

## Sustainable Finance: FORATOM calls for equal treatment of all low-carbon technologies

**FORATOM supports the European Commission’s goal of creating a sustainable finance initiative for technologies that can help Europe decarbonise its economy. We take note of the work undertaken so far to develop an EU classification system for environmentally sustainable economic activities. However, based on the Technical Experts Group Taxonomy Technical Report, we believe that much still needs to be done in order to ensure that the principle of technological neutrality is maintained.**

In its “[A Clean Planet for All](#)” communication, the European Commission confirmed that nuclear will form the backbone of a carbon-free European power system, together with renewables. The latest Intergovernmental Panel on Climate Change (IPCC) report ([Global Warming of 1.5°C](#)) also recognises that nuclear power has an important role to play if the world is to keep global warming to below 1.5 degrees. And according to the IEA ([Nuclear Power in a Clean Energy system](#)), a steep decline in nuclear power would threaten energy security and climate goals, and could result in billions of tonnes of additional carbon emissions.

We therefore strongly believe the decision to not include nuclear at this stage in the taxonomy should be reviewed. Whilst the report clearly outlines the six criteria<sup>1</sup> to be used in identifying whether a technology is sustainable or not, the same cannot be said for the Do No Significant Harm criteria. These remain very vague and, as a result, can be applied differently depending on the desired outcome. In the case of nuclear, for example, the DNSH group have focused on the issue of waste and used it as an excuse to exclude this low carbon technology from the taxonomy. For other technologies, however, the waste criteria do not appear to have been applied in the same way (eg power producing technologies which generate toxic waste at the end of their useful life).

This initiative should not aim to exclude a particular technology without providing a valid justification. In order to identify whether an energy source is sustainable or not, it is important to evaluate each source on the basis of objective criteria (including CO2 emissions, air pollution, raw material consumption and land use impacts) and using a whole life-cycle approach.

In line with the six criteria which are outlined in the report, there is clear evidence to show that nuclear power:

- Contributes significantly to climate change mitigation.
- Is not sensitive to changes in the weather when compared to other low carbon power sources such as wind and solar – an important issue in relation to climate adaptation.
- Has a very limited impact on water and marine resources.
- Requires a much lower volume of raw materials to produce the same amount of power as other low-carbon sources.
- Generates limited volumes of waste throughout its lifecycle, which are accounted for and well managed. The volume of high-level waste is very low. The recycling of spent nuclear fuel may be expanded to make better use of uranium resources (the treatment and recycling of used nuclear fuel currently saves up to around 25% of natural uranium resources) and reduce the

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<sup>1</sup> TEG Taxonomy Technical Report, June 2019, p19

volume (by 5) and long-term radiotoxicity (by 10) of the final waste to be disposed of. For residual waste (very low-, low- and high-level waste) there is a robust European legislative framework provided for by the Euratom Radioactive Waste and Spent Fuel Management Directive. Furthermore, internationally recognised solutions do exist with one repository currently under construction in Finland.

- Does not emit any CO<sub>2</sub> when generating electricity and only very limited volumes of other air pollutants.
- Has a very limited land and biodiversity footprint thanks to the fact that it is one of the most concentrated means of producing energy.

More details can be found under Annex 1.

The Sustainable Finance initiative should maintain the principle of technological neutrality and encourage long-term investments in technologies capable of decarbonising Europe's economy. To do so, it must recognise and include all low-carbon technologies. This will:

- Facilitate a level playing field between different low-carbon technologies.
- Encourage the deployment of flexible and dispatchable low-carbon technologies, like nuclear, to help back up variable renewables – thereby maintaining reliability and resilience of the future energy system.
- Ensure the inclusion of any future breakthrough low-carbon technologies capable of helping Europe achieve its decarbonisation targets.

FORATOM therefore calls on the European Commission to acknowledge the critical role which nuclear has to play alongside renewables under the sustainable finance initiative. It must set up a new group of experts with in-depth technical expertise on nuclear life cycle technologies and the existing and potential environmental impacts across all objectives to take another look at nuclear power in line with the TEG's recommendation. Ideally, this work should be completed before the end of 2019.

FORATOM hopes that future discussions on the taxonomy will remain open and transparent, include real experts on the various issues and adopt a technology neutral and fact-based approach. This will be important to ensure that the taxonomy meets its objectives of adoption by the financial community and increasing the flow of capital to activities that support climate targets.

