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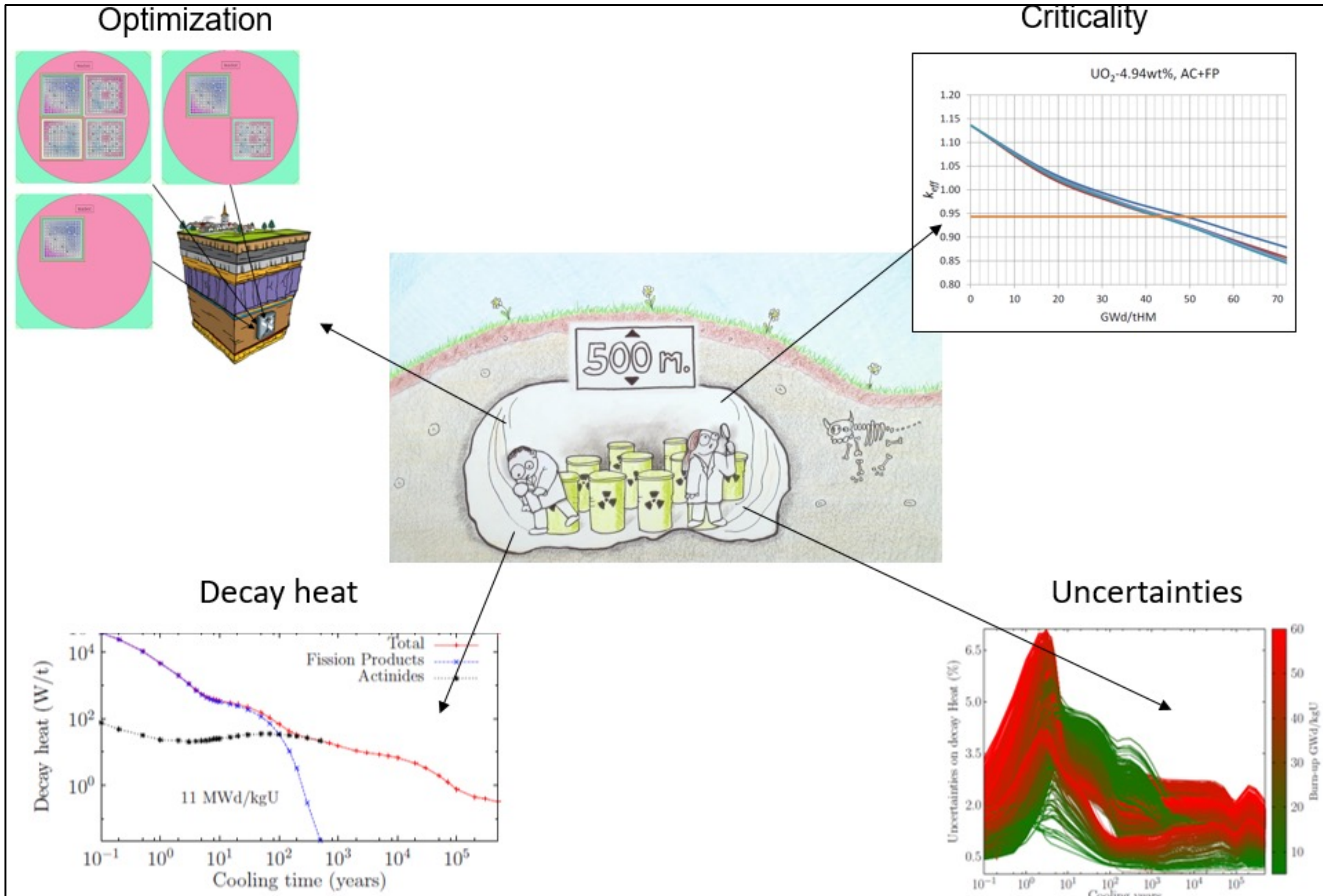
D. Rochman, on behalf of SG12

A brief overview of the OECD NEA WPNCS SG12: Decay heat from existing Spent Nuclear Fuel

ISO/TC 85/SC 6/WG 1 Meeting, May 3th, 2023, online

Summary

- Decay heat Needs
- Subgroup
- Achievements



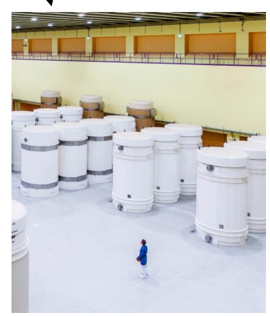
What are the needs for SNF decay heat ?

