CAMIVVER

Codes And Methods Improvements for VVER comprehensive safety assessment

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

November 2022 | Newsletter no. 2

framatome | cea | INRNE | KIT Karlsruher Institut für Technologie | ENERGORISK | Università di Pisa | EDF

Message from the Project Coordinator

Denis VERRIER, Framatome – France
denis.verrier@framatome.com

Already a year has passed since the first edition of this newsletter. You will see that in this year much progress has been accomplished by the different work packages. The project is well underway, and our consortium is in time to carry out the latest tasks that will conclude the project. Among them the International Workshop will be an important appointment to present and share the progress of the project. More information at the end of this edition.

We wish you an interesting reading.

THE CAMIVVER GOALS ACHIEVED

- **Deliverables:** 14 deliverables emitted
- **Milestones:** 9 milestones achieved (such as the 1st version of the multi-library generator prototype, the 1st version of lattice calculation scheme and the definition of CFD models to be used)

THE CAMIVVER TASK LEADERS

WP3	WP4	WP5
A. Hashymov (LLC ENERGORISK)	*A. Brighenti (Framatome)*	*G. Huaccho (KIT)*
P. Groudev (INRNE)	*A. Willien (EDF)*	*B. Calgaro (Framatome)*
	J.-F. Vidal (CEA)	
	S. Santandrea (CEA)	
WP6	**WP7**	**WP8**
O. Bernard (Framatome)	*P. Groudev (INRNE)*	*L. Mercatali (KIT)*
M. Böttcher (KIT)	*O. Bernard (Framatome)*	*D. Verrier (Framatome)*
		B. Vezzoni (Framatome)

WORK PACKAGES HIGHLIGHTS

WP2 - Project Management

Denis VERRIER, Framatome – France
denis.verrier@framatome.com

The interim Periodic Reporting exercise has kept us busy during the first semester of 2022. The fifth meeting of the Executive Committee took place at the end of June still via web conference. We are finalizing the organization of the next one which, for the first time, will be held face-to-face in Framatome's premises in Paris on December 1st and 2nd. This sixth meeting will be the opportunity to measure work progression and to discuss further works after CAMIVVER.

WP3: VVER Data Collection

Prof. Pavlin Petkov GROUDEV, INRNE – Bulgaria
pavlinpg@inrne.bas.bg

WP3 "Establishment of a common VVER database for codes verification and validation" is dedicated to establishing a common and shared database for VVER comprehensive safety assessment codes and methods verification and validation. WP3 intends to prepare requested input data for fulfillment the objectives described in other technical WPs. To achieve this, the WP3 is organized in three sub tasks:

- Within **Task 3.1** "Analysis and classification of available VVER data for verification and validation of neutronics and thermal-hydraulics codes", Deliverable D3.1, issued on April 2021, has been developed by Energorisk and INRNE-BAS to provide an overview of the main VVER experimental and benchmark data available to the International Community (IAEA, OECD/NEA, past European projects, publications, etc.) for verification and validation of neutronics and thermal-hydraulics codes. The information on past experiences on VVER safety analysis, relevant to the project, has been summarized to give general information for VVER reactors.

- Within **Task 3.2** "Establishment of a common database to describe primary and secondary circuits geometry", a Definition report with specification for NPP with VVER-1000 reactor with respect to selected transients (Deliverable 3.2, issued on July 2021) has been developed by INRNE-BAS to provide requested input data for fulfillment the objectives described in the WP6 and WP7, as well as neutronics specifications to be used in WP4 and WP5. The following design data for VVER-1000 were collected and included in the definition report with respect to expected nuclear power plant transients which will be simulated:

  - ✓ Description of the nuclear power plant systems, equipment and plant state information (initial and boundary conditions);
  - ✓ Steady state data before initiating transient;
  - ✓ Nuclear fuel, geometric, thermal-hydraulic, neutronics, effective day of operation and technological data;
  - ✓ Drawing of major primary and secondary systems;
  - ✓ Safety and regulating systems involved in simulation of transients.

