

# Versatile European Reactor for Neutron Irradiation and Nuclear Research (VERONICA): Technical Requirements and Multiphysics Relevance

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## ABSTRACT

New research reactor project VERONICA (Versatile European Reactor for Neutron Irradiation and Nuclear Research) is presented with the emphasis on selection of technical requirements and the multiphysics relevance. In addition to the existing European research reactor projects, there is, due to the ageing of existing RR fleet and the transition to zero-carbon society, a need for both multi-purpose and zero-power RR. Utilization for a possible dual-core facility (MPRR and ZPR) was conducted by analyzing a 3D phase-space, characterized by neutron flux, neutron spectrum and required temperature, giving us the direction in which optimization of the VERONICA reactor will be done. In addition to the existing RR utilizations, the design is focused on supporting Gen-IV and SMR reactor developments by having high-quality, novel multi-physics experimental capabilities providing datasets for inclusion in international multi-physics benchmarks. Key experimental capabilities include reactivity feedback and power distribution measurements, evaluation of coolant velocity and temperature fields and its feedback studies, and the dynamic coupling transients. This paper outlines the main conclusions of the initial strategic development phase led by JSI and CEA, defining the main technical parameters for both RR's in VERONICA facility for the next step in finalizing the design with possible RR vendors and opening the door for participation from prospective users, collaborators and experts across the World.

*Keywords:* New Research Reactor, VERONICA, Multiphysics, Neutron Irradiation, Technical Parameters

## 1. INTRODUCTION

Nuclear research reactors (RR) represent an essential part of the nuclear infrastructure: they advance nuclear science and technology and provide the education of nuclear professionals for academic and industrial applications. They also ensure the production and development of medical isotopes and enable the testing of future energy technologies – such as fusion, small modular reactors (SMRs), generation IV reactors – in addition to all the other RR applications [1].

The number of operable reactors has been decreasing globally, with Europe at the forefront of this negative trend, due to the lack of new builds and aging of the existing fleet. Currently, only 3 new research reactors are in various stages of construction in the EU, Pallas [2], MYRRHA [3], and JHR [4]. These reactors, while each representing a state-of-the-art facility in its own niche application, do not provide the versatility and accessibility needed to maintain or advance European nuclear needs. This was outlined by the Towards Optimized Use of Research Reactors in Europe (TOURR) project [5], in

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which the conclusion and recommendation for the long-term use of RRs in Europe was the construction of at least two RRs, in addition to the ones currently under construction.

In addition to addressing the TOURR findings, new research reactors also contribute to solving the problems addressed in various EU documents. The testing of new nuclear power technologies and education & training of personnel, capable of operating or designing nuclear power plants, contributes to the goal of decreasing greenhouse gas emissions, addressed in the Green Deal [6]. Research reactors offer a competitive advantage to their users, as they allow access to unique testing conditions, making European companies more competitive in the global scale, a goal set in the Draghi Report [7] and EU Competitiveness Compass [8]. The energy and material autonomy, addressed in the Self-Reliance, Defence and REPowerEU strategies, and nuclear large-scale and smaller reactors strategy (8th Nuclear Illustrative Programme [9]) are all topics that can be supported by new RR. The new builds should also fall within the Important Projects of Common European Interest (IPCEI) [10] and BEST Initiatives. Research reactors also align with the United Nations Sustainable Development Goals. All of this is addressed by the VERONICA project, an initiative to construct two new research reactors in one unique facility:

- **Zero Power Reactor - ZPR:** mainly focusing on education and training, reactor design, neutron code validation, nuclear data and benchmark experiments.
- **Multi-Purpose Research Reactor – MPRR:** mainly focusing on instrumentation development, specialized industrial and medical applications, radiochemistry and radiation chemistry, low neutron fluence material testing and radiation effects, neutron beam applications, and multi-physics research capabilities.

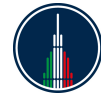
As this project aligns with Europe's nuclear energy goals, including the long-term operation of existing reactors and the development of new nuclear power plants and small modular reactors (SMRs), its clear mission is to make advanced nuclear research more versatile and accessible, from fundamental physics studies to industrial applications. The possibility of a new research reactor in Slovenia was first considered in 2019 [11], due to the further increase of utilization of the current JSI TRIGA Mark II research reactor [12]. The initiative for a new research reactor has gained significant momentum through acknowledgments in major national strategic documents, showing the national recognition of the necessity for the new research reactor in Slovenia. The VERONICA project is currently in its finalization of PHASE 1 (Pre-project), from which the feasibility study for the decision-makers will be done and the project ready for its final decision.

