List of student internships offered by new*cleo*

–academic year–

2024–2025

November 14, 2024

Preface

This document contains the internship offers supported by *new*cleo. Each offer contains the specifications and modalities for the application and execution of the internship work.
Please submit your CV and motivation letter to the contact person indicated in the internship offer.
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About *new*cleo

Privately funded and headquartered in London, *new*cleo was launched in 2021 – and since raised a total of EUR 400m – to be an innovator in the field of nuclear energy. Its mission is to generate safe, clean, economic and practically inexhaustible energy for the world, through a radically innovative combination of existing, accessible technologies.

With visionary co-founders, *new*cleo capitalises on thirty years of R&D activity in metal-cooled fast reactors and liquid-lead cooling systems, and its senior management and advisory team can boast hundreds of years in cumulative hands-on experience.

Counting on around 800 highly skilled employees across Europe, *new*cleo has business, scientific, operations and industrial manufacturing capabilities in a vertically integrated model designed to deliver its ambitious timeline for its plan-to-market.

*new*cleo's technology, mostly comprising a novel approach to already qualified solutions, addresses equally well the three challenges affecting the nuclear industry to date:

- **Waste**: fast reactors are capable of efficient "burning" (i.e., fission) of depleted uranium, plutonium and minor actinides. When operated with mixed-oxide (MOX) fuel generated from reprocessed nuclear waste, *new*cleo's reactors not only ensure sustainability by closing the fuel cycle, but can also boost energy independence;

- **Safety**: lead-cooled reactors operate at atmospheric pressure. The properties of lead (thermal capacity and conductivity, boiling point, chemically inert, low neutron activation, shielding properties) together with *new*cleo's passive safety systems ensure very high levels of safety;

- **Cost**: *new*cleo's reactor design has been optimised over the last 20 years leading to the concept of an ultra-compact and transportable 200MWe module with improvements in energy density compared to other technologies. Costs are kept low by means of simplicity, compactness, modularity, atmospheric pressure operation and elevated output temperature.

*new*cleo is also working to significantly invest in MOX fuel manufacturing in developed countries, extracting energy from the current nuclear industry by-products.

*new*cleo is ready to develop a new, sustainable, and completely safe way of generating nuclear energy that will help humanity reach zero emissions and mitigate global warming.

List of Internships

Modeling of once-through thermal channels with phase separation by centrifugal force

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November 12, 2024

– Internship proposal –
(ID No. 1000073)

***Keywords* —** Bayonet tube, LFR, DHR, flow boiling
***Topics* —** Physical modelling, two-phase thermal-hydraulics, numerical mathematics

Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	5–6 months

Context

*new*cleo has planned an experimental campaign with external partners in order to optimize the design of components for lead-cooled fast reactors. In this framework, mathematical models of the components are needed to reproduce accurately their physical behavior, with the aim of supporting design studies. This internship is proposed to students attending the last year of the Master program in Nuclear Engineering with particular interest in thermal-hydraulics and heat transfer. This internship work could possibly continue with a PhD program.

Description

During this internship, the student will develop a mathematical model of a once-through heat exchanger of bayonet type presenting innovative features capable of preventing possible unstable operation. Such exchangers are made of coaxial tubes, as schematically shown in Figure 1. Subcooled water enters from the top of the inner tube and flows downwards. After, it enters the outer tube, where it flows upwards while being heated by the surrounding lead, eventually leaving the system as superheated steam. The flow boiling occurs in helicoidal parallel channels

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within the outer tube, so that inertial phase separation is expected radially because of the centrifugal force. The outer tube constitutes an inert zone filled by helium to guarantee separation between water and lead. The physical model must describe the different flow boiling regimes encountered within the outer tube, accounting for the presence of inertial phase separation due to the centrifugal force. The full technical details will be provided during the internship, after acceptance of the candidate.

A complete literature review is requested to find the most appropriate physical correlations characterizing the flow and the heat transfer in the channels. The heat exchange between neighbouring channels can be neglected as first approximation (adiabatic assumption). The student will derive the conservation equations to describe the thermal-hydraulic model of the system, and check the validity of suitable closure relations and physical correlations used in the model. The development of a Python code solving the identified equations is requested, with the verification of the numerical solution on simplified case problems. Finally, preliminary investigations about the validation of the model are expected at the end of the internship, despite the complete validation against other computer codes is postponed for future work. At the end of the internship, the preparation of a technical report is expected to describe the work done by the student and to compile the analysis of the results.

This internship will be supervised by an engineer from *new*cleo and the academic staff at PoliTo. This study supports the preparation of an experimental facility whose construction is planned in 2024.

Work plan

1. Literature review and retrieval of the existing work
2. Discussion of the problem
3. Derivation of conservation equations in the channel (adiabatic conditions among channels)
4. Assessment of the physical correlations to characterize the flow and the heat transfer
5. Implementation and verification of the numerical solution
6. Analysis of results and proposal of validation plan
7. Model upgrade with intra-channel heat exchange (optional)
8. Preparation of a technical report

Applicant profile

Master or PhD student in Nuclear, Mechanical or Aeronautical Engineering.
Fundamentals in thermal-hydraulics and heat transfer, multiphase flow.
Required computer skills: Python programming, linux (optional).

References

[1] N. E. Todreas and M. S. Kazimi. *Nuclear systems Volume I: Thermal hydraulic fundamentals*. CRC press, 2021.

[2] N. E. Todreas, M. S. Kazimi, and M. Massoud. *Nuclear systems Volume II: Elements of thermal hydraulic design*. CRC press, 2021.

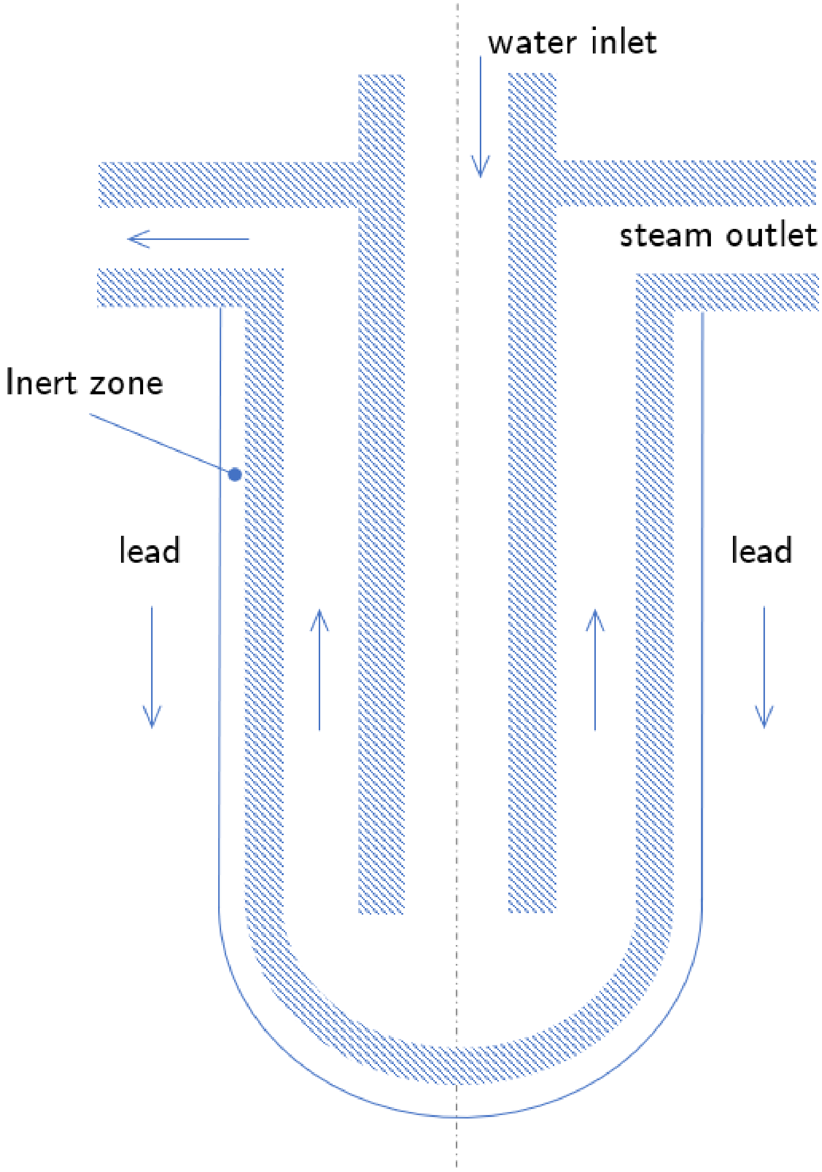

Figure 1: Schematic of a bayonet tube heat exchanger.

[3] A. Bersano, N. Falcone, C. Bertani, M. De Salve, and B. Panella. Conceptual design of a bayonet tube steam generator with heat transfer enhancement using a helical coiled downcomer. *Progress in Nuclear Energy*, 108:243–252, September 2018.

[4] D. Rozzia, A. Toti, M. Tarantino, L. Gramiccia, D. Vitale Di Maio, and F. Giannetti. Double-wall bayonet tube steam generator for LFR application – preliminary characterization. Technical Report NNFISS-LP3–032, ENEA Ricerca Sistema Elettrico, Italy, 2011.

Validation of ECCO calculations of LFR fuel assemblies by Monte Carlo calculations

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November 14, 2024

– Internship proposal –
(ID No. 1000247)

***Keywords* —** LFR, V&V, ECCO, lattice calculations, cross section preparation
***Topics* —** Physical modeling, neutronics, fuel design

Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	As soon as possible
Duration	5–6 months

Context

*new*cleo is designing new units of lead-cooled fast reactors (LFR) aiming to increase the utilization of plutonium produced by the many light water reactors that are currently operating worldwide. The fuel elements are exposed to a fast neutron spectrum favoring fission of heavier actinides.

The computer code ECCO (European Cell COde) from the ERANOS 2.3N [1] code suite is used for all the activities of fuel design. ERANOS is a system of computer codes developed in the 1990s for the calculation of fast reactors. ECCO solves the neutron transport equation by the collision probability method using the subgroup method to shield the cross sections of the resonant nuclides. This internship focuses on the validation of the results obtained by ECCO on typical hexagonal fuel assemblies using the Monte Carlo computer code OpenMC [2].

Description

During this internship, the candidate will calculate a set of fuel assemblies by the Monte Carlo code OpenMC in order to compare pin-wise reaction rates and integral quantities like the neutron multiplication factor with the corresponding quantities obtained with the calculations performed by ECCO. Simplified calculation schemes are generally adopted with ECCO, thus introducing physical approximations in the problem to solve, but with the advantage of achieving fast

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calculations. Instead, Monte Carlo calculations introduce fewer approximations but at the cost of longer calculations. They are then used to validate the deterministic calculations in a representative set of cases, featuring different assembly types. Comparisons of reaction rates in the typical 33-group energy mesh of ERANOS are also requested to validate the self-shielding step done by ECCO. The validation will be performed with fresh fuel, and optionally after exposure at different burnup steps.

Finally, the student will study the anisotropy effects for this kind of assemblies, especially in presence of a central cooling tube. At the end of the internship, the preparation of a technical report is requested to describe the work done by the student and to compile the analysis of the results. This internship will be supervised by engineers from *new*cleo.

Work plan

1. Study of the main approximeation involved in ECCO calculations.
2. Literature review of the existing work about ECCO V&V
3. Analysis of the test cases
4. Problem discussion
5. Calculation of the different cases
6. Analysis of results
7. Preparation of the technical report

Applicant profile

Master or PhD student in Nuclear Engineering, Theoretical or applied Physics.
Background: *fundamentals in reactor physics, neutronics and Monte Carlo methods*.
Required computer skills: Python programming (intermediate level), Linux, LaTeX scientific editing (optional).

References

[1] Gérald Rimpault, Danièle Plisson, Jean Tommasi, Robert Jacqmin, Jean-Marie Rieunier, Denis Verrier, and Didier Biron. The ERANOS code and data system for fast reactor neutronic analyses. In *Proc. Int. Conf. on the New Frontiers of Nuclear Technology PHYSOR2002: Reactor Physics, Safety and High-Performance Computing, Seoul, South Korea*, Oct 7-10 2002.

[2] Paul K Romano, Nicholas E Horelik, Bryan R Herman, Adam G Nelson, Benoit Forget, and Kord Smith. OpenMC: A state-of-the-art Monte Carlo code for research and development. *Annals of Nuclear Energy*, 82:90–97, 2015.

[3] E Garcia, P Sciora, T Kooyman, G Rimpault, H Guo, and B Faure. Flux distribution of the Superphénix start-up core for the validation of neutronic codes. *Annals of Nuclear Energy*, 133:889–899, 2019.

[4] Kenneth Allen, Travis Knight, and Samuel Bays. Benchmark of advanced burner test reactor model using MCNPX 2.6. 0 and ERANOS 2.1. *Progress in Nuclear Energy*, 53(6):633–644, 2011.

