NPP Operational History and the Uncertainties of Radionuclides Relevant for the Final Disposal of PWR Spent Fuel – 15149

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INTRODUCTION

A requisite for the official approval of the safe final disposal of SNF is a comprehensive specification and declaration of the nuclear inventory in SNF by the waste supplier. In the verification process both the values of the radionuclide (RN) activities and their uncertainties are required. Burn-up calculations based on typical and generic reactor operational parameters do not encompass any possible uncertainties observed in real reactor operations. At the same time, the details of the irradiation history are often not well known, which complicates the assessment of declared RN inventories. Here, we have compiled a set of burn-up calculations accounting for the operational history of 339 published or anonymized real PWR fuel assemblies. These histories were used as a basis for a "SRP analysis", to provide information about the range of the values of the associated secondary reactor parameters (SRP's). Hence, we can calculate the realistic variation or spectrum of RN inventories. SCALE 6.1 has been employed for the burn-up calculations. The results have been validated using experimental data from the online database – SFCOMPO-1 and -2 [3],[4].

SECONDARY REACTOR PARAMETER's (SRP) -

parameters of a PWR operational history:

- Specific Power (SP)
- Downtime (DT)
- Irradiation Time (IT)
- Initial Enrichment (IE)
- Fuel Density (FD)
- Fuel Temperature (FT)
- Moderator Density (MD)
- Moderator Temperature (MT)
- Boric Acid concentration (BA)

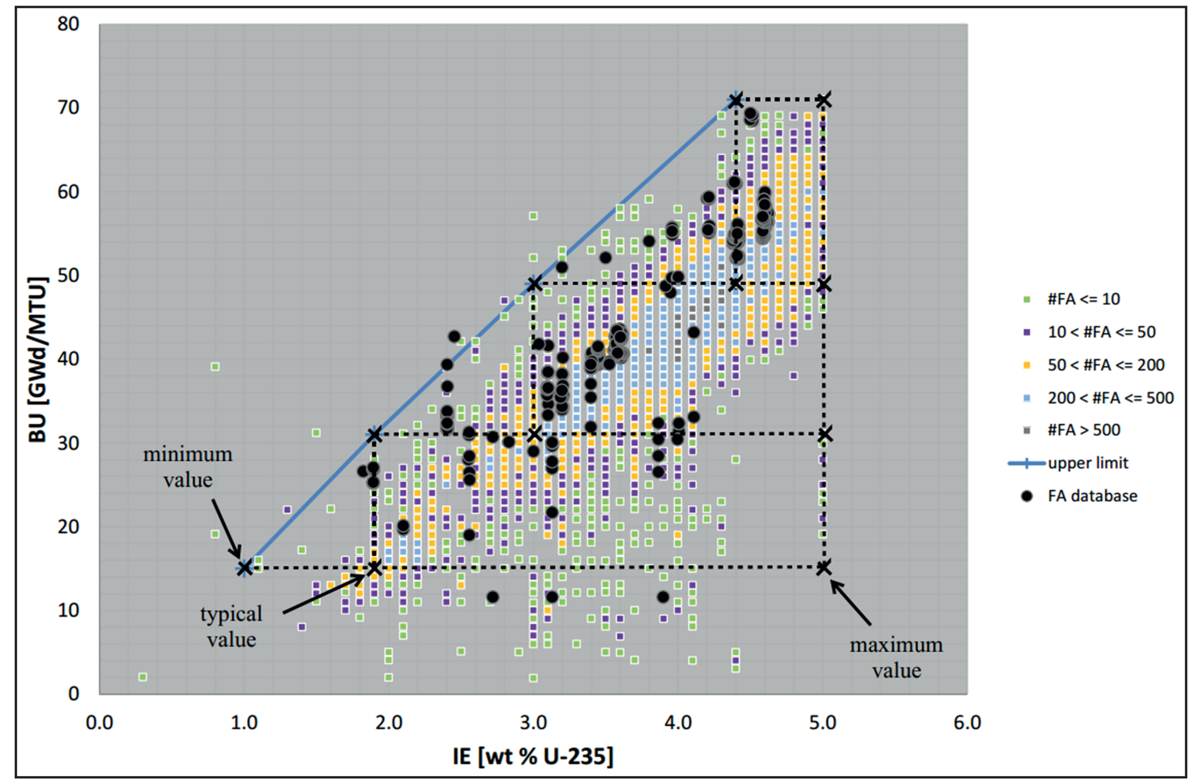

Figure I. Burn-up (BU) vs. Initial Enrichment (IE)

