ISSN 1831-9424

European Commission

JRC Nuclear Foresight Workshop on Shaping the Future for Nuclear Safety, Security and Safeguards

Factors, Forces and Challenges

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2024

Joint Research Centre

EUR 40023

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JRC138550

EUR 40023

Print	ISBN 978-92-68-20592-1	ISSN 1018-5593	doi:10.2760/2746070	KJ-01-24-014-EN-C
PDF	ISBN 978-92-68-20591-4	ISSN 1831-9424	doi:10.2760/6469488	KJ-01-24-014-EN-N

Luxembourg: Publications Office of the European Union, 2024

How to cite this report: European Commission, Joint Research Centre, Aldave De Las Heras, L., Aregbe, Y., Buda, R., Casteleyn, K., Colle, J., Fuetterer, M., Galy, J., Janssens, W., Jenet, A., Martin Ramos, M., Matuzas, V., Mayer, K., Sequeira, V., Sevini, F., Simola, K., Tamborini, G., Tanarro Colodron, J., Toma, M., van Winckel, S. and Wallenius, M., *JRC Nuclear Foresight Workshop on Shaping the Future for Nuclear Safety, Security and Safeguards*, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/6469488, JRC138550.

Contents

Abstract

The European Commission Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting European Union (EU) policies to positively impact society.

In 2023, the JRC released the JRC's re-vitalised strategy 2030[1]. In this new strategy the role of and mandate of the JRC's nuclear activities is reaffirmed, offering a more systemic approach in the frame of cross-cutting portfolios. Particularly, the JRC committed in its Strategy for Nuclear Activities[2] to envision both a medium and a long-term horizon, allowing the strategy to include key foresight elements.

Inspired by the JRC Euratom Horizon Scanning[3] for Nuclear technologies, the European Strategy and Policy Analysis System (ESPAS)[4] and the IAEA Drivers 2057 card deck[5] presented at the IAEA Symposium on International Safeguards in 2022[6], five JRC nuclear and non-nuclear portfolios joined forces to build on their complementarity and synergy. They jointly organised the *JRC nuclear foresight workshop on shaping the future for nuclear safety, security and safeguards* on 5 selected Drivers 2057 of relevance to Europe:

- [SAFETY & SECURITY]
- [GREEN]
- [DIGITAL]
- [DUAL USE]
- [FAIRNESS]

The workshop was held in conjunction with the JRC's 60th anniversary of its Nuclear Safety and Security activities[7]. It encompassed welcome and keynote addresses, an introduction to Euratom foresight at the JRC, and sessions with all participants *imagining the possible* for factors, forces and challenges of each of the Euratom Drivers 2057, including the JRC's roles in navigating future trends up to the year 2057, when Euratom will celebrate its 100th anniversary.

This report presents the purpose, process and organisation of this foresight workshop as a complementary pilot initiative to the well-established Euratom Horizon Scanning[3]. For each Euratom Driver 2057, the report includes a series of considerations and recommendations stemming from the workshop discussions to address future scenarios and enablers but also challenges and potential disruptions. Participants further imagined the future role of the JRC and the adequate resources and competences to be better prepared towards 2057.

The report concludes with a reflection on the outcome and recommendations of the workshop with most recent developments of strategic importance for the European Union (EU). These insights can inspire further JRC's research, science and policy support developments and facilitate to accommodate necessary strategic adjustment in response to the changing scientific and political landscape in the EU and at a global level.

Acknowledgements

The authors of this report would like to thank all in-person and online participants in the workshop from EU Member States, international organisations and the EC. The time they dedicated to the discussions and the intellectual curiosity, imagination and engagement they showed through their active and insightful contributions is very much appreciated.

The authors acknowledge and thank in particular Ms. Elina Martikka, Head of International Cooperation at the Radiation and Nuclear Safety Authority (STUK), Finland and Mr. David Albright, President of the Institute for Science and International Security (ISIS), on their role for setting the scene of the workshop with inspiring keynote lectures for *imagining the possible* around the 5 Euratom Drivers 2057.

The JRC online training organised by the JRC Euratom coordination colleagues with the IAEA symposium 2022 organisers and DG ENER on a Deep Dive into the IAEA Drivers 2057[8] was extremely helpful and inspiring in framing the Drivers and setting up the concept and process of this workshop

The support and engagement that the Director of the JRC's Directorate for Nuclear Safety & Security, Ms. Ulla Engelmann, and her team provided from the beginning to this bottom-up 5 portfolio initiative is very much appreciated. The overall positive response from the JRC management to this 5 portfolio foresight initiative was very encouraging.

The authors would like to thank all project leaders and colleagues contributing to the JRC Portfolios: 4-*NucTec*, 5-*SmallModReact,* 30-*SCISEC*, 31-*NCA*, 33-*InnovPolicy*. In addition, we would like to acknowledge our colleagues from Portfolio 15-*Trustworthy AI* for making available GPT@JRC to scientific and non-scientific staff. Some of the paragraphs in this report were drafted using this JRC exclusive deployment of ChatGPT.

The time, efforts and dedication of Savina Colson, Myriam Ritardo, Alban Kellerbauer and the many JRC colleagues supporting and facilitating this workshop in different ways '*in front of and behind the scene'* from conception to organisation to implementation to technical/logistic support and finally to follow-up, is highly appreciated and at the origin of the success of this pilot foresight initiative. Without them, it would have not been possible to join this portfolio initiative to the Roadmap of the 60 Years of JRC Nuclear Safety and Security celebrations.

Authors

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Executive summary

This report presents the outcome from the JRC NUCLEAR FORESIGHT WORKSHOP on Shaping the Future for Nuclear Safety, Security and Safeguards - Factors, Forces and Challenges that was conducted on 24th November 2023 at the JRC-Karlsruhe in conjunction with "60 Years of JRC Nuclear Safety and Security"[7]. It built on the participation of representatives from EU Member States and international research, governmental and industrial organisations and from the EC, representing a large spectrum of stakeholders. The IAEA Drivers 2057 card deck presented at the IAEA Symposium on International Safeguards in 2022[6] inspired the foresight process used in this workshop. Five nuclear and non-nuclear JRC portfolios jointly organised this pilot foresight initiative to reflect on the following 5 selected, non-exhaustive, Drivers 2057 of relevance to Europe:

From left to right and top to bottom:
Source JRC on licenced Adobe Stock
Source: JRC on licenced Adobe firefly
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Source: JRC on licenced Adobe Stock
Source: JRC on licenced Adobe Stock

The purpose of this workshop initiative was the following:

(i) '***imagine the possible'*** - to harvest on the collective intelligence, imagination and reflections of the workshop participants around the selected 5 Euratom Drivers 2057 supporting the Euratom Horizon Scanning[3] for Nuclear Safety and Security and Safeguards;

(ii) ***reaffirm the role of JRC's nuclear activities'*** - to implement the JRC re-vitalised strategy by increasing the nuclear and non-nuclear synergies with external and internal stakeholders;

(iii) ***'foresight is key'*** - to establish a "safe space" for exchange between workshop participants with various responsibilities in governments, research, industry, universities and laboratories around foresight;

(iv) ***'what science tells us'*** - to provide feedback to the JRC management preparing for the New Commission and for EC initiatives beyond the next framework programme;

(v) ***'inspire'*** to facilitate future JRC strategic preparedness and adjustment in response to the changing scientific and political landscape in the EU and at a global level;

Two distinguished keynote speakers were setting the scene while emphasising the new challenges and opportunities ahead in research & development for nuclear Safeguards, Security and Safety (3S), as well as for non-proliferation. The workshop participants brainstormed on factors, forces and challenges of each of the Euratom Drivers 2057, including the JRC's roles in navigating future trends up to the year 2057, when Euratom will celebrate its 100th anniversary.

The participants in the workshop perceived that nuclear 3S research could have a high impact in the EU for decades to come supporting both, nuclear and non-nuclear energy, climate and health plans. The JRC should increasingly prepare for critical and emerging nuclear technologies, such as small modular reactors in combination with the digital transformation and cyber security in terms of regulatory and 3S challenges.

The foresight process also highlighted main potential disruptive factors: geopolitical threats, fair access to nuclear technology and the loss and ageing of nuclear infrastructure, competences and skilled workforce in Europe. Recommendations were also harvested during the workshop that aim to mitigate those issues and bring opportunities further for the EU. These include: strategic autonomy[9] and international cooperation, strategic trade controls, public engagement, nuclear communication based on holistic scientific evidence, promoting education and training; and retaining and attracting talent in a well-balanced combination with engaging in automation and robotics, establishing a European Nuclear Competence and Skills Centre

1 Introduction

Foresight is the discipline of exploring and anticipating future possible developments to shape the preferable future. To do so, it taps into collective intelligence in a structured and systematic way. EU Strategic foresight[10] is not about predicting the future; it imagines and explores the possible future scenarios, alongside the opportunities and challenges they might present. Ultimately, it is about acting in the present to shape the future of EU policy making.

The European Commission Joint Research Centre (JRC) provides independent, evidence-based knowledge and science, supporting European Union (EU) policies to positively impact society. As outlined in the JRC work programme 2023-2024[11] the new JRC portfolio approach brings together scientific disciplines from across the JRC to address a common theme or issue spanning different priorities to better integrate the JRC's work across scientific and policy domains. Additional emphasis is given to synergies between nuclear and non-nuclear fields of competences. Particularly, the JRC committed in its JRC's re-vitalised strategy 2030[1] and in its Strategy for Nuclear Activities[2] to envision both a medium and a long-term horizon, encouraging the strategy to include key foresight elements.

Figure 1 The European Union Flag

Source: Alexey Larionov on Unsplash

Inspired by the JRC Euratom Horizon Scanning[3] for Nuclear technologies, the European Strategy and Policy Analysis System (ESPAS)[4] and the IAEA Drivers 2057 card deck presented at the IAEA Symposium on International Safeguards in 2022[6], five JRC nuclear and non-nuclear portfolios joined forces to build on their complementarity and synergy. The 5 portfolios[12] are the following:

- Portfolio 4 NucTec: *Safety of nuclear technology in support to the transition towards climate neutrality*.
- Portfolio 5 SmallModReact: *Small Modular Reactors.*
- Portfolio 30 SCISEC: *Science For Security*
- Portfolio 31 NCA: *Support to Nuclear Compliance Assurance*
- Portfolio 33 InnovPolicy: *Innovative policymaking in a complex world: science, foresight and evaluation for policymaking and democracy*

They took the initiative using foresight tools to discuss and present a science-based vision of emerging issues in the *JRC NUCLEAR FORESIGHT WORKSHOP on Shaping the Future for Nuclear Safety, Security and Safeguards - Factors, Forces and Challenges*, held on 24th November 2023 at the JRC-Karlsruhe in conjunction with the JRC's 60th anniversary of its Nuclear Safety and Security activities[7]. The process comprised after the welcome address of the Director of Directorate G of the JRC a combination of keynote addresses and a brief introduction on Euratom foresight[i] at the JRC to set the scene, followed by in depth reflections in breakout sessions around the 5 selected, non-exhaustive, Drivers 2057 of relevance to Europe (**SAFETY & SECURITY**, **GREEN**, **DIGITAL**, **DUAL USE**, **FAIRNESS**). The outcome was subsequently summarised and presented to all participants in a plenary setting to stimulate creative thinking and harvest on the feedback and imagination of all attendees. This participatory process allowed for involving a wide range of stakeholders from the EC, EU Member States, industry, research and international organisations, representing diverse competence domains and fields of expertise and related responsibilities.

It is important to recall that the nature of this workshop is complementary to other Foresight activities at JRC and can be considered as a pilot first of its kind. It is a qualitative and participatory initiative. Consequently, the outcomes described in the report do not represent a forecast based on quantitative or statistical analysis or opinions of the EC or any Member State, but rather imagine and explore possible developments, opportunities and challenges perceived as important for the future by this specific set of participants. The authors conclude the report with a reflection on the outcome and recommendations of the workshop in relation to the most recent developments of strategic importance for the European Union (EU). Finally, the authors consider that the approach developed for this specific workshop, is in itself a contribution for further analogous foresight exercises.