- Within **Task 3.3** "SB LOCA specification + SG line break specification" a Definition report of SB LOCA + SG tubing break benchmark (Deliverable 3.3 issued on August 2021) has been developed by INRNE-BAS. The main objectives of this report are to prepare a plant specific scenario for the VVER-1000 and to provide information on all equipment and systems expected to be initiated during the progression of the selected accident including operator actions if they are assumed based on existing emergency operating procedures.

WP4: Lattice Neutronics Calculations
Dr. Pietro MOSCA, CEA – France
pietro.mosca@cea.fr

In the framework of the H2020 CAMIVVER project, the activities within Work Package 4 (WP4) aim at using the capabilities of the APOLLO3® code to generate multi-parameter neutron data libraries for Gen II and III LWR (VVER and PWR) reactors. The activities in 2022 were focused on:

➢ The development of first prototype of the multi-parametrer neutron data library generator, called NEMESI and based on APOLLO3® (see Figure. 1), in the context of the Task4.1 "*VVER multi-parametric neutron data libraries generation*". Task 4.1 covers all the activities of requirements specification and the development of the multi-parameter neutron data library prototype for industrial applications.. An extended abstract has been submitted to the M&C 2023 conference (A. Brighenti et al., "Development of a multi-parameter library generator prototype for VVER and PWR applications based on APOLLO3"). NEMESI represents an opportunity to analyze the possibility towards an industrialization of the APOLLO3® code;

➢ The development of a tool for the comparison between APOLLO2, APOLLO3®, SERPENT and TRIPOLI-4® simulation results in the context of the Task 4.2 "*Verification of the consistency of the prototype libraries generator based on APOLLO3".* As a reminder this task joins all the work of result comparisons between NEMESI, the industrial neutron data library generator based on APOLLO2 (validated on PWR configurations) and reference stochastic codes, namely SERPENT and TRIPOLI-4®, for PWR et VVER configurations;

➢ The optimization of the neutron scheme to apply for the generation of the VVER multi-parameter libraries in the context of Task 4.3 "*Investigation of possible VVER assembly calculation schemes".* This task investigates and proposes options to optimize the calculation time without altering the accuracy of the results. Figure 2 shows an example of spatial mesh optimization for self-shielding and flux calculations considering 1/6th of VVER assembly.

➢ The impact of the type of radial reflector modeling considering light and heavy reflector (e.g. Figure 3 left) and the validation with respect TRIPOLI-4® of 3D assembly-models for the treatment of the axial reflector (e.g. Figure 3 right) in the context of Task 4.4 "*Evolution of libraries generation by using new advanced 2D and 3D models*".

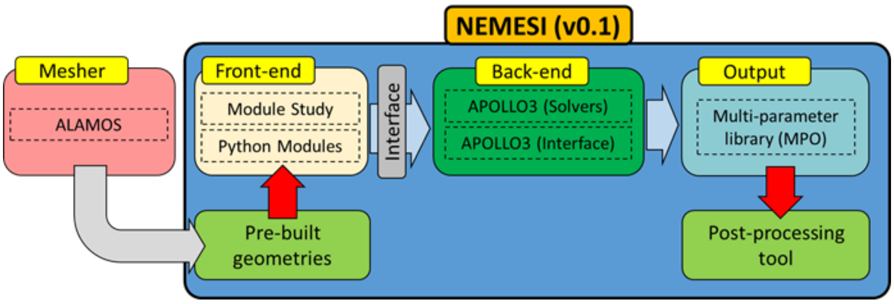
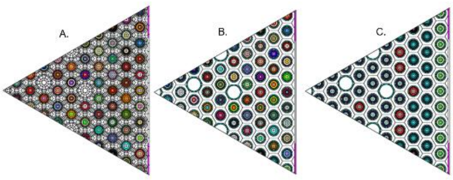


