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Overview of the course package on nuclear data for energy and nonenergy applications

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Summary

This document gives an overview of the course package on Development of a course package on nuclear data for energy and non-energy applications. 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

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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

Executive Summary

This document gives an overview of the course package on Development of a course package on nuclear data for energy and non-energy applications. 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

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 Development of a course package on nuclear data for energy and non-energy applications offered as part of the Work Package 2 (WP) 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 nuclear installations relies on the knowledge of nuclear data of the isotopes/materials present in the systems. For instance, such nuclear data allow expressing the probability of nuclear interaction per unit path length, on which the neutron transport equation is established. The WP2 thus aims at developing course materials giving the students a full and comprehensive overview of:

- The generation and evaluation of nuclear data libraries.
- The processing of nuclear data libraries for use in energy and non-energy applications.
- The assessment of nuclear data uncertainties.

Hands-on training exercises include the use of nuclear databases together with some visualization software, of processing codes, and of sensitivity and uncertainty analysis tools. Combined with these exercises, research reactors will be used for employing different methods for cross section measurements.

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.

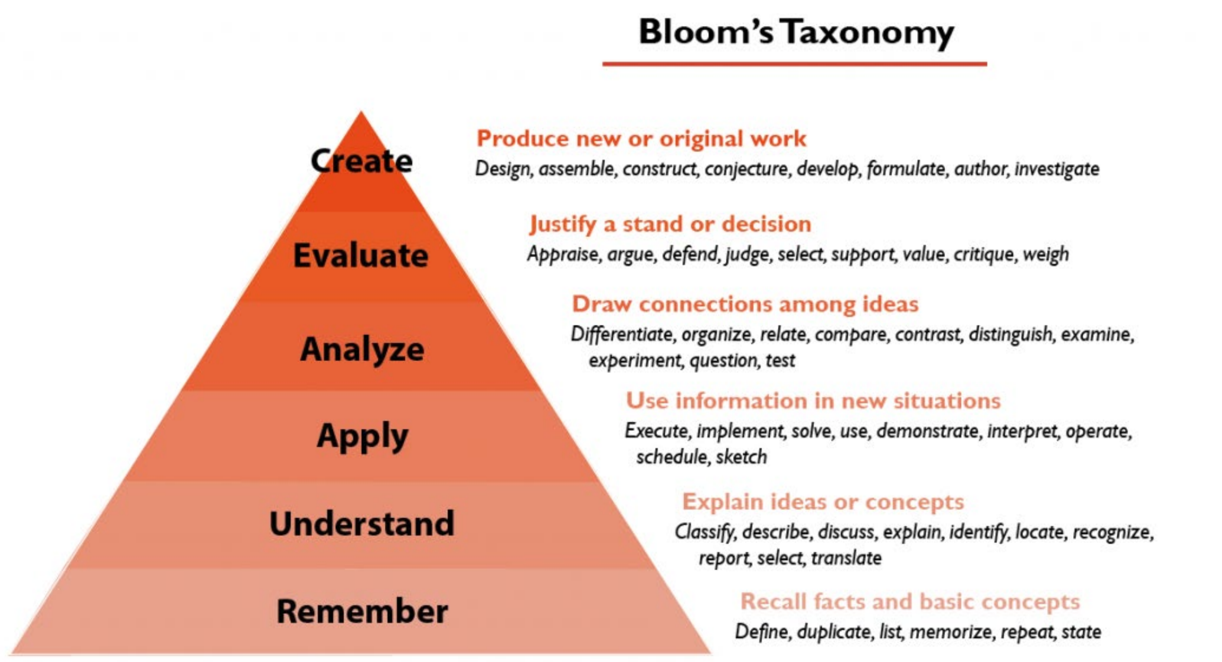

Figure 1. Illustration of Bloom's revised taxonomy for the cognitive domain, with higher order thinking skills at the top of the diagram – adapted from (The Vanderbilt University Center for Teaching, 2021).

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.

