List of student internships offered by new*cleo*

–academic year–

2024–2025

June 1, 2025

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

Daniele Tomatis*[1], Giuseppe Francesco Nallo[2], and Fabio Moretti[1]

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May 27, 2025

– Internship proposal –
(ID No. 1000073)

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

Location	*new*cleo SrL, 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.

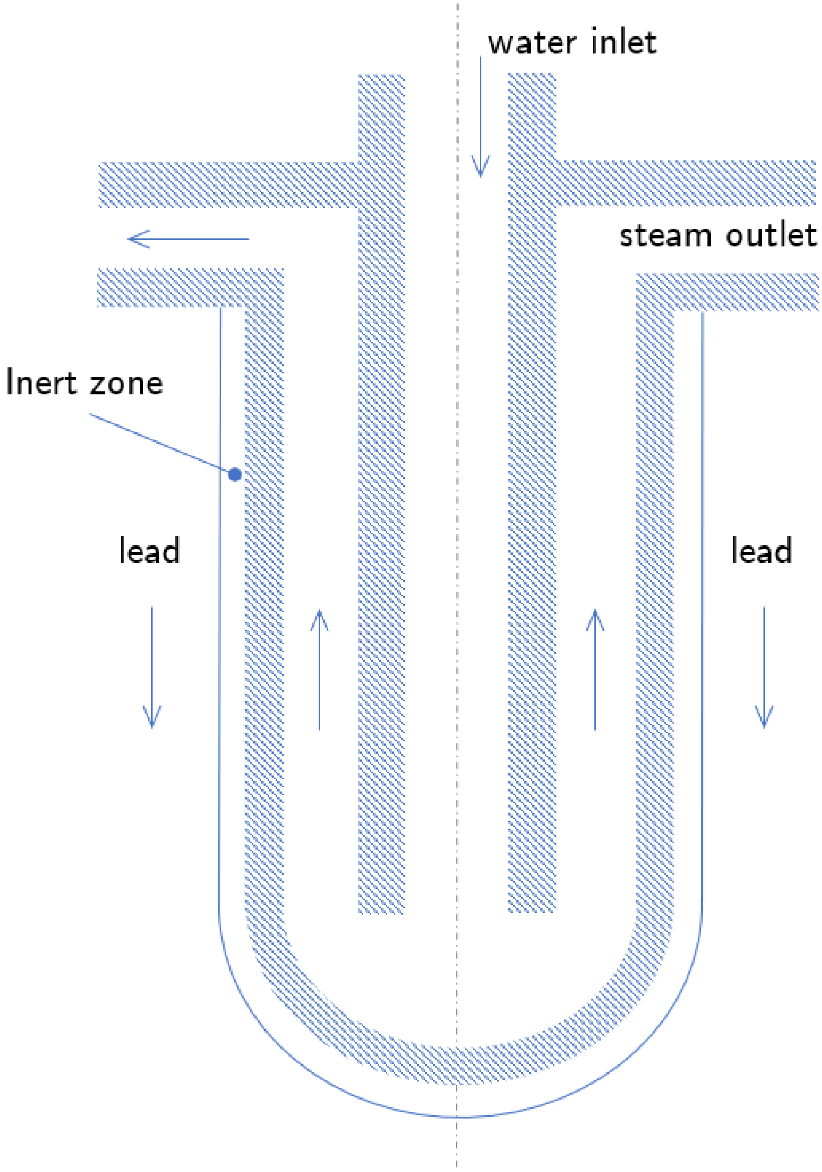

Figure 1: Schematic of a bayonet tube heat exchanger.

[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.

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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May 27, 2025

– Internship proposal –
(ID No. 1000303)

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

Location	*new*cleo SrL, 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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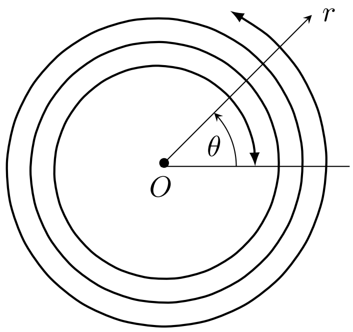

Figure 1: Archimedean spiral.

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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May 27, 2025

– Internship proposal –
(ID No. 1000360)

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

Location	*new*cleo SrL, 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.

Upgrade of the Python package lbh15 with properties of irradiated heavy liquid metals used in nuclear fast reactors

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May 27, 2025

– *Internship proposal* –
(ID No. 1001776)

***Keywords* —** LMFR, irradiated liquid-metal properties, Python
***Topics* —** Radioactive nuclides volatility, confinement and interaction with liquid metals

Location	*new*cleo SrL, Via Galliano 27, 10129 Torino, Italy
Starting date	First or second quarter of 2024
Duration	4–5 months

Context

Chemical control of the primary coolant 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 considers the purification of the coolant from hazardous radioactive nuclides, originated by nuclear reactions, to prevent excessive dose release in case of leaks. Therefore, *new*cleo's activities on lead chemical control are the objects of intensive studies, both in terms of experiments and theoretical modeling. In order to support both types of activities, the Python package lbh15 is under active development within the Codes and Methods team to offer an unique and standardized entry point for the use of empirical correlations of physical properties.