In this paper the formulation of research reactor technical requirements (Second section) is presented with the emphasis of analysing the 3D utilization phase-space, the main part of which is identifying the main parameters for the multiphysics experimental capabilities (Third section).

## 2. REACTOR TECHNICAL REQUIREMENTS

Previous work on the VERONICA project focused on identifying possible stakeholders and utilizations of both the multipurpose and zero power reactors [13]. More than 35 utilizations were identified for the multipurpose research reactor (MPRR) and 15 for the zero-power reactor (ZPR). Each potential application is associated with a set of operating conditions that must be provided by the reactor core and its surroundings, including requirements for neutron flux level and spectral energy distribution, temperature, and neutron fluence [1]. These requirements were formalized by mapping a three-dimensional phase space defined by neutron flux, neutron energy spectrum, and required temperature. This visualization provides a systematic way to compare experimental demands, highlight areas of overlap, and identify potential trade-offs that will shape the design.

The resulting technical requirements phase-space for the MPRR is shown in Figure 1. It represents the first step in moving from a broad set of applications to a structured, defined design. The dataset and the core idea of VERONICA (versatility), indicate, that the new facility must be able to support a broad



range of applications, while focusing on the areas with clustered applications when compromises will inevitably have to be made.

Neutron flux requirements have the widest range, from  $10^5$  n/cm<sup>2</sup>/s up to  $10^{18}$  n/cm<sup>2</sup>/s for high-flux applications (e.g. argon-based geochronology). The lower bound of this range does not play a significant role in reactor design, as it generally represents the minimum flux at which applications are feasible. The main design objective is therefore to maximize the achievable flux in order to support as many high-flux applications as possible, while maintaining flexibility, versatility and accessibility of an open pool-type reactor as this objective is constrained by safety considerations, including delayed heat removal capacity, power density limits, peaking factors, and fuel characteristics. VERONICA aims to be an accessible experimental facility, a goal that should not be sacrificed in the pursuit of ever higher neutron fluxes, as the high-flux applications will be addressed by specific RR's, like the JHR. Based on the utilization distribution shown in Figure 1, a reasonable design target is an in-core neutron flux on the order of  $10^{14}$  n/cm<sup>2</sup>/s.

