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REVIEW ARTICLE

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JRC in Euratom Research and Training Programme – 2014–2020

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Abstract. The Euratom Research and Training Programme 2014–2018 and its extension 2019–2020 (the Euratom Programme) is implemented through direct actions in fission – i.e. research performed by the Commission's Joint Research Centre (JRC), and through indirect actions in fission– i.e. via competitive calls for proposals, and in fusion – i.e. through a comprehensive named-beneficiary co-fund action managed by the Commission's Directorate-General for Research & Innovation (RTD). The general objective of the Programme is "to pursue nuclear research and training activities with an emphasis on the continuous improvement of nuclear safety, security and radiation protection, in particular to potentially contribute to the long-term decarbonisation of the energy system in a safe, efficient and secure way." The Programme is an integral part of Horizon 2020, the EU Framework Programme for Research and Innovation. The direct actions implemented by the JRC constitute an important part of the Euratom Programme and pursue specific objectives covering: nuclear safety, radioactive waste management, decommissioning, emergency preparedness; nuclear security, safeguards and non-proliferation; standardisation; knowledge management; education and training; and support to the policy of the Union on these fields. The JRC multi-annual work programme for nuclear activities fully reflects the aforementioned objectives. It is structured in about 20 projects, and allocates 48% of its resources to nuclear safety, waste management, decommissioning and emergency preparedness, 33% to nuclear security, safeguards and non-proliferation, 12% to reference standards, nuclear science and non-energy applications and 7% to education, training and knowledge management. To ensure that direct actions are in line with and complement the research and training needs of Member States, JRC is continuously interacting with the main research and scientific institutions in the EU, and actively participating in several technological platforms and associations. JRC also participates as part of the consortia in indirect actions, which allows JRC scientist to engage in top level scientific research, and yields maintaining and further developing JRC's scientific excellence. At the same time, the members of the consortia can have access to unique research infrastructure. The participation of JRC in indirect actions can be improved by exploiting synergies inside the Euratom Programme, and also with the future Horizon Europe Framework Programme. In preparation of the next Euratom Programme 2021–2025, two pilot projects on knowledge management and on open access to JRC research infrastructure will explore and test this improved involvement of JRC in indirect actions. The paper highlights some of the achievements of recent JRC direct actions with a focus on the interaction with EU MS research organisations, as well as some of the most important elements of the Commission Proposal for the next (2021–2025) Euratom Programme, with a focus on the new positioning of the JRC as regards its participation in indirect actions.

1 Introduction

Currently, fourteen Member States operate around 130 nuclear power reactors to generate over 25% of all electricity consumed in the EU, contributing to competitiveness, security of energy supply and limitation of CO_2 emissions as part of the European Union energy and climate policy objectives. Regardless of the individual decisions on continuing, phasing out or embarking in new built nuclear power plants, nuclear energy will continue to be part of the energy mix in the European Union for the next decades. Indeed, in recent Communications on the Energy Union and on the European long-term vision for a prosperous, modern competitive and climate neutral economy, the European Commission recognises nuclear energy as an important player to achieve, together with renewable sources, a carbon-free European energy system. Worldwide, about 450 nuclear power plants are in operation and around 50 more are under construction; several of them in EU neighbouring countries.

To ensure the highest levels of nuclear safety and security, the European Union needs to be at the forefront not only in the development and implementation of the

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most advance legislation at regional level, with the Euratom Directives on Nuclear Safety (2009 [1], amended in 2014 [2]), Safe and Responsible Management of Radioactive Waste and Spent Fuel [3] (2011), and the Basic Safety Standards [4] (2013), but also promoting nuclear research and training. Indeed, nuclear research and training is a key factor to help the European Union maintain the scientific and technological leadership in nuclear technologies, also in non-power applications.

The Euratom Treaty [5] establishes that the Commission is responsible for promoting and facilitating nuclear research in the Member States and for complementing it by carrying out a Community research and training programme. These programmes are proposed by the European Commission, and are discussed and adopted by unanimity in the Council. The programmes are funded by the budget of the Community.

2 The Euratom Research and Training Programme

The Euratom Research and Training Programme 2014–2018 [6] and its extension 2019–2020 [7] (the Euratom Programme) is implemented through so called indirect and direct actions. Indirect actions are research activities carried out by consortia of research institutions from EU Member States and associated countries partially funded by the research budget of the European Union. Research focuses in nuclear fission (via competitive calls for proposals), and in nuclear fusion (through a comprehensive named-beneficiary co-fund actions). Direct actions are research activities in nuclear fission carried out by the European Commission's Joint Research Centre (JRC).

