

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

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Abstract. The paper highlights the main features of some Euratom projects, which have been running recently in support to education, training and mobility in the nuclear fields. The described projects address various critical aspects of nuclear knowledge management, aiming at maintaining the wealth of nuclear expertise in Europe in an environment characterised by decreased attractiveness of nuclear careers. In an effort to broaden the cooperation and to further extend the opportunities for mobility, some projects ran in parallel with similar initiatives undertaken beyond the European borders. The lesson learnt in terms of successes achieved and critical aspects revealed by the different actions are finally discussed also considering recent recommendations and assessed scenarios by the European Commission for the decarbonisation of the energy sector.

1 Introduction

Since the early days of its technological deployment, nuclear energy has been the subject of both enthusiasm and aversion. The mass intensive characteristics of nuclear energy is in fact perceived alternatively as an opportunity or a deterrent, the latter view prevailing in public opinion in the periods after the occurred nuclear reactor accidents, despite of any serious technical reflection about the causes of the faulty occurrences. This situation of biased feelings is cyclically weakening the effectiveness of efforts devoted to keep and develop an adequate nuclear workforce, creating a generally unfavourable environment for attracting young human resources to the related careers.

The results of this known phenomenon range from the presence of fluctuations in the availability of nuclear personnel with the requested skills and experience to a general shortage of adequate replacements for retiring “experts” (see, e.g., [1,2]). However, the group of experts in

specific nuclear disciplines is not the only one that must be considered critical; in case of new builds, in fact, also skilled personnel in disciplines other than the nuclear ones, who have anyway to operate in the nuclear sector (e.g., civil, chemical, electrical, mechanical engineers, etc.), may be found lacking in the appropriate number. In this regard, it must be considered that the personnel with these “generic skills”, owing to the fact that they do not pertain specifically to the nuclear sector, may be needed at the same time also in other areas, thus creating a competition between different demands, with the potential for giving rise to bottlenecks and pinch points [3].

In general, the optimal composition of the nuclear workforce in case of new builds is depicted as having a pyramidal (or triangular) structure, at whose tip specifically educated nuclear experts are located, in relatively limited number, while the lower levels are more widely populated with personnel having generic skills, to be “nuclearized” or made “nuclear-aware” at different levels [2–5].

A common feature of all the personnel working in a nuclear environment should be at least a sound basis of education and training in relation to nuclear safety culture,

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as an overriding priority at all the technical and managerial levels, while the depth of competences in the rest of nuclear disciplines may vary depending on the function. In the current descriptions of nuclear workforce, the need for personnel who has received a specific and in-depth nuclear education and training (the “experts”) must be considered also in view of the role it has in providing nuclear knowledge and skills to the other personnel; so, their smaller number should not lead to overlook their relevance as nuclear knowledge and skill “multipliers”. It must be also mentioned that the education and training of nuclear “experts” needs competences, whose accumulation requires decades in research and teaching experience, requesting a long-term investment in nuclear education and training (E&T).

In view of the above, the very reason for devoting efforts in nuclear E&T nowadays is to avoid that the occurring fluctuations in nuclear job demand be directly reflected in a decreased capability of nuclear competence transfer through generations, causing a possible permanent loss of competitiveness in the sector. Moreover, the request of two well-known European directives dealing with nuclear safety and waste management (named in short as “nuclear safety directive” [6] and “nuclear waste directive” [7]) that “*Member States shall ensure that the national framework require all parties to make arrangements for education and training for their staff (...)*” must be therefore considered to imply the mentioned long-term investment.

The projects shortly presented in this paper [8–17] share the common intent to contribute, at different extents and in different contexts, to nuclear E&T and to facilitate cross-border mobility and life-long learning of students and professionals. A number of these projects are led by or include the participation of the European Nuclear Education Network (ENEN). The ENEN AISBL, now an international association under the Belgian law, was constituted in 2003 in France, starting its actions with only 22 members. It celebrated its 10th anniversary in 2013 at the previous FISA/EURAD-WASTE Meeting held in Vilnius (Lithuania) [18] and in 2018 it also celebrated its 15th anniversary, during a ceremony held in Brussels before its annual General Assembly [19]. The association, whose “*mission is the preservation and further development of expertise in the nuclear fields by higher Education and Training*”, has today 77 members who are actively involved in promoting its actions.

ENEN, its members and the other actors in the field of nuclear education and training in Europe, with the financial support of the European Commission, are part of the long-term investment that the European Union is carrying on for assuring an adequate nuclear workforce for a future decarbonised energy market. While similar efforts are needed also at the level of Member States, to assure high standards of safety and to properly deal with nuclear waste management issues [6,7], the coordinated actions described hereafter represent a common response of the European atomic energy community to the challenges posed by the preservation of present high levels of expertise in the nuclear fields.

2 Needs of new member states and specific regional initiatives

In recent years, the need was felt to make sure that New Members States (NMS – this designation is still in use even if these states are full member of the EU for 10 years and more for some of them) would be effectively included into the process of networking and inclusion in the research and education community previously established for Old Members States (OMS). In particular, a good level of participation of NMS in Euratom Projects was identified as an important aspect to be assured in welcoming these states into the European nuclear research and education community. This stimulated launching initiatives aiming at assuring a good level of networking between NMS and OMS.

In addition, the specific situation and key initiatives going on in specific areas of Europe attracted the attention, suggesting to check for the presence of adequate capacitance for carrying on the intended projects or in order to stimulate better cooperation. This was the case of the Lead cooled Fast Reactor demonstrator (called ALFRED), proposed to be built in Romania which, involving the known challenges of Generation IV reactors, requires specific expertise in the related sector. Likewise, the Baltic Region hosts a number of research centres and institutions with a considerable potential in nuclear science and technology, whose level of cooperation was deserving improvements for fully developing their potential.

Projects addressing these issues were conceived and run in order to promote cooperation and developments in nuclear science and education, aiming to respond to the needs described above.

2.1 FP7 NEWLANCER Project (November 2011–October 2013)

NEWLANCER intended to pave the way for a sustainable participation of the research institutes and universities from NMS in nuclear energy research as framed by European policies and initiatives. NEWLANCER consortium consisted of 17 partners representing nuclear research institutes (RATEN ICN, INRNE, LEI, JSI, INCT, MTA EK, CEA, ENEA, SCK•CEN, APRE, NNL), universities (UPB, UL, TUS), implementers (ARAO) and SME (SYMLOG, REC) from both NMS and OMS.

All partners worked together to identify the best applicable solutions to increase the future NMS participation in the Euratom research, exploring three directions: strengthening and catalysing the full R&D potential at national level, increasing cohesion between NMS and improving cooperation with OMS research centres (see the structure of the project in Fig. 1).

A complex multi-level network, gathering a large number of experts in nuclear fields not only from partners’ organisations, but also from many other institutes and universities from the six NMS of the consortium (Bulgaria, Hungary, Lithuania, Poland, Romania, and Slovenia), has been created having as major objective to link national and regional experts in the Euratom fields and connect them to

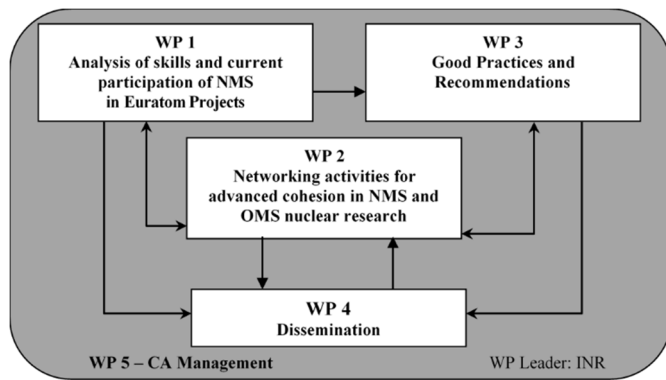


Fig. 1. Functional sketch of the NEWLANCER Project.

OMS research centres with large participation, as well as to the European Technological platforms (SNETP, IGD-TP, MELODI) and other related associations or networks (EERA, NUGENIA, Euratom NCP). Involving around 160 specialists in nuclear safety, Gen III and IV, advanced materials, radioactive waste management, radioprotection and education & training (E&T), this network ensured a good national and regional representativeness. Structured into 19 National Experts Groups and 5 Regional Expert Groups, the network provided deep insights on NMS participation starting from the specialist level up to the organizational management, national and EC policies, strategies and programmes, and also a regional view on the common driving factors, difficulties and barriers in NMS involvement in Euratom.

