ISSN 1831-9424

European Commission

JRC SCIENCE FOR POLICY REPORT

Horizon Scanning for Nuclear Safety and Security Yearly Report - 2022

Creating an anticipatory capacity within the JRC

2023

Joint Research Centre

EUR 31413 EN

Contact information
Name: F. Wastin
Address: Westerduinweg 3, 1755 LE Petten
Email: Franck.Wastin@ec.europa.eu
Tel.: +31-224 56 5066

EU Science Hub
https://joint-research-centre.ec.europa.eu

JRC131993

EUR 31413 EN

PDF ISBN 978-92-76-99063-5 ISSN 1831-9424 doi:10.2760/255856 KJ-NA-31-413-EN-N

Luxembourg: Publications Office of the European Union, 2023

How to cite this report: *Horizon Scanning for Nuclear Safety and Security, Yearly report - 2022*, Publications Office of the European Union, Luxembourg, 2023, JRC131993.

Contents

Abstract

Horizon Scanning (HS) is a systematic outlook to detect early signs of potentially important developments. JRC.I.2 unit introduced the methodology in 2016 and, in collaboration with partner JRC Knowledge Management Units, tested it for a horizon scanning process at JRC level. JRC.G.9 benefited from this support and followed the methodology in subsequent years. Throughout 2022 JRC has collected 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:

- **Energy dependence v. climate objectives: how to improve Western cooperation?**

The energy crisis caused by the Russian military aggression on Ukraine has shown Europe's vulnerability due to the energy dependence, especially on Russian natural gas. On the way to decarbonising its energy mix, the EU should avoid heading next to a dependence on critical raw materials. To succeed, we need to reduce our dependence on Russia and China, and improve our competence in the nuclear industry, which is currently dominated by these two countries. The EU is presently in a perfect position to make use of the momentum due to the war in Ukraine to change the situation, and aim at promoting Western, and first of all European nuclear designs and technologies.

- **Public opinion on nuclear energy: communicating the energy options**

Nuclear energy remains a controversial issue for both policymakers and the general public. Its pros and cons have been relatively little discussed compared to other energy sources. If decisions on decarbonising our energy mix are based on political and ideological opinions rather than scientific facts, it may put our energy supply and economy at risk. A thorough and widespread communication effort would be necessary to bring this complex issue to the public.

Better communication would ideally lead to an informed, holistic discussion of policy makers, including all energy sources and having sustainable energy generation and supply as a common objective.

- **Nuclear industry paradigm shifting driven by the digital transformation and the green transition**

Over decades, the nuclear industry grew to settle on a highly structured and solid workflow and general practice. This led to long developing times, high capital costs and long licensing and construction times, making it less and less apt to a very fast changing world. New technologies, ways of designing and prototyping, and potential applications may trigger a paradigm shift toward a more dynamic, streamlined and flexible nuclear industry, improving the overall sustainability also in terms of safety, security and safeguards.

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

- <u>3D printing nuclear reactor components in silicon carbide</u>

The US Department of Energy's Oak Ridge National Laboratory has recently developed a new advanced additive manufacturing method to 3D print components for nuclear reactors. The technology allows the printing of refractory materials into components with complex shapes enabling new advanced reactor designs. The refractory material chosen for nuclear reactor core components is silicon carbide because of its high temperature resistance and radiation tolerance.

- <u>Nuclear technology against plastic pollution</u>

Nuclear technology can help control plastic pollution by facilitating the characterisation and assessment of marine microplastic pollution and by using ionizing radiation to transform plastic waste into reusable resources. Gamma and electron beam irradiation can complement existing recycling methods.

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

Follow-up actions may include reporting to the management for strategic purposes, in-depth studies and deep-dive discussions at the request of stakeholders and other parties, depending on their interest in any of these subjects.

1 Introduction

The JRC Strategy 2030 stresses explicitly 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 and Security* 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 using *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 and Security are given in Annex 1.
- A sense-making workshop led by *Aggregators* who compiled the ideas selected in the pre-filtering sessions, who selected sets of relevant items, and organised the discussions. The list of Aggregators contributing to the Horizon Scanning for Nuclear Safety and Security are given 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.

This report was prepared by the following contributors: Jorge TANARRO COLODRON (JRC.G.9), Kaisa SIMOLA (JRC.G.9), Milan CIHLAR (JRC.G.9), Ariane LIESSENS (JRC.G.9), Rafael ALVAREZ SARANDES LAVANDERA (JRC.G.I.6), Andrea CAMBRIANI (JRC.G.I.3), David VANLEEUW (JRC.G.2), Guido RENDA (JRC.G.II.7), Olivier Daniel EULAERTS (JRC.I.3) and Marcelina GRABOWSKA (JRC.I.3).

2 Foresight stories

The foresight stories aim to capture the possible impact in ten years and beyond 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 up to 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 paragraphs below.

2.1 Energy dependence v. climate objectives: how to improve Western cooperation?

The Russian military aggression on Ukraine, and the resulting energy crisis in Europe and beyond, have shown how vulnerable Europe is due to its energy dependence on Russia, especially for the natural gas. European countries are taking a step back in their climate ambitions by e.g. reopening coal-fired plants and increasing the use of other polluting energy sources. At the same time, as Europe is struggling to reduce its dependence on fossil fuels, it is heading to a dependence on critical raw materials required for both conventional and advanced low-carbon technologies.

