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Review Article

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Education, training and mobility, knowledge management: towards a common effort to ensure a future workforce in Europe and abroad

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Abstract. Continuous and future-oriented education and training as well as knowledge management for young talents are required for the safe and reliable operation of nuclear reactors and nuclear facilities in Europe. A dedicated line of collaborative projects addresses the specific needs, such as lack of personnel (project ENEN+: "attract, retain and develop new nuclear talents beyond academic curricula"). State-of-the-art approaches and in-depth knowledge are provided when it comes to reactor physics (project GRE@T-PIONEeR: "graduate education alliance for teaching the physics and safety of nuclear reactors") or nuclear radiochemistry (project A-CINCH: "augmented cooperation in education and training in nuclear and radiochemistry"). A highly skilled nuclear engineer must undergo experimental work to better observe theoretical principles at work. Following the ENEEP (European nuclear experimental educational platform) initiative, a network of research reactors and special laboratories is made available for performing such activities. Another issue found is that the results of Euratom-funded research activities are spread across multiple platforms and websites making it difficult to find relevant information within a reasonable timeframe. Such a situation requires the application of knowledge management actions. The PIKNUS project aims to define a concept of a knowledge management method and tool to improve the sharing and availability of Euratom research results. All projects successfully demonstrate that European collaboration could address certain needs to attract, develop and retain young talents in future-oriented nuclear fields.

1 Introduction

The use of nuclear energy is a long-term commitment. Nuclear Power Plants (NPP) could be with us for about 100 years or more[1] since lifetime extensions of several plants are already decided in many European countries. The safe and reliable operation of NPPs requires the best available knowledge and the best available skills of their employees. Therefore, a continuous supply of nuclear talent must be guaranteed, which must be attracted, developed, and retained in the nuclear field.

Expressed in more detail, highly educated personnel with very specific knowledge, skills and competencies will be still required in the future regardless of the development of the nuclear power sector in the EU, as either new builds, development of innovative and advanced reactors, long-term operations, shut-down, decommissioning, waste management and radiation protection all necessitate qualified staff. This is also the case for other industrial and medical applications making use of radionuclides and/or ionising radiation. This situation persists already since the turn of millennia when the OECD/Nuclear Energy Agency's report, "nuclear education and training: cause for concern?" (2000), demonstrated that many nations are training too few scientists to meet the needs of their current and future nuclear industries and authorities and that the European educational skill base has become fragmented to a point where universities in many countries lack sufficient staff and equipment to provide education in all nuclear areas.

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[1] Including licensing, long-term operation and decommissioning.

Many of these challenges have a transnational dimension and can be more efficiently addressed through a joint approach. A closer collaboration of higher education European institutions guarantees very high quality of education and training activities. The access to cross Member States research infrastructures allows students to learn and develop skills, e.g. using training reactors or specialized R&D facilities, not available in each country, as well as building collaboration networks and sharing safety culture fundamentals.

On the long-term perspective, it is important to both give young talents the chance to develop new skills and knowledge, and to manage the existing knowledge, i.e. preservation and dissemination of information and data It means that continuous actions and initiatives are required in education and training (E&T) combined with knowledge management (KM) for the benefit of Europe in all nuclear fields.

Through its Euratom Program, the European Commission continuously supports several E&T and KM initiatives in the nuclear field through both collaborative projects (Indirect Actions) or via direct research activities implemented by the European Commission Joint Research Centre, JRC (so-called Direct Actions). Both types of actions support research contributing to increased knowledge and competencies for nuclear safety, security and safeguards.

A dedicated line of recent collaborative projects addresses the specific needs in the sector to prevent undersupply of personnel (ENEN+) and provide state-of-the-art approaches and in-depth knowledge when it comes to reactor physics (GRE@T-PIONEeR) or nuclear radiochemistry (A-CINCH). A highly skilled nuclear engineer must undergo experimental work to better observe theoretical principles at work. Following the ENEEP initiative, a network of research reactors is made available for performing such activities. Another constraint is that the results of Euratom-funded research activities are spread across multiple platforms and websites making it difficult to find relevant information within a reasonable timeframe. Such a situation requires the application of KM actions. The PIKNUS project aims to develop a concept of a knowledge management method and related tools to improve the sharing and availability of Euratom research results. The projects are described in detail as follows.

Regarding the needs and future challenges within nuclear sciences and engineering, expertise in nuclear and radiochemistry (NRC) is of strategic relevance to the whole nuclear energy sector, being inherently present in safe nuclear installation operations, decontamination and decommissioning processes, and waste management, as described above. The non-energy fields of NRC applications are even broader and range from life sciences – radiopharmaceuticals, radiological diagnostics, and therapy – through to dating in geology and archaeology, (nuclear) forensics and safeguards, radiation protection and radioecology.

One of the challenges in Nuclear and RadioChemistry (NRC) education is the extremely time-consuming, resource and costs demanding "hands-on" laboratory training on how to work safely with possibly very dangerous radioactive material. "Hands-on" means physically working in a real radiochemical laboratory with open radioactive sources. In addition to the specialised skills required by the science, such work of course requires extensive safety training (meeting all EHS – Environment, Health, and Safety – laws and regulations). It should be clearly understood that there is no substitute for such hands-on training. However, modern computer technology offers opportunities for preparing and training for work in a real lab in advance, by using sophisticated simulations and virtual reality environments to an extent (and price), that would be unthinkable only a few years ago. The proper and balanced combination of both real and virtual training and education is one of the arising challenges in this and other nuclear fields, and the A-CINCH project focuses on it.

2 Attract, retain and develop new nuclear talents beyond academic curricula (ENEN+)

2.1 Project objectives

The main goal of the project "Attract, Retain and Develop New Nuclear Talents Beyond Academic Curricula" (ENEN+) [1] is to contribute to the revival of the interest of young generations in careers in the nuclear sector. This can be achieved by pursuing the following main objectives:

- ***Attract*** new talents to careers in nuclear,
- ***Develop*** the attracted talents beyond academic curricula,
- Increase the ***retention*** of attracted talents in nuclear careers
- ***Involve*** the nuclear stakeholders within the EU and beyond,
- ***Sustain*** the revived interest for nuclear careers.

The project itself focuses on the learners and careers in the following nuclear disciplines:

- Nuclear reactor engineering and safety,
- Waste management and geological disposal,
- Radiation protection and
- Medical applications.

Integration of project objectives together with targeted nuclear fields is outlined in Figure 1. Integration of further nuclear disciplines (e.g., nuclear chemistry, decommissioning, fusion engineering, etc.) and sustainability of the ENEN+ accomplishments beyond the project life is foreseen within the existing ENEN (European Nuclear Education Network) Association and its partners. The attraction, retention and development of the new nuclear talent can only be sustained beyond the project life through strong nuclear stakeholders partnership. Various nuclear stakeholders are involved including academia, research, industry, Technical Support Organisations as well as International Organizations.