At national level, the networking activities consolidated the links among scientists as well as their connections with national structures (ministries, research agencies, nuclear authorities) responsible for the construction/implementation of the national research policies, strategies, and programmes. At regional level, activities focused on building advanced cohesion among NMS specialists, as well as among OMS and NMS experts facilitated the access to information and strengthened collaboration between specialists and creation of teams able to plan new projects.

In the field of Education and Training, NEWLANCER concluded that a good participation in international projects exists and as a consequence a real exchange of information about different E&T system and used methods and tools both in NMS and OMS occurred. This is an important gain and a good approach to improve the quality of the graduates. A common issue for NMS consists of a decreasing tendency of youngsters' interest for nuclear education and consequently in reduction of the nuclear education share at the level of universities. Related to nuclear training, some challenges related to implementing Generation IV systems in NMS connected with ALLEGRO and ALFRED demonstrators exist and also with the preparation of technicians to operate the existing and future nuclear installations.

Integration of teams from NMS into existing groups already created by OMS R&D organizations and having a long-time cooperation is quite open, but it is strongly dependent on the visibility of the organization and

researchers itself, and also of the existing expertise. Thus, the national framework is very important to support the local competence development to reach an adequate level for the participation in European projects. The lack of national support for a specific topic creates real difficulties including co-financing aspects.

NEWLANCER's recommendations for wider future participation in Euratom research and education programmes represent the synthesis of the joint activities of the consortium [14] and the consideration of critical success factors identified in the SWOT analysis from six countries:

- improving institutional and national policy making, strategic planning and setting the nuclear research and education among priorities (implementing priorities with resources for training, modernized infrastructure, support, etc.);
- improving cooperation between all activity holders in nuclear research and development, including cooperation with universities and postgraduate students;
- including information on Euratom projects and policy in nuclear study programs;
- ensuring visibility and presence on the European scene, including academic dissemination, researcher networking, scientific lobbying.

The NEWLANCER network, resulting from this project, represented a good basis for information exchange between experts both at national and regional level and allowed incorporation of new participants and organisations. The network activity as proposed and implemented during the project to capitalize the existing expertise and complementarities will continue to provide an open space for discussion and elaboration of future project proposals. The 4 European projects (MACXIMA, EAGLE, ASAMPSA_E and ARCADIA) rooted in the NEWLANCER are a positive example. They insured the continuation of NMS participation in Euratom and offered new opportunities for a further involvement of the NMS in H2020 both in research and education activities.

2.2 FP7 ARCADIA Project (November 2013–October 2016)

ARCADIA – Assessment of Regional Capabilities for new reactors Development through an Integrated Approach – was implemented by a Consortium of 26 members, coordinated by RATEN ICN (Romania) (see Fig. 2).

The Lead Fast Reactor (LFR) is one of the six technologies of Generation IV from which are expected advantages in terms of safety, economics and environmental impact, as well as a large flexibility on the energy market in terms of power capacity. To demonstrate the viability of this technology a demonstrator, called ALFRED, is foreseen to be built in Romania. The FP7 project ARCADIA was started in 2013 with the aim to assess the ALFRED feasibility, exploring the key components of a successful implementation: competences and infrastructure, licensing and public participation, funding and feasibility aspects, national and regional support, each one addressed by a dedicated Work Package.

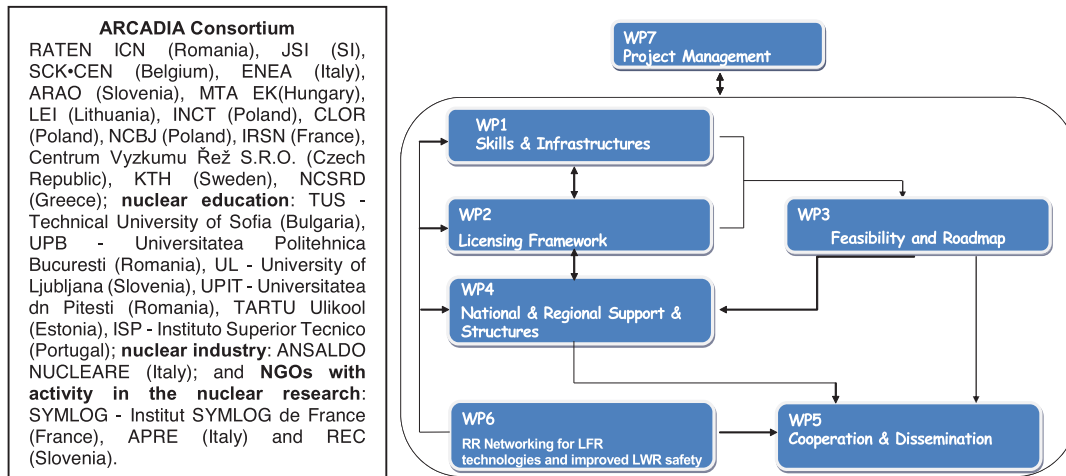


Fig. 2. Consortium composition and functional sketch of the ARCADIA Project.

The education and training aspects related to the development of the LFR technology in general, and the implementation and operation of ALFRED and its supporting R&D infrastructure in particular, have been approached in WP1.

ARCADIA outcomes allowed to conclude that there are good premises for the construction of the ALFRED demonstrator in Romania, in terms of competence and infrastructure, licensing and public acceptability, opportunity and competitive advantages, risks and benefits, funding and national and regional support. The existing competence at regional and European level can cope with the technical and scientific challenges raised by the final R&D on ALFRED. A set of gaps in skills and competence were however identified in a perspective of increased commitment to cope with the successive design, licensing and construction phases; consequently the ARCADIA consortium proposed methods and practical solutions to address the education and training (E&T) required to cover these gaps in due time.

The new technical skills and competences required to cover specific aspects proper of a Fast Reactor, and of a LFR in particular, often common throughout the different phases and actors involved in the project, relate to: nuclear data evaluation and preparation, in a fast spectrum, lead thermal/hydraulics, thermo-mechanics and lead chemistry, disciplines on instrumentation and control devices and systems, specific competences to ensure the management of a project of an international vocation, developed and implemented by an international consortium, and financed from different sources.

Based on the ECVET principles (European Credit System for Vocational Education and Training) and on an outcome-based pedagogical approach to lifelong learning, ARCADIA proposed an E&T programme having as main blocks:

- the application of the outcome-based competence building and the CDIO (Conceive Design Implement Operate) approach in the classic education programme;
- the professional qualification of students and professionals by attending application-specific courses delivered at

Centers of Excellence by teachers and trainers qualified and accredited according to the highest pedagogical standards.

The first concrete results in the process of competence building consist in design and development of a new engineering education programme on energetic and nuclear technologies having specific modules on Gen IV and LFR. The programme was approved by the Romanian Ministry of Education and Research in 2014 and became active in the University of Pitesti starting with 2015.

The academic knowledge and competences are among the critical prerequisites needed to develop the industrial knowledge and competences. Timely filling the gaps in the competences identified in the ARCADIA project is therefore considered as an urgent activity to support a successful development and commissioning of the ALFRED reactor, and represents one of the main concerns of the FALCON consortium, the international partnership in charge with the preparation of the ALFRED project.

2.3 H2020 BRILLIANT Project (July 2015–June 2018)

BRILLIANT Project (Baltic Region Initiative for Long Lasting InnovAtive Nuclear Technologies) was organised to establish and promote the cooperation of the research organisations in the Baltic region [10]. The project is implemented as follows: the coordinator is Lithuanian Energy Institute (LEI) (Lithuania), the partners are Narodowe Centrum Badan Jadrowych (NCBJ) (Poland), Tartu Ulikool (TARTU) (Estonia), Latvijas Universitate (UL) (Latvia), Kungliga Tekniska Hogskolan (KTH) (Sweden), Valstybinis Moksliniu Tyrimu Institutas Fiziniu Ir Technologijos Mokslu Centras (FTMC) (Lithuania) and the industrial partner VAE SPB UAB (VAE SPB) (Lithuania). Each partner has strengths in some specific area, though lack of cooperation prevents the utilisation of full potential in the region.