Description

lbh15 (**L**ead **B**ismuth **H**andbook 20**15**) is a Python package developed by *new*cleo based on the reference handbook edited by OECD-NEA [1], as contribution to the expert group on heavy liquid metal technologies. The metal properties are implemented as analytical functions from

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empirical correlations. The package is also equipped with services for function characterization that use the standard Python packages for scientific computation, namely NumPy and SciPy. The release of the second version of lbh15 is scheduled by the end of 2023: it will implement both thermophysical and thermochemical properties of molten lead (Pb), of bismuth (Bi) and of their eutectic alloy (LBE). The package repository and the related documentation can be found at

`https://newcleo-dev-team.github.io/lbh15/index.html` and
`https://github.com/newcleo-dev-team/lbh15`, respectively.

During the internship, the student will develop new features in lbh15 by implementing the topics covered in chapter 5 of the above-mentioned handbook. Specifically, the student will work on the integration of the following subjects:

a) volatilisation of hazardous nuclides (Polonium, Caesium, Iodine, etc.) from liquid metals;
b) estimation of equilibrium vapour pressure;
c) gas phase purification.

For check and illustration purposes, the student will be involved in the development of one or more simple Python applications/tests focused on the exploitation of the properties just implemented.

lbh15 adopts high quality standards for code development. Hence, the student will develop/consolidate skills about the following aspects of the Python-based software engineering ([2], [3]):

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

The student will be followed by the Codes and Methods group members of *new*cleo that are developing lbh15.

Work plan

1) Handbook [1] review and identification of the main correlations to implement
2) Code architecture design
3) Code implementation
4) Test application definition and implementation
5) Preparation of a technical report

Applicant profile

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

- Fundamentals in thermodynamics and chemistry
- Basic knowledge of software 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] C. Fazio et Al. Handbook on Lead-bismuth Eutectic Alloy and Lead Properties, Materials Compatibility, Thermal-hydraulics and Technologies. Technical Report No. 7268, OECD/Nuclear Energy Agency (NEA), Paris, France, 2015.

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

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

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

Elena Travaglia and Daniele Tomatis*

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May 27, 2025

– *Internship proposal* –

(ID No. 1003986)

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

Location	*new*cleo SrL, 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.

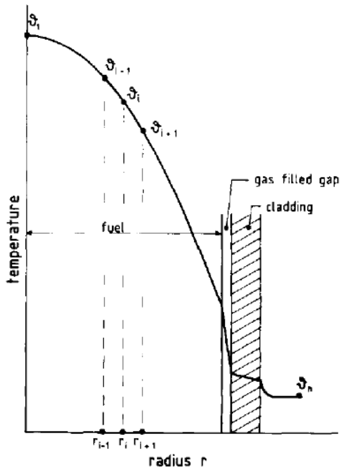

Figure 1: Schematic rappresentation of the stationary radial temperature profile in a slice of the fuel rod

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

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May 27, 2025

– 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 SrL, 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.

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

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May 27, 2025

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

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

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Location	*new*cleo SrL, 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.

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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

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May 27, 2025

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

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

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Location	*new*cleo SrL, 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.

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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.

Calculation of neutron activation under cyclic exposure in LFR

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May 27, 2025

– 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.

Development of additively manufactured sensors for LFR environment

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November 11, 2024

– Internship proposal –

(ID No. 1006289)

***Keywords* —** Additive Manufacturing, sensors, LFR, alloy development
***Topics* —** New alloy development, Sensors development

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

Starting date First quarter of 2025

Duration 6 months

Context

Lead-Cooled Fast Neutron Reactors (LFRs) operate under extreme conditions, requiring robust monitoring and control technologies. The "DAO - Diagnostica in Ambienti Ostili" project led by *new*cleo aims at developing advanced diagnostic systems to monitor components in hostile environments like lead-cooled reactors. Current sensors cannot withstand these conditions, prompting research into new materials and packaging to enhance fiber resistance. Additive Manufacturing (AM) technology will produce sensor prototypes, integrated with IoT platforms and digital twins for advanced data analysis using AI. These sensors will monitor critical components such as reactor steam generators and steel plant equipment, enduring high temperatures and stresses. A key innovation is embedding sensors into components via AM (Laser Powder Bed Fusion technology), optimizing sensitivity and operational integration. This novel approach also scales sensor deployment to larger structures. The project will deliver hardware, software, and demonstrators, advancing diagnostics in hostile environments.

