European Commission

JRC SCIENCE FOR POLICY REPORT

Horizon Scanning for Nuclear Safety, Security & Safeguards Yearly Report - 2019

Creating an anticipatory capacity within the JRC

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2020

Joint Research Centre

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JRC118824

EUR 30153 EN

PDF ISBN 978-92-76-17510-0 ISSN 1831-9424 doi:10.2760/1105

Luxembourg: Publications Office of the European Union, 2020

How to cite this report: Wastin, F., Simola, K., Tanarro Colodron, J., Liessens, A., Simic, Z., Eulaerts, O.D., *Horizon Scanning for Nuclear Safety, Security & Safeguards, Yearly report - 2019*, EUR 30153 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-17510-0, doi:10.2760/1105, JRC118824.

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 2019 a number of ideas related to nuclear technology, later on filtered and clustered in the so called 'sense-making workshops'. This report presents the outcome of this exercise.

1 Introduction

The JRC Strategy 2030 specifically stresses the need for 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.
- Sense-making sessions 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.

The knowledge management team working on nuclear technology (JRC.G.10) has taken up the horizon scanning activity with dedication and enthusiasm since 2017. The original focus has been mainly on nuclear-related issues. In 2019, also other JRC directorates joined the nuclear horizon scanning to broaden scope of the exercise and to include other relevant related domains.

The present report is the result of those multi-directorate sense-making workshops that brought together colleagues from different units in Directorates C, E, F, G and I to discuss about the future of nuclear technology.

2 Outcomes of the HS sense making sessions

During 2019, three sense-making sessions were organised. The first session was organised in collaboration with Dir. C (Energy Transport and Climate) and Dir E (Space, Security and Migration) in order to capture interdisciplinary insights on energy and security issues. The second session was organised in collaboration with Dir F (Health, Consumers and Reference Materials) to cover potential links between nuclear technology and health. The last sense-making session remained focused on Dir. G. In each sense-making workshop, the participants reviewed and clustered about 100 ideas.

During the first two sense-making workshops, the participants also considered the potential impact over time of the most interesting clusters. Three distinctive time horizons mark the reference of the maximum impact:

- H1: Clusters capturing already ongoing trends,
- H2: Clusters representing new emerging trends, which are foreseen to have an impact in the coming 5 years,
- H3: Less obvious weak signals, having their maximum impact in 10 years or later.

Figure 1 illustrates these three time horizons.

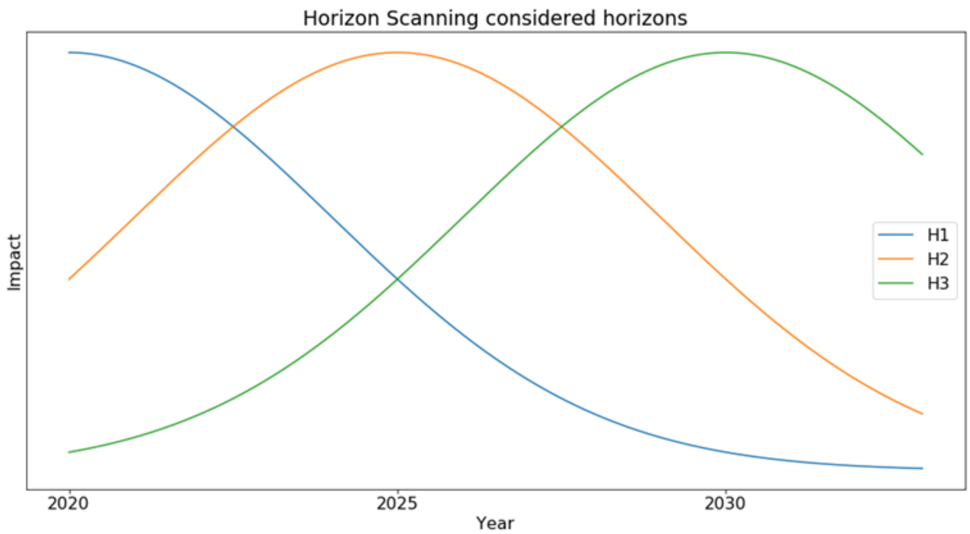


Figure 1. Horizon Scanning three considered time horizons

The summary of the clusters of ideas and their time horizon from the two first workshops are listed in Table 1.

Table 1. Clusters of ideas and their time horizon (1st and 2nd sense-making workshops).

Name of the cluster	Workshop #	Time horizon
Nuclear energy back in the political agenda	1	H1
The globalisation of technological development causing environmental degradation	1	
A complicated relation between the EU and China	1	
Climate change calls for non-ideological assessments of plans for energy mix	2	
Polarisation of public debate is preventing action on climate change	2	
The current policy cycle can't keep up with the rapidly changing world	2	
Trust as the most precious political asset in a culture of fear	1	H2
Nuclear business model getting small	1	
Digital new business models becoming 'physical'	1	
Nuclear micro-reactors powering maritime transportation	1	H3
Governments and corporations knowing you better than you know yourself	1	
Hardware hacking as weapon against energy infrastructure	1	
Access to resources will put a brake on technological deployment	2	
Nuclear energy for climate change mitigation – change in public perception/ new nuclear technologies ; limitations of resources	2	
Global environmental change will soon threaten global population	2	

In the case of the third workshop, a slightly different approach was applied. The focus was on utilising both the most recent scanned items and the clusters of ideas from earlier workshops, in order to merge them in a smaller set of stories for further development.

Based on the discussions at the third workshop, the following significant clusters of ideas were identified:

- The power of meaning in the struggle of facts vs emotions.
- Trust, the great stabiliser of participatory, honest and effective governance.
- The growing gap between evolving technology and its institutional regulation.
- The new look and feel of non-energy nuclear applications.
- Building resilience in a context of changing climate.
- Energy storage making nuclear obsolete for base-load of energy grid.

These clusters were not developed further, but they were considered for the foresight stories of the latest workshop.

3 Foresight stories

The foresight stories refer to the longer-term horizon (H3) and aim to capture the possible impact in ten years of the weak signals considered most interesting today. They are the outcome of a creative process in which the group reflects jointly about the further-reaching consequences of ongoing and emerging trends.

For each of the clusters listed in Table 1, foresight reflections looking ten and more years in the future were developed, identifying risks and opportunities related to the cluster. Brief descriptions for all clusters, with associated risks and opportunities, are collected in Annex 2.

As mentioned earlier, during the third workshop the aim was to integrate the findings of the first two 2019 workshops in the foresight stories to be developed. The new three overarching foresight stories were developed and presented in the following subchapters.

3.1 Evidence-based energy strategy to tackle the climate change

Numerous clusters from the sense-making workshops were related to the role of nuclear in the fight against climate change. The following clusters are considered in relation to this foresight story:

- Climate change calls for non-ideological assessments of plans for energy mix.
- Polarisation of public debate is preventing action on climate change.
- Nuclear energy for climate change mitigation – change in public perception/ new nuclear technologies; limitations of resources.
- The power of meaning in the struggle of facts vs emotions.
- Trust, the great stabiliser of participatory, honest and effective governance.

The workshop discussed the need to design evidence based long-term strategies that gain the trust of citizens rather than focusing on narratives based on fear, false information and emotions. This situation would imply many challenges for the scientific community.

3.1.1 Description and time horizons

At present the issue of climate change has gained high importance in the political agenda, moving up to the main political priorities of the new European Commission's political leadership (The European Green Deal). The related debate has been intensively fed by: 1) the economic focus, 2) the consideration of the global climate change related trends brought to the table by the scientific community and 3) the prioritisation of the protection of environment.

The scientific community does not propose a single answer to the challenge, as there is no unique possible strategy. There are different qualitative factors at play that require political consideration and broad consensus. In order to make the different alternatives comparable, those factors need to be assessed and well understood. In the **midterm**, different energy models and strategies will emerge, taking into account key indicators including considerations such as transition costs and time, long term economic impact, environmental impact, related health and safety risks, level of confidence and completeness of the underlying data, etc.

