# Master's Thesis Engineering Technology

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# *Spent nuclear fuel sensitivity to model parameters*


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## Introduction

Since the achievement of the first nuclear chain reaction nuclear energy has been used to produce electricity. Fissioning the fissile materials contained in the fuel of a Nuclear Power Plant (NPP), mainly $^{235}U$, delivers the energy needed to heat water and produce steam, which in turn is used to spin the large turbines that generate electricity. ***Spent Nuclear Fuel*** (SNF) is highly radioactive, produces decay heat and there is a risk to reach criticality [1].

To ensure a safe and secure handling and storage, the properties of the SNF have to be determined. Measuring the properties of the SNF by absolute measurements is too complex to implement on a large scale [1]. Therefore, the ***properties are derived*** from theoretical model calculations of the isotopic composition using ***fuel depletion codes***, either stochastic or deterministic.

The simulations rely on the input parameters that are subject to uncertainties. As a consequence, if the input parameters do not reflect the correct physical conditions, the output of the simulation will not be accurate. In this thesis, the ***sensitivity*** of modelling and operational parameters on the isotopic composition of the SNF is analysed. Furthermore, two cases are analysed for the ***validation of ALEPH2 [2]***.

## Materials & methods

**ALEPH** version 2.9.0 [2] is used for the simulation of the ***Gösgen-1 and Takahama-3*** cases. It is a Monte Carlo based fuel depletion code, coupling MCNP 6.2.0 for approximating the neutron spectra and the RADAU5 algorithm to solve the depletion part. It is being developed at SCK CEN since 2004. The data are processed using the Python based tool SANDY. Simulations using ALEPH2 are done using ***ENDF/B-VII.1*** nuclear data library.

**Serpent** version 2.1.32 [3] is used for the sensitivity analysis on the ***Tihange-1 D05*** sample, in the scope of the Rod Extremeties and Gadolinia AnaLysis (REGAL) project [4]. It is a Monte Carlo based fuel depletion code being developed since 2004 at VTT in Finland. It has a built-in depletion solver and Monte Carlo particle transport code. Simulations with Serpent 2 have been carried out using ***ENDF/B-VIII.0*** nuclear data library.

Accurate models are produced from data available in official reports, SFCOMPO-2.0 [5] and the REGAL project official documentation. Validation of the codes is achieved by comparing the calculated and experimental results. The sensitivity analysis is carried out by introducing a perturbation on the reference model and determining the ***impact of the perturbed parameter on the decay heat, neutron emission and γ-emission***.

## Gösgen-1 GU1

In Fig. 1 the pin map for the Gösgen-1 GU1 sample can be seen. A previously existing model has been improved. The list can be found in Table 1. In Fig. 2 the effect of the improvements on the isotopic composition can be seen.

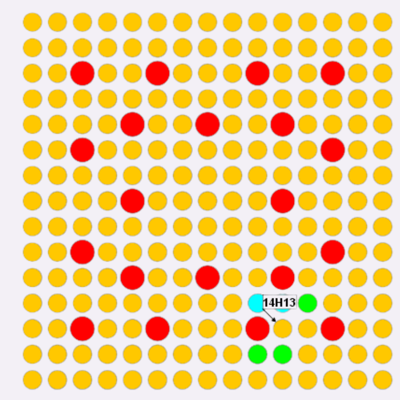

*Fig. 1: Pin map of GU1 assembly $UO_2$-fuel (orange), guide tubes (red), replaced rods (green and cyan)*

*Table 1: Improvements made to the GU1 sample*

| Improvements made |
|---|
| Moderator density |
| Fuel pellet diameter |
| Irradiation time/power |
| Boric acid concentration |
| Tally region definition |