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Description

The internship will focus on activities in Work Packages (WPs) 1.2 and 2.4 of the DAO project. WP 1.2 aims to define use cases, feasibility, requirements, and Key Performance Indexes (KPIs) for the diagnostic platform in hostile environments, considering parameters like operating temperatures, pressures, radiation, and corrosion. This will guide decisions on fiber types, coatings, and packaging materials, using both traditional and AM methods. Two AM technologies, Laser Powder Bed Fusion (LPBF) and Wire-Arc Additive Manufacturing (WAAM), will be studied, with AISI 316L as a substrate material due to its industrial relevance.

WAAM will be explored in WP 2.4 to design and produce fiber-integrated sensor prototypes within structures created through AM, replicating reactor vessel scales. This integration during the manufacturing process allows sensor placement in normally inaccessible locations, preserving material properties and eliminating post-manufacturing inspections. WAAM capability to create complex geometries enables enhanced system monitoring, reducing production and maintenance costs compared to traditional methods.

The project also aims to develop scalable sensor-equipped vessel prototypes, leveraging WAAM to optimize processes and demonstrate practical applications, supported by external expertise to advance WAAM technological maturity.

The internship will be divided into a literature review phase, a visit to partner phase, a laboratory activities phase, a data analyses phase, and a reporting phase.

Work Plan

The internship candidate will be led by *new*cleo internal resources from Materials and Chemistry Areas. During the internship, some visit to partner companies and research institutes will be possibly carried out. The internship will be concluded with the production of the following documentation by the candidate:

- A literary review of use cases of sensors in LFR conditions with identification of the minimum functional requirements that will serve as the basis for sensor design (Word file).

- Definition of the necessary functional requirements and the indices that quantify performance (KPIs). The parameters to be defined will be used to evaluate the feasibility of obtaining useful information for diagnosing structures in hostile environments (Word file).

- Microstructural and mechanical performance analyses of WAAM samples produced. Samples will be provided by external partner(s). The laboratory tests will be conducted in a university or external partner. A subsequent data analyses phase will be performed (Word file).

- A final report in which machine settings for WAAM printing, provided through process files, are explained; in the report, the effects of the process parameters on the produced material characteristics will be indicated (Word file).

Applicant profile

Master or PhD student in Nuclear, Chemistry, Material science, Mechanical or Aeronautical Engineering; Applied Mathematics and Physics.
Required computer skills: work entirely in a terminal without the desktop environment.

References

[1] Morana A, Girard S, Marin E, Marcandella C, Paillet P, Périsse J, Macé JR, Boukenter A, Cannas M, Ouerdane Y. “Radiation tolerant fiber Bragg gratings for high temperature monitoring at MGy dose levels” Opt Lett. 2014 Sep 15;39(18):5313-6. doi: 10.1364/OL.39.005313. PMID: 26466259

[2] Quentin Pouille et Al. “Additive Manufacturing and Optical Sensors, Towards a New Way for Nuclear Material Monitoring”, WM2023 Conference, February 26 – March 2, 2023, Phoenix, Arizona, USA

[3] J.Popławski et Al “Metal-coated optical fiber embedment in WAAM aluminium parts for distributed temperature sensing”. https://indi.to/RP9Ty

Burnup calculation of LFR fuel assemblies by DRAGON5

Sigtryggur Hauksson*[1], Gianluca Cirillo[2], and Daniele Tomatis[2]

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June 1, 2025

– Internship proposal –
(ID No. 1008548)

***Keywords* —** LFR, lattice calculation, burnable absorbers, breedering, DRAGON
***Topics* —** Nuclear fuel management, neutron transport, reactor physics

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Location *new*cleo SA, EDF Lab Paris-Saclay, Bd Gaspard Monge, 91120 Palaiseau, or *new*cleo S.p.A., Via Galliano 27, 10129 Torino, Italy

Starting date Fall 2025

Duration 6 months

Context

*new*cleo is designing new Lead-cooled Fast Reactor (LFR) units for small modular reactors. These reactors sustain a fast neutron spectrum allowing for fission of heavier actinides, such as plutonium that is a by-product of light water reactors. Cooling is done by molten lead which shields photon radiation and has low neutron absorption.

Nuclear fuel management studies can rely on burnup calculations performed through lattice transport computer codes [1, 2]. *new*cleo is currently adapting DRAGON5 [3, 4], a deterministic neutron transport code developed at Polytechnique de Montréal, Canada, to the calculation of LFR. After achieving good results in single fuel pin cells, DRAGON5 is now being upgraded to perform accurate burnup calculations of fuel elements and heterogeneous assembly patterns, comprising burnable absorbers and spectrum softeners. This internship contributes to the verification and validation of the calculation scheme, including the data used to reproduce radioactive decay and isotope transmutation.

