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Horizon Scanning for Nuclear Safety, Security & Safeguards Yearly Report - 2020

Creating an anticipatory capacity within the JRC

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Contents

Abstract

Horizon Scanning (HS) is a systematic outlook to detect early signs of potentially important developments. JRC.I.2 unit created and, in collaboration with partner JRC Knowledge Management Units, tested a methodology for a horizon scanning process at JRC level. Benefiting from this support and following this methodology, JRC.G.10 unit has collected throughout the year 2020 a number of ideas related to nuclear technology, that were later on pre-filtered and finally clustered in a so called 'sense-making workshop'. This report presents the outcome of this yearly exercise.

Executive summary

The JRC has adopted an approach to **strengthen its anticipatory capacity** with the aim to better support the policy-making within the Commission. In this context and within Dir G, the horizon scanning is used as a tool to detect and analyse early signs in order to identify important emerging issues in the field of nuclear safety, security and safeguards.

The scanning of relevant news items, then the filtering of these items followed by a sense-making workshop resulted in the following **foresight stories**:

- The European leadership on radioisotope production

Radioisotopes are materials with very specific radioactive properties that can be manufactured to meet very specific needs.

The most popular radioisotopes are used in like for treating cancerous diseases. Others are used in sensors to detect explosives in airports and leakages in pipes, or to measure the thickness of various materials.

Radioisotopes are produced in research reactors and in particle accelerators. Thanks to the significant proportion of research reactors operating inside Europe, the EU can be considered a leader of radioisotope production at a global level. On the other hand, many of those reactors will soon reach the end of their operating life, what might bring that leadership into question.

- Future of nuclear energy in the EU

With the challenging targets of decarbonisation within the European Green Deal, the transition from fossil fuels to cleaner energy production has become even more topical. The possibilities of nuclear to contribute to the decarbonisation are various: continued operation of existing nuclear power plants can respond to increasing electricity demand and can supply energy for hydrogen production. Small modular nuclear reactors are identified as potential systems in support to the variability of the electrical power generated by intermittent Renewable Energy Sources (RES) like solar panels and/or wind turbines.

Although nuclear could play a central role in reaching the European Commission's ambitious decarbonisation targets, the opinions on the use of nuclear energy are highly polarised. This has caused a detrimental political context for the nuclear industry at the EU level. Meanwhile the European nuclear industry is losing market to Russia and China, who have become dominant players in the nuclear power market.

- Participatory engagement for nuclear

The European nuclear power industry, although not anymore a world leader, is a well-equipped competitor at the global stage. At the same time, European public institutions at different levels of administration are often considered amongst the most transparent, participatory, trusted, and effective in the world. Although one would expect this to give stability to the sector this link has become sensitive to disruptions brought by digital connectivity. The political struggle for higher public engagement in policy making and the intensified dynamics of public perception driving business success is to shape the future of European nuclear power. Starting by bringing the power supply closer to the consumer, it may end up evolving into a more open, future-looking and engaging sector in order to remain afloat.

In parallel to this Horizon Scanning exercise, a **bibliographic data analysis** was performed to add insights about the following technological developments:

- Digital twins

A digital twin is a virtual copy of a real device that simulate its physical processes, characteristics and responses to the interactions with the environment. The measurements of the sensors of the real device are used to feed its virtual copy. That way it is possible to compare their processes and responses in order to identify anomalies and study their causes.

Results of the analysis show that the European Union seems to be well positioned on the related research, although it is important to notice that the results relate to the use of digital or virtual twins in various kinds of installations, reactors or plants, and not specifically in the nuclear sector, where it may remain relatively unexplored.

- Soluble boron-free small modular reactors

In nuclear pressurised water reactors, the core reactivity is often controlled through moveable control rods, burnable neutron absorbers and soluble neutron absorbers such as boron. There could be, however, significant benefits in finding an alternative to the use of soluble boron. Some of them would be the simplification of the reactor design by reducing the purification systems and related components and the avoidance of the degradation produced by the soluble boron on the exposed components of the reactor.

Results of the analysis show that within the European Union only Sweden has participated in the related research.

- Uranium electrochemical recovery from seawater

As seawater desalination intends to address fresh water scarcity, it is still unclear what would be the ideal management of its by-product: the desalination concentrate. As the industrial demand for lithium increases, new advanced electrochemical approaches for the selective extraction of lithium are being developed aiming to improve the current performances.

Following the same principle, and considering that the world's oceans contain hundreds of times more uranium than lands, a similar electromechanical approach would allow the recovery of uranium.

Results of the analysis show that there seems to be no country within the EU publishing research on this topic.

- Integral Molten Salt Reactor

Nuclear Molten Salt Reactors are intrinsically and naturally high-temperature reactors operating at high thermal efficiency. The Integral Molten Salt Reactor (IMSR) integrates into a compact, sealed and replaceable nuclear reactor unit.

In 2016, Terrestrial Energy engaged in a pre-licensing design review for the IMSR with the Canadian Nuclear Safety Commission and entered the second phase of this process in October 2018 after successfully completing the first stage in late 2017.

The further development and adoption of Molten Salt Reactor technology might be hampered by the significant earlier investment in reactor concepts which would risk becoming out-dated.

Results of the analysis show that the main research effort is performed by the Canadian *Terrestrial Energy*, the developers of the design.

The annexes of this report contain a list of staff involved in the process, an explanation about the bibliographic analysis tool and a detailed explanation about the horizon scanning methodology.

Follow-up actions may include in-depth studies and deep-dive discussions carried out on request of stakeholders and other parties, depending on their interest in any of these subjects.

1 Introduction

The JRC Strategy 2030[1] specifically stresses the need for the JRC to develop anticipation by stating the following in its chapter 8 ("*A stronger anticipation culture*"):

"There are many reasons why the Commission's anticipatory capacity needs to be strengthened. First, it would enable it to identify its knowledge needs very early on. This would give it time to amass the evidence it needs to launch well prepared policies and proposals in a timely fashion. It would be able to future-proof its impact assessments and its REFIT evaluations. Anticipating social changes and public opinion movements would contribute to shaping public debates and proposing new narratives, instead of being on the defensive."

In this context, the *horizon scanning* has been identified as one of the necessary tools *"which strives to identify and make sense of weak and diffuse indications of still hazy emerging trends or paradigm shifts"*.

The *Horizon Scanning for Nuclear Safety, Security & Safeguards* exercise is an initiative that attempts to build on this capacity and to provide anticipatory support by:

- Embedding a culture of anticipation throughout Dir G.
- Developing expertise in the use of the *horizon scanning* to detect and analyse early signs in order to identify important emerging issues.

In order to detect these early signs of potentially important developments, three different actions led by groups of experts were carried out in the exercise:

- Continuous scanning of nuclear technology sources by *Scanners* from across the JRC Dir G who picked up single ideas that were recorded in CONNECTED. The list of Horizon Scanners from Dir G can be found in Annex 1.
- Pre-filtering sessions led by *Aggregators* who collected the relevant scanned ideas and organised the discussions for the scanners, to involve them in the selection of ideas and to take the time to discuss and share views and ideas. The list of Scanners and Aggregators contributing to the Horizon Scanning for Nuclear Safety, Security & Safeguards can also be found in Annex 1.
- Sense-making workshop led by *Aggregators* who reviewed the scanned ideas, selected sets of relevant items, and organised the discussions. The list of Aggregators contributing to the Horizon Scanning for Nuclear Safety, Security & Safeguards can also be found in Annex 1.
- Bibliographic data analysis exercises by analysts who performed a quantitative study of the scientific literature addressing the research topics underlying the clusters of ideas identified during the workshops. The data analysts involved are amongst the authors of this report.

The chapter dedicated to the *Nuclear Technology Observatory* summarises the results obtained after studying, with the JRC *Tools for Innovation Monitoring* (TIM), the technologies referenced by the ideas identified during the continuous scanning, thus enabling an assessment and better understanding of their potential importance and implications.

[1] https://ec.europa.eu/jrc/sites/jrcsh/files/jrc-strategy-2030_en.pdf

2 Foresight stories

The foresight stories aim to capture the possible impact in ten years and more of the weak signals considered most interesting today. They are the main outcome of the sense-making workshop, a creative process in which the group reflects jointly about the further-reaching consequences of on-going and emerging trends. Foresight reflections looking ten and more years in the future were developed, identifying the capacities and vulnerabilities related to three selected clusters of ideas, which are developed in the following paragraphs below.

