CAMIVVER

Codes And Methods Improvements

for VVER comprehensive safety assessment

Grant Agreement Number: 945081

Start date: 01/09/2020 - Duration: 36 Months

WP5 - Task 5.1

D5.2 – Description of the core reference test cases – Part1 + Part 2

Gianfranco HUACCHO, Luigi MERCATALI (KIT)

Barbara CALGARO, Barbara VEZZONI (Framatome)

Version 1 – 30/8/2023

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945081.

CAMIVVER – Grant Agreement Number: 945081

Document title	**Description of the core reference test cases – Part1 + Part 2**
Author(s)	Gianfranco HUACCHO, Luigi MERCATALI, Barbara CALGARO, Barbara VEZZONI
Document type	Deliverable
Work Package	WP5
Document number	D5.2 - version 1
Issued by	KIT
Date of completion	30/8/2023
Dissemination level	Public

Summary

In the framework of the H2020 CAMIVVER project, Work Package 5 (WP5) focuses on core calculations and provides coupled neutronics with thermal-hydraulics best estimate solutions for VVER and PWR reactors. The cases to be analyzed in WP5 are specified in D5.1 [1], and this document provides an update of the data needed for carrying out Task 5.2 and Task 5.3.

Additionally, this document provides the core neutronic specifications for assessing Task 7.4 of WP7. In Task 7.4, a Main Steam Line Break (MSLB) transient scenario is analyzed using system plant codes. Readers are referred to D7.4 [2] for a complete description of the scenario. Only core neutronic aspects are specified in this document. The core case selected is a simplified model corresponding to the Kozloduy NPP Unit 6 at cycle 1 with fresh fuel assemblies.

The results obtained from WP5 and WP7 will be used as a starting point for future industrial-level discussions of tools and methodologies to be adopted for VVER cases, and at the same time, they will indicate the status of available best-estimate coupled calculations in support to V&V of industrial approaches compatible with evolving safety regulations for both types of systems (VVER and PWR) [3].

Approval

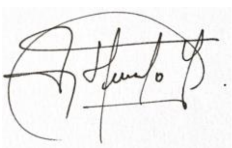
Version	First Author	WP leader	Project Coordinator
1	G. HUACCHO (KIT)	L. MERCATALI (KIT)	D. VERRIER (Framatome)
			

Table of contents

List of Figures

List of Tables

1 INTRODUCTION

In the H2020 CAMIVVER project framework, Work Package 5 (WP5) analyzes and provides coupled neutronics with thermal-hydraulics solutions for VVER and PWR reactors focusing on small core configurations mainly. Task 5.1 provides the reference cases to be investigated in WP5, where two minicores are defined based on VVER and PWR reactors. These are the 7FAs VVER and the 32 FAs PWR. D5.1 [1] provides a very detailed description of the two selected minicores and the transient scenarios to be investigated in Task 5.2 and Task 5.3. During the work progress in WP5, some discrepancies with the data indicated in D4.3 [4] and limitations of the tools to evaluate the transient problem have been identified, and this document provides additional information to assess WP5 objectives. Additionally, this document provides the neutronic core definition for Task 7.4 in WP7, where a Main Steam Line Break (MSLB) transient scenario will be performed using plant system tools. This core description belongs to the Kozloduy NPP Unit 6 at cycle 1 with fresh fuel assemblies.

2 WP5: MINICORES

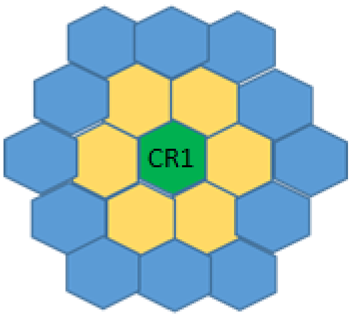
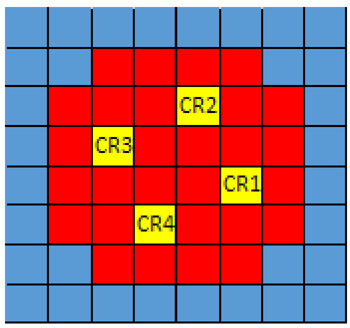
2.1 Initial steady-state conditions

Table 22 in D5.1 [1] provides the initial steady-state conditions for the transient analysis in the two minicore cases. For the 7FA VVER case, two parameters, the boron concentration and the initial control rod position are free to evaluate and fix the initial critical condition before the transient scenario. For the 32 FAs PWR case, control rod one (CR1) is completely inserted, and only boron concentration is free to adjust the initial critical condition. The Scenario 1 description (Section 4.2.1 in D5.1 [1]) details how these remaining parameters can be deduced. Table 1 shows the initial critical conditions deduced by KIT using SERPENT2/SUBCHANFLOW coupled tool[1]. Table 2 shows additional condensed data for bundle-base thermal-hydraulic models.