Increased cooperation is intended to provide for a better solution of the challenges that the participating countries

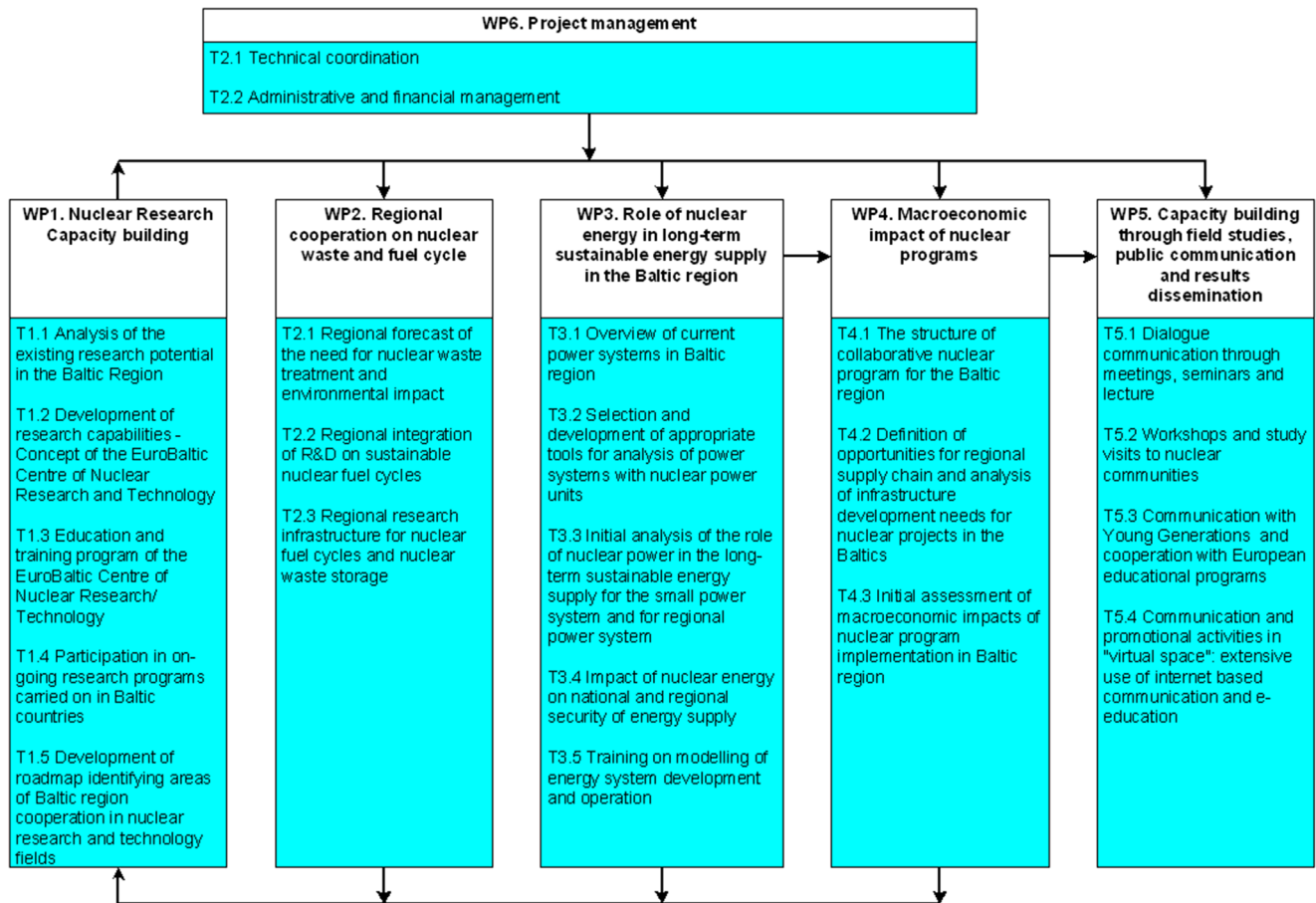


Fig. 3. Functional sketch of the BRILLIANT Project.

face in the field of nuclear energy development, but impact of such cooperation could be seen much broader than only the nuclear energy. The regional competences developed in the frame of the project created the basis for application of a regional approach in the planning of the energy sector in participating countries and those contributed to the implementation of Energy Union in the EU. The ultimate goal of BRILLIANT project was the development of a roadmap to establish the virtual EUROBaltic Centre of Nuclear Research and Technology, with competence centres established in all participating countries. The project covered a broad range of issues linked with the nuclear power industry and its organization is shown in Figure 3, which also gives details of WP objectives. Each country (Estonia, Latvia, Lithuania, and Poland) organised two meetings with the wider public: students, industry, politicians and other stakeholders interested in the issues of nuclear power participated at these meetings.

KTH (Sweden), through cooperation with Nova – Center for University Studies, Research and Development at Oskarshamn (Sweden) in the frame of Nova Research and Development Platform, offered an access to very unique and relevant large infrastructures. The platform offers access to SKB research data and the following facilities:

- Äspö Hard Rock Laboratory – a model for the geological repository site;

- the Bentonite Laboratory;
- the Canister Laboratory;
- site Investigation Oskarshamn.

All project partners and a number of interested experts from all participating countries took the opportunity to visit these facilities in the frame of the BRILLIANT project.

The major result achieved in BRILLIANT is the established effective cooperation among the research organisations in the Baltic region. The strengths, weaknesses, opportunities and threats were identified and a concept of the EuroBaltic Centre of Nuclear Research and Technology was developed together with the roadmap to the establishment of such centre. Information of the amounts of radioactive waste in each participating country was collected. A regional integration and assessment of nuclear fuel cycle (NFC) options is divided into two parts, where the 1st part focuses on issues of regional integration of NFC research and the 2nd on modelling regional nuclear fuel cycle options themselves using FANCSEE code developed at KTH. All partners learned and developed the country specific models of energy sectors for MESSAGE tool. It must be noted that this tool was used in the frame of the project for a training on the assessment of energy security, an exercise that was performed for each country using the methodology developed at the

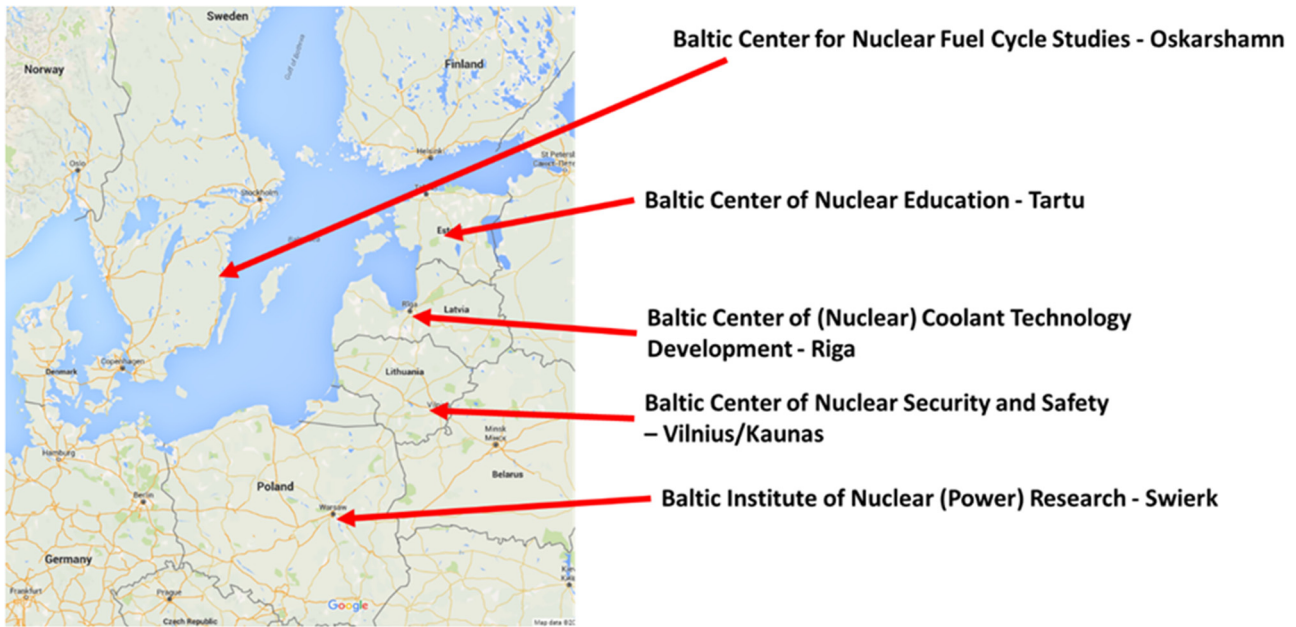


Fig. 4. Centers in the BRILLIANT Project.