2.1 The European leadership on radioisotope production

Radioisotopes are materials with very specific radioactive properties that can be manufactured to meet very specific needs.

The most popular radioisotopes are used in medicine for obtaining internal images of our organism or for treating cancerous diseases. Others are used in sensors to detect explosives in airports, moisture inside materials, leakages in pipes, pollutants in filter paper, or to measure the thickness of plastics, sheet metal, rubber, textiles, etc. Some can even be found in food sterilization plants or powering up our satellites and spaceships.

Radioisotopes are produced in research reactors and in particle accelerators. Thanks to the significant proportion of research reactors operating inside Europe, the European Union can be considered a leader of radioisotope production at a global level. On the other hand, many of those reactors will soon reach the end of their operating life, what might bring that leadership into question.

2.1.1 Time horizons

At present, the European Union does not seem concerned by the International Atomic Energy Agency (IAEA) warning published in April about a potential medical radioisotope shortage following the Covid-19 pandemic. As their communication pointed out, due to the pandemic many airlines stopped operating and borders were closed, affecting the global distribution of medical radioisotopes. Luckily, many of the nuclear research reactors producing those radioisotopes operate within the European Union's borders, sustaining the integrity of the related supply chains within the continent during the period.

In the **midterm**, many of those European research reactors will reach the end of their operating life. High level decisions about very significant public investments will have to be made to satisfy the existing demand for radioisotopes within Europe while guaranteeing the reliability of their supply chains. Those decisions will have to take into consideration potential constraints such as the long-term availability and accessibility of low-enriched uranium (HALEU[2] with enrichment between 5 and 20%) in metallic form, used by research reactors for the production of radioisotopes. No appropriate HALEU production facilities are in place in either the EU or the US, and many of the new small and micro nuclear power reactor designs are also considering using HALEU for extending their continuous operation without refuelling. At the same time, for the effective and

[2] HALEU High-Assay Low-Enriched Uranium. By definition, HALEU is enriched between 5% and 20%. Enrichment above 20% and is not commercially allowed due to nonproliferation reasons as anything above this threshold is considered high enriched or weapons-grade. The desired HALEU enrichment levels vary depending on the application, but most fall into three separate ranges: 6-7% (LEU+); 13-16%, and just below 20% (~19.75%).

timely implementation of those decisions, European nuclear regulatory authorities will have to be ready to tackle the significant technical challenge that implies the licensing of these kinds of installations.

Looking a bit further, into the **longer-term**, we might see new radioisotopes developed and commercialised by those countries with the best radioisotope research and production infrastructure. These new radioisotopes could be able to fight cancer with the greatest efficacy and the least impact on the patient. They could also improve the study of the biological processes on-going within our organism while affected by different diseases. They could even power innovative autonomous devices. Devices that could consist on mobile medical equipment requiring continuous operation in areas with unreliable power supply; micro-drones for measuring pollution, reforesting natural reserves or making Internet available in remote areas; spaceship’s equipment for space exploration or mineral extraction from astronomical objects; and most probably different sorts of military equipment.

2.1.2 Capacities, vulnerabilities and opportunities

Capacities:

- Unlike traditional nuclear power, radioisotopes, and especially those used for medical applications, do not face big difficulties regarding public acceptance. European patients often accept being subject to radiation as long as that is the expert recommended choice for tackling their diseases.
- Inside the European Union there are operating nuclear research reactors in Belgium, Czechia, France, Germany, Hungary, Italy, the Netherlands, Poland and Romania. Apart from those particle accelerators dedicated only to medical or industrial processes, within Europe there are also nuclear research particle accelerators in Belgium, Denmark, Finland, France, Germany, Italy, the Netherlands, Poland, Slovenia, Spain and Sweden. A wide variety of nuclear research infrastructure allows Europe to hold a good share of the global knowledge about radioisotopes.

Vulnerabilities:

- As active research reactors arrive to the end of their operating life, new nuclear facilities need to be designed and built in order to ensure the continuity of radioisotopes supply. As these facilities are technically very complex and entail radiation risks, a necessary step before their construction is the licensing of the design according to the national nuclear regulations. At this point, national nuclear regulatory authorities may experience difficulties in dealing with the task, what may end up causing delays with the related cost overruns and discontinuities in the radioisotope supply.
- As the Euratom Supply Agency (ESA) points out in their report *Securing the European Supply of 19.75% enriched Uranium Fuel*[3]: “The long-term availability and accessibility of HALEU in metallic form is a key issue in guaranteeing the continued operation of research reactors and the production of fission radioisotopes using HALEU. Currently, no appropriate production facilities are in place in either the EU or the US. The only currently used alternative source is Russia. These circumstances create a potential risk to security of supply.”

Opportunities:

- Being in a position of advantage regarding radioisotope research and production could stimulate an emerging leadership in related technologies. For example, scaling-up atomic batteries that use new radioisotopes able to increase their power could boost potential future uses and applications such as:

[3] Securing the European Supply of 19.75% enriched Uranium Fuel , A REVISED ASSESSMENT, Euratom Supply Agency (ESA), May 2019 (https://ec.europa.eu/euratom/docs/ESA_HALEU_report_2019.pdf)

    - Wireless networks and Internet of Things (IoT) sensors.
    - Self-powered mobile medical devices.
    - Space exploration and mining.
    - Autonomous micro-drones.
- Considering not just the radioisotopes themselves but also the devices and facilities where they are produced, it could be possible to incorporate new designs and approaches opening broader opportunities. For example, some particle accelerators are also able to:
    - Bring part of the radioisotope production closer to consumption with smaller cyclotrons.
    - Facilitate the use of irradiation for other medical applications such as sterilization or radiotherapy.
    - Minimize the radioactive waste produced as side-product.
    - Carry out radioactive waste transmutation to neutralize or transform existing waste.
    - Carry out ion implantation for the manufacturing of materials with advanced properties such as semiconductors or superconductors.
    - Develop and produce new different radioisotopes whose potential properties and uses have not been yet considered due to the lack of their wider availability.

2.1.3 Case study: Radioisotope thermoelectric generator for space exploration

The Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) is a power system fuelled by the radioisotope Plutonium-238 used for space exploration. NASA's goal is to be able to produce 1.5 kg of this radioisotope per year by 2025.

The MMRTG is powering the basic operations of the Perseverance rover, able to keep its tools and systems at optimal temperatures during 14 years. The Perseverance rover was launched on 30th July 2020 to seek signs of ancient life and collect rock and soil samples from Mars before an expected return to Earth on February 2021.

The MMRTG is also set to power the Dragonfly 8-bladed rotorcraft lander mission to Titan. The mission is expected to take place from 2026 to 2034. Dragonfly will be dedicated to sample and examine different sites of Saturn's largest moon. The mission marks the first time NASA will fly a multi-rotor vehicle for science on another planet.

This explains the potential of this radioisotope and the strategic importance that the US and the NASA give to it, to the point of establishing clearly defined objectives and deadlines for its production capacity. In spite of the position of advantage of the European Union to produce different types of radioisotopes, the European Space sector seems to be lacking behind in the exploration and research of the advantages related to their potential applications.

Making the effort needed to continue holding the leadership of radioisotope research and production might not be enough to actually take advantage of all the potential benefits that the position entails. All related industries and sectors could benefit from that strategic autonomy and exploit it to the maximum extent, but also, if not remedied, they could end up remaining in any case unconcerned or unaware and therefore still dependent.

Source: Office of NUCLEAR ENERGY (03/06/2020)

2.2 Future of nuclear energy in the EU

With the challenging targets of decarbonisation within the European Green Deal, the transition from fossil fuels to cleaner energy production has become even more topical. The possibilities of nuclear to contribute to the decarbonisation are various: continued operation of existing nuclear power plants can respond to increasing electricity demand due to e.g. electrification of transport system, and can supply energy for hydrogen production. Small modular nuclear reactors can be integrated in distributed smart carbon-free energy systems. They are identified as potential systems in support to the variability of the electrical power generated by intermittent Renewable Energy Sources (RES) like solar panels and/or wind turbines.

