Horizon 2020 Programme

GRE@T-PIONEeR

Coordination and Support Action (CSA)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 890675

Start date : 2020-11-01 Duration : 36 Months

Overview of the course package on neutron transport at the fuel cell and assembly levels

Authors : Pr. Sandra DULLA (Polito), Christophe Demazière (Chalmers), Máté Szieberth (BME)

GRE@T-PIONEeR - Contract Number: 890675

Project officer: Ptackova Katerina

Document title	Overview of the course package on neutron transport at the fuel cell and assembly levels
Author(s)	Pr. Sandra DULLA, Christophe Demazière (Chalmers), Máté Szieberth (BME)
Number of pages	18
Document type	Deliverable
Work Package	WP3
Document number	D3.1
Issued by	Polito
Date of completion	2022-09-05 09:46:33
Dissemination level	Public

Summary

This document gives an overview of the course package on Neutron transport at the fuel cell and assembly levels. More precisely, the objectives with the course package, the pedagogical approach used, the course package structure, the overall contents of the developed handbooks and of the hands-on training exercises are presented.

Approval

Date	By
2022-09-05 09:46:51	Pr. Sandra DULLA (Polito)
2022-09-05 09:52:24	Pr. Christophe DEMAZIERE (Chalmers)

Disclaimer

The content of this document reflects only the authors' view. The European Commission is not responsible for any use that may be made of the information it contains.

History

Date	Version	Submitted by	Reviewed by	Comments
April 13th, 2022	1.0	Christophe Demazière		
July 4th, 2022	1.1	Sandra Dulla	Christophe Demaziere	

Table of Contents

Abbreviations and Acronyms

Acronym	Description
ECTS	European Credit Transfer and Accumulation System
JiTT	Just-in-Time Teaching
LMS	Learning Management System
SOUL	Smart Open Universe of Learning
WP	Work Package
ELO	Expected Learning Outcome

Executive Summary

This document gives an overview of the course package on Neutron transport at the fuel cell and assembly levels. More precisely, the objectives with the course package, the pedagogical approach used, the course package structure, the overall contents of the developed handbooks and of the hands-on training exercises are presented.

Keywords

Active learning, blended learning, flipped classroom, hybrid teaching, neutron transport, deterministic methods, Monte Carlo method, fuel cell calculation

1. Introduction

The EU-funded GRE@T-PIONEeR project aims at developing a specialized education in reactor physics and nuclear reactor safety for PhD and postdoc students, for nuclear engineers, and taken as advanced courses for MSc students. The education encompasses both theory and hands-on training exercises, the latter heavily relying on the use of research/training reactors and of computer-based modelling environments. The aim is for the students to be able to perform nuclear reactor safety simulations understanding all the approximations on which such simulations rely. This is considered essential knowledge in the education of highly skilled nuclear safety analysts. The use of pre-recorded lectures and electronic teaching resources allows students to learn at their own pace and get prepared for the hands-on training sessions. Those sessions, offered both on-site and remotely, use active learning methods under the close supervision and support of the teachers, thus promoting student learning.

In this report, an overview of the course package on Neutron transport at the fuel cell and assembly levels offered as part of the Work Package 3 (WP3) is given. More precisely, the objectives with the course package, the pedagogical approach used, the course package structure, the overall contents of the developed handbooks and of the hands-on training exercises are presented.

2. Objectives of the course package

The simulation of the transport of neutrons in nuclear reactors is typically done in two computational stages when using deterministic methods: at the fuel cell and assembly levels, and thereafter at the core level. The aim of the former is to generate energy- and space-averaged macroscopic cross-section data to be subsequently used by the core simulator. Probabilistic (i.e., Monte Carlo) methods can also be used to generate such data. This WP thus aims at developing course materials giving the students a full and comprehensive overview of:

- The principles of probabilistic methods in steady-state conditions for fuel cell and assembly calculations.
- The principles of deterministic methods in steady-state conditions, their approximations, and their range of validity for fuel cell and assembly calculations.
- The use of those methods for macroscopic cross-section generation.

Hands-on training exercises include the development and implementation of some of the deterministic methods and the use of both deterministic and probabilistic tools used by the nuclear industry. Combined with these exercises, research reactors are used for demonstrating methods that allow the determination of transport parameters in multiplying and non-multiplying media.