Following this trend, the **longer-term** might see the conversation flip towards the meaning and value of key indicators. Just for the shake of imagining a far-fetched future scenario, costs could well end up being the most relevant indicator for countries with struggling economies, the reliability of the underlying data becoming negligible for populists or the most radical environmentalists considering environmental impact as the only indicator worth considering.

3.1.2 Risks and opportunities

- **Risk for the public**: If the discussion about these key indicators fails to engage the average citizen, the general public might end up feeling frustrated and looking for political options that express their distrust against energy experts and scientists.
- **Risk to science**: As the scientific discussion opens to consider values and meaning, it might become also more political and lose its respected neutrality by using the harmful tactics of negative political confrontations.
- **Opportunity**: A long-term evidence based energy strategy would benefit of a broad and inclusive discussion about the meaning of the complex key indicators such as risk and environmental impact in the context of climate change.

3.2 The consequences of the absence of a future oriented nuclear policy

The following clusters are considered in relation to the consequences of a frozen nuclear policy foresight:

- Nuclear energy back in the political agenda.
- The current policy cycle cannot keep up with the rapidly changing world.
- Building resilience in a context of changing climate.
- Trust, the great stabiliser of participatory, honest and effective governance.
- The growing gap between evolving technology and related institutional regulation.

The workshop participants discussed about a scenario in which there is an absence of political action embedding the sustainable use of nuclear technology. The absence of a nuclear policy advancement may prevent licencing, constructing and operation of new reactors.

3.2.1 Description and time horizons

At present many governments in Europe tend to avoid an active policy on nuclear technology. Nuclear power plants continue aging in Europe, approaching the end of their operating life without an alternative backup plan.

If governments are unable to sustain the trust of citizens and the effects of the changing climate worsen, new severe climate-related urgencies and emergencies will overwhelm the political agenda in the **midterm**, leaving no space for decision on long term strategy actions. European nuclear industry might be anchored in the past and it would become less and less attractive to the new generations of professionals looking for emerging innovative career challenges, while new nuclear technologies might have evolved fast in other countries, leaving Europe in a state of dependency.

The consequences would become apparent in the **longer-term**. The energy security being at stake might push private companies to acquire foreign solutions to guarantee the power supply of their investments. This could be the time when foreign advanced designs might escape the technical expertise and capabilities of European nuclear regulators. This would in turn limit the potential of nuclear power to maintain a significant role in the energy mix, thus affecting the reduction of climate change and weakening the energy security and the economy.

3.2.2 Risks and opportunities

- **Risk**: The European nuclear industry will continue weakening and in the future, for new nuclear technologies, Europe might end up relying on foreign technology. Along with the nuclear industry, European manufacturers of larger components will also suffer.

- **Opportunity**: A common future-oriented European nuclear strategy could sustain a common European nuclear technology market and regulation allowing the full use of potential alternative solutions for the climate change problems and challenges.

3.3 Global perspective of nuclear-powered transport

The following related clusters are considered in relation to the nuclear powered transport foresight story beyond Europe:

- Nuclear business model getting small.
- Nuclear micro-reactors powering maritime transportation.
- The growing gap between evolving technology and its institutional regulation.
- The new look and feel of non-energy nuclear applications.

The workshop participants discussed about the opportunities of nuclear propulsion to reduce the emissions coming from transport worldwide, about why these opportunities are more likely to be leveraged outside the EU and about the potential consequences of that scenario for Europe.

3.3.1 Description and time horizons

At present the first floating nuclear power plant designed by the Russian Rosenergoatom, the Akademik Lomonosov, has begun its operation. At the same time, the Russian Atomflot which maintains the world's only fleet of nuclear-powered icebreakers, continues deploying a new generation of nuclear-powered ships for the exploitation of the Northern Sea Route.

As other countries, like China, start deploying their own civil nuclear-powered fleets with different purposes, a demand might start emerging in the **midterm** from countries unable to design and build their own ships but willing to acquire and use those built by others.

In the **longer-term**, we might see powerful global actors like Russia and China supported by other interested countries in Asia, Africa and America, aligning their geopolitical interests and pushing jointly for establishing regional agreements for the civil use of nuclear-powered ships.

3.3.2 Risks and opportunities

- **Risk** - Nuclear technology becoming predominant in powering commercial maritime transportation would imply new significant risks related to safety and security that would have to be properly addressed at an international level with broad agreements addressing new safety and security regulations.
- **Risk** – The absence of a global legal framework would open the development of bilateral or regional agreements addressing the liability of nuclear-powered vessels that could cause geopolitical tensions. The countries not benefiting directly from this activity or potentially suffering a related political disadvantage would be able to refuse nuclear-powered ships anchoring in their harbours and jurisdictional waters, but will not be able to take any measure against nuclear-powered vessels as they navigate international waters and connect foreign harbours.
- **Opportunity** – Nuclear powered maritime transport brings the possibility to renew and improve the sustainability of a currently very polluting activity, namely shipping, by significantly reducing its direct environmental impact.

4 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 scientific institutions with more research publications on the technology.
- The countries with more scientific action on the topic.

For a more extended explanation of the terms and parameters used for this analysis, please consult *Annex 3. Bibliographic analysis tool and approach*.

As explained in the referenced annex, the graph visualisations presented in the following subchapters consist 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.

