A Proposal for a Pan-European E&T Programme Supporting the Development and Deployment of ALFRED

S. Bortot[1], L. Cizelj[2], D. Diaconu[3], F. Di Gabriele[4], G. Grasso[5], I. Tiselj[6], J. Wallenius[1]

[1]Royal Institute of technology (KTH), Stockholm, Sweden

[2]Jožef Stefan Institute (JSI), Ljubljana, Slovenia

[3]Institutul de Cercetări Nucleare (ICN), *Piteşti*, Romania

[4]Centrum výzkumu Řež (CV-REZ), Prague, Czech Republic

[5]Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA), Bologna, Italy

[6]University of Ljubljana, Ljubljana, Slovenia

E-mail contact of main author: bortot@kth.se

Abstract. The EU ARCADIA project was conceived so as to promote the further development of nuclear research programmes in Europe focusing on Generation-IV fast reactor technology, with a primary goal to provide support for the ALFRED project towards its realization in Romania. A comprehensive list of priorities was identified for what concerns Education & Training, supporting facilities and regulatory aspects, based on the investigation of the existing national and regional structures. A proposal was consequently formulated to fill the gaps in competences and infrastructures required for a country to develop and pursue a Generation-IV nuclear programme: two building blocks were identified as essential for developing and implementing such an E&T scheme, the latter consisting in applying an outcome-based pedagogical approach to lifelong learning, and harmonizing with the European Credit System for Vocational Education and Training (ECVET) principles.

Key Words: Generation-IV LFR, outcome-based E&T, CDIO, lifelong learning.

1. Introduction

The entire process of implementation of a nuclear programme relies on the availability of qualified expertise and of national infrastructures providing the general framework for the smooth execution of regulated activities. Building an innovative reactor, besides the challenges related to advanced nuclear technology and the important aspects of costs and financing, implies also the availability of specific theoretical and experimental resources, communication methods and tools, adequate regulatory approaches, building techniques and, of course, connection to the past and current reactors operational experience.

It is acknowledged that the introduction of Generation-IV (Gen-IV), fast spectrum systems would radically change the conditions for nuclear power production in Europe, since the industry would be given a perspective of long-term sustainability and capability to lead the global transition towards a low-carbon society.

The EU ARCADIA project [1] was conceived so as to promote the further development of nuclear research programmes in Europe, including providing support for the Advanced Lead-cooled Fast Reactor European Demonstrator (ALFRED) [2] towards its realization in Romania. Within ARCADIA, crucial focus was put both on the identification of a

comprehensive list of primary requirements for the ALFRED development - mainly for what concerns E&T, supporting infrastructures and regulatory aspects -, and on the review of the existing national and regional facilities – with a particular attention to the ones in Romania and in all the participating new Member States – for defining a map of competences potentially eligible to satisfy the previously identified needs [3].

According to the output of this analysis and to the definition of *Competence* as *"a holistic notion, consisting of cognitive, technical and behavioural aspects, each of them necessary for the complete definition of the job requirements"* found in the nuclear field job taxonomy formulated by the EHRO-N Working Group [4], an approach is here proposed to fill the gaps in competences and infrastructures required for a country to pursue a Gen-IV nuclear programme [5]. In particular, this work aims at setting the foundations for the definition of a pan-European E&T system that shall attract a new generation of talented students to the nuclear field, resulting suitable to developing competences and expertise beyond the existing academic curricula in the field of Gen-IV nuclear technology.

Based on the overall picture of the competences required for the development of the ALFRED demonstrator, two building blocks are identified as essential for conceiving and implementing an apposite Education and Training (E&T) programme: (*i*) the application of an outcome-based pedagogical approach to lifelong learning, and (*ii*) the harmonization with the European Credit System for Vocational Education and Training (ECVET) principles [6].

2. General Approach and Principles

As Human Resources (HRs) represent a key matter for the successful development up to industrial deployment of next generation reactors, it is commonly agreed that the E&T of skilled engineers and professionals is currently high priority for the implementation of ALFRED in Romania[1]. In order to meet the expected HR demand from both the local/national and international nuclear industries, new job profiles are to be defined on the basis of a careful quantitative and qualitative planning and definition of new competences in multidisciplinary areas (*e.g.*, research, design, construction, operation, safety, etc.) specific to the ALFRED (*i.e.*, fast spectrum, lead-cooled) technology.