- Decay heat linked to “source terms”, dose, criticality, safety, economy

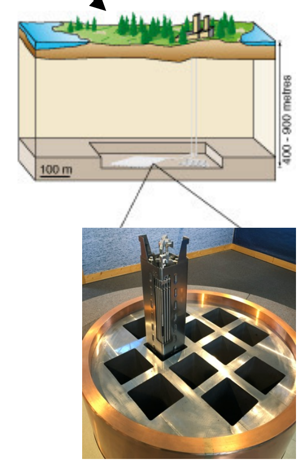
Transients

Transport

Storage

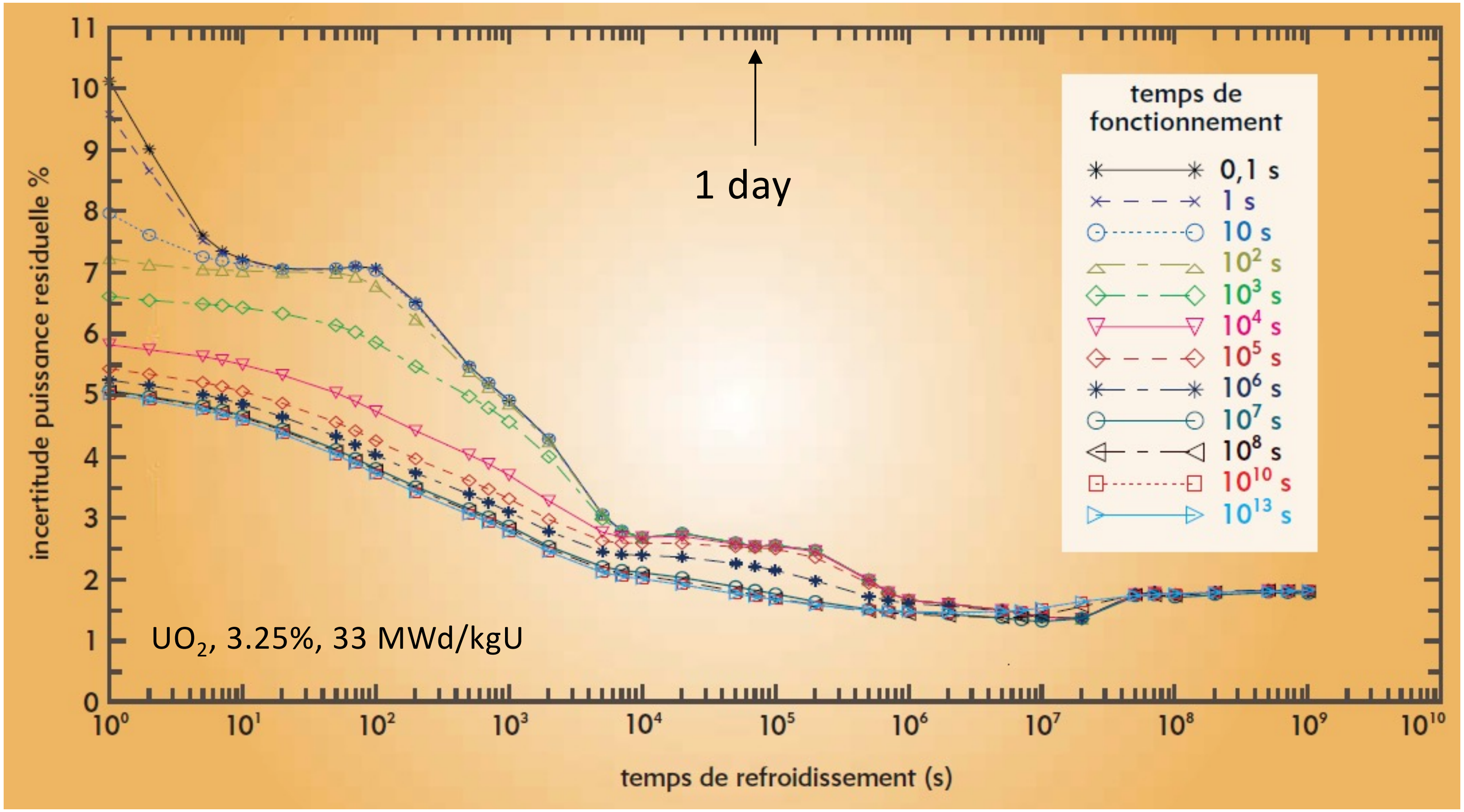


Long-term repository



What are the needs for SNF decay heat ?

- Precise knowledge on SNF decay heat is required for
  - Core transients (short cooling time),



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Open questions

- Same questions as in the EURAD WP8 and the IAEA CRP projects
  - How well can we characterize SNF (nuclides, decay heat)?
  - What are the (industrial) needs ?
  - Source of uncertainties (modelling, 2D, core simulator…)
  - How much do we trust calculated burnup, core power…
  - How blind are we ?
  - New measurements, which ones ?

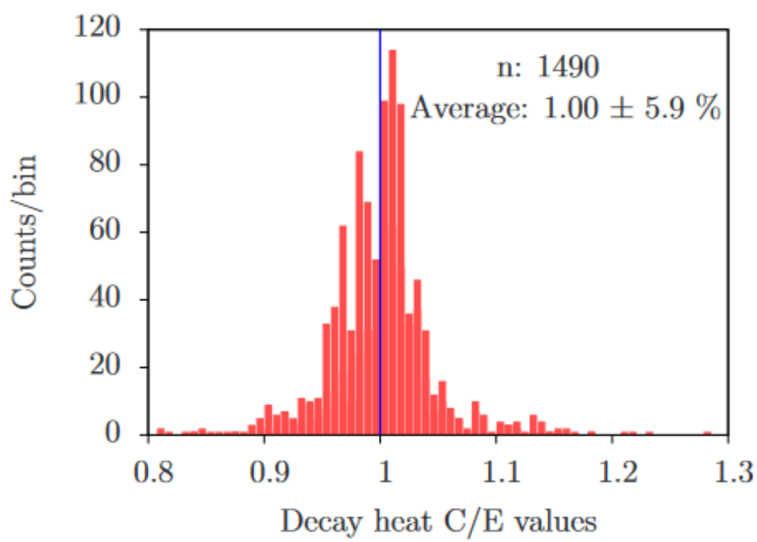


Fig. 2. Histogram of the ratios of calculated (C) over experimental (E) decay heat values from literature studies for calorimetric measurements. Both PWR and BWR assemblies are included.

What are the needs for SNF decay heat ?