Figure 1: Sketch of NEMESI components



	Case 1 (ref.) (A)	Case 2 (C)	Case 3 (B+A)	Case 4 (C+A)
Kinf t0/ Δρ	1.27396	1.27286 / -68 pcm	1.27386 / -6 pcm	1.27386 / -6 pcm
max Δρ over depletion	-	+179 pcm (10.5 GWd/t)	+12 pcm (60 GWd/t)	+11 pcm (60 GWd/t)
Time in self-shielding	16'	4'	4'	40s
Time in transport calc.	2'30s	1'30s	2'30s	2'30s
Total	18'30s	5'30s	6'30s	3'10s

Figure 2: APOLLO3 calculation optimization on a VVER assembly

Figure 3: Radial (left) and axial (right) reflector benchmark configurations

WP5: Core Neutronics/TH Calculations

Dr. Luigi MERCATALI, KIT – Germany
luigi.mercatali@kit.edu

In the framework of the H2020 CAMIVVER project, the activities within Work Package 5 (WP5) are aiming to investigate and develop neutronics/thermal-hydraulics coupling calculation schemes at the core level and the corresponding outome is expected to serve as starting point for future discussions at the industrial level on tools and methods to be adopted in order to cope with the continuous improvement in the nuclear industry safety standards and reactor designers' and operators' goals. In particular, two main approaches are adopted within the project for the multiphysics solutions: i) the APOLLO3®/THEDI in order to investigate the multi-1D thermal-hydraulic feedback model available in the THEDI internal thermal-hydraulic solver of APOLLO3® able to treat single- and two-phase conditions and ii) the newly developed proof-of-concept of the APOLLO3®/CATHARE3 coupling for cartesian geometries which takes advantage of the 3D capabilities of the CATHARE3 thermal-hydraulic code. The solutions obtained by these approaches are also going to be compared against "reference" high-fidelity Monte Carlo based solutions obtained at KIT using a coupling scheme between the SERPENT2 Monte Carlo neutron transport code and the sub-channel thermal-hydraulic code SUBCHANFLOW (SCF). This recently developed state-of-the-art high-fidelity coupling allows performing pin-by-pin transient analysis for both PWR and VVER core configurations. For the verification of the multiphysics schemes developed within WP5, two different simplified test cases are under consideration representative of both cartesian and hexagonal configurations. These two test cases include a 32 PWR-based fuel assemblies (FAs) minicore and a 7 FAs heterogeneous minicore based on the VVER Khmelnytsky-2 benchmark specifications (Figure 4).