According to the approaches to competence building adopted by the European Commission and state-of-the art Engineering Education in the Member States, the proposed E&T scheme envisions a holistic approach to producing the competent workforce for the ALFRED-related nuclear energy industry, that includes the appropriate combination of university education, industrial training and formal instruction.

In the context of economic restructuring, where certain sectors are declining whilst others have difficulties in recruiting adequately qualified staff, there is a need for a flexible workforce. People are expected to have both the aptitude as well as the opportunity to enable continued learning and development of new knowledge, skills and competence. Lifelong learning aims at facilitating the transition between different jobs, companies or sectors, as well as the transition from unemployment or inactivity into employment. It is seen as a means

[1] The first efforts in this regard have been undertaken by the University of Pitesti (UPIT) in collaboration with the University Politechnica Bucharest (UPB) as part of the ARCADIA project by designing a new Energy and Nuclear Technologies Engineering Programme incorporating specific modules on Gen-IV and Lead-cooled Fast Reactors (LFRs), which was approved by the Ministry of Education and Research in 2014 and became active in the University of Pitesti in 2015.

of improving the match between labor market demand and supply, and of supporting social inclusion.

Accordingly, the proposed E&T scheme - and consequently-defined curricula – is to be built upon the proven established practices of the national educational systems, as well as upon the best practices that the international community has developed over decades, including those for a qualified nuclear engineer. The overall programme is finally to be aligned with the European Qualifications Framework for Lifelong Learning (EQF) [7], being founded on the Recommendation of the European Parliament to adopt an Intended Learning Outcomes (ILOs)-based approach [8] at the highest relevant taxonomy levels (skills and competences, and cognitive tasks usually categorized in increasingly sophisticated order [9]), reflecting advances in pedagogical science and making use of teaching approaches developed as a result of evidence-based research.

3. Outcome-based Learning

Intended learning outcomes describe what students should know or be able to do at the end of a course, being consequently focused on student performance. Each individual ILO should support the overarching goal of the course, that is, the thread that unites all the topics that will be covered and all the skills students should have mastered by the end of the semester.

When writing ILOs, experts often talk about using the acronym S-K-A to frame learning objectives. S-K-A stands for:

- Skills: what students should be able to do by the time the course is completed.
- Knowledge: what students should know and understand by the time the course is completed.
- Attitudes: what the students' opinions will be about the subject matter of the course by the time it is completed.

It is here recommended to employ well-defined learning taxonomies (such as Bloom's Taxonomy of Objectives for the Cognitive Domain [10]) in order to create ILOs for both a single course and even for the overall E&T programme.

4. The European Credit System for Vocational Education and Training

The European Credit System for Vocational Education and Training is a technical framework for the transfer, recognition and - where appropriate - accumulation of individuals' learning outcomes with a view to achieving a qualification. ECVET works hand in hand with the EQF to provide greater transparency in European qualifications, promoting the mobility of workers and learners, and facilitating lifelong learning.

4.1.ECVET and Learning Outcomes

Assessed learning outcomes constitute credit; credit is the basis for enabling the transfer between learning contexts (or processes) and for the accumulation of learning outcomes. In ECVET, learning outcomes are used as a basis for credit transfer and accumulation, which enables individuals to fully integrate and recognize mobility-related achievements into new or existing learning pathways.

A successful ECVET implementation requires that qualifications be described in terms of ILOs, with the latter brought together in units, and units often accumulated to form the core of

qualifications or awards. Assessment, validation and recognition processes must also be agreed, and should respect existing national, regional, sectorial or institutional practice.

Currently, ECVET does not provide a template or a taxonomy concerning the format of ILOs descriptions. Such templates or classifications may exist at national, regional or system level. However, it is essential to ensure that ILOs for qualifications and units are clearly identified and described in order for the E&T programme in object to be properly implemented.

4.2.ECVET and the Gen-IV Nuclear Energy Sector

As detailed in the previous sections, ECVET is a tool that can assist lifelong learning by improving the transfer, recognition and accumulation of what has been learned in the past. It can facilitate the development of individualised and flexible lifelong learning paths facilitating individual learners to gain knowledge, skills and competence, and ultimately a qualification. In this sense, ECVET can be considered as a decentralised mechanism that relies on both the voluntary participation of Member States - and wider VET stakeholders - and mutual trust being established among all those involved.

