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Long-Term Horizon Scanning for Nuclear Technologies Yearly Report - 2023

Fostering Forward-thinking in Nuclear Technologies

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Contents

Abstract

This report provides an out-of-the-box analysis of the possible future of nuclear technology in the European Union, based on foresight methodologies and the Joint Research Centre's anticipatory capabilities. It discusses key trends such as the rise of nuclear start-ups, the use of nuclear technology for decarbonization, and the integration of digital technologies in the nuclear sector. The report also projects potential threats and opportunities after 2033. Critical questions underscore the areas that could come up as candidates for further research and clarification, emphasizing the importance of an ongoing anticipatory approach.

Executive summary

The Joint Research Centre of the European Commission has produced this report as part of its ongoing commitment to provide scientific knowledge and technical support to European Union policies, particularly those related to nuclear technology. Drawing on the Centre's foresight capabilities, the report aims to provide an insight to possible scenarios for the future of nuclear technology in the European Union. The findings are intended to facilitate informed, policy-making and strategic planning, ensuring the safe, sustainable, and prosperous development of nuclear technology in the EU.

Policy context

The Joint Research Centre (JRC) of the European Commission plays a key role in providing scientific knowledge and technical support to European Union policies. In the rapidly evolving landscape of nuclear technology, the JRC's anticipatory capabilities are crucial for providing timely, evidence-based advice to policymakers. This report, developed with the support of the European Commission's Competence Centre on Foresight, aims to provide future-oriented input for policies related to the development of nuclear technologies, while fostering an anticipatory culture within the nuclear community of the European Commission.

Key conclusions

The report identified several key trends shaping the future of nuclear technology, such as the rise of nuclear start-ups, the use of nuclear technology for decarbonization, and the integration of digital technologies in the nuclear sector. It also highlighted the potential threats and opportunities these trends might pose in 2033 and 2053, underscoring the need for an ongoing anticipatory approach to policy-making. The report emphasised that continuous anticipation and adaptation are crucial in navigating the evolving technological landscape of nuclear technology.

Main findings

Through foresight methodologies, the report identified 11 topics critical to the future of nuclear technology in the EU. They range from the resurgence of nuclear start-ups to the potential for nuclear technology to aid in decarbonising hard-to-abate sectors and the integration of digital technologies into the nuclear sector. The report also discussed potential threats and opportunities at a mid-term (2033) and longer-term (2053) horizon, providing a roadmap for policy considerations related to the development of nuclear technologies.

Related and future JRC work

The report's findings underscore the pivotal role played by the JRC in anticipating trends and potential disruptions in the realm of nuclear technology. The JRC will continue to lead in the provision of scientific knowledge and technical support to EU policies, with an ongoing commitment to anticipation and adaptation in the rapidly evolving landscape of nuclear technology.

Quick guide

This report provides an in-depth analysis of the future of nuclear technology in the EU, identifying key trends, threats and opportunities. It underscores the importance of continuous anticipation and strategic policy-making amidst a rapidly evolving technological landscape. The findings of the report underscore the necessity of fostering an anticipatory culture within the European Commission's nuclear community and propose critical questions about the future development and application of nuclear technology in the EU.

Introduction

The Joint Research Centre (JRC) of the European Commission is responsible for the provision of scientific knowledge and technical support to European Union policies. One of its core strengths, as pointed out on its revitalised strategy for 2030, is anticipation, using science to exploit the power of foresight and to boost its anticipatory capabilities. Foresight supports the role of the JRC in relation with the Euratom Treaty by bringing the development of nuclear technologies into focus. In a rapidly evolving technological landscape, where nuclear technology continues to play a significant role in energy production, medical applications, and scientific research, the JRC's role in anticipating trends and disruptive developments is crucial. By doing so, it can provide timely, evidence-based advice to policy-makers, facilitating informed decisions that uphold the principles of the Euratom Treaty and contribute to the sustainable, safe, and prosperous future of its citizens.

Relying on the processes and approaches proposed and developed by the European Commission's Competence Centre on Foresight, this report aims to provide strategic and future-oriented input for the consideration of policies related to the development of nuclear technologies while developing an anticipatory culture among the community contributing to the Euratom Research and Training Programme. The Horizon Scanning for Euratom is a yearly exercise that involves colleagues working for the European Commission with different backgrounds and areas of expertise. The exercise aims to complement their academic discussions and contributions with an alternative framework designed to capture and frame their concerns and considerations about possible upcoming future threats and opportunities.

This report presents the findings of the Joint Research Centre's Horizon Scanning exercise specifically focused on the evolving landscape of nuclear technology. The Horizon Scanning is a tool for identifying emerging trends and weak signals deserving attention. It involves colleagues with different expertise and backgrounds enabling fruitful networking and enhancing their 'futures literacy'. Eleven distinct topics are described representing ongoing trends on the sector likely to have a meaningful impact on the development of the technology. By projecting these trends into the future, considerations are presented pointing at potential threats and opportunities that may arise in a mid-term future, referenced as 2033, and in a longer-term future, around 2053. We can only attempt to deliver fair policy outcomes for future generations by bringing to the present their possible perspectives and concerns.