## Annex 1: Nuclear power and the Taxonomy

### The Six Taxonomy Criteria

The European Commission Technical Expert Group uses six criteria to determine “sustainability”. A technology is considered sustainable when it strongly contributes to at least one of the criteria without doing significant harm to any of the other. The six criteria are:

- I. climate change mitigation
- II. climate change adaptation
- III. sustainable use and protection of water and marine resources
- IV. transition to a circular economy, waste prevention and recycling
- V. pollution prevention and control
- VI. protection of healthy ecosystems

This annex concerns the extent to which nuclear power contributes towards sustainable development by describing how it fulfils the criteria. It also demonstrates that nuclear power does not do significant harm to any of the criteria.

### Climate Change Mitigation

Nuclear power makes a significant contribution to climate change mitigation. The greenhouse gas emissions from the lifecycle of nuclear power are very low (12 grammes CO<sub>2</sub> eg/kWh), on par with wind (also 12 grammes CO<sub>2</sub> eg/kWh) and lower than hydro power (24 grammes CO<sub>2</sub> eg/kWh) and solar energy (27 grammes CO<sub>2</sub> eg/kWh for CSP and 48 grammes for PV) [IPCC14, Chapter 3, Page 71]. The emissions that do occur will be further reduced as other sectors decarbonise. The core process, ie the generation of nuclear power, does not emit CO<sub>2</sub><sup>2</sup>.

Nuclear power is both dispatchable and flexible. It can be used on-demand and does not need to be combined with other means of electricity production nor large-scale storage in order to provide electricity 24/7.

Nuclear power is the only dispatchable low-carbon means of producing electricity which may be deployed almost anywhere in the world and can be scaled in production volume virtually without limitations. This is a particularly important characteristic for those countries where other low carbon power generation resources are limited by climate or geography.

Based on existing technology, it has been clearly demonstrated that nuclear must form part of the energy mix in order to fully decarbonise the power sector whilst ensuring security of supply. This is the main reason why the IPCC [IPCC18], the European Commission [EC18], as well as the IEA [IEA19] include nuclear in their modelled energy systems.

Energy mixes with less nuclear generation and more intermittent renewable generation will require much more energy storage. These technologies do not currently exist, there could be many as yet unknown bottlenecks during their development and they could generate significant environmental impacts. For example, in terms of the raw materials and rare earths which would need to be mined

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<sup>2</sup> There are emissions from other parts of the lifecycle than the core process. Transports to and from the power plants, mining, transporting, enriching and manufacturing of the uranium fuel, as well as the construction and decommissioning of the plant (cement, steel) all emit climate gases. The core process is emissions free, but there are emissions from test operation of emergency diesel and gas turbine generators, which is associated with the core process. Normalised to the electricity production from the nuclear power plant, these emissions are insignificant.

given that they use more resources per energy produced [DOE15] compared to nuclear, and this in itself could become a bottleneck [WorldBank17, METABOLIC18].

Even if such technologies are to be developed on a significant scale, it still remains to be proven that an energy system which relies only on variable production and storage could be economically optimal, as well as maintaining security of supply. Costs for such a system are likely to escalate dramatically as emissions requirements go towards zero, making it very attractive to include nuclear power in order to lower the system costs [Hirth15, NEA19, Sepulveda18, MIT18].

Apart from decarbonising electricity production, nuclear energy is well suited as a heat source for district heating and for industrial processes and can be used to run high temperature electrolysis or even thermolysis to make low-carbon hydrogen available on an industrial scale. Nuclear energy may effectively replace fossil fuels in a broad range of sectors, although electricity production is the highest priority since mature nuclear technologies are ready for large scale deployment and the needs of replacing fossil fuels are extensive.

Nuclear power does not (and will not in the future) harm climate change mitigation efforts. On the contrary, nuclear power makes a significant contribution.

## Climate Change Adaption

The Taxonomy gives three principles for evaluating how well a technology fulfils the climate change adaption criteria. **Nuclear power makes a significant contribution** to climate change adaption by being more or less insensitive to changes in the weather and by being implementable regardless of the climate.

A fundamental philosophy in designing, constructing and operating of nuclear power plants is the preparation for extremely unlikely external events such as severe weather events. Nuclear power plants are designed so that even if the weather becomes more extreme considerable safety margins will be maintained [IAEA19].

When siting a new reactor its resistance to a changing climate and the associated weather events is part of the analysis on a very conservative basis (Principle 1) [IAEA19]. Nuclear power – apart from being prepared for different forms of severe weather – is the form of energy production least dependent on its surroundings. Nuclear power plants can be built in most parts of the world regardless of the climate.