The dependence on Russia and China is alarming also outside Europe, and beyond fossil fuels. The Russian and Chinese hegemony in the nuclear market have been a concern of the European nuclear industry for a while. These two countries are leaders in marketing and operating NPPs, and Russia in particular has dominance in nuclear fuel enrichment and fabrication. Further, China has dominance of critical raw materials, which are especially important for "green energies". The lack of new built in nuclear in the EU will even deepen such dependence, implying a further increase in the capacity of renewables and their related technology.

On our way to decarbonise the EU there is a clear need to stop not only Europe's dependence on Russia and China, but also more globally Russia's dominance in the nuclear industry. The EU is presently in a perfect position to make use of the momentum due to the war in Ukraine to change the situation, and promote Western, and first of all European designs and technologies to counteract Russia's and China's dominance. At the same time, Europe needs to create its own sustainable, secure and reliable supply chain to address the scarcity of materials that are critical for the energy transition, as addressed in the recent EC initiative on the European Critical Raw Materials Act.

2.1.1 Time horizons

At present, Russia and China are leading the market on the nuclear supply chain. Currently, 55 new reactors are under construction in 19 countries, and 19 of those are in China. Russia is the world's top nuclear technology exporter. In Europe nearly 20 Russian design nuclear reactors rely on the Russian company Rosatom for the supply of nuclear fuel. At the same time, Europe lacks a consensus on the role of nuclear in fighting climate change, also leading to struggles in the nuclear industry. However, the Russian nuclear industry could severely suffer from the war due to both the "political image" and the sanctions. Western countries are reconsidering their choices on nuclear projects: Czechia has already excluded China and Russia from the tender for a new nuclear unit on security grounds. A Finnish energy company terminated the contract it had awarded to a Rosatom subsidiary soon after the beginning of the war in Ukraine, and Bulgaria is speeding up requirements for nuclear fuel supply to use technologies and licences which are not related to Russia.

In the midterm, it can be expected that the sanctions against Russia will also start harming its nuclear industry. The measures taken to cut out Russia from high tech and strengthen the export control are already showing their effect, such as a shortage of semiconductors or aeroplanes lacking spare parts. Even if many countries still wouldn't exclude Russia as an NPP vendor for political reasons, Russia might have difficulties in some parts of the supply chain to deliver critical components to their nuclear installations.

The EC could play an important role in promoting Western nuclear technologies and approaches by for instance strengthening – and reshaping if needed – its Instrument for Nuclear Safety Cooperation (INSC) program. Third countries that are in the process of evaluating nuclear options could be steered into adopting Western nuclear technologies and suppliers by the prospect of receiving EC support in creating and/or strengthening the necessary institutional and regulatory nuclear infrastructure.

One adverse effect of the increased isolation of Russia could be an increasing concern about nuclear safety, as it may become more challenging to carry out nuclear safety inspections on the Russian territory.

In the longer term, if the EU is successful in reducing China's and Russia's dominance in the market, a renaissance of the Western nuclear industry may be seen. In an optimistic scenario, a stable and diversified supply of uranium and fuel would make the EU fully independent from Russian nuclear fuel. The future role and share of European vendors and suppliers will also depend on the political climate in the EU with regard to nuclear energy.

On a wider scale, in order to have a successful energy transition, Europe needs to reduce its dependence from imports and increase its sovereignty. Efficient recycling and reprocessing of critical minerals are an important part of this, but nuclear can also play a significant role if its share in the production of electricity and heat is increased.

2.1.2 Relevant news

- 05/03/2022 - War in Ukraine and climate change are reshaping the nuclear industry 🌐
- 03/07/2022 - Russian and Chinese designs dominate nuclear reactors 🌐
- 18/03/2022 - Russia's energy clout doesn't just come from oil and gas – it's also a key nuclear supplier 🌐
- 23/03/2022 - The Coming Collapse of Russia's Nuclear Exports: An Opportunity for the U.S. and its Allies 🌐
- 27/01/2022 - Metals needed for hydrogen production could get scarce 🌐
- 23/02/2022 The energy transition and carbon-free technologies may result in dependence on strategic minerals 🌐
- 11/11/2022 Bulgaria / Parliament Passes Motion To Speed Up Supply Of Non-Russian Nuclear Fuel 🌐
- 07/10/2022 Russia's multi-million euro nuclear exports untouched by EU sanctions 🌐

2.2 Public opinion on nuclear energy: communicating the energy options

While a large consensus exists on the need to replace the fossil fuels with close-to-zero CO2 emission energy sources, the nuclear energy remains a controversial issue for both policymakers and the general public. When looking on the one hand at the risk perception of nuclear and on the other hand at the experience so far on e.g. the fatalities caused by nuclear energy production, one can conclude that mortality rates do not correlate with perceived risk. In addition to the biased risk perception, some unrealistic beliefs on decarbonising the energy mix prevail (especially within citizen groups who are opposed to nuclear energy). Replacing fossil energy sources with solar and wind energy combined with gas and energy storage, without including nuclear in the energy mix is more challenging to implement as one may believe.

These perceptions and beliefs can put our energy supply and economy at risk. The responsibility for a sustainable future rests on politicians, but there are driving political decisions that may not necessarily be consistent with sustainability goals and other social values. Until now, energy-related decisions have rather focused on short-term impacts, being mainly driven by the election term and the public opinion. There has been a lack of long-term perspective in the decisions. However, such far-reaching decisions, like dismantling the available and well-functioning energy systems before having a viable alternative, can have long-term negative effects on the entire society and economy.

Energy policies need to stay neutral, i.e. comparing the pros and cons of all sustainable energy sources and include well-being and culture in the studies and decisions. Since it may be difficult for both politicians and for the public to understand the complexity of energy systems, the communication on energy issues need to be redefined so that everyone understands. The messages to the public have to be correctly formulated and comprehensible. They must be based on science rather than notions or ideology. Policy makers must keep the public messages simple, targeting them to each specific audience.