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Description

Nuclear reactors are usually operated with multi-batch reloading plans, which allows reducing the reactivity margin to control at the beginning of cycle, increasing at the same time the overall fuel utilization. The general performance of a core loading plan can be predicted rapidly by means of the linear reactivity model, which makes use of lattice calculations by deterministic transport codes for different fuel assembly types [2]. These first predictions must be confirmed later by coupled full-core calculations, which are more expensive computationally. This work focuses on fuel element design and their burnup calculation.

The lifetime of the fuel cycle can be increased with burnable absorbers. Such burnable absorbers are nuclides with high neutron absorption that transmute into nuclides with lower neutron absorption during the reactor's operation. The associated negative reactivity worth decreases with time reducing the decrease in positive reactivity of the fuel as it becomes more spent. Besides, less reliance on control rods is needed and the fuel cycle can become longer. Good examples of a burnable absorbers used in fast reactor design are erbium and hafnium.

The reactor core can also show assemblies with elements that soften the neutron spectra, designed to favor plutonium breeding along exposure. A breeder reactor produces more fissile or fissionable material at operation than what it consumes. This demands adjusting locally the spectrum of neutrons to maximize the number of fissions that will occur later in time. This can be achieved with yttrium-stabilized zirconium at the periphery of the core to shift the spectrum from the fast region to the epithermal region where most of fission takes place.

After first practice with the different capabilities of DRAGON5, the candidate will select the self-shielding options giving the most accurate calculations for fuel elements with burnable absorbers. This will require comparing DRAGON5 results with the ones obtained by the Monte Carlo code OpenMC [5]. After performing steady-state calculation with fresh fuel, the candidate will perform burnup calculations assuring proper convergence in time. The verification of the calculation scheme will require careful check of the used decay chains and nuclear data libraries, while the validation will be performed against Monte Carlo simulation. Finally, the candidate will produce a technical report at the end of the internship compiling the results.

Work plan

a) Literature review and study of the main physical phenomena.
b) Training and practice with DRAGON.
c) Study of cross-section self-shielding of doping elements.
d) Ensure fitness of nuclear data libraries used for the simulations.
e) Perform, verify and validate burnup calculations.
f) Analyze the results and preparation of the final report.

Applicant profile

Master student in Nuclear Engineering or student in Applied Mathematics and Physics.
Background: fundamentals in applied mathematics and the physics of nuclear reactors.
Required computer skills: Linux, Python (intermediate), LaTeX scientific editing (optional).

References

[1] MR Egan. Elements of nuclear reactor fueling theory. *Progress in Nuclear Energy*, 14(3):313–360, 1984.

[2] Michael J Driscoll, Thomas Joseph Downar, and Edward E Pilat. *The linear reactivity model for nuclear fuel management*. American Nuclear Society, 1990.

[3] Guy Marleau, Alain Hébert, and Robert Roy. A user guide for dragon version 5, 2025.

[4] Cyprien Richard, Mathias François, Lucas Fede, and Alain Hébert. Development of a computational scheme based on the dragon5 code for the neutronic study of vver-type reactor rods and assemblies. *Annals of Nuclear Energy*, 211:110961, 2025.

[5] 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*, 2015.

Cross section preparation for LFR by Monte Carlo computer codes

Gianluca Cirillo*[1] and Daniele Tomatis[1]

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June 1, 2025

– Internship proposal –
(ID No. 1008549)

***Keywords* —** LFR, OpenMC, cross section preparation
***Topics* —** Physical modelling, neutron transport, reactor physics

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Location	*new*cleo S.p.A., Via Galliano 27, 10129 Torino, Italy
Starting date	To be defined
Duration	5 months

Context

*new*cleo is designing small lead fast reactors (LFR) operating in a pool that contains all the primary system components. Cooling is done by molten lead which shields photon radiation and has low neutron absorption.

The core can show high heterogeneity to meet the criteria of compactness, target neutron leakage and power shape, breeding or burning features. The core is made of a main active zone, possibly surrounded by a shielding or breeding blanket.

Although computer simulation by Monte Carlo codes like OpenMC [1] allows today to carefully represent many details of the reactor, simplified calculation schemes relying on homogenization theory and equivalence theory must still be adopted to perform faster core calculations [2, 3], thus easing the whole design process. During this internship, the student will prepare homogenized cross sections by OpenMC and use them after to perform calculations with the deterministic full-core codes VARIANT [4] and DONJON [5].

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Description

Deterministic computer codes allows fast neutron calculations and are largely employed in reactor physics and analysis. They rely on assumptions and approximations that must be carefully verified and validated. For instance, using lattice calculations of fuel elements in fundamental mode neglects the environment effects and the local core conditions, introducing sometimes an inconvenient limitation in the calculation scheme. Provided that the material inventory of all fuel elements is known, the Monte Carlo simulation can be used to overcome this limitation, yet paying a higher computational cost.