The measures taken to protect nuclear power plants from severe weather conditions do not harm other activities (Principle 2, **no significant harm**). Rather, nuclear power plants are important in managing the consequences of severe weather events. Keeping the lights on, or quickly getting them back on is fundamental to limit the consequences of such events to the surrounding society.

Nuclear energy is well suited for large-scale desalination of water. Fossil-free desalination is likely to become increasingly important when major population centres around the world seek means to adapt to a reduced availability of fresh water [IPCC18, Chapter 3, page 213]. There is experience of desalination based on nuclear energy from India, Japan, and Kazakhstan [IAEA16]. Desalination combined with power production is an excellent means of providing flexibility in the power system. Fresh water production could be increased when electricity from weather dependent production is available, while nuclear heat would be utilised for electricity production when the weather dependent production does not provide sufficient power to meet demand.

The ability of a nuclear power plant to withstand external events is well analysed on a conservative basis to ensure very high safety standards and may therefore be assessed (Principle 3) [IAEA19].

## Sustainable use and Protection of Water and Marine Resources

Nuclear power in condensing operation (as opposed e.g. to combined heat and power) emits low quality heat. The recipient may be either a water source or the atmosphere [Macknick12, IAEA12, IAEA16]. When heat is discharged in water, there is a local temperature increase. Though this has a local impact (positive as well as negative) on ecosystems **no significant harm** is done and must comply with existing EU regulations.

When the heat is emitted to a river measures are taken to keep the temperature increase within the safe zone so as not to harm the environment. Operation is reduced and eventually stopped when the river water becomes too warm, as was the case during the recent heatwave in France. [IAEA12, IAEA16]

Air cooling may be achieved through dry or wet cooling towers, which are water-to-air heat exchangers. Wet cooling towers consume water by producing steam. The planning of wet cooling towers is therefore undertaken in such a way that no significant harm is done to local water resources, leading to significant savings in water resources.

Heat emissions from power plants should not be confused with the processes which cause global warming. The scale of global heat emissions generated by human activity is insignificant when compared to the energy deposited on the planet by the sun and trapped by greenhouse gases in our atmosphere.

## Circular economy, Waste Prevention and Recycling

The materials used in the lifecycle of a nuclear power plant and its associated fuel cycle can, to very large extent, be reused or recycled. This includes a large fraction of the metals, but excludes, for example, a small amount of material that becomes activated or contaminated - constituting low-level nuclear waste.

Nuclear waste has two properties which distinguish it from other waste:

1. Radioactive materials decay naturally. The hazard is therefore reduced, quickly at first, and at a slower pace over time. This is an important point when compared to toxic waste from heavy metals which never loses its toxicity.
2. The waste is accounted for and managed with extremely high levels of rigour and governance. The nuclear industry stores and keeps records of its waste while isolating it from the biosphere and from society. There is a robust European Framework provided for by the Euratom Radioactive Waste and Spent Fuel Management Directive. Member States also draw up and implement national programmes.

The fact that nuclear waste loses its radioactivity over time means that it can be handled in a unique way as it can be contained until it becomes harmless, unlike toxic and hazardous wastes from other industries. High-level nuclear waste in particular (such as spent nuclear fuel when not recycled) is stored and kept isolated from the biosphere and from society long enough for it not to cause any harm. Research into how this can be done successfully has been ongoing for decades, resulting in international consensus on deep geological repositories as a solution. Projects are currently being undertaken in several countries and are now focusing on practicalities such as the development of machinery for deployment in the waste repositories. The first operational European repository for spent fuel<sup>3</sup> will be in Finland. It was granted a construction licence in 2015 and is currently under construction. The licensing process for the Swedish repository is also well under way. [Posiva15, SKB19]. A public

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<sup>3</sup> The Waste Isolation Pilot Plant (WIPP) located in New Mexico, USA is the first operating deep geologic disposal facility for the disposal of radioactive waste. WIPP began receiving transuranic (TRU) waste in 1999. TRU waste consists of tools, rags, protective clothing, sludges, soil and other materials contaminated with radioactive elements, mostly plutonium. For additional information about WIPP, see: <https://wipp.energy.gov/tru-waste.asp>.

debate is currently ongoing in France (until end of September 2019) in relation to the 5th edition of the National Plan for the Management of Radioactive Materials and Waste (2019-2021) and to support the creation of a reversible deep geological repository for long-lived high-level and intermediate-level radioactive waste in Bure in the Meuse (France, CIGEO).

