Review of the Taxonomy Regulation and Delegated Act

Technical Aspects: Nuclear Energy

A technical opinion by Dipl. Ing. Oda Becker[1]

This expert opinion looks at the scientific and factual assumptions made by the EU Commission to include nuclear power as environmentally sustainable under the EU Taxonomy Regulation.

It assesses the findings of the JRC Report as well as the opposing opinion of the Article 31 Group of Experts. It was commissioned by Greenpeace Germany on behalf of Rechtsanwälte Günther to underpin the legal arguments made in the request for internal review.

Part A focuses on assumptions and misconceptions regarding risk and severe accidents of and due to nuclear power installations, in particular against requirement of the DNSH principle (do no significant harm), Art. 17 EU Taxonomy Regulation.

Part B focuses on the question of whether such installations can objectively constitute a contribution to climate protection according to Article 10.1 of the Taxonomy Regulation.

The conclusion in each part is that there is no factual basis to include nuclear power as environmentally sustainable in the Commission Delegated Regulation.

[1] Ms. Becker, a physicist by training, has been active for over 20 years as an independent scientist in the field of nuclear safety and risk. From 2006 to 2011, she held an administrative professorship at Hannover University of Applied Sciences. She has worked on various expert reports on the safety of nuclear power plants in different countries on behalf of the Austrian Environmental Protection Agency (for example: Dukovany NPP, Czech Republic; Paks NPP, Hungary; Hinkley Point, UK). Current work includes studies on safety issues in German and European nuclear power plants - e.g. their ageing.

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Part A – Risks and Accidents

A.1 Impacts of Severe Accidents

The main risk of nuclear power is the risk of severe accident. To date, meltdowns at nuclear power plants have been either catastrophic (Chernobyl, Russia in 1986; three reactors at Fukushima Dai-ichi, Japan in 2011) or damaging. There is no doubt that severe accidents at nuclear power plants can lead to considerable adverse effects on environmental objectives; the damage caused by accidents can be particularly serious when compared to other economic activities and extend far beyond national borders.

The JRC Report only considers normal operations at many points; accident scenarios are only studied in the relatively short Part A 3.5. They are only considered in terms of their lethality, and this is compared to other energy sources, but the report does not mention the other aspects of accident risks, which are relevant for taxonomy. Incidents and accidents, particularly when operating nuclear power plants, can lead to the uncontrolled discharge of radioactive substances and therefore cause considerable environmental effects. A holistic assessment of the use of nuclear energy must therefore include a risk assessment related to all the environmental objectives that are relevant to EU taxonomy.

The basis for assessing the consequences and the risk of accidents in the JRC Report is not appropriate at all:

- When presenting the consequences of accidents, the JRC largely restricts itself to considering the numbers of human fatalities. Furthermore, there are shortcomings in analysing the human fatalities. The two major accidents in Chernobyl and Fukushima were not taken into account in assessing the fatality rate for nuclear.
- The JRC Report ignore the long-lasting and wide-spreading consequences of accidents. The JRC Report does not examine how the possible radioactive release caused by an accident would affect the environmental objectives beyond human fatalities. Severe nuclear accidents do not primarily result in immediate fatalities, but in significant long-term health consequences, amongst them latent fatalities. But even where cancer or other severe illnesses do not result in early death, there is surely a loss in quality of life. The JRC Report does not take into account the consequences of severe accidents on people's health, climate protection, biodiversity, protecting soil and water supplies etc...
- The JRC Report does evaluate the risk of accidents inappropriate. Furthermore, the JRC Report failed to consider accidents in other nuclear facilities.

A.1.1 Insufficient Calculation Human Fatalities Resulting from Severe Accidents

The JRC Report (Chapter 4.3) stated: If severe accident fatality rates are compared, then the current Western Gen II NPPs have a very low fatality rate ($\approx 5 \cdot 10^{-7}$ fatalities/GWh). This value is much smaller than that characterising any form of fossil fuel-based electricity production technology and comparable with hydropower in OECD countries and wind power (only solar power has significantly lower fatality rate).

This fatality rate of $5E^{-07}$ per GWh presented in the JRC Report was calculated by Hirschberg et al. (2016). With respect to the method, JRC explained: "*For nuclear energy, due to the very low number of historical severe nuclear accidents and their significance for risk assessment, an approach based on the use of a simplified, site-specific, Level 3 Probabilistic Safety*

Assessment (PSA) is used to quantify the risks associated with hypothetical severe accidents." Footnote 114 explains further: "*Three core-melt events have occurred to date in NPP: Three Mile Island (USA, 1979), Chernobyl (Ukraine, 1986), and Fukushima Daiichi (Japan, 2011). The consequences of the TMI accident were relatively low; the total collective effective dose to the public was about 40 person-Sv, which resulted in an estimation of one cancer fatality. The Chernobyl reactor design is not representative of operating plants in OECD countries using different, safer technologies nor of reactor designs for future deployment globally. The Fukushima accident is not included in the results provided by Hirschberg et al., since a reliable assessment of its consequences were still an open issue at that time*." (JRC Report, p. 175, and footnote 114)

Summarising, the two major accidents in Chernobyl and Fukushima were not taken into account in assessing the fatality rate for nuclear.

When analysing human fatalities, it is clear that the comparison of the numbers of victims from nuclear accidents with those from accidents involving other energy sources is only based on figures, without describing the uncertainties and the different characteristics. When comparing the key figures like the average mortality rate per generated TWh for nuclear energy and fossil energy (JRC Report, Part A, Fig. 3.5–1, p. 176), the very different characteristics of the lethal effects of the different sources of energy in terms of the probability that they might occur and regarding the chronological sequence of lethal impacts or events should be considered and presented when selecting the standard.

- The lethal effects practically occur continually with fossil fuel energy generation. In contrast, accidents may occur rarely when using nuclear energy but with severe consequences.
- In addition, the production of radioactive waste causes a risk, which far exceeds the service life of a nuclear power plant itself, in terms of the time involved.

Severe nuclear energy accidents do not mainly result in immediate fatalities, but in significant long-term health consequences, amongst them latent fatalities. The picture becomes more realistic when these latent health effects are also included, as the following figure from the Intergovernmental panel on Climate Change (IPCC) shows, which includes probabilistic assessments for fatalities of the Chernobyl accident.

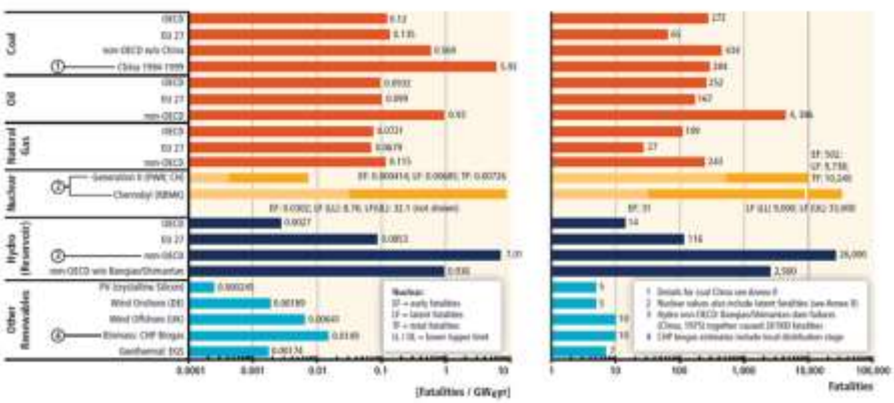

Figure 1: Comparison of fatality rates and maximum consequences of operating large energy technologies, including accidents in the fuel chain; the accident at Fukushima is not included. (IPCC 2012, p. 746)

The fatalities per GWeyr (sum of immediately and latently) in OECD countries are lowest for Photovoltaic (PV), geothermal, onshore wind and hydro, followed by offshore wind and after that nuclear Generation II (i.e. the current operation reactors). When compared to the accident in Chernobyl, nearly all other energy technologies have lower fatality rates (except big dam breaks and some large accidents in coal production). Furthermore, it should be recognised that a big dam break may cause a large number of immediate fatalities but does not necessarily have a long-term (genetic) impact on future generations as does a severe nuclear accident.

The IPPNW (International physicians for the prevention of nuclear war) estimates that several hundred thousand cancer cases result from the Chernobyl catastrophe. Main victims of the accident are the so-called liquidators or clean-up workers (about 800,000 people in total), the evacuees from the immediate area (about 350,000), residents from areas just outside the evacuation zone, and children from all these groups. Assumably, 50,000 to 100,000 liquidators have died already until 2006. "*The exact number of victims may never be known, but 3 million children require treatment,*" said UN secretary-general, Kofi Annan.[2]

The existing nuclear reactor fleet is by no means 'best in class' with respect to the human fatalities and other significant consequences caused by severe accidents.

A 1.2 Inappropriate assessment of the risk of serious accidents

When operating nuclear power plants, severe accidents with far greater effects on the environment can occur; they can go beyond the potential environmental impact described in the JRC Report. The assessment of the ecological sustainability of energy sources may not ignore aspects related to beyond design basis events.