3. Reminder about the pedagogical approach

This Section is a reminder of the pedagogical approach developed and applied across the GRE@T-PIONEeR project. This approach was already described in more detail in the deliverable D1.2 (Demazière, 2021).

3.1. Active learning as the core strategy

The pedagogical approach used and applied throughout the GRE@T-PIONEeR project essentially relies on the concept of *active learning*, according to which students learn much more efficiently when they participate to engaging activities in the classroom with the support from the teachers (Freeman et al., 2014).

Learning can be considered as a process. One paradigm often used to define the various learning steps is Bloom's revised taxonomy of the cognitive domain (Andersson et al., 2000). This process, illustrated in Figure 1, is defined as a sequence of various skills the students develop, starting from lower-order thinking skills to higher-order thinking skills. In the lower order thinking skills, students try to remember and understand the course concepts they were presented. In the higher order thinking skills, students try to utilize such concepts on their own. Those skills include applying, analysing, evaluating the course concepts and creating. What the various skills represent and contain is more precisely exemplified in Figure 1.

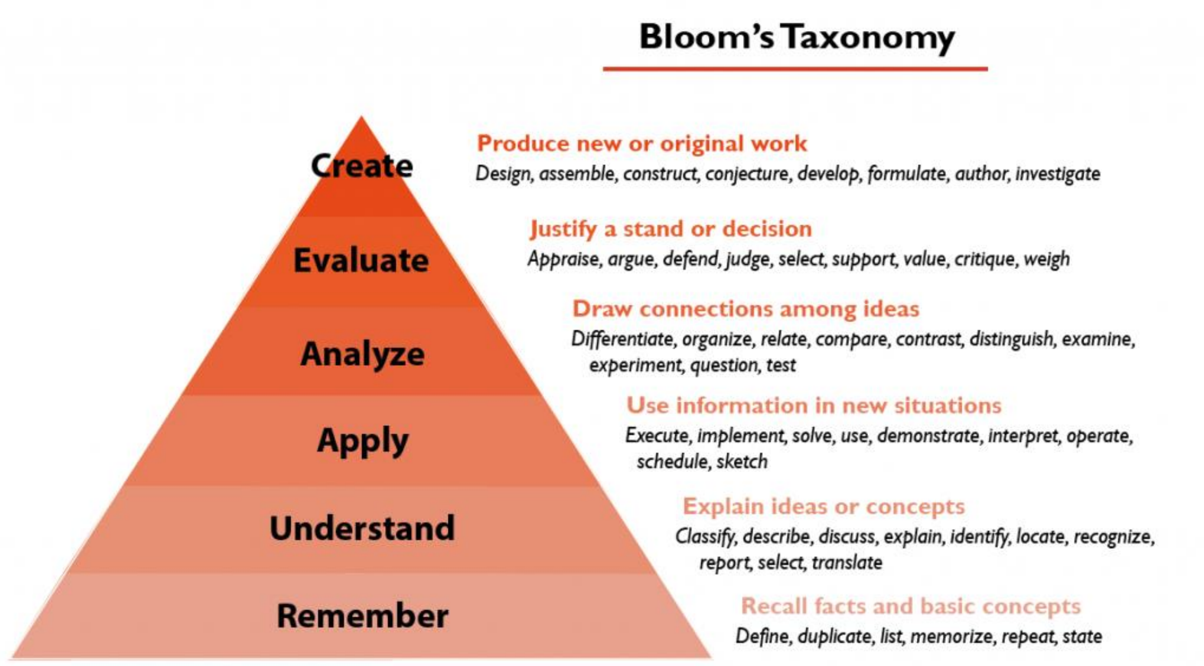

Figure 1. Illustration of Bloom's revised taxonomy for the cognitive domain, with higher order thinking skills at the top of the diagram – adapted from (The Vanderbilt University Center for Teaching, 2021).

In GRE@T-PIONEeR, teachers push the students to develop as high as possible thinking skills. Higher order thinking skills are triggered when students are given the possibility to utilize the concepts they were introduced to. This requires from the teachers designing some engaging activities in which the students are actively involved, during which active learning takes place. The main incentive is the fact that one learns much better by doing and experiencing oneself, a principle called in everyday' s jargon "learning by doing". Practice is the essence in reaching higher order thinking skills in Bloom's revised taxonomy.