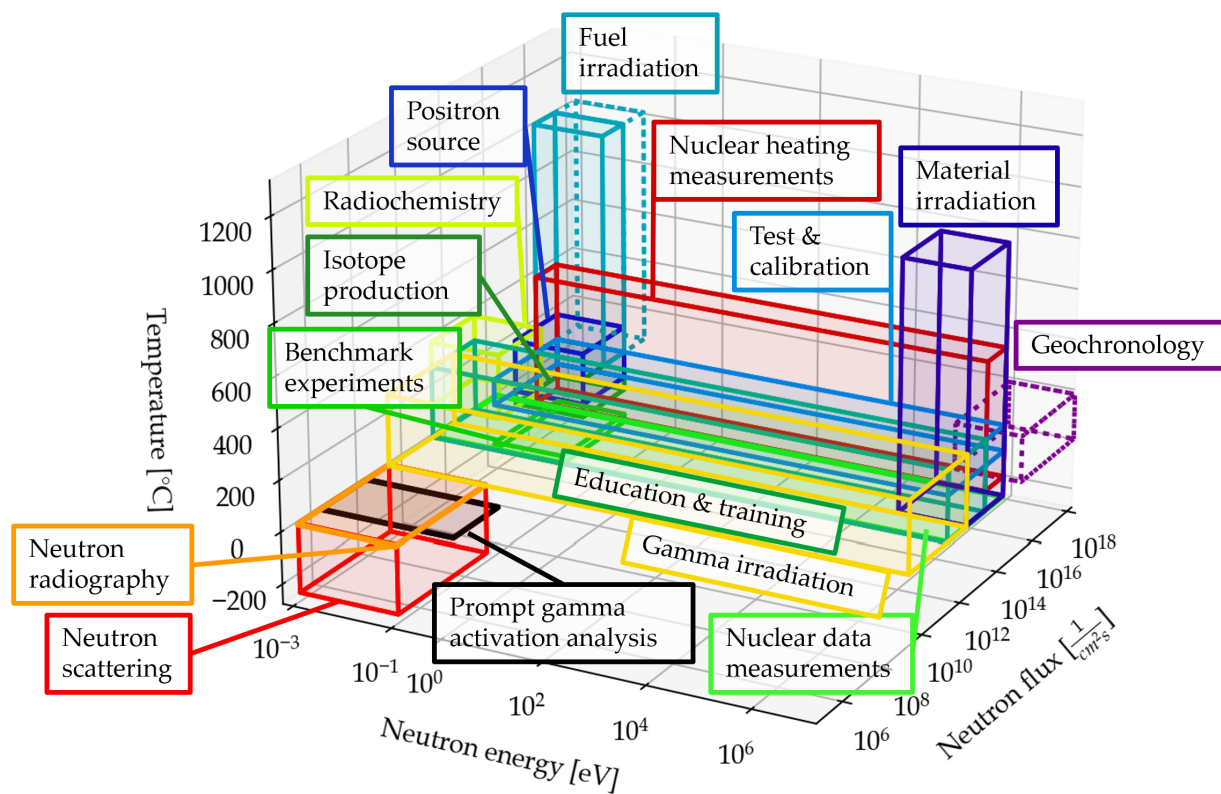


Figure 1. Identified MPRR utilizations in a 3D phase space of reactor technical parameters. Dashed boxes represent applications whose flux requirements exceed  $10^{14}$   $\frac{1}{\text{cm}^2 \cdot \text{s}}$ .

Spectral energy requirements show that most applications concentrate in the thermal and fast regions, though several important utilizations—such as tests and calibrations and nuclear data measurements—lie in the epithermal range. These experiments are essential for the development and validation of new fast reactor designs (SMR, Gen IV), making spectrum tailoring an important technical requirement. This implies that the reactor must be designed to accommodate the insertion of neutron filters or spectrum shifters, either within the core or in surrounding beam ports. Sufficient space should be reserved for such devices, and their insertion must not interfere with safe and stable reactor operation.

Temperature requirements cluster predominantly between room temperature conditions and about 100

°C, which can be readily provided in reflector positions or in peripheral regions of the core. Nevertheless, some applications demand significantly higher temperatures, particularly material and fuel irradiation relevant to advanced reactor systems. Since VERONICA is planned as a pool-type, water-cooled facility (like the OSURR reactor [14]), these high temperatures will need to be achieved through externally heated experimental loops or capsules. The core design must therefore allow for the insertion of heaters and specialized irradiation rigs, enabling experiments under both high-flux and high-temperature conditions.

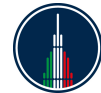
Taken together, the utilization phase space in flux, spectrum, and temperature dimensions provides clear direction for technical requirements. The reactor should be designed to sustain high power density while remaining within safety margins, to provide sufficient experimental volume and flexibility for the insertion of neutron filters, external heaters, and operation of the planned multiphysics experimental loops.

### 3. MULTIPHYSICS RELEVANCE

Accurate prediction of reactor behavior in steady and transient states requires tightly coupled neutronics and thermal-hydraulics (N-TH) models. The neutron field sets power distribution, while coolant flow and material temperatures drive feedbacks (Doppler, moderator density, void) that create non-linearity that shapes the stability, controllability, and safety margins. For conventional designs these effects are relatively well known, however for advanced reactor concepts, such as non-conventional fuels and coolants, heterogeneous core configurations, traditional single-physics assumptions are challenged. Even in thermal systems, local temperature gradients, coolant mixing and flow instabilities can induce significant reactivity perturbations. To address these effects quantitatively, validated, high-fidelity coupled N-TH simulation tools are therefore essential.

Developing confidence in N-TH coupled codes requires experimental benchmarks where feedbacks are active and measurable, enabling assessment of coupling schemes, validation of reactivity feedback models, evaluation of TH correlations under coupled conditions, and robust uncertainty quantification and sensitivity studies. The OECD/NEA Expert Group on Reactor Systems Multi-Physics (EGMUP-Nuclear Energy Agency (NEA) - Expert Group on Reactor Systems Multi-Physics (EGMUP)) recognizes the experimental validation of coupled neutronics–thermal-hydraulics modeling as a core challenge [15]. Indeed, current approaches to validate multi-physics coupling mainly rely upon experimental data from the operation of the current reactor fleet of light water reactors (LWR). These data allow a global experimental validation of the coupled multi-physics simulation tools on macroscopic physical quantities of interest, such as total core power, neutron flux at the center of some assemblies, and critical soluble boron concentration during irradiation. They enable to validate the implementation of physics models from industry practice; they are not sufficient for the validation of advanced physical-based coupled models developed at the pin/sub-pin level.