- Precise knowledge on SNF decay heat is required for
  - Core transients (short cooling time),
  - Safe and economical storage, transport and long-term repository (long cooling time)

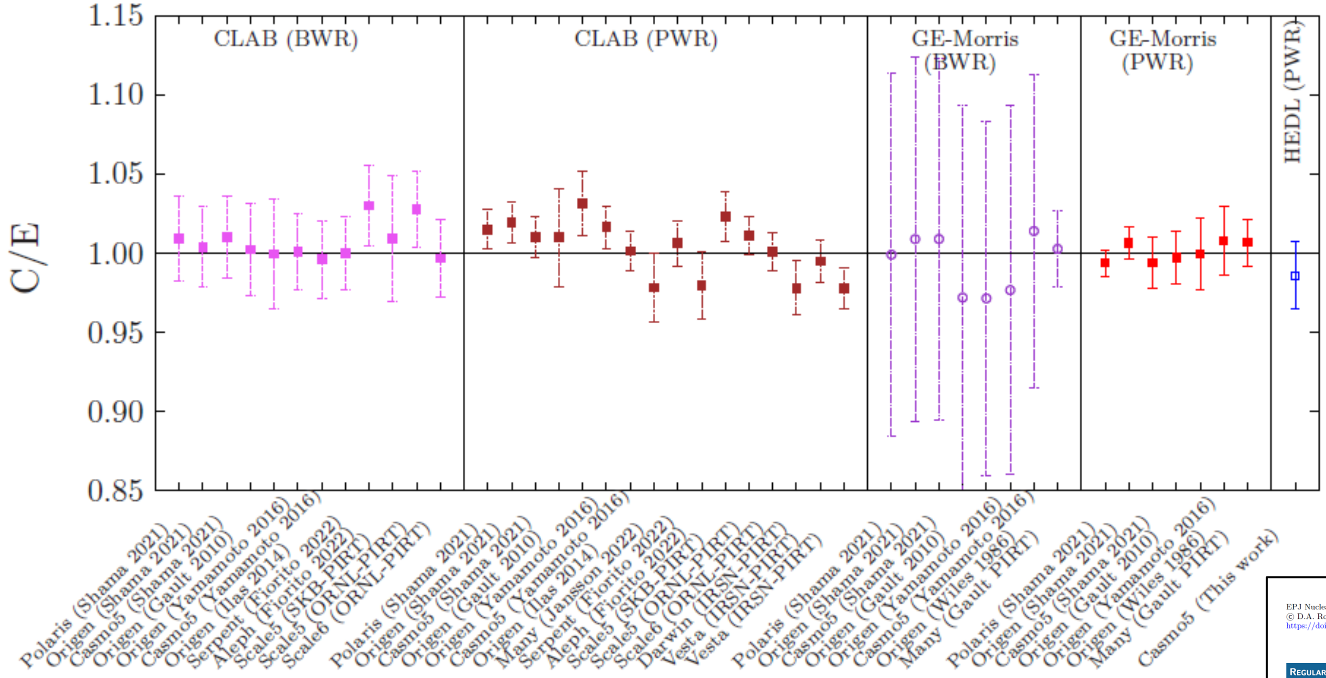
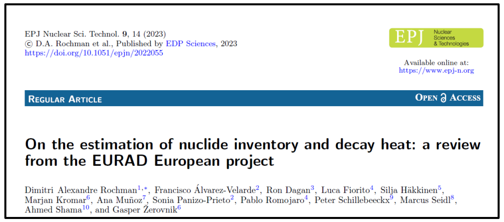


Fig. 7. Plots of the average C/E values for the decay heat from various references.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EPJ Nuclear Sciences & Technologies

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

REGULAR ARTICLE — OPEN ACCESS

On the estimation of nuclide inventory and decay heat: a review from the EURAD European project

Dimitri Alexandre Rochman[1,*], Francisco Álvarez-Velarde[2], Ron Dagan[3], Luca Fiorito[4], Silja Häkkinen[5], Marjan Kromar[6], Ana Muñoz[7], Sonia Panizo-Prieto[2], Pablo Romojaro[4], Peter Schillebeeckx[9], Marcus Seidl[8], Ahmed Shama[10], and Gasper Žerovnik[6]

A simple average of the values presented in this figure leads to an average of 1.002 ± 0.015

What are the needs for SNF decay heat ?

PAUL SCHERRER INSTITUT PSI

- Precise knowledge on SNF decay heat is required for
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NUCLEAR SCIENCE AND ENGINEERING · VOLUME 196 · 1125–1145 · SEPTEMBER 2022