Although nuclear could play a central role in reaching the European Commission's ambitious decarbonisation targets, the opinions on the use of nuclear energy are highly polarised. Some Member States are counting largely on nuclear in their energy mix for achieving climate targets, while other MS do not accept nuclear production and some are even strongly opposing nuclear projects in the whole EU. This polarisation has caused a detrimental political context for the nuclear industry at the EU level, in contrast e.g. to the UK, where the government provides increased political and financial support to the development and deployment of new nuclear capacities in an effort to strengthen and diversify a low-carbon energy mix and to support the economy. Meanwhile the European nuclear industry is losing market to Russia and China, who have become dominant players in the nuclear power market.

2.2.1 Time horizons

In 2019, nuclear power plants generated 27% of the electricity production in the EU, while the share of conventional thermal electricity was 43% (Eurostat)[4]. Of the EU primary energy mix, nuclear represents 13% and renewables 15%, while oil, solid fossil fuels and natural gas represent together 72%. **At present**, nuclear energy is used almost exclusively for electricity production. Nuclear still produces a reliable base load electricity, but the current nuclear fleet is ageing. The European nuclear industry has been struggling with the new-build in Finland and France as can be seen from the huge delays with EPR projects which, together with the high investment costs, has made nuclear economically a less viable option. Some Member States, namely Germany, Belgium and Spain have decided to phase out nuclear, while Finland, France, Hungary, Romania and Slovakia are building new capacity. Poland is a newcomer country, planning to build nuclear power to limit its heavy dependence on coal (75% of electricity production). This shows that countries considering use of nuclear energy view it not just as an alternative to renewables but rather as an equivalent component in their low-carbon energy mix.

In the **mid- and long-term** two alternative scenarios for the nuclear industry in Europe can be envisaged. On one hand, if nuclear is seen as an acceptable and valuable source of energy, it has a large potential also beyond the base load electricity production. Small modular reactors could be integrated in distributed smart energy systems with RES to complement their intermittent production. Co-generation of electricity and (low-temperature) heat e.g. for district heating is in principle possible with current reactor types, and can be seen as a **mid-term** scenario driven by needs to improve energy efficiency. The electricity could also be used for the production of hydrogen by electrolysis (95% of hydrogen worldwide is currently produced by steam reforming technology with a heavy carbon footprint). In the **long-term**, more advanced reactor concepts like high temperature reactors could enable high-temperature applications for industry, including hydrogen production. Thermal and hydrogen production applications could significantly improve the efficiency of nuclear power plants from the current ~35% to more than 60% depending on the application and the type of reactor.

[4] https://ec.europa.eu/eurostat/statistics-explained/pdfscache/9990.pdf

In the **long-term**, after mid of century, there are expectations on the deployment of fusion energy. However, fusion energy is subject of continuous research and its techno-economic feasibility is still being assessed.

However, if the political recognition of nuclear power in the EU continues to decline, the European nuclear industry may disappear in the **long-term** as well the considerable economic asset and potential that it represents.

Although it is likely that the lifetime of operating reactors will be extended as much as possible, they will have to be shut down sooner or later. New-built nuclear power plants in Europe still remain scarce; some of them being even to be supplied by non-European vendors. Building a new power plant in Europe takes more than 10 years since the European nuclear industry is losing its former building and supplying capacity due to the low demand. Potential dependence on non-European vendors such as Russia may also pose a risk to the security of fuel supply, as there is currently limited capacity in Europe to fabricate fuel for all types of reactor designs[5] operated in the EU.

2.2.2 Capacities, vulnerabilities and opportunities

Capacities:

- Nuclear power plants can deliver both electricity and heat in a large scale with low CO2 emissions, while complying with a high level of availability, supply security and power density.
- European nuclear industry remains a central player with reactor designers and suppliers of main nuclear power plant components. The nuclear industry is a strategic sector with a high-level of expertise, and an important contributor to the EU economy in terms of growth and jobs. It currently sustains around 1 million jobs in the EU and generates around €450 billion in GDP[6].
- The EU research is an important contributor to the advancement of Generation IV reactor concepts, with three different prototypes: the gas cooled fast reactor ALLEGRO, the lead-cooled fast reactor ALFRED and the fast spectrum research reactor MYRRHA.

Vulnerabilities:

- Licensing of the new designs: lengthy or uncoordinated licensing processes could represent a bottleneck for the deployment of new technologies. Moreover, the current licensing framework in most of the MS might not be optimal to assess the large variety of technologies and operational conditions of new designs. Finland is currently addressing this issue (see case study below). Similarly, US recently passed a legislation to adapt its licensing framework[7] to take into account innovative designs, whereas EU is funding studies to monitor current EU legislation to identify licensing issues relevant to SMRs[8].
- Nuclear waste: despite the consensus among the international scientific community in the overall safety of geological disposal of high-level nuclear waste, it remains a concern for the public and waste is often perceived as an unresolved problem.

[5] Actually, only the Westinghouse fuel factory in Västerås, Sweden can produce VVER reactor fuel designed by Westinghouse. It has currently been tested at the Temelín NPP in the Czech Republic. All other operating VVER reactors in Europe depend on the fuel supplied by the Russian vendor TVEL.
[6] www.neweurope.eu/article/european-nuclear-industry-has-a-key-role-to-play-in-boosting-eu-economy/
[7] https://www.nei.org/news/2019/president-signs-bill-to-modernize-nuclear
[8] https://cordis.europa.eu/project/id/847553

- Loss of competitiveness of European nuclear industry: the European nuclear industry is at risk of losing the influence/market in the developing world and in other embarking nuclear countries.
- Human resources: the gradual decline of nuclear-related knowledge, human resources and nuclear power plant construction capabilities and capacities within the EU is a risk.
- Costs: High capital costs and delays in return of investment are a major economic challenge of the nuclear industry, especially in case of first-of-a-kind reactor types.

Opportunities:

- Response to the increase of low carbon electricity demand: caused by (i) phasing-out fossil fuel from the energy mix; (ii) increased electrification of transport, industrial processes and residential sector and (iii) clean production of hydrogen.
- Deployment and integration of small modular reactors in distributed smart energy systems: they are designed to operate in a more flexible way and thus allow, through load following, for an increased presence of variable RES in the electricity mix.
- Provision of heat and electricity for hydrogen production: the European climate strategy recognises that hydrogen offers a solution to decarbonise the economy, especially the transport sector where reducing carbon emissions is both urgent and hard to achieve. Nuclear offers a reliable option for a decarbonised hydrogen production.
- Provision of heat for industrial processes with new generation High Temperature Reactors.
- Preservation and further development of the role of nuclear industry in the EU economy.
- Revitalising innovation in the nuclear energy sector while preserving its inherent safety culture.

2.2.3 Case study: Finland reforming nuclear legislation to enable more flexible authorisation of new technologies

Finland’s nuclear regulator STUK is to reform nuclear legislation, changing the way of supervising nuclear safety and operational culture. It shall include technology-neutral safety requirements that will specify target outcomes instead of dictating acceptable solutions.

Under the present provisions, the acceptable solutions for nuclear power plants are specified in deep detail, which imposes restrictions for both the regulator and the license holders, whereas technology neutrality will enable “a more flexible authorisation of new technologies” such as small modular reactors.

The new approach shall bring no changes to the level of safety required at nuclear facilities. It will just strengthen the operators’ responsibility for safety.

STUK believes that “Target-oriented provisions would offer licence holders more leeway for planning and creating the most appropriate solutions in terms of safety before submitting them to the regulator for approval.”

This case shows that some Member States operating nuclear power plants are getting ready to a more adapted regulatory approach. Making the licensing of regulatory requirements more technology-neutral can facilitate the approval and deployment of new reactor concepts or designs, like small modular reactors or micro-reactors.