The overall objective of the Programme currently in force is "to pursue nuclear research and training activities with an emphasis on the continuous improvement of nuclear safety, security and radiation protection, in particular to potentially contribute to the long-term decarbonisation of the energy system in a safe, efficient and secure way."

The Programme also sets specific objectives for both indirect and direct actions. Specific objectives of the indirect actions encompass:
– supporting the safety of nuclear systems;
– contributing to the development of safe, longer-term solutions for the management of ultimate nuclear waste, including final geological disposal as well as partitioning and transmutation;
– supporting the development and sustainability of nuclear expertise and excellence in the Union;
– supporting radiation protection and the development of medical applications of radiation, including, inter alia, the secure and safe supply and use of radioisotopes;
– moving towards demonstrating the feasibility of fusion as a power source by exploiting existing and future fusion facilities;
– laying the foundations for future fusion power plants by developing materials, technologies and conceptual design; and
– promoting innovation and industrial competitiveness;
– ensuring the availability and use of research infrastructures of pan-European relevance.

The direct actions implemented by the JRC constitute an important part of the Euratom Programme and pursue specific objectives covering:
– improving nuclear safety, including: nuclear reactor and fuel safety, waste management, including final geological disposal as well as partitioning and transmutation; decommissioning, and emergency preparedness;
– improving nuclear security, including: nuclear safeguards, non-proliferation, combating illicit trafficking, and nuclear forensics;
– increasing excellence in the nuclear science base for standardisation;
– fostering knowledge management, education and training; and
– supporting the policy of the Union on nuclear safety and security.

The Programme is an integral part of Horizon 2020, the EU Framework Programme for Research and Innovation.

The extension of the Euratom Research and Training Programme for 2019–2020 was adopted on 15 October, 2019. The adopted extension carry over the activities of the 2014–2018 Programme, keeping the same strategy, scope and mode of implementation, introducing as well the recommendations of the interim evaluation of the 2014–2018 Programme issued by a team of reputed international experts.

The recommendations for the JRC were to reinforce its education and training activities; improve communication and reach-out; introduce project management culture in the work programme; ensure a more efficient management or resources; proof that JRC is cost effective; integrate a coherent direct/indirect actions programme; and pursue synergies between the nuclear and the non-nuclear activities.

The implementation of the programme will therefore continue the activities in education and training, reinforce knowledge management, increase the synergies between nuclear and non-nuclear research in the field of nuclear science applications, and improve open access to scientists to JRC research infrastructure.

The budget for the extension rises up to €770.2 million, with €268.8 million for direct actions to be carried out by JRC.

It is clear that most of the challenges and research needs of the current programme will remain for the EU from 2021 onwards. Thus, the Commission proposal for the next framework programme, the Euratom Research and Training Programme 2021–2025 [8] complementing Horizon Europe will need to focus in nuclear safety, security, radioactive waste and spent fuel management, radiation protection and fusion. The programme will expand research into non-power applications of ionising radiation, and make further improvements in the areas of education, training and access to research infrastructure.

Horizon Europe is the most ambitious framework programme for research and innovation ever. The proposed budget for 2021 to 2027 is €100 billion including €2.4 billion

Fig. 1. European Commission's Joint Research Centre sites.

for the Euratom Research and Training Programme. For 2021 to 2025, 619 M€ (out of the 1.6 b€ for Euratom) are for Direct Actions undertaken by JRC.

The proposal of the Commission establishes a common set of objectives for the Direct and Indirect Actions, in order to better streamline the research activities, and allow the combination of instruments and assets, such as JRC's research infrastructure and knowledge base.

The proposal has two general objectives:

– to pursue nuclear research and training activities to support continuous improvement of nuclear safety, security and radiation protection;
– to potentially contribute to the long-term decarbonisation of the energy system in a safe, efficient and secure way.

As well as four specific objectives:

– improve the safe and secure use of nuclear energy and non-power applications of ionizing radiation, including nuclear safety, security, safeguards, radiation protection, safe spent fuel and radioactive waste management and decommissioning;
– maintain and further develop expertise and competence in the Community;
– foster the development of fusion energy and contribute to the implementation of the fusion roadmap; and
– support the policy of the Community on nuclear safety, safeguards and security.

The proposal also includes a focus on non-power applications for medical and industrial use which are clear synergies with Horizon Europe and opens Marie Skłodowska-Curie Actions to nuclear researchers (Fig. 1).

