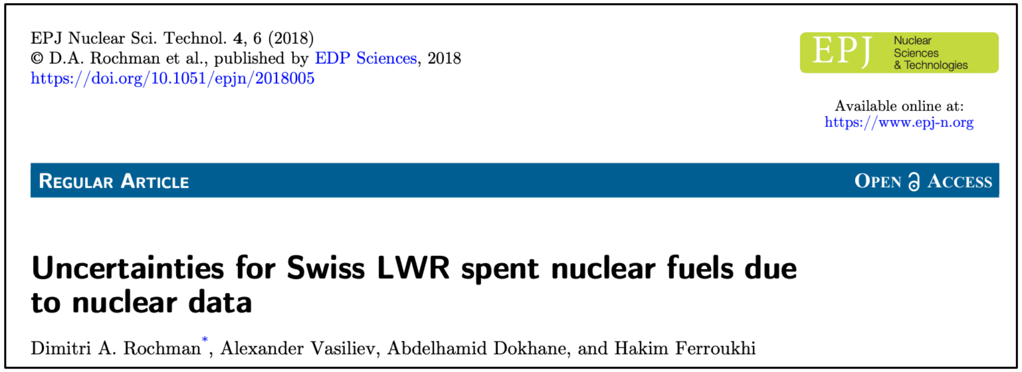
Dimitri A. Rochman*, Alexander Vasiliev, Abdelhamid Dokhane, and Hakim Ferroukhi

Example for neutron/gamma (PWR + BWR)





- ENDF/B-VII.1 covariances



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https://doi.org/10.1051/epjn/2018005

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REGULAR ARTICLE OPEN ACCESS

Uncertainties for Swiss LWR spent nuclear fuels due to nuclear data

Dimitri A. Rochman*, Alexander Vasiliev, Abdelhamid Dokhane, and Hakim Ferroukhi

Spent Fuel Burnup

- Nuclear data impact on SF burnup (with ENDF/B-VII.1), PWR + BWR

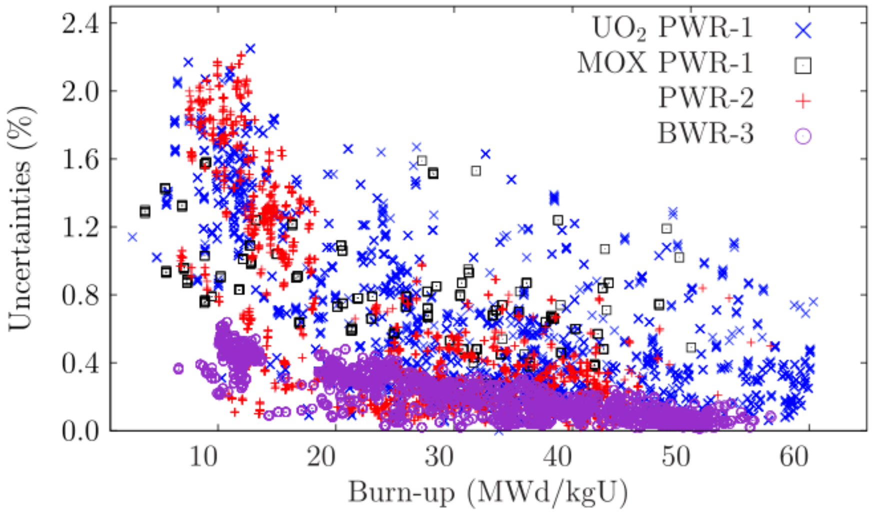

Fig. 9. Uncertainties on the assembly burnup for different exposures, for all assemblies in different cores (PWR and BWR), with UO_2 and MOX fuel.

