EURATOM ACHIEVEMENTS AND CHALLENGES IN FACILITATING PAN-EUROPEAN INFRASTRUCTURE COLLABORATIVE EFFORTS

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ABSTRACT

The European Atomic Energy Community (Euratom) Research and Training framework programmes are benefitting from a consistent success in pursuing excellence in research and facilitating Pan European collaborative efforts across a broad range of nuclear science and technologies, nuclear fission and radiation protection.

To fulfil Euratom R&D programmes keys objectives of maintaining high levels of nuclear knowledge and building a more dynamic and competitive European industry, promotion of Pan-European mobility of researchers are implemented by co-financing transnational access to research infrastructures (RIs) and joint research activities through to Research and Innovation and Coordination and Support Actions funding schemes.

Establishment by the research community of European technology platforms are being capitalised. Mapping of research infrastructures and E&T capabilities is allowing a closer cooperation within the European Union and beyond, benefiting from multilateral international agreements and from closer cooperation between Euratom, OECD/NEA and IAEA and international fora.

'Euratom Achievements and Challenges' in facilitating Pan-European infrastructure collaborative efforts through Research and Training framework programmes show the benefits of research efforts in key fields, of building an effective ‘critical mass’, of promoting the creation of ‘centres of excellence’ with an increased support for ‘open access to key research infrastructures’, exploitation of research results, management of knowledge, dissemination and sharing of learning outcomes.

1. Introduction to the European landscape

Nuclear power plants (NPP) currently provide 30 % of the overall European electricity generated and 15 % of the primary energy consumed in the European Union. In 2016, 135 NPPs are in operation in Europe, representing a total installed electrical capacity of 137 GWe and a gross electricity generation of around 850 TWh per year. Nuclear fission is a major contributor already today as a low-carbon technology in the Energy Union's strategy to reduce its fossil fuel dependency and to fulfil its 2020/2030/2050/COP21/COP22 energy and climate policy objectives [1] however the sector is currently facing several challenges: a) one concerns the plans of most EU Member States (MS) to extend the design lifetime of their nuclear power plants; b) other countries, such as France, Finland, Czech Republic, Hungary and the UK, are planning new builds; c) while others, like Germany, are either considering or have excluded nuclear energy from their energy mix for now; d) a bigger share of renewables should be fostered at European level; and e) fierce international competition is taking place on a global level. Interest in nuclear power is boosted by the need to ensure a secure and competitive supply of energy and by concern over climate change. Finally, whether or not Member States will continue to use nuclear for their electricity production, for both energy and non-energy applications, Europe will need to keep and train highly qualified staff across the whole continent benefitting from hands-on training on key research infrastructures and share its knowledge worldwide.

2. Euratom Treaty and EU/Euratom legislative framework [2]

The Euratom Treaty provides a legal Framework to ensure a safe and sustainable use of peaceful nuclear energy across Europe and helps non-EU countries meet equally high standards of safety and radiation protection, safeguards and security. With legally binding Nuclear Safety Directive (2009/71/Euratom) and its latest amendment (2014/87/Euratom), EU nuclear stress tests, including safety requirements of the Western European Nuclear Regulators Association (WENRA) and the International Atomic Energy Agency (IAEA), the EU became the first major regional nuclear actor with a legally binding regulatory framework as regards to nuclear safety. Furthermore, this legal framework has been recently complemented by the Directive (2011/70/Euratom) that establishes a Community framework for the responsible and safe management of spent fuel and radioactive waste (both from fission and fusion systems), and the Directive (2013/59/Euratom) laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation. Directives on Nuclear Installations' Safety (Art.7), Nuclear Waste Management (Art.8), Basic Safety Standards (Ch.4) and IAEA Convention on Nuclear Safety, all emphasize that each MS shall take the appropriate steps to ensure that sufficient numbers of qualified staff with appropriate education, training and re-training are available for all safety-related activities in - or for each - nuclear installation throughout its life. 'Conclusions' were issued at: a) 'EU Competitiveness Council in November 2008 encouraging Member States and the EC to establish a 'review of EU professional qualifications and skills' in the nuclear field; and b) a 'Second Situation Report on EU E&T in the Nuclear Energy Field' was published in 2014 by the European Human Resources Observatory in the Nuclear Energy Sector (EHRO-N, the latest created in 2009 by the European Nuclear Energy Forum (ENEF)).

The EC promotes and facilitates through the Euratom Framework Programmes (FP) [3] nuclear research and training activities within MS and complements them through its specific Community FP. Horizon 2020 European Atomic Energy Community's (Euratom) Research and Innovation Framework Programme other 2014-2018 has a budget of EUR 1,603 million to implement and is distributed as following: (a) indirect actions for RTD fusion research and development programme, EUR 728 million; (b) indirect actions for RTD nuclear fission, safety and radiation protection, EUR 318 million; and (c) Joint Research Centre (JRC) direct actions, EUR 559 million. In addition, at total of EUR 2 573 million is dedicated to the construction of ITER, one of the world's most ambitious research endeavors and an international collaborative project (EU, US, China, Japan, India Russia, South Korea) to demonstrate the potential of nuclear fusion as an energy source.