A new feature in the code OpenMC to prepare homogenized cross sections on hexagonal grids is currently under development and it will be tested during this internship, together with a reduced nuclide chain suitable to lead fast reactors. After, a suitable interface will be developed to load the set of homogenized data into VARIANT and DONJON, which use different solution methods to obtain the neutron flux distribution over the full core. These codes use low-order transport methods, with a lower computational effort. Besides, the core configurations calculated by OpenMC and used for detailed cross section preparation will allow to assess the performance of low-order transport solutions. The setup of the calculation input files and the interfaces will be performed on git version control. Finally, the candidate will produce a technical report at the end of the internship to compile the results, by quantifying the gain in runtime obtained while using the deterministic codes and by assessing the performance in physical accuracy and numerical precision.

Work plan

a) Literature review and study of homogenization and equivalence theory.
b) Training and practice with the computer codes.
c) Setup of the core model by OpenMC.
d) Preparation of the cross section model.
e) Setup of the core calculations.
f) Analysis of results and preparation of the final report.

Applicant profile

Master student in Nuclear Engineering or student in Applied Mathematics and Physics.
Background: fundamentals in applied mathematics and the physics of nuclear reactors.
Required computer skills: Linux, Python (intermediate), LaTeX scientific editing (optional).

References

[1] P. K. Romano, N. E. Horelik, B. R. Herman, A. G. Nelson, B. Forget, and K. Smith. Openmc: A state-of-the-art monte carlo code for research and development. *Annals of Nuclear Energy*, 82:90–97, 2015.

[2] George I Bell and Samuel Glasstone. *Nuclear reactor theory*. US Atomic Energy Commission, Washington, DC (United States), 1970.

[3] J. R. Lamarsh and A. J. Baratta. *Introduction to Nuclear Engineering. 2nd Edition*. Addison-Wesley, Reading, 1983.

[4] 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 *PHYSOR 2002-International Conference on the New Frontiers of Nuclear Technology: Reactor Physics, Safety and High-Performance Computing*, 2002.

[5] A Hébert. DRAGON and DONJON: a legacy open-source reactor physics project at Polytechnique Montréal. In *Proceedings of the IAEA Technical Meeting on the Development and Application of Open-Source Modelling and Simulation Tools for Nuclear Reactors, Milano, Italy, June*, 2022.

Calculation of long-term sealed LFR

Gianluca Cirillo[1] and Daniele Tomatis*[1]

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May 27, 2025

– Internship proposal –

(ID No. 1008571)

***Keywords* —** LFR, Monte Carlo, high-fidelity neutron calculations.
***Topics* —** Reactor physics and analysis, radiation transport, core design.

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

Context

*new*cleo is developing innovative small modular reactors based on lead-cooled fast reactor (LFR) technology. A sealed unit intended for long-term extended operation is currently under study for ship propulsion and remote power generation. The internship focuses on building a complete LFR model and on performing neutron calculations by the Monte Carlo computer code OpenMC [1], providing the engineering team with essential data to improve reactor design.

Description

The reactor considered in this work is of the sealed type seeking inherent safety by means of passive cooling systems and employing robust materials to ensure long-term reliability, as in [2, 3], thus operating for at least 20 years without refuelling. The core layout is highly heterogeneous with zones keeping a fast neutron spectrum and others with an epithermal one.

The internship focuses on high-fidelity neutron calculations of liquid lead fast reactors (LFRs) using the Monte Carlo method. Calculations are in eigenvalue mode to reproduce operation in critical state by maneuvering control elements. The feasibility of using different types of control elements will be investigated. The calculations will be performed with assumed distributions

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of temperature and thermal expansion for geometry deformation. Machine learning techniques will be used to find clusters within the active core showing similar neutron spectrum.

Several calculations are necessary to find optimal configurations for reactor design, which limits the applicability of the Monte Carlo method indeed. Mixed deterministic-stochastic methods will be explored during the first phase of optimization.

During the internship, the student will be introduced to the physics and engineering of the LFR reactors, acquiring notions and developing skills in Monte Carlo methods and neutral particle transport [4, 5]. The student will become a proficient user of OpenMC, 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 modeling the LFR reactor and calculating maps of the released thermal power.

The student will examine significant topics concerning Monte Carlo simulations. These include the theoretical aspects underlying particle transport simulation and adequate modeling of reactor components.

The expected working plan is detailed in the following:

a) Literature review on off-grid and long-term reactors
b) Literature review on materials softening the neutron spectrum
c) Discussion of current core configurations
d) OpenMC introduction and training
e) Setup of the LFR full reactor model
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 Monte Carlo methods.
Required computer skills: A good knowledge of Python and Linux operating systems (or willingness to learn). Knowledge of LaTeX editing is appreciated.