The main objective of this report is to give an open overview of the lines of development of nuclear technology in the European Union, by seeing the future through the eyes of the nuclear experts working at the European Commission. The insights captured in this report do not follow a pre-determined structure, and do not constitute a roadmap for the work of the JRC, which is shaped by the objectives of the Euratom Research and Traning programme in line with its policy manadate. The report may serve as food-for-thought on the design of nuclear technology and industrial policy initiatives highlighting the need of integrating different disciplines and fields of expertise to tackle upcoming challenges.

In an effort to remain future oriented and to develop certain familiarity with the latest ongoing technological developments, this report has been drafted with the assistance of *GPT@JRC*, a unique implementation of the Large Language Model GPT, exclusively deployed at the JRC.

Euratom Foresight cycle

Foresight shouldn't be confused with forecasting. The aim of foresight is not to predict successfully what would happen without any directed intervention. In fact, when a threat is successfully anticipated, it is prevented from materialising. On the other hand, when an opportunity is anticipated, action would be taken to realise it. In both cases the objective is not to get predictions right, but to achieve the best possible outcome for society.

The Euratom Foresight cycle developed at the JRC consist of five distinct activities: scanning, distilling, sense making, deep diving and policy briefing. The three first steps: scanning, distilling and sense making compose the yearly process of Horizon Scanning for Euratom, which main insights and conclusions are compiled in this report.

Scanning

The first step of the Horizon Scanning is the collection of relevant pieces of news and other references through the contributions of the Scanners' Network and the Europe Media Monitor (EMM), a system developed at the Joint Research Centre which continuously monitors 17.000 web sites and processes about 450.000 publicly available pages every day in 80 languages. All these references are catured as 'ideas' in the *Euratom Foresight Knowledge Base* available as a SharePoint Online intranet site at the European Commission.

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 different domains. Just "opinions" or "advices" are not considered relevant for the exercise. The focus is on what "can be" or "will be" not on what "should be" or "must be".

The items found within the scanning process are stored on the dedicated knowledge base of the European Commission's intranet called *Euratom Foresight*. Once stored there, the items become "*ideas*".

Distilling

Twice a year, as enough new ideas are captured, a distillation session is organised to look at them, propose "*topics"* reflecting overarching trends and select the most relevant references to be considered in the yearly sense-making workshop.

Before the session, the participants must go through the "*Active*" *ideas* on the *Euratom Foresight* knowledge base and vote ("*Like"*) the most interesting. They should also write down why they think the chosen *ideas* are important, preferably by using the "*Comment*" feature under the idea.

The *ideas* receiving the greatest attention from colleagues are discussed during the distillation session. Related arguments and considerations are registered as *comments* to the diferent *ideas* or as new *topics* on the knowledge base. The status or "*step*" of the selected *ideas* is changed from "*Active*" to "*Selected*" and links to them are added on the page with the description of the related *topic* after the meeting. The *step* of the discarded *ideas* is changed from "*Active*" to "*Archived*".

Sense Making

At the last stage of the yearly *Horizon Scanning for Euratom,* a sense-making workshop is organised to reflect on the most relevant ideas and technologies captured throughout the period and prepare prospective scenarios. This way, the trends identified are proyected into the future to reflect about potential threats and opportunities that are later captured in the yearly report. The first *Horizon Scanning for Nuclear Safety, Security & Safeguards* report was issued in 2017, with one report issued yearly since then, the last one published in early 2023 (JRC131993).

About a week before the workshop, the document containing the outcome of the destillation sessions is sent to the scanners together with the instructions for the preparation of the workshop. Before the workshop, the participants must go through the list of ideas and think about how some of them would fit together suggesting a counterintuitive phenomena and gather those mutually reinforcing ideas into clusters. Each participant is expected to present around three or four clusters during the workshop. 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 nature of the exercise entails that its conclusions are neither predictions nor research conclusions; they are only reflections and considerations made using a creative process of proyecting the potential consequences of recent developments.

The structure of the workshop is the following:

- *Clustering of ideas*: Participants write down individually their own clusters with a title, premise, and the numbers of the related ideas.
- *Presentation of clusters*: Participants take turns to present their clusters and put them on a digital whiteboard (Miro).
- *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.
- *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 organisers provide one facilitator for each group to ensure the necessary structure, explanation and moderation of the discussions.
- *Development of foresight scenarios in small groups*: Each small group shall proyect the clusters into two future scenarios: one ten years ahead and a second thirty years ahead. The group should propose the main threats and opportunities that would be materialising at those scenarios related to the clusters of the whiteboard.
- *Critical questions*: after the presentation of the threats and opportunities at the plenary, participants are asked to come up with questions related to concrete aspects of present nuclear technology development deserving further attention and clarification. The purpose is not to answer these questions, but to raise awareness about critical issues.

Deep Diving

Inspired by the conclusion of the *Horizon Scanning for Euratom*, open live-streamed webinars are organised involving invited experts to tackle critical questions about the future deserving further attention and clarification. So far, six 'Deep Dives' (webinars) have been organised exploring the future implications of different nuclear technological developments:

- The IAEA Drivers 2057 (2023)
- Better regulation for nuclear innovation (2022)
- Nuclear power for space exploration (2022)
- Floating nuclear reactors (2021)
- Radioactive Isotopes (2021)
- Nuclear cyber security (2020)

The recordings of the Deep Dives remain open to the public during the two years following the live streaming.