R&D activities supporting the enhancement of the highest nuclear safety standards in Europe are mainly promoted by EC DG RTD indirect actions together with JRC direct actions. JRC has also been providing for 30 years internationally recognized scientific and technical support e.g. training courses, educational modules, support to the European Safeguards R&D Association (ESARDA), and CBRN risk areas of chemical, biological, radiological and nuclear. European and International safeguards authorities such as Euratom, MS and IAEA benefitted from JRC's dedicated R&D and operational support in collaboration with other EC DGs, ENER, TRADE, DEVCO and EEAS [4]. Beyond EU borders, DEVCO manages the 'Instrument for Stability (IfS)' and the 'Instrument for Nuclear Safety Cooperation (INSC)' where among others an initiative on Training and Tutoring (T&T) provided post graduate professional education to expert staff at Nuclear Regulatory Authorities (NRA) and Technical Support Organizations (TSO), both in terms of management and of technical means in the areas of nuclear safety and radiation protection which proved to be very successful in strengthening local organizations and regional cooperation.

3. EU/Euratom initiatives are being capitalized

The European Commission helps to stimulate joint funding from Member States and/or enterprises, and benefits are being capitalised from the increasing interaction between European Technology Platforms (ETPs) [5] launched during the 7th Framework Programme

(2007-2013), namely the ‘Sustainable Nuclear Energy Technology Platform’ (SNETP incorporating NUGENIA Generation II III water cooled reactor technology, ESNII Generation IV fast reactors employing the closed fuel cycle, and NC2I Cogeneration of electricity and heat), the ‘Implementing Geological Disposal of Radioactive Waste Technology Platform’ (IGDTP), the ‘Multidisciplinary European Low Dose Initiative’ (MELODI association), the European Energy Research Alliance (EERA) Joint Programme in Nuclear Materials (JPNM), the Strategic Energy Technology Plan (SET-Plan) [6] and other EU stakeholder fora (ENEF, ENSREG, WENRA, ETSON, FORATOM, etc.) [7] as well as OECD/NEA, GIF and IAEA at international level [8].

Euratom Fission Training Scheme (EFTS) coordination actions aimed at structuring Higher University Education Master of Science (MSc) training and career development benefitting from a European Credit Transfer and Accumulation System (ECTS) initiated by the Bologna Process in 1999 for higher academic education. European Credit System for Vocational Education and Training (ECVET) launched in Copenhagen in 2002 is also promoted today for lifelong learning in the field of nuclear and successfully tested across a wide range of industrial sectors. It is further promoting transparency, mutual trust, continuous professional development based on a modular course approach and recognition of learning outcomes that refer not only to knowledge but also to management of skills and competences [9].

Successful Euratom EFTS - selected on a competitive basis and promoted through the scientific community (detailed information on all projects is available on the European Community R&D Information System (CORDIS and the latest Research Participant Portal [10]) - covered highly relevant E&T needs for industry (energy and non-energy including medical) and associated end-users: ECNET (2011-13), EU-China nuclear cooperation; ENEN-III (2009-13), Generation III and IV engineering training schemes for nuclear systems suppliers and engineering companies; TRASNUSAFE (2010-14) nuclear safety culture in health physics (e.g. ALARA principle applied to both industrial and medical fields); CORONA-II (2015-18) on the creation of a regional center of competence for VVER technology and nuclear applications; CINCH-II (2013-16) cooperation establishing a European MSc in nuclear and radiochemistry; EUTEMPE-RX (2013-16) for Medical Physics Experts in Radiology and focusing on the implementation of the BSS Directive; GENTLE (2013-16) delivering graduate and executive nuclear training and lifelong education with a focus on synergies between industry and academia; NUSHARE (2013-16) on nuclear safety culture competences for policy makers, regulatory authorities and industry; PETRUS III (2013-15) a program for a European RadWaste MSc, E&T research on underground storage addressing mainly radiation waste management agencies; ENEN-RU-II (2014-17), ETKM MSc cooperation with Russia, ROSATOM and MEPhi and VVER technology; and ENETRAP-III (2014-18) MSc in radiological protection addressing mainly nuclear regulatory authorities and TSOs. Some of the above EFTS are developing European Passport (Europass) based on personal transcripts of records and learning outcomes modules obtained through various paths (traditional face-to-face, virtual classroom, training and tutoring, internships, workshops, webinars, on-line or blended learning tools such as e-learning or today’s Massive Open Online Courses (MOOC)). IT technologies are being set to transform today the higher education system, benefitting from the huge capabilities of computer simulations and virtual reality accessible anywhere and at any time, however it will never constitute per se a license of a practice or an official authorization to operate or to supervise nuclear facilities from national nuclear regulatory authorities but complementary IT tools benefits for E&T and KSC management have to be acknowledged.