Since ECVET centres on a series of technical components that, together, facilitate the process of learning recognition, irrespective of the country or educational system where the formation took place, such a framework is advised to be taken as the reference scheme which the Gen-IV E&T programme would be developed and implemented within, according to shared principles, common goals and technical components, and based on an outcome-based pedagogical approach to lifelong learning.

For partners (*i.e.*, universities, research institutes and, possibly, dedicated educational centers) participating and contributing to the programme in the framework of transnational mobility, it will be necessary to define qualifications in terms of ILOs (in turn grouped to create units), and to devise tools (such as grids or templates) directed to:

- comparing qualifications across different qualifications systems;
- highlighting the similarities between qualifications and ILOs among the partner institutions;
- identifying the ILOs that are not foreseen as part of the qualifications awarded by the partner institutions.

When considering the nuclear energy sector in Europe, a number of major challenges are recognized, among which the strong anti-nuclear policy of some Member States, as well as the current structure of electricity markets, which are oriented in support to renewables (*i.e.*, incentives). Nevertheless, strong interest is currently given to decommissioning activities, along with a more moderate focus on research on Gen-IV systems and fusion technology. In order for the latter to be pursued, a considerable increase on the demand of professionals in the nuclear sector is expected to occur, which would be enhanced even further by the development up to industrial deployment of ALFRED and subsequent LFR commercial systems, making the estimate gap between HR demand and supply be over 30 %.

For these reasons, the design and implementation of an E&T programme based on both ILOs and ECVET would be beneficial in bridging such a gap through “nuclearization”, leading to a fully functional free market.

5. A proposal for an E&T Framework Development

Safe operation of future Gen-IV reactors in Europe requires adequate training and education of scientists, engineers, technicians and regulators. Currently, training programmes in academia and elsewhere are fragmented and do not necessarily meet the needs of the industrial initiatives. For this purpose, the formulation and implementation of a pan-European approach is desired.

Analyses of the existing nuclear engineering curricula in Europe show that, whereas the required core competences of relevance for the Light Water Reactor (LWR) industry are provided by most programmes, gaps exist in areas that are needed for a successful implementation of ALFRED. In particular, the information collected from the ARCADIA partners through a specific questionnaire allowed identifying the following specific gaps in the available academic knowledge and competences:

- ALFRED-specific topics: gaps in chemistry and material sciences, especially related to lead environments[2];
- topics specific of peculiar phases/activities of a new project: gaps in electrical engineering, natural sciences, informatics, civil engineering, economics, management and QA/QC.
- general topics: relatively less pronounced gaps in physics, nuclear and mechanical engineering, informatics and security.

From pedagogic research, it has been established that deep learning requires hands-on experience of managing facilities, instruments, tools and other equipment. Such facilities may not necessarily be available in every university, or not even in most countries. In particular, access to zero-power fast reactors, liquid metal loops, and laboratories holding a license to manage plutonium for training of students is highly restricted today. The envisioned E&T programme should therefore address these deficiencies, in order to be able to deliver the ILOs at highest levels of the adopted learning taxonomy.

5.1. Centers of Excellence

Considering that experimental facilities of relevance for ALFRED are expensive to operate and often require permits that academic organization do not have, it is suggested that the pan-European E&T system be based on the creation of Centers of Excellence. Such centers would physically be located at the site of research institutes (or in rarer cases universities) already operating experimental facilities of the kind that would be needed for competence building in the context of ALFRED[3].

The training facilities, be they either existing, or built on purpose for the E&T programme, would be managed by the respective host organization, whereas pedagogically skilled staff

---

[2] Chemistry, material sciences and electrical engineering were identified as key topics to address when developing the framework for the E&T training programme here discussed. In the context of ALFRED, this may be concretized as needs for building competencies within, among the others, heavy liquid metal chemistry and thermal-hydraulics, MOX fuel fabrication and reprocessing, fast reactor safety and I&C.