Lithuanian Energy Institute in cooperation with Vytautas Magnus University (Lithuania). A methodology for the assessment of the macroeconomic impact was developed and tested in assessment of potential implementation of Visaginas NPP project.

To continue cooperation after BRILLIANT and to implement a concept of EuroBaltic Centre of Nuclear Research and Technology a new 2BETINA project (Baltic Basin Education and Training Infrastructure in Nuclear Applications) was developed and submitted to EURATOM call in 2018. This new proposal not only included the same partners, but expanded the geography of cooperation by the involvement of other neighbouring countries and of more universities and research centres (Fig. 4).

3 Exchanges with education systems beyond Europe

The creation of the European Nuclear Education Network (ENEN) in 2003 represented an important step in promoting harmonisation by mutual recognition in nuclear disciplines in Europe, starting with nuclear engineering, but not limiting to it. While the introduction of the European Credit Transfer System (ECTS) and the implementation of the Bologna Convention in Europe were creating a common basis for exchanges and student mobility, the need was felt to approach two different countries whose education environments in the nuclear field were going to play an increasingly important role, being Russia and China. Promoting and easing exchanges of students and teachers between Europe and China was then considered an action worth of a specific efforts. As explained hereafter this operation was more successful in the case of Russia than of China.

3.1 FP7 ECNET Project (March 2011–February 2013)

The main objective of the ECNET project was to coordinate the cooperation between the EU and China in the field of Nuclear Education, Training and Knowledge Management in the three areas of Nuclear Engineering, Radiation Protection and Nuclear Waste Management and Geological Disposal. The expected impacts of the project were:

- to promote mutual recognition of Education and Training programmes of EU and China;
- to expand exchanges of students, lectures and lecturers;
- to secure the knowledge management as appropriate.

As shown in Figure 5, the main work packages were related to the definition of the needs in the three mentioned nuclear fields, linked by specific interests for E&T facilities and to establish a possible system for credit recognition among the two areas of the world.

As in the case of the ENEN-RU projects (see below), ECNET involved two different consortia and mirror structures on the EU and the Chinese sides. The participants on the side of EU were ENEN, SCK•CEN (Belgium), CEA-INSTN (France), the Institute National Polytechnique de Lorraine (France), KIT (Germany), CIRTEN (Italy), the Universidad Politecnica de Madrid (Spain), the Imperial College of Science Technology and Medicine (UK). On the Chinese side, the Tsinghua University, the North China Electric Power University, the Southwest University of Science and Technology, the Harbin Engineering University, the Shanghai Jiao Tong University, the China National Nuclear Corporation Graduate School and the Xi'an Jiao Tong University participated in the endeavour.

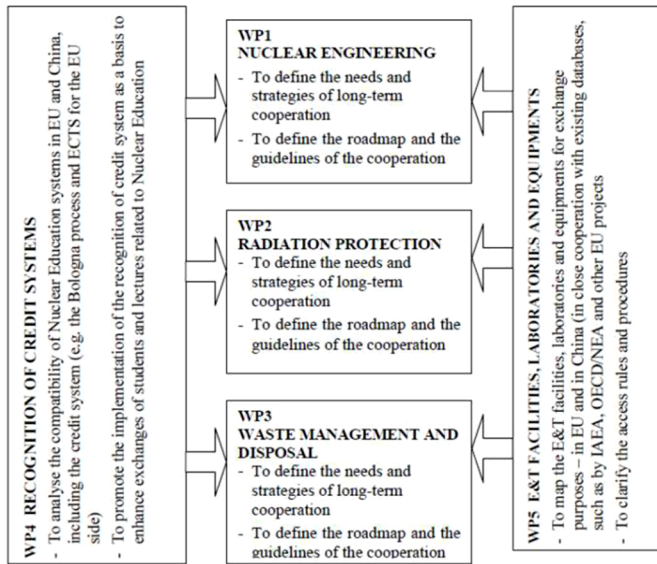


Fig. 5. Functional sketch of the ECNET Project.

The project impacted into some difficulties intrinsic in the exchange at the time, among which the language barrier. As a matter of fact, information received from Chinese partners was not sufficient to allow useful comparisons of the situations in Europe and in the fast growing economy and to develop efficiently a Europe-wide cooperation with China in nuclear E&T. However, some exchanges were possible, e.g., a double degree agreement established between the Politecnico di Torino (belonging to CIRTEN) and the Shanghai Jiao Tong University, to be considered as pilot examples that provided satisfactory results.

Though the experience of this project turned out to be not completely successful, the interest for exchanges between the nuclear education and training system in EU and in China has recently increased. This previous experience, if fuelled by a renewed interest for exchanges on both sides, may provide a useful starting point for setting up a better and deeper cooperation than it was possible with ECNET.

3.2 FP7 ENEN-RU II Project (July 2014–June 2016)

The ENEN-RU II project was aimed at the “Strengthening of Cooperation and Exchange for Nuclear Education and Training between the European Union and the Russian Federation” and consisted of two parallel projects, on the EU side and the Russian side.

The Consortium on the EU side was composed by ENEN (B), SCK•CEN (B), CTU (CZ), Centrum Vyzkumu Rež S.R.O.(CZ), Universität Stuttgart IKE (D), TUM (D), CIRTEN (I), UPB (RO), STUB (SI), TECNATOM (E) and University of Manchester (UK). The Russian Consortium included in particular Rosatom, the MEPhI-National Research Nuclear University (NRNU) and CICET, together with other Russian organisations.

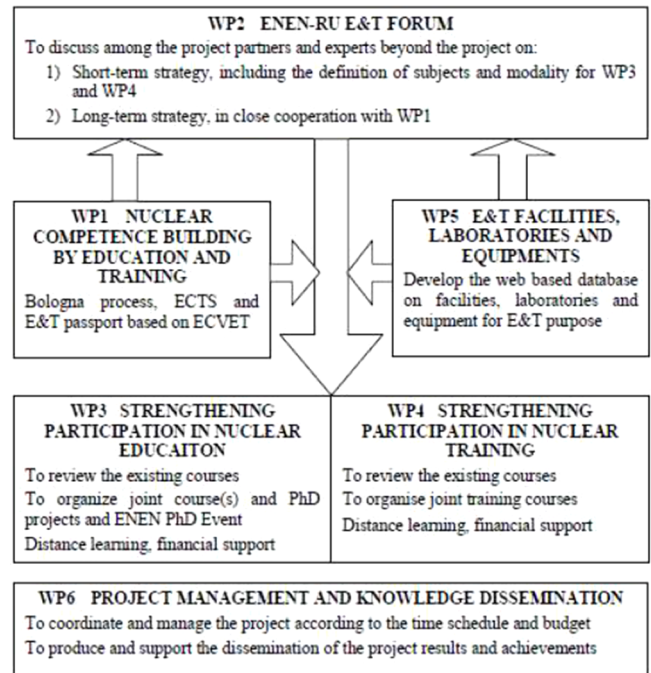


Fig. 6. Functional sketch of the ENEN-RU II Project.

The objectives of the entire project have been:

- to further define a common basis for effective cooperation between the European and Russian networks for nuclear Education & Training (E&T);
- to define an implementation plan based on the needs of cooperation in the long-term;
- to solve the difficulties for cooperation found during the ENEN-RU project;
- to implement a collaboration plan in a sustainable manner;
- to operate the knowledge management framework;
- to list up and promote further use of E&T facilities, laboratories and equipment.

The six work packages in which the project was detailed are represented in Figure 6.