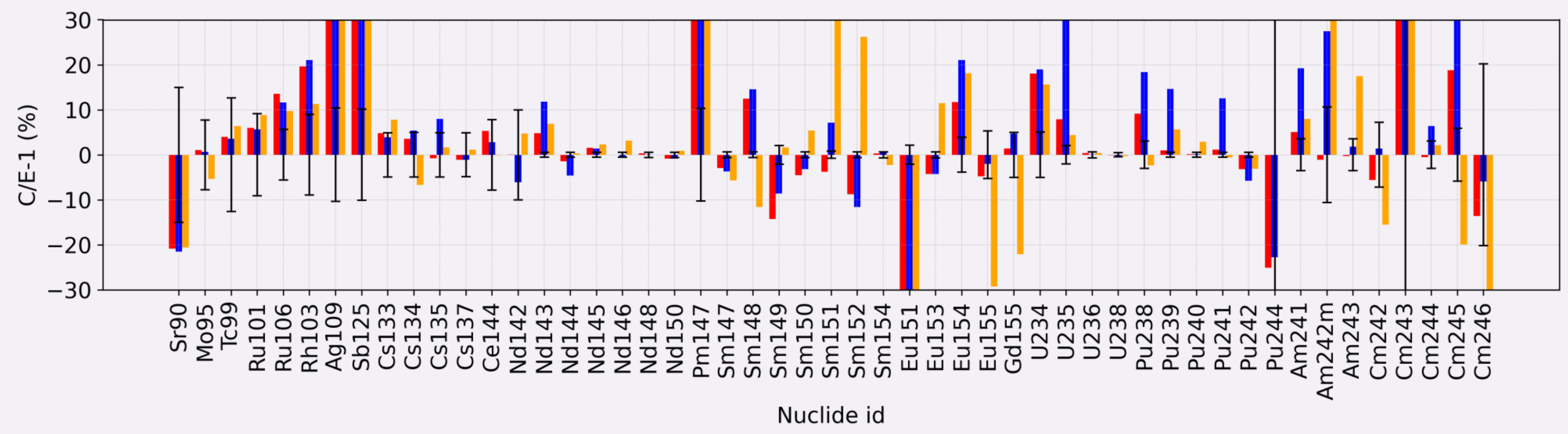


*Fig. 2: Calculated/experimental-1 values for GU1 sample, comparison between new (red), old (blue) and SCALE/TRITON using ENDF/B-V (orange) model*

## REGAL D05

The sensitivity analysis on the REGAL D05 sample is carried out by analysing:

- Fuel pellet diameter
- Fuel cladding thickness
- Fuel pellet height
- Fuel pellet density
- Enrichment fuel
- Core power
- Moderator temperature/density
- Fuel temperature
- Boron concentration

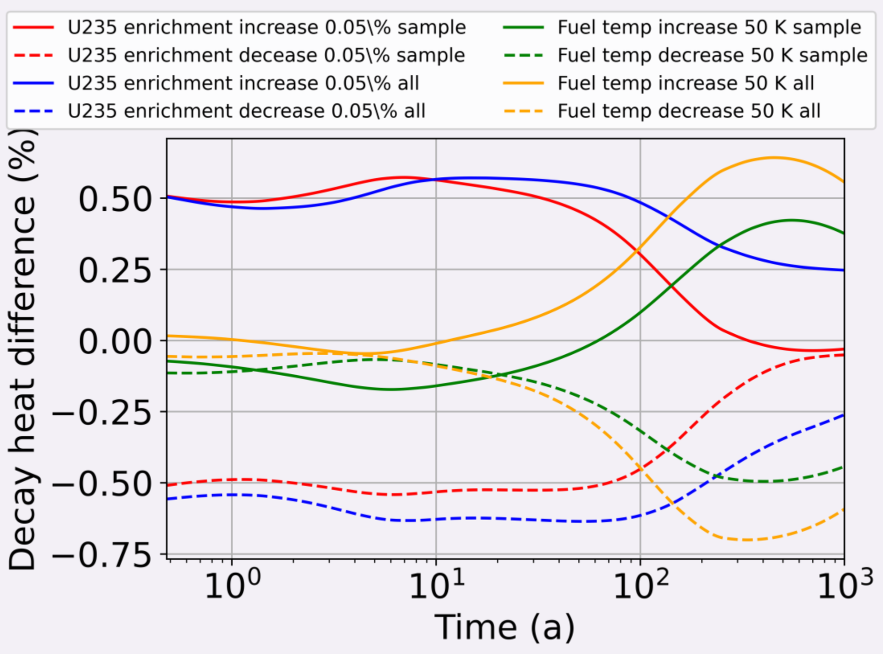


*Fig. 6: Fuel enrichment and temperature influence on the decay heat for cooling times up to 1000 years*

| Negligible | Sensitive for short cooling times | Sensitive for long cooling times |
|---|---|---|
| • Boron concentration | • Fuel enrichment<br>• Power | • Moderator temperature<br>• Fuel density<br>• Pellet diameter<br>• Cladding thickness<br>• Fuel temperature |

## Takahama-3 SF96 sample 1

In Fig 3, the C/E-1 results for the 2D simple model of the Takahama-3 SF96 sample 1 are shown in comparison to the SCALE code using ENDF/B-V and ENDF/B-VI (the latter using 16 BPR instead of 14 BPR). ***Good agreement*** can be found between the SCALE results and ALEPH2, except for $^{154}Eu$ and $^{242m}Am$.

