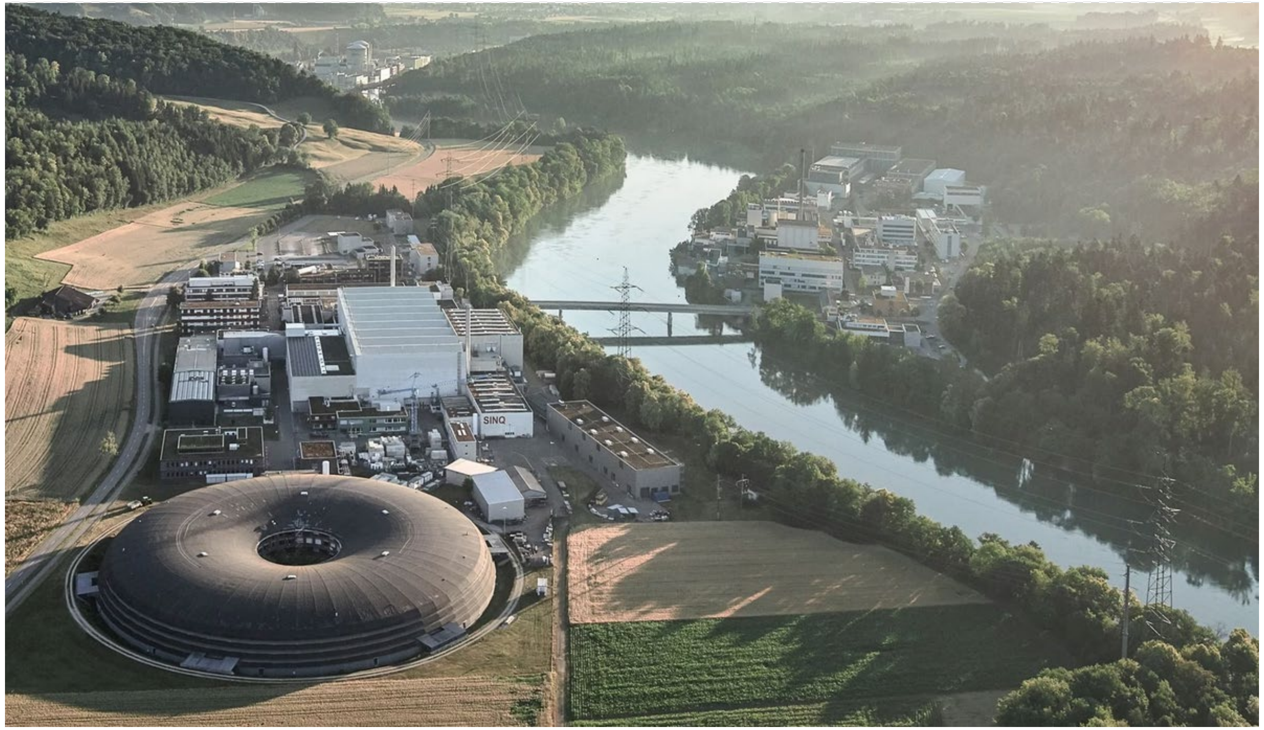
PSI Center for Nuclear Engineering and Sciences