This approach is of primary importance for the success and sustainability of the proposed activities also beyond the life of ENEN+.

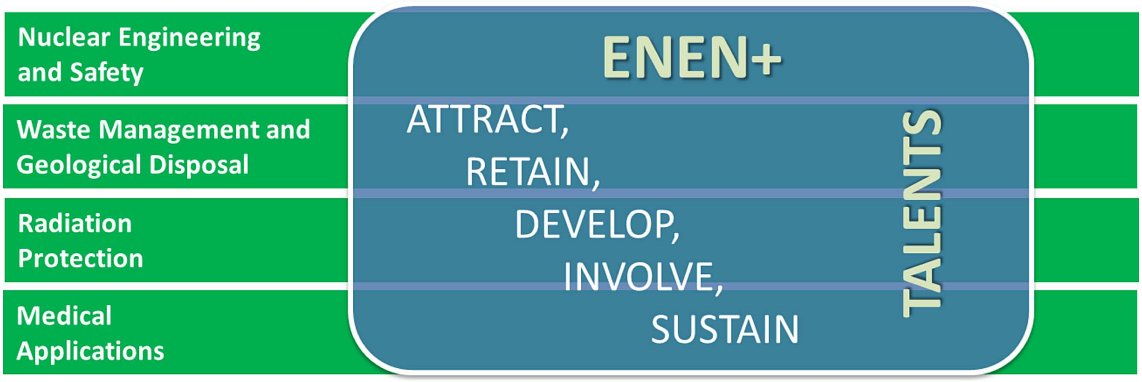


Fig. 1. Outline of the project objectives with the 4 major nuclear fields [1].

2.2 Methodology

In order to achieve the previously mentioned objectives, specific methodologies were designed.

I. Attracting new talents to careers in nuclear
The lack of new talents entering the nuclear fields is closely linked to a general loss of interest in nuclear sciences and insufficient information about the careers. In order to counter these effects, several actions were proposed based on the target groups:

- **Secondary school pupils**. Attractive basic information on careers in nuclear were developed, made available in national languages and complemented with an EU-wide competition of pupils[2]. A summer camp was organized for the winners of the competition. Electronic tools including social media were used thoroughly, especially in the context of the COVID-19 pandemic which influenced a lot the methodology the project was implemented.
- **Bachelor students**. Most of the nuclear academic curricula within the ENEN association members focuses on the master students. The existing efforts to attract the bachelor students to pursue master education in nuclear was strengthened by increasing the level of academic preparation for them.
- **Young professionals after graduation**. The nuclearisation of graduates of non-nuclear sciences and technologies has been a considerable source of nuclear talent throughout the nuclear era. Attracting more graduates to nuclearisation may require strong support from the end-user and will be put in place through attractive e-information and opportunities for individual guidance towards nuclear careers coupled with opportunities to interact with practitioners of nuclear. At the same time, "nuclearists" should get the chance to improve their knowledge and skills and having this way opportunities for better jobs.

[2] For example by creation of a public forum in which anyone can avail themselves of practical information on E&T, careers and scholarship. This may include student fair, flyers, "open door" events, etc.

II. Develop the attracted talents within and beyond academic curricula
The academic education is expected to remain the foundation of future nuclear experts and scientists. A good balance between the knowledge, skills and competencies may nevertheless need a further shift from thinking about pedagogy in terms of "teaching" to one that considers "learning" as the primary goal. This may allow us to more strongly link pedagogy with learning outcomes and student experience, for example, engagement in professional development activities with the support of industry, including course release for such activities. The use of teaching methodologies that include active learning, collaboration, problems/issues-based connections, and critical thinking must be developed in this regard and supported by individual career guidance and mobility funding.

The mobility support focuses on the following target groups and activities:

- Students:
  - Short-term internships,
  - Presentations at conferences.
- "Nuclearisation", life-long learning:
  - Internships,
  - "Nuclearisation" courses.

The mobility funding is provided through competitive calls published on the ENEN website.

III. Increase the retention of attracted talents
The retention is planned to be increased through student support and mentoring, enhanced by the mobility program.

The mobility support focuses on the following target groups and activities:

- M.Sc. students:
  - Mid-term internships (3 months),
  - Presentations at conferences,
  - Exchange compatible with the rules of the European Masters of Nuclear Engineering (EMSNE, >=20 ECTS abroad).
- Ph.D. students and post-docs:
  - Internships,
  - Access to research infrastructures,
  - Access to EURATOM research projects.

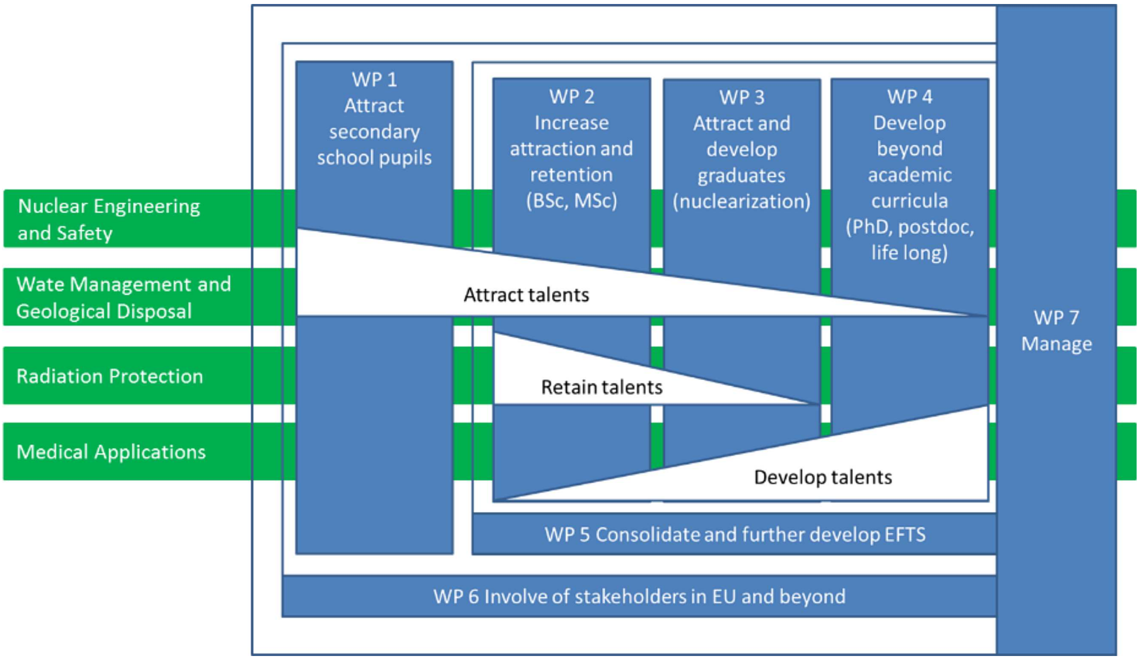


Fig. 2. ENEN+ working plan.