4. EU/Euratom Human Resource needs, key findings and impacts o RIs

EU/Euratom Support to key research infrastructures has proven to be highly beneficial to the scientific community by facilitating pan-European mobility of researchers, engineers or scientists, enabling transnational access to unique and/or large infrastructures, promoting joint research activities and collaborative efforts across a broad range of nuclear science and technologies covering all fields of Euratom. Increased cooperation in research in Europe is also further benefitting from H2020 cross-cutting support from all EU financial instruments available: ERASMUS+ education and training actions (Master of Sciences MSc, Engineers, Bachelors, Lifelong learning funding schemes across the globe), Marie Slodowska Curie Fellowships (PhDs), European Research Council on ‘Excellent Science’ (ERC), EUROfusion and ITER, JRC ETKM support using its world class laboratories, and the European Institute of Technology Knowledge Innovation Centre (EIT KIC InnoEnergy). The latest promoted a highly successful European Master in Innovation in Nuclear Energy (EMINE) involving major industrial partners AREVA, EDF, ENDESA and VATTENFALL, but also CEA (FR) and universities KTH (SE), University of Catalonia (UPC, ES), INP (Grenoble, FR) and Paris-Saclay (FR) [11].

A publication from EHRO-N in 2012 ‘Putting into Perspective the Supply of and Demand for Nuclear Experts by 2020 within the EU-27 Nuclear Energy Sector’ [12] also confirmed today’s EU challenging gap in covering 50% of nuclear experts training needs by 2020 (estimated at around 2000 a year) due to retirement by then. Faced with the challenge of shortages of skilled professionals, the nuclear fission community has called for a steady upgrade of the level of knowledge, skills and competences while striving to attract a new generation of experts to cover the entire life cycle of new nuclear power plants from design and construction to dismantling and green field. The European Union is urged to speed up implementation of EU Directives emphasizing that each MS (governments together with professional organisations and universities ensuring any adequacy between competences needed and jobs available) shall take the appropriate steps to ensure that sufficient numbers of qualified staff with appropriate education, training and re training are available for all safety-related activities in - or for each - nuclear installation throughout its life.

Research Infrastructures, being large- or small- scale research facilities are essential for reinforcing the competitiveness of Europe’s science base, since they do not only allow for the development of new knowledge but are also essential for training the next generation of top researchers and promote technology transfers between research organizations, academia and industry. As the construction of the next generation of large-scale facilities is increasingly complex and costly, EU Member States together with the European Commission have agreed on the development of a European strategy towards large-scale Research Infrastructures the European scientific community needs to be able to carry out top-level research over the next 5–15 years. The latest 2016 European Strategy Forum on Research Infrastructures roadmap (ESFRI) has identified key RIs mainly in the field of physics and engineering but also energy, health and food, social and cultural innovation including e-infrastructures [13]. Research Infrastructures including e-infrastructures are high-level facilities, providing resources and related services used by the scientific community for conducting leading-edge research to foster knowledge transmission, knowledge exchanges and knowledge preservation.

Today’s Research Infrastructures include major scientific equipment, scientific collections, structured information, ICT-based infrastructures, they are single sited or distributed throughout several countries. Europe is faced with a wide spectrum of issues, from infrastructures which are globally unique to many regionally distributed. Many stakeholders are involved, from ministries to researchers and industry, with an underlying and growing use of e-infrastructures. They are opportunities but also difficulties of interaction between basic research and industry, public and private funding is always lacking, and single countries do not have the critical mass or the dimension to implement large research infrastructures. There is a real need to cooperate on a wide European level and further.

Key findings and impacts of Community actions when networking of RIs is implemented [14] are: (i) on research effectiveness, a) pertinent in relation to the needs of the research community, its objectives and EC funding, b) generating new standards and protocols, c) opening to European and International users, d) allowing access to critically important equipment, e) enhancing inter-disciplinary research, f) increasing speed of end-user access; g) improving standing and visibility of European RIs; (ii) on the European Research Area, a) enabling activities not possible otherwise, b) increasing involvement of researchers from New

Member States and improving RIs in New Member States, c) expanding existing and new research networks, d) developing a European spirit versus national one; (iii) on Human Resources; a) allowing access to the 'best' RIs (evaluation of 7000 user groups) and b) enabling mobility of researchers (other 30.000 people during EU/Euratom 2007-2013 FP7 framework programmes).

5. EU/Euratom Legal and Financial instruments supporting key RIs

Euratom research and training programmes have constantly fulfilled their specific objectives of ensuring availability and best use of research infrastructures of pan-European relevance. The framework programme represents a wide spectrum of facilities covering all aspects: reactor safety (research reactors, irradiation facilities, dedicated loops and mock-ups), lifetime management, development of new reactor types with improved use of resources, advanced closed fuel cycle management, partitioning and transmutation (access to hot laboratories), waste management and geological disposal (mainly underground research laboratories) and radiation protection (irradiation facilities, bio-banks, cohort data). Nuclear research infrastructures support the development of nuclear energy and non-energy applications. They are vital irradiation facilities needed for materials research, but also for production of medical isotopes used for diagnosis, therapy and treatments of most cancers, together with the doping of semi-conductors' enabling a digital revolution through technologies used in our 21st century for our societal needs.