# Decay heat of irradiated nuclear fuels – a status report based on WPNCS/SG12 and EURAD WP8

D. Rochman

3rd RCM on Spent Fuel Characterization, Cockermouth, UK, July 1st, 2024

Pre-recorded presentation

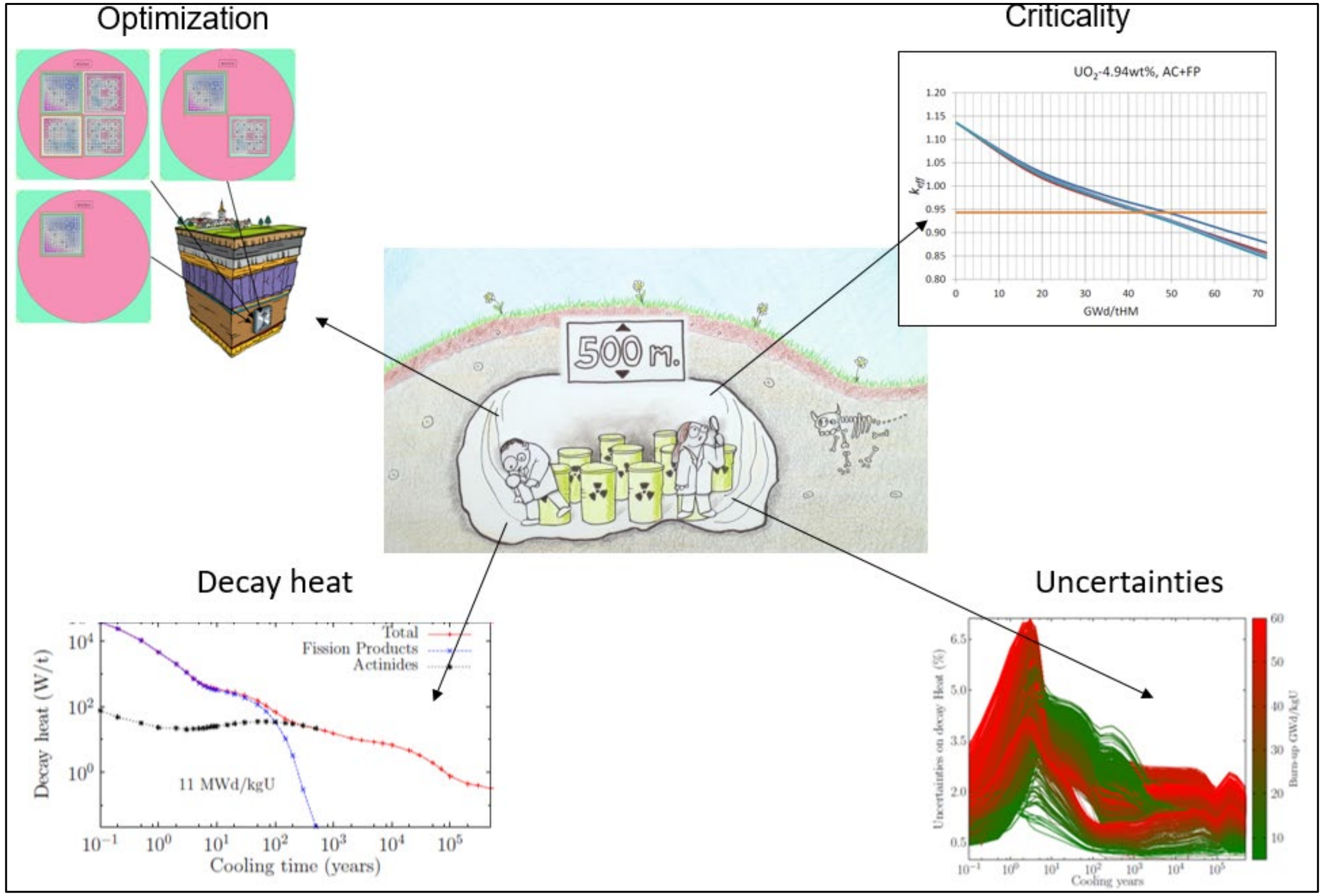
# Summary

- Introduction and background
- Overview of the WPNCS SG12
- Overview of the EURAD WP8 subtask 2.1
- Current and future needs
- Next WPNCS SG16
- Conclusion

# Introduction

Precise knowledge on SNF decay heat is required for

- Core transients (short cooling time, a few seconds to minutes),
- Safe and economical storage, transport and long-term repository (long cooling time, weeks to 1 billion of years)



# Goals of the WPNCS SG12

The WPNCS SG12 was created in January 2022, with about 50 participants and 12 organizations, to:

Gather interested participants from different horizons: industries, technical support organizations, waste management organizations, and safety authorities, in order to **exchange information** on decay heat for existing SNF: current knowledge, interest, needs.

Raise the awareness of the current prediction capabilities, and limitations due to the lack of **experimental data**.

Establish a **state-of-the-art report** regarding the decay heat for existing SNF, leading to discussions on existing biases and uncertainties, the impact of nuclear data libraries, assumptions in modelling, or irradiation history.

Finally organize a **decay heat benchmark**, based on a fuel assembly with measured values, eventually to be started with a new dedicated subgroup.