[i] A Comprehensive list of recent JRC/Euratom foresight activities can be found in Annex 4

2 Setting the Scene

Driven by the EC priorities and the commitment to breaking silos, the JRC now organises its work in portfolios. The new JRC portfolio approach brings together scientific disciplines from across the JRC to address a common theme spanning different priorities. This cross-disciplinary approach allows us to anticipate new challenges and respond in a concerted manner to policy DGs, Member States and societal needs. The 5 portfolios who joined forces to organise this foresight workshop wanted to emphasise the synergies between nuclear and non-nuclear opportunities and challenges when it is about looking at possible future scenarios with societal impact. Since this foresight workshop was a pilot initiative done for the first time within the new JRC portfolio within a limited timeframe of only one single day the expectations and the process had to be pragmatic and feasible without compromising the imaginative and sense making asset of foresight.

As a result, the following five objectives for this workshop initiative were put forward:

(i) '***imagine the possible'*** - to harvest on the collective intelligence, imagination and reflections of the workshop participants around the selected 5 Euratom Drivers 2057 supporting the Euratom Horizon Scanning[3] for Nuclear Technologies;

(ii) ***reaffirm the role of JRC's nuclear activities'*** - to implement the JRC re-vitalised strategy by increasing the nuclear and non-nuclear synergies with external and internal stakeholders;

(iii) **'*foresight is key'*** - to establish a "safe space" for exchange between workshop participants with various responsibilities in governments, research, industry, universities and laboratories around foresight;

(iv) **'*what science tells us'*** - to provide feedback to the JRC management preparing for the New Commission and for EC initiatives beyond the next framework programme;

(v) ***'inspire'*** to facilitate future JRC strategic preparedness and adjustment in response to the changing scientific and political landscape in the EU and at a global level;

The aim was to accommodate in-person participation of invited external participants to the 60 years celebration but also EC and JRC internal participants in a hybrid format. It was decided, due to the limited time of a one-day workshop, to frame the foresight exercise to 5 pre-selected Drivers of relevance to Europe, looking ahead to 2057 when Euratom turns 100 years. The authors literally took the IAEA Drivers 2057 card deck presented at the IAEA Symposium on International Safeguards in 2022[6] and built from there, in cooperation with the colleagues from the 'Euratom foresight' initiative at JRC, a lean foresight process for this workshop. The combination of starting with welcome and keynote addresses, followed by breakout sessions and closing with a final plenary, enabled all in person and on-line participants to engage and to contribute to each of the 5 selected Drivers. This was key to the success of this pilot 5 portfolios foresight activity (see Annex 1 workshop programme).

2.1 Welcome address by Ulla Engelmann, JRC-Director for Nuclear Safety & Security

The JRC's place in the European Commission is at the interface of policy and science, with strong networks in both policy and scientific communities. The JRC actively engages with partners in knowledge production and shares its science output to support EU policies to positively impact society. In the JRC's re-vitalised strategy 2030[1], **anticipation**, with a focus on what is coming at us to be able to provide the scientific underpinning for future policy initiatives, is put forward as one of the three core strengths of JRC, together with **integration** and **impact**. This foresight workshop is part of the roadmap of events within the JRC's 60th anniversary of its Nuclear Safety and Security activities[7] held throughout the whole year 2023 at the four JRC nuclear sites. In the event for the 60 years of JRC-Karlsruhe the Commissioner for Internal Market, Mr. Thierry Breton, said that *nuclear technology is an intrinsic part of European prosperity and an asset towards decarbonisation in 2050*.

EU Member States have different opinions whether or not to include nuclear in their energy & climate plans. However, the nuclear research in safety, security and safeguards done at the JRC with its unique facilities and decades of nuclear competence is beneficial to all EU Member States, regardless of their future envisaged energy mix, as well as to our internal and external partners. Some of the future challenges and opportunities, besides the potential deployment of innovative (small) reactors, are for example innovative nuclear research for medical and space applications. The JRC is and will continue complementing Member States capabilities and capacities in all these domains, building on opportunities. Alike, the JRC will address in its future research the challenges responding to public concerns such as nuclear waste management and the twin transition.

The 5 portfolios have taken their inspiration to organise this workshop from the JRC Horizon Scanning for Nuclear Safety, Security & Safeguards activities starting in 2016 and growing since, from the IAEA Drivers 2057, and from the 2023 European Strategy and Policy Analysis System (ESPAS) Annual Conference[13]. The executive vice-president and Commissioner for European Green Deal, Interinstitutional Relations and Foresight, Mr. Maroš Šefčovič, pointed out during that conference that *foresight is not predicting the future but challenging long-term assumptions. It is now the perfect time for foresight debates before the European elections and before a new European Commission takes office*.

Strategic foresight[10] will remain key during the mandate of the next Commission because it strengthens the unity of the EU, the rule of law in the EU, the resilience and strategic autonomy of Europe and the European Green Deal.

Figure 2 Ulla Engelmann, JRC Director for Nuclear Safety & Security

Source: JRC

2.2 Keynote by Elina Martikka, Head of International Cooperation at STUK, Finland

Under the motto *"never let a good crisis go to waste"*, Ms. Elina Martikka, the Head of Unit, International Cooperation STUK, Radiation and Nuclear Safety Authority, Finland, and a former president of the European Safeguards Research & Development Association (ESARDA[14]) shared her extensive knowledge and experience in the field of nuclear energy and safeguards with the workshop participants. She emphasized the importance of an integrated approach on nuclear safety, security, and safeguards (3S). STUK aims to foster the well-being and satisfaction of its regulatory professionals, recognizing their importance in ensuring the safe, peaceful and responsible use of nuclear energy while mitigating potential risks to people and the environment. The organization's strategy includes a target to cultivate the happiest civil servants in the world. STUK's commitment to promoting flexible and efficient working methods is essential in maintaining a high standard of oversight in the nuclear energy sector.

Balancing between East and West: Finland has played a vital part in implementing the Nuclear Non-Proliferation Treaty (NPT) for the past fifty years[15]. The Chernobyl accident highlighted the importance of maintaining strict safety standards and the need for continuous research and development to prevent similar incidents from occurring in the future. The accident serves as a reminder of the potential risks associated with nuclear technology and the importance of prioritizing safety and security.

Current and future challenges: The Olkiluoto Nuclear Power Plant, home of one of the world's largest reactors, is a key component of Finland's energy infrastructure. STUK plays a crucial role in ensuring the safe and responsible operation of these reactors and builds on public endorsed by the public. Relying on the NPT, Finland has been a committed and responsible user of peaceful nuclear energy for decades, and its soon to start final disposal facility for spent nuclear fuel, ONKALO, with its safeguards solutions, is the first of its kind in the world. This poses new challenges for ensuring the effective safeguarding of the first geological repository and the long-term stability and sustainability of the nuclear energy sector. This new challenge highlights the need for continued research and development in nuclear safety, security safeguards and waste management.

Nuclear newcomers: International cooperation remains key. The importance of supporting newcomers to the nuclear energy industry is part of equality. Almost 40 nuclear newcomers are expected to invest in nuclear power plants, many of them on the African continent. IAEA, together with regional cooperation fora that enable cooperation, such as the African Commission on Nuclear Energy (AFCONE)[16], are therefore playing a key role in promoting safe and secure peaceful applications of nuclear science and technology.

Is it possible to foresee crises? The new Finnish Nuclear Safety Research Programme, SAFER2028[17], aims to identify and mitigate risks through innovative nuclear safety research. By preparing for potential crises, STUK serves as a trusted partner for policymakers, working closely with nuclear operators and engaging in resident engagement, public outreach and education to ensure the safety and security of the Finnish public.

Ms Martikka concluded her keynote address with congratulating the JRC to more than 60 years of commitment to nuclear safety, security, and safeguards. This milestone highlights the importance of continued research, development, and cooperation in the nuclear energy sector, ensuring the safe and responsible use of nuclear technology for generations to come.

Figure 3 Elina Martikka, Head of International Cooperation at STUK, Finland

Source: JRC

2.3 Keynote by David Albright, President of the Institute for Science and International Security, USA

Delivering the keynote speech *"Evolving Threats: Our Adversaries Seek Western Goods and Increased Arsenal"*, Mr. David Albright, an esteemed physicist and founder of the Institute for Science and International Security, sheds light on the growing concern of nuclear proliferation. Nine states are known to possess nuclear weapons. Among these states, the United States and Russia hold the largest stockpiles of nuclear warheads, followed by China and other countries with significantly fewer warheads. Concerns surrounding horizontal nuclear proliferation primarily involve states such as Iran, Saudi Arabia, and South Korea, which are either close to acquiring nuclear weapons, have expressed intentions to do so if certain conditions are met, or fear a nuclear attack from a neighbour. Other horizontal nuclear proliferation threats concern potential nuclear terrorism. Secondary nuclear proliferation concerns countries like Egypt, Turkey, UAE, and Syria, and the possibility of Taiwan and Japan reconsidering their nuclear ambitions due to regional threats. The A.Q. Khan network and Libya's past attempts to acquire nuclear weapons serve as reminders of the need for vigilance and cooperation in preventing the spread of nuclear weapons.

The world might be heading towards a scenario with three major peer nuclear arsenals each possessing significant capabilities and navigating a complex balance of power and deterrence, where maintaining strategic stability and understanding the dynamics of nuclear deterrence becomes increasingly complex. Deterring aggression and avoiding unintended escalation or miscalculation could be achieved through a combination of early warning systems, a robust and adaptable nuclear arsenal, diplomatic efforts, and investments in advanced technologies and capabilities. Challenges stem primarily from the rapidly expanding and evolving threats related to ballistic missiles, unmanned aerial systems and novel weapon systems.

In Mr. Albright's view, a tri-polar nuclear power world can be compared to the complex "three body problem" in physics, where the dynamics are more intricate than a two-body situation, leading to unstable solutions, where minor disruptions can cause significant changes in the system's behaviour. This highlights the increased complexity and challenges in maintaining stability in a tri-polar nuclear world. It would significantly demand more effort than what was required during the cold war. In response to this evolving landscape, the United States is integrating close coordination and synchronization among its allies and partners. To facilitate this integration, the US may need to ease its regulations on arms exports to its closest allies and partners. However, this will also require careful management to ensure that sensitive goods and technology are not obtained by adversaries, challenging allies and partners to control these items effectively. The speaker highlighted the dependency of other countries on western technological components for their military systems, using the example of the "Shahed 136" drone. Many electronic components in this drone are exclusively made in the West, and no Russian company can currently manufacture electronic integrated circuits critical to this drone. Mr. Albright emphasized the importance of Western governments, companies, distributors, and logistic providers focusing on the highest priority items, specifically electronic integrated circuits, which are a critical component in not only the Shaded 136 drone but other weapons fielded by Russia and Iran. Slowing the spread of these components and associated manufacturing capabilities to other countries is therefore a priority, as it can help reduce threat posed by Russia and maintain the technological edge of Western nations and their partners in the face of growing global competition and potential threats.

Some countries are lacking strategic trade controls as mandated by the UN Security Council Resolution - UNSCR 1540[18], which involves items related to Weapons of Mass Destruction (WMD) and their means of delivery. One growing idea is to establish an international standard for minimal export

controls, via the International Organization for Standardization (ISO). The aim is to set out best practice standards for national authorities and other agencies or organizations regarding the basic elements required for an effective strategic trade control system. This initiative was launched under the UK's leadership of the G7 Global Partnership CBRN (Chemical, Biological, Radiological and Nuclear) working group, and the UK has taken further steps to develop this idea. The Institute for Science and International Security is working on an initial draft ISO standard, which will be further developed in a multilateral context to promote the establishment of effective strategic trade control systems worldwide. Other international obligations and multilateral treaties require the implementation of controls over WMD and related goods, such as country-specific UNSC sanctions resolutions, as well as relevant obligations placed on state parties to the NPT, the Chemical Weapons Convention (CWC), and the Biological and Toxin Weapons Convention (BTWC). The development of an international standard for minimal export controls aims to promote the establishment of effective Strategic Trade Control (STC) systems worldwide, addressing the complex challenges and obligations faced by nations in preventing the proliferation of WMD and related goods.