3 European Commission's Joint Research Centre

The Joint Research Centre is the European Commission's science and knowledge service. It employs scientists to carry out research in order to provide independent scientific advice and support to EU policy in areas such as agriculture, food security, environment, climate change, innovation, growth, as well as in nuclear safety and security.

The JRC creates, manages and makes sense of knowledge and anticipates emerging issues that need to be addressed at EU level. It develops innovative tools and makes them available to policy-makers. It explores new and emerging areas of science and hosts specialist laboratories and unique research facilities. Its scientific results are highly ranked by international peer systems.

Established as a Joint Nuclear Research Centre by Article 8 of the Euratom Treaty [9], the JRC draws on 60 years of scientific experience and continually builds its expertise, sharing know-how with EU countries, the scientific community and international partners. With time, the JRC broadened its field of research to non-nuclear disciplines, which now cover around 75% of its entire activities. It works together with over a thousand organisations worldwide in more than 150 networks whose scientists have access to JRC facilities through various collaboration agreements.

The JRC is organised in Directorates, one with corporate responsibilities for strategy, work programme coordination and resources; and one support services. Six scientific directorates dealing with growth and innovation; energy, transport and climate; sustainable resources; space, security and migration; health, consumers and reference materials; and nuclear safety and security. And two cross-JRC directorates dealing with knowledge management and competences. The JRC directorates are spread across six sites in five European Union Member States: Brussels and Geel in Belgium, Petten in The Netherlands, Karlsruhe in Germany, Ispra in Italy, and Sevilla in Spain.

3.1 JRC research and training in nuclear safety and security

The Directorate for Nuclear Safety and Security employs around 500 scientists, technicians and administrative staff in in Petten, Karlsruhe, Geel and Ispra.

The JRC multi-annual work programme for nuclear activities fully reflects the objectives of the Euratom Research and Training Programme. It is structured in about 20 projects, and allocates approximately 48% of its resources to nuclear safety, waste management, decommissioning and emergency preparedness, 33% to nuclear security, safeguards and non-proliferation, 12% to reference standards, nuclear science and non-energy applications and 7% to education, training and knowledge management.

To ensure that direct actions are in line with and complement the research and training needs of Member States, JRC is continuously interacting with the main research and scientific institutions in the EU, and actively participating in several technological platforms and associations. In a few cases, JRC also participates as part of the consortia in indirect actions, which allows JRC scientist to engage in top level scientific research, maintaining and further developing JRC's scientific excellence. At the same time, the members of the consortia can have access to unique research infrastructure.

Without being exhaustive, the JRC's most relevant activities in the nuclear domain encompass, in nuclear safety, research in advanced mechanical tests methods to address creep fatigue or stress corrosion cracking at high temperatures in corrosive environments, such as supercritical water and liquid metals; research in severe accident modelling and analysis with computer codes such as the European software system ASTEC and others. The JRC operates the EU Clearinghouse on Operating Experience Feedback, a regional network constituted by the JRC, nuclear safety regulatory authorities, technical support organisations, and international organisations that aim at enhancing nuclear safety through further use of lessons learned from Operating Experience. Another key activity is the development, operation and maintenance of EURDEP, EU system for almost real-time monitoring of radioactivity in the environment, and support to ECURIE, which is the technical interface of the EU early notification and information exchange system for radiological emergencies.

JRC also carries out research in safety of the nuclear fuel cycle, at in-core, storage and disposal, and under normal, abnormal and accidental conditions. JRC developed and further improves and maintains the TRANSURANUS computer code, which is a widely used independent computer code for fuel performance analysis. JRC research is not limited to current nuclear fuels, but also to advanced and innovative designs. Complementing its European partners, JRC carries out research on safety and safeguards aspects of Generation IV reactors [10].

In the area of radioactive waste management, JRC focuses in non-destructive analyses techniques for the characterisation of waste packages; standardisation of free release measurements, development of novel techniques for mapping contamination, and for decontamination in high activity environments, methods for hard to measure nuclides, etc.

JRC activities in the field of nuclear security and safeguards focuses in four main areas: effective and efficient safeguards (through research in, e.g. nuclear material measurements, containment and surveillance, process monitoring and on-site laboratories), verification of absence of undeclared activities (through e.g. trace and particle analysis, and development of in-field tools), nuclear non-proliferation (through e.g. export control, trade analysis, and studies) and combating illicit trafficking (through, e.g. equipment development, testing, and validation, nuclear forensics, preparedness plans).