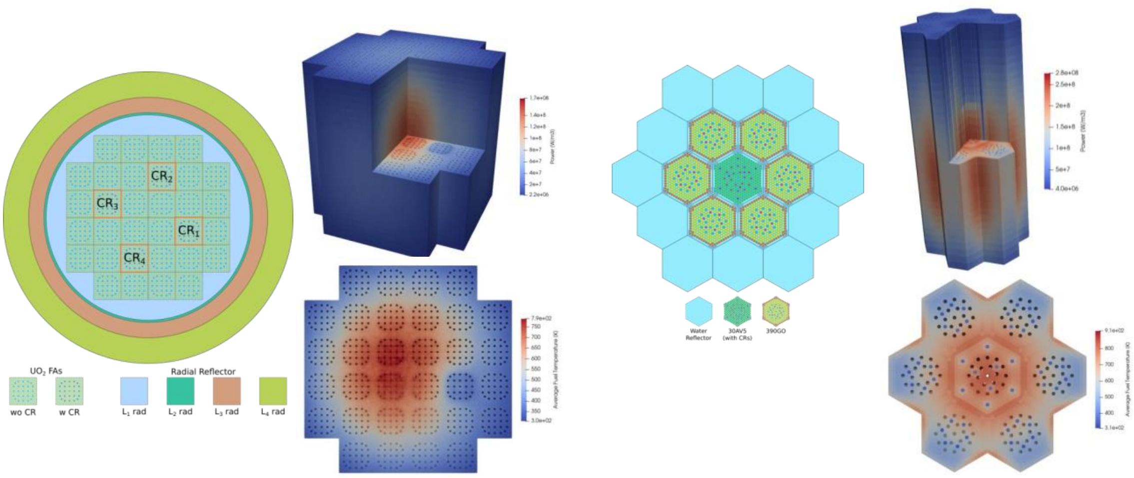


Figure 4: VVER (right) and PWR (left) benchmark configurations

Based on these two minicores, a transient scenario has been defined, consisting in a control rod ejection followed by the increase of the system reactivity and power (Figure 5) with rapid increase of the fuel temperature. The reactivity insertion is mitigated by the feedbacks (mainly Doppler effect) and is followed by a power excursion that depends on the initial core conditions (axial offset, Xe content, boron and temperatures distributions, etc.) and on the type of transient (reactivity inserted, ρ< βeff; ρ≥ βeff).

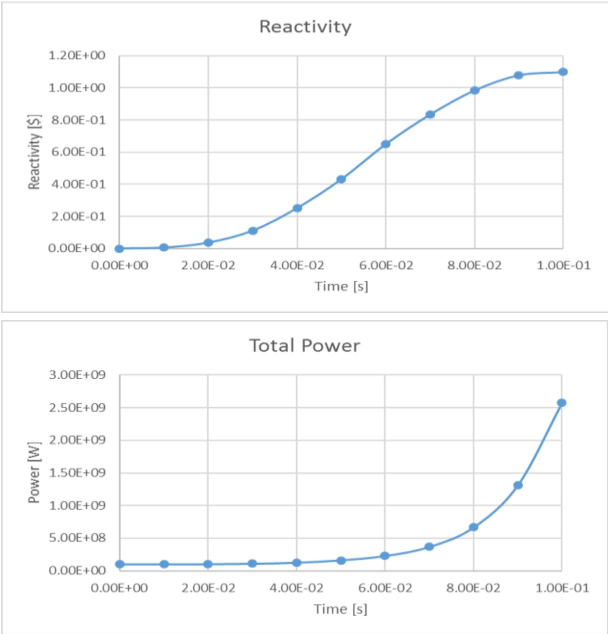


Figure 5: System reactivity and power increase following the RIA transient

WP6: VVER CFD analyses

Mr. Olivier BERNARD, Framatome – France
olivier.bernard1@framatome.com

WP6 objective is to improve and validate CFD modelling of the mixing inside VVER primary vessel. CFD models will include the primary vessel from cold legs to hot legs nozzles. The core-outlet temperature-field is the main output to be analysed. WP6 is organized in the 3 tasks:

- Task 6.1 dedicated to the development of VVER-vessel CFD model. A common geometry CAD file has been built and shared among partners. A first benchmark is being performed on normal-operation steady-state configuration to check the consistency of partners models (example of temperature fields in figure 6). D6.1 has been delivered on February 2022.

- Task 6.2 dedicated to the demonstration and validation of CFD models ability to evaluate the mixing in the vessel in case of unsymmetrical feeding, based on Kozloduy-6 mixing experiment. CFD models have proved to be able to simulate VVER-vessel mixing. CFD models developed by partners have proved to give consistent results despite the use of different codes and different methods. D6.2 is to be delivered in November 2022.

- Task 6.3 dedicated to the propagation of input-data uncertainties through these CFD models. Deterministic sampling method has been used to define a set of approximately 100 CFD calculations that are to be performed by partners altogether by June 2023.