Figure 4 David Albright, President of the Institute for Science and International Security, USA

Source: JRC

3 The selected Euratom Drivers 2057 - Factors, Forces and Challenges

3.1 Introduction on Euratom Foresight

The Euratom Foresight work carried out at the Joint Research Centre (JRC) of the European Commission, engages in an ongoing process known as Horizon Scanning to anticipate and identify emerging trends, challenges, and opportunities in the field of nuclear technology. The initiative is a testament to the JRC's commitment to providing evidence-based scientific support to EU policymaking, particularly in areas governed by the Euratom Treaty.

Horizon Scanning is a systematic examination of potential threats, opportunities, and likely future developments, including those at the margins of current thinking and planning. This process involves gathering intelligence and insights from a wide array of sources to inform strategic decision-making. The aim is not to predict the future but to prepare for it by analysing trends, assessing risks, and identifying emerging issues that could have significant implications for the nuclear sector.

The Euratom Foresight cycle encompassing the Horizon Scanning for nuclear technologies focuses on several key steps:

1. **Scanning**: This initial phase involves the collection and documentation of relevant information, news, and technological advancements from various sources. It is geared toward identifying "raw" data and new developments across different domains related to nuclear technology.
2. **Distilling**: In this phase, the gathered information is reviewed and prioritized. The most pertinent and thought-provoking ideas are selected for further discussion. These ideas are clustered into overarching trends that reflect the evolving landscape of nuclear technology.
3. **Sense Making**: During the sense-making workshop, the JRC brings together experts from different fields to discuss and reflect on the identified trends. The goal is to project these trends into the future and to anticipate the potential challenges and opportunities that may arise. This collaborative effort culminates in the creation of future scenarios that outline the possible states of the nuclear sector in the mid-term (2033) and long-term (2053) future.
4. **Deep Diving**: Following the workshop, webinars and discussions with external experts are organized to delve deeper into critical questions and issues that have been raised. These sessions aim to provide additional clarity and guidance on specific areas of nuclear technology development.
5. **Science for Policy Briefing**: The insights gained from the Horizon Scanning process are synthesized into concise briefs that are accessible to policymakers and stakeholders. These briefs highlight the critical findings and recommendations that can inform policy decisions and strategic planning within the Euratom framework.

Through this anticipatory approach, the JRC ensures that the EU remains prepared and responsive to the dynamic challenges and opportunities that the future may hold for nuclear activities.

The report titled "Long-Term Horizon Scanning for Nuclear Technologies Yearly Report – 2023"[3], as presented in the context, reflects the collaborative efforts of various JRC experts. The report aims to anticipate future developments, challenges, and opportunities in the nuclear sector up to the year

2053, aligning with the broader objectives of the Euratom Research and Training Programme and the European Commission's commitment to evidence-based policymaking. The document underscores the necessity of integrating foresight into the nuclear policy framework to ensure that the EU remains at the forefront of nuclear technology, safety, security, and safeguards.

A Horizon Scanning yearly report with the focus on nuclear technologies has been published since 2017. In order to make the critical issues identified more accessible to a broader audience, the following Science for Policy briefs of two pages were published at the JRC Publications Repository:

— Nuclear Hydrogen for Steelmaking (2024)[19]

— Nuclear power in space (2022)[20]

— Floating Nuclear Reactors (2022)[21]

— Radioactive Isotopes (2021)[22]

By collecting and analysing emerging trends and developments, the JRC equips EU policymakers with evidence-based insights to inform strategic decisions within the nuclear sector. The "Long-Term Horizon Scanning for Nuclear Technologies Yearly Report - 2023" and related Science for Policy briefs are key outputs of this process, ensuring that the EU remains at the cutting edge of nuclear technology, safety, and sustainability, while proactively anticipating future challenges and opportunities.

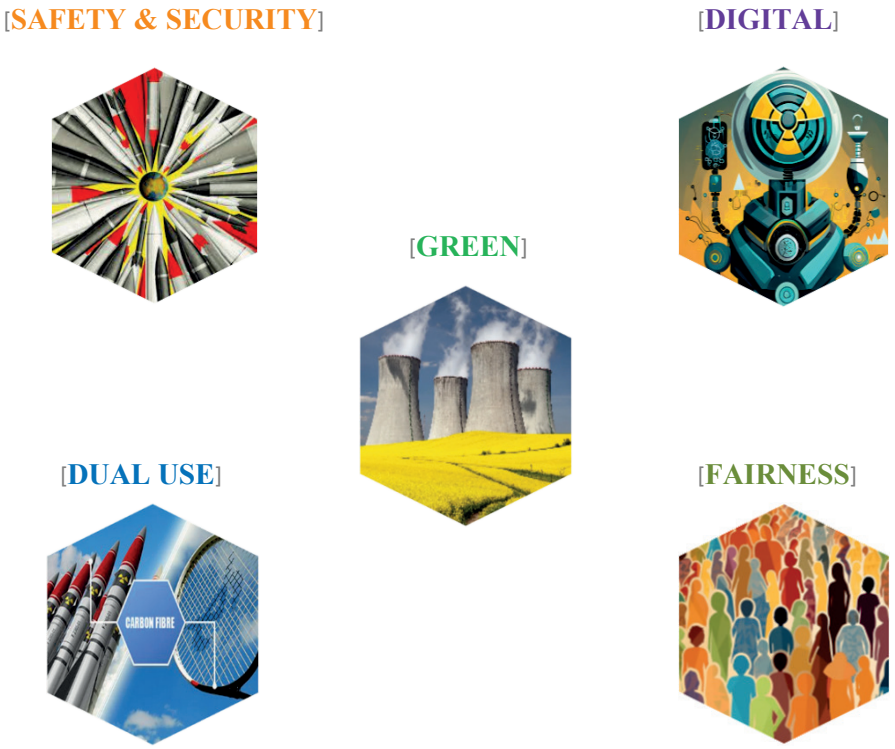
Figure 5 Euratom inspectors conduct safeguards inspections

Source: Dean Calma on IAEA Imagebank

3.2 The selected Euratom Drivers 2057

The JRC has reflected on its history and knows the strong relevance of its present activities. In this workshop the participants turned their attention to the future and were invited to "imagine the possible". They put their 'heads and hearts' together around 5 selected and admittedly not exhaustive Drivers 2057 of relevance to Europe:

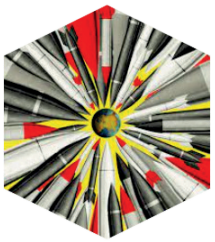
Figure 6 The selected Euratom Drivers 2057



Their framing and relevance to the JRC's and EC mandate were presented to all participants by the rapporteurs in dedicated sessions[ii]. In the following paragraphs only a short summary on the framing is given for each of the Euratom Drivers 2057. The outcome of the in-person and on-line foresight breakout sessions and from the common closing plenary are summarised in detail for each Driver and commented by the respective rapporteurs. Each paragraph closes with recommendations from the workshop participants to the JRC.

[ii] The complete set of presentations can upon individual request be made available. Contact: Gabriele.TAMBORINI@ec.europa.eu

3.2.1 Euratom Drivers 2057: SAFETY & SECURITY



3.2.1.1 Framing

The focus in this Driver was put on three burning issues:

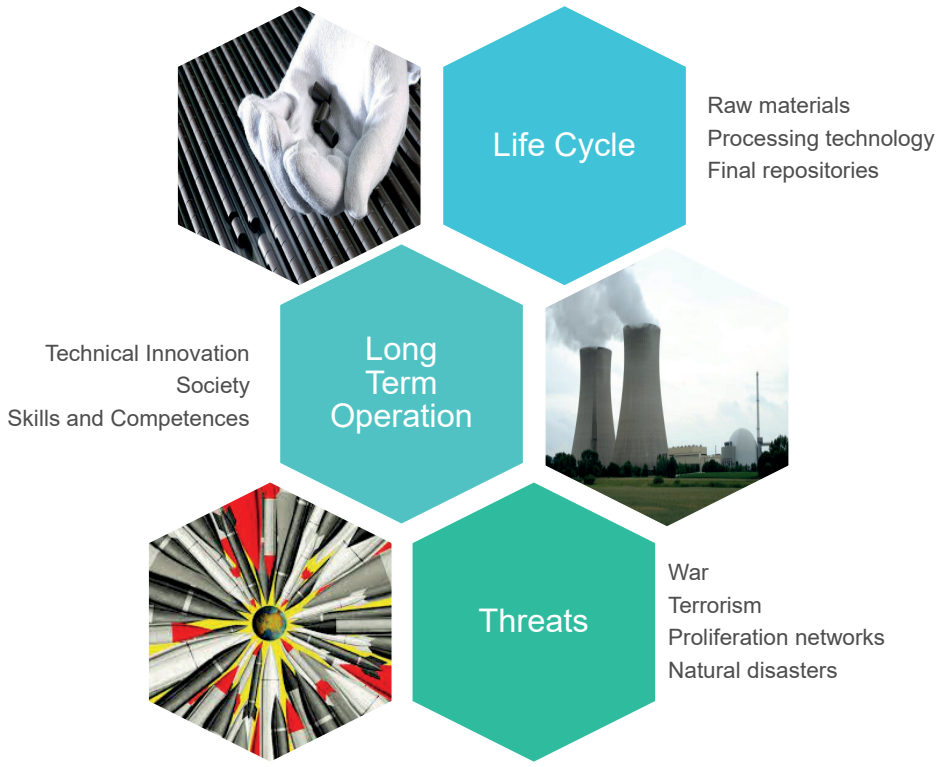
— Threats

— Lifecycle

— Long-term operation

Under each of these three topics a subset of points was given to guide the foresight discussion:

Figure 7 Topics and sub-topics of the Safety & Security Driver 2057



From top left to bottom right:
Source: Nuclear Fuel Pellets on Wikimedia Commons
Source: Massimiliano Saltori on Earth.org
Source: JRC on licenced Adobe Stock

— Threats

- Attacks to nuclear facilities by state or non-state actors
- Climate change leading to extreme weather conditions (e.g. floods, droughts)
- New wave of illicit trafficking of nuclear materials
- Dirty bombs" (RDD)
- "Emerging" nuclear weapons states

— Life cycle

- Availability of raw materials, e.g. IAEA's LEU bank, HALEU
- Energy independence (incl. SMRs and micro-reactors)
- Closed vs. open cycle (economics)
- Processing of fuels from new reactor types
- Waste management and decommissioning
- Science helping "Not in my term of office (NIMTOO)" (governments and regulators)

From left to right:
Source: Reactor core from above - Lowell on Wikimedia Commons
Source: https://www.iaea.org/topics/iaea-low-enriched-uranium-bank on IAEA Imagebank
Source: Nuclear waste image on pixabay
Source: Nuclear Fuel Pellets on Wikimedia Commons

— Long Term Operation

- Europe's nuclear reactors are getting old – ensure and enhance operational safety
- New methods for assessing ageing of reactor components
- Acceptance by society
- Knowledge Management and transfer to the young generation

3.2.1.2 Key questions

— The participants in the break-out session, experts on nuclear security, safety and safeguards from EU Member States, were invited to reflect and answer to the following questions: What are some possible future 2057 scenarios for Nuclear Safety and Security?

— What can we do today concerning Nuclear Safety and Security to prepare for 2057?