In standardisation, the JRC is very active, and is a reference entity in reference measurements and data; basic and pre-normative research; and inter-laboratory comparisons. The JRC develops materials standards, and manufactures reference materials. JRC is a major European provider of nuclear data and standards for nuclear energy applications, due to its experienced and competent staff and unique scientific infrastructure. The main repositories for these data are the databases of Nuclear Data bank of the NEA-OECD and the IAEA, which provide open access to the data to scientific and engineers.

JRC has relevant research activities in the field of nuclear science applications, such as accelerator-based nuclear measurements, basic properties of radionuclides and associated applications, including supporting the authentication and preservation of cultural heritage and archaeological studies, use of tracers for climate modelling, nuclear medicine, such as targeted alpha-immunotherapy, food fraud detection, and space applications.

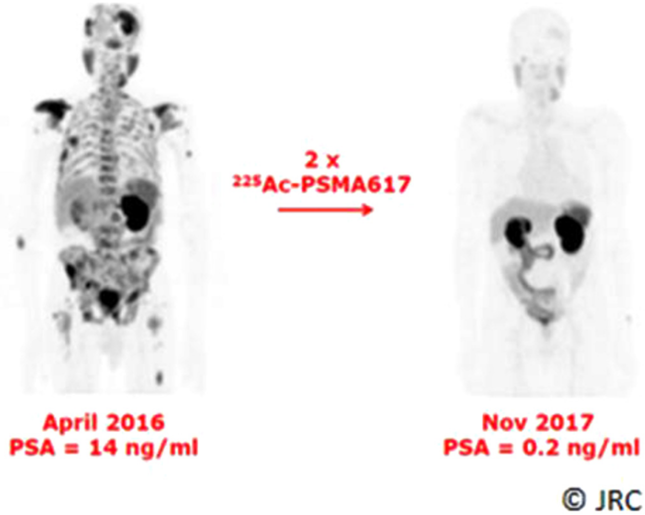

Fig. 2. Targeted alpha-immunotherapy.

JRC activities in knowledge management, education and training include organisation and active participation in expert and scientific conferences, and the participation, preparation and implementation of education and training initiatives such as the European Nuclear Security Training Centre (EUSECTRA), European Safeguards Research and Development Association (ESARDA), education and training of Euratom and IAEA nuclear inspectors, European Learning Initiatives in Nuclear Decommissioning and Environmental Remediation (ELINDER), international summer schools in radioactive waste management and decommissioning, nuclear resonance analysis, radionuclides, as well as a number of other education and training courses in nuclear safety, security, nuclear data, etc (Fig. 2).

3.2 JRC nuclear research infrastructure

The nuclear research experimental facilities of the JRC are distributed in the sites of Geel (Belgium), Petten (the Netherlands), Karlsruhe (Germany) and Ispra (Italy).

JRC-Geel research infrastructure mainly focuses in nuclear data, radioactivity metrology, and nuclear reference materials:

- The neutron time-of-flight linear accelerator (GELINA) is a pulse white spectrum neutron source with the best time resolution in the world. It is a multi-user facility serving up to 12 different experiments simultaneously. GELINA combines four specially designed and distinct units: a high-power pulsed linear electron accelerator, a post-accelerating beam compression magnet system, a mercury-cooled uranium target, and very long (up to 400 m) flight paths.
- The tandem accelerator based fast neutron source (MONNET) is a 3.5 MV electrostatic accelerator for the production of continuous and pulsed proton-, deuteron- and helium ion beams. The combination of both facilities GELINA and MONNET makes JRC-Geel one of the few laboratories in the world which is capable of producing the required accuracy for neutron data needed for the safety assessments of present-day and innovative nuclear energy systems.
- Radionuclide metrology laboratories: a cluster of instruments for high precision radioactivity measurements (RADMET laboratories) and the high activity disposal experimental site (HADES): Laboratory for ultra-sensitive radioactivity measurements 225 m deep underground at the premises of the Belgian nuclear institute SCK.CEN.