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ANS

Blind Benchmark Exercise for Spent Nuclear Fuel Decay Heat

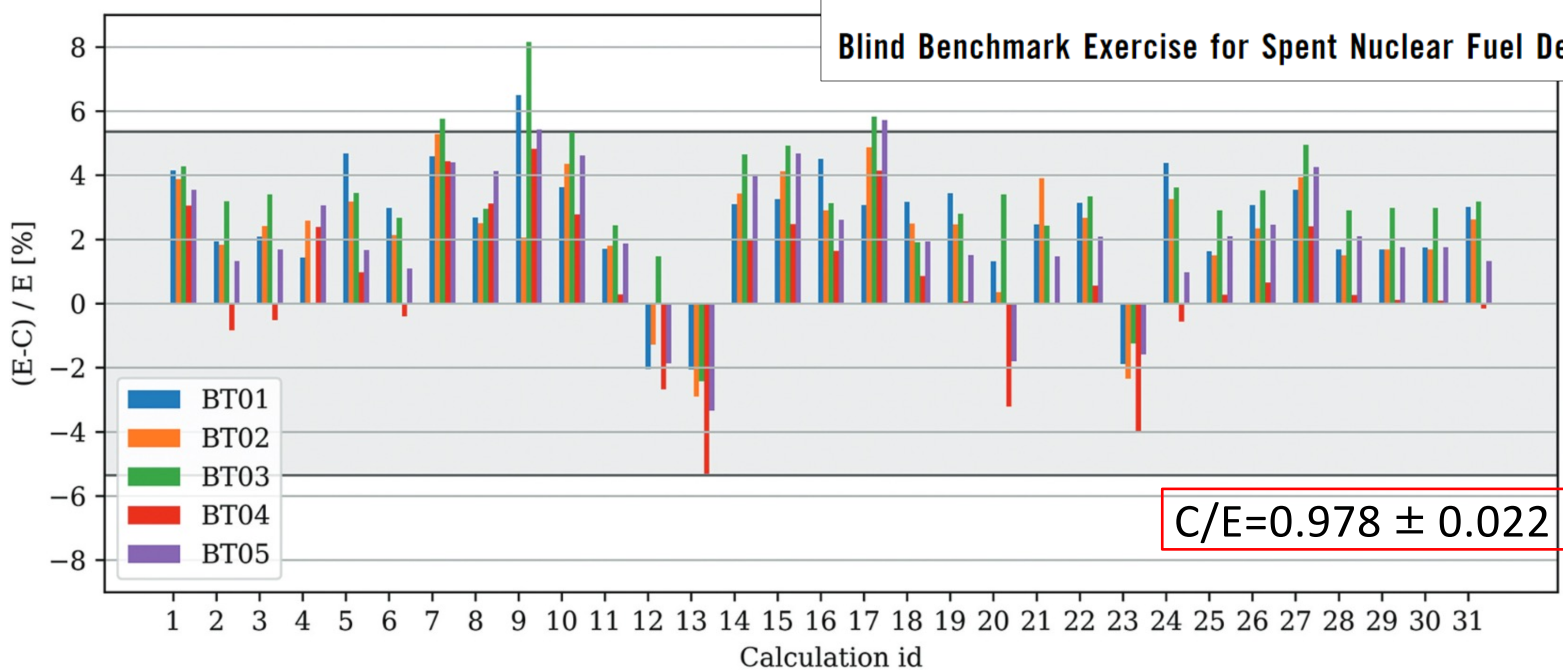
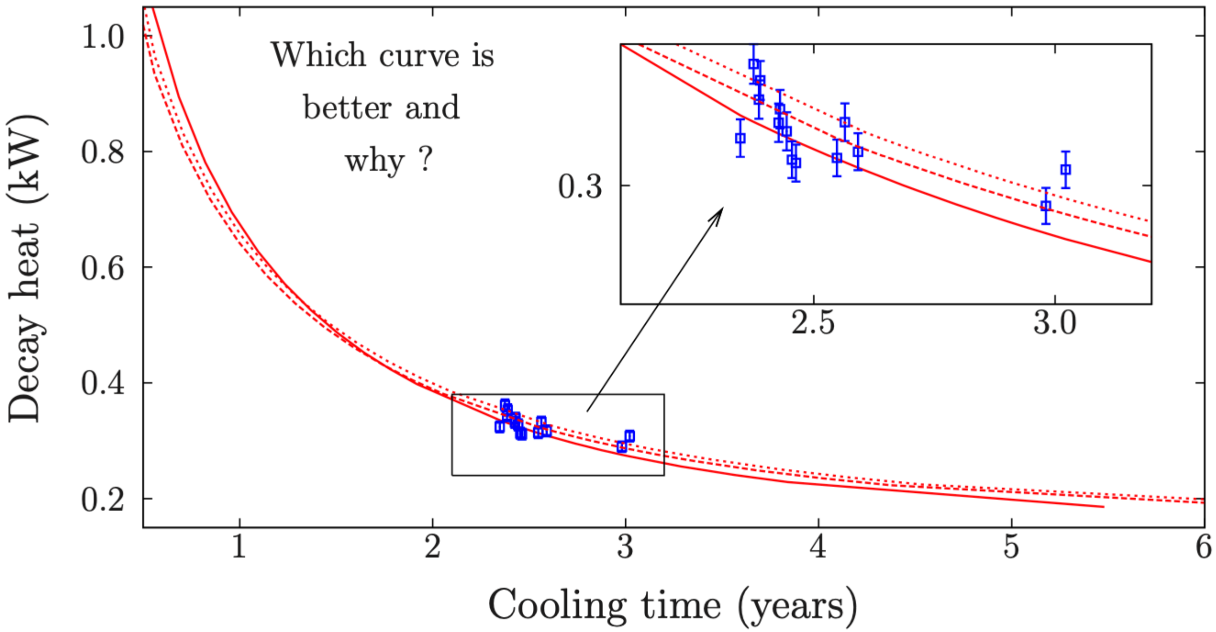


Fig. 8. Relative difference between measured (E) and calculated (C) decay heat rate values for the five different assemblies studied.

A simple average of the values presented in the previous figure leads to an average of 1.002 ± 0.015

What are the needs for SNF decay heat ?

- Best estimate plus uncertainties (BEPU):
  - Last cycle before shutdown
  - cask
  - canister