IV. Sustain the revived interest in nuclear careers
In order to proceed in this direction, a proper communication strategy was planned to ensure consistent communication to the industry that aligns decision-makers around the strategy to provide time and investments for training new young talents. The objective is also to communicate to other stakeholders (including regulators and legislators) the value that can be derived from this initiative to maintain industry excellence and improve safety in a broad sense while ensuring the availability of nuclear expertise in the future.

In order to be able to plan the nuclear Education Training Knowledge Management (ETKM) activities beyond the life of the ENEN+ project, the projection of the nuclear workforce needs to be developed together with JRC EHRO-N (European Human Resources). This will be the basis of a proposal for a joint strategy for European ETKM considering also the developments of other initiatives at the international level.

2.3 Structure

The ENEN+ consortium is composed of twenty-two (22) participants located in different EU countries and abroad. The outline of the project working plan is presented in Figure 2.

The project is structured into six main work packages to which another Management work package is added. The focus of the Work Packages is presented below.

WP 1 – Attract new nuclear talents in secondary schools.
WP 2 – Increase attraction and retention of new talents among undergraduate students.
WP 3 – Attract and develop new talents through nuclearisation.
WP 4 – Develop new nuclear researchers beyond academic curricula.
WP 5 – Consolidate and further develop European Fission Training Scheme and Mobility.
WP 6 – Involvement of stakeholders in the EU and beyond.

2.4 Current status and outlook

The project is currently finished with an important impact on the nuclear community and beyond. Figure 3 contains one of the most successful actions in recent years related to education and training in the nuclear industry. More than 600 “mobilities” have been granted, demonstrating the European dimension for nuclear E&T.

Although the ENEN+ project ended, the consortium decided to continue the initiative and submitted a new proposal to the European Commission in the same line but with an upgraded mobility scheme.

3 Augmented Cooperation in Education and Training in Nuclear and Radiochemistry (A-CINCH)

The EURATOM Work Programme 2019–2020 – Nuclear Fission and Radiation Protection Research of its NFRP-2019–2020-11 topic identifies a loss of the younger generation’s interest in specialized nuclear knowledge and related risk that the current workforce, progressively retiring, could not be replaced as one of the current main concerns in the nuclear sector.

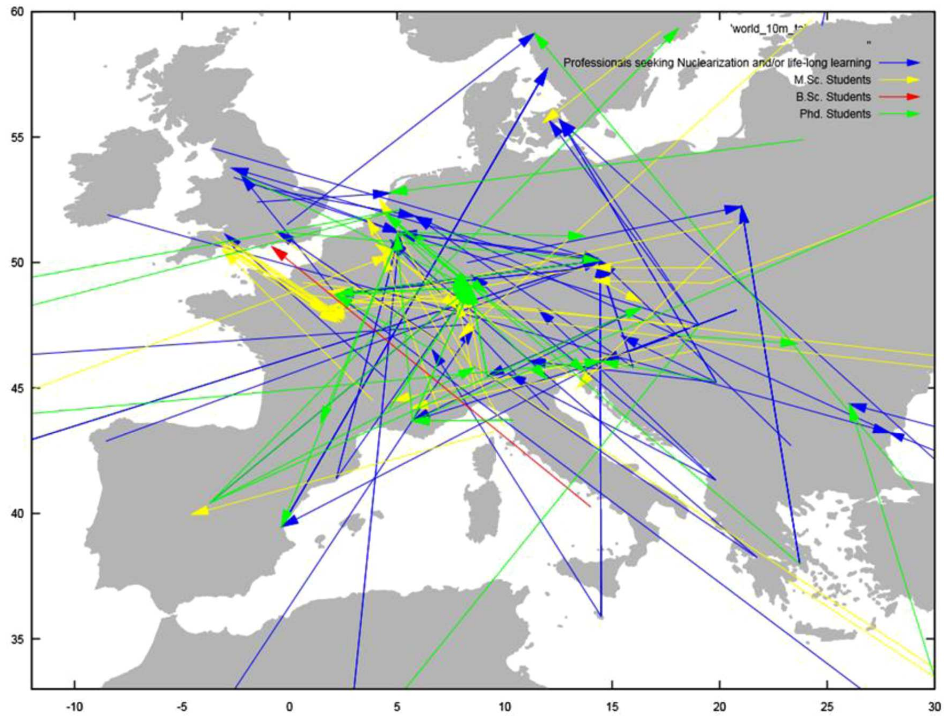


Fig. 3. Mobilities incurred following ENEN+ support.

3.1 Project definition, concept, and objectives

The A-CINCH ("Augmented Cooperation in education and training in nuclear and radio CHemistry") project is corroborating and extending achievements of previous projects. A-CINCH primarily addresses the young generation's and even the public loss of interest in nuclear knowledge by focusing on secondary education, using a "Learn through Play" concept to engage with students and teachers. For such purpose, A-CINCH augments CINCH teaching tools developed in the three previous CINCH projects – CINCH, CINCH II, and MEET-CINCH – the CINCH project series (www.cinch-project.eu), which were supported from FP7 and H2020. A-CINCH is a Horizon 2020 project No. 954301, that started in October 2020 with 17 partners from 13 countries with a duration of 36 months.

The overall objective of the project is to set up the CINCH Hub platform incorporating all previous CINCH results, completing it with newly developed courses and tools, and wrapping it all up into a user-friendly and easy-to-navigate single-page interface. Based on experience from university teaching and being well aware of the lack of valid information about the nuclear field among the public, new target groups were defined – the young generation from secondary school up to university, including the general public and interested professionals engaged through Vocational Education and Training. To address the new target groups and efficiently attract the attention of secondary school students, new didactical tools, suitable for today's youth, are being developed and improved. Implementation of a Virtual Lab, based on the involvement of augmented reality and gamification applied on nuclear and radiochemistry education is an example of the highly innovative ones.

The A-CINCH activities are grouped around three main pillars and divided into 7 work packages (WP):

1. Virtual reality laboratory for NRC education (VR-Lab), which includes VR-Lab platform development and VR Hands-on Training design and implementation (WP1+2).
2. Wrap-ups & Developments (WP3+4), which focuses on updates, improvements, and extensions of the tools, teaching materials, and various courses that are already available from previous CINCH project series or are currently under development in A-CINCH.
3. Nuclear Awareness (WP5), which focuses on making the field attractive to a younger generation and motivating school students to pursue a career in nuclear chemistry in industry or academia via the development of a distributable and sustainable toolkit of standalone resources to promote and increase awareness of the field of nuclear and radiochemistry.