The project involved several meetings and the participation of Workshops and Conferences held on either side, producing a high level of involvement in the respective environments. Among the achievements, the following can be mentioned:

- the comparison of curricula for Nuclear Engineering in EU countries and Russian Federation, showing that the credit systems in use in the two regions are compatible;
- as the outcome of the discussion within the ENEN-RU E&T Forum, bilateral agreements were signed between the participants on either side (e.g., University of Pisa and MEPhI) and ENEN renewed its cooperation with MEPhI and with Rosatom-CICET;
- participation in joint courses at master and PhD levels was made possible for more than 40 students and a distance learning course was deployed;
- more than 30 individuals participated in 4 joint training courses, (“Engineering aspects of Fuel Fabrication” in

Obninsk, Russian Fed. on 23–27 November 2015; Joint Education course on the “Introduction to Nuclear safety analysis of Nuclear Reactors with state-of-art Computer Programs” by TU Munich, Germany, on 25–28 April 2017; Joint Education course on “Multiphysics simulation of nuclear systems” organized at the POLIMI campus in Milan, Italy, on 17–19 May 2017; Joint E&T course on “Simulation of different NPPs operation” organized at CTU in Prague, Czech Republic, on 30 May–2 June 2017), while exchanges of trainees and facilitators were made possible, also performing technical visits to fabrication and training centres;

- a web based database for E&T facilities, laboratories and equipment was developed; access can be granted to it, following a registration process, also to external users: several database access levels being available;
- participation in several important events on either side occurred.

The project put the basis for continuing the cooperation of ENEN with MEPhI-NRNU and Rosatom-CICET, making also possible to establish bilateral agreements among partners. Successfully overcoming the language barriers that were encountered in the first of the ENEN-RU project was another relevant outcome of ENEN-RU II.

4 Continuing education efforts for nuclear technologies

The need for educational opportunities stimulating students to undertake nuclear careers in a period of low attractiveness has been a continuous worry for ENEN and other players involved in the effort to maintain a sufficient level of nuclear workforce and expertise in Europe. Offering to students experiences in high level laboratories, inter-semester courses and the access to that kind of general information that can be provided by Massive Open Online Courses (MOOCs) represented the target of one of the projects described below, aiming to make more lively the panorama of the nuclear educational offer in Europe. A further project moved from consideration of the ongoing introduction in European countries of the VVER technology, requesting specific training capabilities to be provided by a dedicated Academy, whose establishment was conceived in cooperation with ENEN. Both the initiatives, though not directly led by ENEN, represent efforts contributing to that process of maintaining and developing knowledge in the nuclear fields within Europe, which is continuously stimulated by the Association.

4.1 FP7 GENTLE Project (1 January 2013–31 December 2016)

The GENTLE project (Graduate and Executive Nuclear Training and Lifelong Education) ran for four years as part of the seventh Euratom Framework Programme, and was coordinated by TU Delft in the Netherlands. The other participating institutions were Budapest University of Technology and Economics (BME, Hungary), CIRTEN (Italy), the European Commission’s Joint Research

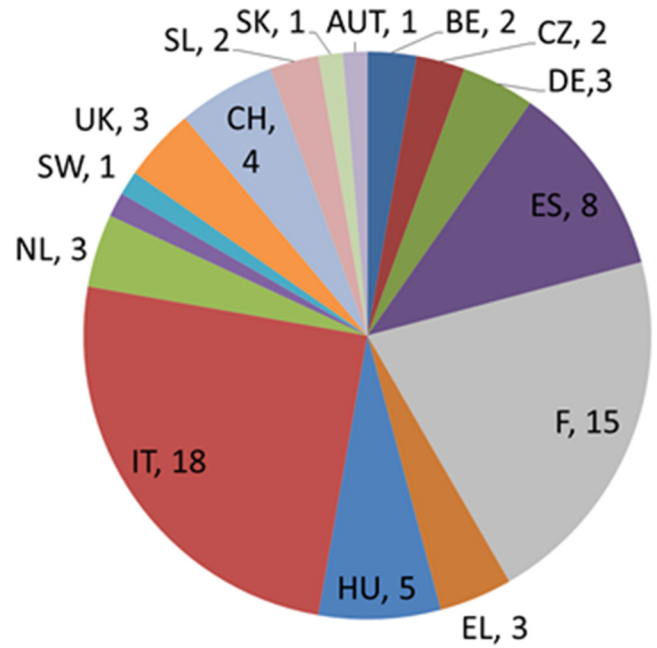


Fig. 7. Breakdown per Country of the 74 SRE attendants in the GENTLE project.

Centre (JRC, EC), Karlsruhe Institute of Technology (KIT, Germany), Lappeenranta University of Technology (LUT, Finland), Paul Scherrer Institute (PSI, Switzerland), Polytechnic University of Madrid (UPM, Spain), SCK•CEN (Belgium), University of Manchester (UMAN, UK), and University of Tartu (UT, Estonia).

The GENTLE project offered training to students via Student Research Experiences (SRE) and Inter-semester Courses for graduate and postgraduate students on special topics that are generally not part of the academic program. Furthermore, a Massive Open Online Course (a so-called MOOC) was compiled and organised for students at the bachelor level interested to learn more about nuclear energy, nuclear reactors, and the nuclear fuel cycle.

- SRE: students could follow internships at the GENTLE project partners’ laboratories for which they could receive a grant. These Student Research Experiences (SREs) could last up to twenty-four months and were open to students enrolled in any European university. SREs were meant to increase the technical and scientific background of students in topics related to nuclear science and engineering. For the selection of the student and the hosting institution, the following criteria were taken into account: scientific quality, equipment, staff, benefit to the applicant, impact on the field, and gender balance. In total, 74 students participated, originating from the countries shown in Figure 7.
- Inter-semester Courses (ISC) have been developed for graduate students and professionals on topics that were not part of the academic curriculum. The ISCs were organized at the participating centres and included on-site demonstrations and excursions. The ISCs typically lasted for five days. The topics and organizing

institutions were: (1) Nuclear Fuels (JRC), (2) Nuclear Safeguards and Security (SCK•CEN), (3) Nuclear Waste Management (KIT, JRC), (4) Nuclear Decommissioning (UMAN), (5) Nuclear Data (JRC, UPM), (6) Reactor Techniques (BME), and (7) Thermal Hydraulics Phenomena (LUT). In total more than hundred students participated in these courses.

- Besides the above-mentioned programs, which require physical attendance of students, a Massive Open Online Course (MOOC) was organised, containing six modules: (1) Fundamentals of Nuclear Science, (2) Nuclear Fission Reactor Principles, (3) Light Water Reactor Systems and Safety, (4) Nuclear Fuel Cycle, (5) Life Cycle Analysis and Social Aspects, and (6) Next Generation Nuclear Power. The MOOC ran for the first time during six weeks from October 4 to November 30, 2016 as an instructor-paced course, which means modules were available to learners only in sequence. Every week a new module was made available to learners and they could not skip ahead. This first time it had 4543 enrolments. In the academic years 2017–2018 and 2018–2019 the MOOC ran as a self-paced course during a full year, and attracted 5878 and 2239 students, respectively. The latter number represents the status in December 2018 and is expected to increase as the course will close only in September 2019. The average age of the learners is around 26 years and the number of nationalities enrolled is typically above 140. This means that this MOOC is attracting many young people from all over the world. In all three runs, the top-3 countries of origin were USA, India and the UK. The MOOC can be followed via the EDX platform and is free to learners aiming at a non-certified enrolment. In conclusion: although the setting up of the MOOC in the consortium needed a lot of time to tune and balance the contents of each module, it has been a very inspiring and rewarding action, eventually leading to a very efficient way of teaching nuclear science and engineering at a basic level to a large community of learners and students.

4.2 H2020 CORONA-II Project (September 2015–August 2018)

The general objective of this project was to enhance the safety of nuclear installations through further improvement of the training capabilities for providing the necessary personnel competencies in VVER area. More specific objective of the project CORONA II was to continue the development of a state-of-the-art regional training network for VVER competence (called CORONA Academy), whose pilot implementation through CORONA project (2011–2014) proved to be a viable solution for supporting transnational mobility and lifelong learning amongst VVER operating countries.