— What are some potential disruptions for Nuclear Safety and Security?

— What resources and competences should the JRC be investing in now to be better prepared for 2057?

— What could be the role of the JRC?

3.2.1.3 Breakout and plenary sessions on factors, forces and challenges

When discussing the future of nuclear energy, advanced nuclear reactor types, e.g. Molten Salt Reactors (MSRs), and Small Modular Reactors (SMRs) are "hot" topics. However, questions related to safety, security and safeguards need to be answered before they can be licensed for commercial use. Although MSRs are not a novel technology, they are a promising option for SMRs, and the development of such technologies has resumed in many countries. For MSRs a reason for concern is that there is no adequate safeguards concept (e.g. sampling, measurements), therefore currently they represent an increased risk for proliferation. Thus, in short term, development of a sampling concept and measurement methods for analysis of new fuel types are required.

The SMRs are currently being developed in many countries, including in the EU. There is a high interest at having them employed as they can be installed in locations, which are not suitable for large nuclear power plants (e.g. near big cities or very remote locations without infrastructure). However, due to their design with reduced human intervention and the feasibility of having them "in your back yard", the discussions revealed security concerns e.g. reduced physical protection, cyber security. Also, as the safety requirements for new reactors differ currently from country to country, a harmonized approach on what is "safe enough" for the SMRs would be beneficial.

A recommendation that came up is that all new reactors should be planned considering a "safeguards by design" concept. Experience has shown that introducing safeguards requirements at a later stage in the reactor's lifecycle is very expensive and labor intensive.

Potential disruptive factors brought up were:

— Supply of raw material: there is a limited number of providers for raw materials (uranium), and the supply chain can be disrupted by political instability. Finding new sources and production places for nuclear material will help mitigating this issue. Furthermore, development of innovative fuels (e.g. Thorium-based fuel) helps to complement the existing supply.

— Infrastructure and skilled people: maintaining the skills and building new competences in the nuclear field is essential for the future. The interest in the nuclear field has decreased in the last decades but in the view of the "nuclear renaissance" and of the continued nuclear work force requirements, there is an urgent need to educate new generations in this field. Equally important is to maintain the aging nuclear infrastructure for the future use.

The existing nuclear power plants are an equally important factor in the energy strategy in many countries, especially in the current context of increased energy demands, political instability and climate change mitigation goals. Currently, the EU Nuclear Safety Directive (2014/87/Euratom)[23] requires a safety re-evaluation for all nuclear power plants to be conducted at least once every 10 years. This 10-year frequency is found to be too restrictive as the process is long and by the time one safety review is ready the next one is due to start. Instead of every 10 years reassessment, 20 years would be preferable from the economical and implementation point of view.

Figure 8 Safeguards inspection at enrichment plant

Source: Dean Calma on IAEA Imagebank

3.2.1.4 Recommendations to the JRC

In this context, JRC could:

- Provide independent and excellent research on new reactor technologies and fuels
- Continue to play a central role in translating science to the policy makers
- Collect and analyse feedback from Member States and support Euratom to produce recommendations for safety and security

Moreover, JRC must increase its visibility, especially at the political level in the Member States.

JRC needs to be first known, before it can be trusted by the Member States and to be reached out for independent expertise!

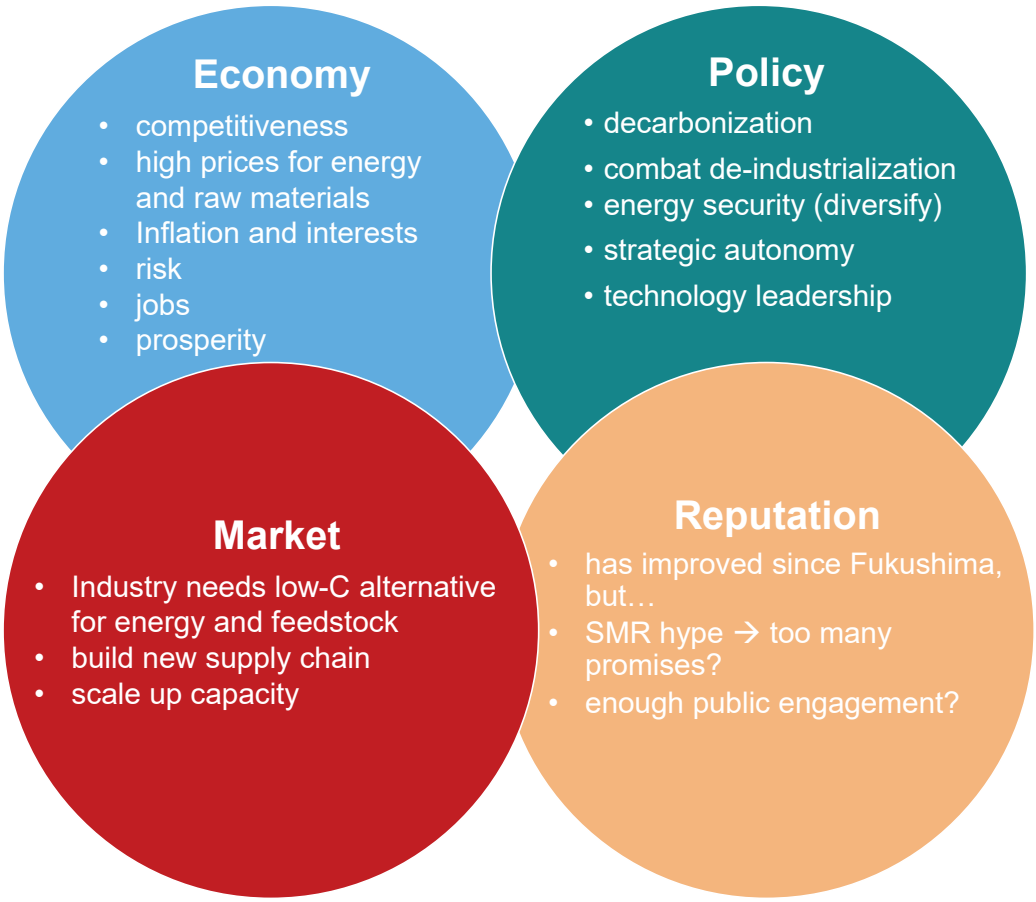
3.2.2 Euratom Drivers 2057: GREEN

3.2.2.1 Framing

Figure 9 below summarises some initial ideas regarding drivers and brakes for decarbonisation and the possible role of nuclear in this. An effort has been made to categorise them under 4 headings (Economy, Policy, Market, Reputation) although there is for sure some overlap in the categories. E.g. political decisions can have an influence on the economy and the market as well as economy and market can lead to political decisions. Public opinion influences politics as well.

The interaction between all these forces (drivers and brakes) led to the key questions for the discussion.

Figure 9 Topics and sub-topics for framing of the Green Driver 2057



3.2.2.2 Key questions

- What are the prevailing forces in your own countries/organizations/companies?
- Which ones are stronger? Is there a trend? Why?
- Should anything be done about it?
- What would need to be done in addition?
- What scenarios do you expect in the next 25 – 30 years for nuclear and decarbonisation?
- Relevance and Consequences for JRC today and in 2057?

3.2.2.3 Breakout and plenary sessions on factors, forces and challenges

In the group dealing with the drivers and brakes for decarbonisation with nuclear energy, there was a non-representative composition of the group, which has probably led to some bias. After a cross-introduction, several participants emphasized the threats of nuclear power, one was neutral and one pointed out the opportunities and benefits.

Some takeaways from the ensuing discussion are the following:

Several participants mentioned a significant change in public acceptance and engagement, and evolving opinions about the role of nuclear in current and future energy systems. It was mentioned that in the past, the nuclear community was often associated with arrogance, which had durably tainted its reputation. Today, in contrast, most nuclear proponents put forward a shared desire to support climate change mitigation efforts.

Several participants pointed at a lack of alternatives to nuclear energy, considering the anticipated growth in electricity consumption[24, 25] due to increasing electrification and other effects. However, the needs in EU Member States are very dissimilar depending on factors such as geography or the degree of industrialization. Also the attitude and cultural background of Member State populations ("the national psyche") seems to play an important part when it comes to acceptability of nuclear energy.

In Euratom, the unanimity of decisions has led safety, security and safeguards to become the smallest common denominator. The question was asked whether this narrow focus would not make the population (and the JRC) blind for the advantages of nuclear energy.

As a positive driver for nuclear it was mentioned that several European regulators are now working together on licensing of certain SMR models. A role for the JRC in recent developments (SMR Industry Alliance) still needs to be agreed upon.

The question/observation was raised whether the positioning of the nuclear directorate at the JRC in an anti-nuclear country has an impact on the attitude and ultimately on the nuclear work programme of the JRC. Some participants thought that after the taxonomy report[26], the JRC was "indelibly stamped" pro-nuclear.

Nuclear at the JRC needs a rejuvenation across all teams and needs to use more modern methods, including for communication to reach its customers and the population. It also needs to employ more holistic multi-criteria assessments of the drivers and brakes regarding nuclear energy for decarbonisation.

Source: Konzept der Harmonie und Gleichgewicht on iStock

3.2.2.4 Recommendations to the JRC

— There might be a coordinating role for the JRC in Technology Platforms or other EU initiatives for the promotion of international collaboration (e.g. regulator cooperation on SMR,…

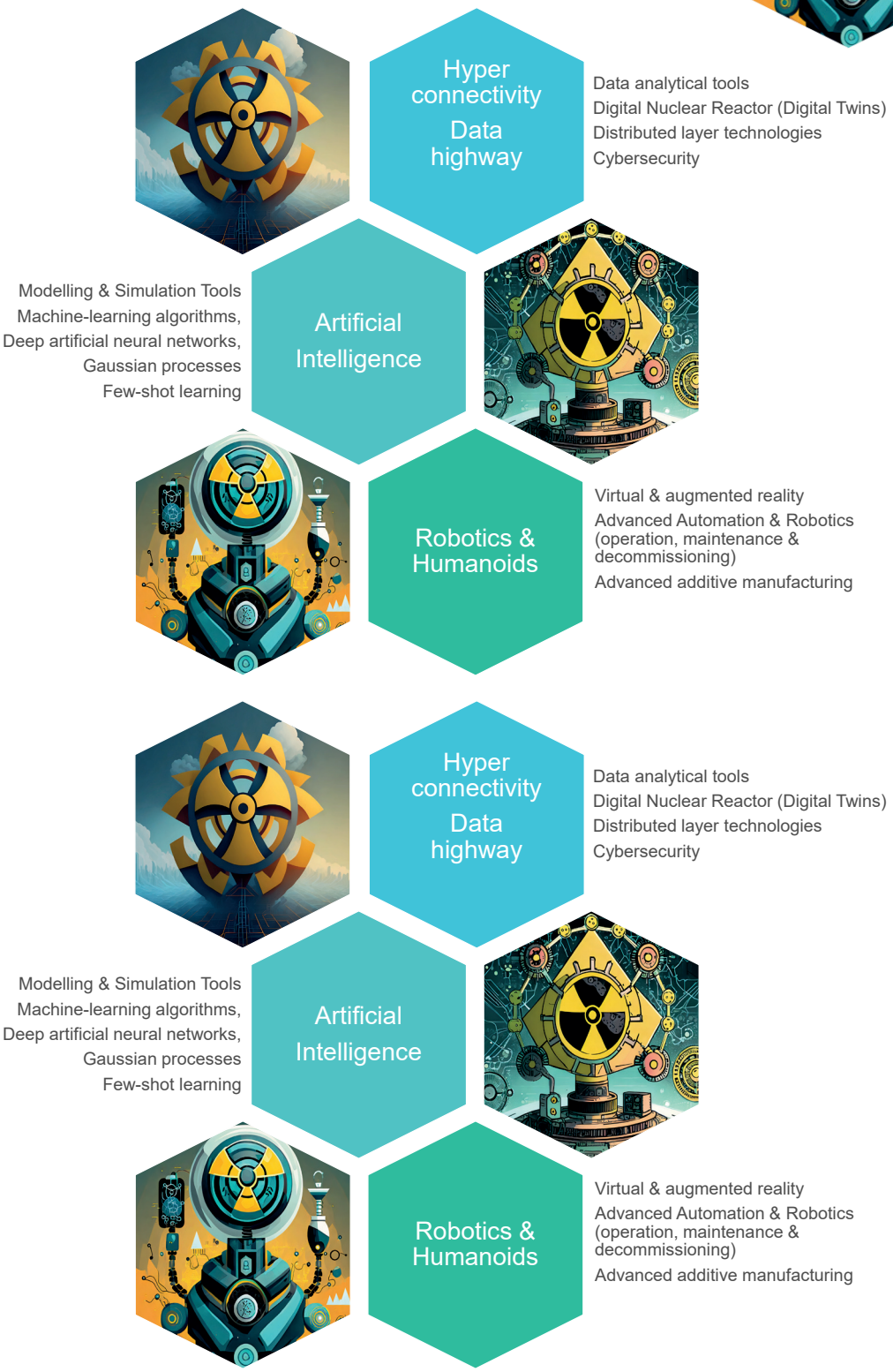
— JRC can play an important role in training and education of the younger generation in nuclear; an increasing interest in nuclear will require additional qualified workforce.