The pillars are supported by two crosscutting activities (a) dissemination and networking (WP6) and (b) mobility and management (WP7).

3.2 Selected developments and progress

Virtual reality laboratory for NRC education
During the first half of the project implementation, the initial concept of the VR environment was redesigned and improved to allow better implementation of VR hands-on scenarios. Visual changes include a completely new

layout of the laboratories, design, and dimensions of the respective rooms. Now the virtual space consists of several rooms such as the main lab, measurement room, neutron activation analysis lab, radiopharmaceutical lab, radioactive waste storage room, changing and locker rooms, and a decontamination room. For the purposes of the virtual environment, a module for the virtual detection of ionizing radiation was developed and implemented. It is now possible to measure radioactive samples and evaluate measured values and spectra. The environment also allows for interaction with objects, transferring, pipetting, and mixing fluids, weighting and dissolving substances, and solution preparations. The whole main lab environment, colours, scene lights, and textures have been improved.

Up to 10 storyboards for virtual hands-on tasks were suggested and described. Now the selected ones are being described in more detail and higher level of interaction. To guide users/players through the lab and particular exercises, the quest system was designed and is in the implementation phase.

Augmented reality application

A simple and smart implementation of augmented reality for NRC-education was developed as a virtual experiment for pupils. The application for Android smartphones was developed, where AR replaces radioactive sources and visualizes radiation. Pupils are able to play with several virtually augmented radiation sources of various types (alpha, beta, gamma), various augmented shielding, and a detector. Radiation from the source is visualised to help understand how the physics and propagation of the radiation works.

Massive open online courses (MOOCs)

MOOCs are powerful awareness and education tools that can deliver information in an attractive way for the target groups. "Nuclear-radiochemistry for society" MOOC was issued on 24 August 2020 and closed on 29 August 2021. During the course, 197 users from 29 countries were enrolled, resulting in 36 certificates with an average grade of 91.4. Most of the participants (65%) joined the course for personal interest and even more (71%) were motivated to complete the course. The second edition was issued immediately on 30 August 2021 and it will be finished again on 29 August 2022. In parallel, the promotion of MOOC was enhanced by addressing partner universities, websites, and YouTube. To enhance MOOC impact and get/deliver additional information, a series of CINCH Talks webinars were launched.

Hands-on training courses (HoT)

A large set of practical courses was developed and issued during the CINCH projects, which are provided on request or regularly depending on the respective target group. The course materials are available on the CINCH Moodle platform. Re-runs of HoT on radiochemical spectroscopic analysis and HoT on working with plutonium and actinides are/were complicated by the Covid-19 pandemic. HoT on Chemical Dosimetry was successfully delivered. During its delivery in September 2021, the Travel Fund procedure and the newly developed CINCH VET e-shop (eshop.cinch-project.eu) were successfully tested, 11 students were finally registered, and 7 were supported by travel fund. All the issued courses are/will be upgraded based on the feedback collected from the previous and current editions. Three new courses are now in development – HoT in decontamination and decommissioning, HoT in nuclear forensics, and HoT in radiopharmaceutical chemistry; these topics were found to be attractive according to current trends and developments in the nuclear- and radiochemistry field. These above-mentioned courses are supposed to be fully ready and available for the public in September 2023, full list of all courses is available at the CINCH VET e-shop.

Nuclear awareness

Current work on Secondary School Packages focuses on the selection of proper strategy and optimum way of delivery and promotion of the package and its content. A dedicated website for hosting educational resources including highly valuable career case videos was created. The teaching materials comprise "teacher" and "student" handbooks for nuclear medicine and Ionlab classrooms. Interactive screen experiments (ISE) and the instructions are ready. Teaching materials for pyro processing of spent nuclear fuel are being drafted. NRC summer schools are aimed at high school and bachelor students to inspire them to pursue a career in nuclear and radiochemistry, they are using a set of lectures, excursions, practical exercises, and topical games showing and explaining nuclear chemistry and related phenomena. The first Summer School under the A-CINCH project took place in Leeds (UK) from the 10th to the 14th of July 2022, and the second is planned for June 2023.

4 Graduate education alliance for teaching the physics and safety of nuclear reactors (GRE@T-PIONEeR)

4.1 Project description and objectives

The GRE@T-PIONEeR project is a project funded by the European Union's Euratom 2019–2020 research and training program. The project started on November 1st, 2020 for a duration of three years. The various partners are Chalmers University of Technology (Sweden – coordinator), Ecole Polytechnique Fédérale de Lausanne (Switzerland), Technical University of Munich (Germany), TU Dresden (Germany), Budapest University of Technology and Economics (Hungary), Politecnico di Torino (Italy), Universidad Politécnica de Madrid (Spain), Universitat Politècnica de València (Spain), the European Nuclear Education Network (Belgium) and LGI Consulting (France).

The project aims at developing and providing specialised and advanced courses in computational and experimental reactor physics at the graduate level (M.Sc. and Ph.D. levels) and post-graduate level, as well as to the staff members working in the nuclear industry. Six-course modules are being developed. Each course module is worth 3 European credit transfer and accumulation system (ECTS). The theoretical, computational, and experimental aspects are tackled in each course. A course module typically requires one full week of self-studying, followed by one full week of hands-on training exercises under the supervision of the teachers involved in the course module. The self-studying part is referred to hereafter as asynchronous learning phase since interactions between the students and teachers do not occur simultaneously but via e-mails and discussion fora. The latter part is referred to as the synchronous learning phase, during which the students and teachers interact in real-time. Because of the self-paced nature of the self-studying phase offered entirely online and of the condensed format of the hands-on training, the course modules are also particularly well suited to industry staff members for life-long learning. This is further enhanced by the offering of the hands-on training session in a hybrid format, i.e., the course participants can decide to come onsite to the organization offering the training or to follow the sessions online. Additionally, a course module devoted to hands-on exercises on a nuclear training reactor is arranged using any of the three training reactors available within the consortium: the CROCUS reactor at Ecole Polytechnique Fédérale de Lausanne, the AKR-2 reactor at TU Dresden, and the BME training reactor at the Budapest University of Technology and Economics.