References

[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. *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] J. Wallenius, S. Qvist, I. Mickus, S. Bortot, P. Szakalos, and J. Ejenstam. Design of sealer, a very small lead-cooled reactor for commercial power production in off-grid applications. *Nuclear Engineering and Design*, 338:23–33, 2018.

[3] Keith E Holbert. A review of maritime nuclear reactor systems. *Journal of Nuclear Engineering*, 6(1):5, 2025.

[4] Jerome Spanier and Ely M Gelbard. *Monte Carlo principles and neutron transport problems*. Courier Corporation, 2008.

[5] George I Bell and Samuel Glasstone. *Nuclear reactor theory*. US Atomic Energy Commission, Washington, DC (United States), 1970.

Implementation and Testing of New Numerical Solvers for the Intra-granular Fission Gas Diffusion Problem in the Computer Code TRANSURANUS

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June 1, 2025

– Internship proposal –
(ID No. 1008576)

***Keywords* —** Intra-granular Diffusion, Numerical Solvers, TRANSURANUS
***Topics* —** nuclear fuel design, fuel performance and thermomechanics, computational modelling

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Location	*new*cleo S.p.A., Via Galliano 27, 10129 Torino, Italy
Starting date	October 2025
Duration	4 months

Context

*new*cleo is designing an advanced modular Lead-cooled nuclear Fast Reactors (LFR). Regarding the fuel performance analysis, *new*cleo relies on the TRANSURANUS (TU) thermo-mechanical computer code, which is provided by the Joint Research Centre of the European Commission in Karlsruhe, Germany, under a collaboration agreement [1, 2]. *new*cleo is performing a verification process including checking the convergence of the employed numerical algorithms and their suitability for the problem under consideration with the final goal of developing an improved version of the code.

Description

Among the many phenomena that occur in a fuel pin under irradiation, Fission Gas Release (FGR) and Fission Gas Swelling (FGS) are fundamental to be correctly modelled in a fuel performance code. They are the result of a continuous production of Fission Gas (FG) atoms, such as Xenon (Xe) and Krypton (Kr), that accumulate in the fuel matrix, causing volume increase

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(swelling) and, consequent enhanced pellet-cladding interaction [3] . When certain saturation conditions are met, they can be released into pin's free volume [4, 5] leading to degradation of the thermal conductivity of the fuel rod filling gas (usually He) and increase of the internal fuel rod pressure. At the core of FGR and FGS modelling, accurately simulating gas diffusion within fuel grains is of paramount importance. This process is described by a Partial Differential Equation (PDE) [6]:

$$\frac{\partial C(r,t)}{\partial t} = D\nabla^2 C(r,t) + \beta(r,t) \tag{1}$$

where $C(r,t)$ is the gas concentration, D is the diffusion coefficient and $\beta(r,t)$ is the gas production rate. Eq.(1) can be referred to as FG diffusion equation and it is solved using *ad-hoc* numerical algorithms [3]. However, these algorithms are often complex to implement and difficult to verify, therefore, exploring new numerical methods for solving the diffusion equation is essential to enhance code readability and maintainability.
During the internship, the student will be asked to perform a literature review of the existing solvers for the FG diffusion equation and of the most recent numerical techniques that can be employed. Then, he/she will implement and test the new numerical solvers, comparing them to the existing algorithms in terms of accuracy and computational efficiency. The student will be introduced to using TU for fuel performance analysis and will become part of the TU development team at *new*cleo. He/she will learn best practices for collaborative work and high-quality, reliable code development. At the end of the internship, the student is expected to produce a technical report.

Work plan

a) Literature review on FG diffusion, current numerical schemes and new suitable numerical algorithms.
b) Implementation and test of the new selected algorithms in TU.
c) Analysis of the results
d) Preparation of a technical report

Applicant profile

BSc or MSc student in Industrial Engineering; Applied Physics.
Computer skills: FORTRAN, Linux, Python.
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. Benk. Modelling of fuel rod behaviour and recent advances of the transurauns code. *Nuclear Engineering and Design*, 106(3):291–313, 1998.

[3] K. Lassmann and H. Benk. Numerical algorithms for intragranular fission gas release. *Journal of Nuclear Materials*, 280(2):127–135, 2000.

[4] R. White. The development of grain-face porosity in irradiated oxide fuel. *Journal of Nuclear Materials*, 325(1):61–77, 2004.

[5] Giovanni Pastore. *Modelling of Fission Gas Swelling and Release in Oxide Nuclear Fuel and Application to the TRANSURANUS Code*. Doctoral dissertation, Politecnico di Milano, Department of Energy, 2012.