# Decay heat estimation

Annals of Nuclear Energy 165 (2022) 108758

Contents lists available at ScienceDirect

Annals of Nuclear Energy

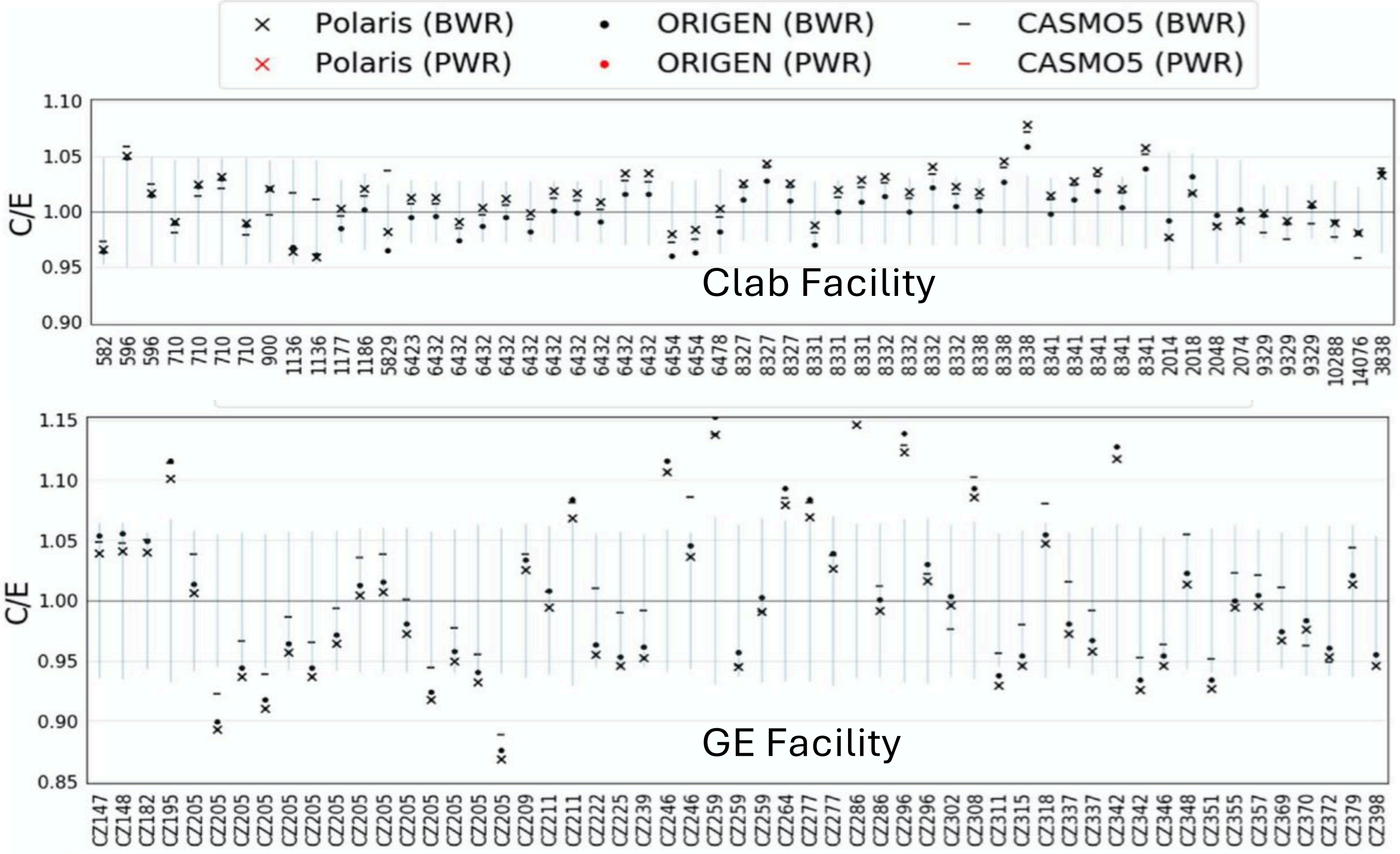
journal homepage: www.elsevier.com/locate/anucene

Validation of spent nuclear fuel decay heat calculations using Polaris, ORIGEN and CASMO5

Ahmed Shama [a,b,*], Dimitri Rochman [c], Stefano Caruso [d,b], Andreas Pautz [a,c]

PSI

How well can we estimate SNF decay heat ?