Sources: NucNet Nuclear News Daily / 6 November 2020.

www.sttinfo.fi/tiedote/stuk-to-launch-reform-of-nuclear-safety-regulations-and-guidelines?publisherId=64456131&releaseId=69893140

2.3 Participatory engagement for nuclear

The European nuclear power industry, although not anymore a world leader, is a well-equipped competitor at the global stage. At the same time, European public institutions at different levels of administration are often considered amongst the most transparent, participatory, trusted, and effective in the world. Although one would expect this to give stability to the sector (considering that the success of the use of nuclear technology for power generation depends on the support and foresight of public institutions) this link has become sensitive to disruptions brought by digital connectivity. The political struggle for a higher degree of public engagement in policy making and the intensified dynamics of public perception driving business success is to shape the future of European nuclear power. Starting by bringing the power supply closer to the consumer, it may end up evolving into a more open, future-looking and engaging sector in order to remain afloat.

2.3.1 Time horizons

At present digital connectivity has opened new opportunities for entrepreneurs and small enterprises as well as new competition fronts amongst bigger corporations. A mistake in the communication strategy on social networks of a brand, a government or a political party can imply very relevant losses, while a good job can attract interest and sympathy. As the concern for the environment gains political relevance, with the focus on recycling and the green economy, addressing the unresolved issues related to hazardous wastes becomes even more politically challenging. At the same time, the perception of nuclear energy differs significantly between different European states as well as between towns and regions inside a same country.

In the midterm, as nuclear reactors succeed in getting smaller, and eventually out of sight, small entrepreneurial initiatives may also emerge aiming to tackle the remaining obstacle: their radioactive waste. We can only expect that radioactive material transport will get even safer (there have been no accidents of any consequence anywhere around the world related to the transport of commercial spent fuel) and digital technologies will allow even more effective tracking and control of moving cargo. If building a final permanent repository becomes politically unbearable in some states, some space may open for consolidated interim storage. A local community might be more inclined to accept and integrate a change that does not arrive as permanent and definitive from the first moment. The efforts of these innovative initiatives to engage the local community will most probably seize the advantages of digitalisation: knowledge sharing and monitoring of opportunities.

Following this trend, **the longer-term** might see how these waste storages grow together with the trust and support of the local community until some decide evolving into final and definitive solutions. The knowledge acquired from the increased transport of radioactive materials and potential improvements and harmonisation to make regulations more efficient could end up also facilitating the mobility of nuclear micro-reactors inside the continent or even in and outside the planet. The experience acquired from engaging and working with local communities might give the European nuclear industry a competitive advantage when operating in foreign markets.

2.3.2 Capacities, vulnerabilities and opportunities

Capacities:

- The European Union counts with a significant pool of knowledge about nuclear technology thanks to its nuclear industry and academia.
- Thanks to the soundness of its democratic institutions, European administrations as well as the related regulatory frameworks are internationally trusted and highly regarded.

Vulnerabilities:

- The political discussion about radioactive waste is often driven by irrational fear and distrust instead of by facts and compromise.
- The overarching priority given to safety and reliability by the nuclear sector has made both the industry and the regulatory authorities naturally conservative and resistant to change and innovation to adapt to new needs and circumstances.

Opportunities:

- A more heterogeneous and transversal nuclear industry that is able to keep its conservative safety culture while incorporating progressive and forward-looking corporate practices may become fitter to engage the local communities wherever it matters most.
- A common set of lean and adaptive nuclear regulatory principles incorporated to oversee small and mobile nuclear, enforced by all European Union states, could have the potential to actually shape the world nuclear products and services.

2.3.3 Case study

As Anu Bradford argues in her book "The Brussels Effect", multinational companies use European Union standards as global standards mainly due to the enormous size and potential of the common European market and the economies of scale encouraging the industrial development of one single product that fits all global markets. This simple effect actually appoints the European Union as the world's regulator in areas as relevant as data privacy, consumer health and safety, environmental protection, antitrust, and online speech.
Looking at this case, it might be interesting to consider the potential effect of a common and forward-looking European nuclear regulation both on the world nuclear industry and on the relevance and influence of the European Union over the future development and applications of nuclear technology. Even when some Europeans might not be interested in engaging in the discussion about the uses and potential opportunities of nuclear technologies, it would still be in everyone's common interest to ensure that wherever it is used, it is used safely.
Source: The Brussels Effect

3 Nuclear Technology Observatory

In parallel to the Horizon Scanning exercise, a bibliographic data analysis was performed with the aim to complement the Horizon Scanning conclusions with additional valuable insights about technologic developments such as:

- The relations amongst technologies, visualising how often they appear together in the same document.
- The maturity of the related research by observing the amount of scientific literature available on the technology as well as its evolution through time.
- Their *"activeness"*, as defined in the TIM tool, considering the number of publications on the technology released over the last three years in relation to the total number of scientific publications for the technology.
- The countries with more scientific activity on the topic.

For a more extended explanation of the terms and parameters used for this analysis, please consult *Annex 2. Bibliographic analysis tool and approach*.

As explained in the referenced annex, the graph visualisations (figure 1)presented in the following subchapters consist of:

- A **label** or dataset title that summarises the meaning of the search query.
- A **node** or circle, corresponding to each label, with an area equivalent to the number of documents retrieved by the search query.
- Several **edges** or relations corresponding to the number of documents retrieved simultaneously by two different searches that correspond to two different nodes.
- A **colour** code identifying the groups of nodes, or clusters, that tend to have more documents in common among each other according to the so-called Louvain Modularity algorithm.

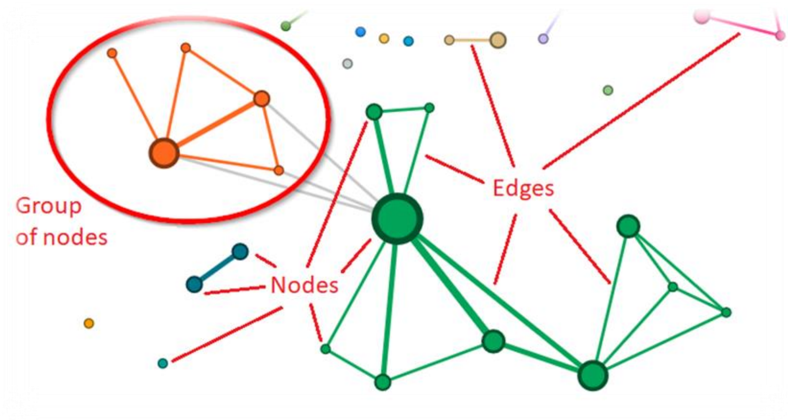
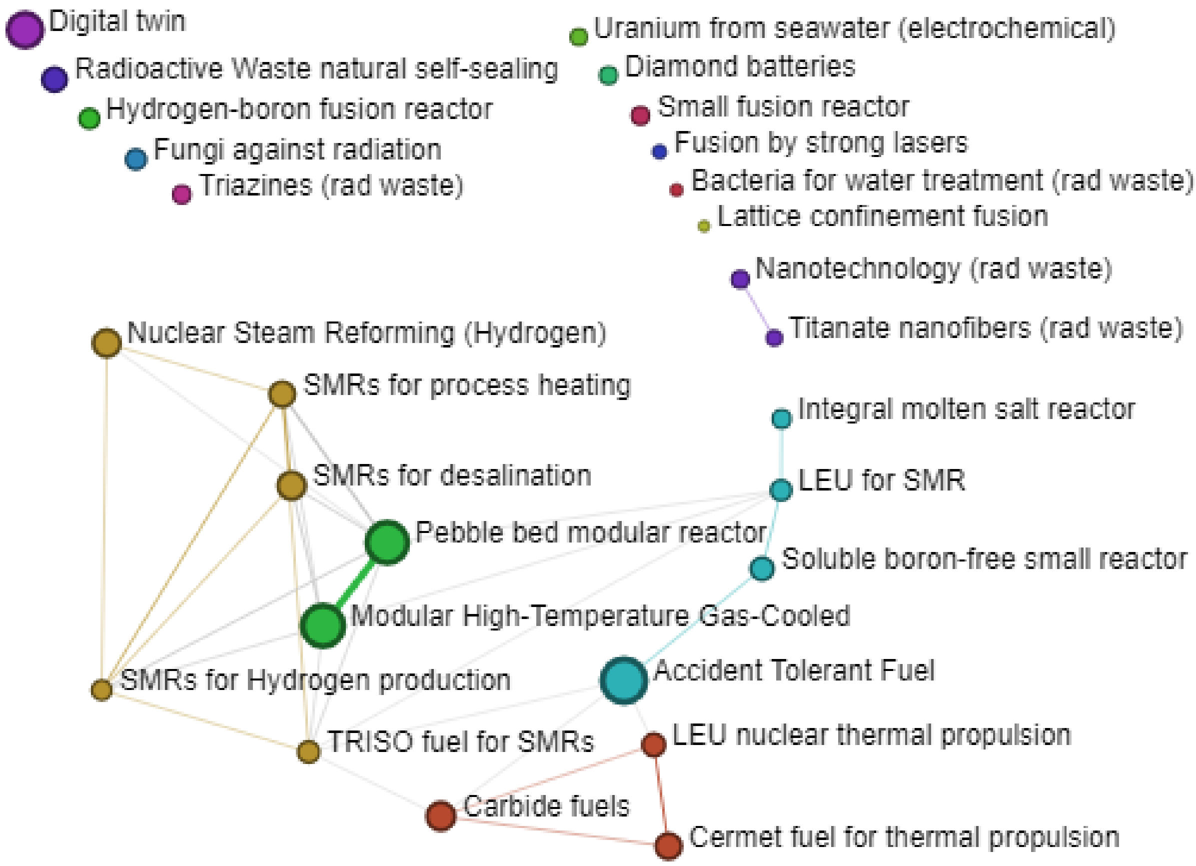