— JRC is encouraged to keep a holistic approach to its assessments, remaining factual, integrating pros and cons; this should help erasing the pro-nuclear stamp JRC has in the eyes of some since the JRC supports all Member States regardless of their choices of energy mix[27].

3.2.3 Euratom Drivers 2057: DIGITAL

3.2.3.1 Framing

Figure 10 Topics and sub-topics for framing of the Digital Driver 2057.



Source: JRC on licenced Adobe firefly

Once upon a time, business as usual was good enough. Not anymore. Science fiction is becoming science fact. Think of self-driving cars or computers that can learn and think. This century saw an exponential increase in digitalisation in society. These changes amplify each other. Quantum computing fuels big data, the internet-of-things fuels artificial intelligence, which fuels robotics.

There are multiple benefits of incorporating digitalisation into production and control, and the nuclear industry must adapt to this revolution to achieve its full potential. Full potential that can help reach the net-zero carbon emissions 2050 target.

Digitalisation is broad, encompassing several topics, and for the ease of discussion, they were grouped into three major themes, all interconnected.

Data and networks, Artificial intelligence (AI) and Robotics

In major engineering industries, significant digitalisation is ongoing. For example, the Industry Internet of Things (IoT) which allows for more efficient predictive maintenance and easier failure detection has an essential impact on safety and costs.

A next step is the creation of a digital twin, which allows for advanced process simulation and modelling and optimisation of the design and processes. There are many initiatives for standardisation and increased security, such as the introduction of the blockchain technology.

A major concern in all of these is cybersecurity.

Digitalisation creates large quantities of data. Machine learning is essential for such analyses. The introduction of AI allows for the optimisation of complex procedures, can help improve the detection of anomalies and intruders, and can improve the efficiency of radiation protection. Moreover, in safeguards, AI can help nuclear inspectors analyse the multitude of data they have to treat.

The nuclear is typically an industry in which automation and robotics are ideal solutions for the hazardous working environments. Several of these are already mature, especially in the field of decommissioning, where timeliness will be reduced for several years or decades. Furthermore, the use of autonomous robots will help bridge the skill gap looming at the horizon.

However, let us remember that human-only traits, such as creativity, imagination, intuition, emotions, and ethics, will be even more important in the future. Machines are good at simulating, but not at being.

3.2.3.2 Key questions

What will the future look like? What are the enablers and barriers for digital transformation? The participant of the workshop discussed the following key questions:

- What are some possible future 2057 scenarios?
- What are the principal enablers?
- What is standing in the way for success?
- What resources and competences should be invested
- What could be the role of the JRC/Euratom?

3.2.3.3 Breakout and plenary sessions on factors, forces and challenges

The following examples were used to guide the participants:

— Hyper connectivity Data highway - data analytical tools, digital twins, distributed layer technologies, cybersecurity

- Virtual replicas for nuclear design and simulation
- Predictive maintenance, downtime reduction, aging, and degradation management in future reactors
- Real-time information for oversight & compliance monitoring
- Avoiding/reducing the severity of emergencies and incidents
- Block chain technology for nuclear material accountancy
- Cyber security - perceived weakness

— Artificial Intelligence - modelling & simulation tools, machine-learning algorithms, deep artificial neural networks, Gaussian processes and few-shot learning

- Radiation protection
- Few-shot learning for nuclear forensics
- Real time monitoring and diagnostics in a NPP
- Reducing number of repetitive inspectors' tasks

— Robotics & Humanoids - reality capture, virtual & augmented reality, advanced automation & robotics

- Remote monitoring
- Sort and segregate (waste streams)
- Size reduction (laser cutting reduce waste volumes)
- Robotic welding for seal transport containers
- Glovebox operations (remote robotic arms)
- Immersive visualisation for design, review, training and site support
- Plugging the skills gap

Possible future scenarios were looked at from 4 angles:

- Optimistic Integration: In this scenario, digital technologies seamlessly integrate into nuclear operations, enhancing safety, efficiency, and sustainability. Advanced AI and automation support decision-making, and cybersecurity measures ensure robust protection against threats.
- Fragmented Innovation: This scenario envisions a future where digital transformation in the nuclear field is fragmented, with various technologies evolving independently. Lack of standardization may lead to challenges in interoperability, but pockets of innovation could emerge in specific areas of nuclear technology.
- Revolutionary Disruption: This scenario anticipates a disruptive transformation where emerging technologies, such as generative AI, revolutionize nuclear processes. Strategic foresight and effective policy frameworks facilitate a rapid and radical shift in the nuclear field.
- Regulatory Hurdles/ Public Pushback: In this scenario, stringent regulatory frameworks impede the rapid integration of digital technologies into the nuclear sector. Concerns over safety and security slow down the adoption of innovative digital solutions/ public concerns about the safety and security of nuclear power plants in the digital age led to resistance against the adoption of new technologies. This could result in a slower pace of digital transformation, highlighting the importance of public engagement and transparency in the nuclear industry.

The ensuing enablers, barriers and resources and competences have been identified:

ENABLERS

— Appropriate available and yet to be developed digital technology/innovation/industrialisation

— Adaptive AI/digital/sustainable technology which preserve natural resources and produce less waste/

— Opportunities for engineers and researchers

— Attractiveness of new working environment with better life-work balance/reduced need to relocate and travel

— Longer-term benefits/business model with long-term vision

— Investments/funding

— Employee: training, communicate changes and emphasize incentives, and encourage questions

— Cybersecurity: available technology to guarantee it

— Increased computing power (and electricity)

BARRIERS

— Change resistance/fear of change/risk averse culture/employee pushback/cultural rigidity

— Security concerns

— Budget/costs/lack of resources/initial investment costs

— Too many tools, too little time/lack of digestible steps

— Lack of technical expertise/shortage of IT skills

— No clear vision/lack of understanding/lack of overall strategy

— Regulation/authorities/licenses

— Legacy systems

— Industry specific challenges

RESOURCES AND COMPETENCIES

— having the right, digital-savvy leaders in place

— building capabilities for the workforce of the future

— empowering people to work in new ways

— giving day-to-day tools a digital upgrade

— communicating frequently via traditional and digital methods

— investing in talent

— laying out clear priorities

— committing time and money

— embracing agility

— empowering people

— Go-to-market strategies

The discussions concentrated around data, regulators and governments, the human factor, cyber-security, public acceptance and the JRC role.

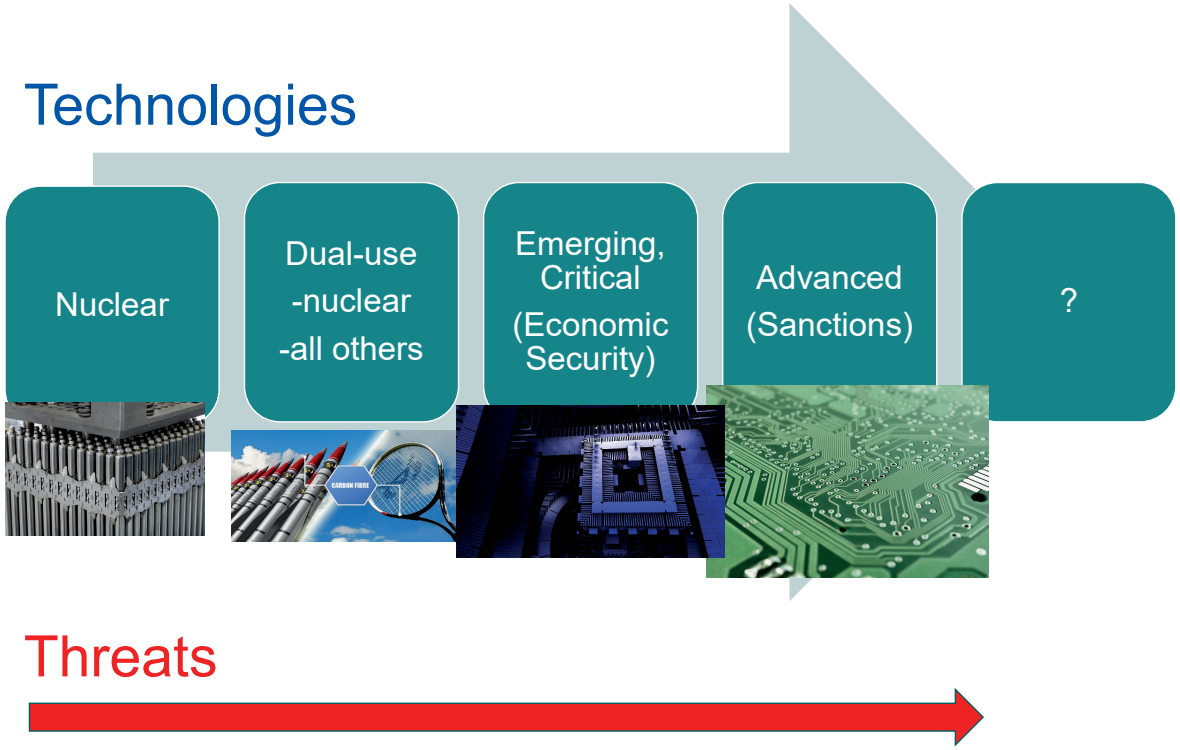
From top to bottom:
Source: virtual reality; image SNC-LAVALIN
Source: X-8 multicopter in action at the BR3 site; image SCK-CEN
Source: quadrupedal robot ; Image ONKALO®

3.2.3.4 Recommendations to the JRC

All participants regarded the JRC as a very reliable organization with an important role to play to enable digitalization in the nuclear field. The JRC is ideally placed to form a bridge between the main stakeholders. According to the participants of the breakout session, access to data is primordial for successful digitalization. Again, an important role for the JRC was mentioned. Most of the participants were optimistic with respect to the nuclear industry being capable to overcome several of the barriers proposed, such as cyber-security and public resistance, and were sure the enablers will realise themselves.

3.2.4 Euratom Drivers 2057: DUAL USE

3.2.4.1 Framing



From left to right
Source: Nuclear image on pixabay
Source: JRC on licenced Adobe Stock
Source: Pete Linforth on pixabay;
Source: Michael Schwarzenberger on pixabay

Strategic, or dual-use, items have both civil and military applications. Since the 80's, undeclared weapon proliferation programmes are largely based on the illicit procurement of a wide range of dual-use equipment, materials, software and technologies. A known example of nuclear "dual-use" proliferation was the AQK Pakistani network, which succeeded to by-pass the "nuclear safeguarded facility-based export controls" set-up by the Nuclear Suppliers Group after the India nuclear test of 1974. The nuclear export control regime was the first to be set up in 1974, following the NPT's entry into force in 1970 and the Indian "peaceful explosion".