Euratom support to infrastructures has proven to be highly beneficial in all domains with the highest integration achieved for nuclear data, partitioning and safe management of minor actinides. Co-funding was provided to support European and Third country researchers, by integrating activities combined in a closely co-ordinated manner: (i) Networking activities, to foster a culture of co-operation between research infrastructures, scientific communities, industries and other stakeholders as appropriate, and to help develop a more efficient and attractive European Research Area; (ii) Trans-national access or virtual access activities, to support scientific communities in their access to identified key research infrastructures; (iii) Joint research activities, to improve, in quality and/or quantity, the integrated services provided at pan-European and international level by these infrastructures.

EU/Euratom framework programmes consistently co-funded dedicated collaborative 'Research and Innovation' (E&T evaluated at around 5% of the total budget for each projects) and 'Coordination and Support' actions (E&T could be up to 100% of the total budget for each projects). All R&D projects incorporated E&T tasks, workshops focused on R&D progress but also training courses for Higher University MSc and PhD students co-organised in collaboration with industrial and research laboratories. They are usually open to participants from partner institutions outside the project and third countries and coordination support from ENEN is systematically provided to strengthen its international visibility and ensure the highest impact of dissemination and sharing of knowledge among the European scientific community. H2020 European Joint Programmes (EJP) launched are also fostering co-funding and joint programming of activities between the EC and Member States organisations such as EUROfusion launched in September 2014 benefitting from the FuseNet Association, and an EJP in the field of radiation protection in 2015.

Out of a total of 136 FP7 projects co-funded by DG RTD, 14 have supported directly infrastructures (with an EC funding of around EUR 39 million, representing 10% of the overall FP7 Euratom DG RTD fission budget) including 10 Transnational Access to Large Scale Infrastructures (TALI) (EC funding of around EUR 17 million, representing 5% of the overall FP7 Euratom DG RTD fission budget). EU/Euratom Education, Training, Skills and Competences sustainable objectives should thankfully be fulfilled as national and European 'Technological schools' are today evolving successfully towards 'International training platforms' (or Centers of Excellence) e.g. in France, Belgium, Germany, Italy, Sweden or the UK.

As the refurbishment and/or construction of the next generation of large-scale facilities is increasingly complex and costly, Euratom funded in 2010 a study to Deloitte to identify any potential European and/or national ‘financial and legal frameworks and/or mechanisms’ needed. Interviews of the main stakeholders were carried out including EU and Member State ministry representatives, research programme owners and programme managers, research and technical organisations, main industrial representatives and relevant international fora. Key recommendations identified were through support of: (a) EIB loans (Euratom, FP7 Risk Sharing Financial Facility (RSFF), the latest being not applicable to Euratom within FP7 but is applicable to Euratom projects within H2020 InnovFin, or today’s European Fund for Strategic Investment EFSI [15]; (b) tax exemptions of up to 15% of the eligible costs of the project equivalent to EUR 150 million for a project evaluated at EUR 1 billion thanks to a Joint Undertaking legal frame or European Research Infrastructure Consortium (ERIC), the latest being not applicable to Euratom but presenting highly interesting features [16]; (c) EU incentives or grants provided through Cohesion Policy funds and European Development Regional Funds (ERDF) dedicated to the construction of research infrastructures, benefitting smart specialisations and establishment of centres of excellence with additional support from H2020 EU/Euratom framework programmes; (d) Private investors, energy providers or research organisations; (e) National public research organisations; (f) public investments from the hosting country to support infrastructures as a host of any new facility.

Euratom has since ensured a direct support to the construction of a key infrastructure of pan-European interest such as Jules Horowitz Reactor (JHR) in Cadarache, in France. A total financial contribution from EC DG RTD and JRC of EUR 31.5 million has been granted by 2016 and DG JRC is a full member of the JHR consortium. Acting on behalf of Euratom research community, the European Commission has secured ‘Access rights to European researchers’ other a 30 years’ period to JHR operations equivalent to a 5% of the total evaluated irradiation time of this unique research infrastructure. [17]

The European Commission also approved in 2011 ERDF funding support of EUR 5.5 million for the construction of a new research facility in Rez in the Czech Republic hosting today helium and supercritical water research loops. Early 2014, the Czech Republic obtained a further EU ERDF funding support of EUR 85 million (total costs of EUR 100 million) towards their SUStainable ENergy project (SUSEN). Building such a research infrastructure extends their energy research possibilities with emphasis on nuclear technologies at the Research Center of Rez and at the Pilsen University of West Bohemia. It also allows them to act as a relevant research partner within the EC smart specialisation platforms promoted for cooperation in the field of energy with the establishment of partnerships and cooperation with other European research centres. [18]

To further increase the impact of the Euratom fission research programme, financial leveraging support through H2020 InnovFin instrument is promoted from 2017 onwards to foster further coordination, cross-border operation and possible integration of national research investment actions of pan-European interest in the specific field of research. With only a EUR 20 million contribution from Euratom, InnovFin could enable total loan investments of around EUR 240 million by 2020 for building new and/or upgrades of fission research infrastructures (applying InnovFin leverage of around 6 to this financial guarantee provided by EC and matched by EIB) out of a total investment of around EUR 1 billion (if estimated at 20% on average of the overall investment on infrastructures).