Although public perception is changing in some countries, the communication campaigns on nuclear energy have not worked well so far. One key problem is the complexity of nuclear issues, making them difficult to be communicated. The nuclear industry and academia have had low voices, and the nuclear communication has traditionally been on the defensive. In discussions on pros and cons political and ideological easily take over on scientific arguments, much more than is the case with other energy sources. A solution can be to convey simple messages on what actually is "green", and addressing the trade-offs across different energy options.

Who should then pass the message to the public and politicians? What about the impact of social networks in creating an opinion on nuclear energy? Closer cooperation between nuclear scientists and policy-makers is desirable to create an informed public opinion. Furthermore, new paths to conveying relevant facts to the public are also necessary. Social media may offer a suitable platform for shaping such a discussion, especially among the younger generation. So-called “influencers” may be able to better convey the message to those used to this type of communication.

What should be the role of JRC in this process? Institutions like JRC have the knowledge and responsibility to speak up while remaining neutral

2.2.1 Time horizons

At present, the debate on the future energy mix is narrowly focused just on some aspects of energy generation. There needs to be more consideration given to the supply security that cannot be achieved by solely using renewable sources. Nuclear energy has an ample supply potential considering its high availability and energy density. Although it is a well-proven fact, the nuclear industry and academia have yet to play a sufficient role in promoting it.

Due to the lack of a holistic view, the actual energy options and the associated risks are not adequately evaluated and understood. Academics and the industry have difficulty to understand and communicate complex technical matters in a simple, comprehensible and credible way to the politicians and the public. This can contribute to a distorted public perception of nuclear energy, as the debate has been essentially focused to nuclear waste and nuclear severe accidents. The recent dispute within the German government over keeping the last three nuclear power plants in operation showed how difficult it is to make a rational decision on a highly politicised issue.

In the midterm, the issue would benefit from involving political and social sciences. Discussions on nuclear would consider all its aspects (incl. social and political) and people could start having a broader view of the role of nuclear energy. The debate would be more informed, considering the issue’s complexity. Messages to the public would be technically correct but still clear and comprehensible, analysing and interpreting the facts from a wide range of perspectives. The communication channels and communicators have to be carefully chosen.

However, there is still a risk of failure to frame the messages in a more holistic way. The debates can also be lengthy at all levels without reaching any neutral and objectively positive conclusion.

In the long term, a holistic discussion may arise among policymakers, including all energy sources and with a common objective – sustainable energy generation and supply. Energy studies and political decisions may also include well-being and culture. The communication strategy contains narratives on the future that will reach everyone.

If the communication strategy or discussion on energy remains the same in the future to reflect the complexity of the entire issue, a sound and long-term political strategy on nuclear is unlikely to emerge. It would prevent viable decisions on the future energy mix and portfolio. The current trends in the perception and development of the energy system would most likely persist.

2.2.2 Relevant news

- 14/02/2021 - We're all radioactive, so let's stop being afraid of it 🌐
- 29/10/2021 - Assessing Views towards Energy Sources with Social Media Data: The Case of Nuclear Energy in the UAE 🌐
- 16/03/2022 - Accepting risk and planning for failure to survive disasters 🌐
- 11/04/2022 - Support for nuclear power in Sweden reaches 'record levels', survey suggests 🌐
- 18/04/2022 - Energy Myths Are Triggering a New Dark Age in Europe 🌐
- 20/06/2022 - The Rich World's Climate Hypocrisy 🌐
- 12/08/2022 - Germany Sees Tidal Shift in Sentiment Toward Atomic Energy
- 16/08/2022 - Lithuania's decision to give up nuclear energy "was a big mistake" 🌐
- 16/08/2022 - How can we combat with an anti-nuclear virus 🌐 🌐 🌐
- 28/08/2022 - Swiss politicians' lobby group calls for rethink on nuclear plant phase-out 🌐
- 28/10/2022 - How Finland's Green Party Chose Nuclear Power 🌐

2.3 Nuclear industry paradigm shifting driven by the digital transformation and the green transition

Over decades, the nuclear industry grew to settle on a highly structured and solid workflow and general practice. This led to very long developing times, very high capital costs and very long licensing and construction times, making it less and less apt to a very fast changing world. New technologies, ways of designing and prototyping, and potential applications may trigger a paradigm shift toward a more dynamic, streamlined and flexible nuclear industry, improving the overall sustainability regarding safety, security and safeguards.

2.3.1 Time horizons

At present, although the nuclear industry is perceived as more corporate, conservative and structured than younger and more dynamic digital industries, evolutionary (evolved from today's water-cooled reactors) and innovative (promising next generation reactors) designs are infusing a new dynamism into the sector. This dynamism is encouraged by public and private efforts within the scope of the so-called 'twin transitions' (green + digital) e.g. the industry may benefit in the future from including nuclear power in the 'Green Taxonomy'. There is no doubt about the related capabilities of the European Union.