Science for Policy briefing

In order to make the critical issues more accessible to a broader audience, a *Science for Policy* brief of two pages is published at the JRC Publications Reposiory:

- Nuclear Hydrogen for Steelmaking (2024)
- Nuclear power in space (2022)
- Floating Nuclear Reactors (2022)
- Radioactive Isotopes (2021)

Topics

Eleven topics were proposed by the participants of the distillation sessions as the most representative ongoing trends on the sector likely to have a meaningful impact on the development of the technology. The topics, described below, were also used to group the references or 'ideas' collected throughout the continuous collaborative 'scanning' work.

Nuclear (re)start-up

The nuclear industry is witnessing a renaissance, largely driven by the advent of Small Modular Reactors (SMRs). These compact and innovative reactors have sparked the emergence of numerous start-ups, particularly in Europe. The start-ups are leveraging the versatility and scalability of SMRs to expand the reach and heterogeneity of the nuclear industry. Furthermore, these companies are utilizing digital tools and technologies in their designs, enabling a more efficient and streamlined development process.

These start-ups are also successful in attracting talent, thus ensuring a steady flow of innovative ideas and robust workforce. They are also developing compelling narratives about innovative business models, which are instrumental in shaping the public perception of nuclear energy. However, there's a potential downside to this growth. Many of these start-ups have made ambitious claims about the capabilities and potential of their technologies, which could potentially backfire if they fail to live up to the expectations.

In the long term, the expansion in the number of nuclear start-ups will be followed by a contraction phase. During this phase, only a few start-ups with viable business models and technologies will survive. The contraction phase will not be entirely driven by the natural selection of the 'fittest.' Public funding might play a significant role in determining the success or failure of these initiatives, thus shaping the future landscape of the nuclear industry.

Related *ideas*:

- US regulator ready for next-generation nuclear (2023/09/01)
- Westinghouse company completes testing of 'novel approach' to Ac-225 production (2023/07/04)
- Insights in the safety analysis of an early microreactor design (2023/04/01)
- Reuse of coal plants can cut small modular nuclear reactor development costs by 35% (2023/03/27)
- The real obstacle to nuclear power is not environmentalists, it's the nuclear-power industry itself (2023/02/07)
- 10,000 Nuclear Microreactors To Wean The World Off Coal (2023/02/03)
- Canadian and UK regulators agree to share experience around reviewing SMRs (2023/01/19)
- Holtec claims SMR-160 can repurpose any coal-fired plant (2023/01/11)
- Why Finding The Money For New Reactors Remains 'Particularly Challenging' (2022/12/09)
- Medical Isotopes / Commercial Production Of Lutetium-177 Begins At Bruce Nuclear Plant (2022/11/02)
- Advanced Nuclear Plants Poised to Benefit from Inflation Reduction Act, Retiring Coal Plants (2022/10/21)

Nuclear for abating the hardest-to-abate

As the world embarks on the path towards decarbonization, certain industrial sectors pose significant challenges. These sectors, including steel, cement, petrochemicals, aluminium, aviation, concrete, shipping, and trucking, collectively account for nearly 30% of global emissions. These sectors are deemed 'hard-to-abate' due to the technical and economic difficulties in reducing their carbon emissions. However, nuclear energy could play a pivotal role in mitigating this issue.

Nuclear reactors, with their capacity to deliver industrial process heat efficiently, could significantly reduce the carbon footprint of these industries. Moreover, some designs of mobile micro-reactors have the potential to operate as large batteries, replacing diesel generators. This could extend the decarbonizing scope of nuclear technology beyond the reach of renewable energies.

Another promising solution is clean hydrogen production. This is achieved through low- and high-temperature electrolysis that splits water into pure hydrogen and oxygen. Both traditional and advanced nuclear reactors can provide the constant heat and electricity required for this process. This could open new markets within these hard-to-abate sectors and facilitate the transition towards a low-carbon economy.

Related *ideas*:

- Ammonia-hydrogen-electricity cogeneration coupled to a very high-temperature heat source (2023/12/01)
- Nuclear Can Be 'Disruptor' For Maritime Shipping Industry (2023/09/07)
- The IMO has changed the calculus over how maritime views nuclear energy (2023/09/04)
- 'Nuclear Diesel' Could Become A Gamechanger In Energy Markets (2023/07/19)
- Swedish Vattenfall explores clean hydrogen production from nuclear reactors (2023/06/05)
- Steel maker considers use of NuScale SMRs at its mills (2023/05/16)
- Industrial users eye small reactors for power supplies (2023/03/23)
- UK urged to be world leader in nuclear-derived synthetic fuels (2023/03/14)
- The race across Europe to build green steel plants (2023/02/17)
- 4 Nuclear Power Plants Gearing Up for Clean Hydrogen Production (2022/11/09/)
- China's demonstration high temperature reactor HTR-PM reaches full power (2022/12/09)
- Social outcomes of energy use in the United Kingdom: Household energy footprints and their links to well-being (2022/12/19)

Nuclear Fuel Strategic Autonomy

In recent years, Europe's dependence on Russian nuclear fuel has become a pressing concern, especially in the wake of rising international tensions. This has put a spotlight on the importance of achieving autonomous production of nuclear fuel needed for its national power plants. As Europe grapples with the need to sanction Rosatom, Russia's state atomic energy corporation, for its alleged support of Russian aggression on Ukraine, the urgency of enhancing Europe's independence in the nuclear fuel cycle has become apparent.