Participants	CFD code
FRAMATOME	STAR-CCM+
UNIPI	STAR-CCM+
KIT	CFX
ENERGORISK	FLUENT
CEA	TRIO-CFD

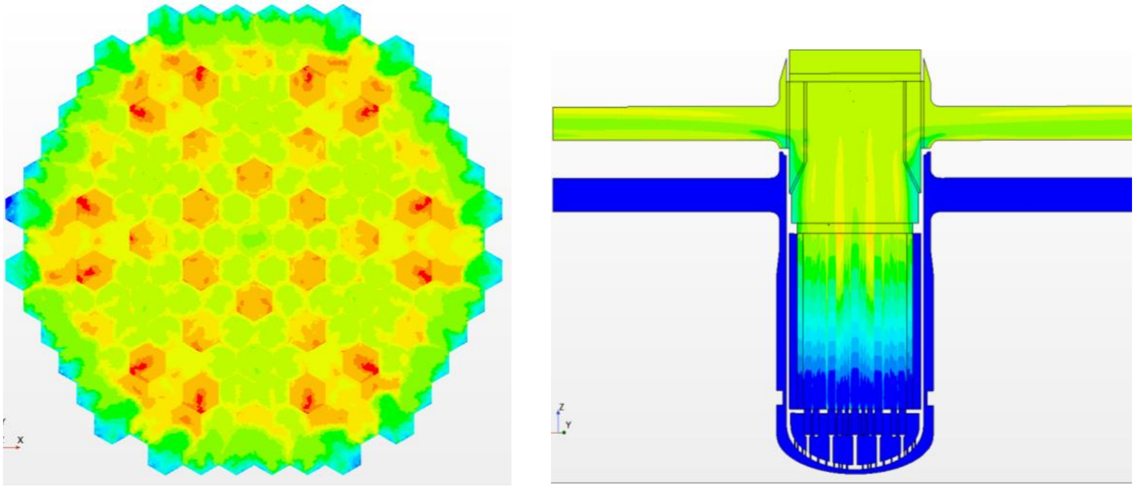


Figure 6: Temperature field at core outlet (left) and in the vessel (right)

WP7: VVER System Calculations

Artur HASHYMOV, LLC ENERGORISK - Ukraine
arturgm@ukr.net

WP7 objectives are to improve thermal-hydraulics modelling of VVER plant, especially implement 3D modelling of VVER system with 3D modules available in thermal-hydraulics code.

As part of the WP7 implementation, Task 7.1 "Development of thermal-hydraulics-code models of VVER primary and secondary circuits; Perform steady-state benchmark to check model's consistency" and 7.2 "Simulation of Kozloduy-6 Main Coolant Pump start-up transient" has been completed. When performing Task 7.1, based on the prepared set of initial data for the Kozloduy-6 Power Unit (WP 3), models of the VVER-1000 were developed. The models were developed using computer codes:

- RELAP5 – INRNE, Energorisk.
- TRACE – KIT, and
- CATHARE3 – Framatome.

When performing task 7.2, the MCP start-up simulation was performed and the results were compared. The results showed a coincidence with acceptable accuracy of the main parameters of the reactor plant by the nature and magnitude of the change. The simulation confirms the possibility of using the computer codes used to analyse the safety of VVER reactor installations in terms of thermohydraulic processes and assess their impact on the main characteristics of the core.

Currently, the implementation of stages 7.3 and 7.4 is continuing. The transients modeled at these stages reproduce active processes in the first and second circuits of the reactor plant, including dynamic changes in the heat flow between the circuits. It is expected that a comparison of the simulation results performed using various computer codes of the participants will allow us to assess the impact of the calculation procedures of each code on the possibility and accuracy of modeling VVER reactors.

During the year, two meetings were held at which the progress of detailed modeling of the spatial distribution of the core parameters (within the framework of the WP5 task) was discussed. The resulting calculated distribution of parameters will be used for detailed modeling in WPs 7.3 and 7.4.

During the last year, the participant in Task 7.4 agreed to focus on BOL KZL-6 core. This allows to suppress source of discrepancies related to burn-up treatment and to reduce the effort on XS preparation for High Fidelity Monte Carlo solutions. The conditions for the benchmark over the MSLB transient have been then updated.

