Annals of Nuclear Energy 117 (2018) 155–164

Contents lists available at ScienceDirect

Annals of Nuclear Energy

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

Comparison of HELIOS-2.1 and SCALE-6.1 codes on pin-cell model

Sabina Maharramova [a,b,*], William Beere [c], Knut Eitrheim [c], Ole Reistad [d], Tord Walderhaug [c]

[a] Department of Physics, University of Oslo, P.O. Box 1048 Blindern, 0316 Oslo, Norway
[b] National Nuclear Research Centre, Insaatchilar Ave. 4, AZ 1143 Baku, Azerbaijan
[c] Institute for Energy Technology, P.O. Box 173, 1751 Halden, Norway
[d] Institute for Energy Technology, P.O. Box 40, 2027 Kjeller, Norway

ARTICLE INFO

Article history:
Received 2 October 2017
Received in revised form 15 March 2018
Accepted 16 March 2018
Available online 23 March 2018

Keywords:
HELIOS-2.1
SCALE-6.1
LWR
HWR
Pin-cell model

ABSTRACT

Deterministic HELIOS-2.1 and SCALE-6.1 codes are compared using pin-cell models for light water reactor (LWR) and heavy water reactor (HWR) cases. The main objective of this study is to identify the origins of any discrepancies between compared codes. The infinite multiplication factor k_{inf}, flux distribution, absorption, fission, production reaction rates, and burn-up dependent concentrations of major fuel isotopes, are investigated herein and compared.

Comparison of k_{inf} has shown that the codes are in good agreement for both the LWR and HWR cases. The codes showed differences in the isotope number density of up to 6% in the case of prominent isotopes, and for ^{235}U and ^{239}Pu at 60 GWd/tU in the LWR case. These differences were, approximately 20% for ^{235}U and 30% for ^{239}Pu in the HWR case.

It is concluded that these discrepancies are attributed to differences in the modelling of the thermalisation process in the HWR case. This needs to be investigated further to determine the root cause. Possible causes could be the neutron group structure, cross section condensation, treatment of upscatter, angle dependence of scatter, and spatial homogenisation during source iterations.

1. Introduction

Many reactor simulation and modelling codes have been developed to predict fuel depletion during the nuclear fuel cycle since the operation of the first reactors. These codes are very important for safe and efficient operation of research reactors and power plants. Multiple benchmark studies have been conducted to assess the accuracy of the depletion codes used to predict the isotopic composition of the spent fuel (Brady, 1992; Brady et al., 1996).

The main objective of this study is the determination of the isotopic distribution of selected actinides at high burn-ups, up to 60 GWd/tU. A secondary purpose is to compare the HELIOS-2.1 and SCALE-6.1 codes, in order to identify systematic differences between these two deterministic codes, and to validate the SCALE/TRITON code for the building the specific cross section libraries for use in the Halden boiling water reactor (HBWR).

This comparison has been made with single fuel region models. The infinite multiplication factor k_{inf}, flux distribution, reaction rates and burn-up dependent concentrations of major fuel isotopes were calculated and compared in this study in order to validate the SCALE code (using the TRITON module) for future use with the Halden reactor.

HELIOS and SCALE codes have also been benchmarked and applied by previous investigators (Brady et al., 1996; OECD/NEA, 2000). HELIOS-1.4 and SCALE-4.4 codes were used on the VENUS-2 MOX (a blind) benchmark study (OECD/NEA, 2000). Contrary to previous benchmarks, this benchmark was based on experimental results. The main objective of the benchmark was to validate and compare the nuclear data sets and codes used for MOX fuel modelling in accordance to the NEA member states. Ten institutions participated in the assessment of this benchmark, and deterministic (HELIOS, WIMS-D and SCALE/XSDRNPM) and Monte Carlo (MCNP-4B, MVP and MCU-B) methods were applied. Furthermore, k_{inf} and reaction rates from the cell calculations and k_{eff} and pin power (fission rate) from the core calculations were investigated and compared with the experimental values. Most of elicited results from the deterministic codes showed that the deviation of k_{inf} from the average values was approximately 0.5%, while Monte Carlo based codes yielded results with a deviation that was less than 0.2%. All reported k_{eff} values showed good agreement with the experimental value. The uncertainty in the experimental determination of this value was 0.5%. The calculated pin power results

* Corresponding author at: Department of Physics, University of Oslo, P.O. Box 1048 Blindern, 0316 Oslo, Norway.
E-mail address: s.a.maharramova@fys.uio.no (S. Maharramova).

https://doi.org/10.1016/j.anucene.2018.03.026
0306-4549/

from both the deterministic and Monte Carlo methods showed excellent agreement with the experimental values.

In another study, the HELIOS-1.5 and SCALE-4.4a codes were compared for nuclide inventory calculations of spent fuel from VVER-1000 in Kozloduy NPP, Bulgaria (Kamenov and Hristov, 2007). Calculated data from SCALE-4.4a was compared with fuel supplier data and with data calculated by using the HELIOS-1.5 code. In addition to the standard 17 × 17 ORIGEN-S libraries, a specific library for VVER fuel was developed for the Kozloduy NPP and was verified against the standard 17 × 17 library and HELIOS-1.5 calculated data. According to this study, it was concluded that ORIGEN-S can provide reliable isotope concentration estimations, if a specific library is used for each fuel type.