Development of the thermal model of a once-through steam generator with spiral geometry and cross-flow

Daniele Tomatis*[1] and Giuseppe Francesco Nallo[2]

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November 12, 2024

– Internship proposal –
(ID No. 1000303)

***Keywords* —** LFR, cross-flow heat exchanger, spiral tube, flow boiling
***Topics* —** Physical modelling, two-phase thermal-hydraulics, numerical mathematics

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Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	5–6 months

Context

*new*cleo has planned an experimental campaign in collaboration with external partners in order to optimize the design of the components for the next units of lead-cooled fast reactors. In this framework, mathematical models of the components are needed to reproduce accurately their physical behavior, with the aim of supporting the design studies.

Description

During this internship, the student will develop a mathematical model of a once-through heat exchanger that presents innovative features to achieve a compact design. The exchanger is made of many layers, each containing a single spiral-shaped tube, arranged in a staggered lattice along the axial direction. The tubes are all immersed in molten lead, which flows outwards from the center to the periphery of the exchanger. The exchanger can be described in cylindrical geometry with the spirals representing the tubes lying in parallel polar planes. Subcooled water enters the spirals at the periphery of the exchanger, flowing inwards inside the tubes, and

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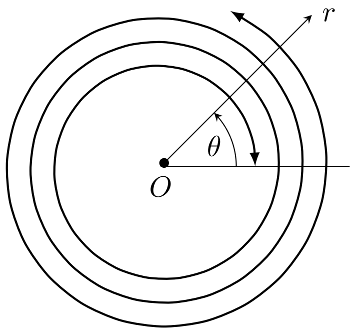

Figure 1: Archimedean spiral.

exits as superheated steam, see Figure 1. The Archimedean or arithmetic spirals are drawn according to the following equation:

$$r = a + b\theta, \tag{1}$$

where a is the centerpoint offset and b is the ratio of the pitch between two consecutive arms of the spiral (pitch) over 2π.

Molten lead flows radially outwards exchanging heat with the water that flows inside the tubes, and can be considered as uniformly distributed along the azimuthal coordinate θ when encountering the first spiral loop. Lead has a very low Prandtl number, so that thermal diffusion shall be taken into account, both radially and azimuthally. Flow-boiling occurs inside the spiral-shaped tubes, and phase separation is expected in the section of the tube because of the centrifugal force applied by the curvilinear motion. Different correlations for heat transfer between lead and water are expected at the two sides of the tube as a consequence of phase separation. Heat-transfer phenomena in presence of phase separation have been extensively studied for helical configurations in the past, but not for spiral configurations. The student will perform a review of the existing literature to find appropriate physical correlations for heat transfer between lead and water in the configuration at hand. New correlations for the distributed friction in cross-flow are expected to become available during the internship thanks to the first results of the experimental campaign.

The student will derive the conservation equations to describe the thermal-hydraulic model of the system, and check the validity of suitable closure relations and physical correlations used in the model. The development of a Python code solving the identified equations is requested, with the verification of the numerical solution in simplified case problems. Finally, preliminary investigations about the validation of the model are expected at the end of the internship, despite the complete validation against other computer codes is postponed for future work. At the end of the internship, the preparation of a technical report is expected to describe the work done by the student and to compile the analysis of the results.

This internship will be supervised by an engineer from *new*cleo and the academic staff at PoliTo. This study supports the preparation of an experimental facility whose construction is planned in 2024.

Work plan

1. Literature review and retrieval of the existing work
2. Problem discussion and definition

3. Derivation of the conservation equations in the spiral-like tube
4. Assessment of the physical correlations to characterize the flow and the heat transfer
5. Implementation and verification of the numerical solution
6. Analysis of results and proposal of validation plan
7. Preparation of a technical report

Applicant profile

Master or PhD student in Nuclear, Mechanical or Aeronautical Engineering. Students in theoretical Physics and applied Mathematics will also be considered for the position.
Background: *fundamentals in thermal-hydraulics and heat transfer, multiphase flow*.
Required computer skills: Python programming, linux, LaTeX scientific editing (optional).

References

[1] N. E. Todreas and M. S. Kazimi. *Nuclear systems Volume I: Thermal hydraulic fundamentals*. CRC press, 2021.

[2] N. E. Todreas, M. S. Kazimi, and M. Massoud. *Nuclear systems Volume II: Elements of thermal hydraulic design*. CRC press, 2021.

[3] Vincenzo Luci and Vittorio Vaiarelli. THEST: an in-house tool for spiral-tube steam generator design and verification. Technical report, *new*cleo SrL, Turin, Italy, 2021. LFR-000-NC-A-T-25-0002.

[4] Andrew Michael Fsadni and Justin P.M. Whitty. A review on the two-phase heat transfer characteristics in helically coiled tube heat exchangers. *International Journal of Heat and Mass Transfer*, 95:551–565, 2016.

[5] Paisarn Naphon and Somchai Wongwises. A review of flow and heat transfer characteristics in curved tubes. *Renewable and Sustainable Energy Reviews*, 10(5):463–490, 2006.

Assessment of neutronic data for the calculation of LFR fuel rods by TRANSURANUS

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November 12, 2024

– Internship proposal –
(ID No. 1000360)

***Keywords* —** LFR, TRANSURANUS, Monte Carlo
***Topics* —** Physical modelling, neutronics, fuel performance and thermo-mechanical codes

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Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	3–4 months

Context

*new*cleo is designing new Lead-cooled Fast Reactor (LFR) units for small and modular reactors using MOx fuel. At *new*cleo, fuel performance analysis is performed by the thermo-mechanical computer code TRANSURANUS (TU) distributed by the Joint Research Center of the European Commission based in Karlsruhe, Germany. *new*cleo has started a careful review of the code in order to ensure its suitability and fitness for the applications with LFR fuel rod types that are currently under design. Such work is also meant producing an upgraded version of the code to extend its range of applications, and in particular, to provide reliable predictions when modelling LFR fuel rods. The goal of this internship is to produce new neutronic data by Monte Carlo calculations that is needed for the TU calculations of LFR fuel rods.

Description

During this internship, the student will perform Monte Carlo calculations of LFR fuel rods by the computer code OpenMC to prepare neutronic data needed by the simplified burnup models implemented in TU. The data represent microscopic one-group reaction rates for the nuclides

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considered in the reduced decay chain of TU. The calculations are requested for both fresh and irradiated fuel, and at different exposure periods. The approach of data preparation will be validated against existing TU data used for LWR fuel types.

Among the target data, the student will have to find feasible and valid means to estimate the radial power distribution inside the hollow fuel pellets by fine tallies, still achieving narrow statistical uncertainty around the expected values in reasonable time. Approximation in the definition of the problem to match the expected critical conditions at operation will be necessary. The production of a technical report is expected at the end of the internship to describe the work done by the student and to compile the analysis of the results.

Work plan

1. Problem discussion and definition
2. Setup of calculations by OpenMC
3. Validation of the approach by comparisons with existing data
4. Analysis of results
5. Preparation of a technical report

Applicant profile

Master or PhD student in Nuclear Engineering. Students in theoretical Physics and applied Mathematics will also be considered for the position.
Background: *fundamentals in Monte Carlo methods for neutral particle transport*.
Required computer skills: Python programming, linux, FORTRAN and LaTeX scientific editing (optional).

References

[1] K Lassmann. TRANSURANUS: a fuel rod analysis code ready for use. *Journal of Nuclear Materials*, 188:295–302, 1992.

[2] K Lassmann and H Blank. Modelling of fuel rod behaviour and recent advances of the TRANSURANUS code. *Nuclear Engineering and design*, 106(3):291–313, 1988.

[3] Paul K Romano, Nicholas E Horelik, Bryan R Herman, Adam G Nelson, Benoit Forget, and Kord Smith. OpenMC: A state-of-the-art Monte Carlo code for research and development. *Annals of Nuclear Energy*, 82:90–97, 2015.

[4] Jerome Spanier and Ely M Gelbard. *Monte Carlo principles and neutron transport problems*. Dover Publications, Inc., Mineola, New York, 2008.

Development of a Python package with thermal-hydraulic correlations for LMFR – lmth23

Daniele Tomatis[*]and Daniele Panico

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November 12, 2024

– *Internship proposal* –
(ID No. 1000378)

***Keywords* —** LMFR, physical correlations, heat exchange, friction factor, fuel bundles, Python
***Topics* —** Heat transfer, thermal-hydraulics, frictional pressure loss, python programming

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Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	4–5 months

Context

*new*cleo is preparing a large experimental campaign of thermal-hydraulic experiments to support the design activities for new LFR units. A compilation of the available empirical correlations from literature in a single and comprehensive library is currently on-going to characterize heat transfer and thermal-hydraulic phenomena with liquid metals. This library will also collect the results from the future experiments. This internship position focuses on the literature review about the existing correlations and supports the development of this library.

Description

Several empirical correlations are available in literature to describe heat transfer, thermal-hydraulics and pressure drop phenomena occurring in presence of liquid metals, which are used as coolant for nuclear fast reactors. Every physical correlation comes with its validity range given in terms of dimensionless numbers, flow conditions, and for particular geometrical configurations. The use of a correlation outside the validity range does not guarantee accurate predictions of the quantity of interest. So a careful check about the correlation's appropriateness must be done before use.

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Some correlations yield directly dimensionless numbers, expressing the importance of a given phenomenon with respect to other competing ones, like in the case of the Nusselt number that measures the ratio between heat transfer by convection and heat transfer by conduction alone. Indeed, heat transfer and pressure drop correlations (Darcy factor for instance) are fundamental for the design of heat exchangers, which constitutes a large part of the forthcoming experimental program planned by *new*cleo.

Unfortunately, it is difficult to find a comprehensive and compact tool to make such correlations readily available for engineers when designing LFR components. For this reason, *new*cleo is implementing a Python package as unique and standardized entry point for evaluating all the empirical correlations needed for general LMFR applications. Moreover, this package will be used to support the next experimental campaign, including possible implementation of the new correlations arising from it.

During this internship the student will participate to the development of the Python package $\mathrm{lmth23}$ (Liquid-Metal Thermal-Hydraulics).

In particular, the correlations for the friction factor and for the Nusselt number in LMFR fuel bundles and once-through heat exchangers with cross-flow will be considered. A wide list of correlations for the friction factor can be found in [1]. Instead, correlations for the Nusselt number are given in [2]. The first release of the package will provide the desired quantity given the characteristic geometric parameters and coolant velocity at input to calculate the Reynolds number appropriately. In addition to reviewing and implementing the physical correlations, the student will focus on implementation techniques and high quality standards for code development. This will make the package easier to maintain and extend in the future, serving both uses in industry and research. Therefore, the student will develop/consolidate skills in the following aspects of software engineering in Python:

- Object-Oriented programming based on SOLID principles;
- Python Dynamic programming;
- design patterns (template and factory patterns in particular);
- CI/CD pipelines (including regression tests);
- write well-documented code for scientific applications.

The internship will be supervised by an engineer from R&D team of *new*cleo.

Work plan

1) Literature review and identification of the main correlations to implement
2) Code architecture design
3) Code implementation
4) Definition and implementation of tests
5) Preparation of a technical report

Applicant profile

Master student in Nuclear, Mechanical or Aerospace Engineering; Applied Physics; Informatics and Computational Sciences.

Skills:

- Fundamentals in thermal-hydraulics and heat transfer
- Basic knowledge of software programming (previous experience in Python is very appreciated)
- Basic knowledge of Linux operative system

Nice to have: experience using git, basic knowledge on liquid metal-cooled fast reactors.

References

[1] S.K. Chen, N.E. Todreas, and N.T. Nguyen. Evaluation of existing correlations for the prediction of pressure drop in wire-wrapped hexagonal array pin bundles. *Nuclear Engineering and Design*, 267:109–131, 2014.

[2] Konstantin Mikityuk. Heat transfer to liquid metal: Review of data and correlations for tube bundles. *Nuclear Engineering and Design*, 239(4):680–687, 2009.

[3] Giridhar Chetan. *Learning Python Design Patterns*. Packt Publishing, Birmingham - Mumbai, 2 edition, 2016.

[4] Mariano Anaya. *Clean Code in Python: Refactor your legacy code base*. Packt Publishing, Birmingham, 2018.

[5] Lutz Mark. *Learning Python: Powerful Object-Oriented Programming*. O'Reilly Media, Sebatopol, USA, 5 edition, 2013.

LFR modeling setup of primary system components in support to safety analyses

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November 12, 2024

– Internship proposal –
(ID No. 1001773)

Keywords — LFR, primary system, core inlet and outlet boundary conditions, system thermal-hydraulics codes, primary system components
Topics — thermal-hydraulics/ multiphysics/ multiscale modelling, safety assessment

Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	5–6 months

Context

Primary system thermal-hydraulic (hereinafter, TH) calculations, [1] and [2], are needed for the design and safety analyses of a nuclear reactor, and in particular of a small LFR. Suitable modelling strategies are to be chosen according to available calculation platforms [3], selecting models and closure laws. For LFR reactors, discussions are still ongoing to define what may be the state-of-the-art approach [4] for pool and components TH analyses. In this context, advanced modeling with TH system codes are to be developed, verified and validated by defining the best practices in the field of numerics or phenomenological representation improvements, especially if supported by international discussions and the interest from industrial stakeholders.

Description

This internship aims to make a step forward to define LFR primary system TH modeling mainly oeriented to its major components to support safety assessments [5], [6]. The model shall

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include robust sub-models of the primary pool, the down-comer, the bottom vessel with dedicated core power radial and axial distribution with the objective of optimising the modeling of the primary system components. The stage may focuses on one of the following components: steam-generator two-phase flows, decay heat removal system, core TH heat removal function, etc.