Figure 1. Network graph legend

The figure below (figure 2) shows all the nuclear technologies recorded during the year and studied for this analysis.



Node label: indicative title of the subject of the related search query.

Node size: number of documents retrieved by the search query.

Node Colour: Clusters according to the Louvain Modularity algorithm.

Edge thickness: number of documents retrieved simultaneously by two different search queries.

Figure 2. TIM nuclear technologies 2020 datasetgram

Four among the technologies that appear in the figure above, apart from the '*Accident Tolerant Fuel*' (already covered in previous yearly reports), have an *"activeness"* indicator higher than 45, meaning that a big number of their related documents were published in the last three years. These technologies are described and analysed in the following subchapters.

3.1 Digital twin

A digital twin is a virtual copy of a real device that simulate its physical processes, characteristics and responses to the interactions with the environment. The measurements of the sensors of the real device are used to feed its virtual copy. That way it is possible to compare their processes and responses in order to identify anomalies and study their causes.

Digital twins can also facilitate solving the problem of parameter tuning of automatic regulators in different operating modes of nuclear power reactors. In principle, this problem could be addressed using the neural network models used in Artificial Intelligence. Unfortunately, the difficulty of deducing the logic incorporated in this kind of models make them inappropriate to control equipment with very high safety requirements. However, these models could be tested without concern on the digital twin opening new opportunities to the potential applications of artificial intelligence on the nuclear industry.

Finally, digital twins can also be used to improve the cyber security of nuclear facilities. The digital twin can be audited subjecting it to different types of cybernetic attacks in order to test its cyber-defences and the resilience of its digital systems.

The following query was used to extract from TIM the information about patents, conference proceedings and scientific articles related to digital twins:

```
topic:(("digital twin" OR "virtual twin") AND (reactor OR plant OR nuclear OR atomic))
```

This query generated a dataset of 143 documents with an 'activeness' TIM indicator of 92, meaning that 92% of those publications were published in the last three years. The historic distribution of those publications is shown in the figure below (figure 3).

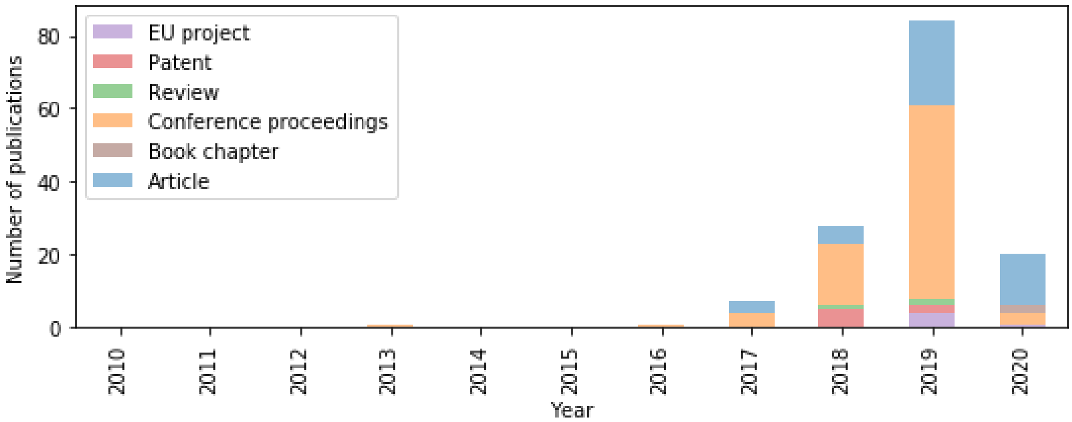
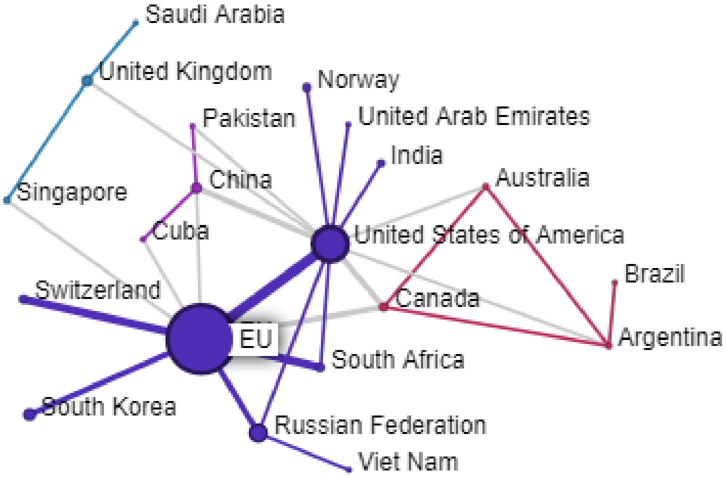


Figure 3. 'Digital twins' dataset document type distribution

According to the figure below (figure 4) the European Union seems to be well positioned on the related research, although it is important to notice that the query retrieved documents related to the use of digital or virtual twins in nuclear or atomic installations as well as other kinds of reactors or plants. Therefore, the figure does not reflect the applications of the '*digital twin*' specifically in the nuclear sector, where it may remain relatively unexplored.



Node label: country of origin of the documents retrieved by the search query.

Node size: number of documents retrieved by the search query.

Edge thickness: number of documents with origin on two different countries.

Figure 4. TIM network graph on 'Digital twins' world publications distribution

3.2 Soluble boron-free small modular reactors

In nuclear pressurised water reactors, the core reactivity is often controlled through moveable control rods, burnable neutron absorbers and soluble neutron absorbers such as boron. There could be, however, significant benefits in finding an alternative to the use of soluble boron. Some of them would be the simplification of the reactor design by reducing the purification systems and related components and the avoidance of the degradation produced by the soluble boron on the exposed components of the reactor.

The main challenge in designing a soluble-boron-free reactor is to minimize the power peaks caused by the distortions in the axial power profile of the reactor core that accompany the action of the control rods. These power peaks restrict the operating margin of the reactor reducing its potential applications and economic profitability. Apart from that, relying too much on the control rods makes the reactor's control system more complex while increasing the risk of its failure.

The following query was used to extract from TIM the data about patents, conference proceedings and scientific articles related to soluble-boron-free small modular reactors:

```
topic:(soluble AND (boron-free OR "boron free") AND ("modular reactor" OR
"modular reactors" OR "SMR" OR "SMRs"))
```

This query generated a dataset of 33 documents with an 'activeness' TIM indicator of 66, meaning that 66% of those publications were published in the last three years. The historic distribution of those publications is shown in the figure below (figure 5).