The production of nuclear fuel for the majority of today's reactors relies on the use of natural uranium enriched typically to 3-5% in U-235, a fissile isotope and major contributor to energy generation (natural uranium contains only about 0.7% U-235, the rest being U-238). Spent nuclear fuel contains fissile material as well as U-238, both of which may be used for producing new fuel. France, for example, is one of the countries which reprocesses its (and other countries') spent nuclear fuel, retrieving fissile material thereby reducing the need for mining uranium and reducing waste volumes for geological disposal. Since 1972, 35 nuclear reactors in the EU have been loaded with recycled materials (Mixed Oxide fuels - MOX): 22 in France, 10 in Germany, 2 in Belgium, 1 in the Netherlands. In France for instance, 1 out of 10 lightbulbs is powered by recycled nuclear materials.

It is also possible to reduce the volume and radiotoxicity of radioactive waste thanks to the implementation of the current "mono-recycling" strategy, consisting in recycling spent nuclear fuel once. R&D programs are underway aiming at fully closing the nuclear fuel and further reducing the waste volume and radiotoxicity. They include developments on multi-recycling (recycling used fuel several times) and on new generation of reactors ("Generation IV"), particularly efficient to "burn" also U-238. Large-scale implementation of nuclear power worldwide would make it more economically viable to close the fuel cycle [NEA18]. This implies breeding fissile material from fertile nuclides (e.g. U-238 constituting 99.3 % of natural uranium). The technology for breeding and reprocessing fuel has been proven but has yet to be demanded on a large scale. Closing the fuel cycle allows for the utilisation of depleted uranium stocks as feed for fast breeder reactors. This has the potential to greatly reduce the need for uranium mining<sup>4</sup>. Uranium can also be harvested from the oceans, where deposits are several orders of magnitude larger than those on land, and which is constantly being replenished through erosion. Together with fast reactors and a closed fuel cycle, this fuel supply from the oceans can be considered as renewable<sup>5</sup> and virtually limitless [Bruntland87, Chapter 7, Paragraph 3].

Over its lifecycle, nuclear produces limited amounts of waste which are accounted for and well managed. Only very small volumes of high-level waste are generated. The recycling of spent nuclear fuel may be expanded to make better use of the uranium resource (the treatment and recycling of used nuclear fuel currently saves up to around 25% of natural uranium resources) and reduce the volume (by 5) and long-term radiotoxicity (by 10) of the final waste to be disposed of.

This shows that the nuclear fuel cycle does not do any significant harm to the biosphere or to society. The concept of isolating nuclear waste until it becomes harmless also guarantees that no significant harm occurs in the future.

## Pollution Prevention and Control

Nuclear power strongly contributes to preventing pollution since it directly replaces fossil fuels in electricity generation which is associated with very significant emissions of various pollutants. This especially applies to the burning of coal which is still significant in Europe and dominating globally [BP19].

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<sup>4</sup> A nuclear fleet of the current size could be fed for thousands of years in a closed fuel cycle by the depleted uranium already in stock. Expanding the reactor fleet would obviously reduce the time before mining would become necessary. When the stocks of depleted uranium run out, mining would be needed. The uranium requirements for breeding reactors are reduced by about a factor 50-70 though as compared to today's reactors.

<sup>5</sup> The Brundtland Commission defined breeder reactors as a "renewable energy source" along with wind and solar already in 1987.

As long as mining activities are carefully monitored and controlled, the lifecycle of nuclear power does not generate significant pollution. There are strict procedures in place to assure the sustainability of mining activities [WNA]. In addition, almost half of uranium today is extracted by in-situ leaching, without any significant disturbance of the land surface, and about 10% is produced as a by-product of other mining activities where the uranium production does not significantly add to the total environmental effect.

The principle of best available techniques is extensively utilised in the nuclear industry. The typical radiation exposure from living next to a nuclear power plant for a year is less than that received during a few minutes on a plane at a high altitude [SSM18, Bottollier00, Feng02]. Emissions of chemical pollutants and of particles are insignificant.

Nuclear power does no significant harm to air, water, or land. This includes pollution.

## Protection of Healthy Ecosystems

Nuclear power is the most concentrated means of producing energy which means it requires less land to produce the same amount of energy as other low-carbon technologies. This limits its ecological footprint, leaving most of the land- and seascape unaffected by the production of energy. Nuclear power has a land footprint that is roughly one hundred times lower than a system based on a mix of wind, solar, hydro and biomass – depending on the assumptions made [Smil15]. This shows nuclear energy's contribution to the protection of healthy ecosystems. Properly sited, nuclear power does no significant harm to ecosystems [IAEA19].