After nuclear export controls, other international export control regimes were established to define guidelines for the control of chemical, biological and missile technologies, as well as the whole spectrum of dual-use technologies ranging from telecommunication to industrial equipment, from sensors and lasers to navigation systems, etc.

The resulting Strategic trade controls (STC) framework restricts and monitor the trade in products with both military and non-military uses. Its aim is to stop these 'dual-use' goods from being used to produce weapons of mass destruction. The rise of global supply makes it easier for dual-use items to fall into the wrong hands. Illicit procurement networks constantly attempt to acquire dual-use items, including software and know-how, from suppliers in the EU and other technology holders.

Export controls apply to the goods identified by the Regimes, integrated into the so-called "EU dual-use control list" (Annex I to Regulation 2021/821) and similar lists of other countries. Controls and authorisations are implemented also to "non-listed items" under conditions specified in the regulation. This applies to emerging, or critical technologies, not yet under control due to the lengthy decisional procedures of the Regimes, which however have an increasing economic and non-proliferation relevance.

The JRC started in 2020 his policy support developments on nuclear export controls as part of its nuclear safeguards and non-proliferation activities. This led to gradually realise that also non-nuclear dual-use items had a great relevance (electronics, bio, chemicals, sensors and lasers, navigation equipment, telecommunication, industrial processing). For these reasons, Dir. G had to broaden its multi-disciplinary competence spectrum by establishing cross-JRC collaborations.

As a result of these developments, since 2010 JRC executes activities supporting DG TRADE in the harmonised implementation of export controls by all EU-27, aiming at a global level playing field. These activities include the annual amendment of the EU dual-use control list based on the export control regimes' decisions, capacity building for national authorities, direct technical support to national licensing authorities through the operation of the EU dual-use Pool of experts, analyses of trade data and of denied export authorisations.

The EU implements also a large export control cooperative programme in more than 30 countries. Since 2013, the JRC provides support to the Service for Foreign Policy Instrument by monitoring and analyses the results of the cooperation projects, as well as analyses for the selection of priority countries and knowledge management.

JRC also executes own research for better support, analysis and anticipation of needs. Examples are: the Export control handbook for Chemicals, useful to authorities and export compliance officers, and the TIM Dual-use web-platform.

The JRC supports also the amendment of EU sanctions, e.g. against DPRK, Iran and the Russian Federation: very intensive measures were adopted in 2022 in response to Russia's invasion of Ukraine, amending the existing EU 2014 sanctions.

3.2.4.2 Key questions

- What are some possible future 2057 scenarios?
- What could be the main threats?
- What could be the main benefits?
- What resources and competences should be invested?
- What could be the role of the JRC?

3.2.4.3 Breakout and plenary sessions on factors, forces and challenges

It's (nearly) all about technologies!

— Developments

— International crises

— International Treaties Multi-lateral export controls

— Geopolitical threats / economic interests

The international political framework's drivers are focussed on dual-use, advanced, critical and emerging technologies seen as an opportunity of trade and development, as well as economic strategic autonomy and geopolitical/economic leverage.

Trade agreements facilitate exchanges while export controls do not prohibit trade but introduce an authorisation process to protect legitimate transactions and prevent illicit military developments. Sanctions represent the extreme measure, prohibiting trade in certain goods in order to limit the economic revenues and proliferation programmes of certain countries.

— Developments

- AI
- Quantum technology
- New nuclear reactors
- New nuclear fuels
- Easier uranium enrichment and plutonium separation processes
- New manufacturing processes (AM 3D printing)

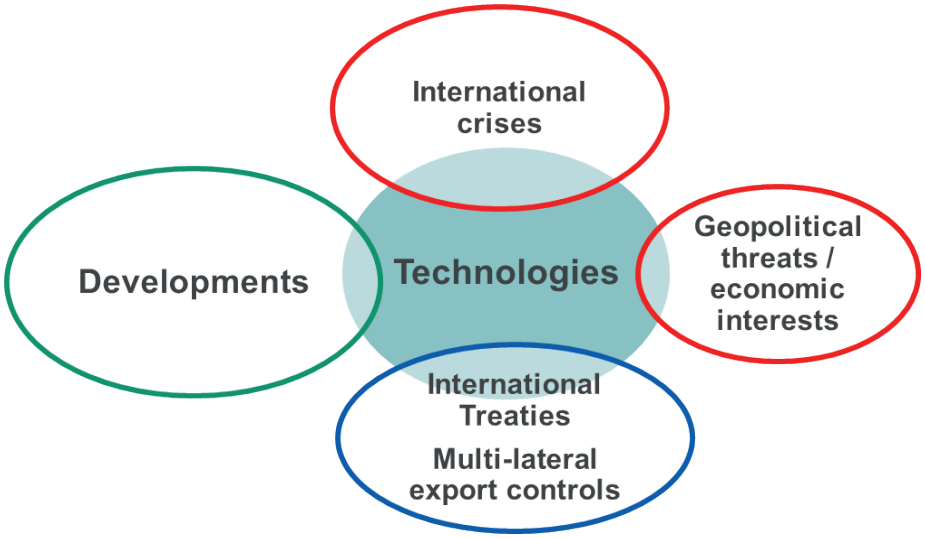
Besides the dual-use technologies currently considered and addressed by the control framework, the breakout group identified other technologies to be kept in mind as new opportunities, such as Artificial Intelligence, with a limitless applications, and various nuclear technology developments.

At the same time, there are new threats, which should be considered for the improvement of the trade control framework to curb military and proliferation programs.

— Threats

- Spread of semiconductors manufacturing capabilities
- More sophisticated trade networks
- Delivery systems, UAV
- (change) countries' geopolitical ambitions and policies
- arms race and emerging nuclear states
- New nuclear weapons production (e.g. 3D printing)

Figure 11 Topics and sub-topics for framing of the Dual Use Driver 2057



3.2.4.4 Recommendations to the JRC

— JRC towards 2057 ?

- Continue developing multi-disciplinary competences (resources)
- Carry out research in anticipation
- Understanding key elements (e.g. drone components), forensics analysis
- Analyse supply chain and circumvention patterns
- Raise awareness (internal and outreach) on non-proliferation
- International cooperation and exchanges

3.2.5 Euratom Drivers 2057: FAIRNESS

The future of nuclear energy production is at a critical juncture, with polarisation, fairness in access to technology, and geopolitical tensions playing significant roles. As we look towards the year 2057, it is crucial to examine the key factors and forces shaping the nuclear industry and the challenges it faces. The role of Euratom in ensuring fair access to nuclear technology and knowledge is of paramount importance, as is the need to guarantee reliable nuclear energy production even in a polarised world.

3.2.5.1 Framing

This section highlights the impact of fairness, peace, and prosperity on the development of nuclear technologies. It emphasizes that unfairness and fear lead to increased polarisation, which acts as a barrier to technological development. On the other hand, fairness, peace, and prosperity contribute to the development of nuclear technologies. The scenario presented suggests that by 2057, there will be an increase in energy transition and nuclear energy production.

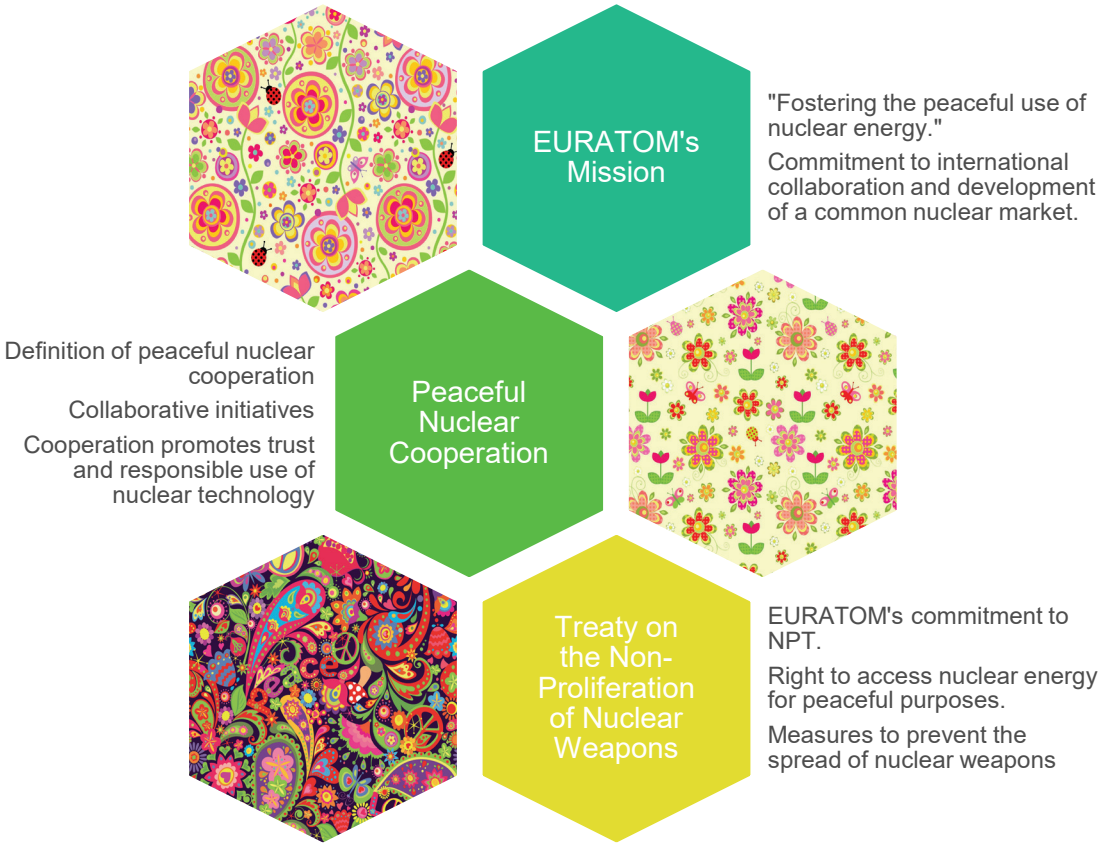
The role of Euratom in peaceful nuclear cooperation and the challenges it faces, such as nuclear waste legacy, non-proliferation, and safety is of growing importance. The commitment of Euratom to the treaty on the non-proliferation of nuclear weapons, emphasizes the right to access nuclear energy for peaceful purposes but also supports measures to prevent the spread of nuclear weapons.

The following **Figure 12** poses several stimulating questions related to the role of fairness, peace, and prosperity in driving nuclear technologies by 2057. The questions address issues such as guaranteeing reliable nuclear energy production in a polarized world, ensuring fair access to nuclear technology and knowledge, and managing the peaceful use of nuclear energy in an aggressive world.

Additionally, the importance of equitable distribution of nuclear advancements, the economic dimensions of fairness in nuclear development, and the responsible and inclusive utilization of nuclear energy was emphasised. The session highlighted the societal and economic benefits of nuclear energy and its contribution to societal needs in electricity, heat, and hydrogen production by 2057.

Further, the forces and factors influencing the development of nuclear energy were addressed. The need for building competences, strategic autonomy, visibility, and credibility to guarantee reliable nuclear energy production in a polarized world was discussed. There is a clear role for Euratom in ensuring fair access to nuclear technology and knowledge, covering aspects such as training, access to electricity, fairness in Africa, and research and innovation in medical, space, and energy applications.

Figure 12 Topics and sub-topics for framing of the Fairness Driver 2057



3.2.5.2 Key questions

How can reliable nuclear energy production be guaranteed in a polarised world?