The different themes covered by the courses follow the various steps a nuclear engineer typically needs to consider when modelling a commercial power reactor, from the preparation of the nuclear cross-sections to full core calculations. More precisely, the following topics are covered:

- Nuclear cross-sections for neutron transport, focusing on:
  - The generation and evaluation of nuclear data libraries,
  - The processing of nuclear data libraries for use in nuclear applications,
  - The assessment of nuclear data uncertainties.
- Neutron transport at the fuel cell and assembly levels, focusing on:
  - 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.
- Core modelling for core design, focusing on:
  - The principles of probabilistic methods in steady-state conditions for core calculations,
  - The principles of deterministic methods in steady-state conditions, their approximations, and their range of validity for core calculations,
  - The use of those methods for reference calculations or core design, operation, and safety analysis.
- Core modelling for transients, focusing on:
  - The principles of deterministic methods in non-steady-state conditions, their approximations, and their range of validity for core calculations,
  - The principles of macroscopic modelling of nuclear thermal-hydraulics and fuel thermo-mechanics,
  - The numerical techniques used for multi-physics coupling.
- Reactor transients, nuclear safety and uncertainty, and sensitivity analysis focusing on:
  - The principles of nuclear reactor safety and system behaviour,
  - The principles of uncertainty and sensitivity analysis applied to reactor transients.
- Radiation protection in a nuclear environment, focusing on:
  - The principles of health physics and radiation protection regulation,
  - Instrumentation for radiation protection in nuclear installations,
  - Shielding calculation methods (both deterministic and probabilistic methods), neutron and gamma transport, and deep penetration problems.

More information about the project can be found in [1].

4.2 Innovations in pedagogy

The key innovative aspects of the project rely on the use of pedagogical approaches favouring learning. Active learning (or *learning by doing*) is a technique demonstrated to lead to student engagement and consequently improved learning [1,2]. The synchronous sessions are thus mostly based on specifically designed activities that the students must participate in. Learning the various theoretical concepts is done via the asynchronous learning elements provided ahead of the synchronous sessions. The asynchronous and synchronous learning sequence often referred to as a flipped classroom [1,3,4], is summarized in Figure 4.

It consists of the following elements implemented on a Learning Management System (LMS):

- *Handbooks* covering the theoretical aspects of the covered topics.
- *Pre-recorded lectures* (or *webcasts*) are available for on-demand viewing and extracting the main features, results, and concepts of the handbooks. Voice and/or video are available.
- *Online quizzes* associated with the webcasts focus on conceptual understanding, with immediate feedback to the students on their learning. The quizzes are designed to develop high-order cognitive skills among the students.
- The possibility to *pose questions* to the teachers while watching the lectures.
- *Active learning sessions* in the forms of wrap-up and tutorials live-broadcasted with synchronous interactions between the students and the teachers.
- Use of *discussion fora* monitored by the teachers. The fora are utilised as a pre- and post-class activity to maintain engagement, favour collaboration between students, and are also used for providing additional feedback and help to the students.

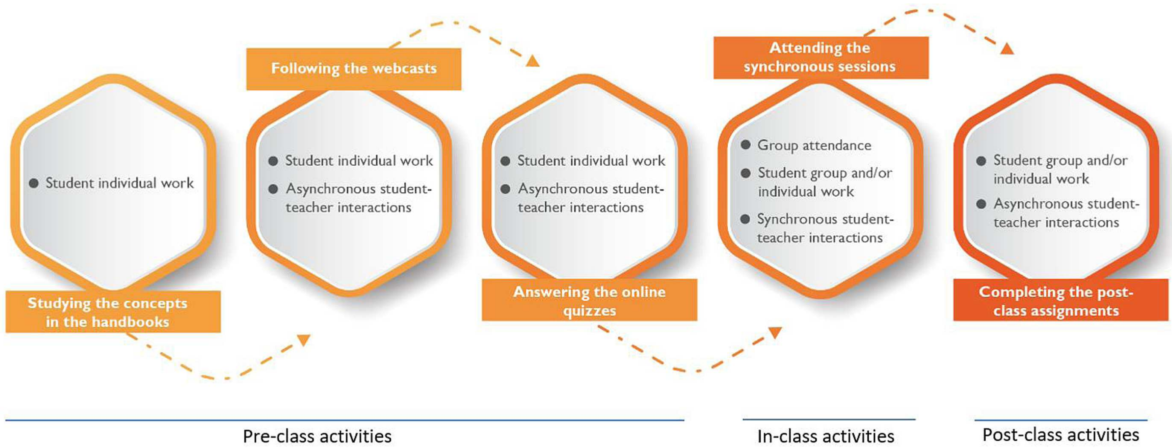


Fig. 4. Illustration of the learning sequence.

As earlier mentioned, the synchronous sessions are offered in a hybrid format, which represents another innovation of the project.

The use of the above hybrid set-up makes the courses attractive to any student, anywhere, without any need for the students to travel, in an increasingly competitive market. Likewise, the teaching staff does not necessarily need to travel for all course elements, even when several teachers contribute to the same course. Finally, offering short-period courses also fits attendees from the industry, without compromising a deep learning approach to the covered topics. The project thus contributes to both maintaining competencies and skills for the industry and life-long learning.

4.3 Key achievements

Since the start of the project, the contents of all handbooks and hands-on exercises have been decided. The writing of the handbooks is ca. 90% complete. The pedagogical method to be used by all teachers was decided and training/discussion sessions on the implementation of the methods were organized. An inventory of the infrastructures required for carrying out the project was performed, and an LMS (SOUL – Smart Open Universe of Learning, from Tecnatom) was purchased specifically for the project. Guidelines for the production of the teaching materials were developed, in order to guarantee the highest possible coherence of the various teaching materials.

Moreover, a mapping of the competencies in the nuclear sector was carried out, together with an assessment of the future needs and skills requirements. This mapping was performed via a questionnaire that was sent to a significant number of nuclear professionals. This questionnaire targeted the different needs of the nuclear industry, to uncover the gaps in the different trainings. Targeted interviews were also conducted with selected stakeholders. Four areas with high foreseen demands were identified: decommissioning, nuclear operations, reactor physics, and new technologies. Furthermore, an assessment of the technical skills, knowledge skills, and critical core skills lacking in the existing curricula was made. Finally, the pedagogical methods used in those curricula were scrutinised. The purpose was to identify good examples to increase the efficacy of teaching/learning. The use of advanced educational techniques in nuclear science and engineering, as well as in other sectors, was benchmarked. Interviews with four teachers using innovative pedagogical methods were carried out. The outcomes of the mapping of competencies, skills, and pedagogical methods are summarized in [5].

4.4 Utilization and cross-fertilization

Since interactions with the various stakeholders (students, teachers, professionals, and the public at large) are essential to guarantee the success of the project, various communication means were implemented. This includes a website, a LinkedIn account, and Twitter account, and newsletters that summarise the results and updates of the project. The project also includes an Advisory Board and an End-User Group, made of utilities, fuel/reactor manufacturers, safety authorities, technical support organizations, engineering companies, training organizations, and international networks. Those organizations are key in guaranteeing the alignment between the teaching resources being developed and the needs of the community.