As severe accidents are not considered beyond the design requirements in the methodology used by the JRC, this has no influence on the assessment of the DNSH criteria by the JRC. The effects of possible beyond design basis events have not been covered in the JRC Report.

The JRC Report tries to make believe that **regulation** prevent severe nuclear accidents: "*The protection of people and the environment in countries with nuclear installations relies on the existence of a solid regulatory framework that oversees the safety and environmental impacts of these installations*." (JRC Report, p. 9)

It is true that the nuclear regulations envisage a defence-in-depth concept to prevent this kind of discharge caused by incidents (WENRA, 2014; BMUB, 2015). However, in principle substances may be released because of accidents and this has already occurred several times during the last few decades.

The JRC Report considers both Generation II reactors (operation plants) and Generation III reactors (new build projects) with respect to the risks of accidents in Part A 3.5. But particularly focuses on generation III nuclear power plants. However, these are currently not in operation in Europe yet; individual reactors are in the construction phase. Europe is almost exclusively operating reactors that are already more than 30 years old.

Current rules were reworked after the accident in Fukushima; the EU Directive 2009/71/EURATOM in particular was strengthened in terms of the safety objectives needing to be achieved and especially the requirements for the design of nuclear power plants that are newly built in 2014/87/EURATOM. However, this does not mean that accidents that discharge

[2] https://cordis.europa.eu/article/id/25525-effects-of-chernobyl-worse-than-expected

substances at nuclear power plants can be categorically ruled out. The member states are obliged to design, build and operate nuclear power plants with the goal of preventing accidents and, if an accident occurs, mitigate its effects. **The fundamental possibility that an accident might occur, however, still exists.**

There is disagreement in the political/social debate not only among the EU member states about whether this risk is acceptable. In the light of this, the reference to the **regulatory framework** is unsatisfactory, because it does not adequately consider severe accidents.

Even if upgrades are repeatedly performed across Europe with the aim of increasing safety levels, the design philosophies of the generations of nuclear power plants differ greatly, particularly when it comes to classifying accidents with a meltdown. Depending on the design of the power plants, there are limits to the possibility of introducing "safety improvements that can be reasonably achieved" (EU Direcitve 2014/87/EURATOM).

The JRC Report also cites the WENRA Safety Objectives for New Nuclear Power Plants (cf. JRC Report, Part A 3.3.7, p. 128f). They are the WENRA safety objectives for the safety of new reactors to be used when designing new nuclear power plants. WENRA's published positions do not provide any binding set of rules but are a voluntary obligation. WENRA demands that accidents involving core meltdowns, which create an early or large discharge of materials, should be practically ruled out at newly constructed nuclear power plants.

Even if various rules mention "excluding" or "practically excluding" particular events or accident scenarios (cf. EU Directive, Article 8a; WENRA, 2010), these technical terms do not mean that these events can be categorically ruled out. In the probabilistic sense, this kind of "exclusion" means that the probability that such an event might occur is sufficiently small because of the measures that have been adopted. The use of this regulatory terminology in the JRC Report suggests, however, that "exclusion" should be understood in a categorical sense.

The scenarios "excluded" here do not aim to prevent accidents with any release, but simply prevent any discharge that is subject to certain defined general conditions (to enable time to implement emergency protection measures outside the power plant or necessary protective measures for the general public, which cannot be restricted in terms of time or place).

A.1.2.1 Not correct exclusion of Severe Accidents of Generation III reactors

After the Chernobyl accident, there were focused international and national efforts to develop Gen III NPP. These plants were designed according to extended requirements related to severe accident prevention and mitigation, for example they ensure the capability to mitigate the consequences of a severe degradation of the reactor core, if such an event ever happens. The main design objective was to ensure that even in the worst case, the impact of any radioactive releases to the environment would be limited to within a few kilometres of the site boundary. (JRC Report Chapter 4.3)

The JRC Report states: These latest technology developments are reflected in the very low fatality rate for the Gen III EPR design ($\approx 8 \cdot 10^{-10}$ fatalities/GWh). The fatality rates characterising state-of-the art Gen III NPPs are the lowest of all the electricity generation technologies. (JRC Report Chapter 4.3)

The EPR developed under European nuclear safety standards are not yet in operation in Europe. Only in China are two EPRs in operation, the first starting in 2018. Consequently, there is very little operational experience, and no experience under European nuclear safety standards. A low fatality rate of EPR is more wishful thinking than a proven fact. However, newer reactor designs can also have severe impacts at long distances from the site.

The EPR in Olkiluoto-3 has been under construction since 2005; it is expected to start operating in 2022. In the flexRISK project, the risk of a severe accident at Olkiluoto-3 was calculated. Dispersion calculations were made for an accident with early containment failure assuming a release of 173.7 PBq Cs-137. Figure 2 shows the weather-related probability of being contaminated with more than 185 Kilobecquerel Cs-137/m^2. After Chernobyl, in regions with > 185 kBq Cs-137/m^2 the population had the right to resettlement. It can be clearly seen that the consequences are not limited to a few kilometres around the site. Even in Austria, at a distance of around 1,600 km away, there is a 0.14% probability of a deposition > 185 kBq Cs-137/m^2 resulting from such a severe accident.

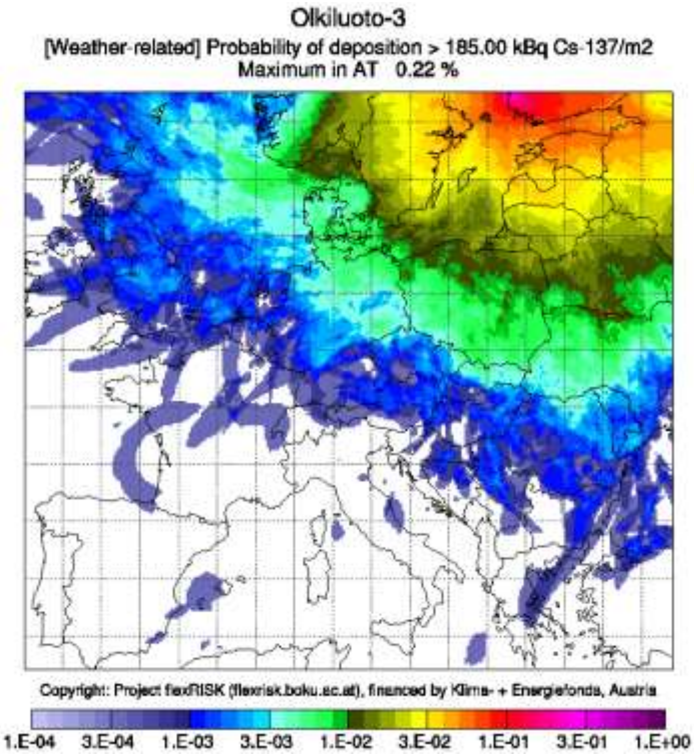

Figure 2: Weather-related probability of a deposition of more than 185 kBq Cs-137/m^2 due to a severe accident in Olkiluoto-3 with a source term of 173.7 PBq Cs-137 (FLEXRISK 2022)

A.1.2.1 Inappropriate focus on the theoretical calculated probability

A distinction must be made between the accident probability determined from theoretical consideration based on the probabilistic safety analyses (PSA) as used in the JRC Report and the accident probability determined from accidents already occurred. It has to recognized that the theoretical calculated accident probability cannot or cannot appropriate) take into account many issues that can trigger an accident (e.g. terror attacks, climate change, ageing effects)

A.1.2.2 Probability of accident calculated by the previous accidents

In 2015, scientists have compiled the most comprehensive list of nuclear accidents ever created and used it to calculate the likelihood of other accidents in future. Their conclusion is that the chances are 50:50 that a major nuclear disaster will occur somewhere in the world before 2050.

The metric they use in assessing each accident is its total cost in U.S. dollars (based on the dollar value in 2013). They define an accident as “an unintentional incident or event at a nuclear energy facility that led to either one death (or more) or at least $50,000 in property damage." Each accident must have occurred during the generation, transmission, or distribution of nuclear energy. That includes accidents at mines, during transportation by truck or pipeline, or at an enrichment facility, a manufacturing plant, and so on. The resulting list ranks 174 accidents between 1946 and 2014. (MIT 2015)

The risk of another severe nuclear accident like Chernobyl or Fukushima has been recalculated. Swiss, Danish and UK researchers analysed 216 nuclear energy accidents and incidents (Wheatley et al. 2016). The authors estimated that there is a 50% chance that a severe accident (which is defined by costing at least 20 million USD in damages) will occur every 60-150 years, i.e. once or even twice in a century. Smaller accidents such as Three Mile Island in the USA could even occur every 10-20 years, according to this statistical assessment.