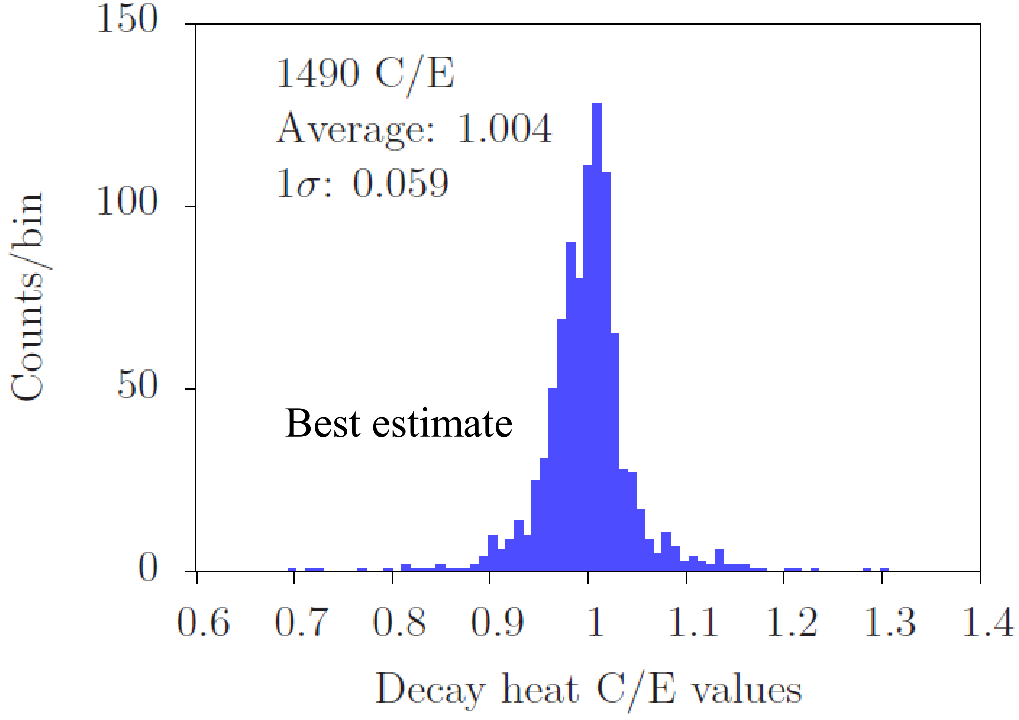


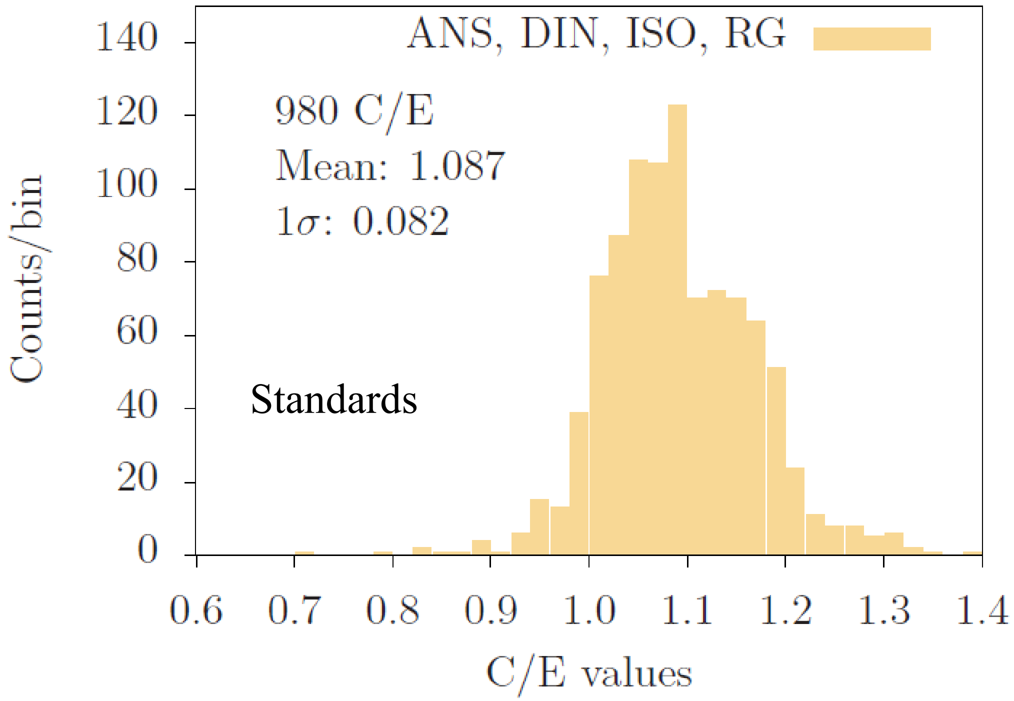

Integral measurements (calorimeter on full SNF): mixed agreement between C and E

# Decay heat estimation

How well can we estimate SNF decay heat ?

Histograms of the ratios of calculated (C) over experimental (E) decay heat values




Best-estimate calculations provide good average C/E, but large 1**σ**

Standard calculations provide on average over-estimated values (but not systematically)