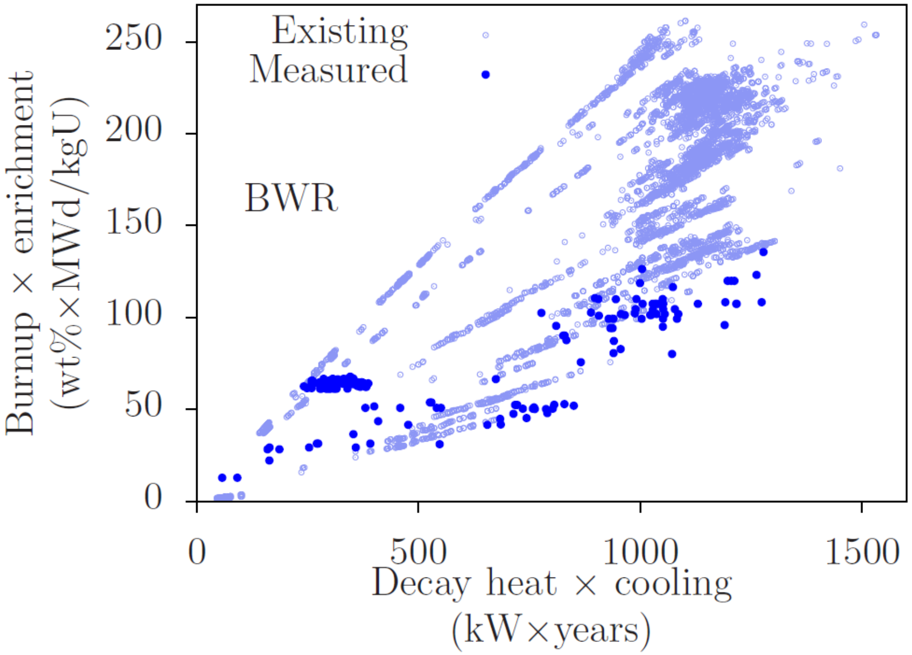
1 % difference in decay heat

⇒1 % difference in canister number

(1 canister ≈ 0.5-1 M€)

What are the needs ?

- Poor overlap between measured SNF decay heat and existing SNF in cask
  - Only 1 device worldwide
  - Current SNF characteristics do not overlap with the measured ones:
    - high enrichment (up to HALEU),
    - high burnup (> 60 MWd/kgU),
    - long cooling,
    - high decay heat
    - ATF, VVER, MOX, CANDU



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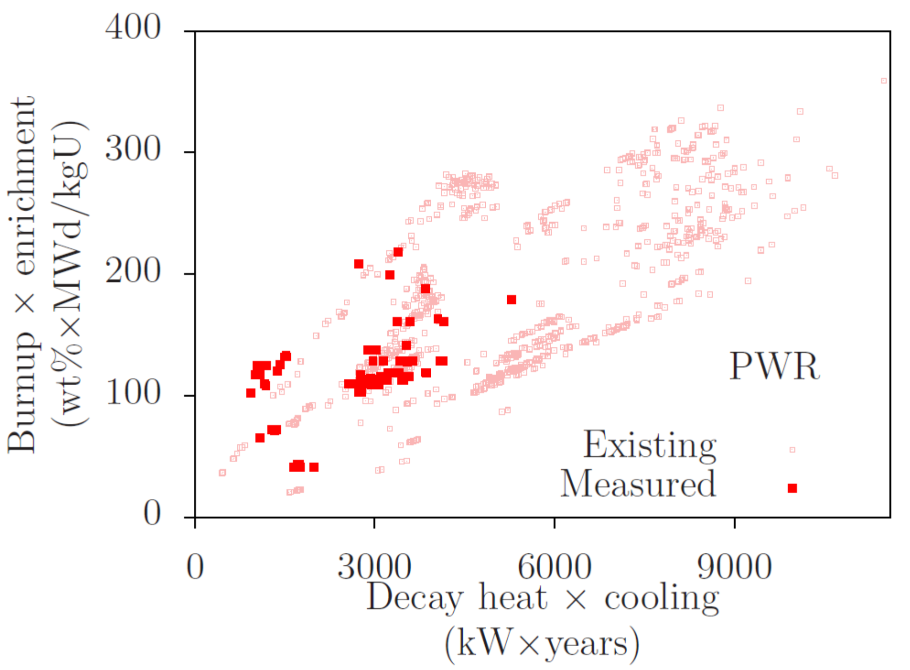


General goals for the WPNCS SG12

- <u>SG12:</u> Decay heat from existing Spent Nuclear Fuel, ≈60 participants, 2 years, started in 2022.

General goals for the WPNCS SG12

- SG12: Decay heat from existing Spent Nuclear Fuel, ≈60 participants, 2 years, started in 2022.

- Long-term goal: provide the user community with reliable estimations of decay heat for spent nuclear fuel from existing power plants, including best estimates, as well as uncertainties (or covariances) for specific cooling times, relevant for severe accident to long-term repository

- Goal 1: Gather the international community

- Goal 2: Raise awareness for new measurements, burnup estimation and evaluations (standards)

- Goal 3: State-of-the art report, codes

- Goal 4: define a new (not blind) benchmark

Activities in 2022

- Online WPNCS meeting (short update), January 28, 2022, official start of the SG12
- 1st meeting (online), March 15, 2022
  - Define the structure of the report, assign persons/sections
  - Discuss, collect ideas for a new DH computational benchmark
- Online meeting, April 1st, 2022
  - Update/debrief on the previous meeting (for participants unable to previously join)
- Online meeting, May 18, 2022
  - Defining a proposal for a DH benchmark, to be presented at the next meeting
- 2nd meeting (hybrid), June 27, 2022 (see next slides).
- 3rd meeting (online), December 1st.
  - DH benchmark proposal
- 4th meeting (hybrid), June 28, 2023.

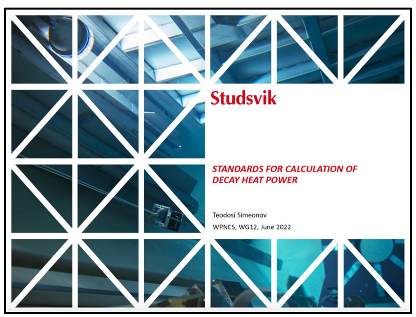
Current outcomes for the WPNCS SG12

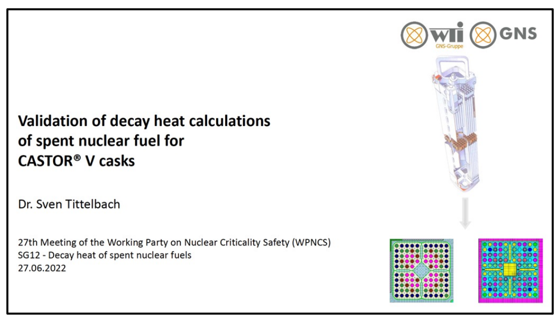
- Draft report schedule for June 2023
- Code for DH standards: available in the SG
- Benchmark definition being finalized
- Linked with EURAD, EURAD-II, IAEA CRP, EPRI-SKB program, national programs
- Future: SMR, GEN-III, IV