[3] Examples of such research centers include SCK•CEN with the VENUS-F facility, CVR and ENEA with a variety of lead-loops and Studsvik and Chalmers, having licenses allowing for students to work hands-on with plutonium.

from academic organizations associated to the Centers of Excellence would lead the training activities. University students participating in the programme as part of the final year in their Master's or Bachelor's education, would receive ECTS credits through these academic organizations. A system for giving learners from industry ECVET credits remains to be elaborated.

The operation of the Centers of Excellence could possibly be funded by a combination of European grants and student fees. The individual programmes and their teachers would be accredited by an international organization, and/or stakeholders, as elaborated in Section 5.3. Besides academia and research centers, active participation from industry, regulatory bodies and technical support organizations would be essential for the functionality of this scheme.

5.2.Pedagogical Approaches

An E&T programme oriented to Gen-IV systems development and deployment should focus on providing students with functional skills that are of direct value for addressing the complex problems they will encounter in industry, in order to reduce the increasing disparity between academic research/education and industrial needs, which has become evident by the end of the last century. Thus, the training approach is to be based on the understanding that learning objectives must be possible to classify within the highest level of learning taxonomies. This means that the aim of learning activities should be to acquire abilities to *analyze, evaluate, synthesize* and *create*. Learning activities are to be aligned with these objectives (implementation of constructive alignment). The innovation adopted by a suitable E&T programme to achieve *deep learning* is a mandatory combination of modeling and experiment in the training package to be defined. Implementing this important innovation is expected to enhance the capabilities of the students to analyze complex phenomena, synthesize experimental data with outcomes of modeling, and thereby provide them with unique abilities to create new knowledge. In order to ensure excellence in an E&T programme, educational standards must be assessed and consequently improved, in the direction of meeting the essential conditions and criteria reported in Table I.

TABLE I: CRITERIA FOR AN E&T PROGRAMME SUCCESS.

Satisfactory resources (funding, labs, computers, libraries)
High qualifications of the teachers
Tight connection between teaching and research
Excellent industrial and scientific networks
High competitiveness of current students
World leading achievements of graduated former students
Satisfied and self-confident students and alumni
Worldwide recognition of the university
Global attraction of both top-students and researchers
Course providing knowledge and skills for solving realistic future tasks

The aimed increasing trend to foster mobility among universities and training centers at both national and European levels is likely to substantially influence the long-term development of high quality E&T, as it stimulates synergies among institutions which present favorable academic environments.

5.3.1. Elements of Course Design and Assessment

A fundamental factor affecting E&T programmes quality and success is accessibility. Clear information is necessary for providing students and trainees with solid guidance throughout education and training, respectively. Accessibility, when it comes to a single course (or programme), can be displayed in a proper course syllabus [4], which represents the teacher/trainer-student/trainee common starting point, setting the stage for learning throughout the course.

In order to provide a broader context, it is desirable to accomplish a certain level of harmonization of the syllabi among different courses, not only concerning the template, but also concerning the expected course-specific outcomes and aimed proficiency that a student should develop in order to become an acknowledgeable professional. Consequently, all the courses foreseen within a programme should be aligned consistently and progressively provide means to form a sort of *forma mentis* that would make the student's ultimate excellence target achieved. This may be summarized by proposing that single course syllabi be designed with clarity and comprehensiveness upon the principles of constructive alignment, and be all mutually aligned in order to become organic components of a holistic, coherent and well-structured context.

5.3.2. Assessment-based Teaching

Concerning the quality of teaching and learning, a feedback-based approach should be adopted combined with constructive alignment, so as to move from understanding who students are (*i.e*., their, backgrounds, prior knowledge, etc.) and where they are (during the course) to accordingly plan the activities that appear – from the collected feedbacks – to be most likely to support their learning and lead them towards the defined goals while helping them acquire and retain skills longer (flexibility). In such a looped structure, the term *feedback* can be categorized as both feedback *to* and *from* students, making the mutual assessments become formative and the learning process be student-centered. In this way, there would be room to enhance mutual motivation by combining teacher support and investment/commitment with high level of expected accomplishments (challenge). In addition, keeping expectations and course requirements transparent is essential, as well as establishing fair and clear grading and assessment policies that need to be relevant to the objectives of the course, which, in turn, must be aligned with the programme's aims as well as industry's requirements and expectations.