Many definitions of active learning exist. The one generally accepted is given by Felder and Brent (2014) as follows: "Active learning is anything course-related that students in a class session are called on to do other than simply watching and listening to a lecture and taking notes."

Many active learning techniques exist. A non-exhaustive list of examples is given in the GRE@T-PIONEeR deliverable D1.1 – Section 7.4 (Jaiyeola A. et al., 2021).

3.2. Flipping to increase pedagogical support

In order to make room for such activities, a flipped classroom is used, with the traditional delivery of lecture-based contents moved outside of the classroom: lecture and materials usually presented in class are instead made available to the students on the web and before (Bishop and Verleger, 2013).

In the flipped classroom model, students learn asynchronously as they can choose when and at what pace to watch/read the course material. In contrast to the traditional teaching format, low order thinking skills are practiced during this asynchronous phase before the students meet the teachers and other students for synchronous interactions. Therefore, the time spent with the teachers can be used more effectively to engage students in high order thinking activities, clarify difficult concepts and provide individual support.

Since the students attend the synchronous sessions much better prepared than in a traditional teaching set-up, flipped classrooms were demonstrated to lead to much better learning outcomes and to contribute to a deeper learning compared to traditional teaching (Bishop and Verleger, 2013; O'Flaherty and Phillips, 2015). The key aspect of flipped classrooms is freeing time in the classroom to organise engaging activities with the students under the teacher's supervision, thus favouring active learning.

Another advantage of the above teaching set-up with respect to synchronous versus asynchronous learning is the possibility for the teachers to gather data about student learning before they meet the students for synchronous interactions. As a result and making use of a Just-in-Time-Teaching (JiTT) philosophy (Watkins and Mazur, 2010), the teachers are able to adjust their synchronous teaching sessions to the students' needs. This further improves student learning.

3.3. Course package structure

The overall methodology for the course implementation relies on the following elements:

- *Handbooks* covering the theoretical aspects of the covered topics.
- *Pre-recorded lectures* (or *webcasts*) available for on-demand viewing and extracting the main features, results, and concepts of the handbooks. The webcasts are recorded with the teacher's voice and, when possible and relevant, video, while using on-screen annotations, thus making the webcasts vivid.
- *Online quizzes* associated with the webcasts, focusing on conceptual understanding, with immediate feedback to the students on their learning. The quizzes are designed in such a way that thinking skills beyond merely remembering concepts are triggered, including the applying, analysing, and evaluating concepts in Bloom's revised taxonomy. Such active learning elements encourage a deep approach to learning. Moreover, embedding quizzes in the pre-recorded webcasts allows for splitting of the lectures (webcasts) into smaller chunks, increasing student attention and thus improving the conditions for learning. As an additional benefit, the quizzes allow the teachers to continuously monitor students' comprehension of key concepts.
- The possibility to *pose questions* to the teachers while watching the lectures. When possible, students are offered to rate, on a voluntary basis, the pre-recorded lectures and to provide comments. Such comments, at the lecture level, provide meaningful information about student learning and can also be used to improve the design of the handbooks, videos, and quizzes.
- *Active learning sessions* in forms of wrap-up and tutorials with synchronous interactions between the students and the teachers. Various active learning methods are implemented depending on the topics and the set-up of that particular course moment. Using JiTT, the synchronous sessions are also designed to address the students' needs.
- Use of *discussion fora* monitored by the teachers. The fora are utilised as a post-class activity to maintain engagement, favour collaboration between students and are also used for providing additional feedback and help to the students.

The entire management of all electronic resources is done via the Learning Management System (LMS) SOUL from Tecnatom (Smart Open Universe of Learning).

All the collected information – the answers to the quizzes, the questions sent to the teachers, the rating of the pre-recorded webcasts, as well as additional comments provided by the students – are used to prepare the synchronous sessions designed to meet the students' needs, building on the concept of JiTT. The sessions contain four key parts: 1) providing a brief summary of the key concepts and their relation to the structure of the covered topic so that the students could relate the details to the overall picture, thus favouring a more holistic approach to learning; 2) answering the questions that the teachers received; 3) going through the quizzes in an interactive way and discussing different alternatives; and 4) going through specifically designed activities, exercises, tutorials or hands-on training. This last part of the synchronous sessions constitutes the most important part, both in terms of devoted time and impact on student learning. Moreover, this last part of the wrap-up sessions is where the degree of interaction between the students and teachers is highest.