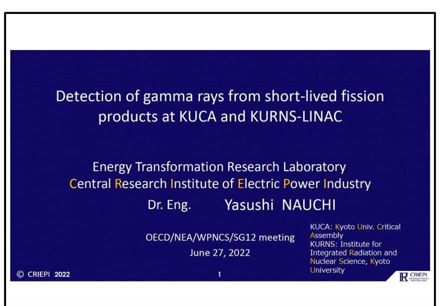
Main outcome of the 2nd meeting

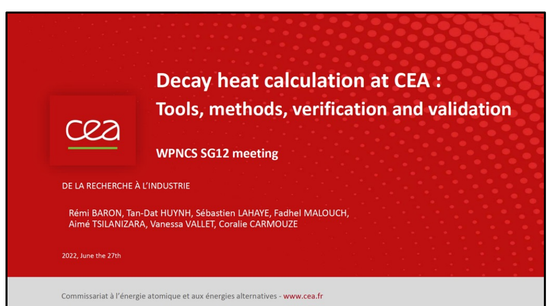
- 62 participants, 21 in person
- 7 technical presentations, 2 overview presentations (1 RWMC, 1 WPNCS)
- Discussion on the SG12 report

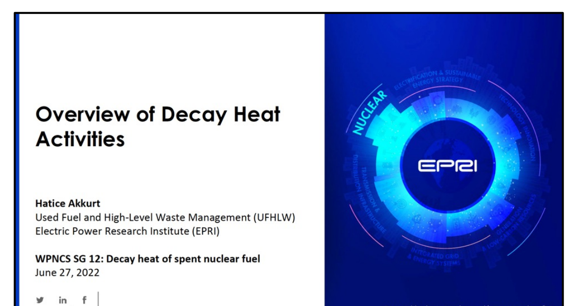
- Decision on future computational benchmark
- Letter of support for the KKG calorimeter, interest in a joint project
- Need of new measurements











Example: H. Akkurt - presentation (EPRI, USA)

- PIRT Report
- EPRI-SKB collaboration
- Extended Storage Collaboration Program

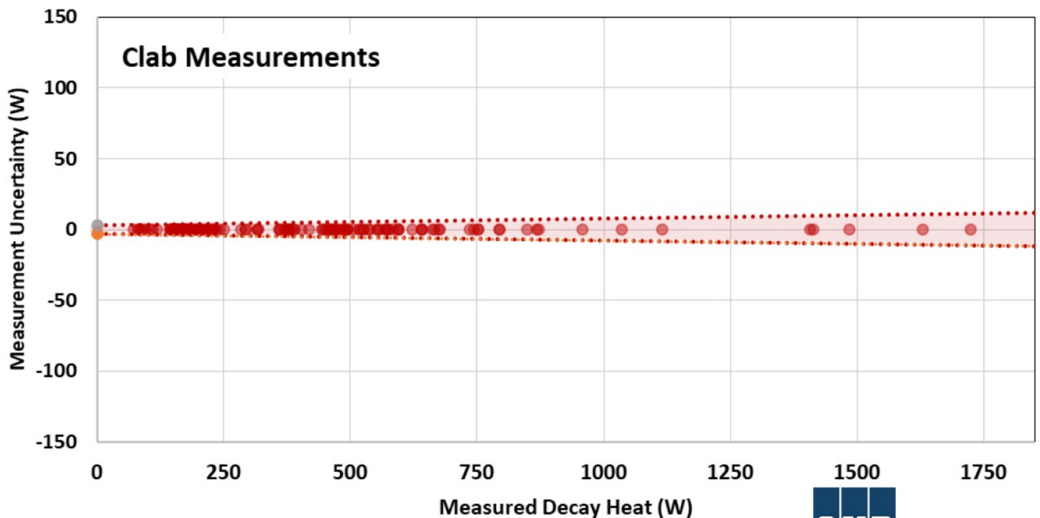
Extending Validation Range for Decay Heat

	Clab-1*	Clab-2**	Clab-3***
Measurement interval	2003-2004	2005-2010	2017-2021
Number of Measurements	109	95	51
Enrichment range (%)	2.1-3.4	2.1-3.7	2.1-4.1
Burnup range (GWd/MTU)	15-51	20-50	20-55
Cooling time range (Years)	11-27	11-27	**1.5-35**
Decay heat range (W)	57-712	91-850	**71-1724**

Recent measurement campaign (2017-2021), significantly extended decay heat validation ranges for cooling time and decay heat

*Published in SKB Report R-05-62 in 2006
**Some validation results published (journal articles) without full specifications
***Not yet published

Uncertainty analysis is still ongoing but preliminary analysis indicate that measurement uncertainty is less than 1% for high decay heat



Example: T. Simeonov - presentation (Studsvik, USA)

- A code for calculating SNF decay heat with standard methods is available in the SG12

SSP-22/446 Rev 0 STDSNF, SNF Standards for DH

Studsvik

SSP-22/446 Rev 0
17 October 2022

STDSNF code Input
Standards
for Decay Heat Power

Digitally signed by Teo Simeonov
Date: 2022.10.17 11:51:19 -04'00'

Prepared by: Teo Simeonov Date

STDSNF, SNF Standards for DH SSP-22/446 Rev 0

CONTENTS

Example: T. Simeonov - presentation (Studsvik, USA)

- A code for calculating SNF decay heat with standard methods is available in the SG12

Table 3. Summary of the C/E averages and standard deviations for the SNF decay heat values as presented in Table 1.