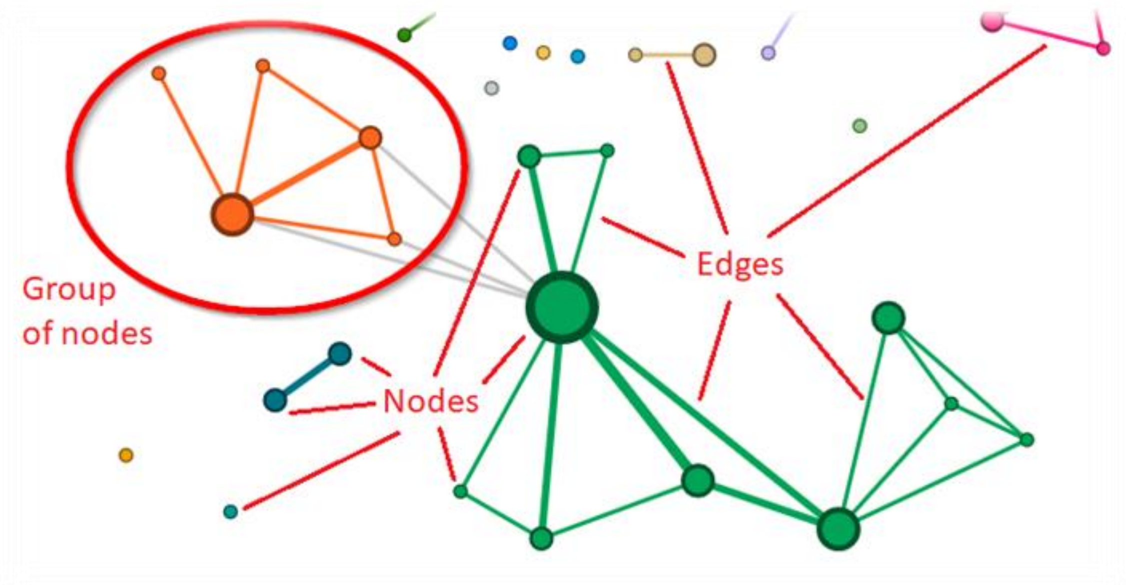


Figure 2. Network graph legend

4.1 Artificial Intelligence for nuclear applications

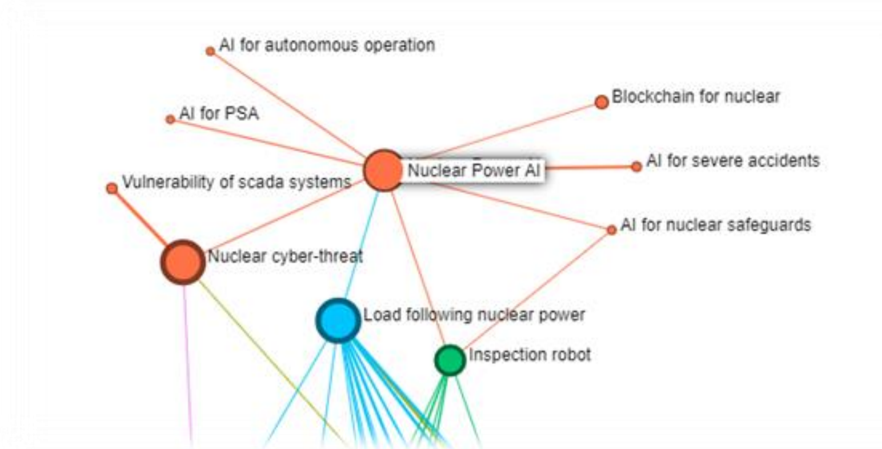
Artificial intelligence refers to the technologies that aim to incorporate autonomous reasoning to machines. It goes from natural language processing to recognise and interpret text and speech; machine learning algorithms that can be trained with available data to recognise similarities and predict trends; and the more sophisticated deep learning used by AlphaGo to beat the world champion of the traditional Chinese board game Go.

In the nuclear sector, artificial intelligence can be used in the area of safeguards and surveillance, helping to filter and identify signatures of nuclear materials; likewise, it can be used for the monitoring and diagnosis of severe accidents or for the identification of nuclear power plant transients.

The following two technologic applications related to artificial intelligence in the nuclear sector were identified as emerging trends:

- *AI for severe accidents*, where 69% of the 13 related scientific publications were published in the last three years.
- *AI for nuclear safeguards*, where 57% of the 8 related scientific publications were published in the last three years.

The figure below (figure 3) shows other applications identified during the analysis; all of them connected to the use of artificial intelligence in the nuclear industry.



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

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

Node Colour: Similarity according to the Louvain Modularity algorithm.

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

Figure 3. TIM datasetgram centred on 'Nuclear Power AI'

The following query was used to extract from TIM the information about patents, conference proceedings and scientific articles related to the different uses of artificial intelligence in the nuclear power industry:

```
topic:((nuclear OR atomic) AND (reactor OR plant) AND ("artificial intelligence" OR "machine learning" OR "deep learning" OR "natural language processing"))
```

This query generated a dataset of 209 documents with an 'activeness' TIM indicator of 40, meaning that 40% of those publications were published in the last three years. The historic distribution of those publications is shown in the figure below (figure 4).

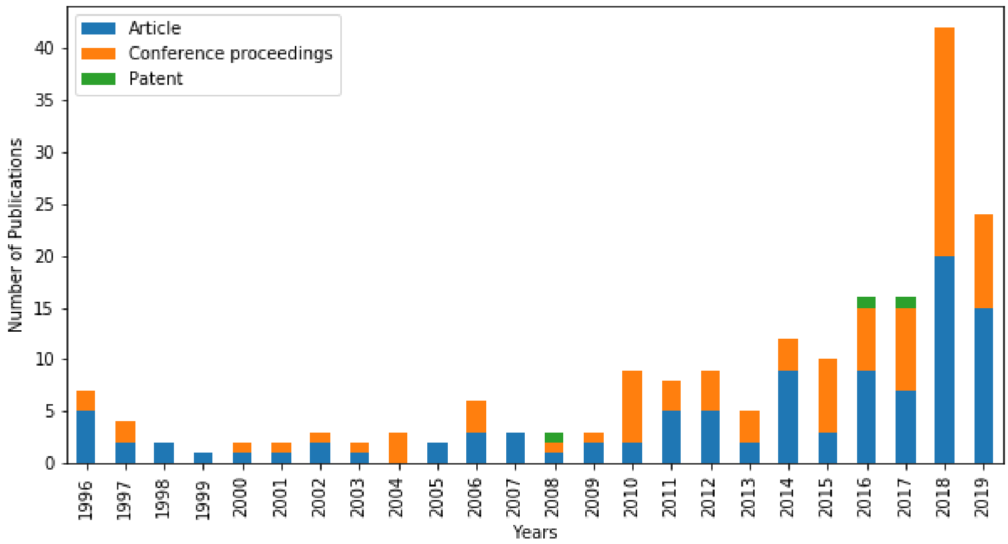


Figure 4. 'Nuclear Power AI' dataset document type distribution

There is a clear and very substantial leap in 2018 that will most probably continue during 2019 as there will be more related documents published before the end of the year.

The number of patents, on the other hand, remains very low, probably due to the patentability conditions of software tools.

The most prolific research institutions on the topic are one Brazilian (Universidade Federal do Rio de Janeiro), two Korean (Education Foundation of Yonsei University and the Korea Atomic Energy Research Institute) and two American (Purdue University and Oregon State University).

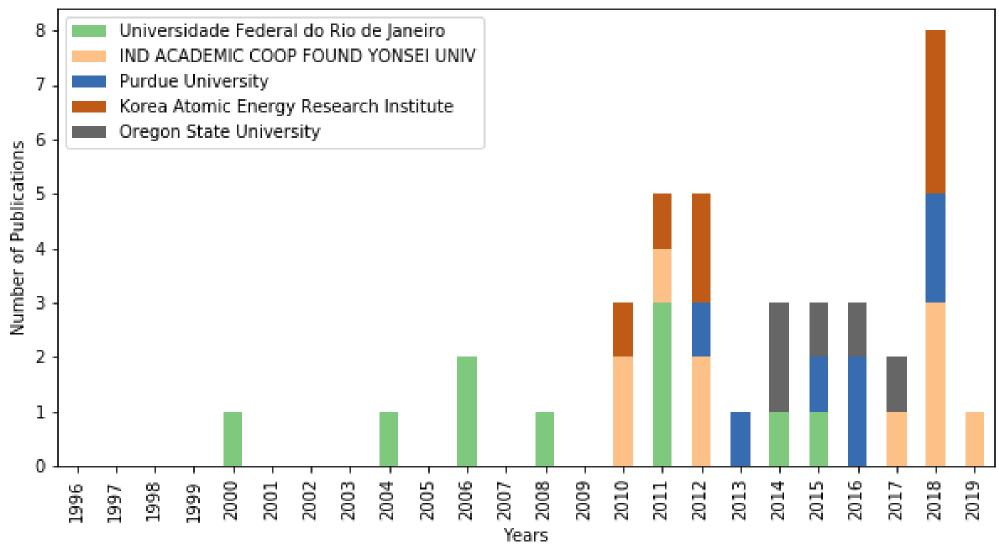


Figure 5. 'Nuclear Power AI' dataset research output of leading institutions

According to the figure below (figure 6) the European Union seems to be relatively well positioned considering the number of publications, as it follows closely the leadership of the United States, with whom it shares a well stablished research partnership, although there is no European research institution amongst the five most prolific.

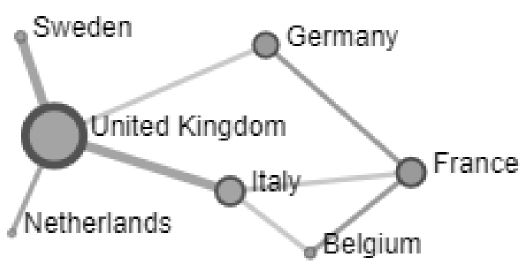
Node label: country of origin of the documents retrieved by the search query.