A 9-partner-strong-consortium has been established to implement the project activities with Kozloduy Nuclear Power Plant (Bulgaria) being the project Coordinator. The rest of consortium partners are: Institute of Nuclear Research and Nuclear Energy – Bulgarian Academy of

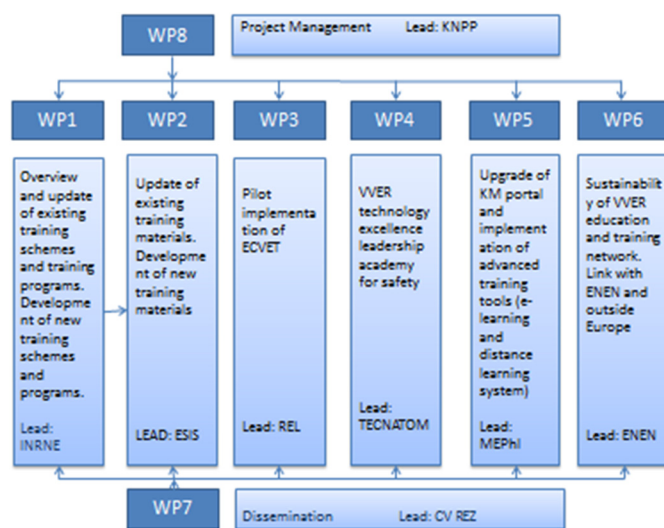


Fig. 8. Functional sketch of the CORONA-II Project.

Sciences (Bulgaria); Engineering Support and Intellectual Solutions (ESIS GmbH Germany); TECNATOM S.A. (Spain); Centrum Vyzkumu Rež S.R.O. (Czech Republic); National Research Nuclear University MEPhI (Russian Federation); Risk Engineering Ltd. (Bulgaria); Budapest University of Technology and Economics (Hungary); and European Nuclear Education Network (Belgium).

The work breakdown was based on the implementation of eight work packages, whose interdependencies are shown in Figure 8.

The first task of CORONA II project was to analyse the proposed corrective measures from CORONA project (2011–2014). Based on the analysis' outputs, training schemes, programs and courses were elaborated to make available an explicit and comprehensive set of training programs, addressing the training needs of the following target groups:

- Group A: specialized training on specific VVER technology aspects for nuclear professionals and researchers;
- Group B: basic training on VVER technology specifics for non-nuclear professionals and subcontractors;
- Group C: specialized technical training on VVER technology for students studying nuclear disciplines;
- Group D: safety culture and soft skills training for nuclear professionals and personnel of nuclear facilities' contractors.

In the frame of CORONA I project (2011–2014) for each of the target groups pilot training was conducted to validate the materials elaborated and draw action plan to refine/ supplement the available training schemes. Within the implementation of CORONA II project the training schemes were finalized resulting in the collection of extensive training material, developed in line with the commonly accepted criteria, recognized in EU and unifying different cultural attitudes and VET approaches used by the participating organizations. In summary, the training programs developed for the identified target groups

consists of 3693 training hours (incl. theoretical, practical, OJT and simulator training) for Group A, 88 training hours for Group B, 177 hours for Group C and 101 training hours for Group D.

The ECVET principle, being the EU instrument promoting mutual trust, transparency and recognition of competences and qualifications, has been embedded in all the training programs developed. The approach was tested by selecting the qualification of radiation protection workers for pilot implementation. In this instance, roles of sending and host provider have been assigned, ECVET oriented pilot training course was elaborated and pilot training was conducted in BME, Hungary from 30 January to 2 February 2017 with 8 trainees (3 from Bulgaria, 3 from Czech Republic and 2 from Russia). Based on the results criteria and procedure for mutual recognition was developed.

Another line of activity in which the Consortium focused its effort was to propose advanced ways of providing training to the trainees by introducing distance training and e-learning approaches in CORONA II portfolio. The CLP4NET platform, dedicated to e-learning activities in the field of nuclear science and technology education, customized with the support of the IAEA, was installed on the project KM portal to allow high standards for nuclear education and training and establishing a framework for e-learning capacity. Eight of the courses from the CORONA II portfolio were adapted for e-learning and pilot sessions were conducted from 22nd to 28th January 2018 by MEPhI, Russia. Thirty (30) trainees: seven (7) from Hungary, seven (7) from Bulgaria, six (6) from Spain, four (4) from Russia, three (3) from Czech Republic and three (3) from Slovakia participated in the training. Fifteen (15) trainees participated in the course *Nuclear technologies used at NPPs with VVER reactors* and twenty two (22) trainees participated in the course *Design of Structures, Systems and Components*.

To complete the idea for state-of-the-art training centre, it was concluded that the establishment of CORONA Academy will benefit vigorously from the natural complement of the theoretical training. In this instance a Human Factor Simulator (HFS), oriented to foster and maintain strong safety culture, was established and tested. Pilot training was carried out to ensure that the developed training materials and selected training aids and equipment ensure enough competences to develop a strong safety culture and to acquire the necessary skills to develop a right attitude to the organizational culture. One week course, combining theoretical and on-the-job training forms was conducted in the specialized training laboratories and workshops of Kozloduy NPP in June 2018 with the participation of 24 trainees from the plant.

In the long term, the specially developed training programs will ease the process of recruitment of new specialists for working with the VVER technology and will ensure the availability of well trained personnel during the whole life-cycle of the VVER installations in EU. The sustainability of education and training efforts in VVER technology cannot be effective without a permanent structure that assures its follow-up and its survey. In this frame, the integration into the ENEN Association was

found to be instrumental. The link of the project with the ENEN Association will contribute to develop a long term vision and to create a coherent and dynamic strategy for achieving the integration of the education and training on VVER technology in the European level.

5 Projects led by ENEN: enhancing nuclear education to keep high nuclear safety levels in Europe

The following three described projects represent major efforts coordinated by ENEN to cover specific needs that emerged in past years, trying to provide a remedy to the decreased interest in nuclear careers. The first project was directly stimulated by the EC after Fukushima, in the aftermath of the concerns raised in relation to the proper implementation of a nuclear safety culture, whose partial lack is often identified at the basis of occurred reactor accidents. Somehow in parallel with the stress tests ongoing in Europe, the NUSHARE project undertook the challenging task to speak about nuclear safety culture not only to usual actors in the fields (TSO and nuclear regulatory agency personnel, industrial managers), but also to a more general public of journalists and policy makers.

The ANNETTE project represents instead the attempt to establish a major long-lasting coordination among course providers in Europe aiming to propose sharp and focused courses for Continuous Professional Development (CPD) to people having already a job in the nuclear fields or wishing to enter them. Though it includes a number of other actions providing further value to the action, ANNETTE is therefore focused on the quite difficult task of proposing courses in a period of low interest for them.

Finally, ENEN+ represents the latest project of the series, based on the awareness that a major effort should be established to attract and retain students in the nuclear fields, starting since the Secondary School, through the BSc, the MSc and PhD levels. It is finally recognised that student mobility, to be favoured, requires the allocation of adequate financial resources to make it feasible at any level, providing adequate grants.

These three projects are based on the conviction that, to maintain a sufficient safety level of our installations, education and training must be kept lively and, as far as possible, attractive to young people: this is the challenge implied in the mission of ENEN.