However, the world's top nuclear technology exporter today is Russia and China plans at least 150 new reactors in the next 15 years, more than the rest of the world has built in the past 35 years. Both countries have clearly demonstrated their capacity and actual capability to leverage existing reactor designs to develop a leading world-class nuclear industry. The United States, on the other hand, is upping the ante by investing in evolutionary and innovative designs. The Transformational Challenge Reactor (TCR) developed in the Oak Ridge National Laboratory, aims to bear additive manufacturing (AM) and artificial intelligence (AI) to deliver enabling technologies for those advanced reactors. The US Department of Defence will also construct a nuclear micro-reactor at the Idaho National Laboratory under project Pele that is expected to be transportable and capable of delivering 1-5 Megawatts of electrical power during three years of continuous operation. On top of that, NASA is working on a fission surface power system to provide 40 kilowatts of power to base camps on the Moon and Mars for ten years. These efforts are probably also directed towards a growing international nuclear reactor market with potential new clients such as Poland, South Africa, Bangladesh, Egypt, Mexico, Jordan, The Philippines, Vietnam, Ghana, Indonesia, Morocco and Thailand. All these countries are to be considered nuclear "Ready" or "Potentially Ready" by 2030, together representing a fifth of the projected additional global electricity demand by 2050.

In the midterm, as the economic consequences of the pandemic followed by the war in Ukraine worsen, investment priorities might oscillate towards ensuring the sustained operation of critical infrastructure under expected serious risks such as severe weather conditions, violent conflict or imposed economic constraints. The increased flexibility of novel advanced reactor initiatives may allow them to incorporate the technical considerations satisfying those concerns in order to gain attractiveness within the investment and political debates. The first scenario for the deployment of these reactor models is to have multi-unit sites to replace old big power plants outside highly densely populated areas. Their reduced size, completely different visual impact, potential new markets and business models (e.g. energy as a service) might bring them within the cities and on the seas. Their reliance on digital enabling technologies such as advanced additive manufacturing or digital twins might facilitate the incorporation of young talent already familiar with these tools and looking for new challenges and innovative applications. However, if no centrally coordinated investment and support are provided to those initiatives and the regulatory harmonisation cannot to integrate the related European market, those efforts might migrate to more favourable business environments. The European Union may become technologically dependence on its OECD partners, especially the United States.

Following this trend, the **longer term** might see how nuclear technology can contribute to decarbonising those sectors where other green energy sources cannot. Nuclear can complement them and sustain the green transition while improving climate change resilience and the most sensible and efficient use of available resources. As new young talent grows within the sector and innovative tools are developed, new innovative approaches and even better solutions may emerge to tackle related challenges such as nuclear fuel availability, radioactive waste management and nuclear proliferation. In case the European nuclear landscape reacts quickly and adapts to the paradigm shift, the EU could deploy autonomously strategic applications of more versatile reactors on earth (e.g. urgent deployment of electricity following disaster scenarios), at sea or in space.

2.3.2 Relevant news

European start-ups bringing forward innovative nuclear reactors:

NAME	COUNTRY	TYPE
JIMMY	France	High Temperature Reactor
NAAREA	France	Molten Salt Reactor
SEABORG	Denmark	Molten Salt Reactor
COPENHAGEN ATOMICS	Denmark	Molten Salt Reactor
MOLTEX FLEX	UK	Molten Salt Reactor
LEADCOLD	Sweden	Lead Cooled Fast Reactor
NEWCLEO	UK and Italy	Lead Cooled Fast Reactor
U BATTERY	UK and the Netherlands	TRISO fuelled reactor
TRANSMUTEX	Switzerland	Subcritical Transmutating Accelerated Reactor

3 Nuclear Technology Observatory

In parallel to the Horizon Scanning exercise, a bibliographic data analysis was performed to complement the Horizon Scanning conclusions with additional valuable insights about technological 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 and its evolution over 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.

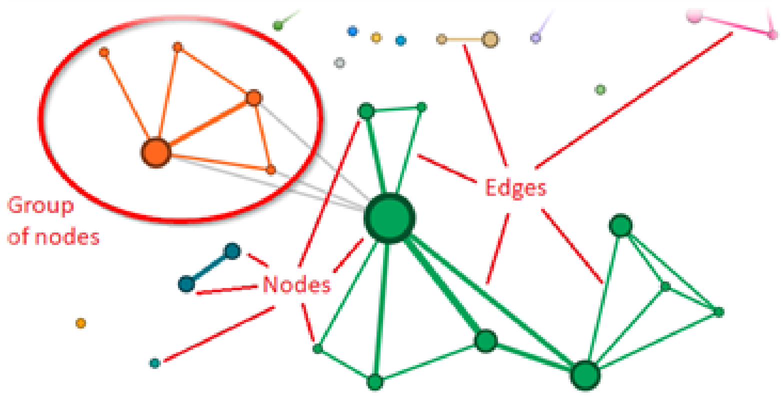
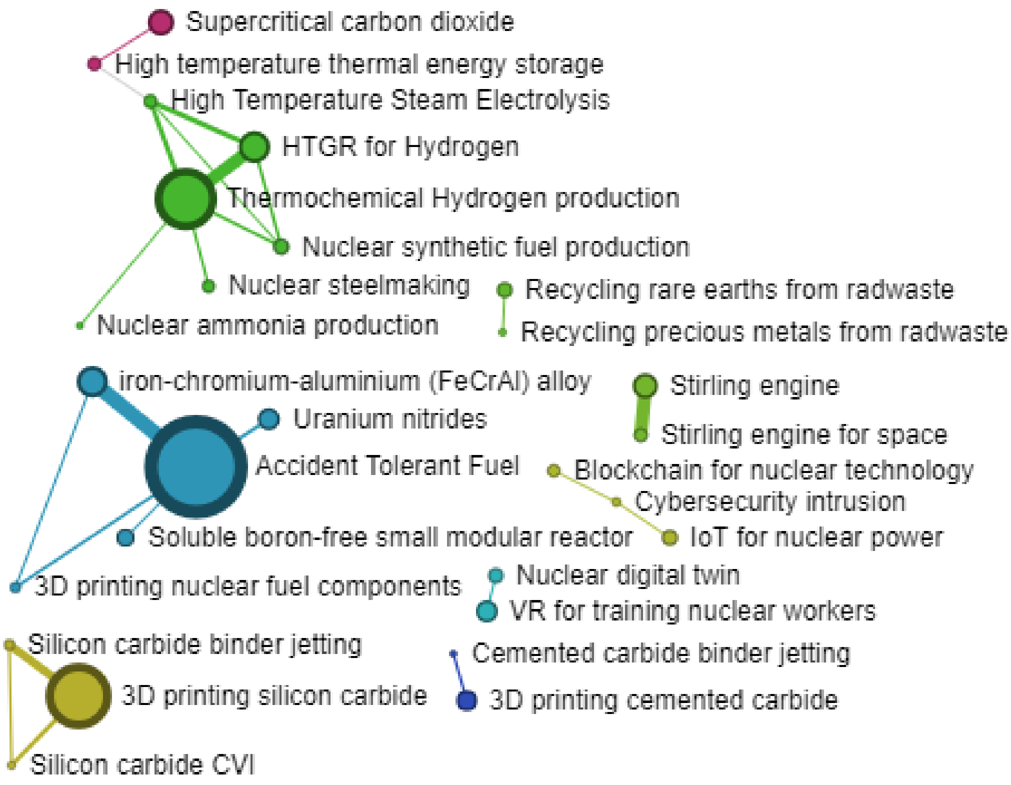


