SafeG

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On-job training activities summary

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EXECUTIVE SUMMARY

On-job training is important part of Euratom projects focused on development of advanced nuclear technologies. Its realisation in frame of SafeG project directed on safe design and operation of gas cooled fast reactors is described in detail.

CONTENT

1 ON-JOB TRAINING – GENERAL OUTCOMES

Generally, the on-job training is a form of training that occurs while the trainee is performing their work duties or specialised studies. On-job training aims to enhance the trainee's performance in their specific job or role in a practical environment. It emphasises the real-world application of skills within the actual work environment. Trainees learn by doing the actual tasks related to their job or by learning from a senior with more experience.

Having in mind smooth development of GenIV line of advanced reactors (including GFRs), highly educated experts with very specific knowledge, skills and competences are needed. For the safe power generation, experts with highly qualified nuclear and radiation protection competences will be needed over a long period to build new facilities and/or to safely operate installations (including radioactive waste management and decommissioning activities) and to deal with radiation protection issues as well.

Policy makers and industry, however, share the concern that human resources could be at risk, especially because of high retirement expectations in "old" countries (with nuclear installations – in some EU Member States) and a lack of nuclear experience (and of nuclear safety culture) in "new" countries (more than 45 Member States of the IAEA have approached the Agency with a serious expression of interest in nuclear power plant construction).

The nuclear sector represents thus in the EU (and of course also world-wide) a source of stable and reliable base load, with low carbon levels and relatively stable costs, which makes it attractive from the point of view of fighting climate change and security of supply. Uranium fuel is abundant, especially if fast neutron reactors are used, based on breeding of fissile Pu-239 fuel from non-fissionable but fertile U-238.

Finally, it is clear that if nuclear power is to have a long-term future, absolute priority should be given world-wide to the safety of current operational reactors and of future reactors (Generation II, III and IV). Much has already been accomplished, and yet further studies and research are still needed. International safety concerns are notably summarized in the warning: "*A (severe) nuclear accident anywhere is an accident everywhere.*"

European commission long-term strategy for on-job training in nuclear is based on EURATOM projects. A number of projects in frame of *Euratom Fission Training Schemes* (EFTS) are funded through several indirect actions, focussing on lifelong learning and cross-border mobility. The concept of "learning outcomes" related to Knowledge (= understanding), Skills (= how to do) and Competences (= how to be) /KSC/ is at the heart of the EFTS. This approach is aligned with the general EU policy in education and culture, i.e.: the "Bologna 1999" process for mutual recognition of academic grades and the "Copenhagen 2002" process for continuous professional development across the EU Member States. It is no surprise that the format adopted by the IAEA training programmes is based on a concept very close to the above KSC approach. Following the IAEA definition (Safety Standard Series, 2001) [1], *competence means the ability to apply knowledge, skills and attitudes so as to perform a job in an effective and efficient manner and to an established standard.*

In the nuclear energy sector during the last four decades, three severe accidents happened (Three Mile Island /TMI/ in 1979 in the USA; Chernobyl in 1986 in the former Soviet Union;

[1] "*Building competence in radiation protection and the safe use of radiation sources*" (jointly sponsored by IAEA, ILO, PAHO, WHO), IAEA 2001 - http://www-ns.iaea.org/standards/documents/pubdoc-list.asp

Fukushima in 2011 in Japan). Lessons however were drawn world-wide, in particular in the EU, which organised the "stress tests" [2] in all European nuclear power plants (NPPs) following the Fukushima Daiichi accident of 11 March 2011 (Great East Japan Earthquake, Tohoku's coastline, Richter magnitude 9). These "stress tests" were defined by the European Commission (EC) as *targeted reassessments of the safety margins of nuclear power plants* and were developed by the *European Nuclear Safety Regulators' Group* (ENSREG). It should be noted that many non-EU countries also conducted comprehensive nuclear risk and safety assessments based on the EU "stress test" model. These include Switzerland and Ukraine (both of which fully participated in the EU "stress tests"), Armenia, Turkey, the Russian Federation and Belarus as well as, to some extent, Taiwan, Japan, South Korea, South Africa and Brazil.