EPJ Nuclear Sci. Technol. **4**, 6 (2018)

https://doi.org/10.1051/epjn/2018005

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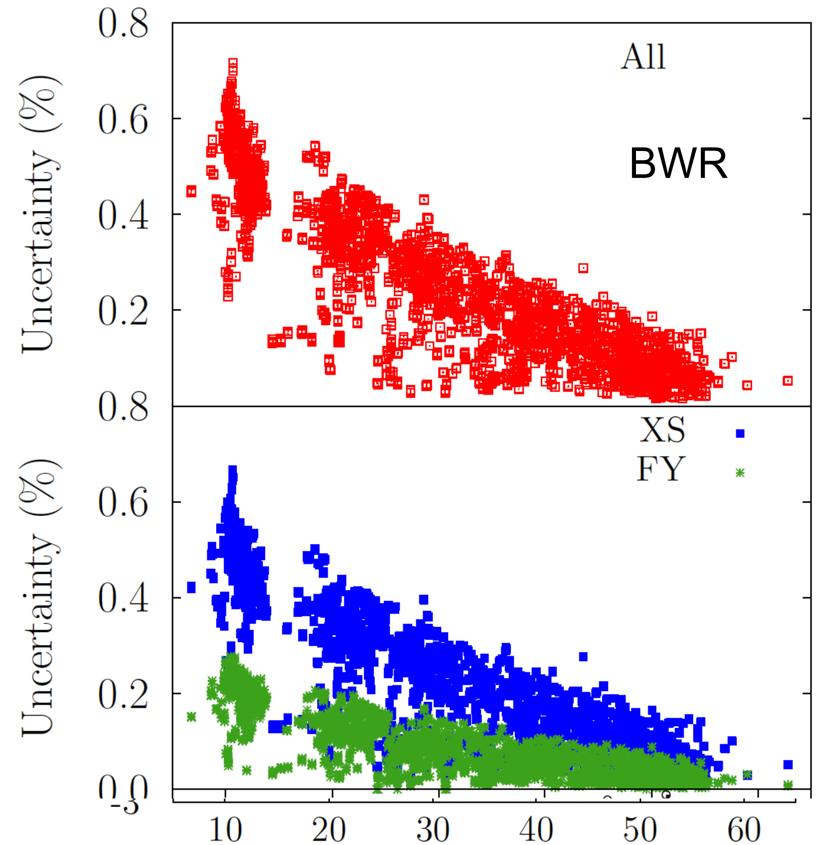

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Nuclear data uncertainties for Swiss BWR spent nuclear fuel characteristics

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Remarks for isotopic contents

- Almost all uncertainties on SFC comes from isotopic content uncertainties
- Post Irradiation Examination (PIE) allows (in principle) to obtain code biases and to compare uncertainties
- PIE data often come with (too) small experimental uncertainties for various reasons. It makes comparisons C and E difficult
- The majority of PIE calculations are normalized (no blind calculations), inducing a possible bias
- The impact of fission yields can be rather high. What to do with the zero-correlation in libraries ?
- Why is ^{235}U (^{239}Pu) systematically under (over) estimated for PIE data ? (implying compensation effects)