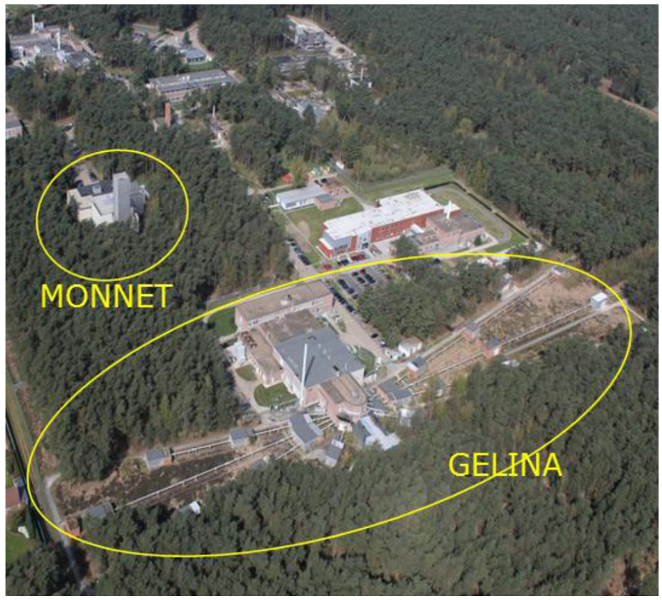

Fig. 3. Accelerators for nuclear data measurements in JRC-Geel.

Nuclear reference materials laboratories for the preparation and provision of certified nuclear reference materials and reference measurements (METRO) and well-defined and well-characterised samples for nuclear data measurements (TARGET). The nuclear reference materials laboratories encompass mass spectrometry equipment, chemical sample preparation equipment in glove boxes, substitution weighing equipment in glove boxes, robot systems for dispensing of radioactive solutions, equipment for production of reference particles and UF6 reference measurements (Fig. 3).

JRC-Petten hosts and operates laboratories for the assessment of materials and components performance under thermo-mechanical loading, corrosion, and neutron irradiation:

- The high flux reactor (HFR, owned by JRC but operated by the Dutch company NRG) is one of the most powerful multi-purpose materials testing research reactors in the world. The HFR is a tank in pool type light water-cooled and moderated and operated at 45 MW. The reactor provides a variety of irradiation facilities and possibilities in the reactor core, in the reflector region and in the poolside facility, as well as neutron beams.
- The laboratory for the ageing of materials in light water reactor (LWR) environments (AMALIA) is a laboratory

for aqueous corrosion and stress corrosion cracking investigations, a unique facility encompassing four recirculating water loops with 6 autoclave systems, all featuring full water chemistry control. The autoclaves ($T_{\max} = 650\,°C$, $P_{\max} = 360$ bar) are equipped with environmental mechanical testing facilities (slow strain-rate tensile tests, crack initiation and crack growth rate tests, fracture mechanics, cone-mandrel tests, small-punch tests), electrochemistry, electric impedance, DC potential drop, and acoustic emission monitoring, to assess coolant compatibility and materials degradation issues in light water reactor environments. The autoclave systems with mechanical test rigs are unique in their high temperature capabilities and in that they feature proprietary bellows-based pneumatic test control.
- The Structural Materials Performance Assessment laboratories (SMPA) are used for the mechanical performance characterisation, life assessment and qualification of structural materials for present and next generation nuclear systems. The test installations include 3 servo-hydraulic and 3 electro-mechanical universal test machines for (thermo-)mechanical tests, low-cycle fatigue, and fracture mechanics tests, 11 uniaxial creep rigs, 5 small-punch creep rigs, 2 Charpy test rigs, a dedicated test rig for thermal fatigue tests of tubular components, and a nano-indentation hardness tester (−150 °C to + 700 °C). Depending on the application, temperature control ranges from cryogenic (liquid nitrogen) to high temperatures (induction heaters, radiation heaters and resistance furnaces).
- The Microstructural Analysis Infrastructure Sharing laboratory (MAIS) is a user lab for microstructural characterisation and materials degradation studies. The facilities include scanning electron microscopy, transmission electron microscopy and atomic force microscopy (AFM), optical microscopy, metallography, 3D X-ray computed tomography with comprehensive image analysis and defect visualization capabilities for cracks, creep damage, grain boundary decohesion, dimensional analysis etc., X-ray diffraction, 3D profilometer, thermo-electric power and Barkhausen noise measurements (Fig. 4).

Fig. 4. AMALIA laboratory.

Karlsruhe mainly focuses in properties of irradiated and non-irradiated nuclear materials, as well as research in fuel, fuel cycle, radioactive waste, security and safeguards. The Karlsruhe site has two nuclear licenses, one collective for the wings A, F and G, in which glove box work with radioactive materials is performed, and one for wing B, the hot cell wing for handling irradiated materials.