The current projection indicates a significant increase in uranium needs by the year 2040. To meet this demand, Europe will need to ramp up its production capabilities. Currently, the option of reprocessing spent nuclear fuel is limited. The European (French) industry appears unable to produce fuel from reprocessed material, a skill that Russia has mastered. This is further complicated by the aging French fabrication and reprocessing facilities.

Moreover, the accumulation of separated Plutonium without integrating it into MOX fuel poses a significant concern. This is because Plutonium cannot be stored long-term due to safeguards. Despite these challenges, fast reactors could offer a more comprehensive solution to Plutonium use. This could pave the way towards Europe's self-reliance in its nuclear fuel production and efficient use of resources, thus strengthening fuel sovereignty.

Related *ideas*:

- Biden's horse-trading on nuclear technology and fuels is an unprecedented proliferation risk (2023/09/06)
- What to do with the UK's civil plutonium? (2023/09/05)
- Supply chain must expand to meet new build plans (2023/08/22)
- Sweden to return to uranium mining (2023/08/18)
- Denmark's Seaborg points to HALEU risks for switch to LEU fuel (2023/07/13)
- Europe looks to develop VVER fuel (2023/07/12)
- Russian nuclear exports are surging (2023/02/14)

- Countries change nuclear policies in response to Ukraine war (2023/01/06)
- Nuclear Waste, a controversial source of carbon-free energy (2023/02/07)
- Finnish company plans to start extracting uranium as a by-product from metal ore (2022/12/29)
- Nuclear demonstration project in Wyoming delayed because Russia was the only fuel source (2022/12/16)

The grid sustaining the green energy mix

The ongoing transition towards a greener energy mix presents several challenges for electric grid stability. The electric grid needs to maintain a delicate balance between harnessing renewable sources and maintaining a reliable baseload. This is particularly challenging in the absence of large-scale storage solutions. In this context, nuclear reactors are being redesigned to enhance their flexibility and adaptability.

One of the ways nuclear reactors are being made more adaptable is through 'load-following.' This is a technique where nuclear reactors adjust their output based on the demand for electricity. This allows nuclear reactors to seamlessly integrate with fluctuating renewable energy sources. Furthermore, nuclear reactors can support hydrogen co-generation, thus facilitating the production of clean hydrogen for diverse applications.

There is also a growing interest in 'hassle-free demand management' strategies like the 'octopus' model. This model, which could be effectively implemented using IoT and public awareness initiatives, regulates energy demand to match the supply. However, the financial implications of the green energy transition are a crucial consideration. The burden of cost resulting from suboptimal political decisions and cross-border implications could slow down the transition towards a greener energy landscape.

Related *ideas*:

- European Commission is 'willing to consider' subsidies for nuclear technology (2023/10/03)
- BRICS Nations Surge Ahead In Nuclear Energy Commitment (2023/10/01)
- Renewables are not enough to save the electricity system of the Canary Islands (2023/09/28)
- Renewable energy has hidden costs (2023/09/21)
- Will batteries usher in a new era of global energy sovereignty? (2023/09/12)
- EU has same amount of solar panels stockpiled as installed (2023/08/18)
- Italian parliament votes in favour of return to nuclear power (2023/05/11)
- Dutch government allocates funding for nuclear programme (2023/04/27)
- It is harder for new electric grids to balance supply and demand (2023/04/05)

The environmentalist nuclear choice

The increasing deployment of wind and solar power, along with the batteries they rely on, has been causing significant environmental impacts. These impacts include a loss of biodiversity due to land use competition, an increase in hazardous waste volumes, and an increased demand for rare earth mining in vast open pits. Such impacts particularly affect the environment and those who deem it essential for the wellbeing of humanity.

However, environmentalists, who have historically opposed nuclear power, are beginning to see the technology's advantages over the alternatives when prioritizing environmental protection. This shift in perspective is not without justification. Nuclear power, when compared to other forms of renewable energy, has a smaller physical footprint, produces no air pollution, and, crucially, generates a continuous supply of power, independent of weather conditions.

In fact, even in the worst possible nuclear accident scenarios of Chernobyl and Fukushima, biodiversity seems to be thriving in the surroundings uplifted by the absence of anthropogenic activity. These areas, which were once densely populated, have transformed into unintentional wildlife reserves, demonstrating the resilience of nature in the absence of human interference. This indicates that when managed responsibly, nuclear power may have less of an environmental impact than other energy sources.