Figure 1. Network graph legend

Source: http://www.timanalytics.eu/

Figure 2 (below) shows the nuclear technologies recorded during the year and studied for this analysis, and how they connect through common publications.



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 2022 datasetgram

Source: http://www.timanalytics.eu/

The focus of this observatory lies on the technologies with an *"activeness 2020-2022"* indicator higher than 50, meaning that the majority of their related documents were published in the last three years, which is considered an indication of emerging technologies, i.e. rapidly growing over the last three years.

The technologies observed are the following:

Technology	Activeness (2020 - 2022)	Number of documents retrieved	Foresight reference
Nuclear digital twin	87%	33	Horizon Scanning for Nuclear Safety, Security & Safeguards Yearly Report - 2020
Blockchain for nuclear technology	80%	25	Horizon Scanning for Nuclear Safety, Security & Safeguards Yearly Report - 2018
Nuclear power plant cybersecurity intrusion	72%	11	Horizon Scanning for Nuclear Safety, Security & Safeguards Yearly Report - 2018
3D printing of silicon carbide with chemical vapor infiltration	71%	7	**New emerging trend**
AI assisted autonomous operation	66%	9	Horizon Scanning for Nuclear Safety, Security & Safeguards Yearly Report - 2021
3D printing of silicon carbide with binder jetting	64%	17	**New emerging trend**
3D printing nuclear fuel components	58%	17	Horizon Scanning for Nuclear Safety, Security & Safeguards Yearly Report - 2021
Microbe protection against radiation	54%	31	Horizon Scanning for Nuclear Safety, Security & Safeguards Yearly Report - 2021
Nuclear technology against plastic pollution	50%	6	**New emerging trend**

Some of these technologies were already identified in previous Horizon Scanning exercises and the fact that they still have an activeness indicator above 50 indicates that they continued growing in the last year.

Below is a presentation of the new emerging trends detected.

3.1 3D printing nuclear reactor components in silicon carbide

The US Department of Energy's Oak Ridge National Laboratory has recently developed a new advanced additive manufacturing method to 3D print components for nuclear reactors. The technology allows the printing of refractory materials into components with complex shapes enabling new advanced reactor designs. The refractory material chosen for nuclear reactor core components is silicon carbide because of its high-temperature resistance and its radiation tolerance. The technology combines binder jet printing as an additive manufacturing technique and a ceramic production process called chemical vapor infiltration. Silicon carbide is also used in tank armour, electronics and aerospace applications. However, using it to forge the complicated shapes of reactor components using conventional methods like machining or casting is too time-intensive and expensive.

To extract from TIM the information about patents, conference proceedings, scientific articles, book chapters, reviews and EU funded projects related to *3D printing of silicon carbide with chemical vapor infiltration*, the following query was used:

topic:(("3D printing" OR "additive manufacturing") AND "silicon carbide" AND "chemical vapor infiltration")

This query generated a dataset of 7 documents. The historic distribution of those publications is shown in the figure below (figure 3).

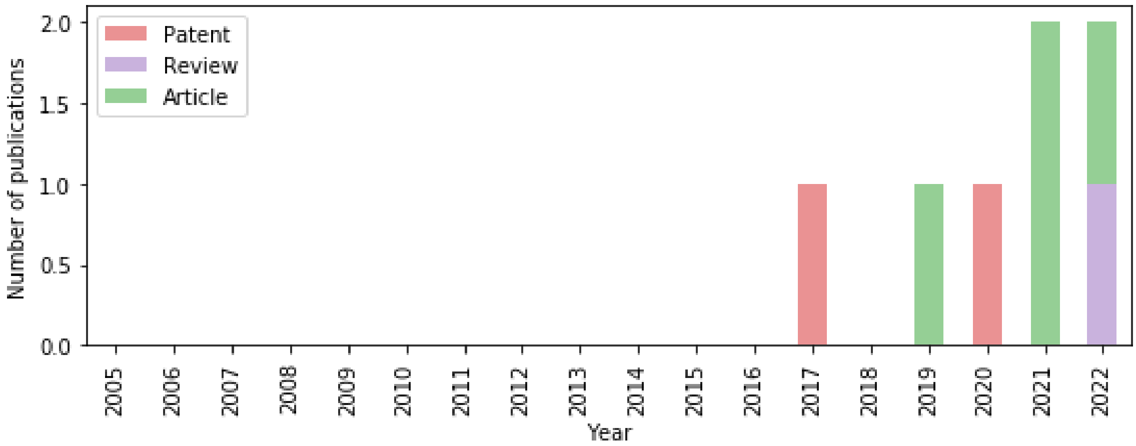


Figure 3. *'3D printing of silicon carbide with chemical vapor infiltration'* dataset document type distribution

Source: https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_2007?ds=260735

The figure below (figure 4) displays the countries involved in the publication of the retrieved documents depicted above.