Table 1. Initial critical steady-state parameters.

Parameter	**7FAs VVER**	**32FAs PWR**
Boron concentration (ppm)	403	2791
Control rod position	65.7 % extracted	Completely inserted
Control rod composition	B_4C	*AIC*

Table 2. Condensed thermal-hydraulic geometrical data.

Parameter	7FAs VVER	32FAs PWR
Core radial geometry		

[1] Particularly for the 7FAs VVER case, a warning is advised in using the data in Table 1 directly. The critical condition in Table 1 was deduced as guaranteeing a 1.2$ in reactivity insertion (steady-state calculations) as specified in [1], and this may be different for other tools, resulting in different transient behaviors.

Total core flow area (m2)	0.18	0.79
Total core cross sections area (m2)	0.34	1.48
Heated perimeter (m)	62.44	252.12
Wetted perimeter (m)	67.7	282.79

2.2 Kinetic data

Table 3 shows kinetic data information deduced by KIT using JEFF 3.1.1 nuclear data library. Values are deduced with SERPENT2/SUBCHANFLOW from critical steady-state calculations presented in Table 1 and adopted for the other codes in order to avoid further discrepancies.

Table 3. Kinetic data for the two selected minicores.

Minicore case	**7FAs VVER**		**32FAs PWR**	
Precursor family	$\boldsymbol{\beta_i}$ **(pcm)**	$\boldsymbol{\lambda_i}$ **(1/s)**	$\boldsymbol{\beta_i}$ **(pcm)**	$\boldsymbol{\lambda_i}$ **(1/s)**
1	22.9	0.0125	21.5	0.0125
2	109.4	0.0283	104.4	0.0283
3	65.9	0.0425	62.3	0.0425
4	143.6	0.1330	137.6	0.1330
5	244.8	0.2925	233.8	0.2925
6	81.1	0.6665	80.5	0.6665
7	67.7	1.6348	67.4	1.6348
8	25.4	3.5546	25.1	3.5546
Total (1 effective group)	**761**	**0.462**	**732**	**0.472**

2.3 Errata corrige

Some discrepancies have been identified and underlined below:

- Table 17 in D4.3 [4] specifies the material composition for the coolant in the VVER minicore, which is based on the Khmelnytsky-2 reactor. The table description indicates that boron concentration belongs to 600 ppm but corresponds to 800 ppm. To avoid inconsistencies, Table 4 presents the updated composition for the coolant with 600 ppm boron concentration.

Table 4. Updated water composition for the 7FAs VVER.

Minicore	**7FAs VVER**
Density (g/cm3)	**0.7526**
Elements	Atomic density (at /b cm)
H2O	2.51494E-02
B-10	4.97996E-06
B-11	2.01713E-05

- In Table 6 in D5.1 [1], there is a mistake in the active core height. A value of $150\ cm$ should be considered.
- On page 18 in D5.1 [1], there is a mistake in the fuel-clad constant gap conductivity. A value of $1e4\ W/m^2K$ should be considered.

3 WP7: CORE DEFINITION FOR TASK 7.4

Task 7.4 was proposed for testing the coupling and 3D capabilities of the current codes against a transient scenario of interest as the Main Steam Line Break (MSLB) [3]. In the past, this transient has been analyzed in an international benchmark using 1D models [5]. In the benchmark, a comparison was proposed against data coming from Kozloduy NPP Unit 6 (KZLD6) plant for cycle eight. The interest in moving to a 3D modeling and more advanced coupling has pushed the partners to choose a configuration that requires small effort on cross-section preparation and may allow reducing the sources of discrepancies due to burnup models. During the Task 7.4 meeting, it was decided to use the core data of the OECD/NEA MCP-Restart benchmark [6] but with fresh fuel composition. This choice is not affecting the interest in this first comparison proposed in the CAMIVVER project and open the discussion to next phases. The present document summarizes the neutronic data needed for the MSLB exercise proposed in Task 7.4 to use it as a common database.

3.1 Core specifications

The core layout is a hexagonal array of elements that comprises 163 hexagonal fuel assemblies (FA) with assembly pitch of 23.6 cm. Simplified 48 radial reflector assemblies with the same hexagonal shape as the FA surround the core. The active core height is 355 cm, and extra widths of 23.6 cm are considered for the bottom and top reflectors. FA with three different enrichments are present in the core leading to four different FA types as shown in Figure 1. Table 5 summarizes the characteristics of each FA type.