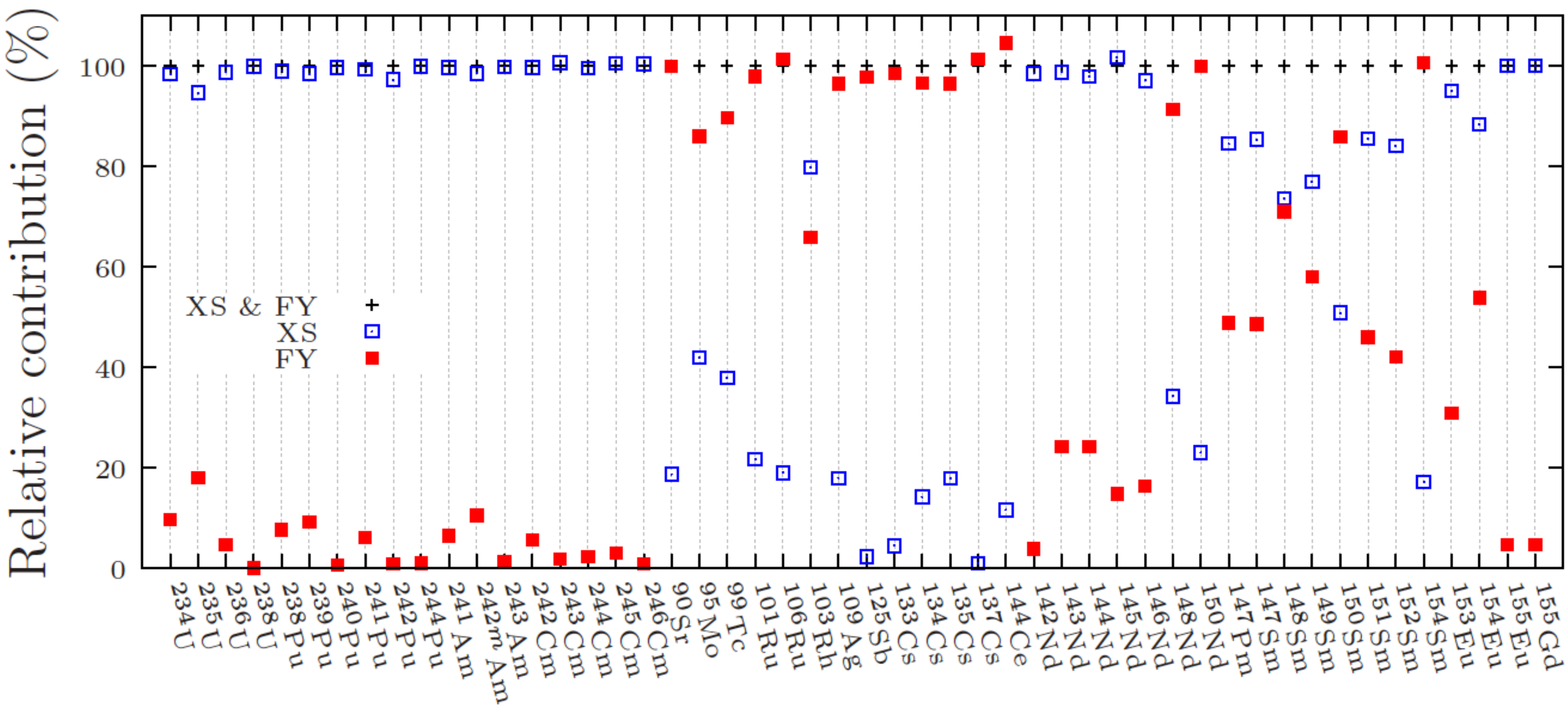
Example for isotopic contents

- Example for the GU1 and GU3 (ARIANE) samples
- ENDF/B-VIII.0 covariances

	CASMO5				(SHARK-X)	
	C/E-1 GU3	ΔE GU3	C/E-1 GU3'	ΔE GU3'	ΔC GU3(')	*ΔC GU1*
^{234}U	+41.3	0.02	+44.5	2.5	2.2	*0.6*
^{235}U	+6.0	2.2	+3.0	0.4	1.2	*2.3*
^{236}U	+0.3	0.8	+3.0	0.4	0.8	*0.5*
^{238}U	+0.0	0.0	+0.0	0.2	0.0	*0.0*
^{237}Np	-15.8	4.8	-13.9	3.8	3.3	-
^{238}Pu	-9.7	0.3	-5.8	1.5	4.8	*2.7*
^{239}Pu	-1.2	0.3	-0.4	0.3	1.9	*1.9*
^{240}Pu	+0.4	0.2	+2.2	0.3	4.2	*4.2*
^{241}Pu	+5.0	0.2	-3.1	0.3	3.2	*3.4*
^{242}Pu	-4.2	0.0	-0.0	0.3	4.8	*5.0*
^{244}Pu	-	-	-73.0	25.	8.8	*8.1*
^{241}Am	+4.1	1.1	+13.8	1.8	3.3	*3.5*
^{242m}Am	-	-	+8.5	5.5	3.8	*4.0*
^{243}Am	-12.0	1.9	-1.0	1.8	8.4	*7.5*
^{242}Cm	-	-	-6.1	3.6	3.5	*3.3*
^{243}Cm	-	-	+38.5	10	11.1	*11.4*
^{244}Cm	-25.3	6.4	-10.7	1.8	9.7	*8.6*
^{245}Cm	-97.0	1.7	-8.6	2.6	15.0	*12.7*
^{246}Cm	-	-	-20.0	5.2	24.4	*13.5*