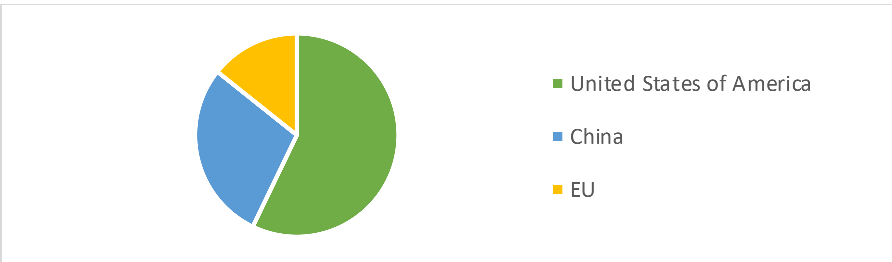


Figure 4. TIM network graph on *'3D printing of silicon carbide with chemical vapor infiltration'* world publications distribution.

Source: https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_2007?ds=260735

To extract from TIM the information about patents, conference proceedings, scientific articles, book chapters, reviews and EU funded projects related to *3D printing of silicon carbide with binder jetting*, the following query was used:

topic: (("3D printing" OR "additive manufacturing") AND "silicon carbide" AND ("binder jetting" OR "binder jet"))

This query generated a dataset of 17 documents. The historical distribution of those publications is shown in the figure below (figure 5).

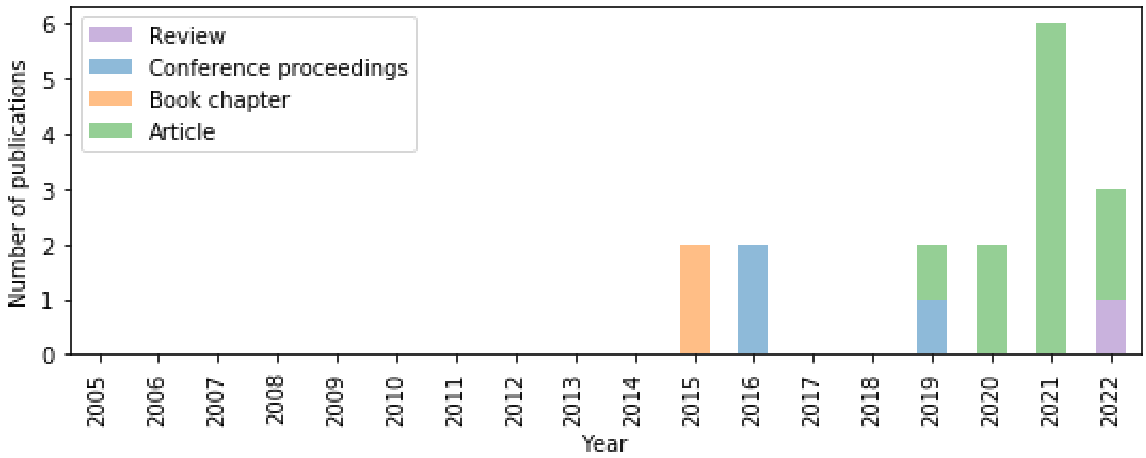
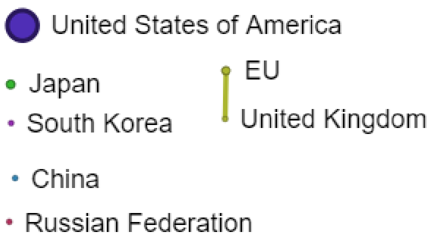


Figure 5. *'3D printing of silicon carbide with binder jetting'* dataset document type distribution

Source: https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_2007?ds=260736

The figure below (figure 6) displays the countries involved in the publication of the retrieved documents depicted above.



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 *'3D printing of silicon carbide with binder jetting'* world publications distribution.

Source: https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_2007?ds=260736

3.2 Nuclear technology against plastic pollution

Nuclear technology can help control plastic pollution by facilitating the characterisation and assessment of marine microplastic pollution and by using ionizing radiation to transform plastic waste into reusable resources. Gamma and electron beam irradiation can complement existing recycling methods.

To extract from TIM the information about patents, conference proceedings, scientific articles, book chapters, reviews and EU funded projects related to *nuclear technology against plastic pollution*, the following query was used:

topic:(("ionizing radiation" OR "electron beam" OR "gamma beam") AND ("plastic pollution" OR "plastic waste" OR "plastic recycling") NOT shielding NOT sterilization)

This query generated a dataset of 5 documents. The historical distribution of those publications is shown in the figure below (figure 7).