[6] P. Van Uffelen, G. Pastore, V. Di Marcello, and L. Luzzi. Multiscale modelling for the fission gas behaviour in the transuranus code. *Nuclear Engineering and Technology*, 43(6):477–488, 2011.

Development of a Software Tool for Depletion Chain Simplification and Representation

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June 1, 2025

– *Internship proposal* –
(ID No. 1008666)

***Keywords* —** depletion, activation, nuclide chain, simplification
***Topics* —** radiation protection, radioactive decay and transmutation, nuclear fuel management

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Location	*new*cleo S.p.A. - C.so Stati Uniti 38, Torino (TO), Italy
Starting date	As soon as possible
Duration	5–6 months

Context

The study of the evolution of the composition of the materials under irradiation is very important in engineering applications using ionizing radiation. Typically in a nuclear reactor neutron-induced reactions cause nuclei to transmute, possibly leading to unstable isotopes, which in turn undergo radioactive decay. As a result, the nuclide inventory of materials exposed to a neutron field changes over time. The changes in the nuclide inventory are of great interest for fuel cycle management, radiation protection and structural mechanics. The evolution of a material under irradiation is modeled by Bateman equations, which are a set of 1^{st} order ordinary differential equations in time usually solved by scientific computer codes. Computer codes need external libraries called nuclide chains, or alternatively depletion chains, to track all types of channels relating different isotopes under decay and transmutation. A simplification of the chains is sometimes necessary to avoid numerical issues (stiffness) or to obtain faster solutions by reducing the complexity of the problem. This also means easing the understanding of the physical system for engineers and scientists. The internship focuses on the development of a scientific software tool to get graphical representation of the nuclide chain and to implement algorithms for the simplification of the chain.

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Description

In nuclear reactors, materials are exposed to high neutron flux during normal reactor operation. This exposure leads to the formation of fission products and activation products, changing the material inventory as well. This implies a change in the response of the material when exposed to neutrons, and a possible change of the material thermo-physical properties after prolonged exposure. The study of the evolution of the material inventory under irradiation is therefore crucial, since it leads to changes in the power distribution in the core, in the mechanical properties of the structural components and in the radiological harmfulness of several reactor components. The number densities of the components of a material exposed to an external neutron field change because of radioactive decay and transmutation according to the Bateman equation:

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

where $\mathbf{n}(t)$ is the vector of nuclide concentrations at time t, and $A(\tau, t)$ is a matrix containing the decay constants and microscopic reaction rates $\tau(\phi)$, depending on the neutron flux level ϕ. $A(\tau, t)$ is also known as depletion matrix [1].

The information contained in the nuclide chain allows building fully the depletion matrix, whereas the inverse operation is not guaranteed. Full depletion chains usually contain several nuclides, connected by a large number of reaction channels. The presence of a high number of isotopes in the chain showing time scales spanning several orders in magnitude can lead to numerical issues. Therefore, chain simplification is generally sought while still ensuring high physical accuracy in the prediction of the number densities in time. Simplification of the decay chain yields depletion matrices of lower rank, allowing for improved performance when solving the Bateman equations numerically. In addition, the graphical representation of such chains helps engineers and scientists to better understand the problem and gain useful insight. Several algorithms for simplifying depletion chains have been proposed in the literature [2] [3] [4].

During the internship, the student will develop a scientific computer tool in Python language to get graphical representation of nuclide chains and to simplify complex chains in a smaller number of isotopes. This activity is continuing previous internship works. It will be carried out on Jupyter notebooks favoring collaborative work though git version control and automatic document preparation. The student will improve his Python programming skills and learn high-level quality standards and best practice for software development.

The student will be followed by the members of the Codes and Methods group of *new*cleo.

Work plan

During the internship, the student will be introduced to the Bateman mathematical model of isotopic depletion and build-up. The student will set up a software tool, in Python, for the graphical representation of full depletion chains. The internship will investigate various algorithms for the depletion chain simplification, in order to find the one, or the ones, which work the best for *new*cleo purposes. Finally, the student will implement the most simple algorithms for the chain simplification in the code.

The expected working plan is detailed in the following:

a) Study of the theory of isotopic decay and transmutation.

b) Definition of the format to store information about the nuclide chain.
c) Fix open issues with the existing nuclide chain plotter.
d) Literature review about chain simplification and implementation.
e) Test algorithms on simple cases.
f) Preparation of a technical report compiling results.

Applicant profile

Master or PhD student in Nuclear Engineering, Applied Mathematics and 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] Alain Hébert. *Applied Reactor Physics, 3rd ed.* 11 2024.

[2] Go Chiba, Masashi Tsuji, Tadashi Narabayashi, Yasunori Ohoka, and Tadashi Ushio. Important fission product nuclides identification method for simplified burnup chain construction: Physor 2014. *Journal of nuclear science and technology*, 52(7-8):953–960, 2015.