An assessment-based teaching approach may be schematically represented and summarized as follows (*Fig.1*.):

---

[4] The common components that a successful academic syllabus shall contain are to be selected based on the simple argument that a comprehensive syllabus should be able to answer the questions that students may have about the course.

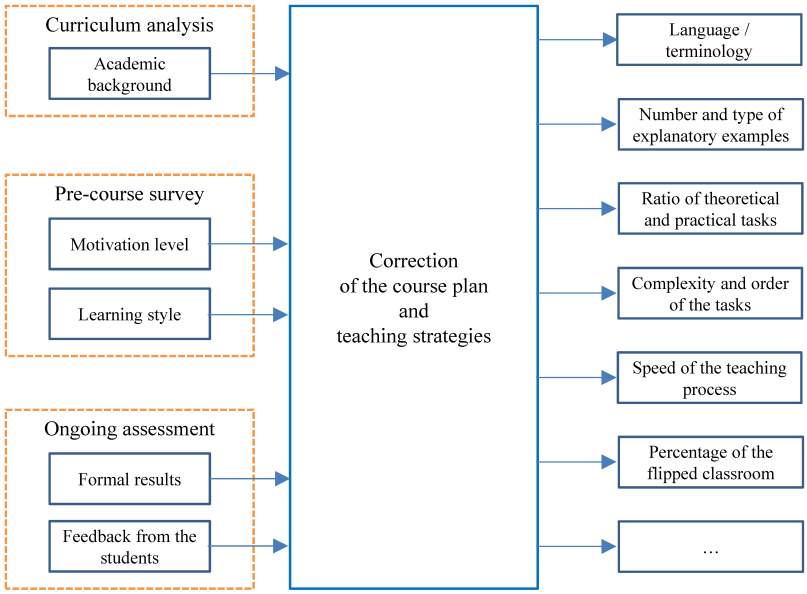

Fig.1. Assessment-based teaching schematics.

5.3.3. CDIO as a Viable Option for E&T of Gen-IV Engineers

The CDIO™ INITIATIVE [11] is an innovative educational framework for producing the next generation of engineers. The framework provides students with an education stressing engineering fundamentals set in the context of Conceiving — Designing — Implementing — Operating (CDIO) real-world systems and products. Throughout the World, CDIO Initiative collaborators have adopted CDIO as the framework of their curricular planning and outcome-based assessment.

As discussed previously, within the ARCADIA project, it was recognized that the whole spectrum of E&T in support of Gen-IV nuclear systems is necessarily to be acquired over a long period (lifelong learning) and, also, in a variety of diverse institutions. In this respect, the CDIO network can welcome members in such a diverse range of institutions ranging from research-led internationally acclaimed universities, to local colleges dedicated to providing students with their initial grounding in engineering, to research institutes, to excellence centers ad hoc created. As CDIO offers open and accessible channels for didactic materials and for disseminating and exchanging resources, it is selected among the viable educational frameworks for implementation within the proposed E&T programme, mainly due to its potentialities to conceive and help develop a new vision of engineering E&T in support to the construction and operation of ALFRED suitable to meet real-world demands of professionals.

Moreover, as mentioned above, CDIO is based on a commonly shared premise that engineering graduates should be able to conceive, design, implement and operate complex value-added engineering systems in a modern team-based engineering environment to create systems and products [12]. For this reason, it is believed that the vision of the CDIO-based education may be a valuable perspective to integrate within the proposed E&T system.

5.3.Programme Accreditation

To assure quality and continued relevance, on-going accreditation of the proposed E&T programme is of major importance. It is necessary that teachers and trainers at the Centers of Excellence are qualified and accredited according to the highest pedagogical standards, for which an accreditation system must be established (*i.e.*, either borrowed from ECVET or

developed on the basis of shared principles and standards), along with an organization responsible for it.

5.3.1. Accrediting organisms

In some countries, the accrediting function is performed by governmental ministries and agencies. Elsewhere it may be handled by professional or learned societies.

A third approach, which is endorsed here, is to have accreditation handled by independent organizations. In particular, it is believed that an industry-governed organism or task force would be the most appropriate to guarantee that the proposed E&T programme meets the needs and expectations in terms of competencies and skills/abilities required to ensure an industrial development and deployment of Gen-IV nuclear systems.