The use of well-controlled experimental data provided by highly-instrumented research reactors has now become essential to implement a rigorous and consistent step-wise validation process of multi-physics coupling. That is why some experimental data, such as the core power evolution in a transient-state coming from the SPERT-III experimental program [16] and the CABRI research reactor [17], are analyzed as a first step towards this objective for the simulation of LWR transients initiated by reactivity insertion. The analysis of the state-of-the-art shows no existing experimental benchmark available worldwide for LWRs to consistently and rigorously validate advanced neutronics/ thermal-hydraulics (potentially also / fuel performance) coupling at the pin- or sub-channel scale [18]. By aligning the VERONICA experimental program with EGMUP objectives for experimental validation of coupled modeling, the project will contribute to the next generation of N-TH benchmark datasets—enabling more rigorous code validation, strengthening confidence in predictive simulations, and supporting the international effort to improve coupled modeling fidelity. In addition, it will imply the development of novel instrumentation and measurement techniques needed to address multi-physics challenges.



### 3.1. Multiphysics experiment features description

The facility is being designed to support a broad spectrum of multiphysics experiments, focusing on the quantitative characterization of neutronics–thermal-hydraulics coupling phenomena. The phase-space coverage for a possible multiphysics loop is presented in Figure 2. The experimental program will include both steady-state and transient conditions, with the aim of producing benchmark-quality datasets for code validation. To achieve the best experimental results, it is essential that technological uncertainties (tolerances, compositions, geometry) should be reduced as low as possible by the design itself. Key experiment types under consideration include:

- **Reactivity Feedback and Power Distribution Experiments**  
Controlled power transients induced by small reactivity insertions will enable precise measurement of fuel temperature, moderator density, and reactivity effects. These tests will serve as reference cases for validating Doppler and moderator temperature feedback models, and for studying core stability under mild perturbations.
- **Evaluation of coolant velocity and temperature fields**  
Measurements complemented by the simulations will provide coolant velocity and temperature fields during various steady-state conditions and transients.
- **Flow and Coolant Temperature Feedback Studies**  
Experiments involving variations in coolant flow rate, inlet temperature, and subcooling will probe the sensitivity of neutron flux and power distribution to thermal-hydraulic boundary conditions. Such tests will allow assessment of coupling fidelity between thermal-fluid models and neutronic response.
- **Spatially Heterogeneous Power Distributions**  
Configurations with asymmetric control rod insertions, local absorber perturbations, or non-uniform power profiles will generate spatially varying feedbacks, providing valuable data for validating 3D coupled solvers and assessing nodal vs. subchannel resolution requirements.
- **Dynamic Coupling Transients**  
Experiments involving time-dependent perturbations (e.g., rod motion, flow oscillations, or temperature ramps) will be used to test the dynamic response and numerical stability of tightly coupled N-TH solvers. These transients are especially relevant for code-to-code comparison exercises under the OECD/NEA EGMUP framework.

### 3.2. Instrumentation for multiphysics measurements

The ability to instrument the VERONICA core and coolant system with high spatial and temporal resolution sensors—including neutron flux detectors [19, 20] will make it possible to generate high-quality, uncertainty-quantified datasets suitable for use as international multiphysics benchmarks. Through close collaboration with the OECD/NEA EGMUP community, these experiments will contribute to the establishment of new standard benchmarks for coupled reactor physics validation, bridging the gap between historical zero-power reactor data and modern high-fidelity simulation needs. All these MP challenges also imply the development of dedicated instrumentation and measurement techniques to provide useful measurements as it has been identified by the EGMUP [15].

Temperature measurements must be developed using already demonstrated “rad-hard techniques” such as optical fiber-based technologies (Bragg Gratings and Brillouin techniques) [21], ultrasonic and acoustic based sensors for characterizing temperature fields [22] and localized temperature gradients. Taking advantage of the relatively low neutron fluence encountered (compared to MTR irradiation), these sensors could survive a significant time (if not the entire irradiation time) to bring on-line information of the temperature evolution during the irradiation experiment.

Flow measurements can be characterized using non-intrusive acoustics and optical sensors [23] for global flow evaluation, but techniques based on temperature correlations along the flow path using