A holistic approach was applied quite successfully in the past Euratom programmes (FP6 /2002 – 2006/, FP7 /2007 – 2013/, Horizon-2020 /2014 – 2020/), as is demonstrated in the following list:

- "Knowledge Triangle" in the EU: national and international programmes for nuclear research, innovation and education with end-user-oriented mindset, for the benefit of both industry and society at large

- synergy between stakeholders: all are on-board through the *Technology Platforms* (ETPs), i.e.: research organisations; systems suppliers; energy providers; regulators and/or TSOs; higher E&T institutions + policy makers and civil society

- RD&DD in large international projects: "Research" and "Development" is being conducted in research organisations, while liaising with industry and regulators who are the main actors of the follow-up steps of "Demonstration" and "Deployment"

- EU research related to energy mix optimisation: system's approach based on complex relationships between production (from primary energy sources); transmission; storage or/and distribution (usually of energy carriers); and consumption (markets)

- sustainable nuclear and renewable convergence: focus on advanced materials and processes for energy challenges; energy storage for the integration of renewable energy production; energy efficiency; and instrumentation and control (I&C) systems

- life cycle assessment of primary energy source applications and evaluation of "total social costs" of energy systems: a multi-sectorial cradle-to-grave approach is applied to evaluate and compare pros and cons of each primary energy source

- from system design to system operation: state-of-the-art modelling and simulation environments are developed to increase energy and transportation system safety, dependability and performance throughout their lifecycle

- assessing software reliability of computer-based safety systems (nuclear I&C standards): develop a common justification framework in synergy with utilities, vendors and TSOs (remember - software can usually not be proven to be completely defect-free, and postulated residual defects might lead to common-cause failure)

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[2] EC Communication COM(2012) 571, dated 4 October 2012 – *"EC Communication on the comprehensive risk and safety assessments ("stress tests") of nuclear power plants in the EU and related activities* "
- http://ec.europa.eu/energy/nuclear/safety/doc/com_2012_0571_en.pdf

- data mining in Nuclear Knowledge Management: involving methods at the intersection of artificial intelligence, machine learning, statistics, and database systems - the goal is to extract information from a data set and transform it into an understandable structure, i.e.: transforming data into knowledge

- High Performance Computing (HPC) for Nuclear Fission Science and Engineering: improve collaboration between the HPC community and Nuclear Engineering and Reactor Physics groups by developing common computational approaches with the aim to explore phenomena beyond the edge of experimental exploration.

Based on understanding that the on-the-job training is an effective way to upskill workers, we tried to apply in frame of SafeG WP5 activities all effective tools and best practices for optimal training and job satisfaction of young professionals.

It is important to note that in contrast to classical classroom training the on-job training is a hands-on method where employees learn by doing, typically at their place of work. Classroom training is often considered a form of off-the-job training. Classroom training occurs in a more traditional, educational setting, away from the direct pressures and context of the work environment. Classroom training often involves a more theoretical or structured approach, where employees learn from instructors or facilitators through lectures, discussions, and interactive activities. This type of training is beneficial for comprehensive understanding of concepts, principles, and broader skill development that may not be specific to immediate job tasks but are essential for professional growth and development.

On-the-job training is important for industries because it creates a workforce that is better equipped to do their jobs. Without proficient workers, industries are susceptible to declining into stagnation or mediocrity.

2 ON-JOB TRAINING ON THE YOUNG PROFESSIONALS LEVEL

Proper on-job training for young professionals is one of important output of the SafeG project. It included both academic development of students on the bachelor, master and PhD level as well as professional development of the young professionals coming to the topic from other areas or only just started their professional carrier.

During the 48 months all organisations participated on SafeG project tasks incorporated their young employees into problems connected to the foreseen safe operation of the gas cooled reactors (GFR).