For each of the studied topics, the learning sequence for the students is made of several parts, as illustrated in Figure 2. The first ones include studying the handbooks, watching the webcasts, and completing the online quizzes. Interactions with the teachers are only possible in an asynchronous fashion, using the communication channels of the LMS. Synchronous interactions become possible during the synchronous sessions. Various active learning techniques are used in such synchronous sessions, representing the course moments during which the students and the teachers interact the most. Finally, the students apply, analyse, and evaluate the studied concepts while solving assignments, thus using high order thinking skills in Bloom's revised taxonomy. Although the biggest part of the assignments is solved during the interactive sessions, the students may be given some extra time to finalize the assignments after the sessions. Discussion fora are also used for peer-instruction, with interventions from the teachers when necessary.

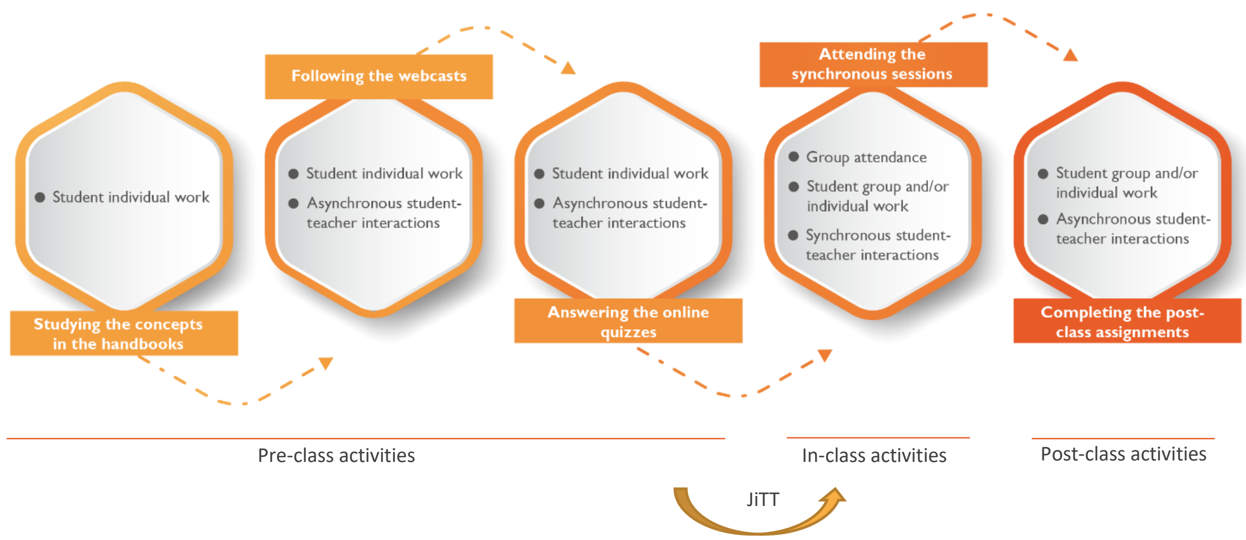

Figure 2. Illustration of the learning sequence.

Hands-on training sessions are split into two categories. The first category typically corresponds to wrap-up sessions, discussions, tutorials, code usage and method implementation and are organized separately for each course module. The second category represents hands-on training exercises organized on one of the training reactors available to the consortium (CROCUS at EPFL, Switzerland; AKR-2 at TU Dresden, Germany; BME Training Reactor at BME, Hungary). It should be emphasized that such hands-on exercises are common to all course modules and are organized as a one week to ten days session given after all course modules were given.

The pre-class activities represent roughly one week of full-time studies. Likewise, the in-class activities also represent one week of full-time studies. The course modules are thus worth 3 European Credit Transfer and Accumulation System (ECTS) each. The attendance of the hands-on activities on the training reactors gives some extra ECTS depending on the length of the corresponding sessions.

Moreover, in GRE@T-PIONEeR, the synchronous sessions of the first category are offered in a hybrid learning environment: students can decide to travel to the host organisation for following the synchronous sessions, or they can follow such sessions remotely on the web. The synchronous sessions are organised in specifically designed interactive teaching rooms: one available at Chalmers University of Technology, Sweden (Demazière et al., 2017) and one at Universitat Politècnica de València, Spain. Such rooms are furnished with movable chairs, tables, and whiteboards enabling the use of a more student-centred pedagogical approach. This is of significance when a flipped classroom model is implemented, so that the in-class activities can focus on higher order thinking skills. In addition, the rooms are equipped with audio and video hardware and software that allow synchronous interactions between the on-site and off-site participants in form of digital content sharing, audio interactions, and video communication.