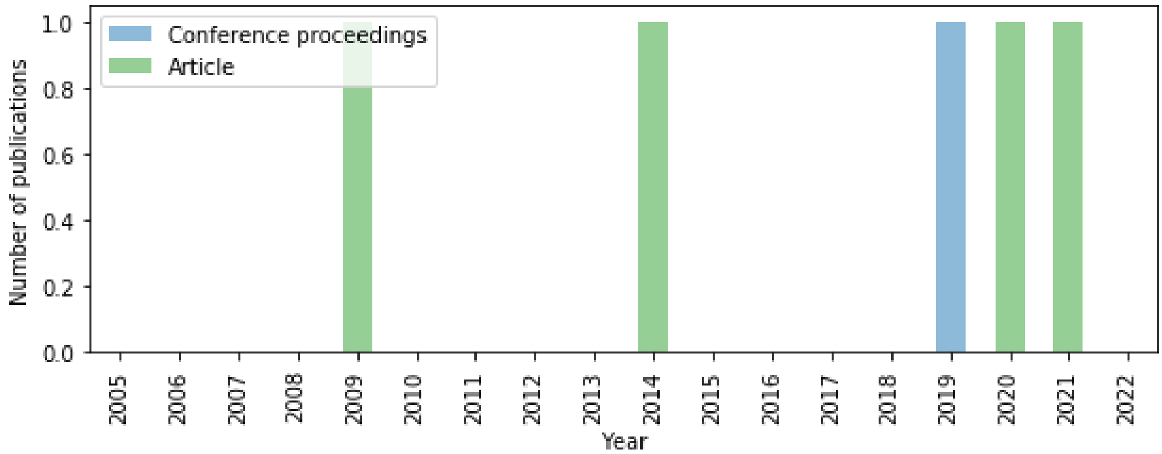
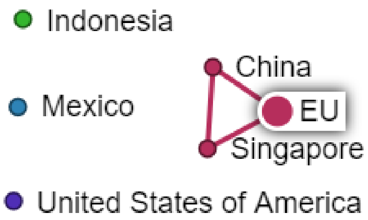


Figure 7. *'Nuclear technology against plastic pollution'* dataset document type distribution

Source: https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_2007?ds=264449

The figure below (figure 8) displays the countries involved in the publication of the retrieved documents depicted above.



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 8. TIM network graph on *'Nuclear technology against plastic pollution'* world publications distribution.

Source: https://www.timanalytics.eu/TimTechPublic/dashboard/index.jsp#/space/s_2007?ds=264449

4 Conclusions

During 2022, about fifteen *Horizon Scanners* from Dir G and external participants identified and recorded in *Connected* about 200 ideas with an impact in the development of nuclear technology. They 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 by analysing the related scientific literature, patent data and data from R&D projects funded by the EU.

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

- *Circular Energy dependence v. climate objectives: how to improve Western cooperation?*
- *Public opinion on nuclear energy: communicating the energy options*
- *A Nuclear industry paradigm shifting driven by the digital transformation and the green transition*

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

1. *3D printing nuclear reactor components in silicon carbide*
2. *Nuclear technology against plastic pollution*

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 reporting to the management for strategic purposes, in-depth studies and deep-dive discussions carried out on the request of stakeholders and other parties, depending on their interest in any of these subjects. Experience showed that involving external participants is beneficial to the process.

References

JRC Strategy 2023, https://ec.europa.eu/jrc/sites/jrcsh/files/jrc-strategy-2030_en.pdf

Models of Horizon Scanning – How to integrate Horizon Scanning into European Research and Innovation Policies, European Commission, 2015.

Krzysztofowicz , M, JRC Horizon scanning pilot project – report of phase I of the pilot, 2017.

Simic, Z, Rossi, F, Tanarro Colodrón, J, Cihlar, M, Simola, K, Horizon Scanning pilot for Nuclear Safety, Security & Safeguards – Phase 1, Publications Office of the European Union, Petten, 2018.

EU, Joint Research Centre, *TIM Analytics,* http://www.timanalytics.eu/

EU, Joint Research Centre, *EMM NEWSBRIEF*, https://nsmm.emm4u.eu/

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)
- VANLEEUW, David – JRC.G.2 (Geel)
- CAMBRIANI, Andrea – JRC.G.I.3 (Karlsruhe)
- COLLE, Jean-Yves – JRC.G.I.3 (Karlsruhe)
- GRIVEAU Jean-Christophe – JRC.G.I.5 (Karlsruhe)
- ALVAREZ SARANDES LAVANDERA, Rafael – JRC.G.I.6 (Karlsruhe)
- FONGARO, Lorenzo – JRC.G.I.6 (Karlsruhe)
- RENDA, Guido – JRC.G.II.7 (Ispra)
- VIGIER, Sandrine – JRC.G.II.8 (Karlsruhe)
- CIHLAR, Milan – JRC.G.9 (Petten)
- GERBELOVA, Hana – JRC.G.9 (Petten)
- SIMOLA, Kaisa – JRC.G.9 (Petten)

5.1.2 List of Aggregators contributing to the Horizon Scanning for Nuclear Safety and security

- LIESSENS, Ariane – JRC.G.9 (Petten)
- TANARRO COLODRON, Jorge – JRC.G.9 (Petten)

5.1.3 List of non-Directorate G participants to the workshops

- DI BUONO, Antonio – ENS (European Nuclear Society)
- GOULART, Margarida - JRC.A.7 (Brussels)
- MARTIN RAMOS, Manuel - JRC.A.7 (Brussels)
- SHORTALL, Ruth – JRC.C.3 (Petten)
- WOOD, Maureen – JRC.E.2 (Ispra)

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 by 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). A graph representing all the datasets defined and their documents in common is created(see figure 2). 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 graphical visualisation of all the resulting datasets consists in:

- 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 corresponding 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 can be identified by analysing the resulting graph. This means that to study one specific technology in TIM, it is necessary to create first its related dataset, one for every technology. This collection of datasets can be then visualised as a graph called '*datasetgram*' in the TIM software.