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 'Nuclear Power AI' world publications distribution

On the other hand the following figure (figure 7) indicates that Brexit might have a very significant (negative) impact on the expertise of the Union about the applications of artificial intelligence for nuclear technology.



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.

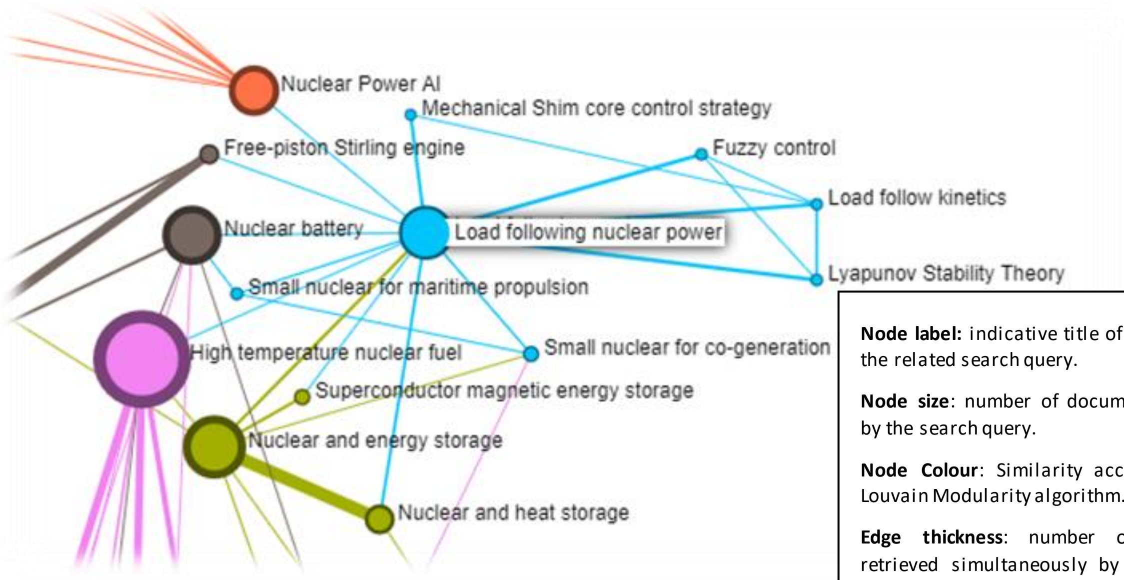
Figure 7. TIM network graph on 'Nuclear Power AI' European publications distribution

4.2 “Load following” impact on nuclear power

“Load following” operation refers to the capacity of a power plant to adjust its power output to satisfy a fluctuating demand. As national energy strategies tend to progressively increase the share of renewable intermittent sources, there is a consequent need for a ‘load following’ solution that could fill the gap between production and demand when required.

In principle, most of the currently operating nuclear power plants were designed to have strong manoeuvring capabilities, but operating at constant power level is simpler and less demanding on the plant’s equipment and fuel. Apart from that, not operating at full load has an important economic cost for the plant as it cannot make any sort of savings while not producing energy, not even on fuel costs.

As can be deducted from the figure below (figure 8), load following is not only relevant to the energy grid but also to other applications that require power output adjustment such as maritime propulsion and some nuclear power space applications. The technology is also clearly related to co-generation as well as to heat and energy storage.



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

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

Node Colour: Similarity according to the Louvain Modularity algorithm.

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

Figure 8. TIM datasetgram centred on 'Load following nuclear power'

The following two technology applications related to the load following operation of nuclear power plants were identified as emerging trends:

- *Lyapunov Stability Theory*, where 64% of the 14 related scientific publications were published in the last three years.
- *Load follow kinetics*, where 61% of the 13 related scientific publications were published in the last three years.

The key technologic feature for load following consists in having rapid and precise power distribution measurements of the core. An imbalance of axial power distribution induces xenon oscillations that have to be maintained within acceptable limits to avoid bringing the reactor to an unstable state. That is where the study of the reactor kinetics and in particular the Lyapunov approach are bringing new insights and understanding to the subject.

The following query was used to extract the information about patents, conference proceedings and scientific articles related to load following with nuclear power plants from TIM:

```
topic:((nuclear OR atomic) AND (energy OR power) AND (reactor OR plant) AND
("load following" OR "load follow"))
```

This query generated a dataset of 224 documents with an 'activeness' TIM indicator of 28, meaning that 28% of those publications were published in the last three years. The historic distribution of those publications is shown in the figure below (figure 9).

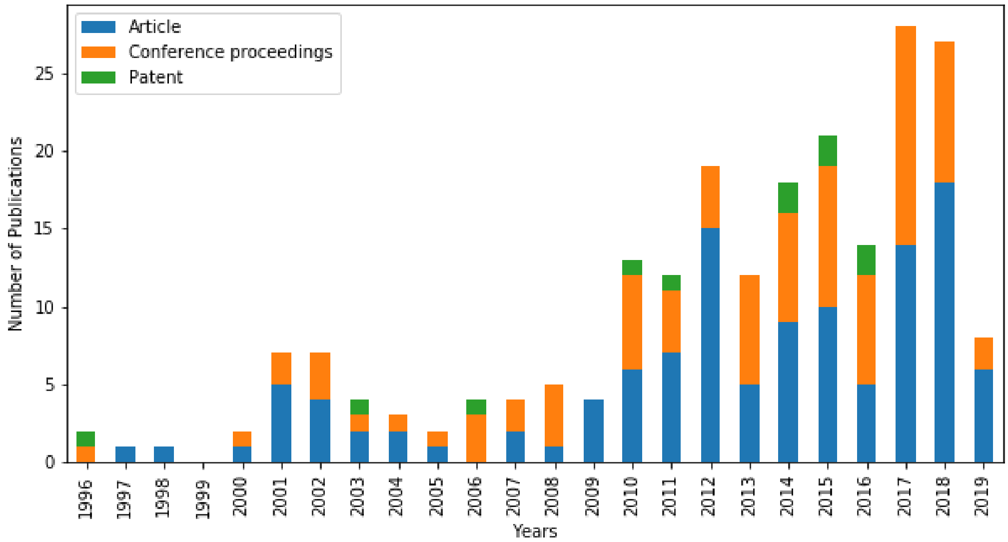


Figure 9. 'Load following nuclear power' dataset document type distribution

Although the growing trend is not as abrupt as in the case of the applications of artificial intelligence in the nuclear sector, a growth pattern can be recognised, with a clear peak since 2017.

The most prolific research institutions on the topic are two Iranian (University of Isfahan and Amirkabir University of Technology), two Chinese (Tsinghua University and Xi'an Jiaotong University) and one American (Idaho National Laboratory).

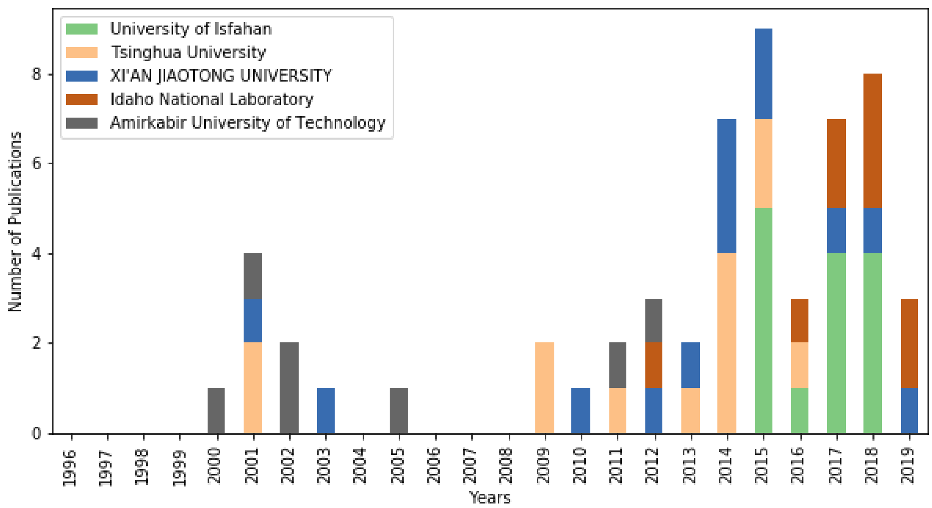
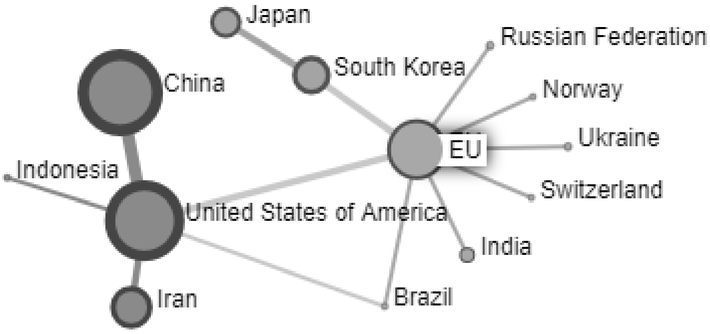