Table 1. Summary of the synchronous hands-on training sessions.

WP	Course module	Week number/year	Location
2	Nuclear data for energy and nonenergy applications	46/2022 (November 14-18, 2022)	UPV, Spain (+ possible remote attendance)
3	Neutron transport at the fuel cell and assembly levels	50/2022 (December 12-16, 2022)	CHALMERS, Sweden (+ possible remote attendance)
4	Core modelling for core design	2/2023 (January 9-13, 2023)	UPV, Spain (+ possible remote attendance)
5	Core modelling for transients	6/2023 (February 6-10, 2023)	UPV, Spain (+ possible remote attendance)
6	Reactor transients, nuclear safety and uncertainty and sensitivity analysis	10/2023 (March 6-12, 2023)	UPV, Spain (+ possible remote attendance)
7	Radiation protection in nuclear environment	13/2023 (March 27-31, 2023)	CHALMERS, Sweden (+ possible remote attendance)
2-7	Exercises at AKR-2	April 2023 (+ backup in August/September 2023)	TUD, Germany (only some of the course elements will be made available to remote attendees)
2-7	Exercises at CROCUS	End of May/beginning of June 2023 (+ backup in September 2023)	EPFL, Switzerland (only some of the course elements will be made available to remote attendees)
2-7	Exercises at BME Training Reactor	June 2023 (+ backup in August/September 2023)	BME, Hungary (only some of the course elements will be made available to remote attendees)

Such teaching rooms allow for courses to be offered to remote students in a pure virtual learning environment without any need to travel. The rooms make offering the synchronous sessions to both the on-site and off-site attendees possible. Furthermore, the two audiences can interact with each other.

The planning of the different hands-on sessions is summarized in Table 1.

4. Overall contents of the developed handbooks

The handbook on neutron transport at the fuel cell and assembly level is composed by 6 chapters, covering the topic from the definition of the problem under consideration to the details related to the numerical solution of the transport equation and its usefulness in the global picture of reactor core analysis. The handbook amounts to a total of 120 pages.

We here report the Table of content of the handbook with a brief description of the content, based on the abstract of each chapter, as provided in the handbook.

In this first chapter, the elementary concepts necessary to derive a balance equation describing the behavior of neutrons in a nuclear reactor are introduced. Thereafter, various forms of the balance equation are presented. This chapter has for primary objective to define the different quantities appearing in neutron transport and to provide background information to the readers not familiar with neutron transport.

The chapter on the analytical approach to the solution of the transport equation deals with one of the simplest forms of this balance model, i.e., planar geometry in the infinite medium with a monokinetic approach. This formulation allows for an analytical solution, based on the use of the Fourier Transform, allowing to infer various physical properties of the transport model and providing a context of application of the diffusion approximation. The equivalence to the singular eigenfunction approach developed by Kenneth Case is also sketched.

The third chapter provides an introduction to the techniques used for modelling nuclear reactor systems. All the various numerical approaches can be categorized under two broad definitions: the deterministic approach and the Monte Carlo approach. The main purpose of this chapter is to give a general, broad overview of the principles at the basis of these approaches. The details of the techniques are then presented in subsequent chapters.

As nuclear reactions are at the core of the physical processes taking place in nuclear reactors, this chapter describes the nuclear data libraries and the various ways of representing the energy dependence of the microscopic cross-sections. Whereas those data are dependent on the energy of the incoming and possibly outgoing particles in a continuous manner, deterministic modelling approaches are based on the averaging of the data on energy intervals, often referred to as a multigroup formalism. The corresponding averaging process is given special attention in this chapter.

This chapter describes the different steps in the deterministic modelling of neutron transport at the fuel lattice level. The purpose of those is to prepare macroscopic cross-section data and kinetic data in an energy representation and spatial discretization compatible with the ones subsequently used for core calculations. Through a multi-stage procedure starting with a treatment of resonances, the results of micro-group/micro-region and of macro-group/macro-region calculations are combined to provide a first estimate of the spatial and energy distribution of the neutron flux at the fuel assembly level, then used for the energy condensation and the spatial homogenization. The preparation of the data for the core simulator is also given special attention, taking into account the effect of instantaneous and history variables (e.g., burnup, control operations, …).