DOWNTIME ANALYSIS

model description:

- Geometry: FA 16×16 AFA 3G
- Burn-up: 65 GWd/tHM
- SP: 36 MW/tHM
- IE: 4.0 % wt U-235
- FT: 900 K
- MT: 580 K
- FD: 10.408 g/cm^3
- MD: 0.73 g/cm^3
- BA: 460 ppm
- 6 Cycles with DT 0, 50, 75, 100, 400 d
- Analysis for cooling time (CT) 0, 1, 3, 5 y

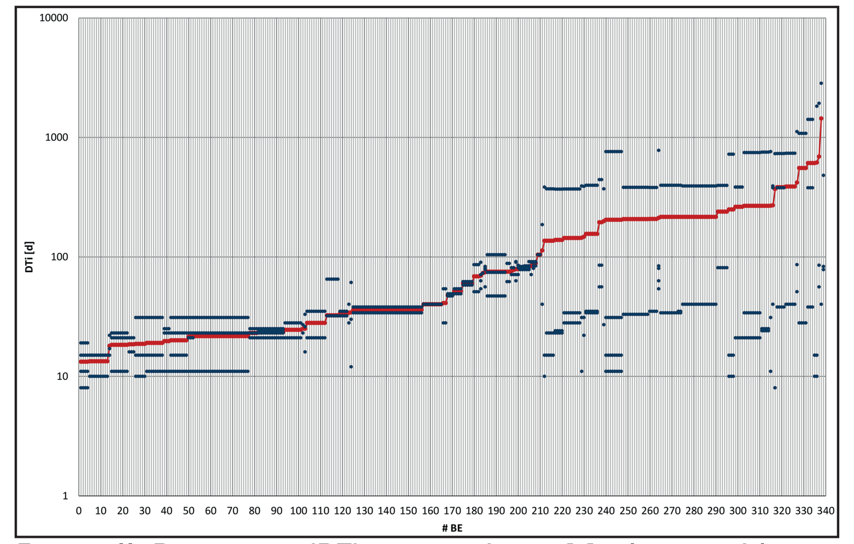

Figure II. Downtime (DT) vs. number of fuel assemblies

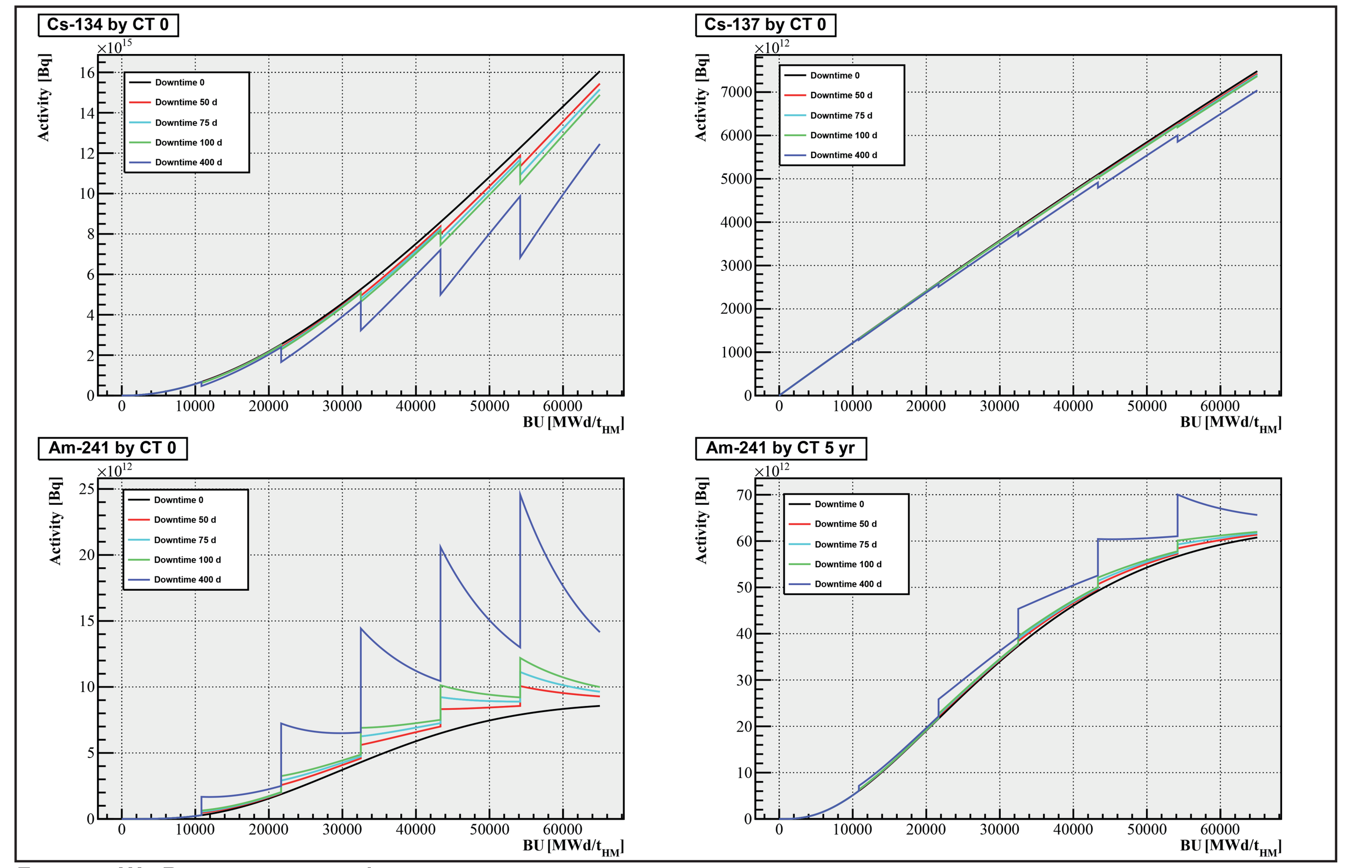

Figure III. Downtime analysis

RADIONUCLIDES - RESULTS

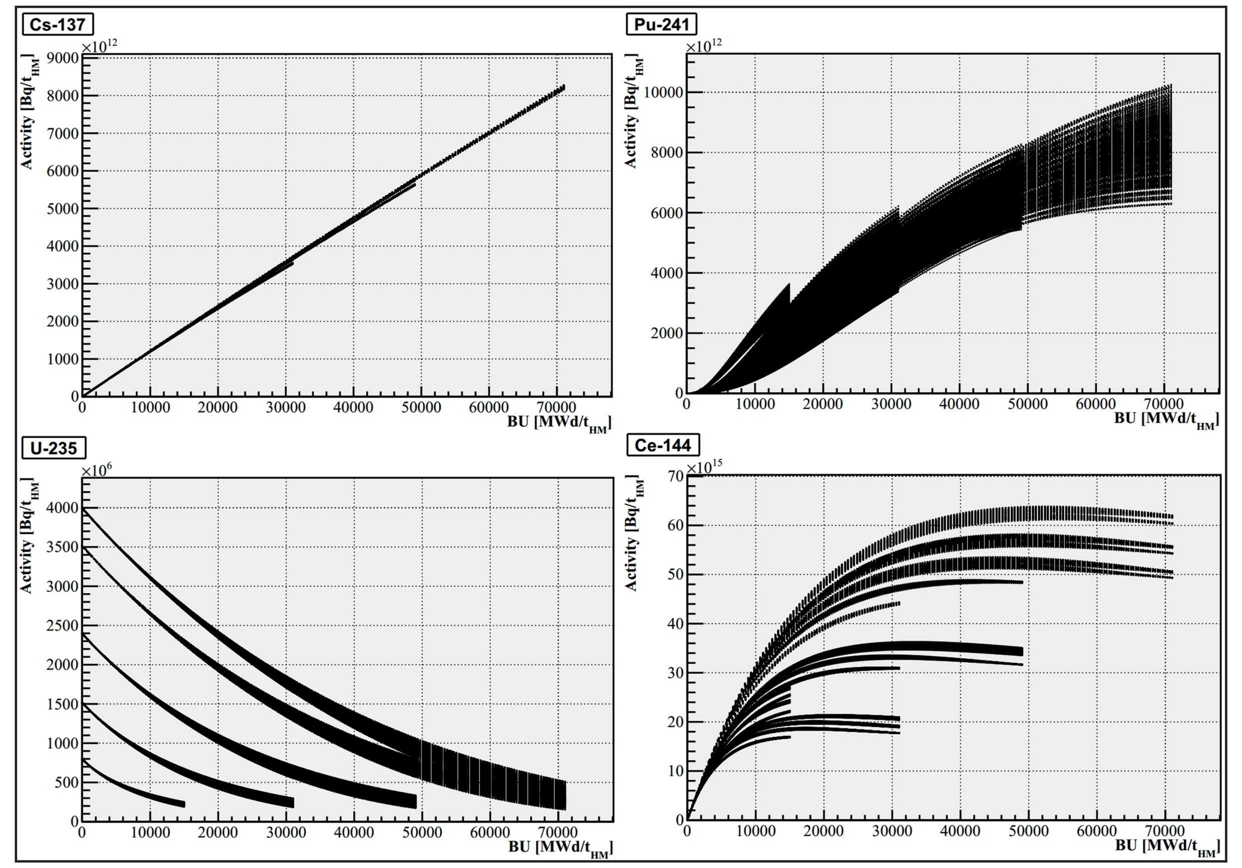

Figure IV. RN behavior by variation of SRP's

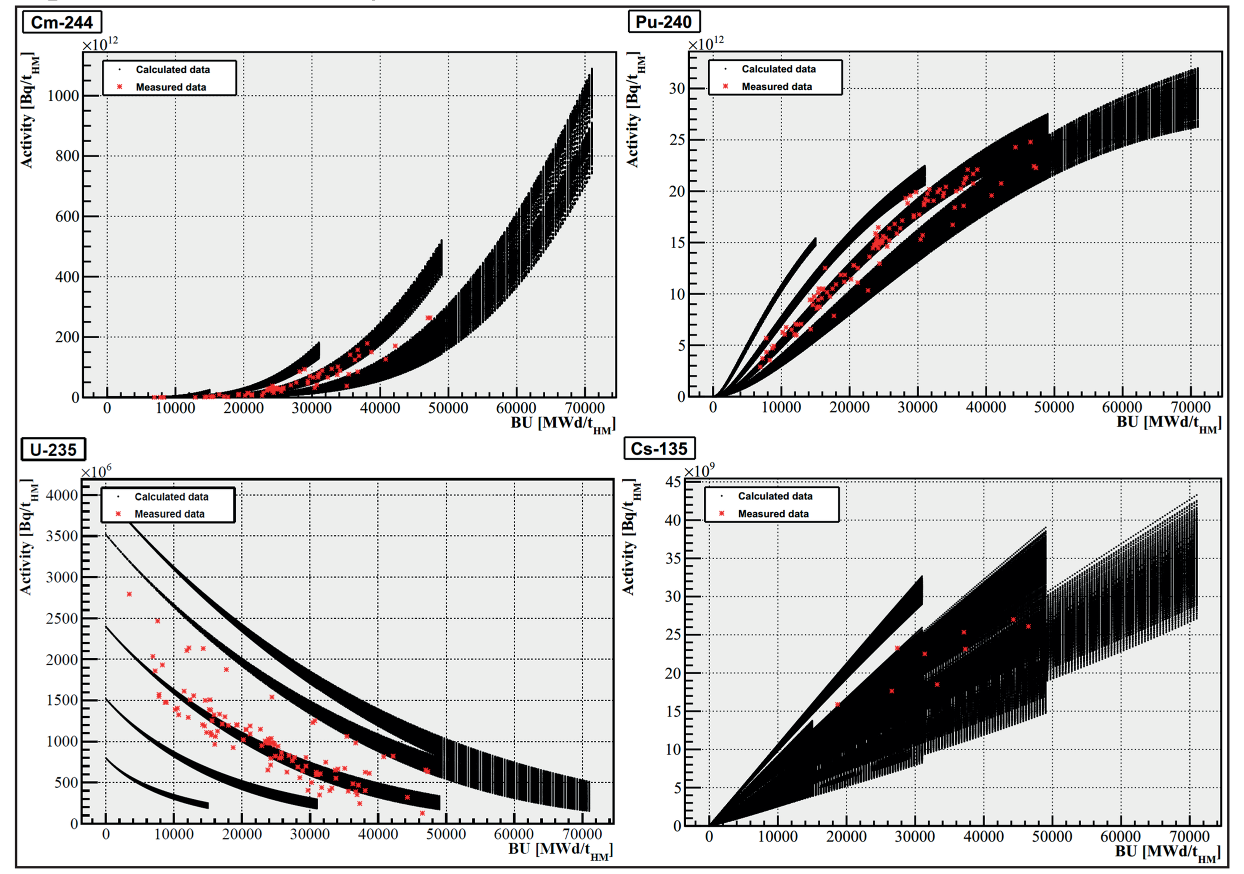

Figure V. Calculated vs. measured data from SFCOMPO-1 [3], 100 % agreement

CONCLUSION

- Experimentally underpinned operation history FA data are often incomplete (especially for cycle values of MD, MT, FD, FT, BA).
- There is a linear correlation between BU and IE, SP, MD, MT.
- There is a very good agreement with the theoretical data for MD vs MT.
- It is feasible to determine SRP limits.
- For most fission products operational history without DT is conservative.
- The activity of most actinides in the case of operational history without DT is either independent of DT (e.g. U-235, U-238, Pu-239, Np-237) or underestimated. However, the strongest influence of DT decreases with increasing CT.
- DT analysis enables calculations with DT=0.
- The RN behavior by variation of SRP's can be generally divided in four subgroups (s. Table I):
  - Independent of all SRP: red
  - Dependent of all SRP: yellow
  - Strongly dependent of IE: green
  - Strongly dependent of IE and SP: blue

  Unmarked RN's are absent in the fuel (e.g. activation product in cladding).
- Preliminary comparison of calc. and meas. data reveals very good agreement. However, for some cases corrections are required.

OPEN QUESTIONS

- Explanation deviations of calculated vs. measured data (e.g. Am-241 factor 4, U-234 factor 10)
- Validation of RN's for which the measured data are not available