One should also highlight the EUROfusion Joint Programme replacing all Euratom/Member States Associations agreements for the 5 years’ period between 2014 and 2018 where an EC grant agreement of around EUR 450 million was provided to implement the latest Fusion roadmap (representing 55% of the total investment and MS providing the remaining 45%). In addition, JET Fusion Tokamak operations, located in Abingdon in Oxfordshire (UK), were also secured until 2018 through a grant agreement of EUR 283 million under Article 10 of the Euratom Treaty, signed on 6 June 2014 between the European Commission and the Culham Centre for Fusion Energy (CCFE). The latest will unfortunately be one of the issue to be solved in the framework of the 2018-2019 Brexit negotiations where JET operations could bridge the respective JET and ITER operations from mid-2020s'.

The European contribution, through the Euratom Joint Undertaking Fusion for Energy (F4E) based in Barcelona in Spain, till 2020 of around of EUR 2.8 billion (which is another order of magnitude as compared to Euratom fission support to infrastructures) is dedicated to the construction of ITER, one of the world's most ambitious research endeavours and an international collaborative project (EU, US, China, Japan, India Russia, South Korea) to demonstrate the potential of nuclear fusion as an energy source.

6. EU/Euratom mapping of key pan-European and International RIs and main priorities [19]

An optimal use of Member States' infrastructures should be vigorously pursued. It is essential to minimise large investment and/or upgrade capital costs, to further improve any cooperation between research facilities, to facilitate trans-national access wherever possible, and to maintain competences in all fields of nuclear sciences.

Euratom mapping of infrastructures elaborated within several FP7 and H2020 projects co-funded by Euratom (detailed information on all projects is available on the European Community R&D Information System CORDIS and the latest Research Participant Portal) is shared within OECD/NEA (Nuclear Energy Agency) Research and Test Facilities Database. RTFDB gives a status of research and test facilities in the field of nuclear science and technology including nuclear data, reactor development, neutron applications, ADS and transmutation systems, fuels, materials, safety, nuclear and radiochemistry research, miscellaneous facilities such as nuclear process heat for hydrogen production, simulation and high-performance computing infrastructures. Mapping of 930 facilities within Europe but also Members of OECD/NEA is available. One of the mandate of OECD/NEA is to keep data banks updated, as a round-check update is usually taking place on a 2 years' basis towards all high-level research organisation representatives, making such data banks highly reliable and useful as they are constantly maintained other time database. An update of the web interface is planned in 2017-2018.

Euratom projects provided updates on infrastructures namely: a) FP7-ADRIANA, H2020-ESNII+ (Gen-IV), NUGENIA+ (Gen-II-III), TALISMAN (Fuel Chemistry and hot laboratories), THINS and SESAME (LWR and Heavy Liquid Metal Thermal-hydraulics); and b) Education and Training projects mostly involving ENEN as coordinator and/or member of a consortium. Taking into account the public health challenge, needs of the nuclear research organisations together with industry, and the strategic importance of Generation-IV reactors developments, a European policy roadmap is encompassing the following European research experimental reactors. Europe can only retain its worldwide leading position if it provides the necessary research infrastructures to maintain the safety and competitiveness in fission technology, to provide long-term waste management solutions, and to substitute ageing facilities OSIRIS in France, the Belgium research reactor (BR2) in Belgium and the High Flux research reactor (HFR) in the Netherlands: a) Jules Horowitz Reactor (JHR), a high performance materials testing research reactor currently being built in France: b) MYRRHA, a flexible irradiation facility supporting Fission/Fusion/radioisotope facility planned in Belgium; and c) PALLAS having the main objective of securing the radioisotope production at European level for medical applications in the Netherlands.

IAEA Department of Nuclear Energy also maintains over 20 Nuclear Energy Databases including nuclear power engineering and technology development, nuclear fuel cycle, research reactor and waste technology, and planning and economic studies, most of them are publicly available.

EC framework programme on infrastructures (complementing Euratom research and training FP) also funded projects in the fields of Physical Sciences and Astronomy, Material sciences and Analytical Facilities, Information Communication Technologies, Energy, Engineering, Life sciences, Social sciences and Humanities, and Environmental Sciences. An interactive map of research infrastructures is available and pan-European research infrastructures listed within the latest ESFRI roadmaps are also shown.

7. EU/Euratom support to sustainable Fast Reactor and closed fuel cycle technologies: from technological workshops and international schools to EU training Centers of Excellence benefitting from the availability of key RIs