5 European nuclear experimental educational platform (ENEEP)

5.1 Challenges and motivation

An essential element in the implementation and safe operation of nuclear facilities is a knowledgeable and skilled workforce. It is widely accepted that the desired nuclear-specific skills and experience of a workforce cannot be built without an experimental hands-on nuclear education and training (E&T) requiring research reactors (RRs) of various types and designs. According to [6], a threefold categorization of the competencies necessary to run a nuclear power plant can be drawn, which includes nuclear personnel, nuclearized

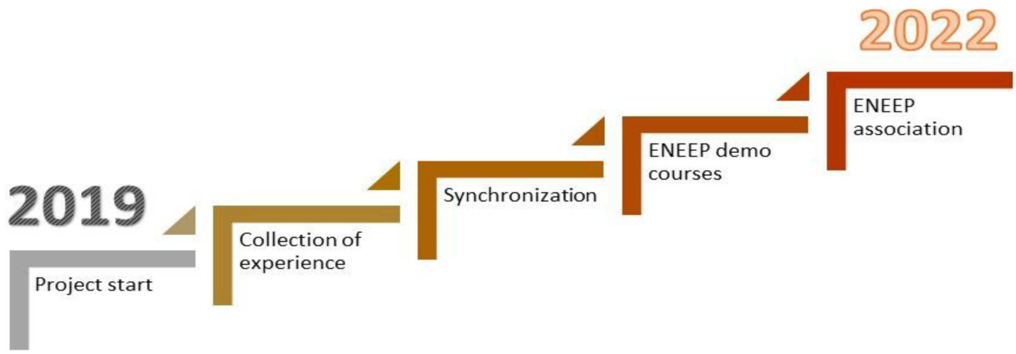


Fig. 5. Timeline of the ENEEP project.

personnel, and nuclear-aware personnel. For all the above-defined categories hands-on experience in the form of a high-quality tailored package need to be provided in the most effective manner. Nowadays it is difficult to enable access to RRs for students, trainees, and their instructors and to provide possibilities for performing nuclear reactor physics experiments. To address these concerns and to deliver high-quality tailored E&T packages and individual access to research infrastructure the European Nuclear Experimental Educational Platform (ENEEP) is being established using funds provided by the European Union under the topic NFRP-2018-7: "availability and use of research infrastructures for education, training and competence building" [7]. There are five ENEEP project partners, the Slovak University of Technology in Bratislava, Slovakia (STU), which is the coordinator; the Czech Technical University in Prague, Czech Republic (CTU); the Vienna University of Technology, Austria (TU Wien); the Jožef Stefan Institute, Slovenia (JSI) and the Budapest University of Technology and Economics, Hungary (BME).

5.2 Objectives and timeline

It is recognized that research programs, international initiatives, and the involvement of government, research centres, and the industry in the education of young professionals are the key to improving the overall level of education and attracting the best students across the EU to stay or to switch to nuclear [6]. Many international projects reflect these challenges, but in addition, the ENEEP project tries to bring nuclear education and training (E&T) closer to almost everyone. Although the ENEEP E&T activities are based on experiments utilizing research reactors and laboratories of nuclear physics, material science, and radiation protection, there are no specific limitations on the educational background of trainees and students. The timeline of the ENEEP project in Figure 5 is showing the sequence of necessary steps leading to the achievement of the project objectives.

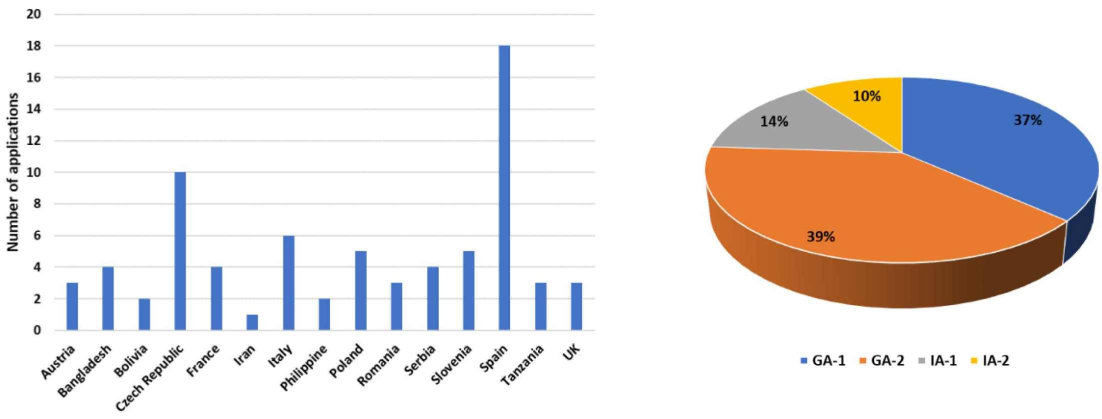
The project started in June 2019 signing the consortium agreement between all five partners. Since each of the partners has been involved in nuclear E&T activities and has its established mechanisms, one of the very first steps in the project implementation was the collection of the experience of each partner. This phase was followed by the analysis of gaps and overlaps in the E&T activities, which lead to the synchronization of activities and processes and the definition of 60+ E&T experiments. In the meantime, the preparation of the ENEEP demo courses took place. These activities are the tools to prove the readiness of ENEEP to provide high-quality E&T activities in the field of nuclear and to cope with the current and potential challenges in the future. In addition, these courses provide a unique opportunity to collect feedback from the real users of the ENEEP infrastructure. This feedback is essential for the establishment of the ENEEP association, before the project end, in 2022.

5.3 Demonstration activities

As one of the most important objectives of the project, the demonstration of the educational and training capabilities of the ENEEP was carried out through dedicated educational activities, organised at the ENEEP partner facilities. The following group and individual education and training courses were organized:

- ***GA1:*** *Safe and secure operation of nuclear installations*
  - 2-week group activity,
  - STU, Bratislava, Slovakia and CTU, Prague, Czech Republic.
- ***GA2:*** *Experimental Reactor Physics*
  - 1-week group activity,
  - JSI, Ljubljana, Slovenia.
- ***IA1:*** *Experiments on the training reactor*
  - 1-week individual activity,
  - BME, Budapest, Hungary.
- ***IA2:*** *Experimental study of the TRIGA fuel characteristics*
  - 1-week individual activity,
  - TUW, Vienna, Austria.

The selected participants from EU member states were given an opportunity to attend the courses for free and were granted the ENEEP fellowship that covered the expenses related to travel, food, and accommodation. The preparation started in October 2021, the deadline



a; applications per country a; applications per course

Fig. 6. Statistics of ENEEP demonstration courses.