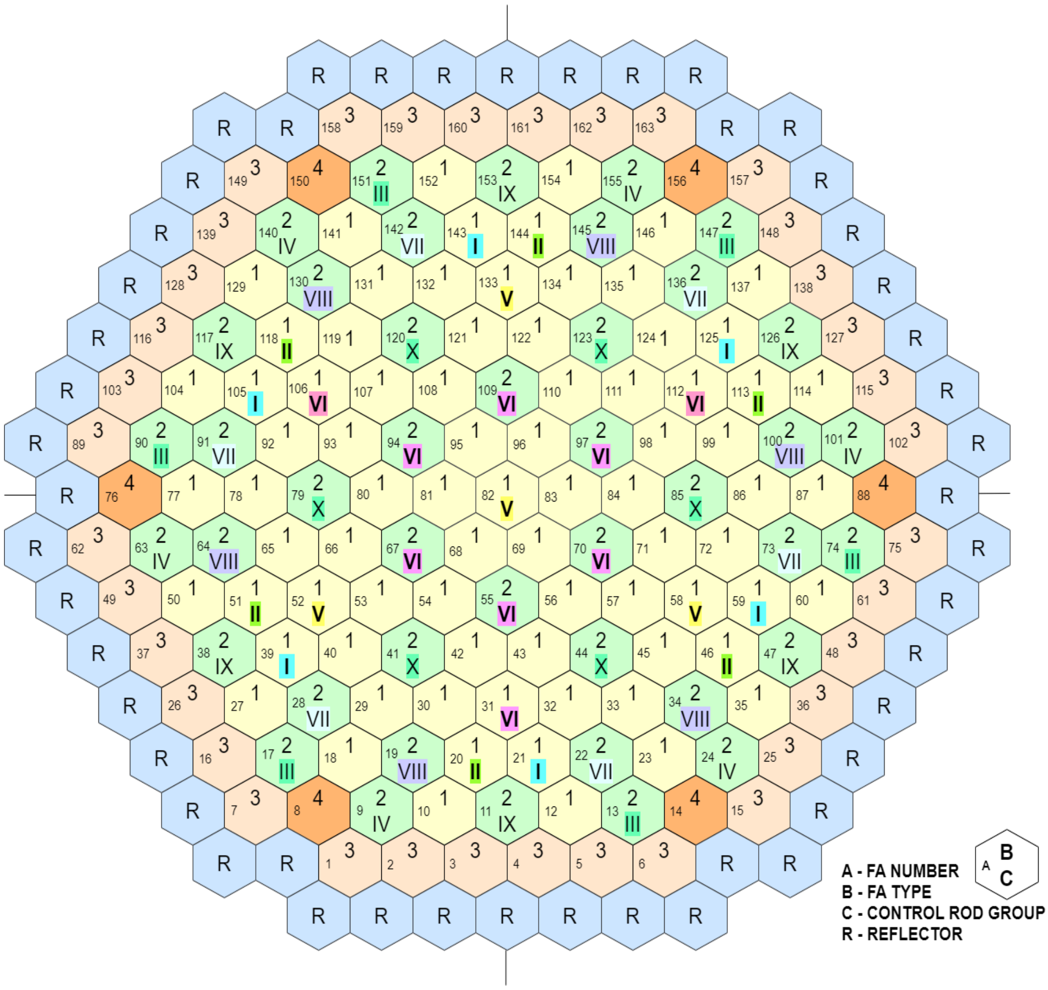


Figure 1. KZLD6 core layout.

Table 5. Fuel assembly types and data references.

Assembly Type	Enrichment	Geometry description	Material data composition
1 **FA2_F**	Homogeneous with UO_2 (2.0%^{235}U) Fuel Pins	Figure 1, and Tables 3 and 4, D4.3 [4]	Tables 7, 21, 22, 25, 26 and 28 in D4.3 [4]
2 **FA3_F**	Homogeneous with UO_2 (3.0%^{235}U) Fuel Pins	Figure 1, and Tables 3 and 4, D4.3 [4]	Tables 7, 21, 22, 25, 26 and 28 in D4.3 [4]
3 **FA3_3_F**	Homogeneous with UO_2 (3.3%^{235}U) Fuel Pins	Figure 1, and Tables 3 and 4, D4.3 [4]	Tables 7, 21, 22, 25, 26 and 28 in D4.3 [4]
4 **FA3_3_G**	Heterogeneous profiled FA with UO_2 (3.0% ^{235}U) and UO_2 (3.3% ^{235}U) Fuel Pins	Figure 6, and Tables 3 and 4, D4.3 [4]	Tables 7, 21, 22, 25, 26 and 28 in D4.3 [4]

For the reactivity control of the reactor core, control assemblies (CA) use B_4C as absorber material and are grouped and distributed within the core in 10 control rod banks, as illustrated in Figure 1. Only FA types 1 and 2 have associated control rods, and a description of the control rod banks is presented in Table 6. The total absorber height is 371 cm, inserted and extracted positions are illustrated in Figure 3.