The accrediting organization should operate by nominating an experienced and acknowledged peer review committee or commission to evaluate the performance of the to-be-accredited faculty/department. In addition, the accrediting organization should seek feedback from the faculty/department regarding the reviewers to assure that they are qualified to serve in this role.

5.3.2. Accreditation Approach and Procedures

Historically, accreditation approaches of academic programmes primarily focused on content. For engineering, this was based on examining the curricula to determine if sufficient attention was being given to areas including mathematics, physical sciences, engineering sciences and design.

An emphasis to extend current accreditation systems to include an outcome-based approach is proposed here. In particular, it is believed that the accreditation review should include assessments of the performance of a graduate in his or her role as an engineer. Therefore, programme outcomes may be best defined as the quality and quantity of graduates, together with the roles and impacts they have in their careers and for their employers. An effective nuclear engineering programme should engage with the organizations that employ their graduates to determine the quality of the preparation of the students for a career in industry. A well-organized link with the employing organizations would provide a critical feedback that leads to continuous improvement.

In order to accomplish this ambitious goal, a well-defined set of criteria should be developed by the aimed industry-governed accrediting organization and presented to the academic institutions and training centers well in advance of an accreditation visit, this being necessary to enable faculties and departments to implement the curriculum/a needed to meet the criteria.

The key elements for a well-established accreditation process are planned to be systematically examined and formulated as a set of guidelines within the ARCADIA follow-up project GENESIS (Generation-IV European Nuclear Education System Innovation Scheme). Qualitative criteria will define the *must-do* of the educational programme, while the quantitative components shall impose a threshold and give the control instrument for quantifying performance. The combination of these criteria will ultimately establish the aimed standard.

6. Conclusions

It is generally recognized that the introduction of Generation-IV, fast spectrum systems would radically change the conditions for nuclear power production in Europe, giving the industry a

perspective of long-term sustainability and capability to lead the global transition towards a low-carbon society.

Based on approaches to competence building adopted by the European Commission and state-of-the art engineering education, a Euratom Fission Training Scheme that shall attract a new generation of talented students to the nuclear field is envisaged.

The design and structure of such an E&T programme is performed aiming at aligning with the European Qualifications Framework for Lifelong Learning, as it is focused on the formulation of learning outcomes at highest relevant taxonomy levels (skills and competences), while applying modern and evidence-proven efficient pedagogical approaches. The training scheme will extend existing academic curricula and shall respond to the needs of nuclear industry, regulatory bodies and technical support organisations, being funded on a defined set of training facilities (Centers of Excellence) providing students opportunities to benefit from hands-on learning activities and to qualify for ECTS as well as ECVET recognition.

References

[1] http://www.arcadia-framework.eu/

[2] http://cordis.europa.eu/result/rcn/147643_en.html

[3] TISELJ, I., et al., “Needs for competences and infrastructure for ALFRED Reactor Implementation”, D.1.1, ARCADIA Project (2016).

[4] http://ehron.jrc.ec.europa.eu/job-taxonomy

[5] CIZELJ, L., et al., “Gaps on the Competences for ALFRED Reactor Implementation”, D.1.2, ARCADIA Project (2016).

[6] https://ec.europa.eu/education/policy/vocational-policy/ecvet_en

[7] EUROPEAN PARLIAMENT COUNCIL, “Recommendation of the European Parliament and of the Council of 23 April 2008 on the establishment of the European Qualifications Framework for lifelong learning”, Official Journal of the European Union, 2008/C 111/01 (2008).

[8] AU, O.T.S., “A Tabular Approach to Outcome-Based Course Planning and Assessment”, Handbook of Research on Hybrid Learning Models: Advanced Tools, Technologies, and Applications, Ed. Fu Lee Wang, Joseph Fong and Reggie Kwan, 64-70 (2010).

[9] ANDERSON, L.W., et al., “A Taxonomy for Learning, Teaching, and Assessing: A revision of Bloom's Taxonomy of Educational Objectives”, New York: Pearson, Allyn & Bacon (2001).

[10] BLOOM, B.S., et al., “Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain”, New York: David McKay Co Inc. (1956).

[11] http://www.cdio.org/cdio-vision

[12] EDSTRÖM, K., KOLMOS, A., “PBL and CDIO: Complementary models for engineering education development”, European Journal of Engineering Education (2013).