## Conclusion

Nuclear power provides a strong beneficial contribution to four out of the six sustainability criteria established by the Technical Expert Group.

At the same time, nuclear power and its associated fuel cycle does not, over all of its life-cycle, significantly harm any of the criteria.

In summary nuclear power is one of the most sustainable energy technologies available today. It is one of the most valuable technologies known to mankind in creating an environmentally, economically and socially sustainable future.

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## Annex 2: Nuclear Waste Management Solutions

### Introduction

Six criteria have been set out by the European Commission's Technical Expert Group to determine a sustainable technology, the fundamental principle being that a technology is sustainable to the extent to which it contributes strongly to at least one of these criteria (please see Annex I) while not doing significant harm (DNSH) to any of the other criteria. According to the TEG report, nuclear cannot currently be included in the taxonomy because the expert group does not believe a solution exists for nuclear waste, thereby negatively affecting criteria IV "transition to a circular economy, waste prevention and recycling".

The purpose of this annex is to respond to these claims and to show how current nuclear waste management practices adhere to these requirements in terms of criteria *IV Transition to a circular economy, waste prevention and recycling* and criteria *V Pollution prevention and control*.

The management of nuclear waste in the European Union is regulated under the Radioactive Waste and Spent Fuel Management Directive which mandates the member states to manage their radioactive waste (low, intermediate and high level waste, including spent nuclear fuel) so that there is no significant harm to people or the environment. Existing EU regulations can underpin the assessment of nuclear waste according to the DNSH criteria consistent with the approach applied to other activities and the EU regulations that apply to them.

Final repositories that meet long-term safety requirements for high-level nuclear waste, primarily spent nuclear fuel, are currently being developed. The Swedish KBS-3 multi-barrier system has become an international reference method and is being implemented in both Sweden and Finland.

Thus, the nuclear industry is at the forefront of taking responsibility for all of its waste in a safe way including far-reaching means of pollution prevention and control. It is highly likely that the approaches and experience gathered from the nuclear industry will make a considerable contribution to dealing with waste from other industrial processes such as arsenic, dioxin, dioxin-like compounds, lead and mercury.

In a nutshell:

- Spent nuclear fuel is accounted for and is held under strict control.
- The reprocessing and reuse of spent nuclear fuel is well established and is common practice in some of the member states.
- The first waste repositories for residual waste – in Finland and Sweden – are well underway, marking the finalisation of research and development that has been ongoing since the 1980s.
- A licensed repository poses a much lower risk to society than other non-nuclear licenced activities.
- Management of waste from the nuclear industry does not cause significant harm to any of the sustainability criteria.

Below is an overview of how the nuclear industry tackles the waste issue. Technologies exist to

- Reduce the amount of waste generated,
- Reuse the material within the process itself
- Recycle the material (including converting it into a resource for other industries)
- Handle all residual waste in a safe manner.

### **Reduce**

Spent nuclear fuel: The reduction of the volume and radiotoxicity of radioactive waste is currently achieved notably by the implementation of the current "mono-recycling" strategy, consisting in recycling spent nuclear fuel once. R&D programs are currently underway to further reduce the waste volume and radiotoxicity; they aim at recycling several times used nuclear fuel ("multi-recycling") in the current

nuclear reactor fleets (medium term) as well as in the next generations of reactors under study (Generation IV reactors). Solutions to further reduce the volume of operation wastes are also under development; they are notably based on an optimal combination of fusion, incineration and vitrification.

Operational radioactive waste: Waste volume reduction techniques include compacting and incinerating solid waste, as well as the use of evaporation and filtration for liquid waste. Compacting and super-compacting activities greatly reduce waste volumes within a container requiring disposal in a repository. Other wastes (e.g., plastic, textiles) are incinerated at high temperatures in a controlled chamber further reducing the volume of waste for disposal. Waste minimization includes the decontamination from surfaces of facilities or equipment “by washing, heating, chemical or electrochemical action, mechanical cleaning, or other techniques”<sup>6</sup>. Decontamination objectives allow for the salvaging of equipment and materials, thereby reducing the volumes requiring storage and/or disposal.

Such solutions, in addition to multi-recycling, will contribute to preserving scarce disposal site resources.