In particular, the SafeG goals were generally formulated towards:

A) Safety strengthening of the GFR demonstrator ALLEGRO using innovative technologies, materials and unique know-how that has been built in this field both in and outside Europe over the last 20 years. The most important areas of ALLEGRO safety improvements addressed by the SafeG project are:

   a. To solve remaining open questions in residual heat removal in accident conditions, leading to practical elimination of severe accidents, through innovative design of the reactor core, diversified ways of passive reactor shutdown, passive decay heat removal systems, and instrumentation.

   b. To strengthen the inherent safety of the key reactor components by review of obsolete material and technology reference options, selection of innovative options, and designs based on these innovative options.

B) Reviewing the GFR reference options in materials and technologies, using experience gained within national research programs, know-how of the consortium and stakeholders, and experience from operation of various research facilities and high-temperature nuclear reactors. The aim is to increase the inherent safety of GFRs.

C) GFR safety adaptation to changing needs in electricity production worldwide with increased and decentralized portion of nuclear electricity by study of various fuel cycles and their suitability from the safety and proliferation resistance points of view.

D) Deepening the collaboration with international non-EU research teams, and relevant European and international bodies (Generation IV International Forum, standardization bodies) and partners with experience/interest in GFR. Reconnection with partners with GFR research and development experience from the past.

E) Bringing students and young professionals, boosting interest in GFR research by wide involvement of universities, promotion of GFR-oriented topics of master theses and dissertations, organizing topical workshops including hands-on training, and on-job training connected with staff exchange between the members of the consortium.

Based on above written goals this delivery 5.6 performed in the WP 5 summarise activities promoting students master theses and fruitful staff exchange between consortium members. International projects like SAFE-G are interesting for young generation, which is seeking for new challenges and comparisons at the European level. It is attractive for them to work in English, in-between colleagues graduated at different universities and to recognize the own level of knowledge and competences. Last, but not least, by working alongside senior experts (sometimes from different countries), students gain valuable mentorship and guidance, helping them to grow and succeed in their chosen field. No doubts, actively engaging students in projects can spark creativity, innovation, and fresh perspectives that can lead to successful outcomes and advancements in the project. Overall, student participation not only benefits the individual students but also contributes to the overall success and impact of the project.

3 ON-JOB TRAINING IN FRAME OF SafeG PROJECT

Students on-job training is mostly based on the proper University study-program (in our case connected to nuclear engineering), bachelor, master or doctoral theses, special workshops, conferences, technical tours and fellowships. Crucial in their leading are pedagogical staff at the universities and consultants from the adequate institutions. The attractiveness of theses or the nuclear study-program can be nowadays enhanced via generally recognized fact, that nuclear energy has a very low CO_2 footprint and currently guarantees the secure and reliable supply of base-load electricity at stable and comparably low price. Nuclear energy is therefore recognized by many of the EU countries as a low-carbon energy source to be included in the future energy mix. Advanced nuclear systems should become the backbone of the European nuclear power generation plants in the mid and long-term. They will respond to the world's future energy needs, in particular increased demand for electricity and reduced CO_2 emissions leading to more widespread use of nuclear energy. Making efficient use of uranium natural resources and minimising waste production become major concerns in such a scenario, in addition to satisfying economic competitiveness and maintaining stringent standards of safety and proliferation resistance.

In frame of SafeG project the gas-cooled fast reactor is considered as one of the six most promising advanced nuclear reactor technologies. For the students, the following main advantages of GFRs were accented:

- High core outlet temperature leading to high thermal efficiency of the reactor for electricity production and makes it an ideal source of high-potential heat for hydrogen production and other industrial applications.
- Improved core neutronic safety due to low void reactivity feedback coefficient.
- Helium is chemically inert and non-corrosive coolant without phase change, reducing risks of accidents caused by coolant chemistry-induced failures.
- Helium is transparent, which allows much easier in-service inspections and maintenance compared to liquid metals and salts coolants.