Related *ideas*:

- Advanced reactors could make carbon capture systems more viable (2023/09/13)
- Young climate activist tells Greenpeace to drop 'old-fashioned' anti-nuclear stance (2023/08/29)
- Inconvenient truths about the green transition (2023/08/07)
- How shutting down nuclear reactors could lead to poor air quality (2023/05/06)
- EU ban on forever chemicals would hit bloc's green transition (2023/04/15)
- Germany's wind energy: Conservationists fear for forests (2023/02/17)
- Germany: 'Overwhelming Majority' Want Nuclear Power (2023/01/30)
- Oliver Stone Goes Nuclear at Davos (2023/01/23)
- Risk of the hydrogen economy for atmospheric methane (2022/12/13)
- Soon-to-be-nationalized German energy firm set to build NPP in Sweden (2022/11/03)

Atoms for space

The concept of using nuclear energy in space might seem like science fiction, but it's becoming more of a reality. Pressurized water reactors (PWRs), initially developed for propelling military submarines, now make up almost 70% of all nuclear reactors producing electricity. This technology is evolving, with the most advanced reactor designs becoming mobile and small enough to compete with diesel generators.

Currently, the nuclear industry is preparing to revolve and evolve these designs to bring them to the market at a competitive price. Russia seems to be investing heavily in the RITM-200 reactor, designed specifically for powering up icebreakers. Meanwhile, nuclear technology innovators in the United States are shifting their focus to the applications of nuclear reactors for space exploration, foreseeing the potential advantages for those who take the lead in the space race.

The European Union, however, is still undecided on its course of action. The bloc must determine whether to focus on enforcing demanding regulation within its borders as a premium client or to become a relevant actor in shaping the revolution of this strategic technology, extending its influence beyond the planet.

Related *ideas*:

- Europe has a productivity problem. It can be solved from space (2023/08/24)
- NASA partners with Zeno Power Systems for moon and exploration technology (2023/07/27)
- Solar Panel Robots and Mini Nuclear Reactors Could Power NASA's Future Moon Base (2023/06/22)
- Mining in space (2023/03/26)
- NASA's space nuclear power program is a hot mess (2023/03/21)
- Packing Aerogel With Uranium Could Give Us The Space Engine We've Been Looking For (2023/02/15)
- A Hybrid Fission/Fusion Reactor Could be the Best way to get Through the ice on Europa (2023/01/15)
- Radioisotope Thermoradiative Cell Power Generator (2023/01/09)
- How nuclear waste will help spacecraft explore the Moon, and beyond (2022/12/06)

Nuclear 2.0

Over past decades, the nuclear industry has established a highly structured workflow and general practice. This approach has led to long development times, high capital costs, and lengthy licensing and construction times. In an increasingly fast-paced world, this static nature is becoming less suitable, and the industry needs to adapt.

The introduction of new technologies and ways of designing and prototyping, along with potential applications, may trigger a paradigm shift toward a more dynamic, streamlined, and flexible nuclear industry.

This could improve the industry's overall sustainability in terms of safety, security, and safeguards. Processes could become leaner and more efficient, with a shorter time to market, making the industry more competitive.

However, this newfound flexibility also presents challenges. The ease with which fissile materials could be worked with and transformed raises security concerns, particularly regarding safeguards. The industry must ensure that these materials do not fall into the wrong hands, and that they are used responsibly and safely.

Related *ideas*:

- Robot 'dog' maps radioactive site at power plant (2023/09/29)
- Researchers prepare for exascale supercomputer simulations of nuclear reactors (2023/09/26)
- How scientists are using artificial intelligence (2023/09/13)
- Radiation detection drones tested at the SKC-GEN site in Mol. (2023/02/16)
- Researchers Successfully 3D Print Using Uranium Dioxide (2023/02/02)
- AI to find the right types of molten salts (2023/01/03)
- 3D imaging of a nuclear reactor using muography measurements (2023/01/03)
- Blockchain could be the key to nuclear material safeguards (2022/10/31)

(Nu)clearing the digital carbon footprint

The increasing reliance on digital infrastructure for communication, productivity, and operations of public administrations, including critical services, makes the need for a sustained and reliable electricity supply more prominent. A growing trend explores the potential of nuclear energy to meet these power demands, specifically for data centres facing an energy crunch amidst their planned expansions and net-zero emissions goals.

An increasing interest is observed from tech giants like Microsoft and other datacentre operators in Small Modular Reactors (SMRs). These are seen as a potential solution due to their ability to provide clean, reliable energy, reduce fossil fuel dependency, and accommodate the escalating power demands of datacentres. SMRs are compact, scalable and they offer the potential to drive down the costs of nuclear energy.

However, integrating nuclear power into the digital infrastructure comes with its own set of challenges, including waste management, safety concerns, and public acceptance. These challenges need to be addressed to fully realize the potential of nuclear energy in clearing the digital carbon footprint.

Related *ideas*:

- Why can't datacenter operators stop thinking about atomic power? (2023/09/27)
- Microsoft's data centers are going nuclear (2023/09/25)
- Microsoft's Rationale For Nuclear Fusion And Direct Air Capture Bets (2023/09/20)
- Nuclear-powered campus in Sweden will power data centers (2023/09/11)
- Finally - a nuclear powered data center? (2023/06/22)
- European datacentre operators worried about energy supply (2023/04/18)
- Swedish datacenter operator wants to go nuclear (2023/03/08)
- First nuclear-powered data centre at Susquehanna completed (2023/01/18)

Euratom lessons for a 'EurAI'

The rapid development of Artificial Intelligence (AI) technology, with its dual-use applications, entails various safety risks and the potential for catastrophic scenarios. These risks closely parallel those once associated with nuclear technology six decades ago. This resemblance is sparking a global AI race, balanced by fervent efforts to regulate and control this potent technology.