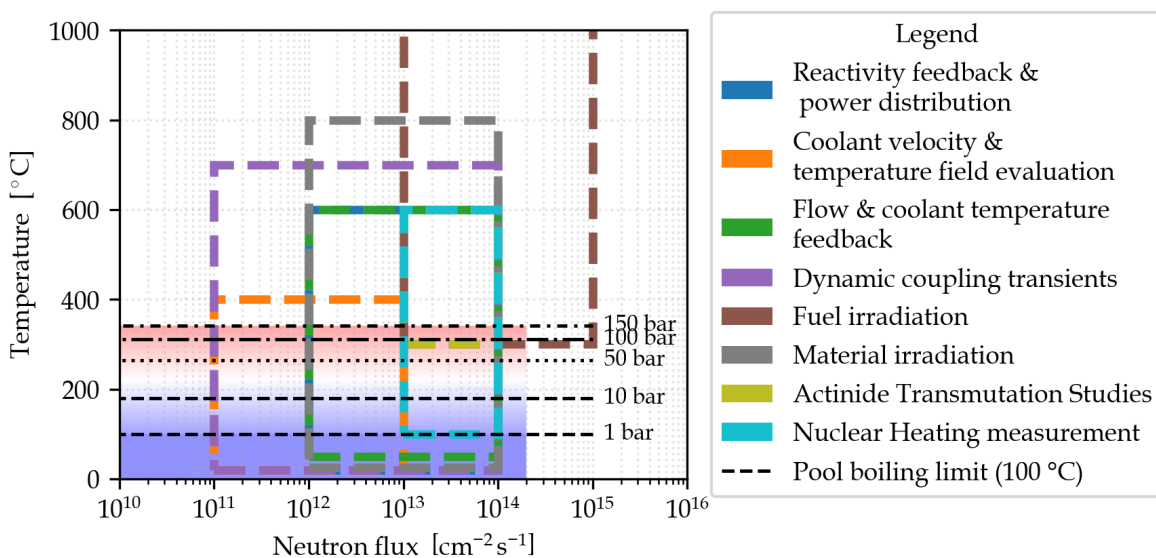


Figure 2. Phase-space coverage for a possible Multi-Physics loop for different loop temperatures and pressures.

thermocouple or optical fiber must be investigated depending on the geometry of the location to be measured.

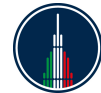
Neutron and gamma fluences could be characterized using activation dosimeters for energy spectrum and neutron fluence taking advantage of their very small dimensions, allowing them to be inserted in the interface and transition zones. Online fast and thermal neutron flux evolutions can be provided by classical miniature fission chambers and Self-Powered Neutron Detectors or using innovative sensors such as optical fiber coupled with miniature scintillator sensors (one shot online core mapping) or SiC based sensors [24] for online fast neutron measurement. Photon flux could be characterized by either ionization chambers for high flux level or optical fiber-based sensor (online OSLD) and scintillator-based sensors for lower gamma fluxes.

In addition, dimensional measurements for characterizing the thermal dilation effects can be characterized using optical and acoustic sensors for contact (Fabry-Perot, Michelson interferometers) and contactless/remote (ultrasonic and confocal chromatic sensors) measurements. Electromagnetic techniques provide also useful sensors such as LVDT (Linear variable differential transformer) and diameter gauges already qualified under irradiation.

The characterization of the coupled effects needed for MP experiments will require the use of several measurement techniques which should be analyzed considering their inter-correlations in time and geometry. Digital Twin of the experiment will be an advantage in this analysis process and to improve the quality of the C/E comparisons. Although, it will be useful only if technological uncertainties (tolerances, compositions, localization of the measure...) are reduced as low as possible by design.

#### 4. CONCLUSIONS

The VERONICA (Versatile European Reactor for Neutron Irradiation and Nuclear Research) new research reactor project in Slovenia was presented, with the emphasis on the utilization of the possible dual-core facility, housing both a Zero-power and Multi-purpose research reactor. The technical parameters were formalized using an analysis of a 3D phase-space of neutron flux, neutron energy spectrum and temperature. Main characteristic of the technical design is versatility and flexibility of the applications that can be performed, and not competing with specialized infrastructure projects. One of the



conclusions is that the MPRR will provide the possibility to perform screening type irradiation experiments and de-risking test irradiations (i.e. validation under irradiation of the designed instrumentation) before launching long and costly MTR irradiations (e.g. in the JHR). The main conclusion for the technical parameters is that the reactor should be designed to sustain high power density while remaining within safety margins, to provide sufficient experimental volume and flexibility for the insertion of neutron filters, external heaters, and operation of the planned multiphysics experimental loops.

Multiphysics simulations have become increasingly affordable, but their application hinges on rigorous verification and validation, enabled by the high-fidelity instrumentation. By developing and integrating novel sensors based on ultrasonic and optical methods in tandem with standard instrumentation and using them over a variety of reactor operation and transient conditions, we aim at generating a high-fidelity experimental database needed for code validation. The ultimate goal is that these techniques become part of standard reactor instrumentation, creating the continuous, large-scale data stream essential for Machine Learning, helping to ensure the safety and efficiency of future reactor operations.

By formalizing the key technical parameters for both RR's in the VERONICA facility, we can now move to the next phase: finalizing the design with potential RR vendors and inviting participation from prospective users, collaborators, and experts worldwide.

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