### **Reuse and Recycle (Closed cycle)**

Around 97% of spent nuclear fuel can be recovered and recycled into new fuels. Indeed, recovering and recycling material from spent nuclear fuel allows for more efficient use of uranium resources and translates into a lower environmental footprint. For over 60 years, reprocessing has enabled the recovery of uranium and plutonium.

Currently, commercial scale nuclear fuel reprocessing uses the PUREX process (**P**lутonium **U**ranium **R**edox **E**Xtraction), whereby the spent nuclear fuel is dissolved in refluxing nitric acid and then solvent extraction is used to extract the uranium and the plutonium. The uranium is then separated from the plutonium by manipulating the oxidation state.

The separated materials can then be used in the production of new enriched recycled uranium (ERU) and Mixed Oxide (MOX) fuels and used in conventional reactors. It has been estimated that this recycled fuel has the potential to save up to 25% in natural uranium<sup>7</sup>.

### **Final repositories for residual waste (Open cycle)**

#### **Current status of final repository solutions in Europe**

##### Finland & Sweden

Finland’s national spent nuclear fuel repository Onkalo is presently being built into the granite bedrock at Eurajoki (the site of the Olkiluoto nuclear power facility) by Posiva. A very thorough site selection process began in 1983. It involved four prospective sites and took into account geological and environmental - as well as democratic and local opinion - factors before the Finnish government made its decision. Already in February 2015 the Finnish safety authority STUK issued a statement to the Ministry of Employment and the Economy indicating that Posiva’s encapsulation plant and final repository for spent nuclear fuel can be safely built and would not pose a risk to the public and the environment. On November 12, 2015, the construction license was issued. At the Onkalo site a research facility was established early on to verify factors such as geology, hydrology and geochemistry. The construction of Onkalo is well under way and Posiva expects the application for the operational license to be submitted in 2020.

The Finnish solution applies what has become an international reference method to ensure safe final repositories for spent nuclear fuel, the KBS-3 method, developed and under implementation by the Swedish company Svensk Kärnbränslehantering AB, SKB. In Sweden well as in Finland R&D work

<sup>6</sup> INTERNATIONAL ATOMIC ENERGY AGENCY, Methods for the Minimization of Radioactive Waste from Decontamination and Decommissioning Activities, Technical Reports Series No. 401, IAEA, Vienna (2001).

<sup>7</sup> “The future of nuclear power, and interdisciplinary MIT Study”, Massachusetts Institute of Technology, 2003

began in the 1980's with multiple candidate sites leading up to Sweden selecting the Forsmark site in 2009. Research and demonstration activities to verify the KBS-3 multi-barrier technology are ongoing at the full-scale underground Äspö Laboratory located north of Oskarshamn. Today, Äspö hosts international research projects for safe final repositories including research which is taking place under the EU Framework programme for Research and Technological Development.

On January 23, 2018, the Swedish Radiation Safety Authority, SSM, completed its review of SKB's application for permission to construct a repository for spent nuclear fuel. SSM recommended that the Swedish government issue such a permit. This approval of SKB's license application was a fundamental step towards the establishment of a Swedish final repository.

Following the legal procedure according to the Environmental Act the Swedish Land and Environmental Court issued a statement indicating that all essential components of SKB's application, such as site selection, had been approved. Nevertheless, the Court has requested further information regarding long-term corrosion and the protective capabilities of the KBS-3 copper canister. The canister is one of the three barriers used in the Swedish method. In April 2019, SKB comprehensively presented the government with its additional research concerning corrosion phenomena. Following confirmation from the municipality in question that it is willing to accept a final repository of this kind, the government can take a final decision on allowing for construction to commence.

Both the Finnish and the Swedish KBS-3 solutions have been researched and developed since the 1980s. The Swedish final repository for spent nuclear fuel is also expected to become operational in the 2020s. The nuclear industry is a pioneer in terms of the treatment and management of hazardous waste as well as in the implementation of R&D programs into geological repositories which aim to meet the extremely high and long-term safety requirements. It could prove to be an example for other industries to follow when it comes to protecting people and the environment from future risks.