- Fuels and materials synthesis and characterisation facility (FMSC): The facility comprises 3 shielded glovebox chains for U/Th, Pu and Am bearing samples respectively for the synthesis and characterisation of actinide materials, including nuclear fuels.
- Hot cells (HC): 24 hot cells with different capabilities for irradiated fuels, cladding and nuclear material detailed scientific investigations covering all aspects related to the safety of nuclear fuels during irradiation under normal and accident conditions, such as non-destructive examinations, destructive physical analyses: structure and microstructure, morphology, fission products and phase distribution and properties; high temperature behaviour during severe accidents; mechanical characterization. Destructive nuclear chemistry tests: dissolution, inventory/burnup determination; separation using aqueous and pyrometallurgy routes; leaching and corrosion behaviour for waste management/disposal studies.
- Materials research laboratories (MRL): Series of unique, mostly home-built experimental installations dedicated to the study of thermodynamic and thermo-physical properties of actinides and nuclear materials.
- Nuclear trace and analyses facility (NTA): Set of installations for the chemical, physical and spectroscopic analysis of actinide and nuclear materials. It encompasses 25 glove boxes, mass spectrometers, titration chain, element analysis, chemical separations, gamma spectrometers, alpha spectrometers, calorimeter, neutron counters and Hybrid K-edge detectors.
- Fundamental properties of actinide materials under extreme conditions (PAMEC): State-of-the-art installations designed for basic research on behaviour and properties of actinide materials under extreme conditions of temperature, pressure, external magnetic field and chemical environment. Surface science laboratory for synthesis, structural, and spectroscopic characterisation of model nuclear materials. The facility includes devices for measurements of crystallographic, magnetic, electrical transport, and thermodynamic properties as well as facilities for Np-237 Mössbauer spectroscopy, and a modular surface science spectroscopy station allowing photoemission, atomic force microscopy, and electron scattering measurements.
- EUSECTRA offers a unique combination of scientific expertise, specific technical infrastructure and availability of a wide range of nuclear materials, to enable unparalleled training opportunities in the field of nuclear security and safeguards. Training areas for EUSECTRA include border detection, train-the-trainers, mobile emergency response (i.e., MEST), reach-back, creation of national response plans, nuclear forensics, radiological crime scene manage-

Fig. 5. JRC hot-cells.

ment, nuclear security awareness and sustainability of a national nuclear security posture. It is based on the JRC facilities at the Ipsra and Karlsruhe sites.
- The large geometry secondary ion mass spectrometry laboratory (LG-SIMS) laboratory is equipped with a highly sensitive mass spectrometer to detect trace quantities of uranium/plutonium in micron-sized particles collected for safeguards purposes.

A new laboratory building, known as wing M, which will contain laboratories involving the handling of significant amounts of radioactive materials is currently being constructed on site. Activities currently distributed among several hot laboratories of JRC Karlsruhe will be transferred into the new dedicated lab (Fig. 5).

JRC-Ispra carries out research in safeguards and security:
- Laser laboratory for nuclear safeguards and security: Laser based systems to carry out containment and surveillance techniques for nuclear safeguards, including fingerprinting of nuclear containers, change detection, design information verification systems and outdoor verification systems (Fig. 6).
- Advanced safeguards, measurement, monitoring and modelling laboratory (AS3ML): Laboratory to measure nuclear material, to monitor the operation of facilities through an extensive collection of data from multiple types of sensors, and to model the plant operations in order to be able to analyse the data collected by the monitoring system. AS3ML is thus used for testing and developing innovative integrated solutions for the implementation of safeguards in the different types of nuclear installations.
- Performance laboratory/Pulse neutron interrogation test assembly (PERLA/PUNITA): Laboratory for the assessment and evaluation of performances for all non-destructive assay (NDA) techniques applied in the safeguards of nuclear materials. PUNITA incorporates a pulsed (D-T) neutron generator.

Fig. 6. Nuclear facilities verification laboratory.

- Tank measurement laboratory/Solution monitoring laboratory (TAME/SML): Bulk handling facilities, which proposes challenges to the performances of inventory quantification and density characterisation.
- Sealing and identification laboratory (SILab): Laboratory for the development, testing and commissioning of security systems used for nuclear and commercial applications.
- Illicit Trafficking Radiation Assessment Programme (ITRAP). The facility is dedicated to perform tests on radiological performances of radiation detection equipment used in nuclear security. It is composed by two laboratories: the static test lab for handheld equipment and the dynamic test lab for portals (Fig. 7).

3.3 Decommissioning and Radioactive Waste Management Programme

The Commission's Joint Research Centre (JRC) owns nuclear research installations in four sites: JRC-Geel in Belgium, JRC-Karlsruhe in Germany, JRC-Ispra in Italy and JRC-Petten in the Netherlands. As nuclear operator and/or owner under Belgian, Dutch, German and Italian laws, the JRC is responsible for the decommissioning of these installations and for the responsible and safe management from generation to disposal of the resulting spent fuel and radioactive waste.