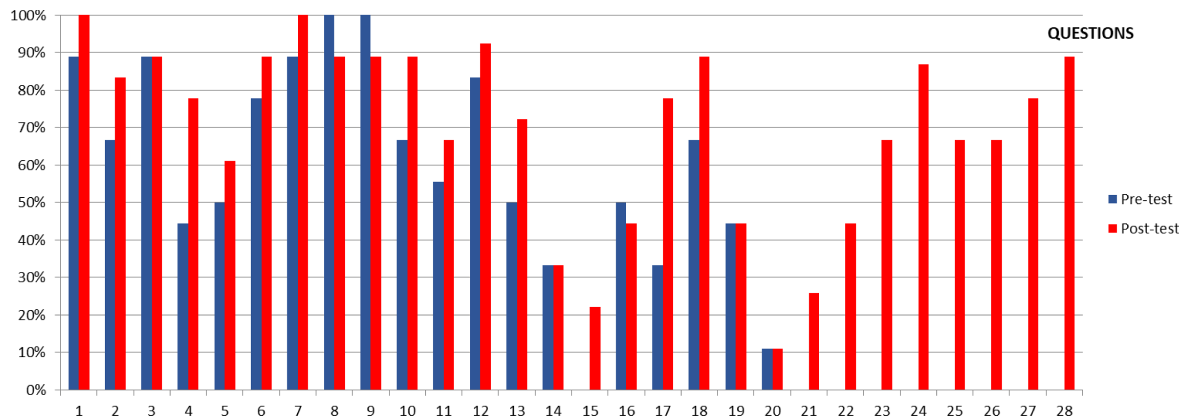


Fig. 7. Progress of the participants of the GA1 ENEEP training course.

for application was November 15, 2021, and the applications were evaluated by the project Scientific and Education Board based on their eligibility, relevance of background, Curriculum Vitae, clarity of motivation letter, recommendation, and the list of previous courses. For the four courses, 73 applications were received from 15 countries, among which 22 participants were directly qualified and 8 were put on the waiting list. 65% of the applicants were male and 35% were female, among which 83% were M.Sc. students, 13% were Ph.D. students, 2 were B.Sc. students, and 1 person was a young professional. The statistics of the training courses are shown in Figure 6.

The progress of students during the course was measured through pre-testing and post-testing, by asking the same questions. In the case of the GA1 training course, the average score of students in the pre-test was 60%, ranging between 28% and 78%. The results of the post-test (see Fig. 7) showed good progress since the average score increased to 69% and the range narrowed to 57%–79%.

The results are clearly showing the success of the GA1 course since we managed to minimize the difference between the participants and increase the knowledge level of each participant. In addition to testing, also feedback forms were distributed, in which the participants could evaluate the quality of the course, reaching the objectives, applicability, organization, and logistics as well as the quality of lectures on a numerical scale. The results showed that the overall score of the GA1 training course was 90.6% ± 5.2%.

5.4 ENEEP association

The main goal of the ENEEP project is to establish coordinated and sustainable access to the infrastructure of project partners also beyond the project duration. The choice made by the ENEEP project partners, as the most promising to achieve this goal, is to establish a non-profit association with the same name ENEEP. The ENEEP association will create a management, communication, and promotion umbrella above all participating institutions. Partial results of the ENEEP project, like the communication plan, evaluation processes, and course preparation procedures, will be directly utilized in the ENEEP association to follow up on the project activities. Moreover, the ENEEP association will represent all member institutions under one brand in the nuclear environment. The E&T activities of the ENEEP association will be based on standard, so-called "à la carte" courses (currently 60), which are the result of the long-term experience of the ENEEP founding members.

6 PIKNUS

6.1 Project objectives

The objective of the Administrative Arrangement PIKNUS (pilot action on knowledge management in the area of nuclear safety) between DG RTD and JRC as part of the Euratom Work Programme 2019–2020, is to define a concept of a knowledge management (KM) method and tool to improve the sharing and availability of Euratom research results for the European nuclear safety research community. A platform enabling access to the results of both indirect and direct actions from Euratom work programmes is under development. Within the pilot action, the work will focus on implementing the KM tool specifically for the area of materials ageing of currently operating nuclear power plant types. Later on, the KM tool could be further developed and extended according to needs.

6.2 End-user needs

One of the first steps in the project was to identify what information should be available on the platform. The sources of information can be classified into the following groups:

- JRC direct actions: these are descriptions and results of relevant research activities undertaken solely by the JRC during the observation period,
- Indirect actions: descriptions and results of Euratom research activities undertaken by multi-partner consortia during the observation period,
- Other relevant information: this is information concerning e.g. European research organisations and infrastructure, education and training, multinational organisations and networks on reactor safety, and JRC websites/repositories. Such information would be linked to the portal to an appropriate extent.

The results of the direct and indirect actions can be mostly retrieved from two sources: from CORDIS in the case of indirect actions, and from JRC Publications Repository PUBSY for the JRC direct actions.

The second step in the project was the identification of user needs. It was originally envisaged to organise a workshop involving a large group of potential end-users, but due to the sanitary crisis, the plans had to be changed. Instead, the following actions were taken:

- Discussions in PIKNUS Steering Group meetings (July and September 2020, February 2021),
- Project presentations of relevant H2020 coordinators at the NUGENIA TA4 meeting (December 2020),
- Survey for relevant H2020 coordinators (January 2021).

Table 1 shows the projects that were selected for the pilot, and their coordinators were accordingly considered as the best representatives of end-users. An online meeting took place in December 2020 with the coordinators of these H2020 projects, and they provided valuable information and feedback, which will be very useful for platform development. In addition, a survey was sent in February 2021 to the same project coordinators for further exploring the end-user needs. The survey comprised questions related to the ways the end-users would search for information, and what kind of use they would see for the platform. The end-users were also asked to express their availability to participate in (1) defining the features and testing the platform, (2) developing taxonomy, and (3) suggesting topics and contributing to the development of synthesis reports. Further, their opinion was asked about handing over project website contents after project closure.

Based on the end-user feedback, the platform should have the following main technical features:

- The core of the system should be accessible to CORDIS and PUBSY, supported with a good search engine,
- Access to other relevant outputs from Euratom- funded projects,
- Interactive part for a forum for exchanges,
- Linking of research institute's websites, infrastructures, international organisations, etc.

6.3 Proposed solution for the platform

The suggested approach to responding to the end-user needs in software development is summarised below.

Access to Euratom deliverables
JRC has developed a Semantic Text Analyser (SeTA) tool that allows document search and extraction over CORDIS and the JRC Publications Repository, the discovery of phrase meaning, context, and temporal development. It can recommend the most relevant documents including their semantic and temporal interdependencies. The tool has been thoroughly tested in real-life conditions in several domains.

The PIKNUS information system will integrate SeTA to retrieve Euratom-related information from CORDIS and the JRC Publications Repository, and continuous synchronisation with CORDIS and the JRC Publications Repository will be developed.

Access to other relevant outputs from Euratom-funded projects
A procedure for taking over relevant documents at the end of Euratom-funded projects needs to be established. This consists of practices for:

- Asking the permission from consortia for transferring documents from the project website at the end of the project,
- Selection of the documents,
- Transfer of the selected documents to the KM platform.

