

Euratom Research and Training in 2022: challenges, achievements and future perspectives*

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The development and safe operation of nuclear installations in Europe is of vital importance for the future of nuclear energy. Helping to ensure the safe operation of nuclear power has always been one of the top priorities of Euratom Research Framework Programmes. With the incentives of Horizon Europe, further integration towards an EU/Euratom Research Area was achieved, better prioritisation at European and International levels based on updates of Research and Innovation agendas or deployment strategies, capitalisation of European Technology platforms and enhanced cooperation with International Organisations or Fora effectively happened. Evolutions towards European Joint Programmes and Partnerships together with EU/Euratom Member States, confirm that research and innovation programmes successfully benefit from the truly added value of a concerted European approach in nuclear safety research and training, radioactive waste management and radiation protection advocated by the European Commission and EU/Euratom Member States.

The 10th European Commission Conferences on EURATOM Research and Training in Safety of Reactor Systems and Radioactive Waste Management – FISA 2022 and EURADWASTE'22 – have been another major milestone on the EU/Euratom agenda. They gathered over 550 scientists from 150 organisations and 50 European countries worldwide, being research and training organisations, academia, industry, technology platforms, European fora, European civil society, and International Organisations participating in EU/Euratom Framework Programmes. These two major scientific and policy events were organ-

ised jointly with the French Presidency of the Council of the EU in 2022 and hosted by the Région Auvergne-Rhône-Alpes, in Lyon, France.

Their success lies in coherently summarising most activities of the main pillars of the EU/Euratom Fission research programmes. The following two sections of this special issue provide peer-reviewed papers, *part (1) on the Safety of reactor systems* and *part (2) on Radioactive waste management*, and highlight major *challenges, achievements, and future perspectives of EU/Euratom Research and Training in 2022*, and towards the next Horizon Europe research framework programme.

This issue is complemented by the 'Euratom Research and Training in 2022: the Awards collection'. It provides peer-reviewed papers on the Nuclear Innovation prizes awarded for the occasion [30–42], and is meant to give visibility to the most dynamic, forward-looking and innovative researchers, research teams or industrial contestants.

Part 1: Safety research and training of reactor systems

Safety of nuclear installations [1–4] is constantly benefitting from research innovations in reactor performance, system reliability, advanced numerical simulation and modelling for reactor safety, applied to long-term operation (LTO) of current Generation II–III reactors. As identified within the European Technology platform SNETP NUGENIA Generation II–III water-cooled reactor technology and technical research areas, LTO is an important challenge since most countries are now considering prolonging the lifetime of their power or research reactors from an originally foreseen 40 years' operation to usually 60 years. In order to safely extend the lifetime of these reactors or nuclear installations, both nuclear operators and regulators need to have, in addition to a skilled and well-trained workforce, robust and reliable research results. With the knowledge, and tools to assess

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and master any ageing and/or degradation process of components and/or structures, as well as methods and science-based guidelines for their validation, safe monitoring, management and operation will be ensured.

Nuclear safety [5–8] is also addressed through research on innovative Generation II–III fuel and materials, and the development of accident tolerant fuels. Moreover, high-performance research reactors have to overcome the challenging conversion from highly enriched to low enriched uranium fuels, to fulfil a worldwide non-proliferation effort. Safety assessments and severe accident analysis, the impact of external events on nuclear power plants, studies on mitigation of strategies, and probabilistic safety assessments were further supported. As a result, nuclear and radiological emergency management and preparedness within Europe and across the whole continent highly benefited from a unified, shared and coordinated approach. As such, joint experimental research activities improve and strengthen any optimal use of shared resources, methodologies, tools, and collaboration at pan-European and international levels. Strategic initiatives high on research and innovation agendas were supported, and lessons learned, as a response to the Fukushima Daiichi accident, reviews of technical and scientific improvements carried out, in the area of severe accident management, emergency preparedness and response.