Table 6. Control rod bank details [5], [4].

Control rod bank	Number of CA	Purpose	Associated FA type	Geometry and Material data
I	6	Safety	1	Table 4, 25, 26 and 28 in D4.3 [4]
II	6	Safety	1	
III	6	Safety	2	
IV	6	Safety	2	
V	4	Partial-length	1	
VI	9	Safety	1 and 2	
VII	6	Safety	2	
VIII	6	Safety	2	
IX	6	Safety	2	
X	6	Regulating	2	

Simple homogeneous reflector models define the radial and axial reflectors in Task 7.4. As mentioned, the core is surrounded by 48 reflector assemblies with the same FA shape. The top and bottom reflectors have 23.6 cm in height, as illustrated in Figure 2. The same material composition as the moderator at nominal conditions has been considered for this first exercises. Moving to more detail models is considered in the project follow-up. For the moderator, D4.3 [4] provides only nominal conditions such as density, temperature, and boron concentration, but the material composition is not available. Therefore, Table 7 provides data composition for the moderator at two different boron concentrations.

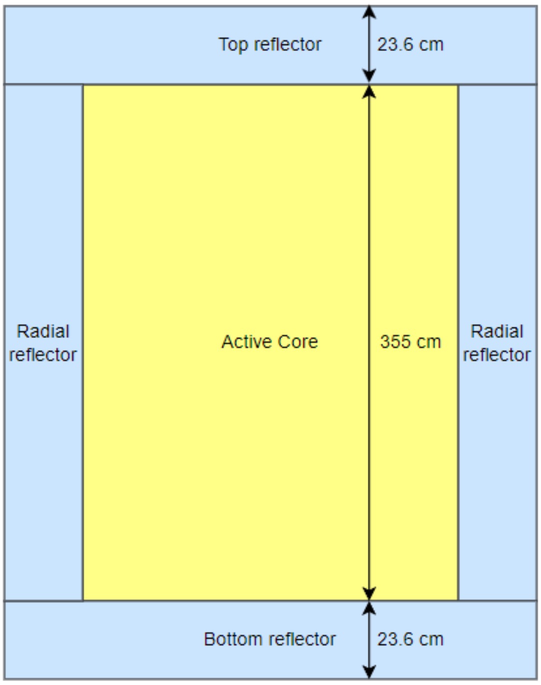


Figure 2. Axial reflector details.

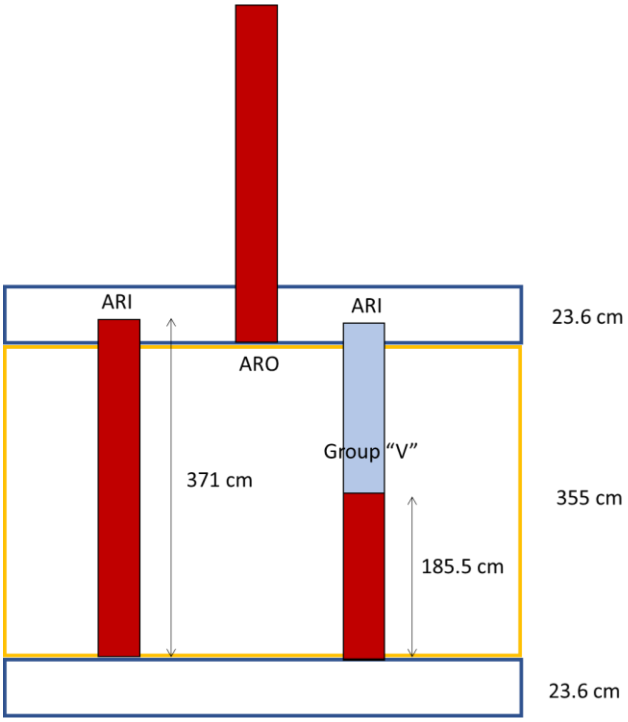


Figure 3. Control rod axial details [5].