# Decay heat origin

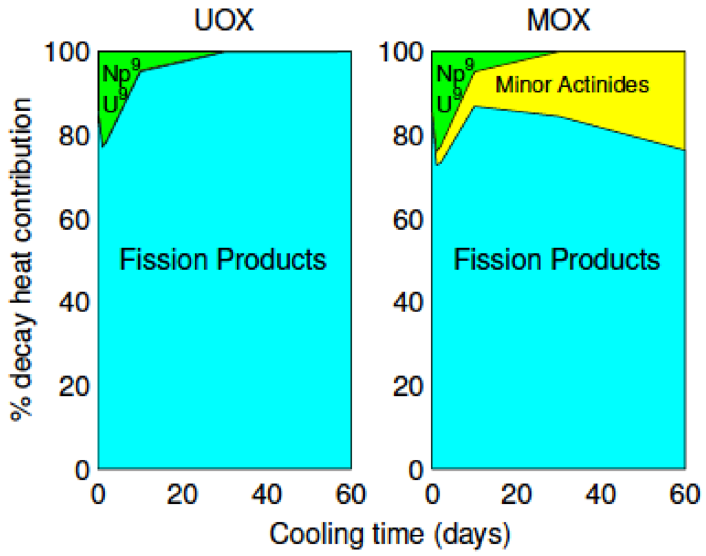


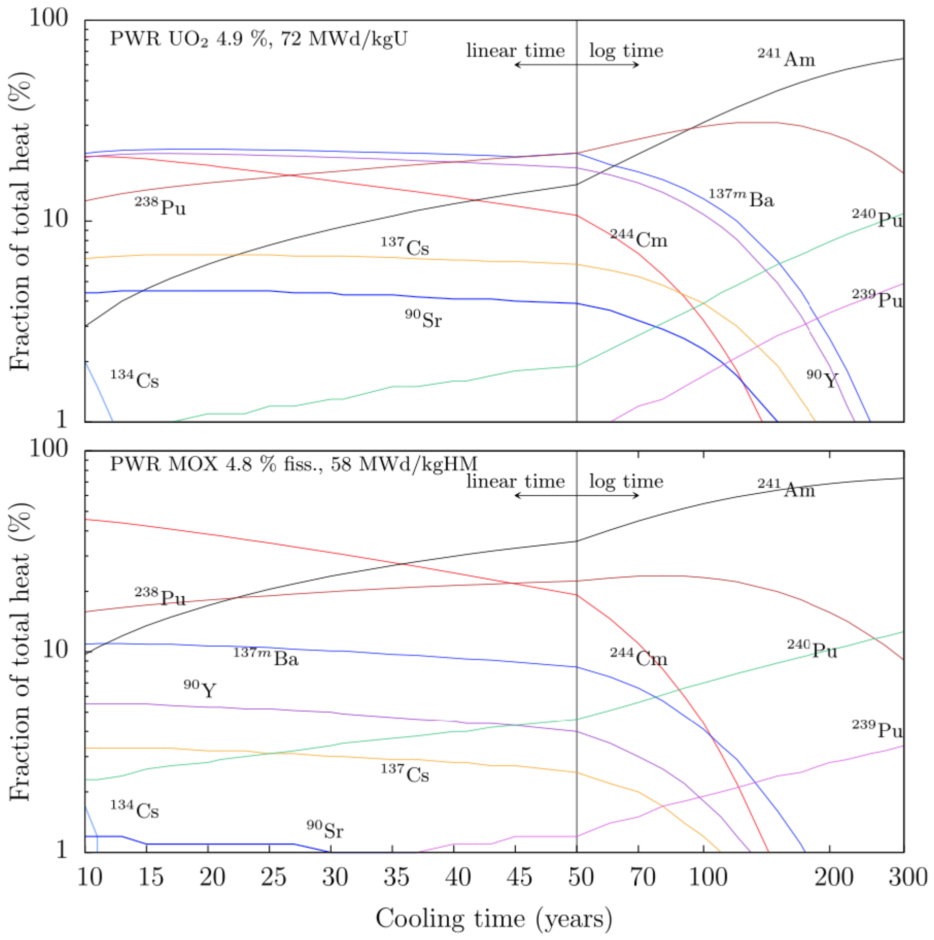

Figure 1 : Contribution of Fission Products, $^{239}$U and $^{239}$Np and other actinides (essentially $^{242}$Cm) in low irradiated (3 GWd/t) UOx with 3.7% $^{235}$U initial enrichment and equivalent MOx fuels.

A new decay heat standard proposition based on a technical specifications guide for computation codes


Frédéric Laugier[a,1], Cheikh Diop[b], Sylvie Ebalard[c], Claude Garzenne[a], Antonio Sargeni[d]



*International Conference on the Physics of reactors "Nuclear Power: A Sustainable Resource"*
Casino-Kursaal Conference Center, Interlaken, Switzerland, September 14-19, 2008