The JRC's Decommissioning and Waste Management Programme [11] launched in 1999 details all the activities that the JRC plans and carries out for the safe decommissioning and dismantling of its obsolete facilities (historical liabilities) and the integration of the decommissioning and dismantling plans of its still operational nuclear research facilities (future liabilities). The programme also covers the management of the historical

Fig. 7. European Nuclear Security Training Centre (EUSECTRA).

Fig. 8. Tomography of waste drums in the characterisation/clearance stage. JRC-Ispra.

radioactive waste and the waste arising from the decommissioning and dismantling activities of the programme up to the disposal of all radioactive waste and unconditional release of the sites.

The scope of the programme includes a variety of installations, ranging from research reactors to hot cells, accelerators, laboratories and other facilities where radioactive substances were and are handled. It also aims to treat "historical" waste and waste arising from the dismantling operations as well as management of nuclear materials used for research during operation of the installation. The Commission issues a Communication to the Council and European Parliament on the progress of the D&WM Programme every four years (2004 [12], 2008 [13], and 2013 [14]).

In 2018, the Commission proposed a Council Regulation [15] to establish a common instrument to address the decommissioning of nuclear facilities of the Kozloduy nuclear power plant units 1-4 (Kozloduy, Bulgaria), the Bohunice V1 nuclear power plant (Jaslovské Bohunice, Slovakia), and the JRC nuclear facilities and the management of the arising waste, in order to to optimise synergies and bring added value through becoming a benchmark within the EU for safely managing technological issues in nuclear decommissioning and disseminating knowledge to Member States (Fig. 8).

3.4 International cooperation and support to EU policies

Along the years, JRC has concluded and maintained agreements of different nature (e.g. Memoranda of Understanding, Collaboration Agreements and others) with relevant research institutions within EU Member States, through which joint projects in nuclear research are being carried out. These agreements foster scientific exchanges and stimulates pursuing excellence. At the same time, regular Steering Committee meetings ensure that the research objectives of both parties are aligned and maintained relevant.

But the JRC does not limit its cooperation to within the European Union. On the contrary, the JRC engages with third countries' actors which are important in the nuclear research landscape, including large nuclear countries and specifically, international organisations such as the IAEA and OECD/NEA. Its involvement in EU and international cooperation activities allows the JRC to be kept up-to-date of the nuclear research trends and challenges, and helps shaping, within the EU framework, its own research programme, with the objective of contributing to maintaining the EU competence and leadership in nuclear safety, nuclear security, and nuclear safeguards. In the field of education and training, JRC cooperates with and hosts one of the offices of the European Nuclear Education Network, (ENEN), an international non-profit organization which main purpose is the preservation and the further development of expertise in the nuclear fields by higher education and training in Europe.

Building upon the scientific expertise and its work with the different partners, including European and third countries reputed research institutions, international organisations, and others, the JRC contributes to the development, implementation and monitoring of nuclear-related EU policy (EU Directives and Euratom Treaty obligations), and instruments (e.g. for nuclear safety and nuclear security), together with other Directorates-General of the European Commission and other Institutions. In particular, and in addition to JRC's research work on the safety and safeguards aspects of innovative Generation IV reactors, the JRC has been entrusted to be the Euratom implementing agent [16] of Generation IV International Forum, which is a co-operative international endeavour was set up to carry out the research and development needed to establish the feasibility and performance capabilities of the next generation nuclear energy systems.

4 The way forward

The long-term safe, secure and sustainable use of nuclear energy must be ensured by a consistent approach to safety (implementation of appropriate and commensurate common principles, rules and standards); safeguards (verification, reporting and non-proliferation commitments such as export controls) and security (prevention, detection and response), as well as international acceptance and mutual trust (transparency). This can only be achieved based on sound scientific evidence, reliable nuclear measurements and appropriate control tools, as well as on public involvement, which at the same time can only be guaranteed if competence and technology leadership are maintained within the EU (research, education, training and knowledge management).

The Commission's proposal for the next Euratom Research and Training Programme (2021–2025), which is currently being discussed at the Council aims at focusing in the same key research areas as the current programme, i.e. nuclear safety, security, radioactive waste and spent fuel management, radiation protection and fusion energy. At the same time, the programme intends to expand research into non-power applications of ionising radiation, and make improvements in the areas of education, training, knowledge management and access to research infrastructure (including in particular the infrastructure operated by JRC), as well as to better exploit the complementarity between research carried out by Member States scientific institutions, and research carried out by the Joint Research Centre.