A.1.2.3 Accidents in other nuclear facilities

In addition, the production of radioactive waste causes a risk, which far exceeds the service life of a nuclear power plant itself, in terms of the time involved. In other respects, it must be remembered that events that release pollutants can also take place during the decommissioning and dismantling phase for nuclear power plants, the storge of nuclear waste and during the much longer periods involved for disposing of radioactive material. This is not mentioned in detail in the JRC Report.

A.1.3 Ignoring long-lasting and wide-spreading Consequences of Severe Accidents

The above-mentioned research flexRISK project demonstrated what consequences can be expected following a severe beyond-design base accident.[3] These consequences are not limited to an area of just a few kilometres around the site. Nuclear energy is inextricably intertwined with the risk of creating significant harm for humans and the environment: the risk of chronic illness due to a severe accident; of losing agricultural areas due to severe contamination; and disastrous social and economic impacts on people forced to live in contaminated territories.

Radioactive pollution following the accident at Chernobyl has led to permanent loss of agricultural and forestry areas: In Belarus, 18.000 km^2 of agricultural area were contaminated after Chernobyl, with more than 2.600 km^2 having to be abandoned, as well as 1.900 km^2 of forest. In Ukraine, 31.000 km^2 of agricultural land, 15.000 km^2 of pasture and 35.000 km^2 of forest (representing 40% of the total Ukrainian forested area) were contaminated; 1.800 km^2 of agricultural land had to be abandoned (Cs-137 > 1.480 kBq/m^2).[4] The well-known fact that entire regions have become inhabitable for decades following the accidents at Chernobyl and

In addition, after the 2011 Fukushima accident, the environmental pollution is still a daily reality. There are plans to release contaminated water from storage tanks into the ocean, because no other solution seems to be viable. The water not only contains the radioactive isotope tritium, but also numerous other harmful radioactive isotopes, including long-lived isotopes such as Caesium-137, Strontium-90 and others. Allison M. Macfarlane, Professor and Director at the School of Public Policy and Global Affairs, University of British Columbia, said in the Bulletin in March 2021: "*Nuclear power advocates claim that the Fukushima accident did not kill anyone directly, with the implication that the accident wasn't that bad. But it was. Many people lost property, land, jobs and community. Over 160.000 people evacuated, but fewer than 35 per cent of them have returned. The fishing industry remains devastated. Agricultural industry is*

[3] http://flexrisk.boku.ac.at/en/index.html
[4] IAEA (1996b): Social, Economic, Institutional and Political Impacts. Report for Ukraine

just beginning to come back. The cost for Fukushima decommissioning, decontamination, and compensation will be at least $188 billion and up to $736 billion. And that doesn't count the loss of the 24 reactors permanently shut down, the updates to existing reactors, and the costs to replace the electricity lost."[5]

As mentioned above also accidents, in nuclear facilities of the whole fuel cycle are possible, as the accident in Mayak illustrates. On 29 September 1957, a tank containing highly radioactive waste explodes in Mayak, Russia. The radioactive cloud travels northeast at an altitude of 1,000 metres: a 40-kilometre-wide, 300-kilometre-long trail. An area of 2,0000 square kilometres with about 270,000 inhabitants is radioactively contaminated. More and more areas have to be evacuated. The explosion remains secret until Moscow confirms it in 1989. According to the International Atomic Energy Agency (IAEA), it is the third most serious nuclear accident in history, after Chernobyl and Fukushima.

Experience proof that significant harm to the environment can be expected for decades after a severe accident has occurred. This is not mentioned in the JRC Report.

The JRC Report also does not mention psycho-social secondary diseases caused by accidents, which have a verifiable impact on the numbers of fatalities either (Hayakawa, 2016).

A.1.4 Severe Accidents omitted in JRC`s assessment of the DNSH criteria

The BASE/BFS criticized that the JRC Report discuss severe accidents (JRC Report, Part A 3.5, p. 175ff and 4.3, p. 186f), but has not included them in the assessment of the DNSH criteria (cf. JRC Report, Executive summary, p. 10, fourth indent).

The work performed by the TEG and the technical screening criteria based on this do not envisage any consideration of severe accidents in the other economic activities assessed so far. On this basis, the statements by the JRC about accidents represent an extra element added to the overall summary of the consequences of using nuclear power but are not taken into account in JRC´s assessment.

The reference in the Taxonomy Regulation to the precautionary principle and the consequential need to look at all the environmental risks tend to support a more comprehensive framework of observation.

Note: Discussions are already taking place in various organisations about the need to identify activities that must be largely excluded in the Taxonomy Regulation because they do not fulfil the DNSH criteria in principle.

The Taxonomy Regulation would also be completely open for an additional regulatory decision, particularly for excluding any use of nuclear energy. For example, there is already a specific exception in the form of Article 19 Para. 3 of the Taxonomy Regulation, even if it does not refer to events causing any damage. The use of solid fossil fuels to generate power is ruled out here. A similar regulation could be used for nuclear energy because of the specific risk of an accident.

A.1.5 Opposing opinion of the Article 31 Group of Experts

The opposing opinion of the Article 31 Group of Experts identified several shortcomings and gaps in the considering of accidents by the JRC Report. **First of all, it is claimed that severe**

[5] https://thebulletin.org/2021/03/the-fukushima-accident-do-we-have-the-wisdom-to-move-forward/

accidents have to be included in the assessment of the DNSH criterium. It is stated if severe accidents would be included, it is clear that the use of nuclear energy in not sustainable. It is also point out that the regulatory framework severe accidents cannot exclude.

- The JRC does not include other direct and indirect impacts of **severe accidents** in the scope of its assessment as such impacts have not been assessed for any other economic activity covered by the EU Taxonomy Regulation. The use of nuclear energy, however, is not comparable to other economic activities. Risk assessment and defence-in-depth including physical barriers, redundant and various key safety functions as well as emergency response measures are fundamental elements in the use of nuclear energy due to the potential consequences associated with its use. Comparable safety features are not required for any other technology covered by the EU Taxonomy Regulation. It stands to reason, therefore, that the consequences of severe accidents potentially caused by human factors, natural events, but also by terrorist attacks must be fully included in the assessment."
- **Severe accidents** play only a minor role in the JRC report. Apart from the number of fatalities, other direct and indirect impacts of severe accidents are not assessed by the JRC. However, actual severe accidents have demonstrated that potential radiological consequences, for example, vast contaminated areas, evacuation and long-term relocation of members of the public, restrictions on food and drinking water supplies, land use restrictions for agriculture and housing, as well as non-radiological consequences, e.g. adverse psychological, societal or economic consequences, have harmful impacts on humans and the environment for decades or even centuries. These consequences affect the host country, but potentially also neighbouring countries. **Against this background, nuclear energy clearly does not satisfy the *do no significant harm* (DNSH) criterion and the answer to the question of whether nuclear energy is environmentally sustainable is very clearly no.**
- The JRC report considers the DNSH criterion for nuclear power activities to be fulfilled if the regulatory requirements are met. From this, the GoE concluded that the requirements in the Technical Screening Criteria (TSC) on the protection of humans and the environment from the harmful effects of ionising radiation are automatically satisfied in the EU if a licence can be issued. However, against the background of the aforementioned severe accidents and the residual risk, an assessment framework that goes beyond the regulatory requirements seems indispensable in order to adequately answer the question as to whether nuclear energy is environmentally sustainable.

A.1.6 Critic by the SCHEER

The SCHEER performed a review of the state-of-the-art to assess nuclear energy generation under the "do no significant harm" (DNSH) criterion (Part A). Concerning the "Impact of severe accidents", the SCHEER identified several gaps:

- The SCHEER is of the view that fatalities is an indicator to assess the impact of severe events but not the only measure for risk assessment.
- The SCHEER also takes the view that concurrent accidents at multiple units on a site can occur in reality.
- In addition, the risks of nuclear accidents will remain irrespective of regulatory safeguards.

A.2 Uranium Mining and Milling

A.2.1 Overestimation of measures to reduce/prevent the environmental impact

The JRC Report mentions the environmental risks of uranium mining (particularly in JRC Report, Part A 3.3.1.2, p. 67ff), but states that they can be contained by suitable measures (particularly JRC Report, Part A 3.3.1.5, p. 77ff).

The JRC Report states: "Provided that all specific industrial activities in the whole nuclear fuel cycle (e.g. uranium mining, nuclear fuel fabrication, etc.) comply with the nuclear and environmental regulatory frameworks and related technical screening criteria, measures to control and prevent potentially harmful impacts on human health and the environment are in place to ensure a very low impact of the use of nuclear energy." (JRC Report, p. 8)

*"Uranium mining and milling also produces large amounts of very low level waste due to formation of waste rock dumps and/or tailings. These dumps and tailings are located close to the uranium mines and the related ore processing plants and their **environmentally safe management can be ensured** by the application of standard tailings and waste rock handling measures." (JRC Report, p. 11)*

Both quotes refer to **control and prevention measures** that are regulated in several Euratom and EU Directives (see JRC Report Chap. 3.3.1.4). But nearly 100% of the uranium used in the EU is imported from countries outside the EU, including Kazakhstan where highly toxic chemical leaching is used, followed by Canada, Australia and several African countries. Here, EU regulations do not apply.