Figure 10. 'Load following nuclear power' dataset research output of leading institutions

Figure 11 shows that the European Union is behind the United States and China; and that there are other important players such as Iran, South Korea or Japan sharing weak or non-existent links with the European Union.



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

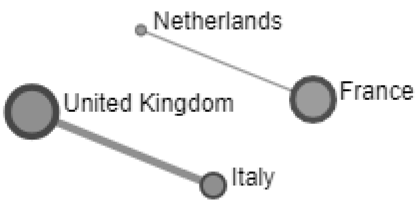
Node size: number of documents retrieved by the search query.

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

Figure 11. TIM network graph on 'Load following nuclear power' world publications distribution

According to figure 12, the United Kingdom seems to be a significant contributor to the European research activity on the topic, followed by France.

In France, in fact, as the national energy mix relies already heavily on nuclear power, load following is used to respond to the daily and weekly energy demand fluctuations.



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 12. TIM network graph on 'Load following nuclear power' European publications distribution

4.3 Accident Tolerant Fuels

The light-water reactor is the most commonly used type of reactor in nuclear electricity power generation. However, there are several other types of power reactors also allowing different types of energy production and application. In particular, nuclear reactors designed for working at very high temperature are used for the production of process heat, which enables the possibility of heat co-generation and "load following". Moreover, their low-pressure operation combined with high power density, offers great advantages for more compact and, eventually, more portable reactor designs.

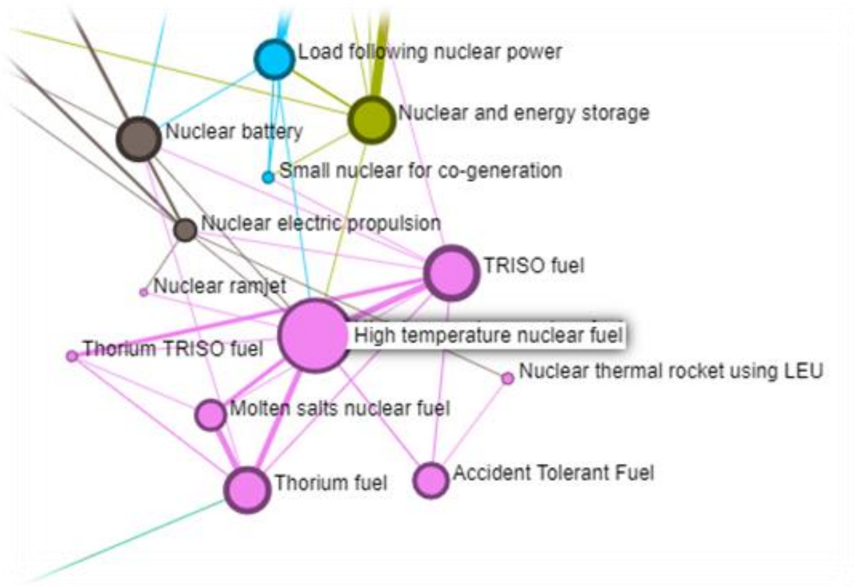
The following technology related to nuclear fuel in high temperature was identified as an emerging trend:

- *Accident Tolerant Fuel,* where 56% of the 196 related scientific publications were published in the last three years.

Since the accident of Fukushima in 2011, the research community started investigating alternative uranium-based fuel materials that, used in currently operating reactors, could withstand better such a severe accident scenario. They are named accident tolerant fuels (ATFs). Part of this research consisted in the study of the reactor products of these materials after being exposed to very high air or water temperatures.

On the other hand, there are other nuclear fuel options such as the TRISO fuel, designed precisely to perform best under those very high temperatures (around 1.000ºC). In a molten salt reactor, for example, the TRISO particles of fuel float in the coolant salt to be brought to the bottom of the pebble bed of the reactor or removed from the top for recirculation. There have been molten salt reactors designed for very different purposes such as aircraft nuclear propulsion or breeding thorium into fissile uranium-233.

The following figure (figure 13) shows that these different subjects are interconnected as it represents the interrelations between the different research topics.



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

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

Node Colour: Similarity according to the Louvain Modularity algorithm.

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

Figure 13. TIM datasetgram centred on 'High temperature nuclear fuel'

The following query was used to extract the information about patents, conference proceedings and academic articles related to nuclear fuel under high temperature from TIM:

```
topic:("high temperature" AND reactor AND "nuclear fuel")
```

This query generated a dataset of 445 documents with an 'activeness' TIM indicator of 18, meaning that 18% of those publications were published in the last three years. The historic distribution of those publications is shown in the figure below (figure 14).

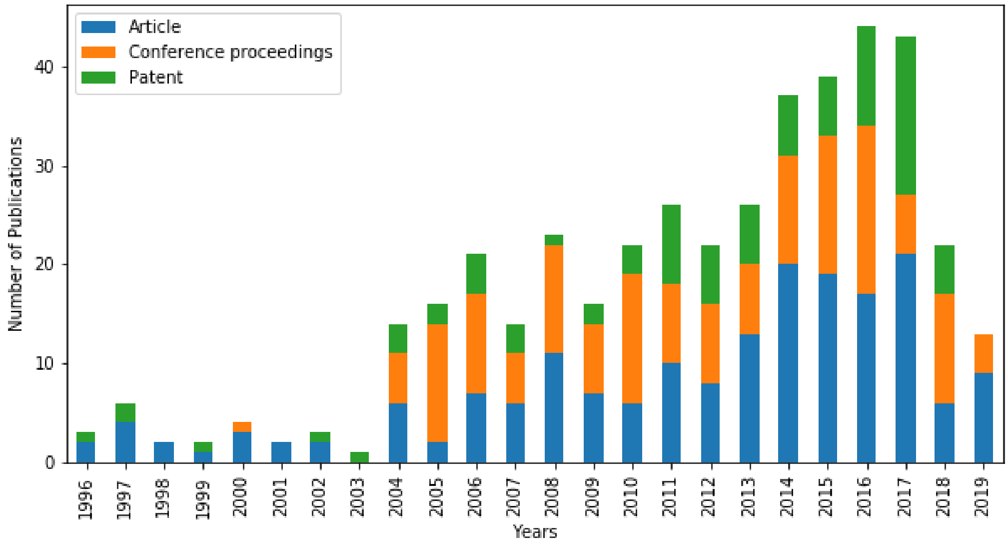


Figure 14. 'High temperature nuclear fuel' dataset document type distribution

As the 'activeness' TIM indicator already signals, this dataset shows the mildest growth pattern of the three *promising technologies* identified, including a setback on 2018. However, looking at the patents data it is important to consider the impact of the 18 moths confidentiality phase applied in most patents.