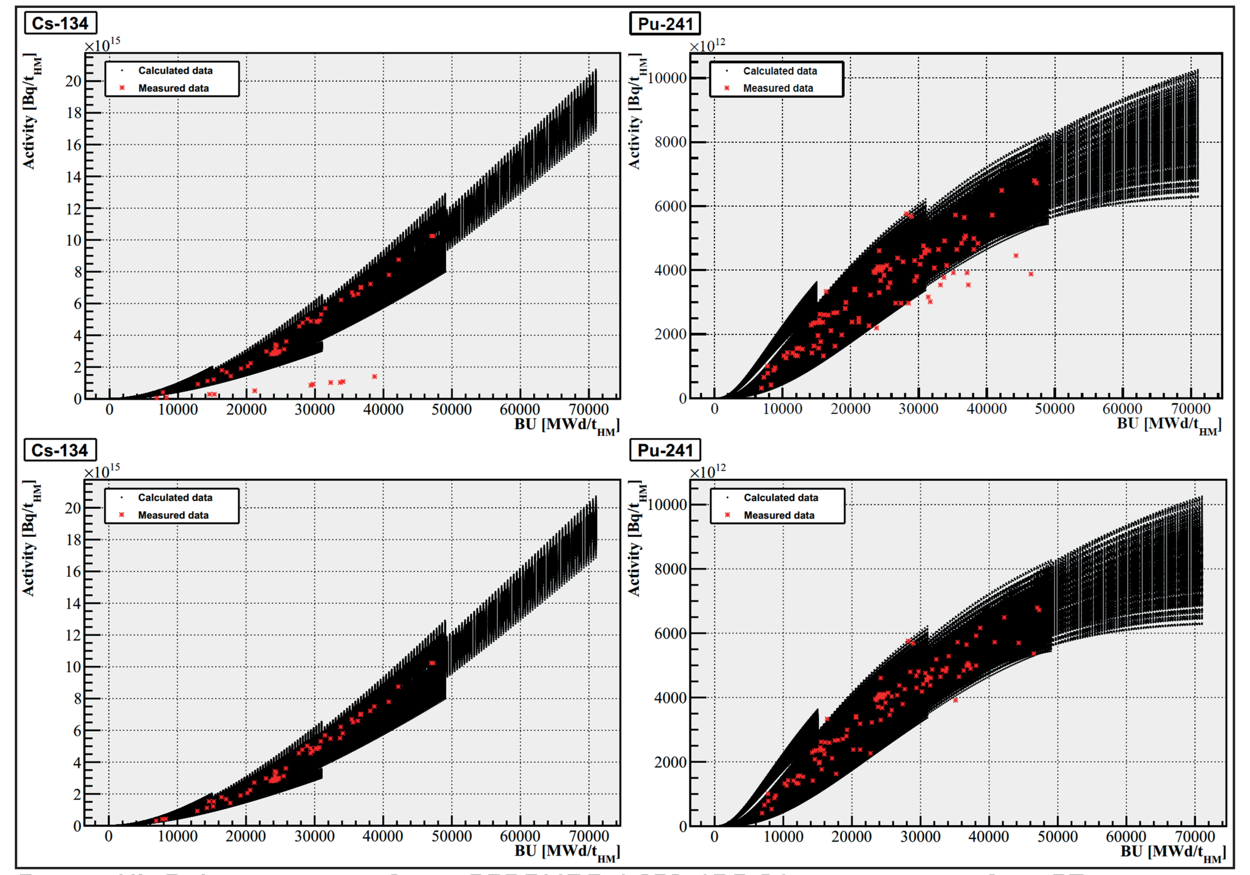

Figure VI. Calc. vs. meas. from SFCOMPO-1 [3], 100 % agreement after CT correction