Within this activity, a simplified model of a lead-cooled fast reactor, capable of addressing the above-mentioned requirements, shall be proposed, with the purpose of assessing a comparison between the maturity level of the most indutrial TH system codes or those under development in terms of their applicability to new reactor concepts.

During this internship, the student will be introduced to small modular reactors and in particular to fast reactors (mainly LFR), considering TH system codes in order to address the required modelling activity. At the end of the internship, the preparation of a technical report with a complete analysis of the results is required.

Work plan

1. Literature review and study of the main physical phenomena
2. Problem discussion and definition
3. Setup of TH system code calculations
4. Verification of the approach through the preparation of a generic LFR test case
5. Analysis of results and proposition of an automation approach for pre- and post-processing oriented to parametric analysis
6. Preparation of the final report

Applicant profile

Master's or PhD student in Nuclear Engineering. Students of theoretical Physics and applied Mathematics will also be considered for the position.
Background: *fundamentals in reactor physics and TH (better if multiphysics) approaches, but also computational TH*.
Required computer skills: Python programming, Linux, LaTeX editing.

References

[1] N. E. Todreas, M. S. Kazimi, and M. Massoud. *Nuclear systems Volume II: Elements of thermal hydraulic design*. CRC press, 2021.

[2] N. E. Todreas and M. S. Kazimi. *Nuclear systems Volume I: Thermal hydraulic fundamentals*. CRC press, 2021.

[3] The RELAP5-3D© Code Development Team INL. *Code Manual Volume IV: Models and Correlations*. INL, Nuclear Safety Analysis Division, USA, 2015.

[4] A. Alemberti and et al. Lead-cooled Fast Reactor, LFR, Risk and Safety Assessment White Paper. *GEN IV international Forum*, 2014.

[5] Barbara Vezzoni and Fabrizio Gabrielli. Optimization of Safety Parameter for an Innovative Fast Reactor Concept. *Special Issue on Sustainability Journal Sustainability*, 4:1274–1291, 2012.

[6] Barbara Calgaro and Barbara Vezzoni. Advanced Couplings and Multiphysics Sensitivity Analysis Supporting the Operation and the Design of Existing and Innovative Reactors. *Energies*, 15:3341, 2022.

Advanced LFR modeling setup in support to safety analyses

Barbara Calgaro *

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November 12, 2024

– Internship proposal –
(ID No. 1001774)

***Keywords* —** LFR, primary system, core inlet and outlet boundary conditions, opensource advanced codes
***Topics* —** multiphysics/multiscale modelling, safety assessment, open source codes

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Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	5–6 months

Context

Coupled neutronics and thermal-hydraulic (hereinafter, TH) calculations, [1] and [2], are needed for the design and safety analyses of a nuclear reactor, and in particular of a small LFR. Suitable modelling strategies are to be chosen according to available calculation platforms, selecting models and closure laws. For LFR reactor, discussions are still ongoing to define what may be the state-of-the-art approach for multiphysics analyses. In this context, advanced open source codes with multiphysics/multiscale capabilities may play an important role in the definition of the best practices and shared innovations in the field of numerics improvements or phenomenological representation, especially if supported by international discussions and interest from industrial stakeholders.

Description

This internship aims to define an initial best-practice proposal for the multiphysics modelling of small modular reactors in support of safety assessments, with a focus on fast reactors and

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in particular to LFRs [3]. Open source tools such as Gen-Foam shall be considered [4]. The model must include robust sub-models of the radial and axial distribution of the core power and of the primary coolant system, and be able to simulate different operating conditions in relatively short timescales. Indeed, the core neutronic feedbacks following any variation in Nuclear Steam Supply System (NSSS) operating conditions, together with the knowledge of the energy deposition in the coolant [5], are part of the key information from the components to the primary system.

Within this activity, a simplified model of a generic lead-cooled fast reactor, capable of addressing the above-mentioned requirements, shall be proposed, with the purpose of assessing the maturity of open source codes in terms of applicability to new reactor concepts. This simplified model will allow to have a first quantification of representative indicators of the safety behaviour of the innovative systems. [4].

During this internship, the student will be introduced to small modular reactors and in particular to fast reactors (mainly LFR), considering multiphysics, multiscale opensource codes to address the required modelling activity. At the end of the internship, the preparation of a technical report with a complete analysis of the results is required.

Work plan

1. Literature review and study of the main physical phenomena
2. Problem discussion and definition
3. Setup of GenFoam calculations
4. Verification of the approach through the preparation of a generic LFR test case
5. Analysis of results and proposition of an automation approach for pre- and post-processing oriented to parametric analysis
6. Preparation of the final report

Applicant profile

Master's or PhD student in Nuclear Engineering. Students of theoretical Physics and applied Mathematics will also be considered for the position.
Background: *fundamentals of reactor physics and multiphysics approaches, but also computational TH*.
Required computer skills: Python programming, Linux, LaTeX editing.

References

[1] N. E. Todreas, M. S. Kazimi, and M. Massoud. *Nuclear systems Volume II: Elements of thermal hydraulic design*. CRC press, 2021.

[2] N. E. Todreas and M. S. Kazimi. *Nuclear systems Volume I: Thermal hydraulic fundamentals*. CRC press, 2021.

[3] Barbara Calgaro and Barbara Vezzoni. Advanced Couplings and Multiphysics Sensitivity Analysis Supporting the Operation and the Design of Existing and Innovative Reactors. *Energies*, 15:3341, 2022.

[4] Carlo Fiorina. GenFOam. *Nuclear Engineering and Design*, 294:24–37, 2015.

[5] Barbara Vezzoni and Fabrizio Gabrielli. Optimization of Safety Parameter for an Innovative Fast Reactor Concept. *Special Issue on Sustainability Journal Sustainability*, 4:1274–1291, 2012.

Improvement in LFR modeling with system codes approach in support to safety analyses

Barbara Calgaro *

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November 12, 2024

– Internship proposal –
(ID No. 1001775)

***Keywords* —** LFR, primary system, core inlet and outlet boundary conditions, system thermal-hydraulic codes
***Topics* —** multiphysics/multiscale modelling, safety assessment, system thermal-hydraulic codes

Location	Pisa
Starting date	To be defined
Duration	5–6 months

Context

Thermal-hydraulic (hereinafter, TH) calculations [1] are needed for the design and safety analyses of a nuclear reactor, and in particular of a small LFR. Suitable modelling strategies are to be chosen according to the available calculation platforms, selecting models and closure laws. For LFR reactors, discussions are still ongoing to define what may be the state of the art approach for TH system analyses dedicated to safety studies. In this context, TH system codes play an important role by allowing the modeling of the entire primary system with a reasonable level of detail. Due to the presence of multi-physics phenomena, the capability of such codes to model the primary system and relevant components, such as the primary pump, the downcomer, the steam-generator, the core, the decay heat removal (DHR), etc. under normal and accidental conditions is of great importance. The state-of-the-art analysis of already proposed approaches and the proposition of a appropriate generic nodalisation for selected steady-state and transient test cases are at the core of this activity for the definition of best practices and shared innovations in the field of numerical improvements or phenomenological representation, especially if supported by international discussions and the interest of industrial stakeholders.

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Description

This internship aims to define an initial best-practice proposal for the system codes application to small modular reactors in support of safety assessments, with specific focus on fast reactors and in particular to LFRs [2]. System code models shall include robust meshing of primary system for LFR composed mainly by a pool and primary components such as the steam generators, primary pumps, the core lower and the upper plena, the decay heat removual, while being capable of simulating different operating conditions in a relatively short time. The core neutronic feedbacks following any variation in Nuclear Steam Supply System (NSSS) operating conditions are modeled with point kinetics in first approximation. Neutronic power, together with the energy deposited in coolant, is part of the major information to be modeled and exchanged among components and primary system [3].

Within this activity, a model of a generic lead-cooled fast reactor, capable of addressing the above-mentioned requirements, shall be proposed, with the purpose of assessing the maturity of TH system codes in terms of applicability to LFRn. This model will provide an initial nodalisation suggested to address parametric analyses on a list of selected steady-state and accidental transient cases (Design Basis or DECs. [4]).

During this internship, the student will be introduced to small modular reactors and in particular to fast reactors (mainly LFR), considering mainly multiphysics, system codes to address the required modelling activity. At the end of the internship, the preparation of a technical report with a complete analysis of the results is required.

Work plan

1. Literature review and study of the main physical phenomena
2. Problem discussion and definition
3. Setup of system codes calculations
4. Verification of the approach through the preparation of a generic LFR test case
5. Analysis of results and proposition of an automation approach for pre- and post-processing oriented to parametric analysis
6. Preparation of the final report

Applicant profile

Master's or PhD student in Nuclear Engineering. Students of theoretical Physics and applied Mathematics will also be considered for the position.
Background: *fundamentals of reactor physics, TH and multiphysics approaches, but also computational TH*.
Required computer skills: Python programming, Linux, LaTeX editing.

References

[1] N. E. Todreas and M. S. Kazimi. *Nuclear systems Volume I: Thermal hydraulic fundamentals*. CRC press, 2021.

[2] M. Angelucci, D. Martelli, G. Barone, I. Di Piazza, and N. Forgione. STH-CFD Codes Coupled Calculations Applied to HLM Loop and Pool Systems. *Science and Technology of Nuclear Installations*, 2017:13, 2017.

[3] Dominique Bestion. 11 - The structure of system thermal-hydraulic (SYS-TH) code for nuclear energy applications. *Thermal-hydraulics of water cooled nuclear reactor*, 4:639–727, 2017.

[4] Barbara Calgaro and Barbara Vezzoni. Advanced Couplings and Multiphysics Sensitivity Analysis Supporting the Operation and the Design of Existing and Innovative Reactors. *Energies*, 15:3341, 2022.

Development of advanced materials for LFR reactors

– Internship Proposal –

(ID No. 1003849)

Marialuisa Gentile*[1] and Francisco Garcia Ferrè[1]

[1]*new*cleo *S.p.A, Via Galliano 27, 10129 Torino, Italia*

March 06, 2024

***Keywords* —** LFR materials, corrosion, metals, ceramic materials, coatings
***Topics* —** stainless steel, optical microscopy, mechanical tests, secondary electron microscopy, x-ray diffraction, surface treatments, wetting

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Location *new*cleo S.p.A, Via Galliano 27, 10129 Torino, Italy

Starting date Between September 2024 and March 2025

Duration 3 – 6 months

Context

Lead-cooled fast reactors (LFRs) are considered one of the most promising technologies to meet the requirements introduced for advanced nuclear systems. The operation of small modular reactors with a fast neutron spectrum poses several material challenges to scientists and engineers due to the extreme environmental conditions inside the reactor [1]. Therefore, the development of advanced materials is fundamental to successfully deploy new power reactors [2]. *new*cleo is committed to a large R&D program to assess the feasibility of metallic materials and coatings for nuclear applications. In this framework, the aim of the internship is to study the current state of the art of nuclear structural materials, to carry out experimental tests in the laboratory, and to apply artificial intelligence (AI) to accelerate material discovery.

Description

Corrosion protection of materials used in LFRs is one of the main issues that hinders the development of this class of nuclear reactors. The integrity of structural materials is strongly affected by neutron doses, burnup level and operating parameters such as temperature and

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oxygen concentration. Understanding the mechanism behind the failure of materials in LFR plays a vital role in improving the safety criteria of nuclear reactors and promoting research on advanced materials.

The successful candidate will analyze data presented in scientific literature to identify gaps in the current state of the art and apply AI to material manufacturing. The intern will work in laboratories to prepare specimens and characterize them through the following techniques:

- Optical microscopy
- Secondary Electron Microscopy
- X-ray diffraction
- Mechanical tests
- Nanoindentation
- Wettability measurements
- Thermal analysis tests
- Heat treatments

The intern will work in collaboration with the *new*cleo's branches in Brasimone and Lion.

Work plan

a) Literature review
b) Materials manufacturing
c) Materials testing
d) Data analysis
e) Preparation of a final report and presentation

Applicant profile

Master student in Nuclear Engineering, Mechanical Engineering, Materials Science, Chemistry, Physics, Chemical Engineering.

Skills:

- Knowledge of material manufacturing processes and characterization techniques.
- Required computer skills: knowledge of Excel and data analysis software. Experience with programming languages (Matlab, Python) is desirable.
- Languages: English (at least B2 level). French is a plus.

References

[1] Malerba, L. et al., Materials for Sustainable Nuclear Energy: A European Strategic Research and Innovation Agenda for All Reactor Generations. *Energies,* **15**, 1845 (2022)

[2] Fulger, M., Khumsa-Ang, K., Šípová, M., Ducu, C. M. & Sáez-Maderuelo, A. Special Issue: Behavior of Materials (Alloys, Coatings) in Conditions Specific to Gen IV Nuclear Reactors., *Coatings.* **13**, 58 (2022)

Implementation of a scientific software providing the thermodynamic properties of gases

Pierre-Alexandre Pantel*[1], Gabriele Ottino[2], and Daniele Tomatis[2]

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November 14, 2024

– *Internship proposal* –
(ID No. 1003858)

***Keywords* —** GERG, gas, computing, Python
***Topics* —** Thermodynamic properties, applied mathematics, programming, OOP, optimization

Location	*new*cleo SA, 9 Rue des Cuirassiers, 69003 Lyon 3e, France
Starting date	To be defined
Duration	5 – 6 months

Context

Chemical control of the primary system in liquid-metal nuclear reactors is of crucial importance during plant operation, preventing alteration or degradation of materials such as steel and other structural alloys by corrosion. In addition, the control system handles the purification of the coolant and other involved elements, such as inert atmosphere system controllers, from hazardous radioactive nuclides, originated by nuclear reactions, to prevent excessive dose release in case of leaks.