The most prolific research institutions on the topic are one Chinese (Tsinghua University), one Korean (Korea Atomic Energy Research Institute) and two American (Idaho National Laboratory and Oak Ridge National Laboratory).

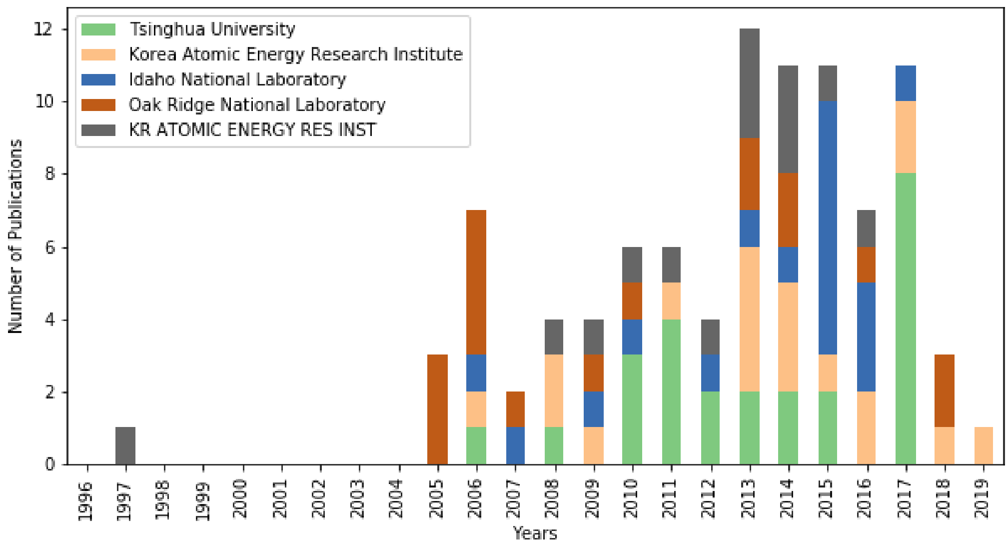


Figure 15. 'High temperature nuclear fuel' dataset research output of leading institutions

The geopolitical picture looks more complex for this topic, with many more players. Once more, the leader is the United States but in very strong collaboration with the European Union, that takes the second position.

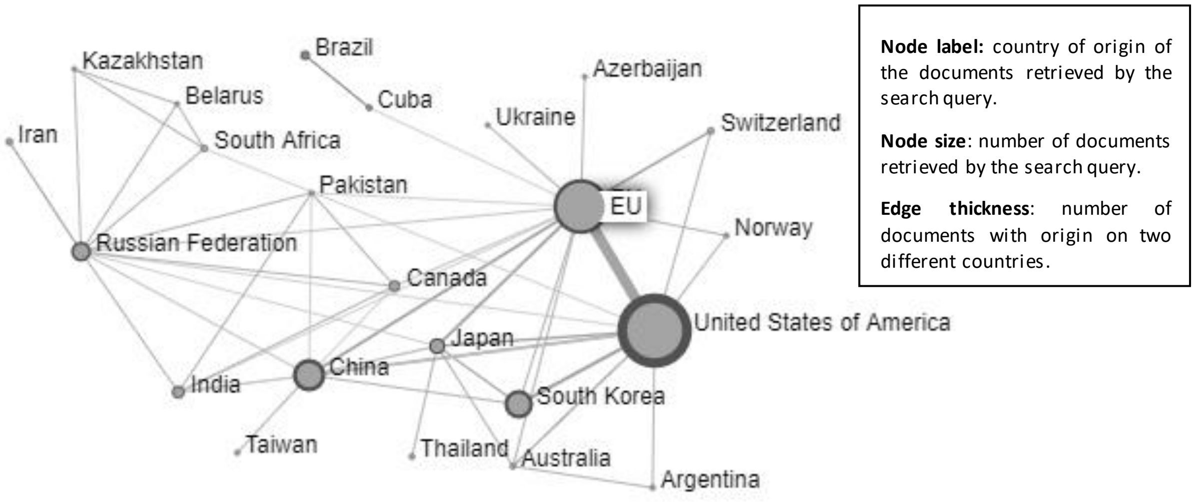


Figure 16. TIM network graph on 'High temperature nuclear fuel' world publications distribution

The picture inside Europe is also quite different, with less research in the United Kingdom than for the previous technologies and with a clear French leadership in strong collaboration with Germany, the United Kingdom, Italy, the Netherlands, Belgium and Czech Republic.

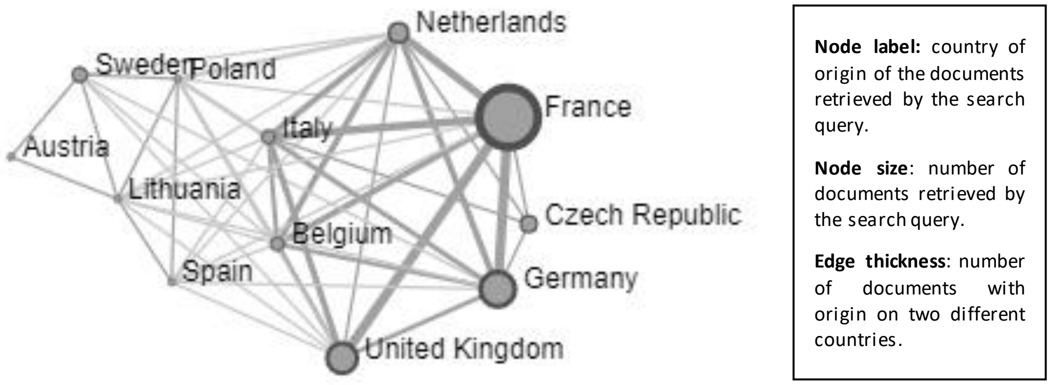


Figure 17. TIM network graph on 'High temperature nuclear fuel' European publications distribution

5 Conclusions

During 2019, the 14 *Horizon Scanners* from Dir G identified and recorded in *Connected* more than 200 ideas with an impact in the development of nuclear technology that were then discussed during the three sense-making workshops organised in Petten, Geel and Karlsruhe. 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.

This cross-site and cross Directorate activity has enabled the development of teamwork, collaboration and networking, increasing awareness of the work performed within Dir G amongst its participants and the possible future opportunities.

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

- *Evidence-based energy strategy to tackle climate change.*
- *The consequences of a stagnant nuclear policy.*
- *Nuclear powered transport beyond Europe.*

On the other hand, the bibliographic data analysis made in TIM suggests that the following technologies are expected to gain weigh significantly in the future:

- *Artificial Intelligence for nuclear applications.*
- *Load following nuclear power.*
- *Nuclear fuel under high temperature.*

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 carried out under request addressing those among them that attract the interest of stakeholders and other parties.