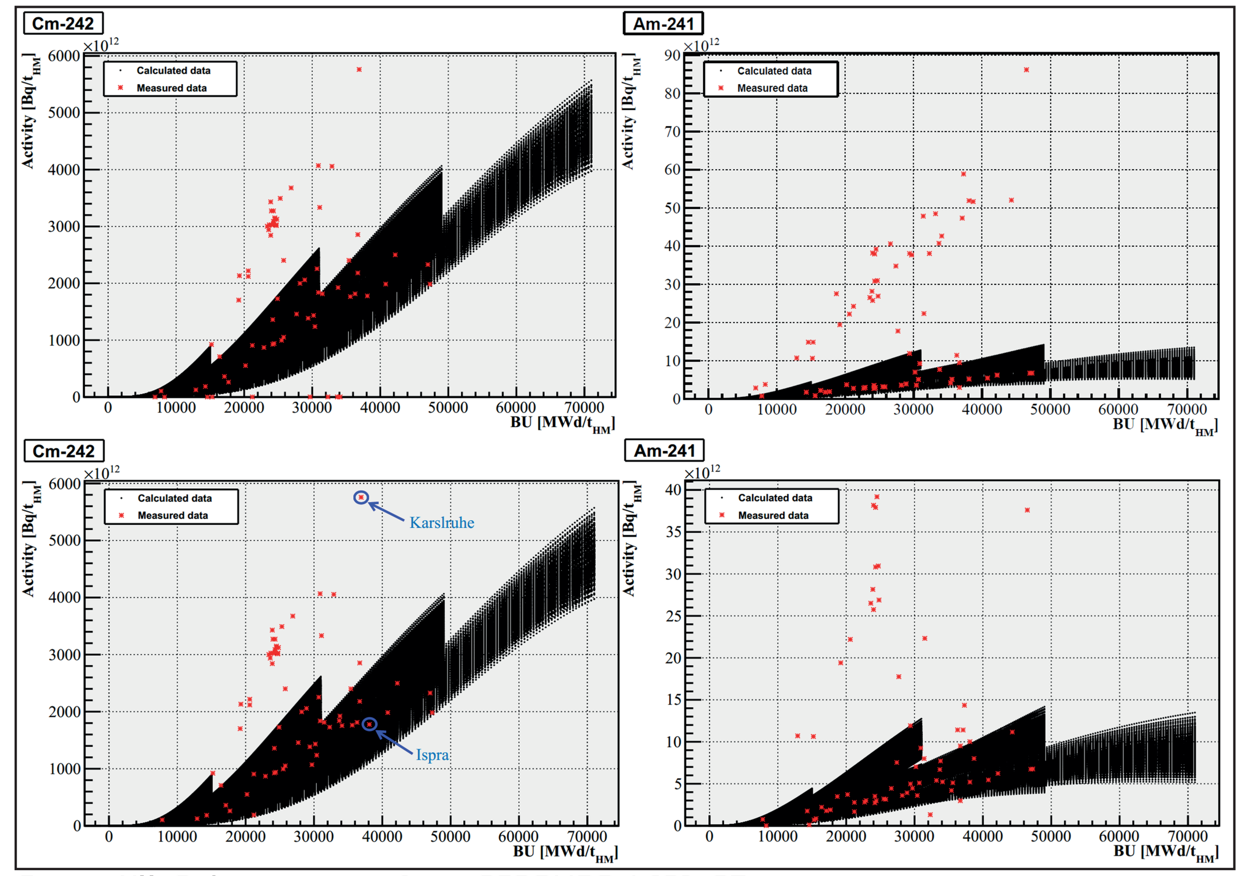

Figure VII. Calc. vs. meas. from SFCOMPO-1 [3], CT correction

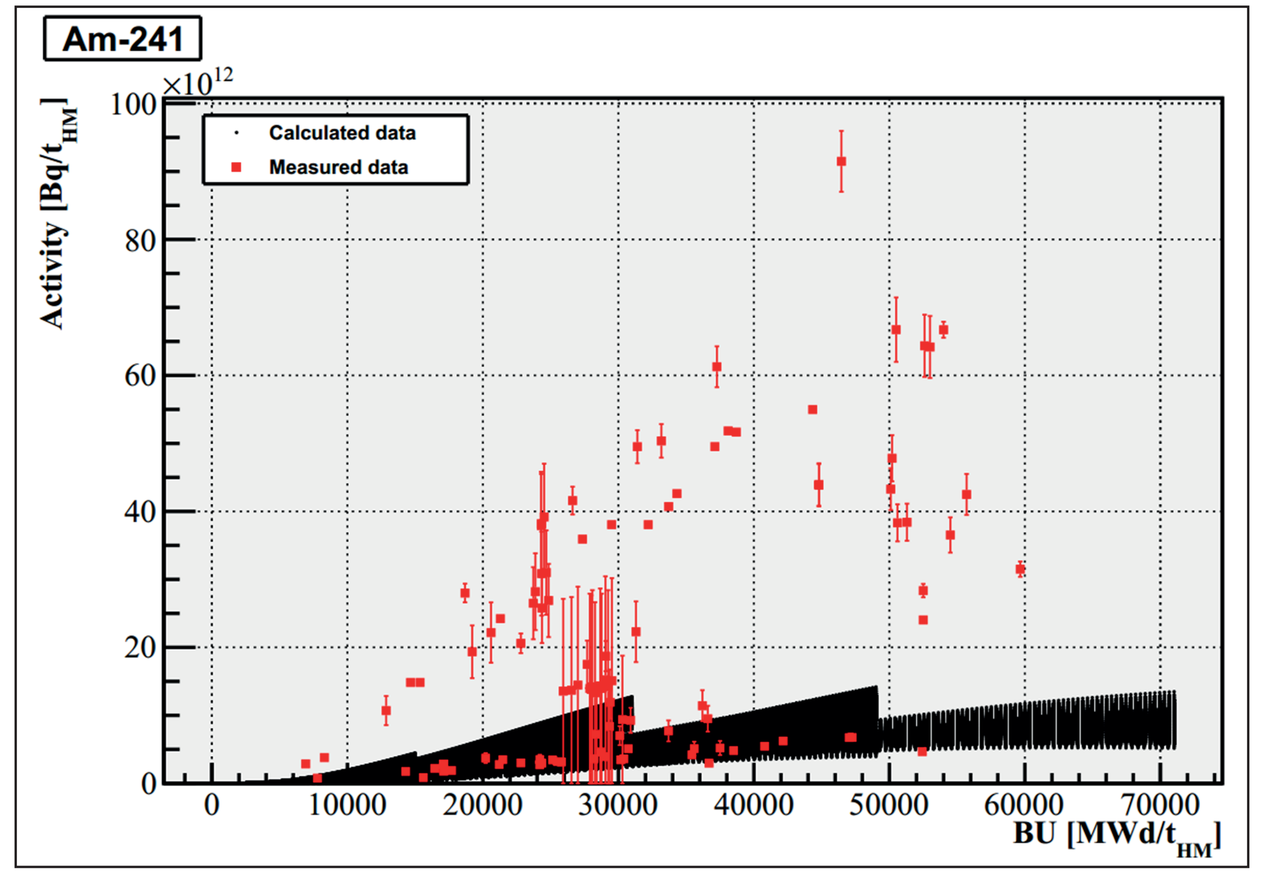

Figure VIII. Calc. vs. meas. from SFCOMPO-2 [4], with meas. uncertainties

OUTLOOK

- Include the measured data from SFCOMPO-2 [4], which contains high burn-up data and meas. uncertainties
- Find an explanation for the poor agreement between calculated and measured data
- Correcting measured data on downtime
- Determine the bandwidth of the nuclides for which measured data are not available
- Further analysis of the results for different scenarios in case if operational history not completely available

REFERENCES

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[2] B. Kienzler, A. Loida, „Endlagerrelevante Eigenschaften von hochraiodaktiven Abfallprodukten", Forschungszentrum Karlruhe GmbH, FZKA 6651, 2001

[3] Nuclear Energy Agency NEA/OECD, SFCOMPO-1 database, http://www.oecd-nea.org/sfcompo/Ver.2/Eng /, 2015

[4] NEA-OECD, SFCOMPO-2 database, https://www.oecd-nea.org/science/wpncs/ADSNF/, 2015

ACKNOWLEDGMENT