In this type of visualisation, each node represents a dataset related to each technology. The colours identify the groups of nodes that tend to have more documents in common with 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 in the last three 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 zero.

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 with another couple of nodes. We selected the ones with 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’s total distribution and their yearly distribution.
- The countries where the documents were produced.

It is also important to notice that TIM contains Scopus references up to August 2022, meaning that when comparing the number of documents retrieved for 2022 with previous years, there might be a drop to be interpreted just as a drop in data coverage. For patents, the time lag is longer, with the majority of the patents available being reported in the European Patent Office before 2019.

5.3 Annex 3. Methodology

The *Horizon Scanning for Nuclear Safety and Security* 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 various 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 "pieces of advice" 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, 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 in 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 are called "ideas". The ideas are established according to 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 check and, if necessary, improve the format of the ideas captured in Connected and provide the participants with instructions on how to prepare for the workshop at least a week in advance of the sense-making workshop.

5.3.2 Pre-filtering

5.3.2.1 Purpose

The methodology updated in 2020 to better suit the needs of the Horizon Scanning within Dir G was continued in 2021 and 2022. The number of ideas submitted on Connected allowed for two pre-filtering sessions to be organised during the year. These sessions not only improve the quality of the input of the sense-making session but also 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) checks the ideas collected on *Connected* and formats them in a way that is user-friendly for the scanners. The instructions for preparing the session 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 are asked to vote for their selected ideas through the dedicated feature on Connected. They should also write down why they think the chosen ideas are important, preferably by using the comment feature under the idea in *Connected*.

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.9 HS team contribute to this reporting.
In 2022, pre-filtering sessions were held in April and September, whereas the sense-making workshop took place in October.

5.3.3 Sense-making workshop

5.3.3.1 Preparation

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, suggest an emerging trend or phenomenon 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 rather 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 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 potentially significant impacts on society and policy. Usually, the emerging issues are developments at an early stage that have yet to be considered seriously.

The participants usually 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. When the workshop is held online, the organiser fulfilling the role of a harvester creates the post-its on a digital whiteboard that is visible to all participants.
2. *Presentation of clusters*: Participants take turns to presenting their clusters and putting them on a board or wall. When the workshop is held online, participants will write their clusters in a digital tool allowing the harvester to put it on the whiteboard.
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. When the workshop is held online, this is coordinated by the harvester on the whiteboard.
4. *Grouping the participants*: The participants separate the groups of clusters on the wall into three sections. Each section will be further developed by the participants in small groups. The participants

can, in principle, choose the section that they would like to work on, but an equal distribution of participants between the smaller groups is preferred. The organisers provide one facilitator for each group to ensure the necessary structure, explanation and moderation of the discussions.

5. *Development of foresight stories in small groups*: Each small group shall develop one foresight story related to the clusters available in their section. For this purpose, a methodology is proposed by the organisers, involving a PowerPoint containing the clusters for each small group and followed by suggestions for the discussions and questions to answer.
6. *Presentation of each foresight story*: a representative of each small group presents and explains the group's foresight story in the plenary meeting. Participants can ask questions and make comments to make sure the story is well understood.
7. *Forward-looking questions*: after each presentation in the plenary, participants are asked to come up with questions related to the future development of the story. The purpose is not to answer these questions but to raise awareness about critical issues.
8. *Final capture*: The results of the session obtained are recorded in pictures, either from the physical wall or from the Miro digital board. The PowerPoint slides are also saved, giving special attention to 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 (stage 3) and for the development of foresight stories (stage 5).

5.3.4 All activities held online in 2022

In 2022, all Horizon Scanning activities were held online. 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 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 makes it imperative to clearly attribute tasks within the organising team. One person took the role of host, moderator and time-keeper; another acted as harvester and (virtual white)board manager. Additionally, three persons from the organising team held the role of moderators during the work in smaller groups.

5.3.5 Reporting

The outcomes of the first pre-filtering session are recorded in a document which contains the ideas (from Connected) that were picked out in the joint exercise, as well as the topics detected from the batch of selected ideas. After each subsequent pre-filtering session, the document is complemented with new joint and new ideas (from Connected). The latter can be related to new topics or to those already identified. This document serves as a basis for the sense-making workshop which takes place every year around October.

The outcomes of the sense-making workshop are recorded in the present yearly report, which explains the three foresight stories developed by the smaller groups during the workshop, identifying the related possible risks and opportunities.

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.

List of abbreviations and definitions

3D	3-dimensional
AI	Artificial Intelligence
AM	Additive Manufacturing
Dir G	Nuclear Safety and Security Directorate
EMM	European Media Monitor
EC	European Commission
EU	European Union
HS	Horizon Scanning
INSC	Instrument for Nuclear Safety Cooperation
JRC	Joint Research Centre
JRC.G.9	Knowledge for Nuclear Safety and Decommissioning unit
JRC.I.2	Foresight, Behavioural Insights & Design for Policy unit
JRC.I.3	Text and Data Mining unit
NPP	Nuclear Power Plant
OECD	Organisation for Economic Co-operation and Development
REFIT	The regulatory fitness and performance programme
TCR	Transformational Challenge Reactor
TIM	JRC Tools for Innovation Monitoring

List of figures

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
joint-research-centre.ec.europa.eu

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

EU Science

Publications Office
of the European Union