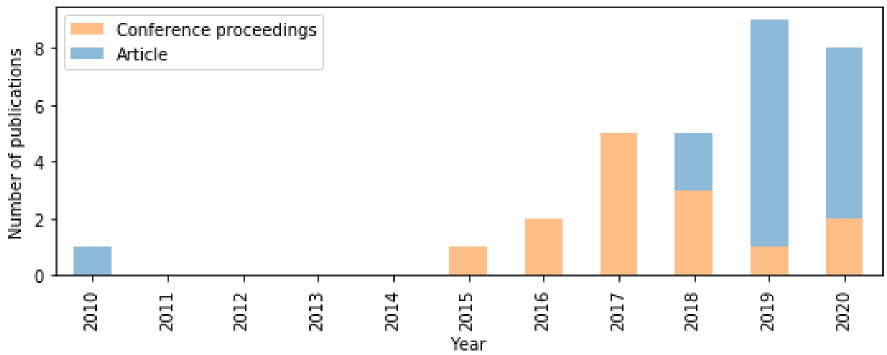
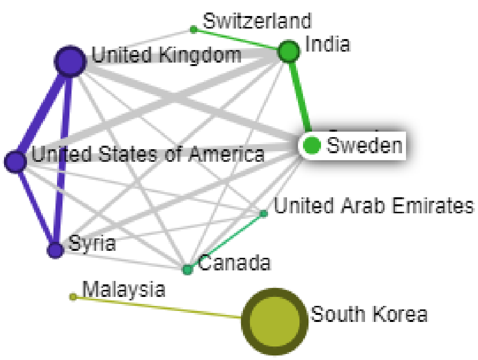


Figure 5. 'Soluble boron-free small modular reactors' dataset document type distribution

According to the figure below (figure 6) within the European Union only Sweden has participated in the related research.



Node label: country of origin of the documents retrieved by the search query.

Node size: number of documents retrieved by the search query.

Edge thickness: number of documents with origin on two different countries.

Figure 6. TIM network graph on 'Soluble boron-free small modular reactors' world publications distribution

3.3 Uranium electrochemical recovery from seawater

As seawater desalination intends to address fresh water scarcity, it is still unclear what would be the ideal management of its by-product: the desalination concentrate. As the industrial demand for lithium increases, new advanced electrochemical approaches for the selective extraction of lithium are being developed aiming to improve the current performances on selectivity, extraction capacity and energy consumption.

Following the same principle, and considering that the world's oceans contain hundreds of times more uranium than lands, a similar electromechanical approach would allow the recovery of uranium.

The following query was used to extract the information about patents, conference proceedings and academic articles related to electrochemical recovery from seawater from TIM:

```
topic:((uranium OR lithium) AND seawater AND (recovery OR extraction) AND electrochemical)
```

This query generated a dataset of 13 documents with an 'activeness' TIM indicator of 69, meaning that 69% of those publications were published in the last three years. The historic distribution of those publications is shown in the figure below (figure 7).

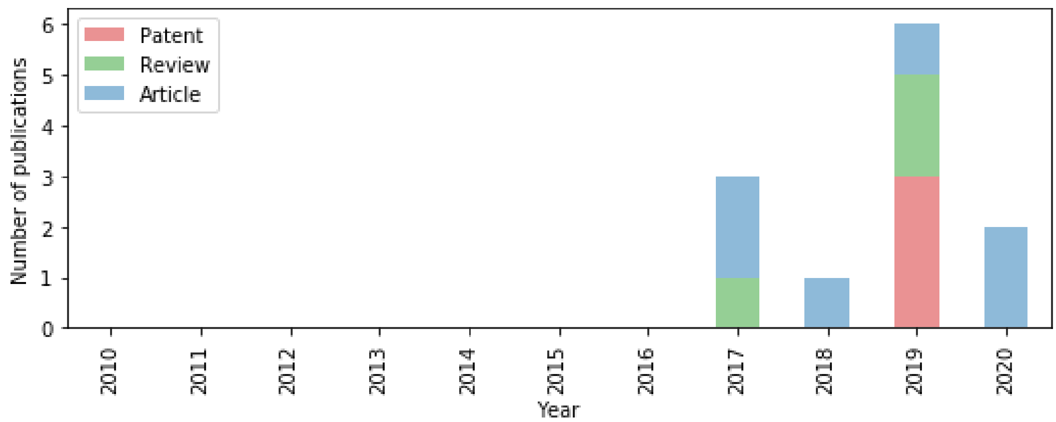


Figure 7. 'Uranium electrochemical recovery from seawater' dataset document type distribution

There seems to be no country within the European Union publishing research on this topic (figure 8).

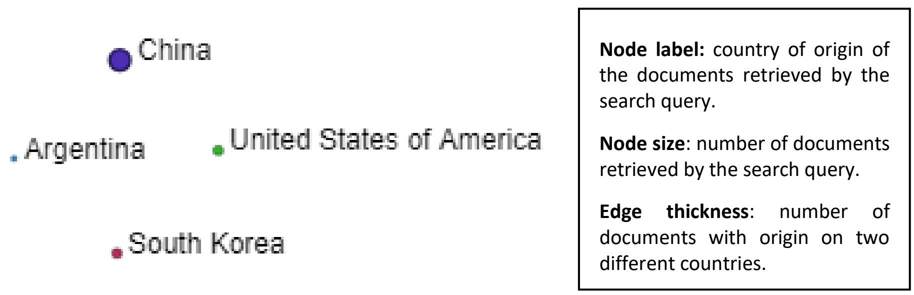


Figure 8. TIM network graph on 'Uranium electrochemical recovery from seawater' world publications distribution

3.4 Integral Molten Salt Reactor

Nuclear Molten Salt Reactors are intrinsically and naturally high-temperature reactors operating at high thermal efficiency. The Integral Molten Salt Reactor (IMSR) integrates into a compact, sealed and replaceable nuclear reactor unit. The core-unit is designed to deliver 400 megawatts of thermal heat and to be completely replaced after a 7-year period of operation.

In 2016, Terrestrial Energy engaged in a pre-licensing design review for the IMSR with the Canadian Nuclear Safety Commission and entered the second phase of this process in October 2018 after successfully completing the first stage in late 2017.

The further development and adoption of Molten Salt Reactor technology might be hampered by the significant earlier investment in reactor concepts which would risk becoming out-dated.

The following query was used to extract the information about patents, conference proceedings and scientific articles related to Integral Molten Salt Reactor from TIM:

```
topic:(("integral molten salt" OR (IMSR AND (reactor OR nuclear))) NOT topic:imidazolyl
```

This query generated a dataset of 15 documents with an 'activeness' TIM indicator of 46, meaning that 46% of those publications were published in the last three years. The historic distribution of those publications is shown in the figure below (figure 9).

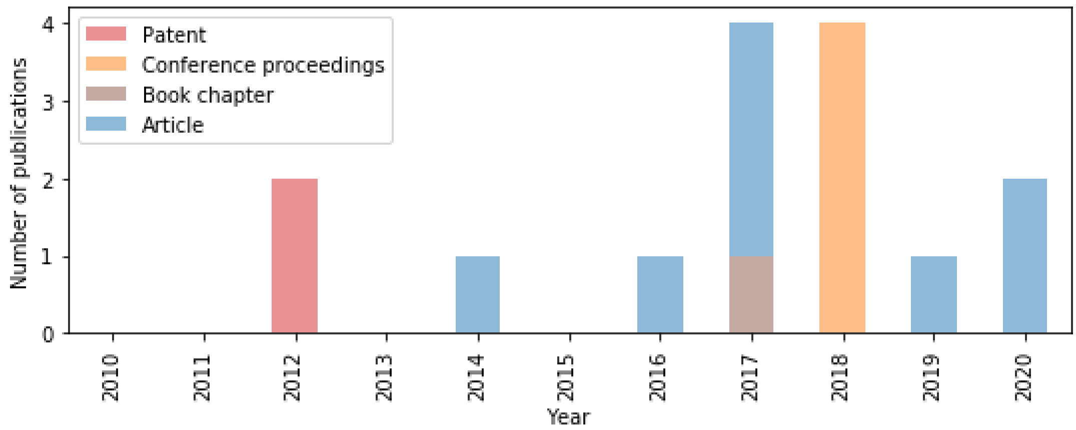


Figure 9. 'Integral Molten Salt Reactor' dataset document type distribution

The main reference regarding the related research effort is the Canadian *Terrestrial Energy*, the developers of the design. Inside the European Union, only Germany and Czechia are involved in related research (figure 10).