Bachelor, master and PhD these were focused on the topics connected to the obove promoting advantages. Viability of the GFR technology was demonstrated by a successful operation of a demonstration unit. It has been developed under the name ALLEGRO, and it will be used not only for technology demonstration, but also for development and qualification of innovative components & systems, first the innovative refractory fuel.

Participants of SafeG project were also in the past involved into ALLEGRO design development. The concept of the ALLEGRO demonstrator was originally developed in the first decade of this century by CEA, featuring a two-loop design, and with thermal power 75 MW. In 2010, four private companies in collaboration with research organisations (VUJE, UJV, MTA-EK and NCBJ) from Slovakia, Czech Republic, Hungary and Poland signed a Memorandum of understanding, which resulted in establishment of a legal entity, the “V4G4 Centre of Excellence” (V4G4 CoE) in 2013. CEA has become an associated member in 2017, and Research Centre Řež (CVR) has been an associated member of the CoE since 2019.

The goal of the V4G4 CoE has been the continuation of the GFR development focused primarily at finishing the conceptual design phase of its demonstrator, ALLEGRO. In the light of the ambitious nature of the whole concept, international cooperation is essential for a timely progress in the development of GFR. The cooperation governed by V4G4 CoE makes it possible to pursue multiple goals and technical options concurrently, and to avoid any premature down selection due to the lack of adequate resources and knowledge on individual national levels.

The SafeG proposal presents a Research and Innovation action aiming at connecting developers of the ALLEGRO reactor (V4G4) with European and international experts having experience in GFR and HTR research, who will utilize their unique expertise, knowledge and experience, bringing fresh ideas to the GFR development to the SafeG project will bring the GFR research and development in Europe a major step forward.

All these summarised issues can imply attractiveness of GFR topic for V4 countries and their young professionals for interesting jobs in Central and Eastern Europe.

Gas-cooled fast reactor (GFR) is considered as one of the six most promising advanced nuclear reactor technologies. The main advantages of GFRs, beside the possibility to close the fuel cycle which is an inherent feature of all fast-spectrum nuclear reactors, are:

- High core outlet temperature leading to high thermal efficiency of the reactor for electricity production, and makes it an ideal source of high-potential heat for hydrogen production and other industrial applications
- Improved core neutronic safety due to low void reactivity feedback coefficient
- Helium is chemically inert and non-corrosive coolant without phase change, reducing risks of accidents caused by coolant chemistry-induced failures
- Helium is transparent, which allows much easier in-service inspections and maintenance compared to liquid metals and salts coolants

In frame of SafeG WP5 activities we tried to apply mostly structured on-job training approach, which was based on proper mentoring, coaching or training performed by expired colleagues to the young professionals or via supervising of diploma or PhD. Work via experts and pedagogical staff at the universities. A special accent was given on the workshops/summer schools organized in frame of SafeG training activities.

The GFR Summer School event was organized by Research Centre Rez within SafeG project WP5 in last august week 2022. The event was focused on students and young professionals through technical lectures given by SafeG experts and technical tours.

The GFR workshops was focused on advanced modelling techniques and organized by University of Cambridge in United Kingdom in first week of July 2023. It was targeted at students and young professionals dealing with CFD and other high-fidelity computational tools. The program comprised also lectures from GFR modelling and technology experts and a technical tour. The participants were students and young professionals from research and academic institutions involved in the SafeG project and those outside the project.

In the SafeG project 5 of 15 project partners are universities. The university members of the project consortium are committed to finding meaningful and engaging topics for students to work on in this project. Our aim is to provide them with valuable learning opportunities that align with their interests and goals, ultimately fostering their growth and development in the nuclear field. By identifying relevant and impactful topics, we aim to empower students to excel in their academic pursuits and contribute meaningfully to the project's success.