Safety of advanced nuclear systems and fuel cycles [9,10] is supported through R&D towards a new generation of more sustainable reactor technologies. Safety design and licensing of technologies are also identified as a high priority by the European Sustainable Nuclear Industrial Initiative of the Strategic Energy Technology Plan SET-Plan (SNETP-ESNII Generation IV fast reactors and closing the fuel cycle). Development of innovative fuels and materials benefits from advancements of the EERA JPNM Joint Programme on Nuclear Materials for fission and fusion. Additionally, the entire nuclear fuel cycle is studied. From fuel fabrication to recycling strategies, partitioning and transmutation, to waste streams and high-level waste management, should help to meet, among others, the sustainable goals of minimisation of waste and better use of natural resources. Development of other applications for nuclear, such as the Nuclear Cogeneration Industrial Initiative with high-temperature reactors (SNETP-NC2I, cogeneration of electricity and heat) is also presented. Cross-cutting nuclear data activities to the level needed by simulation codes to fulfil present requirements, for the safe and sustainable operation, development of existing and future fission and fusion reactors and nuclear fuel cycle facilities, are also presented.

Nuclear safety always remains a high priority and the European Union has an outstanding nuclear safety record. However, research must continue to maintain the *highest level of nuclear safety, security and safeguards* through *Education and training, research infrastructures, low-dose radiation protection, decommissioning and international cooperation* [11–16]. The European nuclear sector is characterised by cutting-edge technology and provides several hundred thousand people with highly skilled employment. To ensure our safety, both now and in the future, skilled people and well-equipped nuclear research

facilities are of paramount importance. The availability of these resources is a crucial prerequisite for maintaining safety no matter what the future holds for the nuclear sector. Europe can retain its technological leadership only if Member States maintain a diverse and well-funded nuclear R&D capability, a fit-for-purpose system for the education and training of scientists and engineers, availability of state-of-the-art research infrastructures, and reinforced international cooperation in key strategic areas with leading third countries, bilaterally or multilaterally. EU/Euratom helps to stimulate joint funding from Member States and/or enterprises, joint programming and dialogue at the EU level, cross-cutting innovation between fission/fusion/non-nuclear/medical applications or decommissioning and benefits are being capitalised, from Horizon Europe, from the increasing interaction between European technology platforms, EU stakeholder fora, as well as International Organisations.

Among others one can highlight the Sustainable Nuclear Energy Technology Platform (SNETP and its pillars NUGENIA, ESNII, NC2I), the Implementing Geological Disposal Technology Platform (IGD-TP) and the Multidisciplinary European Low-Dose Initiative (MELODI), the Consortium of European Radiation Research Platforms (MEENAS, MELODI, EURADOS, EURAMED, NERIS, ALLIANCE and SHARE) and other European forums such as the European Nuclear Energy Forum (ENEF), the European Nuclear Safety Regulators Group (ENSREG), the European Technical Safety Organisations Network (ETSON), the Nuclear Europe Industrial Association (ex-European Atomic Forum (NuclearEurope, ex-FORATOM)), the European Energy Research Alliance Joint Programme on Nuclear Materials (EERA JPNM), the Generation IV International Forum (GIF), the Heads of the European Radiological Protection Competent Authorities (HERCA), as well as as well as international organisations including the International Commission on Radiological Protection (ICRP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the Nuclear Energy Agency (OECD/NEA), the International Atomic Energy Agency (IAEA) and the World Nuclear Association (WNA).

Part 2: Radioactive waste management

Collaborative R&D in Radioactive Waste Management was one of the main objectives promoted by the Euratom Research and Training programme over the last decade. A holistic approach was taken to cover the full range of activities from the generation to the disposal of the radioactive waste. Several Euratom research and innovation projects focused on the characterization of radioactive waste. The DISCO project and the SFC work package [17] examined the characterization of spent fuel at different degradation states, and the CHANCE, MICADO and PREDIS projects [18] addressed the characterization of radioactive waste at different stages of its management. The PREDIS and the THERAMIN projects [19] also focused on some promising techniques and methodologies to treat and condition the waste, while the CORI, CONCORD, FUTURE

and MODATS work packages [20] focused on the long-term behaviour of the waste packages and the long-term retention of radionuclides in the near field. Numerical models were also developed and used to describe the long-term evolution of the engineered barrier systems and their performances in the ACED, DONUT and MAGIC work packages and the BEACON project [21]. At the scale of the host rock, the GAS and HITEC work packages [22] focused on the THMC processes to better understand the gas and heat transport in the context of a geological disposal repository.