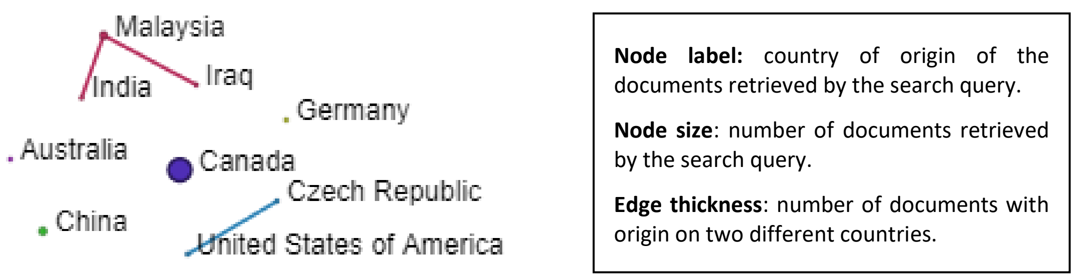


Figure 10. TIM network graph on 'Integral Molten Salt Reactor' world publications distribution

4 Conclusions

During 2020, fifteen *Horizon Scanners* from Dir G identified and recorded in *Connected* about 200 ideas with an impact in the development of nuclear technology that were first discussed during the pre-filtering sessions, and eventually during the sense-making workshop organised remotely using *Microsoft Teams* and *Miro*. In the process, the following JRC tools were used:

- *Connected* for the registration and voting of the new ideas as well as for the organisation of the sense-making workshops.
- The *European Media Monitor* (EMM) to automatically retrieve news about new ideas and developments concerning nuclear technology.
- The *Tools for Innovation Monitoring* (TIM) to explore the characteristics and relations between the identified technologies analysing the related scientific literature, patent data and data from R&D projects funded by the EU.

The topics that occupied most of the time of discussion during the workshop and focused the attention of the participating experts were:

- *The European leadership on radioisotope production.*
- *Future of nuclear energy in the EU.*
- *Participatory engagement for nuclear.*

Additionally, the bibliographic data analysis has been made in TIM. It has identified the following emerging technologies:

1. *Digital twin.*
2. *Soluble boron-free small modular reactors.*
3. *Uranium recovery from seawater.*
4. *Integral Molten Salt Reactor.*

This report contains a brief overview of these subjects as they were identified during the oversight activities carried out during the year. Follow-up actions may include in-depth studies and deep-dive discussions carried out on request of stakeholders and other parties, depending on their interest in any of these subjects.

5 Annexes

5.1 Annex 1. Horizon Scanning participants

5.1.1 List of appointed Horizon Scanners from Dir G

- HEYSE, Jan – JRC.G.2 (Geel)
- CAMBRIANI, Andrea – JRC.G.I.3 (Karlsruhe)
- COLLE, Jean-Yves – JRC.G.I.3 (Karlsruhe)
- STRUCIC, Miodrag– JRC.G.I.4 (Petten)
- ROSENGARD, Ulf– JRC.G.I.4 (Petten)
- GRIVEAU Jean-Christophe – JRC.G.I.5 (Karlsruhe)
- RAUFF-NISTHAR, Nadya – JRC.G.II.6 (Karlsruhe)
- VIGIER, Sandrine – JRC.G.II.6 (Karlsruhe)
- VERSINO, Cristina – JRC.G.II.7 (Ispra)
- ALVAREZ SARANDES LAVANDERA, Rafael – JRC.G.III.8 (Karlsruhe)
- HUBERT, Philippe – JRC.G.III.9 (Ispra)
- CIHLAR, Milan – JRC.G.10 (Petten)
- GERBELOVA, Hana – JRC.G.10 (Petten)
- SIMIC, Zdenko – JRC.G.10 (Petten)
- SIMOLA, Kaisa – JRC.G.10 (Petten)

5.1.2 List of Aggregators contributing to the Horizon Scanning for Nuclear Safety, Security & Safeguards

- LIESSENS, Ariane – JRC.G.10 (Petten)
- TANARRO COLODRON, Jorge – JRC.G.10 (Petten)

5.2 Annex 2. Bibliographic analysis tool and approach

5.2.1 JRC Tools for Innovation Monitoring (TIM)

The JRC *Tools for Innovation Monitoring* (TIM) are used to explore the characteristics and relations between the observed technologies analysing the related scientific literature, patent data and data from R&D projects funded by the EU.

TIM produces visualisations of the data with edges and nodes (i.e., network graphs). In this case, a graph is created with all the datasets defined. These datasets are defined using a search query that should contain the intended keywords connected by Boolean operators for each of the technologies corresponding to the identified cluster. The graph visualisation of all the resulting dataset consists on:

- A **label** or dataset title that summarises the meaning of the search query.
- A **node** or circle, corresponding to each label, with an area equivalent to the number of documents retrieved by the search query.
- Several **edges** or relations corresponding to the number of documents retrieved simultaneously by two different searches that correspond to two different nodes.
- A **colour** code identifying the groups of nodes that tend to have more documents in common among each other according to the so-called Louvain Modularity algorithm.

Datasets referring to the different technologies can be compared and their relations identified by analysing the resulting graph. This means that in order to study one specific technology in TIM, it is necessary to create first its related dataset, one for every technology. This series of datasets can be then visualised as a graph defining what in TIM receives the name of a '*datasetgram*'.

In this type of visualisation, each node represents a dataset related to each of the technologies. The colours identify the groups of nodes that tend to have more documents in common among each other. These groups are detected using the so-called Louvain Modularity algorithm described by Blondel et al in https://arxiv.org/abs/0803.0476

In addition, TIM computes the so-called '*activeness*' score for each of the datasets. The *Activeness indicator* returns the number of documents of a dataset (sign) in the three last years, divided by the total number of documents of the dataset. Thus, nodes with most of their hits falling in the last three years of the time range will get a score closer to 100 and nodes with almost no hit in the last three years will get a score closer to 0.

5.2.2 Approach

Each dataset was studied separately using the insights acquired from TIM in order to identify promising technologies that are non-obvious or just recently identified but likely to gain significant weight in the future.

Promising new technologies can be found in small nodes linked at least with another couple of nodes. They must have an 'activeness' TIM indicator of above 50%.

The proposed query strings for the datasets were reviewed and, when necessary, corrected by experts from JRC.I.3. Their expert assessment and advice on the use of the JRC *Tools for Innovation Monitoring* (TIM) and the interpretation of its results was also taken into account for the preparation of the conclusions of this report.

TIM provided us with the following information:

- The "*activeness*" TIM index.
- The number of connecting edges for each dataset.
- The total number of documents retrieved for each dataset.

- The charts visualising the document type total distribution and their yearly distribution.
- The time series containing the research output of the reference institutions.

Regarding the time series containing the research output of the reference institutions, it is important to notice that it represents the number of documents authored by each of the reference institutions. Therefore, it does not represent the total number of documents because there might be other institutions, not considered "leading institution", producing documents; and the leading institutions considered might have co-authored documents amongst them, so each of these documents would appear counted as many times as co-authoring reference institutions it has.

It is also important to notice that TIM contains references up to August 2020, meaning that when comparing the number of documents retrieved for 2020 with previous years there might be a drop to be interpreted just as a drop in data coverage.

5.3 Annex 3. Methodology

The *Horizon Scanning for Nuclear Safety, Security & Safeguards* as implemented at the JRC consists now of the following stages:

5.3.1 Scanning

Within the scanning phase, the scanners capture items/factual information coming from a large variety of sources. The items should be "raw" information (not necessarily analysed by someone else), reports on single developments, facts based and objective, concise, new developments and from many apparently unrelated domains. Just "opinions" or "advices" are not considered relevant for the exercise. We are looking for what "*can be"* or "*will be"* not for what "*should be"* or "*must be"*.

The sources are the materials or media providing well identified "raw" information on novelties. They may include journals providing concise news reports (e.g. Nature), scientific publications, reports, professional journals, conference proceedings, trade and business publications, magazines and newspaper, social media, blogs etc. The sources may also include already existing specialised scanning systems. For example, the Europe Media Monitor or shortly "EMM" is being used for finding relevant items about innovative developments on nuclear technology.