Beside this, each partner involved in the project brings a unique expertise and focus area that enriches the overall collaboration. By leveraging the diverse perspectives and strengths of each partner, we can ensure that a wide range of topics and perspectives are considered, leading to a more comprehensive and impactful project outcome. This diversity of focus areas allows for a holistic approach to problem-solving and innovation, ultimately benefiting both the project and the participating students.

Students participating in the project can engage in advanced research through master's and PhD. theses, diving deep into complex topics and making significant contributions to the field of nuclear science. These higher-level academic pursuits allow students to develop specialized knowledge and skills, preparing them for successful careers in the nuclear industry or further academic research. By supporting and guiding students through these thesis projects, we aim to cultivate the next generation of experts and innovators in the nuclear field.

No doubts, mentoring coaching or supervising activities requires preparation, knowledge applications and special skills. Combination of these 3 requirements on good qualitative level is serious task and motivate deep understanding of the topic as well as tight collaboration with research institutions solving particular issues in line of previous knowledge in nuclear safety, neutronics, thermohydraulics or materials degradation.

As significant outcome of SafeG project we can consider fruitful collaboration between nuclear research institutions and participated universities in the area of GFR. Both side profit (for university staff deeper understanding of research items stated in SafeG WPs, for researcher from nuclear institution – improving their pedagogical skills mostly via coaching, mentoring or consulting activities or direct participation on SafeG summer schools or workshops.

The universities bring together diverse expertise, resources, and perspectives, creating a rich collaborative environment that fosters innovation and excellence in the field. By leveraging the strengths of each institution, this partnership serves as a hub for cutting-edge research, knowledge exchange, and talent development, shaping the future of nuclear science for the benefit of society.

The focus of National University Corporation Kyoto University in the nuclear field lies in conducting advanced research and education spanning various aspects of nuclear science and engineering, including nuclear energy, radiation safety, and nuclear materials. The university is dedicated to addressing critical issues in the field, such as nuclear power plant safety, nuclear waste management, and the development of next-generation nuclear technologies. Through collaborative projects, partnerships, and academic programs, Kyoto University aims to drive innovation, foster talent, and contribute to the sustainable advancement of nuclear science for the benefit of society.

Slovak University of Technology in Bratislava (STU) is one of the most prestigious technical universities in Slovakia, offering a wide range of engineering, architecture, and IT programs. It is known for its strong focus on practical, hands-on learning, innovative research, and strong industry collaborations. STU is known for its focus on nuclear engineering and nuclear technology research. The university's nuclear program emphasizes reactor physics, nuclear safety, radiation protection, and nuclear materials. STU collaborates with industry partners and research institutions to advance knowledge in the field and develop practical solutions for nuclear energy challenges. Through cutting-edge research and academic programs, STU contributes to the global nuclear community and plays a crucial role in shaping the future of nuclear technology and innovation.

Budapest University of Technology and Economics (BME), has a strong emphasis on nuclear engineering and research within its Faculty of Electrical Engineering and Informatics. The university offers specialized courses in nuclear power plant design, nuclear safety, and nuclear reactor technology. BME collaborates with industry partners and research institutions to address challenges in the nuclear field, with a focus on developing innovative solutions and advancing nuclear science and technology. The university's contributions to the nuclear sector play a significant role in shaping the future of nuclear energy and promoting sustainable development in this crucial field.

The University of Cambridge (UCAM) is one of the oldest and most prestigious universities in the world. Cambridge has a long history of excellence in various disciplines, including nuclear research and technology. The university's Department of Engineering, Department of Physics, and other research centres have been actively involved in nuclear energy research, nuclear physics, nuclear engineering, and related fields for many years. Cambridge's contributions to nuclear science and technology have been significant and have had a lasting impact on the development of nuclear technologies globally.

Final photo of students and their supervisors after state exam at Slovak University of Technology in Bratislava from 6.6.2024. Four of them with Diploma these connected to SafeG project.

The detailed list of the student's diploma theses, as well as the scope of theses and their connection to project ALLEGRO was already published in delivery D5.5 some months before. The same could be written to the PhD. Students and their theses.