*new*cleo's activities on chemical control systems are the objects of intensive studies, both in terms of experiments and numerical modeling. To support both types of activities, *new*cleo needs a new Python package to offer a unique and standardized entry point for the use of empirical correlations for the thermodynamic properties of common gases. *Codes & Methods* team is in charge of this activity.

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Description

The computation of the thermodynamic properties (such as density, enthalpy, etc.) of gases is a crucial subject for many industries, particularly in the energy sector, whether carbon-free or not. To provide a scientific support to these stakeholders, an European research group known as "GERG" (*Groupe Européen de Recherches Gazières*) is compiling all the knowledge available on this subject. In particular, this group has published two documents of interest to us [1, 2] that provide wide-range equations of state for 21 natural gases and their mixtures.

Our final goal is to implement a Python module to compute the thermodynamic properties of gases. In this context, the candidate will actively contribute to the first release of this new tool, based on the results provided by an internal analysis.

This internship consists of creating a Python module that gives the thermophysical properties of gases. Among the options available, one is to wrap the existing implementation (`AGA8`) in Python according to the results of pre-design studies. This will require the use of interface modules such as `ctypes` or `swig`, as well as the adaptation of the existing code whenever the structure of the final tool could be simplified. However, better options may be found: the candidate will be asked to investigate which is the most suitable one and to implement it!

The goal is to implement a complete software package, consisting of base code, test suite and the automated documentation.

The candidate will be supported by the *Codes & Methods* team members of *new*cleo. The team adopts high quality standards for code development, thus allowing the candidate to develop/consolidate her/his skills about the following aspects of the software engineering [3, 4]:

- Object-Oriented programming based on SOLID principles;
- Well-documented code writing for maintainability purposes.

Work plan

1) GERG [1, 2] articles review.
2) Existing tool review (`AGA8`).
3) Wrapping code to a Python environment.
4) Relevant test suite.
5) Preparation of a technical report.

Applicant profile

Master student in Industrial Engineering, Chemistry, Applied Physics, Informatics or Computer Science.
Skills and background:

- Fundamentals in thermodynamics.
- Basic knowledge of object-oriented programming (previous experience in Python appreciated, but not fundamental).
- Basic knowledge of Linux operative system.

Nice to have: experience using `git`, basic knowledge on liquid metal-cooled fast reactors.

References

[1] O. Kunz, R. Klimeck, W. Wagner, and M. Jaeschke. The GERG-2004 Wide-Range Equation of State for Natural Gases and Other Mixtures. Technical report, 2007.

[2] O. Kunz and W. Wagner. The GERG-2008 Wide-Range Equation of State for Natural Gases and Other Mixtures: An Expansion of GERG-2004. *Journal of Chemical & Engineering Data*, 57(11):3032–3091, 2012.

[3] Chetan Giridhar. *Learning Python Design Patterns*. Packt Publishing, Birmingham - Mumbai, 2 edition, 2016.

[4] Mark Lutz. *Learning Python: Powerful Object-Oriented Programming*. O'Reilly Media, Sebastopol, USA, 5 edition, 2013.

Comparison of numerical acceleration methods for nonlinear iterations used in the computer code TRANSURANUS

Elena Travaglia and Daniele Tomatis*

newcleo SpA, Via Galliano 27, 10129 Torino, Italy

November 14, 2024

– Internship proposal –
(ID No. 1003986)

***Keywords* —** TRANSURANUS, numerical acceleration, non-linear iterations
***Topics* —** fuel performance, numerical mathematics, computational modelling

Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	4–6 months

Context

*new*cleo is currently in the process of developing advanced Lead-cooled Fast Reactor (LFR) units tailored for small and modular reactors. These units incorporate innovative features aimed at addressing the unique challenges associated with LFR technology. Simultaneously, the company is committed to meeting sustainability, economic, and safety objectives, aligning with the criteria set for the fourth generation of nuclear reactors.

In the context of fuel performance analysis, newcleo relies on the TRANSURANUS (TU) thermo-mechanical computer code, which is distributed by the Joint Research Center of the European Commission in Karlsruhe, Germany, under a collaboration research agreement [1, 2]. Newcleo has initiated a meticulous examination of the code to ensure its suitability and adaptability for applications involving LFR technology. The goal is to employ precise physical models that guarantee reliable results in numerical simulations. This ongoing effort also includes improving the code to broaden its scope and enhancing its performances.

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Description

The thermal analysis of an integral fuel rod can be treated by superposing one-dimensional radial and axial solutions. Given the multitude of non-linearities inherent in these processes, only numerical solution techniques prove feasible. These techniques are of critical importance as they determine numerical stability and, to a considerable extent, the overall computational cost.

TU solves heat transfer by the Fourier equation in the radial coordinate of the fuel rod, whose discretized form brings to a tridiagonal system. The nonlinearity of the coefficients in the second order differential equation is handled by successive substitutions. The resulting non-linear iterations are accelerated by minimizing the residuals through a numerical scheme based on Regula Falsi, initially implemented by Lassmann [3].
This procedure was adopted because calculating the temperature of a fuel rod, which is schematically shown in Fig. 1, is a computationally intensive task. Therefore, it is important to focus on obtaining convergence and minimizing the total numerical effort required.

In the current internship the student will perform a complete literature review of the existing models to solve heat conduction equation and techique to accelerate the convergence of such numerical method. Some of this techinque will be implemented and their performance will be compared.

The student will be introduced to the use of TU and will join the team of TU developers at *new*cleo, learning the best practices for collaborative work and quality-assured code development. The production of a technical report is expected at the end of the internship to describe the work done by the student and to compile the analysis of the results.

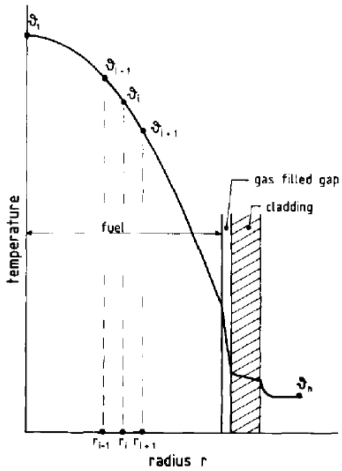

Figure 1: Schematic rappresentation of the stationary radial temperature profile in a slice of the fuel rod

Work plan

a) Litterature review and retrieval of the existing work
b) Discussion of the problem
c) Implementation and verification of the numerical solution

d) Analysis of the numerical results
e) Preparation of a technical report

Applicant profile

Master or PhD student in Nuclear, industrial or Software Engineering; Applied Physics; Mathematics.
Required computer skills: Basic knowledge of Linux operative system and software programming (previous experience in FORTRAN is appreciated, but not fundamental).
Knowledge of LaTeX editing is appreciated, but not required.

References

[1] K Lassmann. Transuranus: a fuel rod analysis code ready for use. *Journal of Nuclear Materials*, 188:295–302, 1992.

[2] K Lassmann and H Blank. Modelling of fuel rod behaviour and recent advances of the transuranus code. *Nuclear Engineering and design*, 106(3):291–313, 1988.

[3] K. Lassmann. A fast and simple iteration scheme for the temperature calculation in a fuel rod. *Nuclear Engineering and Design*, 103(2):211–214, 1987.

Analysis and verification of the burnup model implemented in the computer code TRANSURANUS

Elena Travaglia and Daniele Tomatis*

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November 12, 2024

– Internship proposal –
(ID No. 1003987)

***Keywords* —** TRANSURANUS, Burnup model, LFR
***Topics* —** nuclear fuel design, fuel performance and thermomechanics, computational modeling

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Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	5–6 months

Context

Currently, *new*cleo is designing advanced Lead-cooled nuclear Fast Reactors (LFR). These units incorporate innovative features aimed to address the unique challenges associated with the decarbonization of the energy market and reprocessing of spent nuclear fuel. Concurrently, the company is dedicated to fulfilling sustainability, economic, and safety goals, in line with the criteria established for the fourth generation of nuclear reactors.

In the domain of fuel performance analysis, *new*cleo relies on the TRANSURANUS (TU) thermo-mechanical computer code, which is provided by the Joint Research Center of the European Commission in Karlsruhe, Germany, under a collaboration agreement [1, 2]. *new*cleo is performing a thorough examination of the code to check that it can reliably reproduce the physical behavior of LFR fuel rods.

This ongoing endeavour also includes improving the code to broaden its range of applications, with a specific focus on providing trustworthy predictions for modeling LFR fuel rods. The final goal of this initiative is to develop an improved version of the code.

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Description

The performance of a fuel rod is greatly influenced by several physical phenomena. The exposure of the fuel rod to neutron irradiation determines the time evolution of the isotopic concentrations, and of the power density distribution within the fuel. The power density is the main driving force of the local temperature profile. The temperature heavily affects material properties and many physical phenomena, such as fuel restructuring, actinide redistribution, fission gas release, creep of fuel and cladding [1, 2]. A thorough description of the time evolution of the isotopic concentration of heavy metals in the fuel is thus crucial. Accordingly, one of the first stages in describing fuel rod behaviour is to compute at each radial position in the fuel: the local burnup, the build-up of heavy metal nuclides and the formation of fission products. The equations used to describe these phenomena constitute the so-called burnup models.

A model called TUBRNP, developed by Lassmann in 1994 [3], is implemented in TU. This model predicts the radial power density distribution based on burnup together with the radial profiles of actinide concentrations.

During the internship, the student will study and verify the implementation of the simplified burnup model. In particular, it will be requested to revise the implementation of the calculation of the radial neutron flux distribution in the fuel slices that is currently preventing the use of user-input distributions.

In addition, to assess the physical consistency of the isotopic composition evolution in case of anomalous behavior, a parallel inventory analysis of LFR fuel rods will be performed using the depletion module of the OpenMC Monte Carlo code.

The student will be introduced to the use of TU for the calculation of fuel rods used in nuclear reactors. He/she will join the team of TU developers at *new*cleo where he will learn effective collaborative practices and methods for developing code with ensured quality. At the conclusion of the internship, the student is expected to produce a technical report detailing his/her contributions and experiences during the internship period.

Work plan

a) Literature review and retrieval of the existing work relating to TUBRNP
b) Code implementation
c) Analysis of the results
d) Preparation of a technical report

Applicant profile

Master or PhD student in Nuclear, Industrial or Software Engineering; Applied Physics
Computer skills: FORTRAN, Linux.
Knowledge of LaTeX editing is appreciated, but not required.

References

[1] K Lassmann. Transuranus: a fuel rod analysis code ready for use. *Journal of Nuclear Materials*, 188:295–302, 1992.

[2] K Lassmann and H Blank. Modelling of fuel rod behaviour and recent advances of the transuranus code. *Nuclear Engineering and design*, 106(3):291–313, 1988.

[3] K. Lassmann, C. O'Carroll, J. van de Laar, and C.T. Walker. The radial distribution of plutonium in high burnup uo2 fuels. *Journal of Nuclear Materials*, 208(3):223–231, 1994.

Advancements in the thermal-hydraulic modelling of a lead cooled modular fast reactor (LFR) and related experimental facilities with CFD/TH system codes

Barbara Calgaro *[1] and Prof. Nicola Forgione[2]

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[2]*Università di Pisa, via Diotisalvi 2, 56125 Pisa, Italy*

November 12, 2024

– *Internship proposal* –
(ID No. 1005141)

***Keywords* —** LFR, primary system, core inlet-outlet boundary conditions, open-source, advanced codes
***Topics* —** multiphysics/multiscale modelling, safety assessment, open-source codes

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Location	Dipartimento di Ingegneria Civile Industriale - DICI - Università di Pisa
Starting date	09 September 2024
Duration	5–6 months

Context

Lead technology is one of the most promising alternatives for the development of advanced nuclear reactors and sustainable energy scenarios. In this context, *new*cleo is involved in the design and construction of Advanced Modular Reactors (AMR) based on lead technology.

Thermal-hydraulic (hereinafter, TH) scientific codes are used for the design and safety analyses of LFR. Suitable modelling strategies are yet to be chosen according to the available calculation platforms, including the selection of the most appropriate models and closure laws. For LFR reactors, discussions are still ongoing to define what may be the approach to use as reference for multi-scale analyses [1].

Both advanced 3D CFD codes and 1D system TH codes may play an important role in the definition of the best practices to follow for improving the modelling of physical phenomena, such as head losses and heat exchanges. In this context, special focus should be provided to open-source codes, thanks to their potential in supporting a wider community and facilitating education and training activities.