Monte Carlo methods are based on sampling probability distributions with the help of quasi random numbers. When applied for particle transport it is often considered as the simulation of random physical processes with known distributions. This approach is called analogous Monte Carlo. However, in a more general view the Monte Carlo methods are numerical methods which are used predominantly for the determination integrals involving probability distributions. As such it can also be used for the solution of integral equations, like the one describing particle transport processes. This chapter of the book introduces this more theoretical, non-analogous approach to Monte Carlo methods, presenting the concept of integration and solution of integral equation, the Monte Carlo game to solve the Boltzmann transport equation and the estimators for the particle flux and related quantities.

Conclusions 119

The conclusion section summarized the content of the handbook, highlighting the expected learning outcomes that are expected to be achieved by the students when completing their study of this text.

5. Overall contents of the hands-on training exercises

As earlier mentioned, the hands-on training exercises are divided into a one-week long set of synchronous session specific to the considered WP and three sets of hands-on activities common to all WP and offered at each of the training reactors – see Section 3.3 and Table 1.

The details of the WP-specific hands-on exercises during the synchronous sessions are detailed in Table 2, whereas the planning of the activities is given in Table 3.

Table 2. Description of the hands-on exercises offered during the WP-specific synchronous sessions.

Exercise	Responsible organizatio n/person	Format	Background knowledge	Restrictions
Method of collision probabilities in multi-group formalism + inner/outer iterations	CHALMERS/ Christophe Demazière	Hybrid Using MATLAB Grader	Provided in the T3.1 handbook	Max. 15-20 onsite participants Max. 25-30 offsite participants
Use of deterministic code	CHALMERS/ Christophe Demazière	Hybrid Using CASMO	Provided in the T3.1 handbook	Max. 15-20 onsite participants Max. 25-30 offsite participants
Use of Monte Carlo code	BME/Máté Szieberth	Hybrid Using OpenMC (+emphasize cross-sections generation for deterministic codes)	Provided in the T3.1 handbook	Max. 15-20 onsite participants Max. 25-30 offsite participants

Table 3. Planning of the various activities during the WP-specific synchronous sessions.

Day 1		
Time	Activity	Teacher
09:00-10:00	Start of the course: introduction of the teachers and participants, schedule for the week	All
10:00-12:00	Deterministic modelling: interactive discussions on overall strategy + pin cell calculations	C. Demazière
13:00-16:00	Analytical solution to the neutron transport equation: interactive discussions	S. Dulla
Day 2		
Time	Activity	Teacher
9:00-12:00	Analytical solution to the neutron transport equation: hands-on	S. Dulla
13:00-16:00	Method implementation: development of a collision probability module - Part I: derivation of the equations + numerical estimation of the probabilities	C. Demazière
Day 3		
Time	Activity	Teacher
09:00-12:00	Deterministic modelling: interactive discussions on assembly calculations + data preparation for core calculations	C. Demazière
13:00-16:00	Method implementation: development of a collision probability module - Part II: numerical estimation of the solution + discussion	C. Demazière
Day 4		
Time	Activity	Teacher
9:00-12:00	Use of deterministic code: fuel assembly modelling using CASMO-4	C. Demazière
13:00-16:00	Monte Carlo modelling: interactive discussions	M. Szieberth
Day 5		
Time	Activity	Teacher
9:00-12:00	Use of Monte Carlo code: fuel assembly modelling using OpenMC	M. Szieberth
13:00-15:00	Use of Monte Carlo code: case study on the BME Training Reactor using OpenMC	M. Szieberth
15:00-16:00	Closing of the course: course certificates and course evaluation	All

The details of the hands-on exercises on the training reactors are given in Table 4.

Table 4. Description of the hands-on exercises offered during the hands-on exercises on the training reactors.