Moreover, the reference to appropriate measures does not include ensuring that these measures are actually implemented. Even if measures "can" be ensured, is it no guarantee that they "will" be ensured.

Suitable measures are not discussed in the depth required in this context nor when assessing the DNSH criteria (JRC Report, Part A 4.2 p. 182ff) nor for developing TSCs (JRC Report, Part A 5.5, p. 195f with Annex 4.2) – and there is no explanation of how they should be implemented. **The report does not indicate either how state institutions and regulatory authorities could exercise some influence on the uranium mining industry to ensure that the aforementioned suitable measures achieve the environmental objectives in the EU's Taxonomy Regulation.** The fact that most uranium mines are located outside the EU plays an important role here – uranium ore is only extracted within the EU at the Crucea mine in Romania.

A.2.2 Underestimation of possible Consequences

A.2.2.1 Inappropriate Evaluation of Dam Failures

The safe storage of tailings over hundreds or thousands of years cannot be assumed, as shown by the example of **dam failures**: "*Abandoned or improperly constructed uranium mill tailings can lead to significant contamination of the soil, surface waters and groundwaters, if a proper containment of the tailings is not established or maintained*." (JRC Report, p. 69)

The JRC Report describes the Church Rock dam failure in Arizona, US, which led to a higher release of radioactivity than the Three Mile Island accident in the same year. The description of the dam breach at Church Rock This is an example of the imprecise and unclear treatment of environmental risks in the JRC Report (JRC Report, Part A 3.3.1.2.2, p. 70, lines 1 ff). This is the only time that the JRC Report mentions a mining accident and it is only described very briefly. The dam of a mining sludge pond (SRIC, 2007) burst at Church Rock in New Mexico, USA (on the territory of the Navajo Nation) on 16 July 1979. More than 1,000 t of radioactive mining sludge and about 360,000 m^3 of radioactively contaminated water escaped into the Puerco River in this tailings pond accident. **The Church Rock disaster released the largest amounts of radioactivity ever in the USA. The surrounding area and its residents are still suffering from the consequences of the accident** (Knutson, 2021). The impact of the disaster, which is still continuing today, and the intensive uranium mining around Church Rock, i. e. serious environmental and health problems, are described in the Report of the Church Rock Uranium Monitoring Project 2003–2007, which has been published by the Southwest Research and Information Center (SRIC). **In contrast, the long-term, negative consequences of the Church Rock disaster are not even mentioned in the JRC Report.**

Tailing dams failures occur rather often and pose a great threat: see "*Chronology of major tailings dam failures*," WISE Uranium Project, last updated 5 April 2021 (www.wise-uranium.org/mdaf.html). The UNEP, the UN Environmental Program, has also listed such accidents and commissioned major studies. (UNEP 2017)

A.2.2.2 Inappropriate evaluation of radioactive emissions of tailings

In addition to dam failures, radioactive emissions of tailings are a huge problem, especially if a mine is abandoned and remediation measures are delayed or have not yet started. The last of the 250 former uranium mines in France closed 20 years ago. But in 2021, radioactive waste from abandoned uranium mines was found in publicly accessible areas, as a new documentation (June 2021) by the French CRIIRAD shows. The radiation level was 20 times the background level.

In Příbram (Czech Republic), for example, 26 mining dumps with almost 28 million m^3 of rock residues were left behind on an area of 52 m^2. When the question of whether these contaminated sites should be removed was discussed in 2020, the local residents protested: They feared that remediation would release radioactive dust and contaminate the entire region.

A.2.2.3 Inappropriate Evaluation of the Technology (In situ leaching)

When it comes to extraction methods for uranium, the JRC Report focuses on in-situ leaching (e.g. JRC Report, Part A 3.3.1.1, p. 65–66). This is a mining technology that causes less surface environmental damage than conventional mining and is therefore apparently more environmentally-friendly. However, the JRC Report remains very superficial about in-situ leaching. The environmental risks, particularly the contamination of groundwater, are mentioned, but not described in any detail or with the help of case studies. This needs to be done, however, to actually do justice to the environmental objective of "**sustainable use and protection of water and marine resources**" according to Article 9 c of the Taxonomy Regulation. Negative cases with serious environmental damage, such as Königstein (Saxony), Stráz pod Ralskem (Czech Republic; Andel and Pribán, 1996) or Devladovo (Ukraine; Molchanov et al., 1995), are not even mentioned.

The consequences of the in-situ leach process can be seen at the Stráž uranium deposit: There were 2,210 exploration and 7,684 production drillings there to dissolve uranium from the rock with concentrated sulphuric acid. In total, more than four million tonnes of sulphuric acid, 320,000 tonnes of nitric acid, 26,000 tonnes of hydrofluoric acid and 111,000 tonnes of ammonia were injected into uranium-bearing strata by this method. Over 350 million cubic metres of groundwater have been contaminated; to date, the entire drinking water supply in northern Bohemia is at risk.

Lung cancer

The JRC Report argues that measures to control and prevent harmful impacts in the whole nuclear chain are in place to ensure very low impact. Consequences related to uranium mining is not only land degradation but also the risk of lung cancer. Uranium mining causes lung cancer in large numbers of miners because uranium mines contain natural radon gas, some of whose decay products are carcinogenic. Several studies have found a link between high radon levels and cancer. A study of 4,000 uranium miners between 1950 and 2000 found that 405 (10 percent) died of lung cancer, a rate six times that expected based on smoking rates alone. (JACOBSEN 2019) This effect is not mentioned in the JRC Report.

A.2.2.4 Inappropriate comparison between coal and uranium mining

The JRC Report compares uranium and coal mining and concludes that uranium mining is much more effective and "more environmentally-friendly" than coal mining (JRC Report, Part A 3.3.1.1, p. 64ff). While about 50,000 t of uranium are enough to operate all the nuclear power plants around the globe every year, a single 1-GW coal-fired power plants requires 9,000 t of coal every day. However, this argument has not been thoroughly thought through: neither coal mining nor uranium mining can be viewed as sustainable – irrespective of the amounts involved in each case. **The JRC Report wrongly confuses the comparison levels here**: coal mining involves mining hydrocarbons, while uranium mining means extracting ore. The mining and processing techniques for both minerals are very different. Uranium mining principally creates radioactive waste and requires significantly more expensive waste management than coal mining. In the past, handling the legacy of mining was left to the community at large. The old sites in the uranium mining areas in Thuringia are one example of this.

A.2.2.5 Inappropriate Evaluation of Cleaning up uranium mining sites

The JRC Report describes how abandoned uranium mining sites are decontaminated, waste and processing tips are removed and opencast mining pits are filled. Cleaning up the SDAG Wismut sites in Saxony and Thuringia after the demise of East Germany in 1990 are mentioned as a classic example here (JRC Report, Part A 3.3.1.2.1, p. 67, lines 7ff).

However, the history of Wismut (the legal successor of SDG Wismut) recultivation and decontamination is more complicated than described at the JRC Report. Wismut GmbH has spent 6.8 billion euros of taxpayers' money on its part of the clean-up until the end of 2020. The costs will rise to around eight billion euros in Thuringia and Saxony by 2045, almost two billion more than originally estimated. This is because environmental monitoring and water purification in particular will remain an issue for a long time. The storage structures in decontaminated areas and their radioactive content will require constant monitoring for many years to come. Rivers and groundwater in Eastern Thuringia are exposed to risks of contamination. **The JRC Report seems to suggest that even massive, polluted areas like these, which involve decades of decontamination work, do not lead to environmental objectives not being met.**

Despite this immense effort, the pollution cannot be completely eliminated. In almost all other regions of the world where uranium has been and is being mined, this problem is not even being addressed. There is a lack of interest and, above all, a lack of the billions of dollars required.

Contamination of water, air, sediments, soil, humans and wildlife from uranium mining and milling legacies is expensive and difficult to remediate, measures are often postponed and radiotoxic contaminations continue. Abandoned waste can be easily accessed by the public. None of these issues is mentioned in the JRC Report sufficient. To conclude, the JRC Report describes the risk-filled reality of extracting uranium ore and its processing to an inadequate degree.

A.2.3 Specific requirements for sustainable mining not considered

Uranium mining, respectively the issues combined with uranium mining, call for a separate consideration of the issues of intergenerational justice and participation in terms of the sustainability of using nuclear energy. The term sustainability, which actually has its roots in forestry and therefore relates to the renewable resource of wood, is now being discussed in mining too, although the latter involves extracting minerals, which cannot grow again. In the light of this fact, sustainability in mining needs to be defined differently. The discussion about defining sustainable or eco-friendly mining is still continuing (e.g. Gorman & Dzombak, 2018; Lahiry, 2017; Tyson, 2020). Gorman & Dzombak (2018) focus on the need to view sustainability throughout the usage cycle of a mining operation and apply existing environmental rules for sustainability.