Nuclear Engineering and Design 410 (2023) 112392

Contents lists available at ScienceDirect

Nuclear Engineering and Design

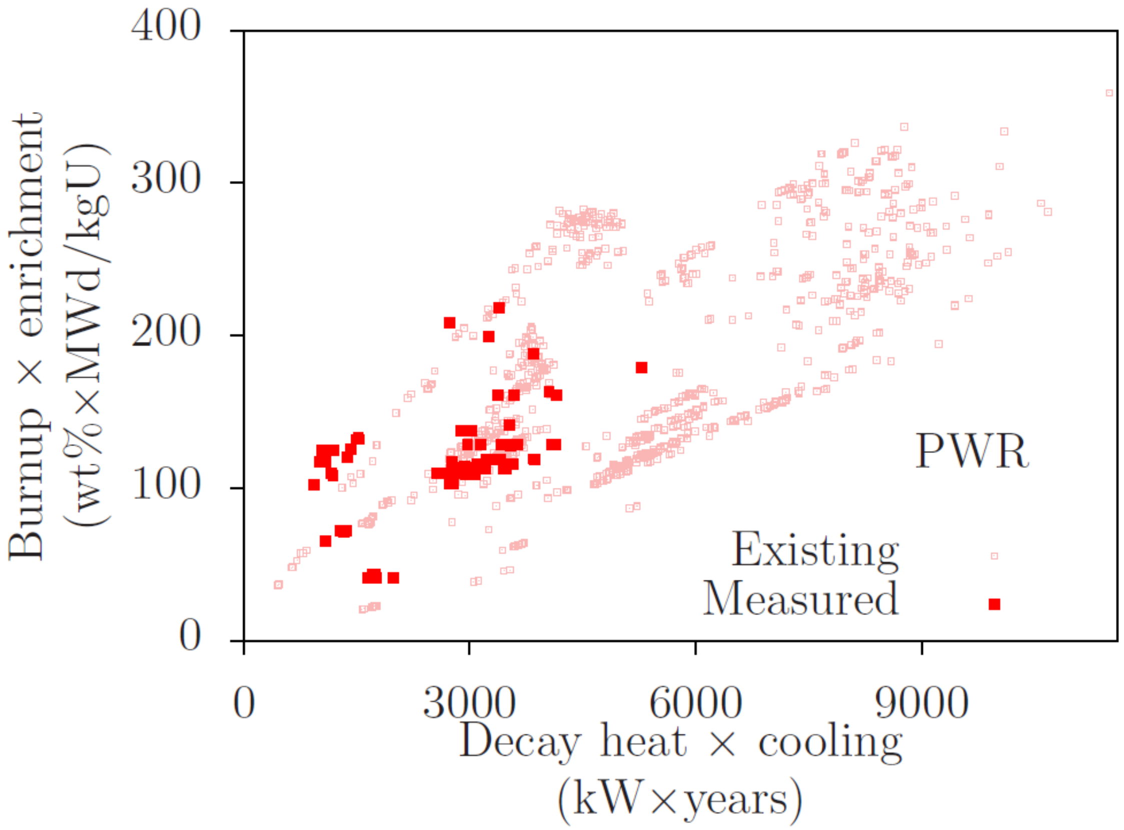
journal homepage: www.elsevier.com/locate/nucengdes


Comparison of calculated and measured spent nuclear fuel decay heat with CASMO5, *SNF* and standard methods