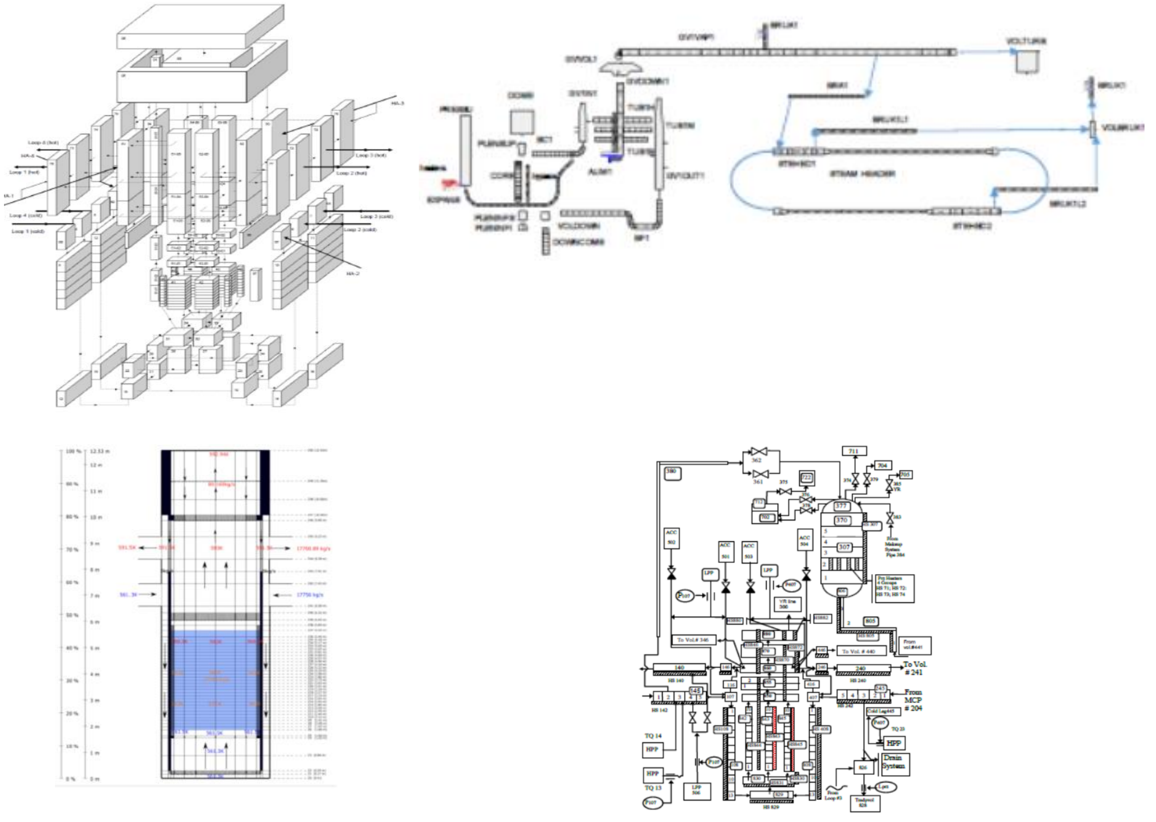


Figure 7: RELAP5/Mod3.2, CATHARE3, RELAP5/Mod3.3 and TRACE models (Clockwise)

WP8: Communication, Dissemination, Educational and Training

Prof. Nicola Forgione, University of Pisa - Italy
nicola.forgione@unipi.it

The Dissemination, Communication and Exploitation (DC&E) strategy plan has been developed within Task 8.1 “Development of the CAMIVVER dissemination and exploitation plan” by Framatome and UNIPI.

The CAMIVVER DC&E strategy plan includes:

- ✓ A detailed planning of all communication actions, their goals and timing;
- ✓ Key messages and defined target audiences;
- ✓ An event and publications management plan;
- ✓ Identification of DC&E key performance indicators for the goals to be reached, as the number of international journal papers, the number of website views or the engagement on social media.

A series of communication actions have been implemented following the DC&E. The intermediate report has been issued. The communications tools have been kept updated with the project information.

One of the main occasions for the future dissemination of the CAMIVVER results will be the final **CAMIVVER Workshop that will be held at Karlsruhe Institute of Technology from 3 to 5 July 2023**, where a series of presentations related to CAMIVVER activities, performed in the different Work Packages, will be shown to the Scientific Community. The Workshop is free of charge and is open to a wide audience (research institutions, academia, industries, operators, regulatory bodies) and, to increase the number of participants, it will be arranged both in presence and online.