The items found within the scanning process are stored on the dedicated site of *Connected,* called *Horizon scanning – submit*. Once stored on *Connected*, the items become "ideas". The ideas are established according the following principles:

- An idea is created by choosing *Create an Idea* on the "Actions" menu or the box on the left of the screen.
- The new idea describing the item must have a clear title, a brief summary (maximum ½ page), a short explanation about its importance, the date of publication and the link to the source or attachment.
- The idea can be classified under one or more categories available in the edition screen, ticking at least the "*nuclear"* category.
- The idea is registered after clicking the button "Publish" at the bottom of the edition screen.

Before every workshop, which takes place several times a year, the aggregators select, prepare and format the ideas captured in Connected and provide the list to all participants in advance of the sense-making workshop.

5.3.2 Pre-filtering

5.3.2.1 Purpose

In 2020, the methodology was updated to better suit the needs of the Horizon Scanning within Dir G. The purpose was to improve the quality of the input of the sense-making session. Therefore, the sense-making workshops normally held in spring and summer were replaced with pre-filtering sessions. These sessions allow to involve the scanners in the selection of ideas and to take the time to discuss and share views and ideas.

5.3.2.2 Preparation

When a reasonable number (80-100) of ideas related to nuclear are published on the dedicated site of *Connected*, a pre-filtering session is planned, to which all scanners are invited.

The aggregator responsible for managing the session (the facilitator) extracts the ideas collected on *Connected* and formats them in a way that is user-friendly for the scanners. They are sent to the participating scanners about a week in advance of the pre-filtering session.

Before the session, the participants must go through the list of ideas and select their top 5-10 ideas that are the most interesting. They should also write down why they think the chosen ideas are important.

5.3.2.3 Participation

During the session, the participants put forward their selected ideas, explaining why they are important. This key aspect of the selection is the basis for discussions.

The aggregator(s) write down the selected ideas and harvest the essence of the discussions.

5.3.2.4 Reporting

The outcomes of each pre-filtering session are recorded in a document, which is complemented with each following pre-filtering session. The colleagues from the G.10 HS team contribute to this reporting.
The ideas that have been selected for the sense-making workshop get the status "Coming soon" on Connected, the other ones "For future consideration".
In 2020, pre-filtering sessions were held in March and September, whereas the sense-making workshop took place in October.

5.3.3 Sense-making workshop

5.3.3.1 Preparation

As soon as the date for the sense-making workshop is set, an event is created in Connected including the instructions for the session. As soon as it is available, the list of ideas is attached. The link to the event is included in the email invitations and outlook calls. After the event, the pictures can be shared on the same page and the participants can comment and record their feedback about the session, so all related conversations remain centralised and easily accessible.

About a week before the workshop, the document containing the outcome of the pre-filtering sessions aggregator is sent to the scanners together with the instructions for the preparation of the workshop.

Before the workshop, the participants must go through the list of ideas and think about how some of them would fit together suggesting an emerging trend or phenomena and gather those fitting together into clusters. They should write down the names and numbers of the ideas clustered and give the cluster a title to be presented during the workshop session.

The workshop is not a classification exercise, so there is no need to include all ideas in clusters. The aim of the workshop session is neither to criticise the abstracts nor to cover everything but to collect the concepts which indicate new trends and emerging issues. Each participant is expected to present around three clusters.

5.3.3.2 Participation

In the sense-making workshop, participants try to cluster different ideas together to see what emerging issues can be found.

A cluster is a group of two or more ideas that can be linked in some way as a potential evidence for an emerging issue. Emerging issues may be new trends, weak signals, drivers of change, or discontinuities. They may also include outlier behaviour, unconventional wisdom or new technologies that could indicate future changes with potential significant impact on society and policy. Usually, the emerging issues are developments at an early stage that had not been seriously considered yet.

The participants usually tend to find clusters that confirm their previous ideas, which may not be a problem. However, as the workshop is meant to be an open and creative exercise, the participants should not hold back, even if they may feel that the cluster is "unthinkable".

The structure of the workshop is the following:

1. *Clustering of ideas*: Participants write down individually their own clusters (title, premise, and the numbers of the related ideas) on yellow post-its.
2. *Presentation of clusters*: Participants take turns to present their clusters and put them on a board or wall.
3. *Grouping the clusters*: The participants discuss the clusters to validate their different titles and group the ones strongly related into wider or more accurate narratives recorded (title and numbers) on pink post-its.
4. *Grouping the participants*: The participants separate the groups of clusters on the wall into three or four sections. The participants can freely choose the section that they would like to work on, and the organisers cover the topics of the least chosen ones. Each small group shall develop one or two foresight stories related to the clusters available in their section.
5. *Development of foresight stories*: a representative of each small groups presents and explains the groups foresight stories in the plenary meeting. Participants can ask questions and make comment to make sure the story is well understood. After reformulating if needed, each final story is put to the wall in a pink post-it, aiming to capture a total of 3-5 stories.
6. *Prioritisation on horizon line*: The stories are prioritised using a three horizons model that is often adopted in horizon scanning to define time frames for thinking about emerging issues (e.g. Garnett at al. 2016[9]). In this model Horizon 1 is the present and the near future (1-5 years), Horizon 2 is the less immediate future (5-10 years) and Horizon 3 is the mid to long term future (10+ years).
7. *Link with the EURATOM programme*: for each of the stories, participants examine where the emerging issue fits in the EURATOM programme. For this part, one of the scanners was asked in advance to prepare an overview of the EUROTOM programme.
8. *Final capture*: The results of the session are recorded in pictures, giving special attention to the list of early signs and the codes of the ideas related to each of them.

Teamwork and collaboration among the participants are especially relevant for refining and merging the clusters into stories (stage 3) and for the development of foresight stories (stage 4).

Teamwork and collaboration among the participants is especially relevant for refining and merging the clusters into stories (stage 3) and for mapping the stories (stage 6).

5.3.4 Switch to online in 2020

In 2020, all Horizon Scanning activities were held online due to the restrictions on physical meetings related to the COVID-19 pandemic.

The pre-filtering sessions were held in a virtual meeting room. For the sense-making workshops, the virtual meeting room was complemented with the use of breakout rooms

[9] Garnett, K., Lickorish, F.A., Rocks, S.A., Prpich, G., Rathe, A.A. and Pollard, S.J.T. (2016). Integrating horizon scanning and strategic risk prioritisation using a weight of evidence framework to inform policy decisions. Science of the Total Environment, 560-561: 82-91.

for parallel discussions in smaller groups. Also, special software allowing to work with all participants together on a virtual whiteboard was used.

Holding the activities online also generated the need to divide attribute tasks more clearly with the organising team. One person took the role of host, moderator and time-keeper; another acted as harvester and (virtual white)board manager. Additionally the organising team asked the help of a number of scanners for specific tasks.

5.3.5 Reporting

The outcomes of each sense-making workshop are recorded in a document explaining the identified early signs and the prioritisation process, which is then uploaded to the event about the workshop that was created in Connected.

The nature of the exercise entails that these signs are neither predictions nor research conclusions; they are only indications or intuitive guesses made using a creative process of connecting the potential consequences of different recent developments.

The report focuses on three foresight stories developed out of the 5-6 clusters of ideas mapped during the workshop, identifying the related possible risks and opportunities.

List of abbreviations and definitions

Dir G	Nuclear Safety and Security Directorate
EMM	European Media Monitor
ESA	Euratom Supply Agency
EU	European Union
HALEU	High-Assay Low-Enriched Uranium
HS	Horizon Scanning
IMSR	Integral Molten Salt Reactor
IoT	Internet of Things
JRC	Joint Research Centre
JRC.C.7	Knowledge for the Energy Union unit
JRC.G.10	Knowledge for Nuclear Safety, Security and Safeguards unit
JRC.I.2	Foresight, Behavioural Insights & Design for Policy unit
JRC.I.3	Text and Data Mining unit
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
NASA	National Aeronautics and Space Administration
R&D	Research and Development
REFIT	The regulatory fitness and performance programme
RES	Renewable Energy Sources
SMR	Small Modular Reactor
TIM	JRC Tools for Innovation Monitoring

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