5.1 FP7 NUSHARE Project (January 2013–June 2017)

NUSHARE was a project implementing a European Education, Training and Information (ETI) initiative proposed by the Commissioner for Research and Innovation and the Commissioner for Energy after the Great East Japan Earthquake and Tsunami on 11 March 2011 (Fukushima). Its main objective was to develop and implement education, training and information programmes strengthening competences required for achieving excellence in nuclear safety culture. Particular attention was paid to lessons learned from

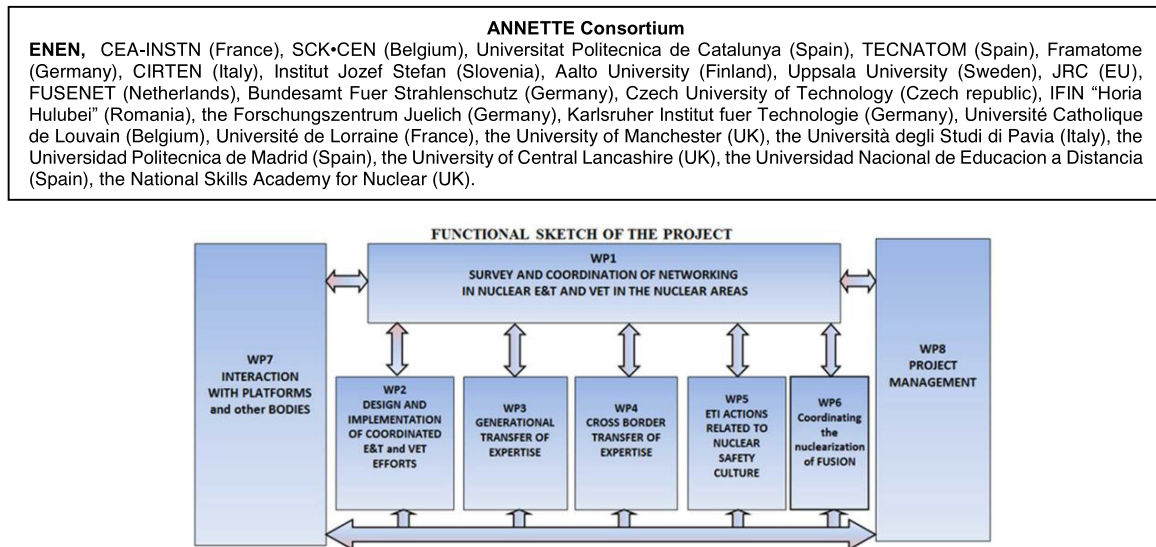


Fig. 9. Functional sketch of the ANNETTE Project.

stress tests conducted on all EU nuclear Power Plants in response to the Fukushima accident and to sharing best practices at the European level.

NUSHARE addressed the specific needs of different stakeholders in nuclear safety by the development and EU-wide dissemination of programmes for three target groups:

- Target Group 1 (TG1), represented by journalists and civil society representatives;
- Target Group 2 (TG2), represented by staff members of Nuclear Regulatory Authorities (NRAs) and Technical Safety Organisations (TSOs);
- Target Group 3 (TG 3), represented by electric utilities, systems suppliers, and providers of nuclear services at the level of responsible personnel, in particular managers.

As a result of a planned restructuring of the initial Consortium, composed by ENEN as main beneficiary and CEA-INSTN, UPM and TECNATOM, as Third parties, with ENSTII as subcontractor, other parties joined, namely ISaR, INBEx, the World Federation of Science Journalists (WFSJ), IRSN and ENS.

Nuclear safety culture is known to be a fundamental concept, whose neglect can be easily found as an important contributor in occurred nuclear reactor accidents. As such, the project addressed its components, undertaking the difficult task to speak about it in the language appropriate to the different target groups. In relation to TG1, a first approach was based on workshops addressing French organisations of journalists. After this first phase, also owing to the stepping in of the new parties, it was possible to set up a more general Media Educational Package developed by journalists for journalists and the wider society, on the basis of the material provided by the experts of the other parties (<http://wfsj.org/v2/2017/06/15/new-toolkit-on-nuclear-safety-for-journalists/>).

TG2 was managed since the very beginning in a very systematic way by ENSTII, developing training modules targeted for personnel of NRAs and TSOs. To this, INBEx

added the implementation of pilot courses held in different parts of Europe with a specific training tool (named after Fermi) which gained great recognition.

Finally, TG3 was addressed by TECNATOM mainly considering the managerial levels, having so fundamental relevance in promoting safety culture among the nuclear workforce. Specific learning outcomes and pilot sessions (also with the use of micro-e-learning tools) were developed and implemented, gaining in return a positive assessment of the overall activities.

The efforts spent in the frame of NUSHARE coped with a definitely challenging subject, as implied by the ETI character of the action: the different languages to be spoken with the target groups were reflected in the diversity of the products and in the countless workshops, meetings and sessions delivered in the four and more years in which the project was developed. NUSHARE leaves behind a wake of useful material and reflections that inspired also the specific stress on nuclear safety culture impressed in the ANNETTE project.

5.2 H2020 ANNETTE Project (January 2016–December 2019)

ANNETTE (Advanced Networking for Nuclear Education and Training and Transfer of Expertise) represents an effort delivered by a Consortium of 25 members, coordinated by ENEN. The project responded to the Euratom call of 2014 under item NFRP-10, mainly asking for Masters and Summer Schools for CPD. It is structured into eight Work Packages (WP), as shown in Figure 9.

The first work package is devoted to “coordination” among the different nuclear fields of nuclear technology and safety, radiation protection, waste management and nuclear fusion, the latter represented in the project by the sister network of ENEN, Fusetnet (<https://www.fusetnet.eu/>) and by its third parties. Together with networking, coordination represents the leitmotiv of the project that, in

addition to the specific actions developed under the different work packages, aims at catalysing the cooperation among the different nuclear sectors. Coordinated E&T efforts in terms of a Summer School and of pilot courses for a “master” for CPD, to be established at the end of the project through an appropriate certification, are the subject of WP2. WP3 aims at reviving the production of educational material in the frame of ENEN and in Europe in general, while WP4 develops a challenging first-of-the-kind cross-border and cross-company mobility of professionals under the rules being established for granting European Credits for Vocational Education and Training (ECVET). WP5 and WP6 are assigned the task to set up courses for reinforcing nuclear safety culture and to address the novel issues coming from the process of “nuclearization” of fusion, i.e., the transformation of the nuclear fusion sector into an industrially mature field. WP7 and WP8 keep the necessary contacts with stakeholders and manage the whole project.

WP1, thanks to a detailed planning, has already reached most of its objectives, carrying on a broad inquiry on the state-of-the-art about nuclear E&T and the facilities available for life-long learning, exploring networking mechanisms, studying tools for information exchange and reflecting on the ENEN certifications, to plan for future ones. WP2, WP5 and WP6 offered pilot courses, being delivered from June 2018 to July 2019, and collected more than 230 multiple expressions of interest for courses to date, though actual attendance figures are expectedly less exciting. In this frame, a very successful Summer School was organized by the Aalto University in June 2018 (www.annette.eu/summer-school/), involving lecturers selected among project participants and hosting 52 students for a full week. The students of the Summer School were selected among 85 applicants from over 20 nationalities, on the basis of nine criteria including background, command of English language, recommendation by a supervisor, gender balance, etc. MOOCs are also being prepared on nuclear safety culture and nuclear safeguards. WP3 has already planned the delivery of educational documentation in selected nuclear sectors. WP4 has successfully tackled a challenging exchange of personnel, producing reflections on ECVET use in industry, worth of a future project to be fully exploited. WP7 is keeping tight contacts with platforms, industrial representatives and stakeholders in general; it organised an ANNETTE event at the NESTet Conference held in Berlin in 2016 and Stakeholders’ events were organised as side events of the General Assembly of ENEN and at this FISA Meeting.

The most challenging part of the project will be certainly the long-term sustainability of the educational offer for the “master”, to be broadened and settled into a permanent pan-European effort by catalysing the joining of additional actors, also involving the release of a new ENEN certification based on modular courses to be attended in incremental steps. The process of advanced networking, led by ENEN and materialised in the consortium by the representation of the most important nuclear fields, needs also to be settled, by coagulating further contributions, aiming to create synergies among the different groups operating in favour of E&T in the nuclear fields.

5.3 H2020 ENEN+ Project (October 2017–September 2020)

The ENEN+ project (Attract, Retain and Develop New Nuclear Talents Beyond Academic Curricula) proposes cost-effective actions to attract, develop and retain new talents in nuclear professions. This is a contribution of the ENEN Association, supported by the European Commission, to the common strategic goal of all nuclear stakeholders: to preserve, maintain and further develop the valuable nuclear knowledge for today's and future generations. The ENEN+ project focuses on learners and careers in nuclear reactor engineering and safety, waste management and geological disposal, radiation protection and medical applications.

The project activities are organized in 7 work packages, depicted in Figure 10. Work packages 1–4 are devoted to the attraction, development and retention of learners in different stages within the education systems (1: high school pupils, 2: B.Sc. and M.Sc., 3: nuclearization and 4: Ph.D., postdoc and lifelong learning). Work package 5 is focusing on the development of voluntary accreditation functionality within ENEN. The project is supported by the WP 6 focussing on informing and consolidating the nuclear stakeholders and WP7 dealing with the management of the project.