Code or method	version	library	BWR + PWR Average	BWR + PWR 1σ	BWR Average	BWR 1σ	PWR Average	PWR 1σ
CASMO5	2.03	ENDF/B-VII.1 (201)	1.006	0.043	1.008	0.052	1.001	0.018
CASMO5	2.13	ENDF/B-VII.1 (201)	0.989	0.041	0.991	0.050	0.982	0.016
CASMO5	2.13	ENDF/B-VII.1 (202)	0.988	0.041	0.991	0.050	0.982	0.017
CASMO5	3.05	ENDF/B-VII.1 (202)	0.987	0.041	0.991	0.050	0.982	0.017
CASMO5	3.05	ENDF/B-VIII.0 (300)	0.986	0.041	0.990	0.051	0.980	0.017
CASMO5	3.05	JEFF-3.2 (202)	0.981	0.042	0.986	0.051	0.973	0.016
CASMO5	3.05	JEFF-3.1.1 (200)	0.975	0.042	0.979	0.051	0.968	0.016
CASMO5	3.05	JEF-2.2 (300)	0.982	0.042	0.988	0.051	0.975	0.016
SNF	1.6	ENDF/B-VII.1 (201)	1.003	0.048	1.004	0.057	1.002	0.027
SNF	1.07	ENDF/B-VII.1 (202)	0.987	0.046	0.989	0.053	0.984	0.030
ANS	2014		1.119	0.071	1.124	0.080	1.111	0.054
ISO	2022		1.121	0.088	1.141	0.088	1.090	0.078
RG-3.54	2018		1.087	0.041	1.095	0.073	1.076	0.040
DIN	2014		1.015	0.037	-	-	1.015	0.037

Table 1. Summary of the experiments considered in this study. Original information can be found in Refs. [15,20–25], The abbreviations W14, W15, W17, GE7, GE8, GE9, S64 and S100 correspond to the following designs: Westinghouse 14x14, 15x15, 17x17, General Electric 7x7, 8x8, 9x9, SVEA-64 and SVEA-100, respectively.

Facility	Reactor type	Reactor	SFA design	Measured decay heat (W)	Enrichment ^{235}U (wt%)	Burnup (MWd/kgU)	Cooling time (years)	Nbr SFA	Nbr Meas.
Clab	PWR	Ringhals-3	W17	661-1662	3.60-3.95	50-55	4.5-21	5	5
Clab	BWR	Ringhals-1	GE8	88-211	2.3-2.9	21-45	13-24	17	44
Clab	PWR	Ringhals-2	W15	357-692	3.1-3.3	34-51	16-27	18	33
Clab	PWR	Ringhals-3	W17	210-714	2.1-3.4	20-47	13-26	16	38
Clab	BWR	Barsebäck-1,2	GE8	83-240	2.3-3.2	20-41	11-25	7	9
Clab	BWR	Oskarshamn-2,3	GE8	56-283	2.2-2.9	15-47	12-27	14	14
			S64, S100						
Clab	BWR	Forsmark-1,2,3	GE8, GE9	85-218	2.1-3.0	20-38	11-15	11	13
			S64, S100						
GE-Morris	BWR	Cooper	GE7	62-392	1.1-2.5	12-28	2-7	54	80
GE-Morris	PWR	Point Beach-2	W14	724-934	3.4	32-39	4	6	6
GE-Morris	PWR	San Onofre-1	W14	359-934	3.9-4.0	27-32	3-8	8	8
EMAD	PWR	Turkey Point	W15	625-1423	2.6	26-28	2-6	4	6
Total	PWR			210-1662	2.1-4.0	20-55	2-27	57	96
	BWR			56-392	1.1-3.2	12-47	2-27	103	160

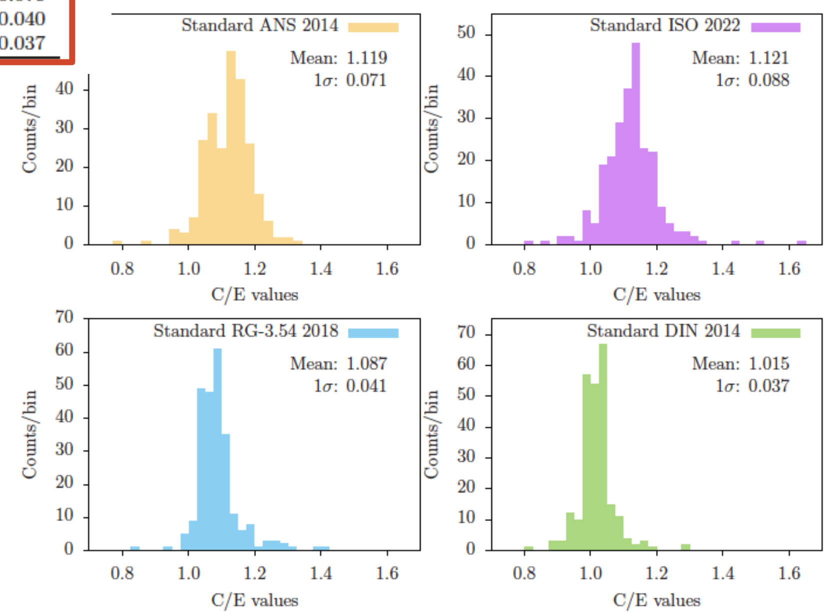


Fig. 5. Histograms for the C/E ratios using four standard methods.