[3] Takanori Kajihara, Masashi Tsuji, Go Chiba, Yosuke Kawamoto, Yasunori Ohoka, and Tadashi Ushio. Automatic construction of a simplified burn-up chain model by the singular value decomposition. *Annals of Nuclear Energy*, 94:742–749, 2016.

[4] Olin Calvin. Depletion chain simplification using pseudo-nuclides. *Annals of Nuclear Energy*, 193:110011, 2023.

Review about the utilization of Beryllium in reactor design

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June 1, 2025

– *Internship proposal* –
(ID No. 1008987)

***Keywords* —** FBR, nuclear fuel management, fuel design, core cycle, neutron activation
***Topics* —** Reactor physics and analysis, radiation transport, core design.

Location	*new*cleo S.p.A. - C.so Stati Uniti 38, Torino (TO), Italy
Starting date	To be defined
Duration	3 months

Context

*new*cleo is developing innovative small modular reactors based on lead-cooled fast reactor (LFR) technology. The use of alternative materials is considered to achieve target performance for long-term operation without refueling. This internship focuses on performing a complete literature review about the utilization of Beryllium in nuclear reactors, providing the engineering teams with essential data to improve the design of future reactor units.

Description

The results provided by this internship will support the design of a small modular LFR, where the employment of beryllium could be particularly beneficial in reducing the size of the systems.

The internship focuses on a bibliographic review about the possibility of employing beryillium as a reflector in LFRs, with specific interest on applications to small modular reactors in the fast neutron regime. In the literature, there are studies which show the impact in terms of reactivity of the (n,2n) reactions of beryllium, leading to systems with smaller critical dimensions [1]. The above mentioned feature is of particular interest for small modular reactors [2]. However, other studies show that beryllium is affected by severe issues in terms of neutron activation and gas production, making the disposal of systems employing beryllium an even more delicate task [3].

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Additionally, beryllium is characterized by quite high values of (γ,n) cross sections at energies characteristic of fission product's γ radiation: it has been shown that the impact of photonuclear neutrons can be neglected for stationary states, but it has non-negligible effects on the kinetics of the reactor [4, 5]. The presence of lead, which has a strong shielding effect against photons, could possibly alleviate the magnitude of these phenomena.

The student will have to find several references in the literature in order to understand if the advantages of using beryllium in fast fission reactors are supported by physical and engineering considerations, taking into account all the pros and the cons of employing such a nuclide and analysing its behaviour in the presence of lead.

During the internship, the student will have to collect as many data as possible, with the aim of providing valuable information about the possible use of beryllium in the design of a small modular LFR, supporting the design of this nuclear system. At the end of the internship, the student will write a technical report summarizing all the main findings of the bibliographic review. The student will be followed by the Codes and Methods group members of *new*cleo.

Work plan

During the internship, the student will need to perform a detailed bibliographic review in order to conclude if the use of beryllium can be beneficial in small modular LFRs, considering both aspects related to change in reactivity due to (n,2n) and (γ,n) reactions, and to safety and radiological issues related to the presence of beryllium.

The student will examine significant topics concerning reactor physics of fast reactors. These include mainly theoretical and engineering aspects underlying the behaviour of neutrons and photons in the presence of beryllium and lead.

The expected working plan is detailed in the following:

a) Literature review on beryllium behaviour in fast systems
b) Literature review on fission systems employing beryllium
c) Discussion of current core configurations
d) Analysis of bibliographic references
e) Preparation of a technical report

Applicant profile

Bachelor student in Nuclear Engineering, Applied Mathematics and Physics.
Background: fundamentals in reactor physics.
Required computer skills: Knowledge of LaTeX editing is appreciated.

References

[1] P.K. Job and M. Srinivasan. Evaluation of reactivity bonus due to (n, 2n) multiplication in Be/BeO-reflected 233u uranyl nitrate solution systems. *Annals of Nuclear Energy*, 9(4):209–213, 1982.

[2] A. Tomberlin T. *Beryllium-a unique material in nuclear applications*. Citeseer, 2004.

[3] G. R. Longhurst, K. Tsuchiya, C. H. Dorn, S. L. Folkman, T. H. Fronk, M. Ishihara, H. Kawamura, T. N. Tranter, R. Rohe, M. Uchida, and E. Vidal and. Managing beryllium in nuclear facility applications. *Nuclear Technology*, 176(3):430–441, 2011.

[4] Tsuyoshi Misawa, Seiji Shiroya, and Keiji Kanda and. Study on reactivity worth of beryllium by (n,2n) and (γ,n) reactions. *Nuclear Technology*, 116(1):9–18, 1996.

[5] G Hordósy, Andras Keresztúri, Cs Hegedûs, and P Vértes. Influence of the photoneutrons on the kinetics of beryllium reflected core of the budapest research reactor. 1998.