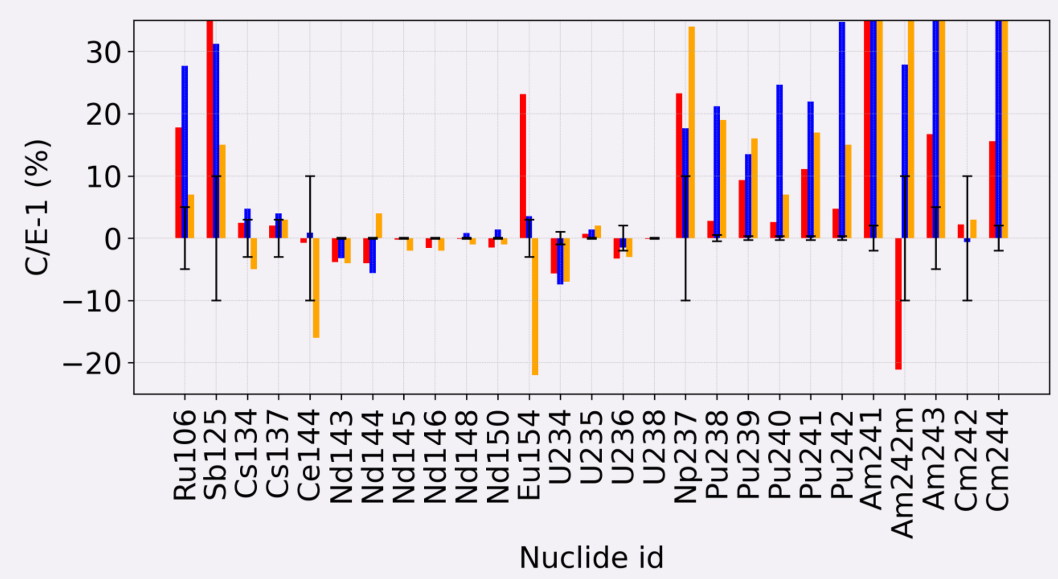


*Fig. 3: Calculated/experimental-1 values for Takahma sample, comparison between simple model (red), SCALE ENDF/B-VI using 16 BPR (blue) and SCALE ENDF/B-V (orange)*

The impact of the number of burnable poison rods (BPR) and the moderator density is shown in Fig. 4. Changing the moderator density results in ***a harder spectrum***, therefore more TRUs are produced. More burnable poison rods results in ***spectral changes***.

The 3D model resulted in an ***underestimation*** of the burnup in sample one of over 50%.

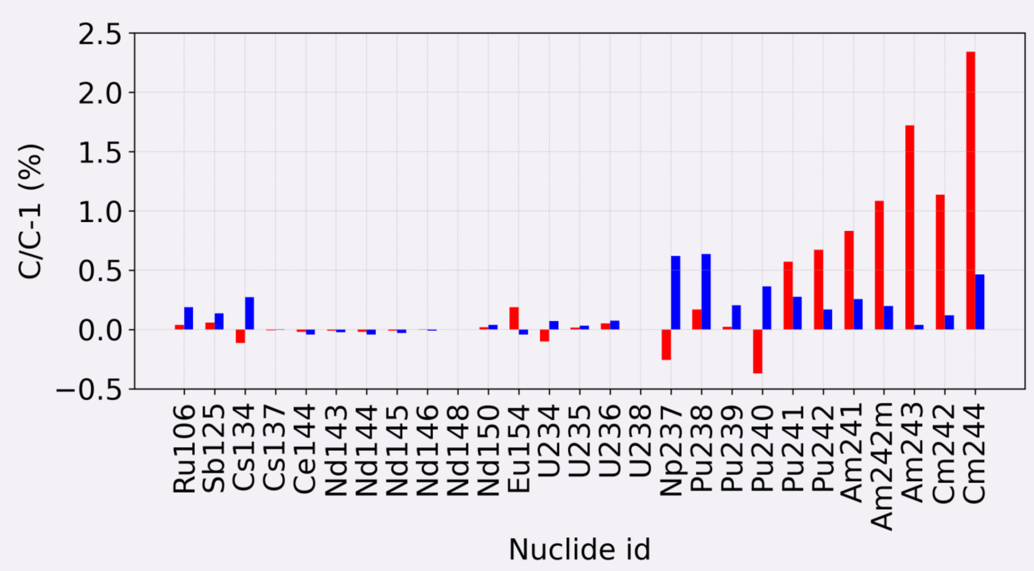


*Fig. 4: Results for the sensitivity analyses of moderator density 0.67764/0.6803-1 (blue) and the number of burnable poison rods 16BPR/14BPR-1 (blue)*

## Conclusion

- The Gösgen-1 GU1 sample has been significantly improved.
- The 2D model of Takahama is in good agreement with the experimental values and with the literature.
- The source of underestimation in the 3D model of Takahama is to be investigated.
- The sensitivity analyses for the REGAL D05 sample showed greatest importance for moderator temperature, fuel enrichment, fuel density and pellet diameter.

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[1] G. Žerovnik et al., *Observables of interest for the characterisation of Spent Nuclear Fuel*, EUR 29301 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-90347-2, doi 10.2760/418524, PUBSY No JRC112361.
[2] A. Stankovskiy, G. Van den Eynde, and L. Fiorito, *ALEPH A Monte Carlo Depletion Code - Version 2.9*. SCK CEN, Mol, Belgium, 2022.
[3] J. Leppänen, M. Pusa, T. Viitanen, V. Valtavirta, and T. Kaltiaisenaho, The Serpent Monte Carlo code: Status, development and applications in 2013," *Annals of Nuclear Energy*, vol. 82, pp. 142-150, 2015. Available: https://doi.org/10.1016/j.anucene.2014.08.024
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