Strategic issues in Radioactive Waste Management are crucial, as some programs evolve from development to industrial implementation, making them site-specific and leaving less room for research activities of common interest [23]. As licenses are granted or applied for disposal facilities, the respective programmes have reached the necessary level of maturity to support the design and safety assessment. Nevertheless, strategic studies are essential to identify and address remaining or emerging challenges, as well as topics of common interest related to operation, closure, and oversight periods. For instance, the UMAN work package [24] focused on the management of uncertainties when dealing with radioactive waste management, while the ROUTES work package [25] identified the key issues and open questions about waste management routes in Europe from cradle to grave. The strategic aim of the Euratom R&T programme is to deploy a Joint Programming plan on RWM, helping Member States implement Directive 2011/70/Euratom by coordinating national research programs. Joint Programming represents a fundamental change in the governance of EC co-funded projects, moving from top-down governance managed by the Commission to cooperative governance managed by Member States together with the Commission.

Knowledge management in Radioactive Waste Management involves not only the waste and its physical and chemical characteristics, but also the records of all the operations carried out during treatment and storage. Since RWM spans long periods of time and involves multiple stages, keeping and transferring knowledge over those periods is extremely challenging. Managing and transferring this knowledge capital is a major endeavour [26]. The State-of-Knowledge (SoK) reports [27] will be established for the different WPs to gather the most relevant knowledge and associated uncertainties regarding issues of relevance for safe disposal by contextualizing content relative to generic safety statements (safety functions). The main goal of methodological guidance [28] is to provide Member States with RWM programs at an early stage of development with a set of methods, procedures, and guidance specifically dedicated to implementing a comprehensive KM system from the start of their program. Qualifying training programmes [29] were also set up in cooperation with national universities and schools, and a “School of Radioactive Waste Management” could be created, building on existing international initiatives like IAEA and NEA. This would allow for training a new generation of scientists and ensure a smooth transition of knowledge as

personnel changes and retirements occur. The success of the first EJP has paved the way for a new Partnership on RWM under the Horizon Europe program, set to launch in 2024. The partnership will encompass predisposal activities and promote further interactions with international organizations, such as NEA/OECD and IAEA, and relevant stakeholders such as waste generators and regulatory bodies.

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Appendix: List of PROJECT [Grant Agreement number] covered

FISA 2022

ENTENTE [900018], ATLASplus [754589], NOMAD [755330], STRUMAT-LTO [945272], FRACTESUS [900014], MEACTOS [755151], INCEFA-SCALE [945300], sCO2-4-NPP [847606], APAL [945253], CAMIVVER [945081], TEAM-CABLES [755183], El-Peacetolero [945320], CORTEX [745316], McSAFER [945063], METIS [945121], ELSMOR [847553], PAS-

TELS [945275], EU-QUALIFY [945009], LEU-FOREVER [754378], MUSA [847441], PIACE [847715], AMHYCO [945057], BESEP [945138], NARSIS [755349], R2CA [847656], ESFR-SMART [754501], SafeG [945041], ECC-SMART [945234], ACES [900012], SAMOSAFER [847527], PUMMA [945022], GENIORS [755171], INSPYRE [754329], PATRICIA [945077], PASCAL [945341], ORIENT-NM [899997], GEMMA [755269], M4F [755039], NUCOBAM [945313], GEMINI-PLUS [755478], SANDA [847552], ARIEL [847594], ENENplus [755576], GREaT-PIONEer [847502], ENEEP [845555], PIKNUS, A-CINCH [945301], SINFONIA [945196], EURAMED rocc-n-roll [899995], MEDIRAD [755523], HARMONIC [847707], RadoNorm [900009], SHARE [847626], INNO4GRAPH [945273], PLEIADES [899990], LD-SAFE [945255], CLEAN-DEM [945335], INSIDER [755554], JHOP2040 [899360], TOURR [945269], JHR ACCESS RIGHTS, OASIS JRC Open Access

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EURAD [847599], CHANCE [755371], MICADO [847641], PREDIS [945098], CORI, FUTURE, MODATS, CONCORD, ACED, DONUT, BEACON [745942], MAGIC, GAS, HITEC, SFC, UMAN, ROUTES, SOK, GUIDANCE, T&M, IGD-TP, SITEX

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