Building competences, retaining young talents, and ensuring strategic autonomy in the nuclear industry are essentials of the roadmap to guarantee reliable nuclear energy production in the future. The need for visibility, credibility, and purpose in nuclear industrial innovation, particularly in applications such as medical, space, and energy sectors, is equally paramount. Financial instruments and responsible use of the Euratom treaty are essential factors in guaranteeing reliable nuclear energy production. The question highlights the challenges of maintaining stability and progress in the nuclear energy sector amidst geopolitical polarisation.

How can Euratom ensure fair access to nuclear technology and knowledge?

Ensuring fair access to nuclear technology and knowledge involves nurturing a healthy nuclear culture through training and education initiatives, providing access to electricity and energy mix, and enabling open access for non-EU countries. Fairness in Africa and the management of resources, such as uranium, are crucial aspects of promoting equitable access to nuclear technology. Furthermore, research and innovation in medical, space, and energy applications are essential for fostering fair access to nuclear technology and knowledge. A key role is played by the ESFRI roadmap and the European Charter to Access Research Infrastructure[28] which has been adopted to provide a fair access to JRC nuclear infrastructures.

How does the fairness driver shape the role of the JRC towards 2057?

The fairness driver, characterized by principles of peace, prosperity, and fairness, significantly influences the role of the JRC towards 2057. The JRC is tasked with addressing challenges related to polarisation, autonomy, tribalism, and resilience, while ensuring a safe and inclusive environment for nuclear development. The JRC aims to foster industrial nuclear development, reduce cultural, economic, and legal barriers, and promote growth and prosperity in the nuclear energy sector. The role of the JRC towards 2057 is shaped by the need to navigate geopolitical challenges and promote fairness, peace, and prosperity in the development of nuclear technologies.

3.2.5.3 Breakout and plenary sessions on factors, forces and challenges

Critical challenges and opportunities facing the industry have been assessed in the session. In addressing the question of how to guarantee reliable nuclear energy production in a polarised world, global forces of polarisation, autonomy, and tribalism have been identified as potential barriers. However, with the strategic resilience and safety provided by Euratom, the EU is better equipped to navigate these challenges and maintain a secure nuclear energy landscape. The lessons learned from the complexities of providing a complete new nuclear country program for a newcomer have emphasized the importance of exploring Small Modular Reactors (SMRs) as a reasonably easier and less risky solution. Furthermore, the risk of countries weaponising peaceful technologies underscores the need for vigilant oversight and strategic management, as demonstrated by historical events such as Japan's potential nuclear weaponisation[29] or the Atom for Peace initiative that has led in some cases to proliferation attempts. Current global threats and insecurity are fuelling situations in which outspoken advocates against nuclear weapons are re-evaluating their position. These actions would severely undermine the Non-Proliferation Treaty. The only barrier may be the strength of strong international alliances.

In addressing the factors related to how Euratom can ensure fair access to nuclear technology and knowledge, a multi-angled approach has been proposed. This includes fostering industrial nuclear development and reducing cultural, economic, and legal barriers to promote growth and prosperity. Building competences in Europe, as well as retaining young competences, is essential, especially considering the trend of countries exiting nuclear energy production. Strategic autonomy, visibility, and credibility in the nuclear industry, particularly in applications such as medical, space, and energy sectors, have been emphasised. Additionally, the focus on nuclear industrial innovation to build prosperity and support to Small and Medium-sized Enterprises (SMEs) is crucial. The need to ensure that financial instruments of the Euratom treaty are used strictly within the limits of the treaty especially in the domains of application and aims.

3.2.5.4 Recommendations to the JRC

The fairness driver has a significant impact on shaping the role of the JRC towards 2057. The recommendations put forward include nurturing a healthy nuclear culture through training initiatives, ensuring access to research infrastructures, and exploring opportunities for open access to non-EU countries while making fair decisions. Engaging in fairness initiatives in Africa and effectively managing resources to benefit from the increasing demand for uranium are also crucial aspects. Furthermore, developing competences and addressing the economic, societal, and strategic dimensions of fairness will be instrumental in shaping the role of the JRC towards 2057.

The fairness breakout session has provided awareness into the forces and factors influencing reliable nuclear energy production and fair access to technology and knowledge. The recommendations to the JRC underline the importance of aligning efforts using the fairness driver to shape the future of nuclear energy development.

3.2.6 Online Session on all 5 selected Euratom Drivers 2057

3.2.6.1 Framing

Points of discussions in the online breakout session

— Introducing the spent nuclear fuel in the circular economy

— The future role of JRC: informing or advising European citizens

3.2.6.2 Key questions and summary from the online breakout session (using SLIDO)

— Q1: Which particular factors (specific technologies, social dynamics, (geo)political developments etc.) you expect having the greatest impact on the future development of nuclear technology?

- Economy; geopolitics

— Q2: By 2057 how likely is, in your opinion, that the nuclear European market is an actual integrated single market with common regulations and standards?

- Somewhat likely

— Q3: How many EU countries do you expect to have Small Modular Reactors by 2057?

- Five to ten

— Q4: By 2057, where would you expect to find more floating nuclear reactors?

- Asia

— Q5: Considering the current differences in public perception of nuclear technologies between EU members, how will this evolve in your opinion, by 2057?

- The division between nuclear friendly and anti-nuclear countries will remain highly controversial and divisive

— Q6: By 2057, in your opinion, how many countries that today do not have nuclear weapons will have managed to acquire them?

- Between three and five

— : Q7: Which would be, in your opinion, the first Space Agency to deploy a small or micro nuclear reactor on the moon to power a human settlement?

- China National Space Administration (CNSA)

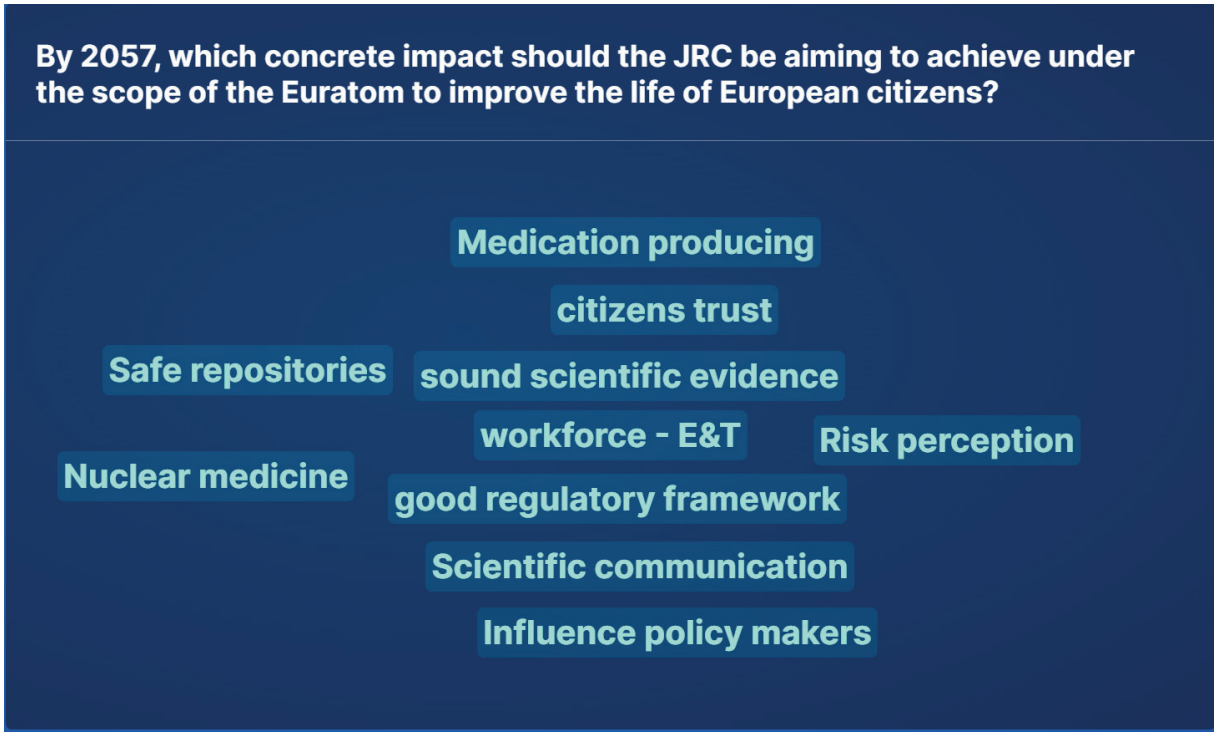
— Q8: By 2057, what very concrete and direct benefit coming from nuclear technology will citizens be able to enjoy?

- Affordable energy

— Q9: By 2057, what very present threat, disturbance or inconvenience coming from nuclear technology will citizens have to endure?

- Waste, mining, public fear

3.2.6.3 Recommendations to the JRC



4 What happened since….

Every single moment of our lives takes place *Between Past and Future*[iii] but 'the gap' between them has many 'shades' depending on physical definition[iv], individual perception and believes and (common) points in history. This JRC nuclear foresight workshop was held end of 2023, and it seems just at the right point in time between past and future. Since then, initiatives and events of European and global importance were launched relevant to the Euratom Drivers 2057 and to the recommendations put forward by the workshop participants. In addition, the ESPAS Launch of the 2024 Global Trends Report[30] took place in the library of the European Parliament in Brussels.

Some of the workshop recommendations have been put forward by the authors of this report to the JRC management preparing for the New Commission. Particularly in the JRC briefing books and in the JRC note for the new Commission *"What science tell us - A spotlight on 15 policy issues for the future"* that are currently in preparation[31] selected issues related to the 5 Euratom Drivers 2057 were deemed by JRC researchers as relevant for EU policymaking during the next mandate and beyond.

To give a more comprehensive picture, the authors would like to draw the attention of the readers to some of the most recent initiatives, policies and events that, to our opinion, will definitely shape the future for nuclear safety, security and safeguards and should be taken into consideration in any follow-up nuclear (and non-nuclear) foresight discussion.

Source: Nuclear Energy Summit 2024 on IAEA Imagebank

[iii] *Arendt, Hannah (2006) [1961, New York: Viking]. Between Past and Future. Penguin Publishing Group. ISBN 978-1-101-66265-6.*

[iv] Statement attributed to Albert Einstein: "*People like us, who believe in physics, know that the distinction between past, present, and future is only a stubbornly persistent illusion*"

Table 1. Recent initiatives, developments and releases shaping the future of nuclear safety, security and safeguards

— SAFETY & SECURITY

- First Nuclear Energy Summit held[32]
- JRC activities for a safe and secure nuclear in Europe - *Side event of the Nuclear Energy Summit*[33]
- European Nuclear Alliance Leader's declaration[34]
- Nuclear Safety, Security and Safeguards in Ukraine[35]
- EU statement on nuclear safety, security and safeguards in Ukraine[36]
- CSNI Technical Opinion Paper No. 21: Research Recommendations to Support the Safe Deployment of Small Modular Reactors[37]
- The Joint Research Centre supporting nuclear safeguards[38]
- Revision of the regulation on the application of the Euratom safeguards[39]

— GREEN

- COP28 recognises the critical role of nuclear energy for reducing the effects of climate change[40]
- US New Steps to Bolster Domestic Nuclear Industry and Advance America's Clean Energy Future[41]
- Net-Zero Industry Act: Making the EU the home of clean technologies manufacturing and green jobs[42]
- Net-Zero Industry Act: Council and Parliament strike a deal to boost EU's green industry[43]
- Commission to ally with industry on Small Modular Reactors[44]
- 1st General Assembly of the European Industrial Alliance on SMRs[45]
- The NEA Small Modular Reactor Dashboard[46]

— DIGITAL

- Shaping Europe's digital future: AI Act[47]
- The G7 is committed to promoting safe, secure, and trustworthy AI[48]
- European Centre for Algorithmic Transparency[49]
- Critical Raw Materials Act[50]
- Artificial Intelligence Index Report[51]

— DUAL USE

- Risk assessments on four critical technology areas[52]
- EU enlargement – European Council decides to open accession negotiations with Ukraine[53]
- EC White paper on Export Controls[54]

— FAIRNESS

- European Elections 2024[55]
- European Court of Human Rights: Grand Chamber rulings in the climate change cases[56]
- In Antwerp, European industry kicks off fight for its future[57]
- Right to repair[58]
- MEPs approve the new Migration and Asylum Pact[59]
- JRC Fairness Policy Briefs 2024[60]
- Europe's Choice[61]

5 Conclusions and recommendations

The JRC's re-vitalised strategy 2030[1] enabled 5 nuclear and non-nuclear JRC portfolios with the support of the JRC management to organise and host this pilot foresight initiative pooling synergies together around the 5 selected Euratom Drivers 2057 together. Participants in the 60 Years of JRC Nuclear Safety and Security celebrations and other stakeholders, partners and EC colleagues engaged in person or online in the first JRC nuclear foresight workshop on shaping the future for nuclear safety, security and safeguards. The participants imagined possible future scenarios up to the year 2057 when the Euratom Treaty[62] will celebrate its 100th anniversary and reflected on factor, forces and challenges enabling to prepare now for a European future strategic autonomy and the envisaged climate neutrality.