The details of the Workshop (Technical Program, Venue Information, etc.) will be made available soon via the **public website** and the **LinkedIn account**.

RECENT AND UPCOMING INTERNATIONAL EVENTS

- **VVER2022 - 8th International Conference**
10-11 October 2022, Řež, Czech Republic. www.vver2022.com
- **CONTE 2023 - Conference on Nuclear Training and Education)**
06 Feb 2023 - 09 Feb 2023, Amelia Island, FL, United States.
https://www.ans.org/meetings/conte23
- **COURSE: Decommissioning of Nuclear Installations**
27 Feb - 3 Mar, Mol, Belgium. More information
- **ICAPP2023 - The International Congress on Advances in Nuclear Power Plants**
23-27 April 2023, Geyongju, Korea. www.icapp2023.org
- **M&C 2023 - International Conference on Mathematics and Computational Methods Applied to Nuclear Science and Engineering**
13-17 August 2023, Niagara Falls, Canada. https://mc2023.com
- **NURETH-20 - International Topical Meeting on Nuclear Reactor Thermal Hydraulics**
20-25 August 2023, Washington, DC, USA. www.ans.org/meetings/nureth20
- **NURER 2024 - 7th International Conference on Nuclear and Renewable Energy Resources**
25-29 May 2024, Ankara, Turkey. www.nurer2020.org/en

PUBLICATIONS CONCERNING CAMIVVER PROJECT

- D. Verrier et al., “Codes and Methods Improvements for VVER Comprehensive Safety Assessment: The Camivver H2020 Project”, Proceedings of the 2021 28th International Conference on Nuclear Engineering (ICONE28), August 4-6, 2021, Virtual, Online.
- O. Halim, A. Pucciarelli & N. Forgione. " CFD Simulation of a VVER-1000/320 at Nominal Operating Conditions", NENE2022 31th International Conference Nuclear Energy for New Europe, 12-15 September, Portorož, Slovenia.
- A. Cagnac, D. Verrier, V. Pištora, Codes and Methods Improvements for Safety Assessment and LTO: Varied Approaches, 10th Edition of Euratom Conferences on Reactor Safety (FISA 2022) and Radioactive Waste Management (EURADWASTE’22), 30 May – 3 June 2022 in Lyon, France.
- D. Verrier et al., “The CAMIVVER Project for Codes And Methods Improvements For VVER”, VVER-2022, 10-11 October 2022, Řež, Czech Republic.
- B. Vezzoni et al., “Advanced Simulations and Multi-physics lattice and core modeling for VVER applications”, VVER-2022, 10-11 October 2022, Řež, Czech Republic.
- P. Petkov Groudev et al., “Validation of a VVER 1000 TRACE Model”, Comptes rendus de l'Académie bulgare des Sciences, Tome 75, no. 5, pp. 655-662, 2022.
- B. Calgaro & B. Vezzoni, “Advanced Couplings and Multiphysics Sensitivity Analysis Supporting the Operation and the Design of Existing and Innovative Reactors”, Energies 2022, 15(9), 3341; https://doi.org/10.3390/en15093341.
- A. Brighenti et al., “Development of a multi-parameter library generator prototype for VVER and PWR applications based on APOLLO3” submitted for M&C2023 Conference.
- L. Mercatali et al., “Advanced Multiphysics Modeling for PWR and VVER Applications”, submitted for ICAPP2023 Conference.
- A. Gammicchia et al., “Cross sections polynomial axial expansion within APOLLO3® 3D characterisics method”, Annals of Nuclear Energy, Volume 165.

Feel free to forward this Newsletter to friends that can be interested to be informed about CAMIVVER Project.

If you no longer wish to receive Newsletters from EU-CAMIVVER Project, please send an email to denis.verrier@framatome.com with subject “Unsubscribe from CAMIVVER Newsletters”.