The Generation-IV International Forum (GIF) [20] has stimulated innovation towards sustainable nuclear reactor technologies since the year 2001 such as Sodium-cooled Fast Reactor (SFR), Lead-cooled Fast Reactor (LFR), Very High-Temperature Reactor (VHTR), Gas-Cooled Fast Reactor (GFR), Supercritical Water Cooled Reactor (SCWR) and Molten Salt Reactor (MSR). On the basis of an EU Commission Decision, EU/Euratom acceded to GIF by signing in July 2003 the 'Charter of the Generation IV Forum' and the International 'Framework Agreement' existing between all Members of the Generation IV International Forum. The Joint Research Centre (JRC) of the European Commission is the Implementing Agent for EU/Euratom within GIF. In November 2016, EU Commissioner T. Navracsics has signed on behalf of EU/Euratom the agreement to extend for another ten years the Framework Agreement for an International Cooperation on Research and Development of Generation IV Nuclear Energy Systems. EU/Euratom contributions shall also be extended towards all respective six GIF Systems Arrangements as Fast Neutron Reactor systems are considered as key for the deployment of sustainable nuclear fission energy. EU/Euratom framework programmes constantly promote research and training, innovation and demonstration of nuclear fission technologies to achieve EU SET-Plan objectives being: by 2020, (1) to maintain the safety and competitiveness in fission technology, and (2) to provide long-term waste management solutions; and by 2050, (3) to complete the demonstration of a new generation (Gen-IV) of fission reactors with increased sustainability namely via the European Sustainable Nuclear Fission Industrial Initiative (ESNII), and (4) to enlarge nuclear fission applications beyond electricity production through the Nuclear Cogeneration Industrial Initiative (NC2I).

The European Commission has also promoted since 2007 the establishment of technology platforms such as the Sustainable Nuclear Energy Technology Platform (SNETP) gathering today around 100 key stakeholders mainly from research organisations, industry and academia. Its latest 2013 Strategic Research and Innovation Agenda (SRiA) and 2015 Deployment Strategy gave prioritization between all GIF systems to the three most advanced. Sodium Fast Reactor (SFR) is the reference technology since it already has substantial technological and operations feedback in Europe and today's French ASTRID demonstrator lead by CEA is promoted. Lead Fast Reactor (LFR) technology has significantly extended its technological base. It can be considered as the shorter-term alternative technology with support first from MYRRHA (Multi-purpose hYbrid Research Reactor at SCK CEN (BE), a Pb-Bi Accelerator Driven System) and later ALFRED projects. Gas Fast Reactor (GFR) technology is considered to be a longer-term alternative option and ALLEGRO is supported by the Visegrad 4 central European countries (CZ, SK, HU and PL). With innovative emerging technologies fostering increased efficiency, competitiveness and enhanced safety through design, one could expect: a) by 2025, a licensed SMR and/or cogeneration (V)HTR design(s) available in the EU, with operating demonstrator(s) by 2030; and b) by 2030, at least one Gen-IV demonstrator fast reactor in Europe, including associated fuel cycle facilities.

Gen-IV innovative nuclear reactors are very attractive to young students, scientists and engineers engaging in a nuclear career thanks to the related scientific challenges characterized by higher operating temperatures, studies on high temperature materials, corrosion effects, heavy liquid metal thermodynamics, innovative heat exchangers, fast neutron fluxes for both breeding and enhanced burning of long-lived wastes. Development, fabrication and testing of entirely new nuclear fuels, advanced fuel cycles, fuel recycling concepts including partitioning and transmutation are required, all promoting excellent topical opportunities for internships or PhD studies within R&D laboratories. Beyond the obvious educational merit for young engineers investing on average into additional two years' fast reactor studies, scientists and engineers would also have a broader expertise when working on enhanced LWR technology and cross-cutting safety, core physics, engineering and materials areas. Also, a successful Gen-IV design team would highly benefit from 'systemic' and 'interdisciplinary' specialists in the various scientific disciplines involved such as neutronics, thermal-hydraulics, materials science, coolant technologies together with 'assembling' engineers capable to perform optimized integrations of all topical results into 'realistic' reactor components and 'most efficient' balance of plants.

As an illustration, France is providing an important nuclear teaching platform organized around engineering schools, universities, research laboratories, technical schools but also nuclear companies or dedicated entities for professional training. Within this context, the Institut National des Sciences et Technologies Nucléaires (INSTN), with its own Nuclear Engineering Master level (or specialization) degree and a catalogue of more than 200 vocational training courses, is a major nuclear E&T operator in Europe [21].

In Belgium, SCK•CEN Academy for Nuclear Science and Technology was established at the beginning of 2012 benefitting from sixty years of research into peaceful applications of nuclear science and technology, material and fuel research performed today at the BR2 reactor. With such an extensive experience and involvement in the development of an innovative Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA), major nuclear installations and specialist laboratories are available today on site, SCK•CEN is well placed to take on the role of an international education and training platform on Heavy Liquid Metal (Pb-Bi). In addition, IAEA and SCK•CEN Academy have agreed in 2015, CEA-INSTN and SCK•CEN have also signed in September 2016 cooperation framework agreements on E&T.

EU/Euratom Education and Training initiatives are increasingly being organized with the support of the European Commission to the European Nuclear Education Network (ENEN), and within the frame of projects co-funded through the Euratom Framework Programmes. ENEN was established in 2003 as a French non-profit association to preserve and further develop expertise in the nuclear fields through Higher Education and Training. ENEN has currently over 60 members, mainly in Europe but also from Japan, Russia, South Africa, Canada, Ukraine including strengthen cooperation with IAEA. This objective is realized through the co-operation between universities, research organizations, regulatory bodies, industry and any other organizations involved in the application of nuclear science and radiation protection and by fostering students' mobility schemes within Europe and beyond. National and international organizations currently undertaking E&T activities in support to Fast Reactor and closed fuel cycle technologies are all very keen to cooperate and to share their resources, to open key research infrastructures in support to common challenging initiatives to the highest benefit of the entire nuclear community (IAEA initiative on the creation of International Centers of Excellence on Research Reactors (ICERR), OECD/NEA Nuclear Initiative NI2050 and NESTet are very welcome), supporting international mobility of young scientists or researchers and mutual recognition of competences, giving overall a new impetus, high incentives and perspectives for E&T within Europe and beyond.