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Description

In the framework of the collaboration between DICI UNIPI and *new*cleo, and in continuity with and support of a PhD programme already activated, the present internship programme is proposed focusing on how to approach multi-scale 3D/1D problems and the potential benefit of coupling TH system codes and CFD codes.

The proposed internship will contribute to identify improvements in the modelling of head loss and heat exchange phenomena in liquid metals that are used as coolant of core hexagonal fuel pin bundle or primary system components of a pool-type nuclear fast reactor. The purpose is to capture the main 3D phenomena by detailing accurately their features and by looking for their most appropriate representation, mainly focusing on CFD and TH system codes requirements. This internship will provide the criteria for selecting the most appropriate modelling approach between 3D and 1D according to the specific application and will propose an approach for making them interact.

The target is to meet the R&D needs of *new*cleo C&M department by providing preliminary methodologies associated to the identified use case to be applied lately for safety analysis. Such methodologies will be tested and deployed against open literature mock-ups and available measurements or new experimental campaigns ongoing or foreseen by *new*cleo.

Work plan

The workplan is structured according to the following items:

1. Open literature short review of 1D/3D modelling and simulation of liquid metal flows by both alone and coupled 1D and 3D codes.
2. Selection of a representative geometry and phenomena to be reproduced with CFD codes and/or TH system codes.
3. Automation of pre- and post-processing to perform parametric and sensitivity analysis with respect to different closure laws.
4. Presentation of the work done in terms of adopted mesh, modelling approaches, tools and physical results.
5. Formalisation with a final report.

Applicant profile

Master's student in Nuclear Engineering. Students of theoretical Physics and applied Mathematics will also be considered for the position.
Background: *fundamentals of reactor physics and multiphysics approaches, but also computational TH*.

References

[1] Ferry Roelofs. *Thermal hydraulics aspects of liquid metal cooled nuclear reactors*. Woodhead Publishing, 2018.

[2] N. E. Todreas and M. S. Kazimi. *Nuclear systems Volume I: Thermal hydraulic fundamentals*. CRC press, 2021.

[3] N. E. Todreas, M. S. Kazimi, and M. Massoud. *Nuclear systems Volume II: Elements of thermal hydraulic design*. CRC press, 2021.

[4] Barbara Calgaro and Barbara Vezzoni. Advanced Couplings and Multiphysics Sensitivity Analysis Supporting the Operation and the Design of Existing and Innovative Reactors. *Energies*, 15:3341, 2022.

Numerical modelling and analysis of high-pressure water leakage in liquid lead pool

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[2]*Politecnico di Torino - DIMEAS, Corso Duca degli Abruzzi 24, 10129 Torino, Italy*

November 12, 2024

– Internship proposal –
(ID No. 1005388)

Keywords — Steam generator tube rupture, LFR, liquid lead pool, CFD
Topics — Fluid dynamics, numerical modelling, multiphase, safety analysis

Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	6 months

Context

*new*cleo is involved in the design of lead-cooled fast reactors (LFR). Experimental campaigns and numerical simulations are the main tools used to support all the necessary design phases. In this context, safety analyses are also important, as they provide a clear overview of the possible incidental scenario, thus allowing the most appropriate measures to be defined. Among the others, there is an incidental case where a well-defined modelling approach is still lacking, and experimental activities have yet to be defined. This is the case when a tube in the spiral water-steam generator suddenly ruptures, creating a high-pressure wave that propagates through the liquid lead. The aim of this internship is to get a clear view of the state of the art in numerical modeling of this phenomenon and to try to estimate the source term following the tube rupture: such source term will represent the initial condition to be applied in future work to estimate the consequences of the tube rupture in the liquid lead vessel.

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Description

The physics related to the phenomenon of steam generator tube rupture is very complex and must be studied in depth and accurately in each of its aspects [1]. The first objective of this work is to perform a thorough literature review to acquire knowledge of the state-of-the-art models and numerical methods used to investigate this or similar problems. The literature review will consider all the elements related to the rupture:

1. the phase of the water fluid within the pipes at the moment of the rupture and its relation with the pipe shape and how it may be predicted with reduced-order models or CFD;
2. the effect of the geometric form and type of the rupture on the water jet entering the liquid lead bath;
3. the interaction of the water jet with the liquid lead;
4. the propagation of waves within the liquid lead;
5. the potential risks associated with points 3 and 4.

It is expected that this review will be conducted and reported, aiming to be useful in defining the main steps of future related research activities.

The second part of the thesis will focus on the estimation of the source term to be used as the initial condition of numerical models to reproduce the effect of such a rupture in the liquid lead vessel. As the water/steam flow is at a pressure a few orders of magnitude higher than the pressure of the liquid lead, it is expected that a chocking condition will occur across the rupture section. The investigation of the phenomena in the tube can then be separated from those relating to the propagation of the water/steam in the liquid lead.

During the thesis, the student will try to identify all the possible scenarios that could arise depending on the location of the rupture in the steam generator tube. The flow in the tube undergoes several regime transitions that change its physical properties: the liquid single phase is mainly close to the entrance, the vapour single phase is close to the outlet, and in between there are intermediate conditions that require appropriate modelling treatment depending, for example, on the location of the rupture along the tube cross section. Apart from the analytical models available in the literature, the student will assess which models and numerical methods are implemented in available CFD tools, and will begin analyses on simple configurations to familiarize herself/himself with the code. In this context, she/he will compare results, computational time, and resources associated with each method. Finally, she/he will consider scenarios close to the actual ones, selecting the methodology that appears most appropriate in terms of accuracy and cost trade-off.

Work plan

The expected work plan is detailed below:

1. A literature review that will include all the physical aspects arising from the rupture of a steam generator tube adjacent to a liquid lead bath.
2. Definition of a plan of action with the final aim of studying the phenomenon as a whole.

3. Identification of scenarios to be investigated for estimating the conditions at the rupture of a steam generator tube.
4. Analysis of physical models and numerical methods implemented in at least one CFD tool to estimate such conditions.
5. Selection of the most appropriate models and methods and application to the previously identified scenarios.
6. Preparation of the thesis report.

Applicant profile

Master's student in Aerospace or Nuclear Engineering, preferably with a specialization in Aerogasdynamics (not mandatory).

Required computer skills: Aerospace Engineering Master's level knowledge of Computational Fluid Dynamics, some experience with commercial CFD codes (attendance of university-level CFD courses, or courses where CFD was used, is sufficient).

Knowledge of LaTeX editing is appreciated, but not mandatory.

References

[1] Nicolò. Garelli and Michel Gaetan. Steam generator tube rupture: state-of-the-art review. Internal report, newcleo SpA, June 2023.

[2] Xi Huang, Peng Chen, Yuan Yin, Bo Pang, Yongchun Li, Xing Gong, and Yangbin Deng. Numerical investigation on lbe-water interaction for heavy liquid metal cooled fast reactors. *Nuclear Engineering and Design*, 361:110567, 2020.

[3] Sergey E Yakush, Nikita S Sivakov, Oleg I Melikhov, and Vladimir I Melikhov. Numerical modeling of water jet plunging in molten heavy metal pool. *Mathematics*, 12(1):12, 2023.

[4] Junjie Yuan, Li Liu, Ruiqi Bao, Da Li, Xiaoyan Tian, Haotian Luo, Zheng Jia, Maolong Liu, and Hanyang Gu. Numerical simulation of jet boiling characteristics of high-pressure water injected into high-temperature liquid lead–bismuth in a confined space. *Applied Thermal Engineering*, page 123432, 2024.

This internship is in collaboration with:

POLITECNICO DI TORINO

Validation of lead-water heat exchangers modelling in ATHLET through benchmarking with simplified tools

Barbara Calgaro *[1]

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November 14, 2024

– *Internship proposal* –
(ID No. 1005558)

***Keywords* —** LFR, Heat Transfer, separate effect test, system TH codes
***Topics* —** multiphysics/multiscale modelling, safety assessment, scientific codes

Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	5–6 months

Context

Lead technology is one of the most promising alternatives for the development of advanced nuclear reactors and sustainable energy scenarios. In this context, *new*cleo is involved in the design and construction of Advanced Modular Reactors (AMR) lead-cooled.

For Lead Fast Reactor (LFR), a major role for compactness is played by the efficiency of the in pool heat exchangers (Steam Generator, Decay Heat Removal) and the optimization of their working point is under discussion. Thermal-hydraulic system codes (hereinafter, STH) are used for the design and safety analyses of LFRs [1]. Suitable modelling strategies are yet to be chosen according to the available calculation environment, including the selection of the most appropriate models and closure laws.

The development of tools and models able to support the design phase is of major importance, as well as the justification of the assumptions of adopted tools.

The code validation against the available experimental measurements for the specific purpose of the LFR is done through the choice of the most suitable closure laws, having a direct influence on the results provided by the code itself.

It may also support the validation of the ATHLET code, thus improving the selection of the most suitable closure laws.

The validation effort will be part of a wider activity dedicated to the STH codes Validation and Verification (V&V) to attein a reasonable level of robustness for the adopted tools.

*Contact person, barbara.calgaro@newcleo.com

Description

This internship will support the identification and modelling of heat exchange phenomena occuring between lead coolant, reactor internals and secondary water loop in different scenarios (steady state, transient and accidental).

The focus will be the assessment of the the most appropriate closure laws for irradiation, conduction and convection justifying this choice and highligthing the differences. This task will be carried out by means of the analysis of heat exchanges regimes and flow pattern maps.

In the hypothesis of a geometry representative of a LFR pool, this internship will provide the criteria for selecting the most appropriate closure laws among the ones available in the ATHLET code and/or asking for the implementation of new ones and the justification behind this choice.

For these purposes, simplified Python tool will be associated to the STH code in order to facilitate the assessment of selected closure laws and heat transfer mechanisms providing a first comparison against ATHLET.

Parametric and sensitivity analysis will be performed in order to understand the differences among assessed closure laws, their validity domain and the possible extrapolation to reactor operating conditions. As optional work, dimensional analisys may be used to justify the semi-empirical form of the correlations and to propose possible improvements.

The target is to meet the *new*cleo Codes & Methods (C&M) department needs in term of codes V&V. Such methodology will be tested and deployed against open literature mock-ups with available measurements and lay the groundwork for new experimental campaigns ongoing or foreseen by *new*cleo.

Work plan

The work plan is structured according to the following items:

1. Review of the state-of-the-art literature with focus on available experimental measurements and mock-ups but and on heat exchange phenomena and modelling between liquid metal flows and water.
2. Adaptation of available simplified python tools to the selected mock-ups test section geometries.
3. Automation of pre- and post-processing to analyse experimental measurements and closure laws.
4. Proposition of a benchmark against ATHLET and the simplified tool in a geometry representative of an heat exchanger for LFR applications.
5. Presentation of the work done in terms of adopted theory, modelling approaches, tools and physical results.
6. Drafting of a final report.

Applicant profile

Master's student in Nuclear Engineering. Students of theoretical Physics and applied Mathematics will also be considered for the position.
Background: *fundamentals of reactor physics and multiphysics approaches, but also computational Thermal-hydraulics*.

References

[1] Ferry Roelofs. *Thermal hydraulics aspects of liquid metal cooled nuclear reactors*. Woodhead Publishing, 2018.

[2] N. E. Todreas and M. S. Kazimi. *Nuclear systems Volume I: Thermal hydraulic fundamentals*. CRC press, 2021.

[3] N. E. Todreas, M. S. Kazimi, and M. Massoud. *Nuclear systems Volume II: Elements of thermal hydraulic design*. CRC press, 2021.

[4] Barbara Calgaro and Barbara Vezzoni. Advanced Couplings and Multiphysics Sensitivity Analysis Supporting the Operation and the Design of Existing and Innovative Reactors. *Energies*, 15:3341, 2022.

Validation of liquid lead flow patterns modelling in ATHLET through benchmarking activities

Barbara Calgaro *[1] and Matteo Rostagno[1]

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November 14, 2024

– *Internship proposal* –
(ID No. 1005559)

***Keywords* —** LFR, Heat Transfer, separate effect test, system TH codes
***Topics* —** multiphysics/multiscale modelling, safety assessment, scientific codes

Location	*new*cleo SpA, Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	5–6 months

Context

Lead technology is one of the most promising alternatives for the development of advanced nuclear reactors and sustainable energy scenarios. In this context, *new*cleo is involved in the design and construction of Advanced Modular Reactors (AMR) lead-cooled.

Thermal-hydraulic system codes (hereinafter, STH) are used for the design and safety analyses of Lead Fast Reactors (LFR) [1]. Suitable modelling strategies are yet to be chosen according to the available calculation environment.

The development of tools and models able to support the design phase is of major importance, as well as the justification of the assumptions of adopted tools.

Closure laws directly influence the results provided by a STH code.

Their assessment done by means of experimental measurements or by comparison with other codes is crucial to have reliable results from the STH code. The focus of this activity is the assessment of the flow pattern regimes and head losses correlation with the support of specialized tools, as OpenModelica, frequently used to optimize the hydraulic network and to perform balance of plan analyses.

The activity will support the validation of the ATHLET code, improving the selection of the most suitable closure laws.

The validation effort will be part of a wider activity dedicated to the STH codes Validation and Verification (V&V) to attein a reasonable level of robustness for the adopted tools.