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- NEA-OECD for providing of the access to SFCOMPO-2 database

Table I. RN relevant for the final disposal of PWR spent fuel

RN name	Cs-134	Eu-154	Pu-241	Sm-151	Am-243	Cm-244	Cm-245	Cm-246	Cm-247	Cs-135	Pu-240	U-235	Am-241	Am-242m	Ce-144	Cm-242	Cs-137	Pu-238
RN list for long-term safety [1]	x	x	x	x	x	x	x	x		x	x	x	x	x	x		x	x
CSD-C[1] list	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Calculated data (only fuel)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Measured data [3], [4]	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
100% agreement calc-vs-meas	x[2]	x[2]	x[2]	x	x	x	x	x	x	x	x	x						
CT correction required	x	x	x			x							x	x	x	x	x	

RN name	Ru-106	Sb-125	Sr-90	U-232	U-234	Np-237	Pu-239	Pu-242	Se-79	Sn-126	Tc-99	U-238	Ac-227	Ag-108m	Ag-110m	C-14	Cf-249	Cf-251
RN list for long-term safety [1]	x	x	x	x	x	x	x	x	x	x	x	x	x			x		
CSD-C[1] list	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Calculated data (only fuel)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Measured data [3], [4]	x	x	x	x	x	x	x	x	x	x	x	x						