8. EU/Euratom research perspectives and outreach

The 'Euratom experience' with the Framework Programmes has been one of consistent success in pursuing excellence in research and facilitating pan-European collaborative efforts across a broad range of nuclear science and technologies including nuclear safety, safeguards and security within EU and non-EU countries. Associated education and training activities are in line with Horizon 2020's key priorities, excellent science, industrial leadership, and societal challenges, one of the latter being the secure, clean and competitive energy challenge for Europe in the context of the Energy Union.

Nuclear ‘Research and Innovation and Demonstration’ needs a policy-driven programmatic approach, to meet the strategic objectives of EU 2020/2030/2050/COP21/COP22 Energy and Climate policies. Lack of coordinated research leads to national or bilateral programmes in countries with large capabilities, threatening smaller countries with scientific isolation and loss of expertise. In nuclear medical applications, proliferation vigilance and waste management, non-participating countries risk to become second-class.

In contrast to earlier approaches characterised by a bottom-up projects’ selection on a competitive basis and their following implementation, future nuclear R&D should be policy driven. A programmatic approach involving all relevant stakeholders and fora at an early stage - rather than a project approach - should be called for, to meet the strategic objectives of EU energy and climate policies: sustainability, security of supply and competitiveness for a future low-carbon economy. EU energy R&D should satisfy all three policy pillars simultaneously, in a coordinated and output oriented manner. This type of structured R&D organisation should nevertheless not exclude some funding being reserved for good ideas by small research groups (technology watch), since creative solutions often emerge from unexpected initiatives.

National laws and EU Directives should play a bigger role in the organisation of research and training (typically through a roadmap, deployment strategies and priorities), with national organisations (e.g. for nuclear waste management) taking the lead in R&D programmes which should be coordinated at the EU level.

It seems appropriate to use different partnerships for collaboration depending on the subjects treated. Public/public partnerships between the European Commission and EU Members States remain crucial to long term R&D (especially infrastructures, demonstration and prototype plants, and basic nuclear education, training, skills and competences) and to societal R&D (such as external costs and radiation protection). In contrast, public-private partnerships are more appropriate for short-term work (design and operation of reactors and waste facilities, regulation, procedures and practical training). For management and operation of large infrastructures of common interest, legal schemes such as a joint technological initiative or European research consortiums should be considered. In addition, use of all H2020 funding instruments available should be capitalised together with the KIC InnoEnergy of the EU's European Institute of Innovation and Technology, and where needed, of EU structural funds in combination with H2020.

Instruments used so far for Euratom fission research are well suited for leveraging R&D activities of high European added value in nuclear safety, radiation protection, and geological disposal. Completion of the European Research Area should lead to increased cooperation in research in Europe to ensure there is an effective ‘critical mass’ of research effort in key fields, the creation of ‘centres of excellence’, greater emphasis on competitiveness and public/private partnerships, increased support for research infrastructures and the exploitation and management of knowledge which contributes to maintaining high levels of knowledge and competitiveness of industry in the nuclear fields.

All EU stakeholders, from policy-makers, academia, research organisations, regulators, and industry are unanimous in stating that ‘a common pan European approach is the way forward’, benefitting from EFTS, ECTS and ECVET in combination to ‘Open Access to key or world class infrastructures’. For the funding of education and training, beyond the usual programmes in schools and universities, creative instruments could be envisaged. For example, should the minimal educational and training be better specified within national law or by a Euratom Directive? Also, it could maybe be reasonable to set up a common education and training fund jointly managed by the European Commission and Member States and, similarly to the funds for waste management, financed by a mandatory levy on nuclear generators based on nuclear MWh produced if we wish to ensure the meeting of all challenging targets.

References

[1] European Energy Strategy: Secure, competitive, and sustainable energy http://ec.europa.eu/energy/en/topics/energy-strategy

[2] EU/Euratom legislative framework http://ec.europa.eu/energy/en/topics/nuclear-energy

[3] Horizon 2020 European Research Framework Programmes http://ec.europa.eu/research/horizon2020/index_en.cfm http://ec.europa.eu/programmes/horizon2020/h2020-sections

[4] European Commission Departments (Directorates-General) and services http://ec.europa.eu/about/ds_en.htm

[5] European Technology Platforms (ETPs) http://cordis.europa.eu/technology-platforms/
SNETP Sustainable Nuclear Energy Technology Platform http://www.snetp.eu/
IGDTP Implementing Geological Disposal of Radioactive Waste http://www.igdtp.eu/
MELODI Multi-disciplinary European Low Dose Initiative http://www.melodi-online.eu/

[6] Strategic Energy Technology Plan (SET-Plan) http://ec.europa.eu/energy/technology/set_plan/set_plan_en.htm
EERA European Energy Research Alliance https://www.eera-set.eu/