Reporting

- Main goal of the SG12: SOTA report (available on Overleaf)
- To be finalized in June 2023

EPJ manuscript No.
(will be inserted by the editor)

An introduction to Spent Nuclear Fuel decay heat for Light Water Reactors

D. Rochman[1], J.-F. Martin[2], L. Giot[3], R.W. Mills[4], S. Sato[5,*], A. Algora[6,7], F. Álvarez-Velarde[8], K. Govers[9], Y. Nauchi[5], V. Hannstein[10], R. Dagan[11], E. Vlassopoulos[12], A. Shama[12], Pl. Petkov[13], R. Ichou[14], F. Minato[15], S. Häkkinen[16], V. Léger[17], T.D. Huynh[18], S. Lahaye[18], F. Malouch[18], A. Tsilanizara[18], T. Watanabe[15], Ø. Bremnes[19], G. Ilas[20] [add your name here; and prepare copyright form to send to wpncs@oecd-nea.org - see template in appendix]

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2 Division of Nuclear Science and Education, OECD Nuclear Energy Agency (NEA), Paris, France
3 Subatech (CNRS/IN2P3, IMT Atlantique, Université de Nantes), Nantes, France
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5 Central Research Institute of Electric Power Industry (CRIEPI), Japan
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9 Federal Agency for nuclear Control, Brussels, Belgium
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11 KIT- Karlruhe Institue of Technology, Germany
12 Nagra - Nationale Genossenschaft für die Lagerung radioaktiver Abfälle, Switzerland
13 Sofia University "St. Kliment Ohridski", Sofia, Bulgaria
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PACS. XX.XX.XX No PACS code given

Contents

DH future benchmark

PAUL SCHERRER INSTITUT

Decay heat computational benchmark: definition for a PWR UO_2 assembly and pincell

WPNCS SG12

D. Rochman[1]

[1]**Reactor Physics and Thermal hydraulic Laboratory, PSI, Switzerland**

Version 0.1

February 9st, 2023

2 BENCHMARK DESCRIPTION

In the following, both cases of the pincell and assembly will be described. For geometric and fuel descriptions, the pincell is directly extracted from the assembly case. All original information can be found in Ref.[1] and specific references (pages, tables) are also provided in the following.

2.1 Description of assembly 0E2

The description of the 0E2 assembly and its irradiation history are presented in Tables 1 to 3. References to publications are included. When an information provided in the tables does not originate from a specific reference, a note is added. The assembly average burnup is 41.6 MWd/kgU, and the initial enrichment in U-235 is 3.1 %. The assembly can be described using a quarter symmetry, as presented in Fig. 1 using CASMO5 and SCALE plots. For the 2D simulation, no modelling for the spacers is required, and no specific material at the top and bottom of the assembly needs to be modelled.

Table 1: General information for assembly 0E2 – part 1.

Generic data		Reference
Reactor type	Westinghouse 3 loop PWR	
Reactor name	Ringhals 3	[1], page 15/253, table 3-2
Reactor coolant system pressure	155 bar	[1], page 226/253
Number of assembly in core	157	[1], page 226/253
Centrum distance between fuel assemblies	21.50 cm	[1], page 226/253
Active length	3658 mm	[1], page 227/253
Average temperature into core at full power	600 K	See note 1
Average temperature in pellets at full power	900 K	See note 1
Coolant density	0.72 g/cm^3	[3], page 84/180
Reactor Power	2775 MW	[1], page 226/253, see note 4

Future DH computational benchmark

- 2D simulations: assembly and pincell
- CLAB-2006 measurement: PWR 17x17 assembly 0E2, 3.1 %, 41.6 MWd/kgU
- Multiple measurements

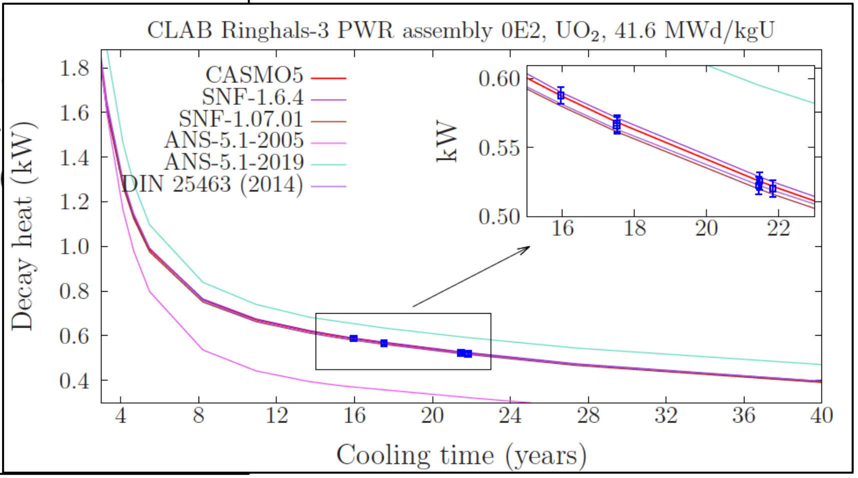
Required input/output

- Input details provided by the SG12

- Irradiation steps and cooling steps for the pincell and assembly
- Code, important methods, libraries

- Calculated DH + standard DH values
- Calculated neutron/gamma emission, activity
- k_{inf} during irradiation
- Nuclide concentrations during irradiation + cooling tim
  - U-234,235,236,238, Pu238-242, Am241-243, Cm242-
  - Nd146-148, Rh103,106, Cs133,134,137, Ba137m, Sr9
- fission rates (separate between 4 main actinides)
- Delayed fission

- Sensitivity ?
- Gaps ?



Conclusion

- Decay heat for existing SNF is still a subject where improvements are needed (computational and experimental)
  - Belief of ”high precision” prediction, not systematically backed up by facts
  - Scarcity of integral experiments

- Linked to criticality, dose, optimization (safety and economy)

- Validation gaps still exist: high burnup, high enrichment, short & long cooling time, MOX

- SG12:
  - gather specialists/non specialists,
  - State of current knowledge,
  - Raise awareness,
  - Prepare “evaluation” of decay heat

Wir schaffen Wissen – heute für morgen