Table 7. Moderator composition for KZLD6.

Density (g/cm3)	**0.725**	
Boron concentration (ppm)	**600**	**1200**
Elements	Atomic density (at /b cm)	
H2O	2.42271E-02	2.42125E-02
B-10	4.79733E-06	9.59450E-06
B-11	1.94316E-05	3.88626E-05

Data for spacer grids is provided in D4.3, and they may be modelled as an additional thickness of the fuel cladding, preserving alloy mass [4]. However, for Task 7.4, spacer grids will not be considered in the first approach to simplify the cross-sections generation process.

3.2 Nominal condition

The following core state is defined to make neutronic stand-alone comparisons previous to the MSLB transient problem. The state corresponds to a Hot Full Power (HFP) condition without poison absorbers (e.g., Xenon, Samarium) and with homogeneous and average values for temperatures and density. Table 8 presents a summary of the HFP state.

Table 8. HFP nominal condition [4].

Parameter	**HFP state**
Reactor thermal power (MW)	3000

Xenon, Samarium[2]	Null
Average fuel temperature (K)	900
Average coolant temperature (K)	574
Average coolant density (g/cm3)	0.725
Boron concentration (ppm)[3]	1200

3.3 Cross-sections branch considerations

Macroscopic cross sections dependent on the TH parameters are needed to cover all the states during the MSLB transient scenario. Initial variations points presented in [5] were taken into account, but as suggested in [7], the original wide fuel temperature range offered in [5] is not enough to cover all the TH states during the transient evolution. Therefore, Table 9 presents the TH variation points (including nominal condition points) for the branching during the cross-sections generation process.

Table 9. Variation points for branch XS generation.

Parameter	**Variation Points**
Coolant density (g/cm3)	0.1, 0.2, 0.3, 0.4, 0.5, 0.6, **0.725**, 0.8, 0.9
Boron concentration (ppm)	1, **1200**, 2000
Fuel temperature (K)	470, **900**, 1500
Coolant temperature (K)	470, **574**, 620

3.4 Initial steady-state conditions

The initial TH boundary conditions for the MSLB transient should be specified in D7.4 [2]. For the initial critical steady-state core, it is suggested to have the same control rod position presented in [5], and the critical core ($k_{eff} = 1$) can be achieved by iterating the boron concentration. Some preliminary results are presented in D5.4 and D7.4 deliverables.

Table 10. Conditions for the initial steady-state critical core.

Control rod banks 1 to 9	Totally extracted
Control rod bank 10	283.2 cm from the bottom of the core, or 306.8 cm from the bottom of the lower reflector
Boron concentration	Critical search

[2] Due to an agreement between the partners, it was decided to simplify the cross-sections generation process without considering poison absorbers.

[3] Due to model simplifications (e.g., Spacer Grids, Xe, Sm), an initial boron concentration of 1200 ppm is selected instead of 600 ppm.

4 References

[1] J. Blanco and B. Calgaro, “Description of the core reference test cases - Part 1,” CAMIVVER Deliverable 5.1, 2021.

[2] V. H. Sanchez, “Results of transient-2 MLSB benchmark,” CAMIVVER Deliverable 7.4, 2023.

[3] “Codes and Methods Improvement for VVER Comprehensive Safety Assesment,” CAMIVVER Project. Horizon 2020. Proposal number 945081..

[4] A. Willien and B. Vezzoni, “Definitions of tests cases for the verification phases of the multi-parametric library generator,” CAMIVVER Deliverable 4.3, 2021.

[5] N. Kolev, N. Petrov, J. Donov, D. Angelova, S. Aniel, E. Royer, B. Ivanov, K. Ivanov, E. Lukanov, Y. Dinkov, D. Povov and S. Nikonov, “VVER-1000 Coolant Transient Benchmark. Phase 2 (V1000CT-2) Vol. II: MSLB Problem - Final Specifications,” NEA/NSC/DOC(2006)6, 2006.

[6] B. Ivanov, K. Ivanov, P. Groudev, M. Pavlova and V. Hadjiev, “VVER-1000 Coolant Transient Benchmark - Phase 1 (V1000CT-1). Volume 1: Final Specifications (Revision 4).,” NEA/NSC/DOC(2002)6, 2004.

[7] N. Kolev, E. Royer, B. Ivanov, K. Ivanov and N. Petrov, “Comparative analysis of exercise 2 results of the OECD VVER-1000 MSLB benchmark,” in *16th Symposium of AER on VVER Reactor Physics and Safety*, Bratislava, Slovak Republic, 2006.