[7] Independent authoritative expert body with regulatory backgrounds for the stress tests
ENSREG European Nuclear Safety Regulator Group http://ec.europa.eu/energy/nuclear/ensreg/ensreg_en.htm
ENEF European Nuclear Forum Energy http://ec.europa.eu/energy/nuclear/forum/forum_en.htm

[8] OECD/NEA Nuclear Energy Agency http://www.oecd-nea.org/
GIF Generation-IV International Forum http://www.gen-4.org/
IAEA International Atomic Energy Agency http://www.iaea.org/

[9] Bologna Process in 1999 http://ec.europa.eu/education/policies/educ/bologna/bologna_en.html
Copenhagen Declaration in 2002 http://ec.europa.eu/education/lifelong-learning-policy/ecvet_en.htm
ECVET European Credit System for Vocational Education and Training http://www.ecvet-team.eu/

[10] CORDIS, European Community Research and Development Information Service http://cordis.europa.eu/home_en.html EU Participant Portal http://ec.europa.eu/research/participants/portal/desktop/en/home.html

[11] EIT KIC InnoEnergy MSc EMINE – European Master in Nuclear Energy http://www.innoenergy.com/education/master-school/msc-emine-european-master-in-nuclear-energy/
ERC European Research Council https://erc.europa.eu/ and FP7 Scientists create 'trophy molecule' that could revolutionise nuclear industry http://cordis.europa.eu/fetch?CALLER=EN_NEWS&ACTION=D&SESSION=&RCN=34791
DG EAC (Education, Audiovisual and Culture Executive Agency) ERASMUS+ http://ec.europa.eu/programmes/erasmus-plus/ and EUJEP-1and-2 projects Post-Fukushima European Japanese Exchange Project in Nuclear Education and Training http://www.enen-assoc.org/en/training/eujep-21/eujep-21.html
EUROfusion https://www.euro-fusion.org/ , ITER http://www.iter.org/ and JET Tokamak http://www.ccfe.ac.uk/JET.aspx

[12] EHRO-N, European Human Resources Observatory for the Nuclear sector, Perspective report http://ehron.jrc.ec.europa.eu/sites/ehron/files/documents/public/ehro-n_putting_into_perspective_report_2012_05_25_0.pdf

[13] EC framework programme on infrastructures (complementary to Euratom FP) http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=mapri
Pan-European research infrastructures that are also listed within the ESFRI roadmap of 2010 http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=mapri_european

[14] Evaluation of pertinence and impact of the EU research infrastructure activity in FP7 https://ec.europa.eu/digital-single-market/en/news/evaluation-pertinence-and-impact-research-infrastructure-activity-fp7-epiria-smart-20120045

[15] 2010 Deloitte study on the funding of ESNII industrial initiative http://cordis.europa.eu/pub/fp7/euratom-fission/docs/deloitte-gen4-022010-full-report.pdf
European Investment Bank EIB http://www.eib.org/
EIB RSFF InnovFin http://www.eib.org/products/blending/innovfin/index.htm
EIB EFSI European Fund for Strategic Investments http://www.eib.org/efsi/

[16] European Research Infrastructure Consortium (ERIC) legal framework http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=eric

[17] JHR Jules Horowitz Reactor http://www-rjh.cea.fr/general-description.html

[18] EU Regional Policy, European Regional Development Fund ERDF http://ec.europa.eu/regional_policy/en/funding/erdf/
The Sustainable Energy Project (SUStainable ENergy, SUSEN) project http://susen2020.cz/en/
EC JRC Smart Specialisation Platform http://s3platform.jrc.ec.europa.eu/

[19] OECD/NEA (Nuclear Energy Agency) Research and Test Facilities Database (RTFDB), http://www.oecd-nea.org/rtfdb/
IAEA Department of Nuclear Energy maintains over 20 Nuclear Energy Databases in its areas of activities . http://www.iaea.org/OurWork/ST/NE/Main/databases.html
ADRIANA final report ftp://ftp.cordis.europa.eu/pub/fp7/euratom-fission/docs/adriana-final-report_en.pdf

[20] GIF Generation-IV International Forum Progress in Nuclear Energy, volume 77 http://www.sciencedirect.com/science/journal/01491970/77
GIF Annual reports https://www.gen-4.org/gif/jcms/c_44720/annual-reports

[21] INSTN, Institut National des Sciences et Technologies Nucléaires http://www-instn.cea.fr
I2EN, the International Institute for Nuclear Energy http://www.i2en.fr
SCK•CEN Academy for Nuclear Science and Technology http://www.sckcen.be/en/Education_training/SCKCEN_academy
ENEN European Nuclear Education Network Association http://www.enen-assoc.org
FR13 Conference Proceedings held in Paris, France, from 4 to 7 March 2013 http://www-pub.iaea.org/books/IAEABooks/10682/Fast-Reactors-and-Related-Fuel-Cycles-Safe-Technologies-and-Sustainable-Scenarios-FR13-Proceedings-of-an-International-Conference-on-Fast-Reactors-and-Related-Fuel-Cycles-Paris-France-4-7-March-2013