6 Annexes

6.1 Annex 1. Horizon Scanning participants

6.1.1 List of appointed Horizon Scanners from Dir G

- HEYSE, Jan – JRC.G.2 (Geel)
- CAMBRIANI, Andrea – JRC.G.I.3 (Karlsruhe)
- BRUMM, Stephan – JRC.G.I.4 (Petten)
- GRIVEAU Jean-Christophe – JRC.G.I.5 (Karlsruhe)
- RAUFF-NISTHAR, Nadya – 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)
- SIMIC, Zdenko – JRC.G.10 (Petten)
- SIMOLA, Kaisa – JRC.G.10 (Petten)
- ROSSI, François – JRC.G.10 (Petten)

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

- KRZYSZTOFOWICZ, Maciej – JRC.I.2 (Brussels)
- BONTOUX, Laurent – JRC.I.2 (Brussels)
- LIESSENS, Ariane – JRC.G.10 (Petten)
- TANARRO COLODRON, Jorge – JRC.G.10 (Petten)

6.1.3 List of other contributors to the Horizon Scanning sense-making sessions

- WASTIN, Franck – JRC.G.10 (Petten)
- VAN KALLEVEEN, Alexandra – JRC.G.10 (Karlsruhe)
- MICHAILIDOU, Eirini – JRC.G.10 (Karlsruhe)
- COLLE, Jean-Yves – JRC.G.I.3 (Karlsruhe)
- BAUDOT, Denis – JRC.G.III.8 (Karlsruhe)

- HELD, Andrea – JRC.F.7 (Geel)
- MUNOZ PINEIRO, Amalia – JRC.F.7 (Geel)
- JOANNY, Geraldine – JRC.I.3 (Brussels)
- WILKENING, heinz – JRC.C.3 (Petten)
- TSAKALIDIS, Anastasios – JRC.C.4 (Ispra)
- MARMIER, Alain – JRC.C.7 (Petten)
- BINET, Silvia – JRC.C.7 (Petten)
- BOELMAN, Elisa – JRC.C.7 (Petten)
- LYONS, Lorcan – JRC.C.7 (Petten)
- CONTOR, Laura – JRC.C.7 (Petten)
- TELSNIG, Thomas – JRC.C.7 (Petten)

6.2 Annex 2. Descriptions of clusters with associated risks and opportunities

<table>
<tr><th colspan="2">Nuclear energy back in the political agenda</th></tr>
<tr><td colspan="2">Recently, voices have appeared in Europe arguing that we have to either accept more nuclear energy or suffer the climate change. Others, however, consider that technologies such as electricity storage, trans-European grids or negative emissions will make the nuclear option unnecessary.</td></tr>
<tr><td>Risk – A potential political convergence on nuclear energy might create tensions between the EU members using nuclear energy and those who opted for excluding its use.

Risk - A political confrontation displayed as 'science war' among scientists supporting specific energy technologies could weaken the public trust in scientific institutions, ending up driven by the social with the consequent loss of trustworthiness and accountability.</td><td>Opportunity - Europe can change and adapt its nuclear industry, reinventing its traditional business model and culture, in order to complement and reinforce its competitive and carbon free energy mix based on renewable sources.</td></tr>
<tr><th colspan="2">The globalisation of technological development causing environmental degradation/damage?</th></tr>
<tr><td colspan="2">While technological development is improving living conditions mostly in the western world, it has a high impact on the environment at global scale. As these developments become more affordable, their use and application increases their environmental impact. This puts further pressure on the environment potentially widening inequalities for those who still cannot afford them.</td></tr>
<tr><td>Risk - The finite nature of resources poses a risk of conflict amongst societies and civilizations for their control and use.

Risk - The unequal distribution of costs and efforts invested in mitigating environmental degradation might acquire a prevailing political significance in democratic societies that could lead to new tensions and confrontation between countries with different energy strategies, as well as to new diplomatic coalitions developed around this particular aspect.</td><td>Opportunity - A context of scarcity might enable new opportunities of collaboration and integration, seeking to align efforts in order to achieve better efficiencies</td></tr>
</table>

A complicated relation between the EU and China	
While China gradually acquires world economic power and technological leadership, the EU seems to be losing its political influence outside and inside Europe and has to face greater interferences within its border.	
Risk – Dissension between democratic institutions and stability and leadership of more authoritarian regimes might lead to open or latent conflicts. **Risk –** Development of antagonistic political options could escalate tensions, resulting in a large-scale conflict.	**Opportunity** – The economic and technologic success of China and the importance and complexity of its implications could trigger European Member States to develop a more efficient common policy to defend and protect European values and interests like freedom and democracy inside and also outside Europe.
Climate change calls for non-ideological assessments of plans for energy mix	
An increasing number of scientists agree that the climate change is far more advanced than we like to think and that the urgency of the crisis does not allow us to take half measures. Scientists' considerations should get a much stronger role in defining the measures that need to be taken to mitigate consequences of climate change.	
Risk – Dichotomy between experts' advice on the severity of the crisis and the political decisions that threaten the reciprocal coherency and public acceptance.	**Opportunity –** Demonstrating stronger cohesion between scientific facts and policy making.
Polarisation of public debate is preventing action on climate change	
Climate change is a hot topic nowadays, but both opinions on the severity of the situation and the responses put forward are contradicting each other. There is no clear line, let alone a majority to take drastic action.	
Risk – Polarisation feeds the extreme opinions, taking away the voice of the moderates. Furthermore, people with a more moderate opinion on the subject will stake back if the public debate polarises, thus worsening the situation.	**Opportunity** – The public debate can change very fast with social media. It can therefore convey the message that any individual can make a difference by changing their lifestyle and talking about it in their social network. But also any big company or institution,

<table>
<tr><td></td><td>whether private or public, can make a difference and bring about change by setting an example in taking drastic measures.</td></tr>
<tr><td colspan="2" align="center">The current policy cycle can't keep up with the rapidly changing world</td></tr>
<tr><td colspan="2">Societal and technological developments require legislation and regulations to be adapted in order to protect citizens and tackle ethical questions. However, in our rapidly changing world these protection mechanisms take too long to be agreed upon, then developed and put in place, whether it is at local, regional, national, European or international level.</td></tr>
<tr><td>Risk – The rapidly changing world will increasingly become a "wild west" as the strong basis given by the state institutions is becoming less efficient, thus threatening the democratic process. An example in nuclear technology is the development of micro-reactors by private groups in the race for climate impact mitigation.</td><td>Opportunity – There are more possibilities for grassroots movements to be set up. The well-known examples of AirBNB and Uber have shown that there is a huge potential for these initiatives.</td></tr>
<tr><td colspan="2" align="center">Trust as the most precious political asset in a culture of fear</td></tr>
<tr><td colspan="2">While our trust in the administration, science and technology is challenged by cases of corruption, conflict of interests, unaddressed real risks and vulnerabilities… populistic political movements in Europe can exploit fear of the unknown (the migrants and the changes brought by technical progress and globalisation, just to name few) to attract public attention and gain more support.</td></tr>
<tr><td>Risk - Science, technology and the administration becoming untrustworthy in the eyes of the citizen will boost demagogic political practices in established democracies.

Risk - Democratic societies unable to trust their scientists, engineers and politicians run the risk of becoming averse to technology and innovation and therefore of losing power and influence against authoritarian regimes eager to use them on their advantage.</td><td>Opportunity - Demagogic politics might stimulate the state governance, the scientific institutions and the regulatory bodies to assume more transparency and accountability in a visible way.</td></tr>
<tr><td colspan="2" align="center">Nuclear business model getting small</td></tr>
<tr><td colspan="2">While the renewable energy industry in the EU thrives, benefiting from political and corporate support, crowd funding and a relatively</td></tr>
</table>

<table>
<tr><td colspan="2">newly acquired economy of scale; the traditional nuclear industry suffers from large capital costs, encouraging the establishment of new small and innovative (high risk) companies trying to resolve persisting technical challenges</td></tr>
<tr><td> Risk – In order to carry out research and development with radioactive materials, a great amount of regulations and standards need to be satisfied. Regulations and standards vary and depend on the country, making this kind of research impossible for small companies with limited resources in many countries. Risk – Small 'risky' companies managing nuclear installations entail certain safety concerns and financial risk for the state, because if the company would become financially inviable and go bankrupt, its nuclear installation would still need to be safely decommissioned, what usually results in a costly effort that the state would have to assume. </td><td>Opportunity – Making broader use of common framework like the Euratom could facilitate the access to nuclear laboratories and nuclear materials to European (small and start-up) companies with innovative ideas in order to facilitate their viability and mitigate the associated potential risks.</td></tr>
<tr><td colspan="2" align="center">Digital new business models becoming 'physical'</td></tr>
<tr><td colspan="2">In the revolutionary business model of Google, the user is not anymore the 'client', who has to pay for the cost of the service. The user actually becomes 'actor', 'contributor' and even the 'product' due to the value of the data produced and the attention invested while using the service. This same model might cross the boundaries of the digital world to deal with physical goods that could eventually save lives, or put them at risk.</td></tr>
<tr><td> Risk - Services advertised as 'free of charge' have the risk of becoming 'free of accountability' making a malicious and harmful treatment/use of the users' data. Risk - Users might get used to a particular free service in a particular country without realizing that the usage of that same service while travelling in a different country might entail completely different risks and implications due to a different legal framework. </td><td>Opportunity – A thorough and independent regulation of the digital business model could open new opportunities for private-public cooperation, enabling innovative approaches of conventional public funded services while satisfying a new business demand for data coming from the private sector.</td></tr>
<tr><td colspan="2" align="center">Nuclear micro-reactors powering maritime transportation</td></tr>
</table>