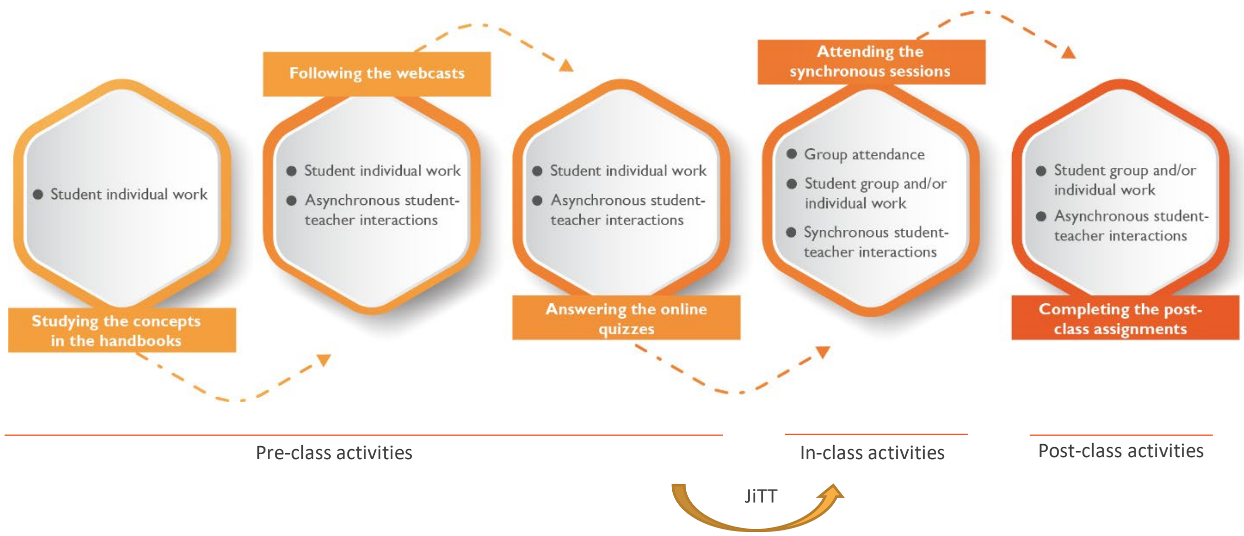

Figure 2. Illustration of the learning sequence.

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.

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.

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)

4. Overall contents of the developed handbooks

The contents of this Handbook outline the importance of neutron/proton/gamma-induced reactions for nuclear applications.

The Handbook is structured in 10 CHAPTERS.

Some basic principles in nuclear physics are introduced with respect to nuclear reaction cross-sections, decay data and fission yields (**CHAPTER 1**). The production and use of nuclear data for particle-induced reactions are presented, together with the nuclear data libraries and databases.

CHAPTER 1: NUCLEAR DATA FOR NUCLEAR APPLICATIONS (80 pages)

- The role of nuclear data for nuclear applications
- The role of nuclear data for modelling nuclear systems
- Nuclear Data: Basic concepts: Nuclear structure and decay data, Nuclear reaction cross-sections, Neutron sources and fission multiplicities, Energy release, Fission fragments and products, Photon multiplicities, The neutron-nucleus resonance interaction: The compounds nucleus, Level density, average distance between levels and partial widths, The R-matrix theory, The Breit-Wigner formula, R-matrix formalism used in the evaluated data files
- Activities associated with nuclear data

The EXFOR experimental database (**CHAPTER 2**) and general purpose evaluated nuclear data libraries (**CHAPTER 3**) (JEFF and ENDF/B among others) are illustrated with practical examples.

CHAPTER 2: THE EXPERIMENTAL NUCLEAR DATA (30 pages)

- Introduction: EXFOR: “the mother of all libraries”
- The EXFOR format
- Experimental techniques in nuclear data: Time-of-flight, Transmission data and capture yields
- Uncertainties in experimental measurements: Constructing covariance matrix from EXFOR uncertainties

CHAPTER 3: Evaluated Data Libraries (50 pages)

- Introduction: The nuclear data evaluation pipeline
- Nuclear reaction codes: Modelling versus measurements
- Evaluation of cross-sections in different energy ranges: Thermal region, Resolved and unresolved resonance region and the High energy – the continuum
- The evaluation of nuclear data: The Bayesian’s Approach
- GLLS applied in the evaluation of nuclear data
- Uncertainties in the evaluated nuclear data
- Nuclear data and the compensating effects in keff
- Nuclear Data Evaluations Libraries: Dosimetry Libraries and Standards Library

- The format for the Evaluated Nuclear Data: The ENDF-6 format and the GNDS format

The tools for visualization (**CHAPTER 4**) and processing (**CHAPTER 5**) nuclear data (and their covariance if available) are touched upon, as well as the use of integral benchmarking (**CHAPTER 6**) for nuclear data validation.

CHAPTER 4: Nuclear Data Visualization Tools (14 pages)

- JANIS software: JANIS Basics and JANIS Books
- IAEA software visualization tools
- NNDC software visualization tools
- JENDL software

CHAPTER 5: Tools for Processing Nuclear Data (70 pages)

- Introduction: Tools for Processing Nuclear Data
- ENSDF Analysis and Utility Programs
- ENDF Processing and Utility Programs
- PREPRO system
- NJOY code
- INTEGRAL data
- Verification tools

CHAPTER 6: Benchmarking and Validation (16 pages)

- Integral Databases for Benchmarking and Validation: ICSBEP, IRPHEP, SINBAD, SFCOMPO
- Tools for validation: DICE basics, IDAT basics
- Benchmark suites

Different sensitivity and uncertainty analysis techniques are introduced to calculate uncertainties for integral quantities such as keff (**CHAPTER 7**). In addition, current “adjustment methodologies” are introduced to adjust nuclear data and their covariances to integral data that represent the physics of the system, for which the nuclear data are used, namely the nuclear data libraries for specific applications (**CHAPTER 8**) .