Although the scope of theses directed to the safe operation of GFR, participation of the graduates on the SafeG summer school in Řež in 2022 or workshop in Cambridge in 2023 or some other SafeG meetings, there is no guaranty that these young professionals will be dealing in the next carrier exclusively in the area of GFR. We can only conclude that we tried to do our best and the goals of SafeG project were fulfilled.

Summary:

As the main output in the area of on-job training we can declare that within the SafeG project 2 major on-job training activities within WP5 have been performed. The TH and CFD benchmark linked to S-Allegro and PIROUETTE test facility, respectively.

1. The TH and CFD benchmarks linked to S-ALLEGRO loop in Řež were deeply explained at the GFR summer school which was organized at CVR in Řež near Prague in simmer 2022. The event was aimed at Master and PhD students and young professionals with an interest in the field of GFR technology. The GFR school was composed of lectures given by experts from the project partners institutions. The lectures covered wide range of topics related to the GFR such as reactor concept and design, safety, materials, neutronics modelling and the core layout and thermal-hydraulic. A major part of the school was focused on practical exercises and hand-on experiments on facilities operated at CVR, such as HTHL loop for materials tests or thermal-hydraulic S-Allegro loop. Detailed description of lesson and handbooks from GFR Summer School (CVŘ) was published in Deliverable D5.1.
2. Advanced modelling techniques workshop (organized in summer 2023 by UCAM) was focused on CFD and other high-fidelity computational tools. The program comprised also lectures from GFR modelling and technology expert consultations and a technical tour. Deep theoretical explanation as well as large scope for practical exercises provided excellent opportunity for specific on-job training in this area. Details from this event was summarised in Delivery 5.2.

Direct impact on the on-job training we can assign also to performed CFD study of core cooling in LOFAs (for details see Deliverable D3.10) as well as to extended thermal-hydraulic benchmark described in Deliverable D5.3 and Deliverable D5.4. The scope of Bachelor, Master and PhD theses connected to the project was deeply described in Deliverable D5.5.

4 CONCLUSIONS

This delivery is focused on the on-job training performed in frame of SafeG activities during whole period of its duration (48 months). No doubts, the collaboration between students, academic institutions, and senior experts leads to innovative solutions, fresh perspectives, and successful project outcomes. Student participation in the project is crucial for their academic and professional development, providing practical experience that complements theoretical knowledge.

Having in mind the main objectives of Euratom programmes strategy – *"to bridge the gap in science and technology existing between countries in a common effort towards continuous improvement of nuclear safety and security"* – it can be realised only via high skilled experts. Consequently, scientific, human and organisational excellence is continually improved in all nuclear sectors in the EU Member States. Euratom experience of including energy, socioeconomics, environmental sciences and ethics is well recognised. Wherever advisable, the implementation instruments of Euratom programmes facilitate synergy between the scientific-technological and socio-political communities concerned, thereby meeting the needs of society and industry.

SafeG project contributed positively to the emergence of a new generation of highly qualified experts in nuclear fission energy sector with special focus on GFR and its safe utilisation. We hope that young experts (including those, which prepared their Bc., MSc. and PhD. theses in this area) gained valuable international experience. Through various lessons, summer schools, workshops or consultations in international environment, young experts continued in their professional development based on the best knowledge, skills and competences. This new generation of nuclear experts is expected to solve also increasingly complex problems related to energy, safety and security as well as health and environmental protection.

As other outcome from the SafeG project we could consider quantitative as well as qualitative development of pedagogical staff at the universities, which was included into preparation of workshop and summer school. The effort directed to the preparation of lessons, adaptation of computer codes to the practical exercises as well as issuing of textbooks contributed also to enhanced competencies of academical institutions in area of GFR applications and their safety analyses. The same qualitative benefits had impact also on the staff of other project partners and collaboration institutions.

We hope that on-job training performed in different forms in frame of SafeG project was successful for all participated institutions as well as for nuclear power industry in all participated EU countries.

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