#### France<sup>8</sup>

Responsibility for the development and operation of a final disposal facility for radioactive waste in France lies with the National Radioactive Waste Management Agency (Andra). Work already began in 1988 for the purpose of identifying a suitable site for a high-level radioactive waste repository. Authorisation for an underground laboratory in the Bure municipality in France was granted in 1999, with construction beginning soon after. Research at this site led to the publication of a basic feasibility report by Andra in 2005 and in 2012 Bure was officially proposed as the site for underground disposal. Planning Act No. 2006-739 formally declares deep geologic disposal as the method for managing high-level and long-lived radioactive waste. The 2006 legislation outlines the path and processes for the sustainable management of radioactive materials and waste in France. The Act is codified in the Environment Code, with an ordinance of 10th February 2016 providing for the complete transposition of directive 2011/70/EURATOM. Nuclear waste management activities in France enjoyed further enhanced updates centred in Act No. 2016-1015 (2016 Act), which considers a system for specifying procedures for creating a reversible deep geologic repository for long-lived medium and high-level radioactive waste. The 2016 Act amends in particular Article L. 542-10-1 of the French Environmental Code (Code de l'environnement) defining reversibility as the ability for future generations to "reassess previous choices and develop waste management solutions" according to the sustainable solutions enjoyed by a successive generation<sup>9</sup>.

A public debate is currently ongoing in France (until end of September 2019) in relation to the 5th edition of the National Plan for the Management of Radioactive Materials and Waste (2019-2021) and to support the creation of a reversible deep geological repository for long-lived high-level and intermediate-level radioactive waste in Bure in the Meuse (France, CIGEO).

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<sup>8</sup> Reh binder, E. 2014, "Final Disposal of High-level Radioactive Waste: A Never-ending Story?", *Environmental Policy and Law*, vol. 44, no. 1, pp. 256-266.

<sup>9</sup> Sanders, M and Sanders, C., 'Nuclear Waste Management Strategies – An International Perspective', Academic Press, 2019, ISBN 978-0-12-813738-3, DOI: 10.1016/B978-0-12-813738-3.00001-7.

### Switzerland<sup>10</sup>

Responsibility for developing and operating future radioactive waste repositories in Switzerland lies with the National Cooperative for Disposal of Radioactive Waste (Nagra). In 2008, Nagra identified six potential sites in Northern Switzerland for the storage of radioactive waste, three of which were deemed suitable as repositories of high-level waste. All of them were in opalinus clay formations. In 2011, the Swiss government decided that two of the sites should be selected for in-depth underground investigation.

**Decades of experience with such waste-management, R&D programs and international experience exchange are now bearing fruit and must be taken into account in the taxonomy.**

### **Final repositories and the transition to a circular economy, waste prevention and recycling**

Nuclear has an important role to play in decarbonising the power sector whilst at the same time ensure people and businesses have access to the electricity they need when they need it. Indeed, this significance has been confirmed both by the IPCC and the European Commission's Energy Roadmap 2050, "A Clean Planet for All". At no point does nuclear power pose any significant harm to the biosphere or to society.

The current status of final repositories for spent nuclear fuel and high-level radioactive waste shows that nuclear power presents no significant harm to any of the six key criteria outlined in the report. On the contrary: the final repository solutions currently being implemented will enable future recycling and final storage of spent nuclear fuel. Direct disposal of spent fuel is in accordance with the requirements set by national legislation.

In parallel, the technology to recycle and reuse spent nuclear fuel is industrialised and is an available option for the member states that would want to select this route.

### **Repositories, pollution prevention and control**

Nuclear power does no significant harm to air, water or land. The procedures leading from the safe temporary storage of spent nuclear fuel on site and the transportation to centralized interim storage facilities, such as Clab in Sweden, have been designed to prevent pollution and to ensure strict and uninterrupted accounting and control throughout the transport chain. The same now goes for solutions leading up to final storage, from encapsulation to transportation and disposal into final repositories. The nuclear material is strictly contained and accounted for at all stages of the process.

Regarding pro-active and responsible waste management the nuclear industry is in a league of its own with its approach to protecting society and the environment from harm. Legal requirements such as polluter-pays regimes and industry stock-taking have been in place for decades and the expert organizations at member state level, e.g. the aforementioned Posiva, SKB and Andra, have performed R&D work involving experts from the international scientific community and this work has regularly been reviewed and approved by the authorities and the government. In comparison to other heavy industrial sectors, nuclear power has been a frontrunner when it comes to setting an example for responsible waste management. One important aspect is how all nuclear waste is accounted for and managed. There are detailed requirements and regulatory oversight on how to document, categorize and manage and contain nuclear waste in a safe way. The levels of rigorous monitoring and governance are unique to the nuclear industry.