A study was performed at the Los Alamos National Laboratory to explore the accuracy of reactor analysis codes (HELIOS-1.4, ORIGEN2 and Monteburns-3.01) in calculating ^{241}Am and ^{243}Am concentrations in spent fuel from light water reactors (PWR, BWR, VVER) (Charlton, 2000). Calculated concentrations were compared to measured values from the literature for PWR fuel from Mihama Unit 3, Garigliano BWR fuel and VVER-440 fuel. It was determined that all codes performed well for the Mihama Unit 3 and Garigliano measurements, while HELIOS and Monteburns codes both demonstrated good ability to calculate these isotopes for VVER fuel. However, ORIGEN2 was insufficient for VVER-440 measurements.

This study is organised as follows: the HELIOS-2.1 and SCALE-6.1 codes are briefly described in Section 2. Section 3 presents the pin-cell model. The results from the HELIOS and SCALE code comparisons and the relevant discussion are presented in Section 4. Finally, Section 5 concludes the study.

2. Code descriptions

HELIOS-2.1 and SCALE-6.1 versions were used to perform depletion calculations in this study. Depletion calculations were modelled using 0.1 GWd/tU steps within the range of 0 to 0.5 GWd/tU, and 1 GWd/tU steps within the range of 0.5 to 60 GWd/tU for both HELIOS-2.1 and SCALE-6.1. As described below, the calculations were performed by using the same data library (ENDF/B-VII.0), but different neutron energy group structures. HELIOS-2.1 used the 177-energy-group, while SCALE-6.1 used the 238-energy-group.

2.1. HELIOS-2.1

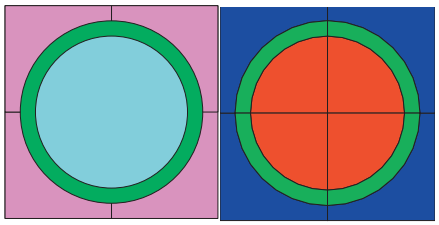
HELIOS-2.1. is a deterministic neutron and gamma transport code designed by Studsvik Scandpower to perform nuclear fuel analyses (Studsvik, 2012). HELIOS-2.1 is capable of analysing nuclear fuel designs for different types of nuclear power plants and experimental reactors.

The HELIOS-2.1 code comes with default nuclear data libraries, which are based on ENDF/B-VII.0 data files and are available in several group structures ranging from the 49–177 neutron energy groups (Chadwick et al., 2006). The base nuclear data library uses the 177 neutron and the 48 photon energy groups. The library contains neutron data for 360 isotopes, including 178 fission products and 95 resonance isotopes. The photon cross section data is available for 356 isotopes. Previous HELIOS versions (older than HELIOS-2.0) were available in two different sets of libraries, that is, the libraries in which the ^{238}U absorption cross section has been adjusted (reduced) by 3.4% and in unadjusted libraries. The adjusted libraries were added to yield better agreement for ^{238}U in LWR.

The main cross section processing was performed with the NJOY code (MacFarlane and Kahler, 2010). In this study, the current coupling and collision probabilities (CCCP) method is used for transport calculations. HELIOS-2.1 uses an intermediate resonance approximation (IR method) for homogeneous systems and the subgroup method for heterogeneous systems for resonance treatments.

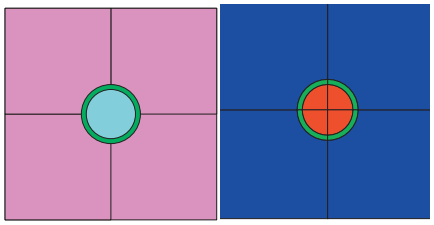
Table 1
Pin-cell specifications.

Parameter	LWR	HWR
Pin pitch radius (cm)	1.4	4.3
Fuel pellet radius (cm)	0.5	0.5
Fuel pellet material	UO_2	UO_2
Fuel density (g/cm^3)	10.96	10.96
Fuel enrichment (w/o)	6.0	6.0
Fuel temperature (K)	300	300
Cladding radius (cm)	0.6	0.6
Cladding material	Zr-2	Zr-2
Cladding density (g/cm^3)	8.4	8.4
Moderator material	H_2O	D_2O
Moderator density (g/cm^3)	0.75	1.1
Power (W/g)	40	40



a. HELIOS model b. SCALE/TRITON model

Fig. 1. LWR pin-cell models.



a. HELIOS model b. SCALE/TRITON model

Fig. 2. HWR pin-cell models.

Table 2
Figures colour key.

Regions	HELIOS-2.1	SCALE-6.1
Fuel	Light blue	Red
Clad	Dark green	Light green
Moderator	Pink	Dark blue

Table 3
Comparison of k_{inf} estimated using HELIOS-2.1 and HELIOS-1.4 (VENUS-2).

Method	Library	UO_2 3.3%	UO_2 4.0%	MOX
HELIOS-1.4 (190 g)	ENDF/B-VI.1	1.4084	1.3433	1.2625
HELIOS-2.1 (177 g)	ENDF/B-VII.0	1.4094	1.3432	1.2651
*Difference (%)		0.071	−0.007	0.206

* (HELIOS-2.1/HELIOS-1.4-1) × 100.