In the future, AI supremacy could become as significant as the possession of nuclear weapons and other weapons of mass destruction. This potential reality compels the establishment of a governing body akin to the International Atomic Energy Agency. Following the Second World War, fears and uncertainties over nuclear technology led to the unanimous approval of the Agency's statute by 81 countries to promote safe, secure, and peaceful nuclear technologies.

Today, these historical measures offer a roadmap for managing the emerging challenges of AI technology development. The establishment of the International Atomic Energy Agency and the signing of the Euratom treaty in response to nuclear technology development may now be mirrored in the potential formation of a 'EurAI'. The lessons learned from Euratom could provide essential insights to consider in this context, helping to establish a firm foundation for the safe and responsible use of AI technology.

Related *ideas*:

- AI is supposedly the new nuclear weapons (2023/06/29)
- The world needs an international agency for artificial intelligence (2023/04/18)
- As AI weaponry enters the arms race, America is feeling very, very afraid (2023/04/08)
- A.I. Like ChatGPT Is Revealing the Insidious Disease at the Heart of Our Scientific Process 2023/01/31)
- AI experts are increasingly afraid of what they're creating (2022/11/28)
- The Tiny and Nightmarishly Efficient Future of Drone Warfare (2022/11/22)
- Drones are increasing risk to critical/ nuclear infrastructure (2022/11/06) *2 references

Technology and Talent for Long Term Operation

An emerging trend in the nuclear energy sector involves extending the operating life of power plants far beyond their initial expected lifetimes, a process known as 'Long Term Operation'. This approach offers continued energy provision from existing infrastructure, maximizing the value of these significant investments. However, it also comes with a unique set of challenges that the sector must address to ensure the sustainability of this practice.

Key among these challenges is the need to attract young, skilled talent to replace retiring experts. As the nuclear industry's workforce ages, there is a growing risk of losing valuable knowledge and expertise. To mitigate this, the sector must develop appealing career pathways for younger generations. This includes opportunities for professional development and advancement, as well as the chance to work with innovative technologies.

Moreover, the necessity to integrate innovative technology advances to ensure and enhance operational safety is paramount. The incorporation of digital technologies in the nuclear sector presents a significant opportunity in this regard. Technologies such as automation, machine learning, and predictive analytics have the potential to drastically improve the safety, security, and efficiency of nuclear energy. In this context, the effective deployment of new technologies and the fostering of a new generation of nuclear professionals become crucial components in the sustainable and safe extension of nuclear power plant operations.

Related *ideas*:

- Making Nuclear Energy Use Safer with Artificial Intelligence (2023/09/14)
- Europe's atomic reactors are getting old (2023/08/22)
- New method for assessing ageing of reactor components (2023/01/11)
- Accord reached on extending operation of two Belgian reactor units (2023/01/10) *4 references
- Nuclear Industry: 'Must prepare now' for future job shortages (2022/12/14)
- Why digitalisation is crucial to the nuclear industry delivering on its potential (2022/12/13)
- Operating nuclear plants beyond 60 years could help Switzerland reach net zero (2022/10/28)

Nuclear fuelling a circular economy

To mitigate the effects of radioactive waste, innovative solutions are being explored. One such approach involves the recycling of radioactive materials, transforming what was once waste into a valuable resource. The European Union is at the forefront of these efforts, actively enhancing its recycling capacity to lessen its dependence on critical materials.

This strategic vision includes using nuclear technologies to advance the EU's circular economy. The circular economy model aims to minimize waste and make the most of resources, both key aspects of sustainable development. In this context, nuclear technology offers significant potential, with its capacity to recycle radioactive materials into useful products.

For example, some of the radioisotopes in radioactive waste could be used in the healthcare industry to treat various conditions. They can also be used in space exploration to power missions, rovers, and probes. This illustrates a promising synergy between nuclear technologies and a circular economy, suggesting a sustainable pathway for the future. By seeing waste as a resource rather than a problem, we can harness the full potential of nuclear technology while minimizing its environmental impact.

Related *ideas*:

- France taps nuclear know-how to recycle electric car batteries (2023/09/27)
- "The Octopus" Molecules – A New Potential Solution to Nuclear Waste (2023/07/27)
- Radiation-Eating Bacteria Can Help Clean Up Nuclear Wastes (2023/07/04)
- Homing in on effective separation of radionuclides to fuel a circular economy (2023/06/21)

Future Scenarios

At the sense-making workshop the trends underlying the identified topics were proyected into the future at two horizons, a mid-term future on 2033 and a longer-term future on 2053. This way, the participants worked on anticipating and harvesting the most relevant threats and oporunities that might be materialising at those two horizons. The conclusions of the discussions are presented below.

Euratom 2033

Here, we lay out the potential threats and opportunities that the European Union might face by 2033. The identified threats include the potential for a more advanced and competitive start-up environment in the United States, increased international tensions, and the challenges posed by demographic shifts and climate change. On the other hand, opportunities like the deployment of demonstrator projects, increased internal competition, and the potential for the nuclear industry to attract talent are also highlighted.