The taxonomy environmental objective no. 4 "*Moving towards a circular economy, preventing waste and recycling*" is relevant here. Lahiry (2017) calls for strong supervision through government authorities to enforce sustainability and reliable environmental standards.

There is no real discussion of the term "sustainable mining" in the JRC Report. It does not examine whether the discussion about sustainable mining has any repercussions for investigating the environmental effects of uranium mining. However, it is important in terms of other sustainability goals or the minimum safeguards laid down in Article 18 of the Taxonomy Regulation.

All those involved in mining and processing uranium ore should be mentioned in conjunction with sustainability. **The impact on indigenous peoples, on whose land most of the uranium mines are located, is not mentioned in the report, for example**. The rights of these people for a just share in all the resources (ranging from clean water to reasonable healthcare and even the ownership of the raw material, uranium) are not taken into account, but should be considered to an extensive degree from a sustainability point of view as regards taxonomy.

A.2.4 Critic by the SCHEER

The SCHEER performed a review of the state-of-the-art to assess nuclear energy generation under the "do no significant harm" (DNSH) criterion (Part A). The SCHEER explains that the JRC report concludes that NPP operation activities do not represent unavertable harm to human health or to the environment, provided that the associated industrial activities satisfy appropriate Technical Screening Criteria ((Regulation (EU) 2020/8521. "**The SCHEER ….. is of the view that dependence on an operational regulatory framework is not in itself sufficient to mitigate these impacts, e.g. in mining and milling where the burden of the impacts are felt outside Europe**."

A.3 Fuel cycle facilities

A.3.1 General Deficits and Gaps concerning fuel production

The process stages for uranium enrichment, the fabrication of uranium dioxide (UO_2) fuel – manufacturing fuel rods and fuel assemblies, the reprocessing of spent nuclear fuel and the fabrication of mixed oxide (MOX) fuel elements are examined in the JRC Report Part A 3.3.3–3.3.6 with regard to their influence on the DNSH criteria in the Taxonomy Regulation.

- In general, the four chapters merely take into account the technical process stages, **but safety aspects are not adequately considered in their scope or suitable depth**.
- The JRC Report describes the necessary technical processes for manufacturing and reprocessing fuel elements and examines the effects on the DNSH criteria. **No consideration is given to transportation between the facilities**. This would have been necessary for a conclusive overall presentation of all the aspects of nuclear power. The discharge of radioactive substances cannot be fully excluded by incidents during transportation, even if the current requirements in hazardous goods law are followed. Beyond design basis accidents or beyond-design threat interventions by third parties during transport cannot be completely ruled our; therefore, the corresponding risks cannot be excluded, even if international rules are followed.
- **The JRC Report fails to consider producing fuel elements and processing natural uranium appropriate**. Reference is constantly made to contamination with short-lived radionuclides in the context of producing fuel elements and processing natural uranium (JRC Report, Part A 3.3.2.2.2, p. 85f and 3.3.5 p. 105ff). No mention is made of the importance of the radionuclides formed in the uranium actinium or uranium radium decay chain with long half-lives (Pa-231: half-life of ~ 32,000 years; Th 230: half-life of ~ 75,000 years and Ra-226: half-life of ~ 1,600 years).
- The JRC Report argues that large amounts of liquid radioactive waste outside the EU come from military programmes (Russia, USA) and are not further considered within the report. This fails to mention the fact that Slovakia, for example, transported spent fuel elements from power reactors to the USSR or Russian Federation for reprocessing in the past (SLOV, 2017). These exports produce radioactive waste water outside the EU. **The JRC Report fails to include radioactive waste water in its "waste balance area" outside the EU that resulted from exports of waste from the EU**.
- The **JRC Report does not examine the necessary decommissioning measures for these facilities** either.

A.3.2 Inappropriate Description and Assessment of the so-called fuel cycle

A.3.2.1 Inappropriate Evaluation of Reprocessing of spent nuclear fuel

The reprocessing of spent nuclear fuel (JRC Report, Part A 3.3.5, p. 105ff) is presented in the JRC Report as an opportunity for achieving a so-called closed fuel cycle.

Using the "partially closed fuel cycle", uranium oxide fuel elements from light water reactors are reprocessed once. This involves using the plutonium and some of the uranium to produce mixed oxide (MOX) fuel elements. This is fed into light water reactors again. After having been used once in a light water reactor, no further reprocessing of the MOX fuel elements is envisaged because of technical problems.

The JRC Report states: “*It has to be noted that about 30% of the total amount of SF [spent fuel] produced globally in the NPP has been reprocessed, saving large amount of direct uranium mining capacity*.” (JRC Report, p.63)

The statement that reprocessing SF has avoided a large amount of direct uranium mining capacity is not the case in the EU. ESA (2019) gave the following numbers for the reprocessed fuel (MOX): “*MOX fuel loaded into NPPs in the EU contained 5,241 kg Pu in 2019 (a 35% decrease compared with 2018), resulting in estimated savings of 470 tU and 331 tSW*,” which is certainly not a large amount.

The JRC Report present reprocessing as a part of the “closed” nuclear life cycle:” Today, *reprocessing is a mature technology that has been practised at industrial scale in the civil nuclear industry for four decades*.” (JRC Report, p.108) However, this technology has hardly been applied. The US abandoned this technology in 1977, and in Europe only a single reprocessing plant (La Hague, France) will be operating after 2021, as the UK will have closed its plants by then.

The JRC Report describes the impact of reprocessing on non-proliferation in Chapter 3.3.5.1.5 but without noting that reprocessing is still one of the riskiest technologies in terms of weapons proliferation. The NPEC report tries to alert the world to China´s intention to increase its reprocessing capacities. Like all other reprocessing and enrichment programmes elsewhere, it is not really possible to safeguard these activities in a fashion that can reliably assure timely warning of possible abrupt or incremental military diversions. (NPEC 2021)

The JRC Report ignores the **environmental impact** of reprocessing. As part of the reprocessing process, plutonium is separated from the uranium in the spent fuel: “*Plutonium separation generates the largest radioactive emissions in the overall nuclear fuel chain and has significant contribution to the collective global dose (of radiation). The processing plants in France and the UK have been disposing radioactive emissions into the ocean. One of the radioactive materials, iodine 129, has been found on the northern Norwegian coast and the Baltic Sea, according to the Riso National Laboratory in Denmark. Some 4 tonnes of iodine 129 had been discharged by the reprocessing plants by 2004, and the concentration of iodine 129 in the Baltic Sea in 2000 was 1,000 times higher than before nuclear energy existed.*” [6]

A.3.2.2 Inappropriate Evaluation of P&T and the so-called “closed fuel cycle”

In the case of a “fully closed cycle”, fuel elements, which come from the reprocessing, could also be reprocessed. A “fully closed cycle” requires the use of fast reactors. The JRC Report itself does not elaborate on how a “fully closed cycle” can be implemented. However, it has to be noted that the fuel cycle is not fully closed, as waste accrues here too and has to be removed from the cycle and taken to a repository. New fuel also has to be added to the cycle.

The JRC Report explains that recycled fuel is used in advanced reactors operating with a fast neutron spectrum and only with a footnote pointing out that in Europe, prototype and commercial scale demonstration fast neutron reactors have been developed, built and operated,

[6] http://large.stanford.edu/publications/coal/references/arita/ accessed April 28, 2021.

but fast reactors are not yet commercially available. They remain under development for future deployment.

The JRC Report described a process which has been researched for several decades already: A process complementary to the fully closed cycle is “partitioning and transmutation (P&T)” in which not only plutonium and uranium, but also the other long-lived radiotoxic residues (the minor actinides and some of the fission products) are separated and extracted. Their transformation into short-lived products would generate waste that decays over much shorter timeframes. This would be done by adapted fast neutron reactors or in dedicated waste burning reactors. Development of P&T is currently only at an experimental scale.

The “experimental scale” has been the status of for 50 years, the underlying technologies still do not exist. Whether and when they could be available for use on a large scale is unknown.

Results are available from a very recent investigation project that looked at various concepts for P&T of high-level radioactive waste. The results of this study show a number of critical aspects in relation to P&T, some of which are listed below as examples (Friess et al, 2021):

- A P&T concept requires a large number of nuclear facilities and long-term operations there. The safety risks caused by operating nuclear facilities in the long term would have to be accommodated in a P&T programme.
- The nuclear facilities required for P&T are not available on such a large technical scale.
- Many decades of research and development work would be necessary before introducing any P&T programme.
- It is still unclear whether it will be possible to achieve the necessary technical development stage for implementing a P&T programme on a large scale.
- A repository for high-level radioactive waste will still be needed.
- Operating nuclear facilities within a P&T programme in the long term would give rise to proliferation risks.

The list illustrates that research into P&T is also associated with the possibility that the original intention or goal of this approach might fail. Even if this technology could be used in future, it gives rise to other risks, which would need to be considered in the light of the risks of disposal without allowing for P&T.