*Contact person, barbara.calgaro@newcleo.com

Description

The proposed internship will deal with the simulation representative of the primary circuit of a simplified model of an LFR in different operating conditions. ATHLET will be the STH code that will profit the work realized by this study but, initially, to easily compare experienced flow pattern regimes and head losses correlation (concentrated and distributed) other simplified tools will be associated.

After a review of the available literature focusing on the characterization of the typical flow pattern in lead cooled primary system by means of similar approaches, a feasibility analysis will be carried out with the aim of investigating the OpenModelica support to STH V&V practices.

The proposed internship will contribute to identify experimental measurement campaigns or test cases available in literature for Liquid Metal Fast Reactors (LMFR), or to valorize those already identified, and to prepare the appropriate pre- and post-processing data for calculations and associated results for OpenModelica.

Those comparisons will be used firstly to assess closure laws and flow pattern regimes. Parametric and sensitivity analysis is performed in order to understand the differences among assessed closure laws, their validity domain and the possible extrapolation to reactor operating conditions. As optional work, dimentional analisys may be used to justify the correlation semi-empirical forms and to propose possible improvements.

The target is to meet the *new*cleo Codes & Methods (C&M) department needs in term of codes V&V. Such methodology will be tested and deployed against open literature mock-ups with available measurements and lay the groundwork for new experimental campaigns ongoing or foreseen by *new*cleo.

Work plan

The work plan is structured according to the following items:

1. Review of the state-of-the-art in the usage of system thermal-hydraulic codes for LFRs modelling or process tools.
2. Getting started with the simulation of the simplified loop representative of LFR's primary system model with ATHLET.
3. Reproduction of the same simplified model with OpenModelica.
4. Comprehension, assessment and comparison of the behavior of above-mentioned codes on such simplified configuration.
5. Improvement of the full scale primary system input deck with correlations and models assessed in the previous activities trying to retrieve from the OpenModelica model as much information as possible for improving the corresponding ATHLET model.
6. Identification of the layout of some possible tool chains to exploit at best the thermal-hydraulic software used in this work.
7. Drafting of a final report.

Applicant profile

Master's student in Nuclear Engineering. Students of theoretical Physics and applied Mathematics will also be considered for the position.

Background: *fundamentals of reactor physics and multiphysics approaches, but also computational thermal-hydraulic*.

References

[1] Ferry Roelofs. *Thermal hydraulics aspects of liquid metal cooled nuclear reactors*. Woodhead Publishing, 2018.

[2] N. E. Todreas and M. S. Kazimi. *Nuclear systems Volume I: Thermal hydraulic fundamentals*. CRC press, 2021.

[3] N. E. Todreas, M. S. Kazimi, and M. Massoud. *Nuclear systems Volume II: Elements of thermal hydraulic design*. CRC press, 2021.

[4] Barbara Calgaro and Barbara Vezzoni. Advanced Couplings and Multiphysics Sensitivity Analysis Supporting the Operation and the Design of Existing and Innovative Reactors. *Energies*, 15:3341, 2022.

Création d'un outil de prédimensionnement mécanique et thermomécanique selon les critères du RCC-MRx

Grabon Stanislas*[1]

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1er Octobre, 2024

– Offre de stage –

(ID No. 1005678)

Mots-clés — Mécanique, calcul, Ansys, RCC-MRx, codes de calculs scientifiques, calcul par éléments finis, Python
Sujets — Ingénierie mécanique, mode de ruine, RCC-MRx, calcul, critère, développement d'outil

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Lieu *new*cleo SA – Tour Silex[2], 9 rue des Cuirassiers - 69003 Lyon, France

Date de début mars 2025

Durée 5–6 mois

Contexte

Le réacteur à neutrons rapides refroidi au plomb (Lead Fast Reactor) développé par *new*cleo doit respecter les normes en vigueur et être validé par l'Autorité de Sûreté nucléaire (ASN). Suivre les recommandations du code RCC-MRx est l'un des aspects qui nous permettra d'atteindre cet objectif.

Le code RCC-MRx propose notamment des critères qui doivent être vérifiés afin de prévenir différents modes de ruine dans les structures. Cette validation est effectuée par le service calcul qui remonte les informations au service de conception. Ainsi tout au long du développement du réacteur, une bonne communication entre les différents services est primordiale pour réduire le nombre d'itérations du design et prévenir les risques le plus en amont possible.

Description

Le but de ce stage est de créer un outil simplifié pour estimer les marges par rapport aux critères du code RCC-MRx afin d'aider l'équipe de conception à réduire le nombre

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d'itérations lors des phases de design. Une première phase de prise en main du sujet vous conduira à établir un cahier des charges et à prendre connaissance du code RCC-MRx.
Le cœur du sujet sera la création d'un outil de calcul simple d'utilisation et utilisant des formules analytiques pour estimer des contraintes et les différentes grandeurs physiques entrant en compte dans le calcul des critères (comme par exemple : les contraintes dans l'épaisseur d'une plaque soumise à un gradient de température, celles dans une cuve sous pression etc…). Cet outil pourra prendre la forme d'un code python, VBA ou bien encore de feuilles d'abaque consultables.

Dans un second temps, viendra la phase de qualification de l'outil en comparant ces résultats à ceux obtenus sur des cas simples en utilisant le logiciel Ansys (ANSYS APDL 2023 R2) ainsi que le post processeur *new*cleo, qui est un programme python.

Cet outil pourra évoluer pour prendre en comptes plus de situations et différents modes de ruines et sera utilisé par les équipes de *new*cleo lors des prochains choix de design.

Feuille de route

- Lecture de documents techniques internes pour comprendre le projet.
- Prise en main du code RCC-MRx.
- Echanges avec l'équipe de conception, établissement d'un cahier des charges.
- Création d'un outil de calcul (Python ou VBA et/ou abaques).
- Qualification de l'outil à travers des cas test, utilisation d'ANSYS et du post-processeur *new*cleo.
- Préparation d'un rapport technique.

Profil du candidat

- Formation en école d'ingénieur avec spécialisation en génie nucléaire ou mécanique.
- Connaissance de l'environnement informatique pour des calculs scientifiques (Calcul par élément finis, environnement linux, langage informatique par ex. Python ou VBA, la maitrise de GIT est un plus).
- Maîtrise de l'anglais, l'italien est un plus.
- Vous aimez la technique et les sciences en général.
- Vous êtes une personne confiante et vous vous efforcez chaque jour à être digne de la confiance de vos collègues.
- Vous cherchez activement à être une personne curieuse, raisonnable, attentionnée et engagée.

Références

[1] RCC-MRx Design and Construction Rules for Mechanical Components of Nuclear Installations: High Temperature, Research and Fusion Reactors; 2022 edition
[2] https://ansyshelp.ansys.com/public/account/secured?returnurl=/Views/Secured/prod_page.html?pn=Mechanical%20APDL&pid=MechanicalAPDL&lang=en&prodver=24.2

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Etudes de radioprotection en support à la conception du réacteur LFR

Anne-Claire Scholer*[1]

[1]newcleo SA, Tour Silex[2], 9 rue des Cuirassiers - 69003 Lyon, France

9 septembre 2024

– *Proposition de stage* –

(N° ID : 1005685)

Mots-clés — radioprotection, flux neutroniques, codes de calculs scientifiques, Python
Sujets — études de radioprotection dans et autour de la cuve du réacteur et dans les locaux du bâtiment réacteur.

Lieu	*new*cleo SA – Tour Silex[2], 9 rue des Cuirassiers - 69003 Lyon, France
Date de début	premier trimestre 2025
Durée	4–6 mois

Contexte

Le réacteur à neutrons rapides refroidi au plomb (Lead Fast Reactor) développé par newcleo est un concept intégré. Le caloporteur plomb reste dans la cuve primaire. Ainsi les inventaires radiologiques restent principalement dans la cuve primaire ce qui est favorable pour les problématiques de radioprotection. Des études de radioprotection doivent démontrer le respect des contraintes de dose qui seront fixées pour les travailleurs.

Une partie du flux neutronique du cœur et de ses assemblages combustibles se propage dans la cuve, cette propagation doit être finement calculée afin de calculer ensuite l'activation et l'inventaire radiologique de tout l'environnement du cœur (assemblages combustibles, plomb, gaz du ciel de pile, structures et composants de la cuve primaire…). Des calculs de débit d'équivalent de dose (DeD) sont ensuite réalisés dans l'environnement de la cuve, à proximité de composants manutentionnés ou autour des tuyauteries. Dans certains cas, des protections neutroniques ou biologiques devront être dimensionnées.

L'équipe radioprotection de newcleo travaille sur toute cette séquence : identification des sources et inventaires radiologiques, calculs de propagation du flux neutronique et calculs de flux gamma,

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calculs d'activation, calculs de débit d'équivalent de dose, dimensionnement de protections neutroniques et biologiques, établissement des cartes de zonage radiologique.

Description

L'objectif du stage est de contribuer à ces études de radioprotection autour de la cuve du réacteur et dans les locaux du bâtiments réacteur (selon la réglementation [3] et [4]).

Votre mission consiste à prendre en main les outils de calcul pour la radio protection : calculs de flux neutroniques, propagation, activation (codes Monte Carlo principalement tels que [1] et [2], par exemple, et codes déterministes ponctuellement et codes d'évolution[†]) avec les bibliothèques de données nucléaires (par ex [5]).

Ensuite, vous contribuez à la modélisation de certaines parties du réacteur ou de son environnement.

Enfin, vous appliquez ces modèles pour évaluer les inventaires radiologiques, les flux, les activations et les débits d'équivalents de dose pour différentes configurations, et pour des situations de fonctionnement variées. Vous proposez des optimisations et apportez votre soutien à la conception avec comme objectif final de respecter les contraintes de dose pour les travailleurs.

Les résultats produits complèteront les informations nécessaires pour le développement du réacteur développé par newcleo.

Feuille de route

- Lecture de documents techniques internes pour comprendre le projet.
- Prise en main des codes de calculs scientifiques (Monte Carlo et code d'évolution).
- Préparation des jeux de données de calculs, réalisation des calculs et études de sensibilités.
- Préparation d'un rapport technique.

Profil du candidat

- Formation en école d'ingénieur dans le domaine de la physique avec spécialisation en génie nucléaire, neutronique ou radioprotection.
- Connaissance de l'environnement informatique pour des calculs scientifiques (environnement linux, langage informatique par ex-Python).
- Maîtrise de l'anglais, l'italien est un plus.
- Vous êtes une personne confiante et vous vous efforcez chaque jour à être digne de la confiance de vos collègues.
- Vous cherchez activement à être une personne curieuse, raisonnable, attentionnée et engagée.

[†] FISPACT – FISPACT-II Wiki (ukaea.uk) https://fispact.ukaea.uk/fr/

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Références

[1] Paul K. Romano, Nicholas E. Horelik, Bryan R. Herman, Adam G. Nelson, Benoit Forget, and Kord Smith, “OpenMC: A State-of-the-Art Monte Carlo Code for Research and Development,” Ann. Nucl. Energy, 82, 90–97 (2015).

[2] Jaakko Leppänen et al. The Serpent Monte Carlo code: Status, development and applications in 2013. Annals of Nuclear Energy, 82:142–150, 2015

[3] Arrêté du 15 mai 2006 modifié relatif aux conditions de délimitation et de signalisation des zones surveillées et contrôlées dites zones délimitées compte tenu de l’exposition aux rayonnements ionisants, NOR : SOCT0611077A.

[4] ICRP, 1996. Conversion Coefficients for use in Radiological Protection against External Radiation. ICRP Publication 74. Ann. ICRP 26 (3-4).

[5] D.A. Brown, M.B. Chadwick, R. Capote, et al., "ENDF/B-VIII.0: The 8th Major Release of the Nuclear Reaction Data Library with CIELO-project Cross Sections, New Standards and Thermal Scattering Data", Nuclear Data Sheets, 148: pp. 1-142 (2018).

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Études de sensibilité sur l'activation en support à l'ingénierie du réacteur

Thomas Fréněhard[1], Chloé Largeron[1], Anne-Claire Scholer[*1]

[1]*newcleo SA, Tour Silex[2], 9 rue des Cuirassiers - 69003 Lyon, France*

26 septembre 2024

– *Proposition de stage* –

(N° ID : 1005772)

Mots-clés — Radioprotection, activation, codes de calculs scientifiques, Python
Sujets — Études de sensibilités pour l'activation des matériaux dans le réacteur

Lieu	*new*cleo SA – Tour Silex[2], 9 rue des Cuirassiers - 69003 Lyon, France
Date de début	premier trimestre 2025
Durée	4–6 mois

Contexte

Le réacteur à neutrons rapides refroidi au plomb (Lead Fast Reactor) développé par *new*cleo est un concept intégré. Le caloporteur plomb reste dans la cuve primaire. Ainsi les inventaires radiologiques restent principalement dans la cuve primaire ce qui est favorable pour les problématiques de radioprotection. Des études de radioprotection doivent démontrer le respect des contraintes de dose qui seront fixées pour les travailleurs.

Une partie du flux neutronique du cœur et de ses assemblages combustibles se propage dans la cuve, cette propagation doit être finement calculée afin de calculer ensuite l'activation et l'inventaire radiologique de tout l'environnement du cœur (assemblages combustibles, plomb, gaz du ciel de pile, structures et composants de la cuve primaire…). Des calculs de débit d'équivalent de dose (DeD) sont ensuite réalisés dans l'environnement de la cuve, à proximité de composants manutentionnés ou autour des tuyauteries. Dans certains cas, des protections neutroniques ou biologiques devront être dimensionnées.