Detailed summaries of the outcome of the workshop and the recommendations to the JRC are discussed in Chapter 3.

The following was perceived by the participants as essential in order to be well prepared for various future scenarios up to the year 2057 in relation to all the 5 Drivers and is as a concluding reflection presented as non-exhaustive but representative set of ***ENABLERS*** and ***DISRUPTORS***:

Box 1. ENABLERS

- **Nuclear Research & Development for nuclear safety, security and safeguards (3S) remains key for Europe, regardless of the future share of nuclear energy. It will not only support nuclear power innovations, such as hydrogen production and SMRs but also non-power applications in nuclear medicine, health and food.**
- **Europe needs to invest in advanced technologies and capabilities, and the JRC needs to strengthen the twin green & digital transition with relevant nuclear and non-nuclear research.**
- **The JRC needs to be abreast of critical and emerging nuclear technologies, particularly all research related to 3S for Small Modular Reactors and Dual Use items.**
- **The world is already in the middle of the digital transformation. Robotics and AI will become more prominent and change society, requiring transparent new regulations; building on nuclear and non-nuclear synergies.**
- **Public engagement and transparency in the nuclear industry for existing and innovative nuclear applications. Reconciliation of the energy & climate plans of the EU nuclear alliance and the other EU countries.**
- **JRC in a pole position to build on international cooperation and reach out to public engagement with nuclear communication based on holistic scientific evidence, playing a central role in translating science to policy makers to the benefit of society**
- **JRC promoting education and training; and retaining and attracting talent in a well-balanced combination with engaging in innovation, automation and robotics, supporting the establishment of a European Nuclear Competence and Skills Centre.**

Box 2. DISRUPTORS

- **There was a common agreement among participants that Europe and the JRC need to keep their nuclear competences and a skilled and talented workforce in nuclear research. Currently the infrastructure and workforce is ageing at JRC and other parts in Europe. Recruiting the next generation of nuclear and interdisciplinary researchers has to start now in Europe.**
- **JRC still has the problem that it is not well known by Member States decision makers to be considered as an asset for Europe and for their Member State.**
- **Geopolitical uncertainties and threats will continue to ask for strategic decisions, quick but well-balanced reactions and adaptations to prevent major crises and guarantee (nuclear) safety.**
- **Lack of goal-oriented investment and funding**
- **Cyber security is one of the major challenges for any future scenario.**
- **Fair access to 3S for nuclear newcomer countries; access to JRC nuclear infrastructure beyond EU.**
- **Central parts of the twin transitions promoted by the EC – or at least the public's perception of them – are at risk of losing societal buy-in due to disinformation, whereas in reality people across the world, and the political spectrum, underestimate levels of societal support for mitigating effectively global warming[63]**
- **Safety, security and nuclear waste management concerns within the EU might slow down the implementation of innovative nuclear and digital solutions and the adoption of respective regulations; being not in time for NetZero in 2050.**

Summarising, with this first pilot foresight workshop the JRC was able to harvest on the collective intelligence, imagination and reflections of participants with diverse profiles and origin around the selected 5 Euratom Drivers 2057. Considering the limited time of only one workshop day the outcome is quite impressive. Topics, thoughts, scenarios and recommendations put forward in this workshop have already been included in JRC briefings for the next European Commission. In more detail, the topics and recommendations related to the 5 Euratom Drivers will be followed in the next Euratom Horizon Scanning[3] for Nuclear Technology exercises.

Finally, the authors consider that the approach developed for this specific workshop, is in itself a contribution for further analogous foresight exercises. We hope that we could provide "high-grade food for thought" and create awareness among the participants and the readers of this report for timely actions and a positive attitude that the future holds a number of enablers for sustainable peace and prosperity, nuclear being part of it.

We would be happy to get feedback from the readers, and invite you to contact us in case you envisage joining one of the JRC foresight activities or you consider the contribution of the JRC to your own planned foresight activities of being useful.

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At this workshop we started our travel to the future, and by traveling together we will certainly reach the furthest.

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List of abbreviations and definitions

Abbreviations	Definitions
3S	nuclear safety, security and safeguards
AFCONE	African Commission on Nuclear Energy
AI	Artificial Intelligence
AM	Additive Manufacturing
BTWC	Biological and Toxin Weapons Convention
CNSA	China National Space Administration
CSNI	Committee on the Safety of Nuclear Installations
CWC	Chemical Weapons Convention
DPRK	Democratic People's Republic of Korea
ESARDA	European Safeguards Research & Development Association
ESFRI	European Strategy Forum on Research Infrastructures
ESPAS	European Strategy and Policy Analysis System
EU	European Union
HALEU	High-Assay Low-Enriched Uranium
IAEA	International Atomic Energy Agency
IoT	Internet of Things
ISIS	Institute for Science and International Security
ISO	International Organization for Standardization
JRC	European Commission Joint Research Centre (JRC)
LEU	Low-Enriched Uranium
MSRs	Molten Salt Reactors
NIMTOO	Not in my term of office
NPT	Nuclear Non-Proliferation Treaty
RDD	Radiological Dispersal Device
SMEs	Small and Medium-sized Enterprises
SMR	Small Modular Reactor
STC	Strategic Trade Control

Abbreviations	Definitions
STUK	Radiation and Nuclear Safety Authority, Finland
UAE	United Arab Emirates
UAV	Unmanned Aerial Vehicle
WMD	Weapons of Mass Destruction

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Annexes

Annex 1. Workshop agenda

09:00 - 10:00 **Welcome and opening session (Colloquium)**

- *Chaired* by **Ulla Engelmann**, Director for nuclear safety & security, Joint Research Centre, European Commission
- *Welcome by* **Ulla Engelmann**
- *Keynote address by* **Elina Martikka**, *Head of International Cooperation at STUK, Finland*
- *Keynote address by* **David Albright,** *President of the Institute for Science and International Security, USA*

10:00 - 11:00 **Presentation and detailed framing of the five Drivers 2057**

- EURATOM foresight at the JRC by **Manuel Martin Ramos**

1. [**SAFETY & SECURITY**] - by **Maria Wallenius**
2. [**GREEN**] - by **Michael Fütterer**
3. [**DIGITAL**] - by **Laura Aldave de las Heras**
4. [**DUAL USE**] – by **Filippo Sevini**
5. [**FAIRNESS**] – by **Andreas Jenet**

11:00 - 11:20 Coffee Break

11:20 -12:15 - **Parallel break-out foresight sessions[v] on the five Drivers 2057 in seminar rooms**

Each break-out session will be hosted by a rapporteur and a co-rapporteur

12:15 – 13:15 **Lunch Buffet**

13:15 – 14:15 **Reporting from the break-out sessions in plenary setting**

by the **rapporteurs**

14:15 – 15:00 **Closing discussion in plenary setting**

15:00 **End of workshop and departure**

[v] Please note that participants will be attributed to only one parallel session by the workshop organisers

Annex 2. Keynote speaker biographies

Elina Martikka:

Elina Martikka graduated from the University of Jyväskylä in nuclear physics. She started to work at STUK in 1989; the first job was communications specialist. In 1994, Finland started to prepare for EU membership, and someone was needed to learn about Euratom safeguards system. That was the start of Elina's career with safeguards and non-proliferation.

Elina is familiar with many duties at the regulator, and personal experiences in implementation of safety, security and safeguards, regulations, legislation, emergency preparedness, licensing, and cooperation with ministries and other national stakeholders. Elina has led the Finnish national safeguards system from 1998 to 2018. She was the President of ESARDA in 2009-2010.

Today Elina leads international cooperation at STUK and participate as an expert several international projects. Elina is a member of IAEA DG's Standing Advisory Group on Safeguards Implementation (SAGSI).

David Albright:

David Albright, a physicist, is founder and President of the non-profit Institute for Science and International Security in Washington, D.C. He has assessed the means states and terrorists use to obtain nuclear weapons capabilities and defeat export controls for four decades. During his career, Albright has testified numerous times on nuclear issues before the U.S. Congress and advised numerous governments.

He has published in the Bulletin of the Atomic Scientists, Science, Scientific American, Science and Global Security, the New York Times, the Washington Post, the Wall Street Journal, Washington Quarterly, and Arms Control Today. Albright has authored or co-authored nine books, including Revisiting South Africa's Nuclear Weapons Program; Illicit Trade Networks - Connecting the Dots; Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies; Taiwan's Former Nuclear Weapons Program: Nuclear Weapons On-Demand; Peddling Peril Index; and Iran's Perilous Pursuit of Nuclear Weapons.

Most recently, because of the war in Ukraine, he has focused on the Shahed 136 kamikaze drone, particularly its production in Russia at JSC Alabuga with Iranian assistance, its Western components, and Alabuga's supply chain.

Source: Speakers

Annex 3. JRC/Euratom Foresight

Comprehensive list of recent activities

- First *Horizon Scanning for Nuclear Safety, Security & Safeguards* report issued in 2017, with one report issued yearly since then (last: JRC131993)
- Long-Term Horizon Scanning for Nuclear Technologies Yearly Report - 2023
- Initially, the main purpose of the nuclear foresight initiative was to increase the forward looking professional awareness of JRC.G colleagues.
- For that we brought together the Euratom Horizon Scanning network, involving colleagues from every unit in JRC.G and now including JRC.J.
- In order to feed our network with relevant information, we started making use of sophisticated text mining and text generation tools developed at the JRC: EMM, TIM and *GPT@JRC* (a JRC exclusive deployment of ChatGPT)
- As a result, so far, we have produced 5 *Science for Policy Briefs* about nuclear technology:
    - Cybersecurity of nuclear facilities (2021) - JRC124625
    - Radioactive Isotopes (2021) - JRC126700
    - Floating Nuclear Reactors (2022) - JRC128888
    - Nuclear power in space (2022) - JRC131078
    - Nuclear Hydrogen for Steelmaking (2023) - JRC135624
- We have organised 6 *Deep Dives* (webinars) into different nuclear technological aspects with invited external experts for colleagues from the European Commission:
    - Deep Dive into nuclear cyber security (2020) - 38853993
    - Deep Dive into Radioactive Isotopes (2021) - 43796911
    - Deep Dive into floating nuclear reactors (2021) - 48000006
    - Deep Dive into nuclear power for space exploration (2022) - 52231379
    - Deep Dive into better regulation for nuclear innovation (2022) - 56148662
    - Deep Dive into the IAEA Drivers 2057 (2023) - 68626824
- And we have supported general JRC foresight related initiatives such as
    - Foresight on synergies between civil, defence and space industries (2021) - link
    - Identifying future critical technologies for space, defence and related civil industries (2023) - JRC134926
- Now actively working on adapting our processes and deliverables to incorporate the dimension of the JRC Portfolios.

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