In relation to fully using the fuel, the JRC Report, Part B 6.3, p. 280 and the ‘Executive summary’, ‘Main Findings’, p. 12–13, state that “fast reactors” allow multiple recycling and the complete fuel is exploited at the end; as a result, the share of long-lived nuclides (mostly in the form of minor actinides) remaining in the spent fuel would continually decrease in number. It should be noted here that it has not yet been possible to feed any minor actinides into the fuel. In this sense, this is simply a prediction. It is unclear to what degree minor actinides can be fed into the fuel, as they can have a negative effect on the safety properties of the fuel (Kirchner et al., 2015).

Moreover, the JRC Report states that a closed fuel cycle provides the advantage of significantly reducing the space required for a deep geological repository for HLW. It is necessary to add here that not only the volume, but also the decay heat at the time of disposing of the waste is relevant for the size of the disposal facility (KOM, 2016, p. 227). Additional low- and intermediate-level waste would also be produced and this would increase the disposal volume.

Reprocessing ("partly closed fuel cycle") has been almost completely abandoned as a technology in Europe - especially because of the significant environmental impacts. P&T (closed fuel cycle) is not yet operational, and it is even unclear whether this technology will ever be operational on a commercial scale. Moreover, even this technology would not be fully closed, as radioactive waste is produced. Moreover, reprocessing and P&T are risky technologies in terms of nuclear proliferation and development.

A.3.3 Underestimation of the Risk of Operation of Nuclear Power Plants

The JRC Report states: *"Operating NPP are subject to continuous improvement. (···) The result of this continuous improvement is that the calculated frequency of severe accidents in the plant specific PSA reduces over time. Further reductions may be expected in future, although they may become more marginal as the most important safety improvements have probably been made already, including those following the EU nuclear stress tests*." (JRC Report p. 176)

Continuous improvements do not necessarily lead to greater safety or a reduction in severe accident frequency, since plant ageing and ongoing material degradation continuously decreases safety. The EU nuclear stress tests delivered recommendations for safety improvements. However, they largely failed to be implemented and were often declared unnecessary by the national nuclear regulators and operators. A recent study revealed that the EU nuclear safety stress test recommendations have not been implemented[7]. The study is based on the official reports made by the individual national regulators. None of the eleven NPP in the EU which were evaluated in 2021 have implemented all the measures which the EU expert peer review teams, representatives from nuclear safety authorities, recommended after the stress tests. In many cases, even the key measure will never be implemented.

Many national nuclear regulators delayed implementing the recommendations made by the EU stress tests: e. g., in France the so called "hardened core" was decided for all NPPs in France to remedy the deficiencies the stress teste revealed at least to some extent. As of today, not a single hardened core has been implemented. It will take at least until 2030 or 2040 until the hardened cores have been implemented at all reactors.

A.3.3.2 No Experience with Lifetime Extension of NPP

The JRC Report states: "*The design of most reactors currently operating assumed a service life of 30-40 years, but experience shows that service life extensions up to 60 or 80 years can be achieved subject to certain conditions (···)*" on p. 124 of the Chapter 3.3.7.1.2 NPP operation.

The JRC Report fails in using the term "experience" in a world in which the oldest reactor is around 51 years old (Beznau 1 in Switzerland). The age structure of the completes the picture. Only 24 reactors of the 181 reactors already closed operated for 41 years or more. Considering that the mean age of the closed units is 25.8 years, there are not experience for a lifetime of 60 to 80 years.

A.3.3.2 Increasing Risks of Operation with Lifetime Extension of NPP

[7] https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/20210303-greenpeace-akweuropa-fukushima.pdf

Even more important, the risk associated with the operation of nuclear power will increase with the age of the nuclear power plants. This is the result of a comprehensive study published by the INRAG. (see chapter D.8) This fact is not mentioned by the JCR.

A.3.4 Insufficient Description of Dismantling nuclear power plants

So far, some power plants have been fully dismantled and released from nuclear regulatory control worldwide (the report talks about “green fields”, JRC Report, Part A 3.3.7.1.4, p. 129). It should be generally noted that comparatively little space is dedicated to the topic of decommissioning and dismantling in the JRC Report.

The life cycle of nuclear power plants can be divided into several phases: the design and construction phase, operations, decommissioning and dismantling. This is generally handled in the same way in the JRC Report, but inconsistencies do occur if decommissioning is attributed to the operating phase. The assignment of decommissioning to the overall power generation phase is factually incorrect, as a nuclear power plant consumes energy during the decommissioning phase. The incorrect classification leads to uncertainties when interpreting the following results.

- One major element when dismantling a nuclear power plant is the waste balance sheet, particularly with a view to the amount of radioactive waste. The JRC Report in Part B 2.1, p. 210 takes over a table (Table 2.1–1) from the IAEA document entitled TECDOC 1817 (IAEA, 2017), which illustrates typical annual waste generation rates. The figure quoted for decommissioning power plants has a footnote in the JRC Report, which does not exist in the IAEA source. The footnote in the JRC Report states that the unit is [m^3 per plant (1 GW)], while in the IAEA source it is specified as [m^3/GW x year], i. e. an annual waste generation rate. While the JRC Report mentions a waste volume arising from the decommissioning of a nuclear power plant of “375 m^3 per plant (1 GW)” in Part B 2.1, the associated IAEA source refers to an annual waste generation rate. **The volume of waste arising from decommissioning a power plant would therefore be significantly higher than specified in the JRC Report in Part B 2.1, depending on the time required to dismantle it.**
- A further inaccuracy arises from the later statement about disposing of radioactive waste with low levels of radioactivity. In contrast to the practice mentioned in the report in other countries, Germany, for example does not operate a near surface repository. Low-level and intermediate-level radioactive waste, which are not subject to clearance, will be permanently taken to a deep geological repository in Germany too.

Due to the importance of the dismantling process in the life cycle of nuclear power plants and because of the increasing need for information about the challenges and risks associated with this greater importance should be given to the phase of decommissioning and dismantling when examining the DNSH criteria.

A.3.5 Critic by the SCHEER

The SCHEER criticized that the JRC Report assumed that the compliance with the regulations ensure that there is no unavertable harm to human health or to the environment.

“The JRC reports states that, provided that nuclear power plants are built, operated and decommissioned within the limits set by existing regulations, and that the associated industrial activities satisfy appropriate Technical Screening Criteria, they do not pose a significant harm to any of the TEG objectives and that it can be concluded that NPP operation activities do not represent unavertable harm to human health or to the environment." "**The SCHEER …. is of the view that, while the regulatory regimes exists and in principle should be sufficient, there is a valid concern regarding the implementation of the regulations, and appropriate monitoring of the effectiveness of such regimes**."

Furthermore, the SCHEER criticized that the comparison for the impact of the different energy generating technologies is not appropriate: "**It is the opinion of the SCHEER that, in many cases, the comparison is quite superficial, without the necessary detail, e.g. the origin of impacts determined by the various phases of the life cycle for different energy generating technologies**."

A.4 Radiation Health Effects Due to Normal Operation

A.4.1 Lack of considering possible Radiation Health Effects for the public

The average annual exposure to a member of the public due to effects attributable to nuclear energy-based electricity production is about 0.2 microsievert, which is 10 thousand times less than the average annual dose due to natural background radiation. (JRC Report, Chapter. 4.3) The argument that radiation received from the natural background is on average so much higher than from nuclear energy production is missleading.

Firstly, radiation from the natural background is not harmless. Secondly the higher the radiation dose resulting from the natural background, plus artificial sources such as nuclear energy production, the higher the total health risk.

Furthermore, the JRC Report does not match the latest findings in radiation protection when specifying average effective doses per head of the population for nuclear facilities and installations. According to the latest recommendations of the International Commission on Radiological Protection (ICRP), the so-called "representative person" in the sense of the ICRP has to be considered an individual in the population, who is exposed to higher levels of radiation because of his or her lifestyle habits. (BFS 2022)

A.4.1.1 Studies prove the impact of natural background radiation

A Swiss study investigated childhood leukaemia and lymphoma caused by natural background radiation from terrestrial gamma and cosmic rays. (Spycher et al. 2015) This nationwide censusbased cohort study was conducted for children < 16 years in 1990 and 2000, with follow-up until 2008. The study found evidence of an increased risk of cancer among children exposed to external dose rates of background ionising radiation of ≥200 nSv/h (1.75 mSv/a) compared to those exposed to <100 nSv/h (0.88 mSv/a).

Kendall et al. (2013) conducted a large record-based case-control study testing associations between childhood cancer and natural background radiation. Cases (27.447) born and diagnosed in Great Britain between 1980 and 2006 and matched cancer-free controls (36.793) were taken from the National Registry of Childhood Tumours. There was 12% excess relative risk (ERR) of childhood leukaemia per mSv of cumulative RBM dose from gamma radiation. **The authors concluded: The results of the study contradict the idea that there are no adverse radiation effects, or even possible beneficial effects, at these very low doses and dose rates.**

A.4.1.2 Studies prove the impact of low radiation doses

Radioactive pollution increases the risk of cancer and other health effects. The effects of high radiation doses on humans (such as acute radiation sickness) are quite well documented. But the effects of low doses are still disputed among experts and nuclear lobby groups.