While the shipping industry is struggling to reduce CO2 emissions, nuclear reactors seem to be getting smaller and safer. Putting the two pieces together will certainly reduce the carbon footprint of maritime transportation, but it will also pose new challenges and risks related to nuclear safety and security.	
Risk – A wide application of nuclear technology in powering commercial maritime transportation would imply new significant risks related to safety and security that would require to be addressed at an international level with adapted safety and security regulations. **Risk** - The need of international insurance schemes and regulations might provoke geopolitical tensions and conflicts between the countries defending the assumption of the related risks and those who will not benefit directly from a positive economic impact or that will suffer nationally a political cost. The lack of international agreement will restrict the technology to military uses.	**Opportunity** – Nuclear powered commercial maritime transportation brings the possibility to renew and improve the sustainability of a very pollutant activity, shipping, reducing dramatically its CO_2 environmental impact.
Governments and corporations knowing you better than you know yourself	
Corporations and governments might soon have enough understanding of our cognitive processes to be able to predict our choices and 'guide' or 'correct' them. For that, they just need to know us a little better than we know ourselves.	
Risk –Authoritarian regimes might find out how to acquire sustained public support through the use of these technologies. **Risk** - Private corporations might use these technologies for commercial interests leaving behind a deep cultural change always evolving towards more and more severe consumerism.	**Opportunity** – Potential as tools for education and self-development at individual and societal levels.
Hardware hacking as weapon against energy infrastructure	
While measures are being implemented already to protect the energy grid against on-line hacking, hardware hacking taking place at the factory during the fabrication process could only be avoided with very disruptive measures that would require 'rewinding' globalisation and fabricating locally each electronic component.	

Risk - The safety and security cost of energy infrastructures might increase as the threats that they could be exposed to, become more complex and sophisticated. **Risk** - Hardware hacking would always have a geopolitical component and be used by states against each other.	**Opportunity** – Better control and accountability at an international level could support global trust and regulations, the interdependence generated by globalization might end up in developing a global culture in which a complex industrial plot orchestrated by a particular country against the others would be literally unthinkable.
Access to resources will put a brake on technological deployment	
Technological developments have been ever increasing in the history of humanity, resulting in an equally increasing use of resources. However many of the resources are not unlimited. Their increasing scarceness will make them more expensive and will hamper the development and spreading of new technologies.	
Risk – Existing technologies will not be able to be implemented/spread to the extent that would benefit people and planet. **Risk** – The use of new technologies will be reserved for the rich elite.	**Opportunity** – Rediscovering ancient means, methods and skills to achieve what today is brought to us by technology.
Nuclear energy for climate change mitigation – change in public perception/ new nuclear technologies ; limitations of resources	
The major source of climate change is due to fossil fuels. To tackle this problem but also the limited amount of non-renewable resources, all types of energy with less impact have to be considered. A more inclusive view and understanding of the potentials of nuclear technologies might lead to a change in public perception and acceptance, leading to a better and more adapted integration of nuclear energy in the energy mix.	
Risk – Phasing out of the nuclear option is a long term no return choice as building the expertise needed is a long time process. **Risk –** New technologies take a long time to be developed, tested, regulated and implemented/spread. Additionally the sustainability of adequate raw materials and resources needs to be ensured.	**Opportunity** – A thorough assessment of the role and applications of nuclear energy in the energy mix stimulates opportunities for new development and better adaptability of (new nuclear) technologies.

Global environmental change will soon threaten global population	
The last decade has witnessed an increasing number of climate-related disasters. Predictions foresees an increase in number and severity that could lead to substantial impact on the world population.	
Risk – A major disaster caused by extreme meteorological conditions, even localised at a regional level, could have a severe impact on economies throughout the world due to the economic interdependence. Similarly, a major outbreak of a virus could result in either a pandemic or if just infecting a specific group/sector of the population could destabilise the existing balance in society.	**Opportunity** – A major disaster affecting a big part of the world's population could activate all emergency mechanisms and speed up the process of working together to adapt to the new circumstances, thus creating public support for the drastic changes that are still slowed down a lot by the established culture and/or bureaucracy. Better preparedness and anticipation (lessons learned) are stimulated after a major accident of emergency has happened.

6.3 Annex 3. Bibliographic analysis tool and approach

6.3.1 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 describe by Blondel et al in arXiv:0803.0476 **[physics.soc-ph]**

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.

6.3.2 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 2019, meaning that when comparing the number of documents retrieved for 2019 with previous years there might be a drop to be interpreted just as a drop in data coverage.

6.4 Annex 4. Methodology

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

6.4.1 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, blogs, newspapers, magazines, 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*. Once stored on *Connected*, the items become "ideas" The ideas are established according the following principles:

- An idea is created by choosing *Create and 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 sense-making 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.

6.4.2 Sense-making workshop

6.4.2.1 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 two weeks before the workshop, an aggregator responsible for managing the workshop session (the facilitator) goes through the ideas collected on *Connected* and selects those that will be of interest for the workshop: a total of 90 to 120 ideas. Each selected item is then edited and formatted in a coherent style, setting the "*Stage*" of the idea as "*Delivered*" (or an alternative empty stage in case "*Delivered*" is being used by another Horizon Scanning team).

About a week before the workshop, the aggregator downloads the "*Delivered*" ideas from *Connected* to integrate them in a digital document that is submitted to the workshop participants. The event created in *Connected* including the instructions for the session is updated with the list of ideas as attachment.

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.

6.4.2.2 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 around three foresight stories related to the clusters available in their section.
5. *Development of foresight stories*: Grouped in small groups, the participants present and explain their foresight stories. Everyone participates asking questions and posing 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 9-12 stories.
6. *Voting*: Each participant gets three votes to vote for the three different stories that, according to them, are the most novel, likely to have the most impact, the most controversial, potentially creates tensions or could lead to very different outcomes.
7. *Mapping*: The stories with the most votes will be placed on a graph with

   Axis X: now – 5 years – 10 years

   Axis Y: Importance/ relevance for JRC policies

The position of theses top stories will be subject to discussion until the group agrees.

The other stories are put on the graph, without changing the position of the ones already agreed on. Short possibility to discuss/reposition the newly added narratives if needed.

8. *Final capture*: Once the agreement is reached, 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.

Team work 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).

6.4.3 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 9 to 12 clusters of ideas mapped during the workshop, identifying the related possible risks and opportunities.

List of abbreviations and definitions

ACE	Aggregative Contingent Estimation
Dir G	Nuclear Safety and Security Directorate
EMM	European Media Monitor
EU	European Union
HS	Horizon Scanning
JRC	Joint Research Centre
JRC.C.7	Knowledge for the Energy Union unit
JRC.E.7	Knowledge for Security & Migration unit
JRC.F.7	Knowledge for Health & Consumer Safety 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
R&D	Research and Development
REFIT	The regulatory fitness and performance programme
TIM	JRC Tools for Innovation Monitoring

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KJ-NA-30153-EN-N

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doi:10.2760/1105

ISBN 978-92-76-17510-0