100% agreement calc-vs-meas																		
CT correction required	x	x	x	x	x								x		x			

RN name	Cm-243	Cm-248	Eu-152	Eu-155	H-3	I-129	Kr-85	Mo-93	Nb-94	Nb-95	Pa-231	Pd-107	Pm-147	Pr-144	Pu-243	Pu-244	Ra-226	Rh-106
RN list for long-term safety [1]	x	x				x		x	x		x	x		x		x	x	x
CSD-C[1] list	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Calculated data (only fuel)	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Measured data [3], [4]																		
100% agreement calc-vs-meas																		
CT correction required	x		x	x	x		x			x			x	x			x	x

RN name	Ru-103	Sb-124	Th-229	Th-230	Th-232	U-233	U-236	Y-90	Zr-93	Zr-95	Cf-252	Ca-41	Cl-36	Co-58	Co-60	Fe-55	Mn-54	Ni-59	Ni-63
RN list for long-term safety [1]			x	x	x	x	x	x	x			x	x		x			x	x
CSD-C[1] list	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Calculated data (only fuel)	x	x	x	x	x	x	x	x	x	x									
Measured data [3], [4]																			
100% agreement calc-vs-meas																			
CT correction required	x	x		x	x	x		x		x									

1: Colis Standard de Déchets Compactés [2]. 2: 100% agreement calc-vs-meas after CT correction