However, there is evidence that even low radiation doses from nuclear energy production activities can result in severe health impacts: Of particular concern is the impact on childhood leukaemia and other forms of childhood cancers showing higher incidence rates in populations living in the vicinity of NPP, with a clear correlation between cancer risk and the distance to the plant even during normal operation. A global pattern of epidemiological evidence now clearly indicates increased leukaemia risks near NPP. Laurier and Bard (1999) and Laurier et al. (2008) examined the literature on childhood leukaemia near NPPs worldwide. Result: Over 60 epidemiological studies around the world have examined cancer incidences in children living near NPPs. An independent review of these studies showed that most of them (>70%) indicate leukaemia increases (Fairlie 2013; Fairlie 2014).

The German KIKK[8] study (Kaatsch et al. 2007) commissioned by the German Government found relative risks (RR) of 1.6 in total cancers and 2.2 in leukaemia among children under the age of 5 years living within 5 km of all German NPPs. In this study, the surroundings of all German NPP were examined between 1980 and 2003; equivalent cases outside this area were studied as controls (Spix et al. 2008). As a result of these findings, governments in France (Sermage-Faure et al. 2012), Switzerland (Spycher et al. 2011) and the UK (COMARE 2011) hurriedly set up studies near their own NPPs. All of them found leukaemia increases but because their numbers were small the increases are not of statistical significance.

Körblein and Fairlie (2012) combined datasets in a meta-study to generate larger numbers, achieving higher levels of statistical significance. They pooled the data of acute leukaemia in children under 5 years within 5 km of NPPs from four studies. Their results reveal a highly statistically significant 37% increase in childhood leukaemia within 5 km of almost all NPPs in the UK, Germany, France and Switzerland. Thus, there is a noticeably clear association between increased childhood leukaemia and proximity to NPPs. A suggested hypothesis is that the increased cancer incidence results from radiation exposures of pregnant women near NPPs. One explanation may be that doses from spikes in NPP radionuclide emissions are significantly larger than those estimated by official models which are diluted through the use of annual averages. In addition, risks to embryos/fetuses are greater than those to adults, and haematopoietic tissues appear more radiosensitive in embryos/fetuses than in newborn babies. The product of possible increased doses and possible increased risk per dose may provide an explanation. (Fairlie 2014)

A.4.3 Lack of Considering possible Health Effects for Nuclear Workers

The JRC Reports stated: As far as staff members working at nuclear facilities are concerned, they are protected from the harmful effects of ionising radiation by strict radioprotection measures monitoring and limiting occupational doses. The ALARA (as low as reasonably achievable) principle is also applied here to optimise plant maintenance works and minimise worker' s radiation doses. (JRC Report, Chapter 4.3)

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[8] 7 KIKK=Kinderkrebs in der Umgebung von Kernkraftwerken (English: Childhood Cancer in the Vicinity of Nuclear Power Plants).

However, this statement does not correspond to the findings of the major research studies of the last decade. The argument that radiation protection measures prevent health effects of ionising radiation on nuclear workers is misleading. Studies on the effects of radiation on nuclear workers' health prove that nuclear workers have a higher incidence risk than others. Additionally, there is the genetic and teratogenic risk to their children and grandchildren.

Cancer mortality from higher doses of ionising radiation has been fairly well researched, especially in the Lifespan Study (LSS) cohort of the Japanese atomic bomb survivors. But what was missing until recently were studies of the effects of low or very low doses of ionising radiation. To fill this gap, a major international study of nuclear workers has been conducted: the INWORKS study investigated cancer mortality among a cohort of 308.297 nuclear workers from three different countries (France, USA and UK) (Richardson et al. 2015). The workers were mostly men who received an average cumulative colon dose of 20.9 mGy. Results show a linear increase in the rate of cancer with increasing radiation exposure. The estimated association of dose and risk over the dose range of 0-100 mGy was similar in magnitude to that obtained over the entire dose range, but less statistically precise. The study provides a direct estimate of the association between protracted low dose exposure to ionising radiation and solid cancer mortality.

A German investigation of occupationally-exposed females showed a significant 3.2-fold increase in congenital abnormalities, including malformations, in offspring. (Wiesel et al. 2011) Malformations, cancers, and numerous other health effects in the children of populations who were exposed to low doses of ionising radiation have been unequivocally demonstrated in scientific investigations (Schmitz-Feuerhake et al. 2016).

The comparison of radiation due to normal operation of NPPs with natural background radiation is misleading: First there are studies that prove that children's rates of cancer and Leukemia raise with higher backgrounds radiation. The assumption that natural background radiation does not harm is outdated. Second, if people receive not only background doses but also doses from nuclear energy production, their risk will increase.

Nuclear energy does significantly harm human health, even in the low dose range resulting from normal NPP operation and nuclear workplaces. Even low ionising radiation has been proven harmful for human health, resulting in a higher risk for various cancers and other health effects, including genetic and teratogenic effects. There is no safe level of radiation exposure. A pattern of epidemiological evidence clearly indicates a significantly increased leukaemia risk for children living within 5 km to NPPs in many European countries. Nuclear workers have a significantly higher risk of getting cancer than workers in other industries. There is evidence for genetically induced malformations, cancers, and numerous other health effects in the children of fathers and/or mothers who were exposed to low doses of ionising radiation.

A.4.4 Opposing Opinion of the Article 31 Group of Experts

According to the question "Whether the legal framework established under the Euratom Treaty provides an adequate system of protection of workers, members of the public and of the environment and whether there are any residual risks?", it was stated in the opposing opinion the aim of the legal framework and its implementation is to manage the risks in a manner that ensures the residual risk is as low as possible. The decision whether the remaining risk is acceptable or not is a sovereign decision of each individual EU Member State. **The acceptance**

of the residual risk does not mean that the corresponding technology can be classified as sustainable.

A.4.5 Comments by the SCHEER

The SCHEER identified several issues which are missing in the assessment of the potential radiological impacts of ionizing radiation on the environment and human health.

- The SCHEER considers it relevant to complement the Life-Cycle-Analysis based on the dominant NPP phases with a more **deterministic effect analysis per unit of electricity generated, targeting workers on-site and general public living in the vicinity of the reactor(s) unit(s) by quantifying dose-response and cancer/non-cancer effects** (number of cases, cancer incidence and other indicators i.e. per geographic region).
- In addition, it would be important to disaggregate the normal operations, in order to **identify the major contributors to possible human health effects, observed at low doses of radioactive emissions** (radon, uranium isotopes, etc.) **and non-radioactive emissions** (nitric acid; hydrofluoride; fluorine gas, etc.).
- The SCHEER also stresses the importance of **conducting risk analysis of NPP operation and reprocessing of spent nuclear fuels** in terms of human health and environmental impacts, **by evaluating multi-unit as well as single-unit site risks**.
- In the last part of the section, the concept expressed is that, since mammals are the most sensitive organisms to radiation exposure, "the standards of environmental control needed to protect the general public are likely to be sufficient to ensure that other species are not put at risk". It is opinion of the SCHEER that this statement is simplistic and does not allow **estimation of the potential risk for the environment, without an assessment of the potential exposures and sensitivities of the different components of the ecosystems**.

A 5 Interim storage of radioactive waste

The detailed descriptions in Part B 4.1, p. 181f and 4.2, p. 182ff of the JRC Report provide a good summary of the various types of storage for low-, intermediate- and high-level radioactive waste and the specific requirements for this, without, however, going into any detail.

Only the storage of high-level radioactive waste is dealt with in Part A 3.3.8.3, p. 156ff of the JRC Report. The presentation in the JRC Report related to storing high-level radioactive waste is restricted to a brief description of the most common types of storage. The JRC Report briefly mentions dry and wet storage as storage options for high-level radioactive waste. Whereas Germany is exclusively using dry storage for the purpose of storage of waste until it is taken to a repository, a large proportion of the spent fuel worldwide is stored in wet storage facilities (IAEA, 1999). However, the report fails to provide any detailed discussion of the specific safety features of these technologies. Wet storage facilities, for example, require active cooling systems.

The discussion in the JRC Report gives rise to the impression that only normal operations are relevant for assessing storage. Only after considering the technical screening criteria developed by the JRC and presented in the JRC Report in Part A, Annex 4, No. 4, p. 366ff, it (implicitly) becomes clear that the design basis accidents as defined in the relevant regulations and beyond design accidents must also be included in the assessment of any storage of radioactive waste.

As a result, the assessment of interim storage consistently takes place according to the standard adopted by the JRC, which, however, is inadequate from an expert point of view. For beyond design basis events it is impossible to exclude that uncontrolled discharges of radioactive substances and therefore considerable effects on the environment may occur through incidents and accidents or by some other intrusion involving third parties (e.g. terrorist attacks) when operating storage facilities; a risk therefore remains.