CHAPTER 7: Sensitivity Analysis and Uncertainty Quantification (16 pages)

- Introduction: S/A and UQ
- Sensitivity Analysis - sensitivity coefficients
- Uncertainty Analysis based on S/A: Error propagation
- Similarities and correlations between integral experiments
- NDaST Tool: Uncertainty Analysis in criticality databases
- Uncertainty Analysis based on Monte Carlo technique

CHAPTER 8: Nuclear Data Adjustment Methodologies (14 pages)

- Nuclear Data Adjustment Methodologies
- Nuclear data adjustment methodologies based on deterministic methods
- Nuclear data adjustment methodologies based on stochastics methods
- The Bayesian Monte Carlo (BMC) approach
- Selection of integral Benchmarks
- Procedure for improved predictions of integral functions

An overview of the international activities on nuclear data is given (**CHAPTER 9** and **CHAPTER 10**). Those include the efforts led by organizations such as the OECD/NEA and the IAEA, working parties or networks (OECD/WPEC, IAEA/INDEN, …), or via evaluation projects (JEFF, ENDF, JENDL, …).

CHAPTER 9: Nuclear data needs: Target Accuracy Requirements (5 pages)

- Definition of Target Accuracy Requirements
- Example of methodology of the "inverse problem" via sensitivity analysis
- The HPRL

CHAPTER 10: Overview of International Organizations (5 pages)

- IAEA/NDS
- IAEA/NRDC
- NEA/NSC/WPEC
- NEA/Data Bank

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 organization/person	Format	Background knowledge	Restrictions
Hands-on on ENDF, NJOY, PREPRO, JANIS, DICE, NDaST, overview of nuclear data	UPM/Oscar Cabellos	Hybrid • Using Fortran codes (ENDF Utilities, NJOY, PREPRO …)	Provided in the T2.1 handbook and with dedicated set of lecture notes	• Max. 15-20 onsite participants • Max. 25-30 offsite participants

adjustment techniques		openly available and precompiled in Windows and/or Unix • Web applications: JANIS, DICE and NDAST • Excel Sheets for GLLS techniques in adjustment exercises	provided, if needed.	

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

Day 1	Day 2	Day 3	Day 4	Day 5
(1hour) Start of the course: introduction of the teachers and participants, schedule for the week	(4 hours) • ND Evaluations - Nuclear Data Libraries: Decay, FYs, TSLs, Neutron, Proton, ... • Evaluation I: GLLS Technique	(4 hours) • Processing I: NJOY - RECONR, BROADR, HEATR, THERMR, GASPR, MIXR • NJOY - GROUPR, ACE, WIMSR • NJOY - ERRORR, COVR	(4 hours) • Benchmarking I: ICSBEP/DICE Basis, IRPHEP/IDAT Basis, SFCOMPO Basis, SINBAD Basis • DICE: Searching by sensitivities, similarities in Benchmarks, user keff	(4 hours) • Benchmarking II/Validation II: NDaST: Assessing impact of different ND Evaluations • International Activities on ND: The HPRL
(3 hours) • Sources of ND information • Experimental Data: EXFOR • ND formats	(3 hours) • Evaluation II: Bayesian Technique • RRR formalisms • Basics on processing with NJOY: RECONR+BROADR	(3 hours) • Processing II: NJOY, PREPRO, INTER • Create JANIS database: HENDF Files	(3 hours) • Validation I: SA/UQ, ND adjustment (JANIS, DICE, NDAST) • NDAST: UQ, perturbation calculations and similarities in Benchmarks, user sensitivities	(1 hour) Closing of the course: course certificates and course evaluation
(3 hours) • Visualization & Processing				

(EXFOR, ZVIEW, JANIS) • JANIS capabilities: Simple operations, Weighting				

The details of the hands-on exercises on the training reactors are given in Table 3.

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
Neutron transmission measurements and pile oscillator experiment 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
Gold foil activation experiment 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
Gold foil activation 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
Reactivity worth of samples with pile oscillator (POLLEN) 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
Cross section measurement by activation analysis (effective cross	BME/Szieberth Máté	4-6 h for measurements and 4-6 hours for evaluations (morning/afternoon)	Dedicated set of lecture notes provided	4-5 participants/group with max. 2 groups in parallel

section) at the BME Training Reactor		Onsite Possibility of hybrid format (audio/video sharing) for the evaluation sessions + pre-recording of measurements		Radiation protection briefing required before entire the first time
Measurement of the Doppler effect at the BME Training Reactor	BME/Szieberth Máté	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

6. Conclusions

As demonstrated in this report, the handbook on Development of a course package on nuclear data for energy and non-energy applications was developed as a collective effort 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.

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