First contacts have been made to make a case study.

Table 1. H2020 projects included in the pilot.

H2020 Call	Shortname	Project full name
2014–15	SOTERIA	Safe long-term operation of light water reactors based on improved understanding of radiation effects in nuclear structural materials
2014–15	INCEFA-PLUS	INcreasing Safety in NPPs by Covering gaps in Environmental Fatigue Assessment
2016	ADVISE	ADVanced Inspection of Complex StructurEs
2016	ATLASplus	Advanced Structural Integrity Assessment Tools for Safe Long-Term Operation
2016	MEACTOS	Mitigating Environmentally Assisted Cracking Through Optimisation of Surface Condition
2016	NOMAD	Nondestructive Evaluation (NDE) System for the Inspection of Operation-Induced Material Degradation in Nuclear Power Plants
2016	TeaM Cables	European Tools and Methodologies for efficient ageing management of nuclear power plant Cables
2019	ENTENTE	European Database for Multiscale Modelling of Radiation Damage
2019	ACES	Towards improved assessment of safety performance for long-term operation of nuclear civil engineering structures
2019	INCEFA-SCALE	INcreasing safety in NPPs by Covering gaps in Environmental Fatigue Assessment - focusing on gaps between laboratory data and component SCALE
2019	STRUMAT-LTO	STRUctural MATerials research for safe Long Term Operation of LWR NPPs
2019	FRACTESUS	Fracture mechanics testing of irradiated RPV steels by means of sub-sized specimens
2019	El-Peacetolero	Embedded Electronic solutions for Polymer Innovative Scanning Tools using Light Emitting devices for diagnostic Routines

Interactive part of a forum for exchangess
In order to offer an interactive platform for the community of users, it is envisaged to use the tool developed at the European Commission, CIRCABC: *Communication and Information Resource Centre for Administrations, Businesses, and Citizens.* As the CIRCABC is accessible to any user inside or outside of the European Institutions, it was considered a practical solution for the collaborative part of the KM platform. The CIRCABC uses the EU Login, the European Commission's Authentication Service, as authentication. The same system is used for logging on to a whole range of websites and online services run by the European Commission.

In the CIRCABC, one can create collaborative spaces where users spread over the web can work together, sharing information and resources.

Linking of research institute's websites, infrastructures, international organisations, etc.
Even if the main aim of the KM platform is to improve the availability of Euratom research results for the European nuclear safety research community, it is advisable to provide links to other sources from the system for easy access to the most relevant external information. Such information is e.g.

- European research organisations,
- European research infrastructure,
- Multinational organisations and networks on reactor safety,
- JRC websites/repositories.

Further, EU legislation, such as the Euratom treaty and nuclear directives, and other cross-cutting knowledge can be linked to the platform.

Due to the sanitary crisis and delays in the IT process, the project duration has been extended until February 2023. The platform development has started with tailoring the semantic text analysis tool to the need of the platform. This will enable the retrieval of documents from CORDIS and PUBSY. This retrieval will not be limited to the pilot scope but allows access to all public deliverables of Euratom-funded projects and actions.

Front-end development has also recently started. This work comprises e.g. development of the user interface, visualisations, access tools, and the interactive workspace. The first version of the system should be available for testing in autumn 2022.

7 Summary and conclusion

Continuous and future-oriented education and training as well as knowledge management for young talents are required for the safe and reliable operation of nuclear reactors or nuclear facilities in Europe.

In the project ENEN+, several activities, such as summer camps, and specialized courses, have been carried out in order to attract, develop and retain young talents in the nuclear field. The most successful measure was the grant of more than 600 mobilities to B.Sc., M.Sc., Ph.D. and other young professionals to perform an E&T measure outside of their home country. This demand clearly demonstrates the European dimension of this action and the direct benefit to European citizens.

The A-CINCH project shows that cooperation in education among universities, research institutions, and end-users brings valuable outputs contributing to the solution of the identified gaps in education and combining classical and alternative/virtual teaching methods. There is much more work in the A-CINCH project, that has not been mentioned in more detail – RoboLabs (Remotely operated robotic laboratory) maintenance, Interactive Screens Experiments development and use in teaching, NucWik (nuclear wiki database of NRC teaching materials) updates, Open Educational Resources (OER) to be shared, or Citizen NRC MOOC preparation. Materials and tools are also analysed to identify missing parts through gap analysis, and quality assurance guideline is being prepared.

The project GRE@T-PIONEeR aims to close an E&T gap in reactor physics by means of developing and providing specialised and advanced courses in computational and experimental reactor physics at the graduate level (M.Sc. and Ph.D. levels) and post-graduate level, as well as the staff members working in the nuclear industry. New pedagogical approaches relying on active learning have been applied successfully.

The consortium forming the ENEEP project enables access to various research reactors and laboratories of nuclear physics, material science, and radiation protection. For four training courses offered so far at different research reactor locations, 73 applications were received from 15 countries, among which 22 participants were directly qualified and 8 were put on the waiting list. 83% were M.Sc. students, 13% were Ph.D. students, 2 B.Sc. students, and 1 person was a young professional. ENEEP could clearly demonstrate the European dimension of their E&T activities and the high attractiveness of the courses offered, which are also planned after the project end, through the ENEEP association.

In the PIKNUS project, a Knowledge Management platform is being developed to improve the accessibility to the results of various EURATOM-funded projects. The pilot focuses on recent "materials projects". An end-user group has provided valuable recommendations concerning the main features of the system. The website development has recently started, comprising e.g. tailoring the search and extraction of project results, and development of the user interface, visualisations, access tools, and interactive workspace. The first version of the system should be available for testing in autumn 2022. The start of operation is foreseen in 2023.

Conflict of interests

– ENEN+: No conflict of interest
– ENEEP: No conflict of interest.
– Great Pioneer: No conflict of interest.
– PIKNUS: No conflict of interest.
– A-CINCH: No conflict of interest.

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Data availability statement

– ENEN+: no associated data generated and/or analyzed.
– ENEEP: no associated data generated and/or analyzed.
– Great Pioneer: no associated data generated and/or analyzed.
– PIKNUS: no associated data generated and/or analyzed.
– A-CINCH: no associated data generated and/or analyzed.

Author contribution statement

– ENEN+: Mr. Gabriel Lazaro Pavel and Joerg Starflinger contributed to the section describing the ENEN+ project.
– ENEEP: Mr. Stefan Cerba, contributed to the section describing the ENEEP project.
– Great Pioneer: Mr. Christophe Demaziere contributed to the section describing the Great Pioneer project.
– PIKNUS: Ms. Kaisa Simola contributed to the section describing the PIKNUS project.
– A-CINCH: Mr. Mojmir Nemec contributed to the section describing the A-CINCH project.

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