Threats

In 2033, Europe could face a host of challenges that could potentially disrupt its progress in the nuclear technology sector. One of the major threats could be the increasingly competitive start-up environment in the United States. With greater financial backing and a more conducive environment for innovation, the U.S. could potentially outpace Europe in terms of technological advancements and market dynamics.

Another significant concern for Europe could be the continued growth of China and Russia in the nuclear sector, supported by substantial financial backing both within their borders and abroad. This could potentially lead to an international environment with less collaboration among like-minded blocks, thereby affecting Europe's alliances and partnerships as well its role in geopolitical matters.

Moreover, Europe's dependence on public opinion for energy infrastructure deployment could be undermined by disinformation and misinformation driven by malicious actors. In a world where deep fakes are becoming a high precision weapon for disinformation, this could pose a significant threat to Europe's nuclear industry.

Adding to these challenges is the expected demographic shift in Europe, which could lead to a high competition for knowledgeable workers. This could hinder the development and deployment of demonstrator projects. Regulatory disparities between countries, with differing levels of expertise and resources, could also challenge the convergence towards a real European common nuclear market and impede the deployment of innovation.

Finally, Europe's environmental footprint also comes into consideration. Mining uranium and other nuclear fuels in Europe could have a significant environmental impact, which could then lead to public opposition and regulatory hurdles. The deployment of new nuclear business models, driven by private entrepreneurs might challenge existing regulatory processes, potentially leading to conflicts and slowing down progress. Overall, these threats underline the need for a robust, anticipatory approach in policymaking and strategic planning for Europe's nuclear future.

Opportunities

By 2033, Europe could have a unique opportunity to become a world leader in nuclear technology. One of the potential avenues for this is the deployment of new demonstrator projects. Small modular reactors based on pressurised water could replace coal boilers in former coal plants, showcasing Europe's commitment to clean energy and technological innovation.

European academia's ongoing efforts in training knowledgeable scientists and conducting state-of-the-art research could also provide the region with a competitive edge. In addition, the operation of state-of-the-art nuclear research facilities within the EU would further consolidate Europe's position in the global nuclear industry.

Another promising prospect lies in the potential success of European nuclear start-ups, with countries like France leading the way in finalizing their prototypes. This could stimulate competition and innovation within the European nuclear sector, contributing to the global advancement of nuclear technology.

Europe's reserves of Uranium, Thorium, and other nuclear fuels also present a significant opportunity for the region to enhance its energy sovereignty. With the right regulatory framework and technological advancements, Europe could potentially start mining these resources, reducing its dependence on external suppliers.

In a broader context, the permeation of digital technologies in the nuclear industry could lead to transformative changes, improving the safety, security, and efficiency of nuclear energy. With the right strategies in place, Europe could attract highly skilled workers into the nuclear industry, further strengthening its position on the global stage.

In sum, with a focus on innovation, sustainability, and skilled workforce development, Europe could seize these opportunities to become a global frontrunner in the nuclear energy sector by 2033.

Euratom 2053

In this section, we project further into the future to identify potential threats and opportunities for the European Union in 2053. The threats encompass issues like political instability, dependency on automation, and the risks associated with the widespread deployment of fissile material. Conversely, opportunities include the potential for the commercial operation of a nuclear fusion power plant, the advancement of recycling technologies, and the potential for the European Union to become climate neutral.

Threats

Looking further into 2053, Europe's landscape could be marked by a complex array of threats that could impact the region's progress in nuclear technology. One potential challenge could arise from political instability within OECD countries, underpinned by democracy and political uncertainty. As these countries strive to share markets for mutual economic benefit while upholding their strategic autonomy, tensions could arise, particularly in areas related to space and defence. At this point the European nuclear industry might have lost its competitive edge making European energy security and climate goals more challenging and dependent on the geopolitical context.

Another threat could arise from increasing dependence on automation and robotics. While these technologies could enhance efficiency and productivity, they also carry the risk of leading to a loss of critical knowledge and a reduced understanding of risks, particularly in the nuclear sector.

By 2053, the global population is expected to reach a tipping point, with an increasingly diverse and aging population in the European Union. This demographic shift could pose significant challenges to Europe's nuclear industry, especially in terms of meeting the growing demand for energy while maintaining a skilled workforce.

Another major threat could come from climate change, which is expected to intensify by 2053. Severe extreme weather events, droughts triggering massive forest fires, and heatwaves could pose significant challenges to the region's infrastructure and energy systems, including nuclear power plants.

The widespread deployment of fissile material in smaller, more numerous nuclear sites could increase the risk of hybrid threats. This could pose significant challenges to safety and security, requiring more robust and sophisticated safeguards.

Lastly, the increasing reliance on digital technologies in the nuclear industry could lead to new vulnerabilities. As the 'human' factor is replaced by the 'digital' factor, questions about trustworthiness, security, and alignment with human values may arise. In summary, these threats underline the need for a proactive, anticipatory approach in policymaking and strategic planning for Europe's nuclear future.