D. Rochman[a,*], J. Taforeau[b], T. Simeonov[c], A. Shama[d]

# Decay heat origin

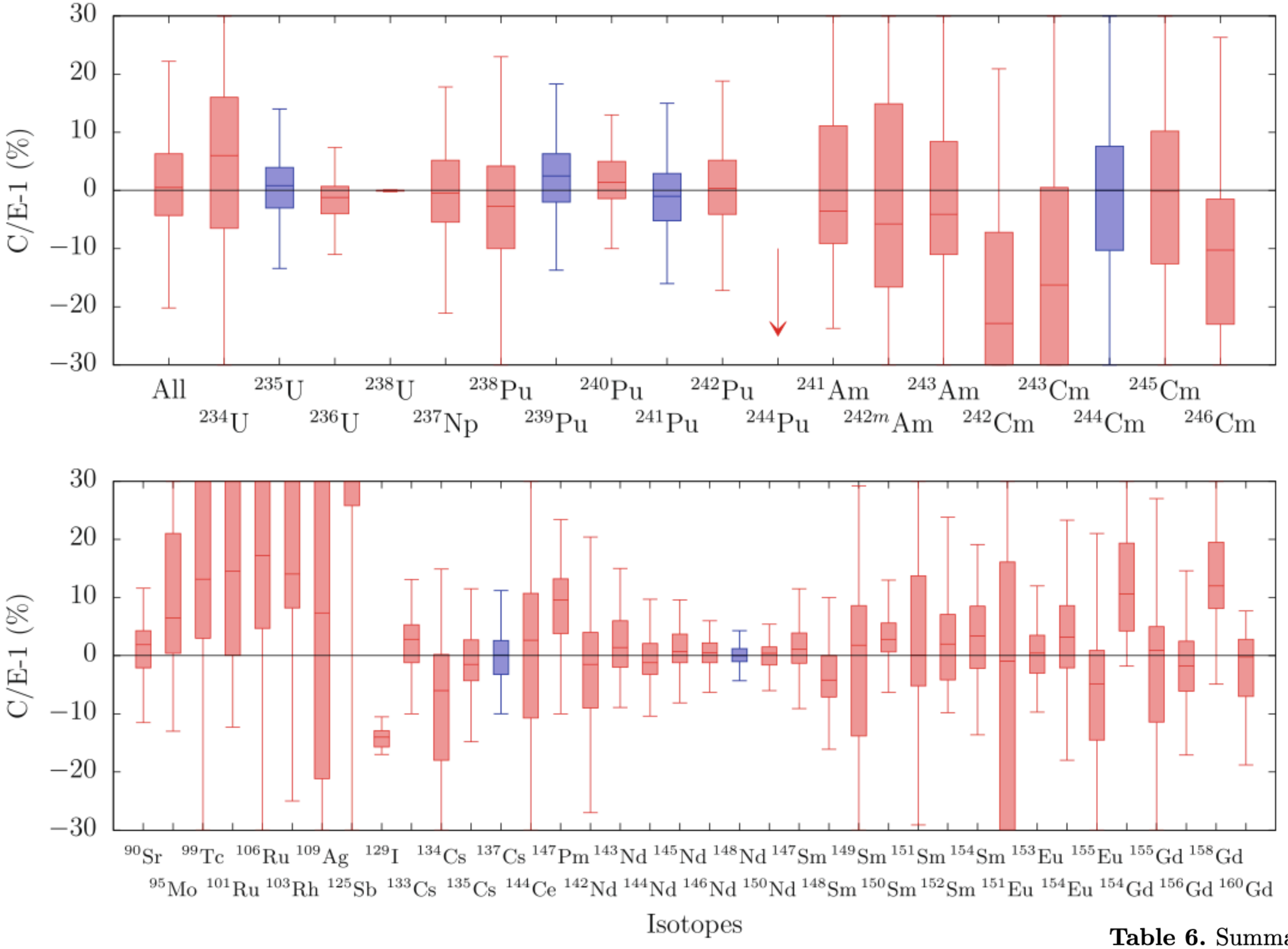
- Limited overlap between measured SNF decay heat and SNF currently in storage
- Current SNF:
  - high enrichment,
  - high burnup,
  - long cooling,
  - high decay heat




- No measurements for MOX, ERU, and for VVER or CANDU fuels
- Only one (currently in Sweden) existing calorimeter (two additional in design/plan phase, France and Switzerland)

# Recommendations from EURAD WP8 subtask 2.1

PSI




EPJ Nuclear Sci. Technol. **9**, 14 (2023)
© D.A. Rochman et al., Published by EDP Sciences, 2023
https://doi.org/10.1051/epjn/2022055

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**

**Table 6.** Summary of the recommendations concerning some SNF calculated nuclide concentrations and decay heat, for the cooling period between 1 and 1000 years

| | $^{148}$Nd | $^{137}$Cs | $^{235}$U | $^{239}$Pu | Average burnup | Decay heat |
|---|---|---|---|---|---|---|
| Uncertainty | 4% | 5% | 4% | 4% | 5% | > 4% |
| Bias | −0.1% | −0.4% | +0.2% | +2.5% | – | See Figure 9 |

The uncertainty represents one standard deviation ($1\sigma$).

https://doi.org/10.1051/epjn/2022055

# Recommendations from EURAD WP8 1/3

PSI

Current experimental uncertainties: between 1 and 5 %

eurad
European Joint Programme on Radioactive Waste Management

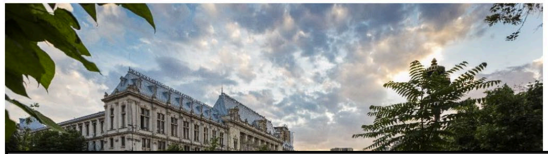
Newsletter 14
September 2023

Table of contents



## EURAD's final annual event!

*TAKE A LOOK AT THE DRAFT AGENDA*



eurad
Newslette
Septem

## INTERVIEW WITH ANDERS SJÖLAND (SFC WP LEADER)

**In a nutshell, could you describe how SFC contributes to a safer disposal of spent nuclear fuel?**
The spent nuclear fuel has a number of very dangerous properties, which make us go to such length to safely dispose of it, literally forever. These properties are the radiation, the ability to become critical, the decay power giving heat, and the nuclide inventory giving radiation on release (as well as, in some cases, being chemically toxic). In order to safely handle the spent fuel, these properties must be accurately known in all steps of the back-end of the nuclear fuel cycle. There are limits on how many of these can be accepted in the various parts of the cycle

information on the composite nuclides. For the operational situation, it is not possible to routinely destroy the fuel in order to analyse it.