L'équipe radioprotection de *new*cleo travaille sur toute cette séquence : identification des sources et inventaires radiologiques, calculs de propagation du flux neutronique et calculs de flux gamma, calculs d'activation, calculs de débit d'équivalent de dose, dimensionnement de protections neutroniques et biologiques, établissement des cartes de zonage radiologique.

[*] Contact : anne-claire.scholer@newcleo.com

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Description

L'objectif du stage est de contribuer à ces études de radioprotection en étudiant la sensibilité de différents paramètres à l'activation, c'est-à-dire, la création de nucléides sous irradiation, ainsi qu'à la décroissance engendrée dans les matériaux selon la sensibilité aux flux (intensité et spectre) et aux conditions d'irradiation.

Votre mission consiste à prendre en main les outils de calcul pour l'activation (code d'évolution FISPACT principalement [1] mais aussi possibilité d'utiliser des codes Monte Carlo comme [2] et [3] par exemple), le tout en rapport avec les bibliothèques de données nucléaires (par ex [4]).

Ensuite, vous réaliserez des analyses de sensibilités sur les matériaux (composition, radionucléides d'intérêt) et leur localisation (intensité et spectre du flux neutronique). Vous étudierez l'impact des variations de spectre et d'intensité du flux sur la production des radionucléides, afin d'aider à l'optimisation des protections neutroniques à apporter, analyser la sensibilité à la composition initiale des matériaux en fonction des chaînes d'activation et de décroissances, propager les incertitudes dans la chaine de calculs, pour consolider les schémas de calculs existants et participer à leur expansion.
Vous participerez ainsi à la mise à jour des méthodes liées à l'étude de l'activation en liaison avec les besoins des équipes concernées (typiquement la sûreté, la gestion des déchets…).

Vous proposez des optimisations et apportez votre soutien à la conception avec comme objectif final de respecter les contraintes multiples pouvant être associées à la radioprotection, aux rejets radiologiques, à l'exposition des travailleurs…

Les résultats produits complèteront les informations nécessaires pour le développement du réacteur développé par *new*cleo.

Feuille de route

- Lecture de documents techniques internes pour comprendre le projet.
- Prise en main des codes de calculs scientifiques (code d'évolution et Monte Carlo).
- Collecte des besoins et restitutions des résultats auprès des équipes projets en interface.
- Préparation des jeux de données de calculs, réalisation des calculs, études de sensibilités et analyses des résultats.
- Préparation d'un rapport technique.

Profil du candidat

- Formation en école d'ingénieur ou équivalent dans le domaine de la physique avec spécialisation en génie nucléaire, neutronique ou radioprotection.
- Connaissance de l'environnement informatique pour des calculs scientifiques (environnement linux, langage informatique par ex-Python).
- Maîtrise de l'anglais, l'italien est un plus.
- Vous êtes une personne confiante et vous vous efforcez chaque jour à être digne de la confiance de vos collègues.
- Vous cherchez activement à être une personne curieuse, raisonnable, attentionnée et engagée.

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Références

[1] FISPACT – FISPACT-II Wiki (ukaea.uk) https://fispact.ukaea.uk/fr/
[2] Paul K. Romano, Nicholas E. Horelik, Bryan R. Herman, Adam G. Nelson, Benoit Forget, and Kord Smith, “OpenMC: A State-of-the-Art Monte Carlo Code for Research and Development,” Ann. Nucl. Energy, 82, 90–97 (2015).
[3] Jaakko Leppänen et al. The Serpent Monte Carlo code: Status, development and applications in 2013. Annals of Nuclear Energy, 82:142–150, 2015
[4] D.A. Brown, M.B. Chadwick, R. Capote, et al., "ENDF/B-VIII.0: The 8th Major Release of the Nuclear Reaction Data Library with CIELO-project Cross Sections, New Standards and Thermal Scattering Data", Nuclear Data Sheets, 148: pp. 1-142 (2018).

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Criticality analysis for LFR fuel assemblies storage with Monte Carlo computer codes

Matteo Zammataro[1], Anne-Claire Scholer[2], and Daniele Tomatis *[1]

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November 12, 2024

– Internship proposal –
(ID No. 1005824)

***Keywords* —** Monte Carlo, safety, criticality
***Topics* —** Numerical simulation, modeling, criticality analysis

Location	*new*cleo SpA, C.so Stati Uniti 38, 10129 Torino, Italy
Starting date	To be defined
Duration	4-6 months

Context

*new*cleo is developing innovative Generation IV lead-cooled small modular reactors using mixed oxide fuel (MOX) as nuclear fuel. The storage of fresh and spent fuel assemblies will take place in a dedicated room within the reactor building, ensuring adequate safety level for radiation protection and criticality. The design of the building requires criticality studies with different configurations of fuel elements, so that operation can happen far from criticality and in safe conditions. These analyses can be performed by using Monte Carlo computer codes. The internship focuses on the criticality analysis of the fuel storage rooms using the Monte Carlo codes OpenMC [1] and SERPENT II [2].

Description

The small modular LFRs developed by *new*cleo will use MOX as their nuclear fuel. The fuel is organized in hexagonal fuel assemblies that are stored in the reactor building before and after use in the reactor core. For the design of the fuel storage compartments, it is crucial to

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ensure safe operation sufficiently far from criticality. This condition is verified by solving many k-eigenvalue problems, where k is the neutron multiplication factor [3]. The factors influencing k are the layout of the fuel assemblies positioning, the air humidity in the fuel storage room [4] and the neutron reflectivity of the walls. Criticality could also be achieved after unwanted or accidental operations, for example after the fall of a single fuel assembly inside the storage room.
This type of analysis is typically performed using Monte Carlo codes, which requires fewer approximations with respect to deterministic computer codes. During the internship, the student will use the Monte Carlo transport codes OpenMC and SERPENT II to create a model of the fuel storage rooms and perform criticality analysis. Emphasis will be given to the sensitivity analysis of the geometric layout, to the amount of water mist and to the optimization of the model, taking into account simplifications of the geometry where possible.
This internship will result in a better understanding of neutronic and criticality analysis. The student will become proficient in the use of OpenMC and SERPENT II and will also learn how to program in Python. At the end of the internship, the student will write a technical report analyzing the results of the numerical simulations. The student will be supervised by the members of the Codes and Methods group of *new*cleo.

Work plan

During the internship, the student will be introduced to the OpenMC open source Monte Carlo transport code and to the SERPENT II Monte Carlo code for the simulation of stationary neutron problems featuring fuel elements in the fuel storage room in eigenvalue calculation mode. The student will set up input decks for the fresh and spent fuel storage room in different configurations.

The expected working plan is detailed in the following:

a) Literature review of fuel storage plants
b) Analysis of similar study cases and discussion of the problem
c) OpenMC introduction and training
d) SERPENT II introduction and training
e) Set up of spent and fresh fuel rooms input deck in different configurations
f) Analysis of the results
g) Preparation of a technical report

Applicant profile

Master or PhD student in Nuclear Engineering, Applied Mathematics and Physics.
Background: fundamentals in reactor physics and radiation transport.
Required computer skills: A good knowledge of Python and Linux operating systems (or willingness to learn). Knowledge of the MCNP code and LaTeX editing are appreciated, but not required.

References

[1] Paul K. Romano et al. OpenMC: A state-of-the-art Monte Carlo code for research and development. *Annals of Nuclear Energy*, 82:90–97, 2015. Joint International Conference on Supercomputing in Nuclear Applications and Monte Carlo 2013, SNA + MC 2013. Pluri- and Trans-disciplinarity, Towards New Modeling and Numerical Simulation Paradigms.

[2] Jaakko Leppänen et al. The Serpent Monte Carlo code: Status, development and applications in 2013. *Annals of Nuclear Energy*, 82:142–150, 2015.

[3] U.S. Nuclear Regulatory Commission NUREG-0800. Criticality Safety of Fresh and Spent Fuel Storage and Handling. 2007.

[4] Sungwook Choi, Sungmin Kim, and Bon-Seung Koo. Criticality Analysis for SMART Fuel Storage. Transactions of the Korean Nuclear Society Autumn Meeting Yeosu, Korea, October 25-26, 2018.

Development of a fire ignition frequency database for the Probabilistic Safety Assessment of newcleo's LFR

Guido Gerra *[1] and Georgi Georgiev[2]

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October 10, 2024

– *Internship proposal* –

(ID No. 1005899)

Keywords — Probabilistic Safety Assessment, Risk Analysis, Nuclear Safety
Topics — Internal Fire Risk Analysis, Fire Frequency Data Analysis, Analysis Tools Development

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Location	*new*cleo SA – Tour Silex[2], 9 rue des Cuirassiers - 69003 Lyon, France
Starting date	first quarter 2025
Duration	4–6 months

Context

The Probabilistic Safety Assessment (PSA) is a systematic approach used to evaluate the safety of nuclear reactors by assessing the likelihood and consequences of potential accidents. The PSA is an integral part of the safety demonstration of a reactor. At *new*cleo we are following a graded approach towards the development of a comprehensive PSA for our Lead-cooled Fast Reactors (LFR) in order to support the design and, later on, site licensing of our technology.
While PSA has a set of well-established methods and techniques tested on a wide range of nuclear reactors, their application to LFRs is a novel endeavour. Hence, there are opportunities for development of new methods and techniques to streamline the analysis process.

Description

The goal of this internship is the development of a fire ignition frequency database for *new*cleo LFR. This task consists of developing the method and tools for estimating the likelihood of fire starting at specified zones within the power station boundaries. The generic

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guidance for this task was developed by the Electric Power Research Institute (EPRI) [1.] in the United States and was endorsed by the U.S. Nuclear Regulatory Commission [2.]. It consists of reviewing the potential sources of fire on the power plant and comparing against a list of generic fire frequency data sets. The task consists primarily of data processing either in spreadsheets or SQL databases with the end results forming part of a technical report.

Work plan

a) Generic fire event data review and screening.
b) Establishing equipment (ignition source) count by compartment.
c) Apportioning of ignition frequencies according to compartment-specific configurations.
d) Uncertainty considerations in the fire frequencies.
e) Organising the process in a database suitable for regular updates following reactor/layout design evolution.
f) Drafting a final report.

Applicant profile

The ideal candidate is a nuclear/mechanical/electrical engineering or physics student, with a good knowledge of typical power plant components (such as pumps, valves, electric commutation equipment or I&C).
Some data analysis experience using SQL would be beneficial but not strictly required as the necessary initial training will be provided.

References

[1.] EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities, Final Report, (NUREG/CR-6850, EPRI 1011989) (https://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6850/index.html)

[2.] Nuclear Power Plant Fire Ignition Frequency and Non-Suppression Probability Estimation Using the Updated Fire Events Database: United States Fire Event Experience Through 2009(NUREG-2169, EPRI 3002002936) (https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr2169/index.html#pub-info)

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Fault Tree Analysis Automation Tools for the Probabilistic Safety Assessment of newcleo's LFR

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October 9, 2024

– *Internship proposal* –

(ID No. 1005900)

***Keywords* —** Probabilistic Safety Assessment, Risk Analysis, Nuclear Safety
***Topics* —** System Analysis, Fault Tree Analysis, Analysis Tools Development

Location	*new*cleo SA – Tour Silex[2], 9 rue des Cuirassiers - 69003 Lyon, France
Starting date	first quarter 2025
Duration	4–6 months

Context

The Probabilistic Safety Assessment (PSA) is a systematic approach used to evaluate the safety of nuclear reactors by assessing the likelihood and consequences of potential accidents. The PSA is an integral part of the safety demonstration of a reactor. At *new*cleo we are following a graded approach towards the development of a comprehensive PSA for our Lead-cooled Fast Reactors (LFR) in order to support the design licensing and, later on, site licensing of our technology.
While PSA has a set of well-established methods and techniques tested on a wide range of nuclear reactors, their application to LFRs is a novel endeavour. Hence, there are opportunities for development of new methods and techniques to streamline the analysis process.

Description

The development of a new reactor design requires the creation of a large number of Fault Trees (FT) to quantify the reliability of the reactor systems. This task needs to be optimized by the development of Python codes that automate the conversion of process and system diagrams into FTs. The activities to be performed during the internship include writing code

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to optimise FT generations process, testing and integrating with the existing code modules, and writing code documentation into a technical report.

Work plan

a) Identify component failure modes.
b) Create a computer code to process the input data and generate FTs.
c) Program the data input/output interfaces with existing computer programs.
d) Testing and documentation.
e) Draft a final technical report.

Applicant profile

Engineering, physics or computer science student with a strong background in Python programming.
Knowledge of data processing packages (e.g. pandas) is an advantage.
Some basic knowledge of power plant components would be beneficial.