### **The long-term safety case for spent nuclear fuel**

The long-term safety case for spent nuclear fuel is essential to validating the performance of a final repository solution for spent nuclear fuel. The safety case is unique in the way in which it considers

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<sup>10</sup> Rehbinder, E. 2014, "Final Disposal of High-level Radioactive Waste: A Never-ending Story?", Environmental Policy and Law, vol. 44, no. 1, pp. 256-266.

climate change in the very long-term and its impact on the safety of a final repository (in the case of Sweden it looks at a period of over a million years meaning that the technology implemented must withstand multiple periods of glaciation). No other infrastructure project assumes such standards when it comes to long-term risk assessments. The main scenario for the final repository included studies of more than 100 different thermal, hydrological, mechanical and chemical processes covering encapsulation, bentonite buffer, bedrock and the environment. Obviously, these vary depending on where the repository is located. Some member states are also working on different repository concepts. The principles for proving the safety case are similar though.

The scope of site investigations when it comes to the protection of healthy ecosystems is far-reaching and has been publicly documented and successively presented over the years to the general public in the concerned communities. Worst-case scenarios (which should always be included in such conservative decision-making as is called for in this case) include, for example, major earthquakes over a time-scale of up to a million years following periods of glaciation.

The methodology per se behind the safety cases for the repositories is developed through extensive international co-operation. In the case of the safety case presented by SKB, this includes the OECD Nuclear Energy Agency (NEA) and international scientific expertise. Research projects at universities, as well as at SKB's own laboratories, have contributed to the establishment of cutting-edge technical know-how on how to construct a final repository for spent nuclear fuel which will have no negative impact on the local community nor the environment. This includes, for instance, the Greenland Analogue Project involving implementor organizations in Finland, Sweden and Canada together with some 20 universities with field studies from 2008 to 2013. The initiative confirmed the expected conditions in a final repository during a glaciation period.

Nuclear waste repositories are regulated by strict criteria from the regulators. These vary somewhat between different countries but are all designed so that the repository will not pose any significant risk to people or the environment<sup>11</sup>.

In the safety case for a repository, a large number of scenarios are tested to ensure that the repository will not cause any harm. The vast majority of these different scenarios result in dose contributions far below the regulatory limits. To test the robustness of the safety case, SKB has constructed a scenario where all canisters are postulated to be defective (4 mm holes) when deposited. In reality this scenario could be excluded since defects on all canisters would not pass the quality control. But, nevertheless, it was modelled. Also, in this scenario the conservative dose limit corresponding to a three-hour flight is met<sup>12</sup>. The explanation is that the safety of the repository is based on several barriers – the waste itself, the canister, the material surrounding the canister, and the bed rock. Even with one barrier failing, the long-term management of nuclear waste does not cause any significant harm to people or the environment.

## Innovation

Ongoing innovation, research and development could provide new waste management solutions for the nuclear industry:

- Gen IV reactors are expected to utilise recovered uranium and plutonium from spent fuel more efficiently. They can also transmute the transuranic actinides, americium and curium, converting them into fission products that decay over a shorter timescale.
- Closing the nuclear fuel cycle and using fast reactors improves the utilisation of the uranium resource by a factor of 50-70 and it can also prevent the accumulation of irradiated nuclear fuel

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<sup>11</sup> As an example, the Swedish regulator Strålsäkerhetsmyndigheten allows an increased mortality for a hypothetical person living on top of the repository of one in a million. Translated to an increase in the radiation dose that this person would receive, this corresponds to 14 µSv per year which is equivalent to the additional dose received when flying for three hours each year

and minimising the volume of long-lived radioactive waste by recovering the trans-uranium-plutonium elements.<sup>13</sup>

- Some Small Modular Reactor (SMR) designs also have the potential to transmute spent nuclear fuel.
- Partitioning and transmutation which could potentially reduce the long-term challenge of repository sites thanks to the burning of existing spent nuclear fuel without the need for prior reprocessing.<sup>14</sup>

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<sup>13</sup> Shadrin, A.Y., Ivanov, V.B., Skupov, M.V., Troyanov, V.M. & Zherebtsov, A.A. 2016, "Comparison of Closed Nuclear Fuel Cycle Technologies", *Atomic Energy*, vol. 121, no. 2, pp. 119-126.

<sup>14</sup> Merk, B. et al. (2017) 'An innovative way of thinking nuclear waste management – Neutron physics of a reactor directly operating on SNF', *PLoS ONE*, 12(7), pp. 1–19. doi: 10.1371/journal.pone.0180703.