Simply put, a one sigma uncertainty of 2 % is a realistic aim for a well characterised fuel. For other fuels, it has been shown in a number of prominent SFC journal papers that the uncertainties in nuclear data (cross sections etc.) can be up to 10 % on the calculated decay power. The question on the number of sigma's to apply is a complicated one because of the complicated statistics of the spent fuels, and is the focus of an intense international debate in various organisations. The result

P. 3

# Recommendations from EURAD WP8 2/3

PSI

- Current experimental uncertainties: between 1 and 5 %
- Current calculated uncertainties: between 2 and 10 %
  - Nuclear data
  - Operating conditions & Modeling impact
  - Manufacturing tolerances
  - Burnup induced changes

- Need for new measurements (burnup, enrichment, cooling time, fuel type) and facilities

- Need for improved theoretical understanding and nuclear data
  - For different cooling periods
  - For different fuel types

- Recommendations are needed for the use of standards, calculation methods, code improvement

# Recommendations from EURAD WP8 3/3

PSI

- Redundancy
  - Experimental (multi measurements of same SNF, and multi facility)
  - Simulation (double check, different codes)

- Comparisons of code implementation
  - Module
  - Solvers, inputs, assumed values

- Use of blind benchmarks
  - Based on experimental values
  - Or computational benchmark

- User effect due to
  - Interpretation of the same information
  - Ambiguity of definition
  - Different options
  - Mistakes

# Next WPNCS SG16

PSI

- A new group of people gathered to study a decay heat benchmark

NEA
Nuclear Energy Agency

NEA/NSC/WPNCS/WD(2024)1

For Official Use | English text only
27 May 2024

NUCLEAR ENERGY AGENCY
NUCLEAR SCIENCE COMMITTEE

Working Party on Nuclear Criticality Safety (WPNCS)

**Decay heat computational comparison exercise: definition for a PWR UO2 assembly and pincell**

**Specifications for the exercise of WPNCS SG16**

10 | NEA/NSC/WPNCS/WD(2024)1

## 3 Decay heat measurements for assembly 0E2

A total of 6 measurements was performed for assembly 0E2. The first one is mentioned in Ref. [1], and the 5 later ones in Ref. [2]. They are listed in Table 4, with the cooling time relative to the shutdown date for cycle C5: July 7, 1988.

**Table 5:** Decay heat measurements for assembly 0E2.

| Cooling time (days) | Measurement date | Gamma escape (W) | Total decay heat (W) | Uncertainty (in W, 1σ) | Reference |
|---|---|---|---|---|---|
| 5823 | 16/06/2004 | 15.5 | 587.9 | 7.0 | [1], pages 19,34/253, [2], Table A.2 |
| 6389 | 03/01/2006 | | 566.0 | 6.9 | [2], Table A.2 |
| 6390 | 04/01/2006 | | 567.7 | 6.9 | [2], Table A.2 |
| 7826 | 10/12/2009 | | 522.4 | 6.6 | [2], Table A.2 |
| 7837 | 21/12/2009 | | 525.6 | 6.6 | [2], Table A.2 |
| 7970 | 03/05/2010 | | 520.1 | 6.6 | [2], Table A.2 |

- Starting this September 2024

# Next efforts

- EPRI report on Clab decay heat measurements on

  "*Spent Fuel Decay Heat Measurements at Clab Facility: Description of Decay Heat Measurements from 2003–2021 under EPRI-SKB Collaboration*"

  - (see F. Johansson during this meeting)
  - New SNF measurements (higher enrichment, higher burnup, different cooling time)
  - New evaluation of past measurements

- EURAD
  - WP8 (on SFC) is finished.
  - Follow-up in EURAD-2 (start in 2024)
  - Different focus (WP17 on *Criticality-Safety for Final Disposal*)

- Measurements
  - Studies on calorimeters going on (France, Switzerland)
  - Inestimable help from SKB/Vattenfall, hopefully to go on.

# Conclusion

- Decay heat is one of the most important quantities from SNF characterization perspective

- It is linked to other SNF quantities, such as criticality, burnup, as well as in-core irradiation, nuclear data

- WPNCS SG12 and EURAD WP8 has successfully gather actors of the nuclear industry, leading to common understandings regarding
  - State-of-the art (submitted to a journal)
  - Needs (seconds to billion years)
  - Future developments

- More measurements needed (using recent fuel assemblies)

- Smaller estimated uncertainties for predictions (simulations)

- Next step in WPNCS: setting up of a computational benchmark.

# Many thanks

- Questions ?