Up to now, JRC participated in indirect actions by taking part of consortia, which would compete against national research institutions in the different calls prepared by the Commission. [17] The recommendations from STC and from the various independent experts panels (that carried out the interim and ex-post evaluations of Euratom research and training programmes) underlined the necessity of exploiting synergies inside the Euratom Programme, and also with the future Horizon Europe Framework Programme. The Commission proposal reflects the need to streamline and foster the complementarity between the nuclear research carried out by the Member States and the one carried out directly by the JRC by establishing a single set of objectives for both direct and indirect actions. It is also envisaged that projects can be drawn up by combining different instruments and assets, such as JRC's knowledge base and research infrastructure.

Starting in the next Euratom Programme, it is proposed that the JRC participates in indirect actions where the JRC has a specific competence. In this way, the JRC, through direct actions, would complement consortia's activities where the JRC has the necessary expertise or dedicated infrastructure without participating in competitive biddings against research institutions of the Member States.

In preparation for this approach, three pilot projects [18] on knowledge management in nuclear safety, open access to JRC research infrastructure, and roadmap for access to the Jules Horowitz Reactor, will explore and test this improved involvement of JRC in indirect actions.

In the project on knowledge management in nuclear safety, JRC will provide technical and scientific support for the management of the created knowledge in both indirect and direct actions of the successive Euratom Programmes. The JRC should develop methods and tools to gather and valorise that knowledge making it available to the European research Community.

The project on open access to JRC research infrastructure aims at making the JRC research infrastructure available for the use by the Euratom research community. Scientists of Member States will have the financial support of RTD to facilitate the experimental research in JRC laboratories.

In the project developing the Jules Horowitz Reactor operation plan 2040, the JRC participation is expected to ensure that the full use of the Euratom access rights is covered, while taking into account the JRC planned activities.

In all these three pilot projects, JRC personnel costs as well as the operational costs of JRC research infrastructure will be covered exclusively by the JRC direct actions budget.

5 Conclusions

Regardless of the EU Member States decisions on continuing, phasing out or embarking in new built nuclear power plants, nuclear energy will continue to be part of the energy mix in the European Union for the next decades, and also in neighbouring countries. The EU must ensure that Member States use the highest standards of safety, security, waste management and non-proliferation. The EU should also ensure that it maintains technological leadership in the nuclear domain so as not to increase energy and technology dependence. Efficient research and training at EU level are key elements to achieve these objectives.

The JRC is a very important partner in European research, which aims at complementing the nuclear research and training carried out by the research institutions of EU Member States through its scientific expertise and research infrastructure. JRC's areas of work cover ample disciplines in the field of nuclear safety, nuclear security, nuclear safeguards, and nuclear science applications ranging from basic research up to ready to use applications, as well as development of reference measurements and supply of reference materials. To this end, the JRC operates cutting-edge laboratories and research infrastructure, in many cases with unique characteristics and capabilities.

Although cooperation in nuclear research has been always a key objective in the work programme of the JRC, the Commission proposal for the next Research and Training Programme, which is still under discussion, has taken further concrete actions towards a more efficient alignment of the research and training activities of Member States and those of the Joint Research Centre.

The JRC, together with its partners is getting ready to this new approach by proposing and new way of implementation, in which the JRC will not bid with research institutions of the Member States in competitive processes, but rather will form part of those projects for which the knowledge and capacities (including infrastructure) of the JRC are significant or relevant. This new way of implementation will be tested through three specific pilot projects on knowledge management, open access to JRC research infrastructure, and access rights to the Jules Horowitz Reactor.

For more than 60 years, the Joint Research Centre has developed a sound knowledge base and expertise in nuclear matters, continually pursuing scientific excellence. It shares its know-how and achievements with EU Member States, the scientific community, and international partners. It works together with over a thousand organisations worldwide in more than 150 networks whose scientists have access to JRC facilities through various collaboration agreements. The JRC will continue to be a relevant actor in the nuclear research arena, focusing on nuclear safety, responsible and safe management of radioactive waste and spent fuel, radiation protection, nuclear science applications, nuclear security, nuclear safeguards, and standardisation as the challenges of today will still outstand in the next years. The next Euratom Programme will, in addition, reinforce JRC education and training as well as knowledge management activities, increase synergies with non-nuclear activities, further develop nuclear science applications, and improve access of scientists to JRC research infrastructure.

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