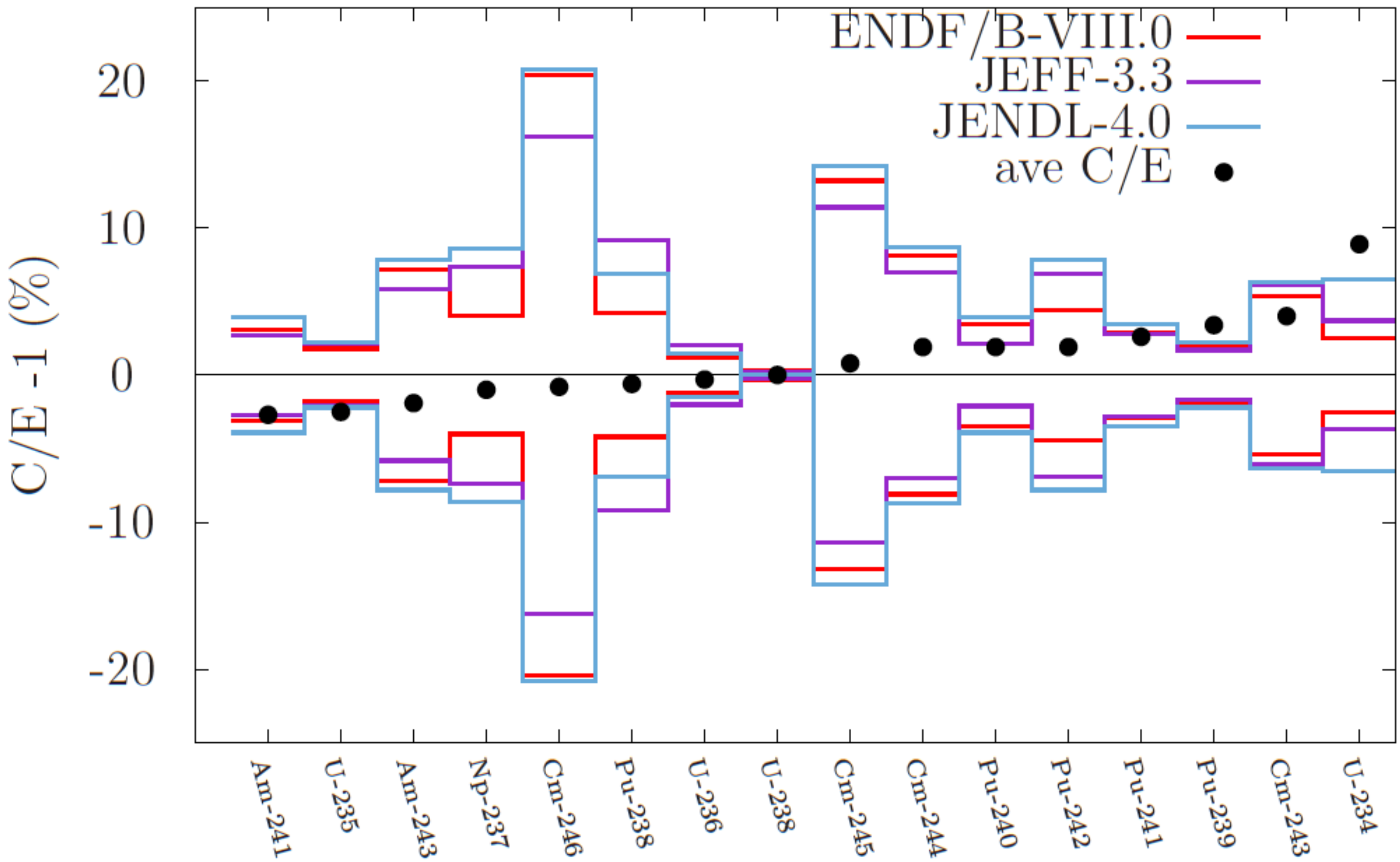
Example for isotopic contents

- Example for the GU1 sample, ENDF/B-VIII.0 covariances



Example for isotopic contents

- Example for the 17 samples, ENDF/B-VIII.0, JEFF-3.3 and JENDL-4.0 covariances



Conclusion

- Nuclear data play an important role in Spent Fuel Characterisation
- Their knowledge affect the economy and design of transport and storage

- Other forces and parameters are at play:
  – operation history, manufacturing tolerances, temperature effect, fuel behavior & failure, thermal hydraulic…

- Many challenges ahead:
  – trustful experimental data and simulation
  – Consistent nuclear data (best estimate plus uncertainties): no there yet
  – General purpose or adjusted library ?
  – Non linear effects

- How much improvement is needed ?
  – Depends on utilities, waste management organization and safety authorities
  – No clear answer yet

Wir schaffen Wissen – heute für morgen