Exercise	Responsible organization/person	Format	Background knowledge	Restrictions
Estimation of the neutron spectrum by activation of samples with well-known XS in certain energy regions at AKR-2	TUD/Carsten Lange and Alexander Knospe	3 h to one day Onsite Possibility of hybrid format (audio/video sharing)	Dedicated set of lecture notes provided	Max. 8 onsite participants
Time-of-flight measurements at AKR-2	TUD/Carsten Lange and Alexander Knospe	3 h to one day Onsite Possibility of hybrid format (audio/video sharing)	Dedicated set of lecture notes provided	Max. 8 onsite participants
Spectral indices with foils and/or fission chambers at CROCUS	EPFL/Alessandro Scolaro, Vincent Lamirand and Mathieu Hursin	4 h Onsite Possibility of hybrid format (audio/video sharing + remote control of acquisition systems)	Basics in reactor physics and radiation matter interaction	Max. 4-6 onsite participants
Measurements of diffusion length, absorption XS/migration area (CARROUSEL) at CROCUS	EPFL/Alessandro Scolaro, Vincent Lamirand and Mathieu Hursin	4 h Onsite Possibility of hybrid format (audio/video sharing + remote control of acquisition systems)	Basics in reactor physics and radiation matter interaction	Max. 4-6 onsite participants
Irradiation for spectral indices at the BME Training Reactor	BME/Mate Szieberth	4-6 h for measurements and 4-6 hours for evaluations (morning/afternoon) Onsite Possibility of hybrid format (audio/video sharing) for the evaluation	Dedicated set of lecture notes provided	4-5 participants/ group with max. 2 groups in parallel Radiation protection briefing required before entire the first time

		sessions + pre-recording of measurements		
Measurement of diffusion length in graphite thermal column at the BME Training Reactor	BME/Mate Szieberth	4-6 h for measurements and 4-6 hours for evaluations (morning/afternoon) Onsite Possibility of hybrid format (audio/video sharing) for the evaluation sessions + pre-recording of measurements	Dedicated set of lecture notes provided	4-5 participants/ group with max. 2 groups in parallel Radiation protection briefing required before entire the first time

The hands-on training sessions organized by the technical teams at the experimental facilities allow the students to gain direct experience on the analysis of measurements, with a specific focus on the quantities that characterize the behaviour of a nuclear reactor core, such as the spectral index. As the exercises are carried out in different facilities, the comparison of the obtained results is also helping the students to understand how the core composition and layout influence the relevant neutronic parameters.

6. Conclusions

As demonstrated in this report, the handbook on neutron transport at the fuel cell and assembly level was developed as a collective effort between different teachers and is already available. Likewise, the planning and content of the corresponding synchronous sessions were established. Beyond the development of such sessions, the coming months will also be devoted to the development of the webcasts, quizzes and on the structuring of all electronic resources on the LMS.

7. References

Anderson L.W., Krathwohl D.R., Airasian P.W., Cruikshank K.A., Mayer R.E., Pintrich P.R., Raths J. and Wittrock M.C., A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives, Pearson, Allyn & Bacon (2000).

Jaiyeola A., Erim S., Balech S., and Stöhr C., Mapping analysis. GRE@T-PIONEeR deliverable D1.1 (2021).

Bishop J. L. and Verleger M. A., The flipped classroom: A survey of the research, ASEE National Conference Proceedings, Atlanta, GA, USA, 30 (9) (2013).

Demazière C., Operative structure. GRE@T-PIONEeR deviverable D1.2 (2021).

Demazière C., Apell P., Stöhr C. and Adawi T., Setting up a room to cater to online learners' needs, Proc. Conf. Nuclear Training and Education (CONTE 2017), Jacksonville, FL, USA, February 5-8, 2017 (2017).

Felder R. M. and Brent R., Teaching and learning STEM: A Practical Guide. John Wiley & Sons, Incorporated (2016).

Freeman S., Eddy S.L., McDonough M., Smith M.K., Okoroafor N., Jordt H. and Wenderoth M.P., Active learning increases student performance in science, engineering, and mathematics, Proceedings of the National Academy of Sciences of the United States of America, 111 (23), pp. 8410-8415 (2014).

O'Flaherty J. and Phillips C., The use of flipped classrooms in higher education: A scoping review, The Internet and Higher Education, 25, pp. 85-95 (2015).

The Vanderbilt University Center for Teaching, "Bloom's taxonomy", available online. URL https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/ (2021).

Watkins J. and Mazur E., Just-in-time teaching and peer instruction, In Simkins S. and Maier M. (eds.), Just-in-time teaching: Across the disciplines, and across the academy, Stylus Publishing, Sterlin, VA, USA (2010).