Opportunities

By 2053, Europe could be positioned at the forefront of global nuclear technology advancements. One of the most significant opportunities could lie in the extended operation of small modular reactors based on pressurised water and advanced nuclear reactors. This development could not only strengthen the European nuclear industry but also pave the way for using spent fuel and stored Plutonium as fresh fuel for these advanced reactors.

Amendments or reinventions to the European Union treaties to accommodate new members like Ukraine could breathe new life into nuclear research and development. This could lead to a stronger, more unified Europe in the nuclear sector.

Moreover, the commercial operation of a nuclear fusion power plant could mark a significant milestone for Europe. With its promise of virtually limitless, clean energy, nuclear fusion could revolutionize Europe's energy landscape and make a significant contribution to global efforts to combat climate change.

In the realm of space exploration, Europe could potentially establish a settlement on the Moon powered by a European-made nuclear micro-reactor. Such a development would not only mark a significant achievement in space exploration but also demonstrate the versatility of nuclear technology.

On Earth, the implementation of nuclear district heating in Finland and nuclear hydrogen steel-making in Sweden could serve as successful examples of how nuclear technology can be used for more than just power generation.

Furthermore, the advancement of recycling technologies could enable Europe to extract Uranium from waste and seawater, further enhancing its energy sovereignty. Meanwhile, the deployment of nuclear micro-reactors could support data centers and industry hubs close to cities, contributing to their decarbonization.

By 2053, the European Union could potentially achieve its ambitious goal of becoming climate neutral. Through strategic planning, innovation, and a steadfast commitment to sustainability, Europe has the opportunity to lead the world in harnessing the transformative power of nuclear technology.

Critical questions

Considering these future scenarios, five concrete aspects of present nuclear technology development bring forward a number of critical 'unknowns' deserving further attention and clarification:

European SMR Fuel Strategic Autonomy

- To what extent are we dependent on Russia for the HALEU fuel that Advanced Modular Reactors might be using?
- How is global uranium supply expected to evolve in the following years?
- What is the current state of European fuel conversion, enrichment, and assembly facilities?
- Should this be a European or just a national concern?
- Can fuel producers start developing a whole production line for a new product (HALEU, new types of fuel such as TRISO) without knowing even if there would be a client?
- What could be the impact of the absence of HALEU production capacity over the number of deployable SMR concepts?
- How is the US handling their own dependence towards Rusia?

The challenges of the construction of SMR demonstrator projects

- What are the main challenges for the construction of SMR demonstrator projects: funding, licensing, access to a licenced facility, access to nuclear fuel, recruitment of skilled workers?
- How can the Euratom facilitate the construction of SMR demonstrator projects?
- What are the incentives for private/public investors to participate in the construction of SMR demonstrator projects?

Skilled nuclear workforce

- To what extent could automation mitigate the scarcity of skilled nuclear workers constraining the European industry?
- Could education and training innovative strategies as the ones applied by the big tech (Google, Amazon, etc.) or public/industrial partnerships at EU level (Airbus, Ariane, defence industry, etc.) to speedup the deployment of their technologies have a similar success on the nuclear industry?
- In what position is the European Union to attract talent beyond its borders with respect to other OECD countries?

- To what extent would the deployment of nuclear reactors in embarking countries have a positive effect enlarging the available pool of nuclear expertise worldwide, or the opposite?

Misinformation and disinformation about nuclear energy

- Is planned and targeted action of malicious foreign actors taking place to damage the reputation of nuclear technology in the EU undermining the competitivity of its industry?
- How could it be measured or monitored?
- Can public administration intervene effectively on the subject given the high sensitivity of the topic?

SMRs powering critical infrastructure:

- What are the main nuclear micro-reactor specific features required by critical infrastructure such as hospitals, water purification, transportation and communication networks?
- To what extent data centres can be considered or become critical infrastructure?
- Have nuclear micro-reactors and data centres similar needs in terms of security, reliability or decommissioning?
- Would it make sense to place a nuclear powered data centre in the bottom of the ocean? And on the moon?

Conclusions

The *Horizon Scanning for Euratom Yearly Report - 2023* outlines the potential trajectories for the development and application of nuclear technology in the European Union in the coming decades, as envisaged by experts working at the Joint Research Centre. Through the implementation of foresight methodologies, the report has identified key trends and topics that will shape the future of nuclear technology, from the rise of nuclear start-ups and the utilization of nuclear technology for abating the hardest-to-abate industries, to the potential long-term operation of nuclear facilities and the increasing integration of digital technologies in the nuclear sector.

The report has also highlighted the multitude of threats and opportunities that these trends may bring, at both a mid-term (2033) and longer-term (2053) horizon. By anticipating these future scenarios, the report seeks to facilitate the creation of evidence-based policy and decision-making processes, aimed at ensuring the safe, sustainable and prosperous development of nuclear technology in alignment with the principles of the Euratom Treaty.

The critical questions raised in the report underscore the complexities and uncertainties inherent in the realm of nuclear technology. These questions point towards areas requiring further research and clarification, and call for an ongoing, anticipatory approach to policy-making.

The report's findings underscore the importance of fostering an anticipatory culture among the European Commission's nuclear community. By regularly scanning the horizon for emerging trends and potential disruptions, the JRC can continue to provide timely, strategic advice to policy-makers, thereby contributing to the advancement of nuclear technology in the European Union.

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