References

[1.] NUREG -0492, FAULT TREE HANDBOOK, U.S. NRC, JANUARY 1981

[2.] G. van Rossum, BA. Coghlan, *PEP 8 – Style Guide for Python Code*, 2001, HTTPS://PEPS.PYTHON.ORG/PEP-0008/

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Probabilistic Solution to Fire Models in the Safety Assessment of a Lead-cooled Fast Reactor

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October 9, 2024

– *Internship proposal* –

(ID No. 1005901)

***Keywords* —** Probabilistic Safety Assessment, Risk Analysis, Nuclear Safety
***Topics* —** Internal Fire Risk Analysis, Fire Frequency Data Analysis, Analysis Tools Development

Location	*new*cleo SA – Tour Silex[2], 9 rue des Cuirassiers - 69003 Lyon, France
Starting date	first quarter 2025
Duration	4–6 months

Context

Probabilistic Safety Assessment (PSA) is a systematic method for evaluating the safety of nuclear reactors by analysing the probabilities and consequences of potential accidents. It plays a crucial role in demonstrating the safety of a reactor. At *new*cleo, we are adopting a graded approach to develop a comprehensive PSA for our Lead-cooled Fast Reactors (LFRs) to support the design and site licensing of our technology.
Although PSA methods and techniques are well-established for various nuclear reactors, applying them to LFRs represents a novel challenge. This presents opportunities to develop new methods and techniques that can enhance and streamline the analysis process.

Description

Deterministic fire modelling relies on established methods but typically generates a single, precise estimate based on specific initial and boundary conditions. These models often overlook how uncertainties in input data affect the results. From a PSA perspective, it is crucial that simulation models consider a broad range of input data and uncertainties, ultimately producing a probabilistic distribution of outcomes.

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The goal of this internship is to develop a fire model that accounts for known parametric uncertainties. This involves using a chosen sampling technique to run the model, followed by statistical analysis of the output to derive a range of results that reflect the uncertainties involved.

Work plan

a) Identify the input parameters that may have uncertainties.
b) Characterize these uncertainties for propagation within the model.
c) Choose a suitable sampling technique (such as Monte Carlo or Latin Hypercube).
d) Develop a fire model for a specific fire compartment.
e) Execute the calculations.
f) Analyse and interpret the results after the calculations.
g) Draft a final technical report.

Applicant profile

Engineering or physics student with a background in process simulations.
Some basic knowledge of statistics is beneficial, though not essential as the basic training materials are available.
Some knowledge of computer programming in Python will be an advantage.

References

[1.] Nuclear Power Plant Fire Modeling Analysis Guidelines (NPP FIRE MAG) — Final Report (NUREG-1934, EPRI 1023259) (https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1934/index.html#pubinfo)

[2.] Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decisionmaking, Final Report (NUREG-1855, Revision 1) (https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1855/r1/index.html)

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Conception d'un échangeur de chaleur pour l'évacuation de la puissance résiduelle

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2 septembre 2024

– *Proposition de stage* –

(N° ID : 1005978)

Mots-clés — Conception, SolidWorks, échangeur
Sujets — Conception mécanique, échangeur de chaleur, prédimensionnement thermique et mécanique

Lieu	*new*cleo SA – Tour Silex[2], 9 rue des Cuirassiers - 69003 Lyon, France
Date de début	premier trimestre 2025
Durée	4–6 mois

Contexte

L'évacuation de la puissance résiduelle constitue l'une des trois fonctions fondamentales de sûreté pour un réacteur nucléaire. Elle permet de maintenir le réacteur à des niveaux de température acceptables dans les conditions de fonctionnement normales et/ou accidentelles.
Plusieurs systèmes sont mis en place pour assurer cette fonction. Afin de garantir un haut niveau d'indépendance entre ces systèmes, *new*cleo a fait le choix d'implémenter un système permettant le refroidissement par l'extérieur de la cuve principale du réacteur.

L'échangeur principale de ce système présente une conception complexe qui doit répondre à de nombreuses exigences, du fait de sa position et de l'importance de la fonction à laquelle il contribue.

Description

Le stage consistera à concevoir l'échangeur d'évacuation de la puissance résiduelle par l'extérieur de la cuve principales des réacteurs LFR de *new*cleo.
Les activités à réaliser comprendront :

- De la conception mécanique assistée par ordinateur (CAO – Solidworks)

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  - o Proposition de principes de conception répondant à l'ensemble des exigences
    - Agencement des tubes,
    - Principes de supportage,
    - …
  - o Création de maquette 3D
- Des calculs de prédimensionnement thermiques (évaluation préliminaire des performances thermiques de l'échangeur) à l'aide d'outil analytiques internes (Excel VBA)
- Des calculs de prédimensionnement mécaniques : Statiques et dynamiques (SolidWorks)

Feuille de route

a) Analyse fonctionnelle
b) Proposition de principes de conception
c) Création de maquette 3D
d) Calculs thermiques
e) Calculs mécaniques
f) Préparation d'un rapport technique.

Profil du candidat

Etudiant en master d'ingénierie mécanique.
Compétences :

- Conception mécanique.
- Maitrise de logiciel CAO.
- Calcul mécanique.
- Autonomie.
- Force de proposition.

Références

[1] D. Lisowski, Q. Lv, B. Alexandreanu, Y. Chen, R. Hu, T. Sofu., *An Overview of Non-LWR Vessel Cooling Systems for Passive Decay Heat Removal (Technical Letter Final report)*, 2021.

[2] M. Tarantino, *ALFRED overview and safety features*. 2021.

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Calculation of neutron activation under cyclic exposure in LFR

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November 14, 2024

– Internship proposal –

(ID No. 1006013)

***Keywords* —** LFR, neutron activation, depletion and transmutation, cyclic exposure
***Topics* —** Reactor physics and analysis, radiation dose, reactor analysis, physical modeling

Location	C.so Stati Uniti 38, Torino (TO), Italy
Starting date	As soon as possible
Duration	5–6 months

Context

*new*cleo is developing innovative small modular reactors that use lead as a coolant. The molten lead flows through the reactor core to cool it, and is then recirculated in an outer loop. This system periodically exposes the lead coolant to high neutron fluxes. Lead may contain impurities from the manufacturing process or because of chemical corrosion occurring within the components of the reactor during its lifetime. Activation studies are required to quantify the harmfulness of the irradiated lead coolant and to assess the maximum amount of impurities that can be tolerated at the reactor startup. The internship focuses on developing a methodology to calculate the lead activation under periodic, or cyclic, neutron flux exposure in *new*cleo LFRs. The mathematical framework of the methodology could also be applied to other problems showing activation of radioactive material during reactor operation.

Description

In nuclear reactors, the coolant is exposed to high neutron flux during normal reactor operation. This exposure leads to the formation of activation products. Therefore, activation studies must

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be performed to estimate the exposure and dose rates of the coolant after being irradiated in the reactor. These dose rate data are used by the engineering teams to design radiation shielding components and to estimate potential radiation damage to steel structures.
The lead-cooled SMR designed by newcleo is the subject of this study. In a pool reactor, lead flows through the reactor core where it is exposed to a high neutron flux. It is then recirculated in an outer loop with a lower neutron flux.
The evolution of a material under neutron irradiation by transmutation and radioactive decay is described by the Bateman equation:

$$\frac{d\mathbf{n}}{dt} = \mathbf{A}(\mathbf{n}(t), t)\mathbf{n}(t), \qquad \mathbf{n}(t=0) = \mathbf{n}_0 \tag{1}$$

where $\mathbf{n}(t)$ is the vector of nuclide concentrations at time t, and $\mathbf{A}(\mathbf{n}(t), t)$ is a matrix containing the decay constants and microscopic reaction rates, also known as depletion matrix. Indeed, the build-up and depletion of harmful isotopes in the reactor coolant is strongly correlated with the reaction rates, which vary with the intensity and spectrum of the neutron flux, and must be known as an input to the problem [1]. Computer codes that solve the neutron transport problem are used to calculate the rates in advance in realistic core configurations. The OpenMC Monte Carlo transport code [2] will be used for the simulation of the neutron transport and the calculation of the reaction rates in the zones of interest.
Although mass inventory calculations under the influence of decay and transmutation are generally quite fast, their successive execution reproducing cyclic exposure can bring to unacceptable runtime because of a very high number of loop passages. The solution of 1 for the irradiation of a material with constant neutron flux for a time interval h is given by:

$$\mathbf{n}(t_0 + h) = \mathbf{n}(t_0) exp\left[\mathbf{A}(\mathbf{n}(t_0), t_0)h\right] \tag{2}$$

While the solution of 2 requires the solution of a single matrix exponential, an inventory analysis in circulating conditions requires the solution of many, especially after partitioning the reactor in zones characterized by different magnitude of the same reaction rates. The simplification of the depletion chains, in this context, is necessary to reduce the dimension of **A** and to avoid possible ill-conditioning due to a large amount of nuclides varying with very different time scales. Simplified chains also allow a deeper understanding of the physics involved in the problem. Solutions obtained with the FISPACT II code [3] are used as a reference to assess the reliability of the results.
The methodology developed for lead activation could be applied in the future to the evolution of any circulating fluid in the reactor, such as secondary water in the steam generators.
During the internship, the student will be introduced to the physics and engineering of the LFR reactors, acquiring notions and developing skills in mathematical modeling, particle transport and evolution problems. The student will learn how to use OpenMC and FISPACT II, learning Python programming too. At the end of the internship, the student will write a technical report on the analysis of the results from the numerical simulations.
The student will be followed by the Codes and Methods group members of *new*cleo.

Work plan

During the internship, the student will be introduced to the open source Monte Carlo transport code OpenMC for calculating neutron and photon fluxes in specific zones of interest. The student will also set up input decks for the lead activation study. The internship will investigate and

model a complex problem exploring theoretical aspects of neutron transport and transmutation. Fundamental aspects of Monte Carlo modeling and simulation of nuclear reactors, as well as important topics related to radiation protection, will also be covered during the internship. Finally, the goal is to enhance the student's Python programming skills and confidence in the modeling and analysis of complex phenomena.
The expected working plan is detailed in the following:

a) Literature review of activation problems
b) Analysis of similar study cases and discussion of the problem
c) OpenMC and FISPACT II introduction and training
d) Calculation of neutron flux and reaction rates in specific areas using an existing OpenMC full reactor model
e) Setup of the activation calculation
f) Analysis of the results
g) Preparation of a technical report

Applicant profile

Master or PhD student in Nuclear Engineering, Applied Mathematics and Physics.
Background: fundamentals in reactor physics.
Required computer skills: A good knowledge of Python and Linux operating systems (or willingness to learn). Knowledge of LaTeX editing is appreciated, but not required.

References

[1] Fredrik Dehlin and Janne Wallenius. Activation analysis of the lead coolant in SUNRISE-LFR. *Nuclear Engineering and Design*, 414:112503, 2023.

[2] Paul K. Romano, Nicholas E. Horelik, Bryan R. Herman, Adam G. Nelson, Benoit Forget, and Kord Smith. OpenMC: A state-of-the-art Monte Carlo code for research and development. *Annals of Nuclear Energy*, 82:90–97, 2015. Joint International Conference on Supercomputing in Nuclear Applications and Monte Carlo 2013, SNA + MC 2013. Pluri- and Trans-disciplinarity, Towards New Modeling and Numerical Simulation Paradigms.

[3] FISPACT-II: An Advanced Simulation System for Activation, Transmutation and Material Modelling. *Nuclear Data Sheets*, 139:77–137, 2017. Special Issue on Nuclear Reaction Data.

Conception mécanique du circuit primaire H/F

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2 octobre 2024

– *Proposition de stage* –

(ID No. 1006030)

***Mots Clefs* –** Circuit primaire, structure de supportage
***Sujets* –** Conception mécanique structure de supportage

Lieu	*new*cleo SA – Tour Silex[2], 9 rue des Cuirassiers - 69003 Lyon, France
Date de début	premier trimestre 2025
Durée	5–6 mois

Contexte

Le réacteur à neutrons rapides refroidi au plomb (Lead Fast Reactor) développé par *new*cleo est un concept intégré. Cela induit un inventaire en plomb important au sein de la cuve primaire, avec un point d'attention important concernant les structures de supportage et en particulier la justification sismique de celle-ci.

Description

Au sein du service de conception du circuit primaire du réacteur, vous serez amené à vous familiariser avec les pratiques en vigueur dans le nucléaire, (sureté, code de construction, requis sismiques).

Puis accompagné de l'équipe conception de Newcleo vous pourrez mettre en pratique ces notions afin de participer à la proposition d'un système de supportage du réacteur. Vous serez également amené utiliser vos acquis scolaires afin de justifier sommairement ce système de supportage vis-à-vis de contraintes spécifiques liées au réacteurs (requis sismiques et de températures, requis d'extrapolation au LFR 200).

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Feuille de route

- Conception et prédimensionnement de pièces mécaniques selon le code de construction applicable [1].
- Bibliographie, conception et calcul du système de supportage du réacteur.
- Préparation d'un rapport technique.

Profil du candidat

- 3ième année de formation école ingénieur.
- Conception mécanique.
- Maitrise des outils de CAO, Solidworks est un plus.
- Transfert thermique.
- Calculs éléments finis.
- Profil curieux, autonome et avec une appétence pour la conception mécanique.
- Maîtrise de l'anglais, l'italien est un plus.

Références:

[1] RCC MRx - Règles de conception et de construction des matériels mécaniques des installations nucléaires hautes températures, expérimentales et de fusion. ed. 2022.