The ENEN+ project consortium is a well-balanced blend of relevant actors in the development of knowledge, competences and skills in different nuclear sectors in Europe. It is formed by 22 partners consisting of 9 universities (Université de Lorraine (France), Aalto Korkeakouluosaatio (Finland), Budapesti Muszaki és Gazdaságtudományi Egyetem (Hungary), Universidad nacional de educación a distancia (Spain), Univerza v Ljubljani (Slovenia), Universidad Politécnica de Madrid (Spain), Universitatea politehnică din București (Romania), Consorzio Interuniversitario Nazionale per la Ricerca Tecnologica Nucleare (Italy) and Institut Mines-Télécom (France)), 6 international organisations (ENS, FORATOM, NUGENIA, EFOMP, JRC and ENEN), 4 leading nuclear research centres (SCK-CEN (Belgium), CEA (France), Jožef Stefan Institute (Slovenia), Centrum Vyzkumu Řež (Czech republic)) and, last but not least, 3 major industrial companies (Westinghouse (France), Tecnatom (Spain) and EDF (France)). In addition, several third parties including IAEA and further members of the ENEN and NUGENIA are contributing to the project.

The academic education is expected to remain the very basic building block of the future nuclear experts and scientists. A sound balance between the knowledge, skills and responsibilities may nevertheless need further shift from thinking about pedagogy in terms of “teaching” to one that considers “learning” as the primary goal. This may allow to associate pedagogy more strongly with learning outcomes and student experience, as for example engagement in the professional development activities with the support of industry, including course-release for such activities. For the main nuclear fields, the strategic priority of the community has changed to the consolidation and sustainable development of the existing courses and programs. This will be achieved through a mobility grant program for learners and the development of the voluntary

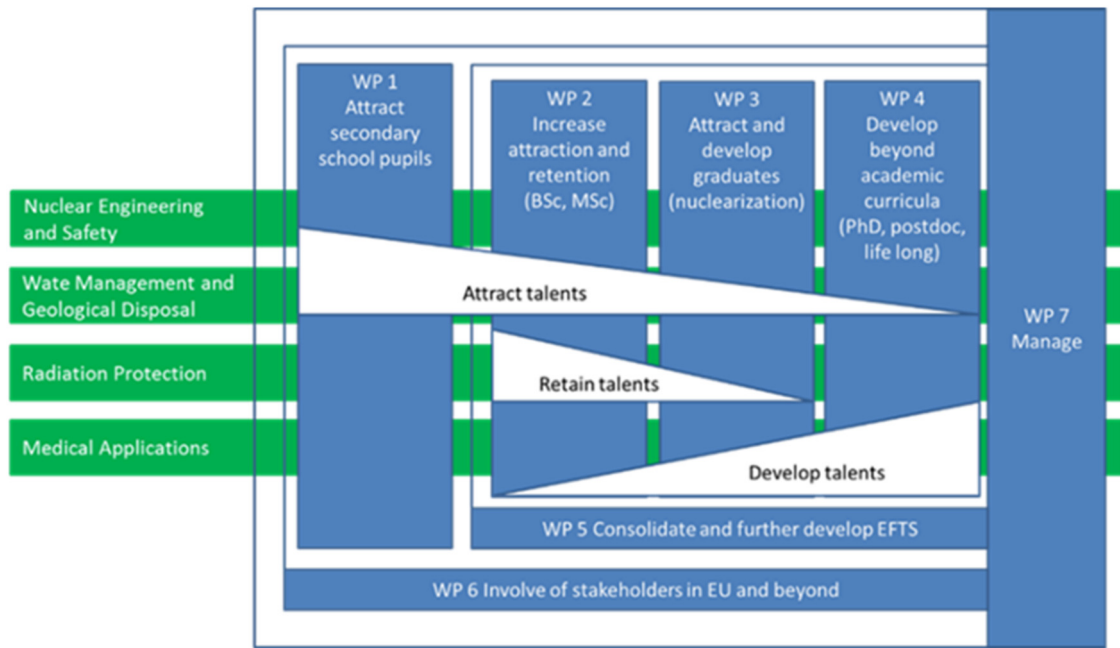


Fig. 10. Functional sketch of the ENEN+ Project.

accreditation functionality for nuclear education and training activities within the ENEN AISBL (AISBL = “International Non-Profit Organization” in French).

The most notable action of the ENEN+ project is mobility funding for learners at different stages of the early career. The budget for mobility grants exceeds 1 million EUR and represents more than 1/3 of the EC contribution to the project. The mobility grants are accessible through the web application and selection system (<http://plus.enen.eu>) to the individuals aiming at starting or improving their careers in nuclear. The individual career guidance resulting in “Personal Career Plans”, developed jointly by the candidate with mentors from industry and academia, represents an essential part of the selection process, which is performed and managed by the ENEN+ project management committee. In the first 12 months of the project execution, more than 120 applicants have received mobility grants totalling at roughly 300.000 EUR.

Another notable action of the ENEN+ project is development and introduction of a communication strategy ensuring active industry and policy maker engagement in the ENEN+ initiative. The purpose of the communication strategy is to ensure consistent communication to the industry, regulators and legislators to align all stakeholders around the strategy to provide sufficient and sustainable resources for attraction, development and retention of new nuclear talents. Making the case for adequate and sustained funding and support is principally a matter of giving clear indication of the benefits to be accrued as well as periodic updates of progress achieved. ENEN+ will need to lead an advocacy effort to influence policy-making and increase the commitment towards nuclear education and research. Partnerships with media will also be attempted to develop pop-culture appeal.

The attraction, retention and development of the new nuclear talent can only be sustained beyond the project

life through strong partnership and support of all nuclear stakeholders. Involvement of various nuclear stakeholders including academia, industry, international organisations (ENS, FORATOM, IAEA, NUGENIA) in the ENEN+ consortium and its communication strategy is therefore of primary importance for the success and sustainability of the proposed activities also beyond the life of ENEN+.

6 Conclusions

The projects described in this paper address, inter alia, different relevant aspects of nuclear E&T in Europe. From the above sections, it is clear that the deep worry for preservation and further development of competences in relation to nuclear reactors of different types and generations has motivated each specific action. In fact, while nuclear matters and careers are still attractive for many gifted students and technicians, it is anyway a fact that in different European member states the acquisition of nuclear competences is not favoured at the levels required to maintain competitiveness with other areas in the world. This displeasing feature of present policies, mostly driven by a public opinion biased by a wrong perception of nuclear risks, is endangering the wealth of experience accumulated in decades in the nuclear sectors.

An important problem to be tackled in this context is the one of the sustainability of the above described efforts, requiring the persistent and consistent communication with industry, regulators and legislators mentioned as an ongoing action of the ENEN+ project. It is important that all stakeholders be aware of and agree on the need to provide sustainable resources for attraction, development and retention of new nuclear talents.

The recent Communication of the European Commission entitled “A Clean Planet for all” [23], stating that

renewable energies “together with a nuclear power share of ca. 15%, (...) will be the backbone of a carbon-free European power system” in 2050, confirms that the efforts for preserving nuclear competences are directed towards the right target and need renewed commitment from all the stakeholders. The implications of this statement by the European Commission must be considered in view of the following additional information:

- FORATOM, in a press release [20], basing on a commissioned study [21], suggests that: “*If Europe is serious about decarbonising its economy by 2050 then one quarter of the electricity produced in the EU will need to come from nuclear*”;
- previous estimates of the effort needed for preserving an adequate share of electricity produced by nuclear in Europe led to the conclusion that: “*An extrapolation to 2050 of the ‘20% nuclear’ scenario indicates that 100-120 units should be built in Europe.*” [22].

Whatever will be the exact share of electricity produced in Europe by nuclear energy in 2050, it seems quite probable since now that decommissioning, and several nuclear new builds will be needed by that time. Preserving education and training in the nuclear fields even in adverse policy conditions, as achieved through the projects described in this paper, will certainly turn out as a valuable common investment, which will maintain the competences in a technology having a vital role for the sustainable development of Europe.

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