More extensive presentations – particularly about the events needing to be considered and the effects resulting from them – would have been desirable at this point. **The implicit conclusion of the JRC – i. e. that the interim storage of radioactive waste in comparison with other activities when using nuclear technology is not the crucial activity in terms of the DNSH criteria – is therefore not clearly deduced** (JRC Report, Part A 4.2).

A.5.1 Insufficient Considering of Long-term or extended interim storage of Spent Fuel

The JRC Report deals with long-term or extended interim storage without, however, discussing whether the DNSH criteria have been met in line with the standards applied in the JRC Report. "*As the storage of spent fuel is expected to last much longer than initially foreseen, the effects of the extended storage conditions on the conditions and behaviour of the spent fuel assemblies after such long storage periods are currently the subject of systematic research programmes*." (JRC Report, p. 239)

As a consequence of the unexpected long time periods in the seeking a final disposal, the interim storage facilities keep filling up, leading to new and unexpected problems requiring new research. The interim storage facilities in operation have not been designed for the long-term use that is becoming necessary as no final disposal site will be available for several decades. The interim storage buildings for spent fuel, in Germany for example, need to be upgraded, e.g. with thicker walls to withstand terror attacks and airplane crashes.

For interim storage over long time periods, assesments about the future effectiveness of protective measures can only be made to a limited degree. It is true that a framework is defined through international agreements and requirements, but it must be assumed that permanent protection can only be guaranteed by continually reviewing the threat assessment in line with events and – where appropriate – adapting or optimising existing physical protection measures. It is impossible to absolutely rule out a large-scale discharge of radioactive substances, which would be associated with the far-reaching consequences.

The JRC Report (p. 242) describes: "Extending the safety assessment to cover very long storage timespans requires the characterisation and full understanding of potential long-term ageing mechanisms (e.g. the effect of thermal cycles/history on spent fuel rods during the different steps of spent fuel management, effects of auto-irradiation) and their potential effect on the relevant properties of the spent fuel assemblies and of the container system (e.g. mechanical integrity, resistance against corrosion, tightness)."

The long-term safety of interim storage facilities has not yet been proven; safety analyses typically only guarantee safety for a period of 40 years. The JRC Report acknowledges this fact, but does not draw any conclusions from it.

Even if there is currently no information available that extended storage is not possible from a safety point of view consideration of this issue has a crucial influence on the disposal pathway, as storage must safely provide an interim solution until the disposal of the material.

A.6 Disposing of low- and intermediate-level radioactive waste

With regard to the final disposal of low- and intermediate-level radioactive waste, incomprehensible or incomplete technical statements by the JRC Report were noticed. The same applies to the technical screening criteria developed by the JRC.

A.6.1 Deficits in the JRC Report

Focus on disposal of low-level radioactive waste at near surface repositories: There are statements at various points in the JRC Report (e.g. Part B 5, p. 242) that low-level waste (LLW) is disposed in near surface repositories. This statement gives the impression that the disposal of LLW in facilities in near surface repositories is the common approach of disposal. There are certainly a number of countries that have exclusively envisaged deep geological disposal for LLW and all other kinds of radioactive waste (e.g. Switzerland, Finland, Sweden and Germany) (KOM, 2015).

The German "Storage of High-Level Radioactive Waste" committee has concluded with regard to the disposal of LLW that long-term storage near surface disposal is not an acceptable option for handling radioactive waste in a verifiably safe manner in the long term because of the unreliable prediction regarding social and political developments, the danger of accidents (e.g. caused by a lack of maintenance), and attacks caused by war or terrorism, the risk of proliferation, the huge organisational effort and financial expenditure for future generations and climate uncertainties (KOM, 2016).

The statement (JRC Report, Part B 5.1, p. 244) that there is no need to emplace LLW in deep geological disposal facilities is incomprehensible. Near surface repositories are believed to be more susceptible to human intrusion than deep geological repositories (IAEA, 2012). Aspects like robustness, accessibility, protection, loss of knowledge etc. must also be taken into account when judging their safety.

Period of time and material behaviour: With regard to the isolation period, the JRC Report states (Part B 5.1, p. 244) that the typical period for isolating LLW in near surface repositories is 300 years. It also asserts that the material behaviour of the technical barriers is well-known during this period and it is therefore possible to predict that the barriers will be sufficiently reliable. This statement about the isolation period of 300 years is not explained in any greater detail and/or supported by references. Overall, it is necessary to view the details about the aspects mentioned here as a generalisation. After all, the isolation period depends on the disposal concept in question, technical facilities and the components used.

The need to act in case of complications/Asse: The JRC Report mentions the Asse II mine, which is located in the Federal Republic of Germany, in relation to the statements about the content of periodical safety checks, their reliability and their contribution towards the safety of facilities near the surface (JRC Report, Part B 5.1, p. 249). The JRC Report mentions the salt mine, which was used to dispose of low- and intermediate-level radioactive waste between 1967 and 1978, as an example of the fact that a renewed safety review on the basis of the Atomic Energy Act, which has applied since 2009, has led to the decision to remove the stored waste, recondition it and dispose of it at another facility.[9]

[9] The mine was operated on the basis of German mining law and was originally set to be decommissioned according to this. A long-term safety analysis or a safety case under German atomic energy law was not performed for Asse II.

The Asse II mine can rightly be viewed as an example of a failure of safety mechanisms and processes – it is, however, a deep geological disposal facility. In this connection, it seems important to point out that there is no close temporal link between recognising the safety problems and the decision to remove the waste. It is actually possible to see that the shortcomings of the old extraction mine had already been recognised in the 1960s and had become clear to a broader circle of state and non-state players by the end of the 1970s/beginning of the 1980s (Möller, 2016).

In the end, the example of Asse II underlines the importance of regular critical safety checks for nuclear disposal facilities and the need to place greater importance on safety than economic considerations. The example also illustrates the enormous financial and social follow-up costs of incorrect decisions that have been taken in the field of nuclear disposal. **This shows furthermore that these kinds of incorrect developments or decisions must be viewed as a risk factor when using nuclear energy.**

A.6.2 Deficits and Gaps in the Technical Screening Criteria

Differences between deep geological and near surface repositories: It must also be assumed that the design and concept for the robustness of deep-geological repositories will have a different quality level to near surface repositories, which are normal for LLW, according to the JRC Report (Part B 5.1, p. 244). Facilities for LLW, for example, which are created near the surface, must be viewed as more prone to extreme external events and processes (LLW, 2011), e.g. natural phenomena, accidents and effects caused by humans, including intentional human intrusion (HI) (IAEA, 2012).

Another difference relates to the generally lower distance from layers carrying groundwater for near surface repositories as opposed to deep geological repositories. If there is a leak, it can have more unfavourable effects on the environment in near surface repositories than in a deep geological repository.

Further differences exist in relation to human intrusion (HI), which cannot be ruled out for near surface repositories or those at a deep level. The technical possibilities for HI at near surface repositories compared to those at a deep level must be viewed as technically simpler, given the fact that the envisaged institutional controls cannot be guaranteed during the complete envisaged isolation period. **In principle, the possibilities for intrusion at great depths, where deep geological repositories are located, represent just some of the possibilities that could impair compliance with the DNSH criteria for a near surface repository**.

A separate consideration of the specific TSC for the near surface disposal and the geological disposal of radioactive waste therefore appears to be technically necessary. However, this was not considered by the JRC Report.

Compatibility of the TSCs for HLW with those for LLW: The TSCs for storing and disposing of HLW and spent fuel elements are outlined in Annex 4 of the JRC Report. The JRC Report does not list any special TSCs for LLW and ILW and states that the TSCs developed for HLW and spent fuel elements are believed to be satisfactory (cf. JRC Report, Part A 5.7, p. 196f). The reasoning leading to this conclusion is not mentioned in the JRC Report and the statement is generally incorrect. If the TSCs for HLW are also used for LLW, there are doubts whether the aforementioned condition for complying with the TSCs, e.g. when considering extreme natural phenomena, is comprehensively met.

The firm conclusion drawn in the JRC Report for disposing of low- and intermediate-level waste at near surface repositories – i. e. that no significant damage can occur to people's health or the environment as a result – is therefore impossible to comprehend.

A.7 Disposing of high radioactive waste and Spent Fuel

The JRC Report contains unfounded generalisation at many points. Conclusions are drawn from individual, selected examples and their global validity is assumed. Readers without any detailed specialist expertise will find it hard or impossible to recognise this.

The conclusions in Part A 3.3.8.9, p. 165 of the JRC Report, e.g. "*The disposal […] does not contribute (the results are zero or negligible) to those indicators representative of the impacts to the Taxonomy Regulation objectives*", are only inadequately supported by the analyses and discussions that are presented. Based on the information in Part A 3 of the JRC Report, this statement is premature and insufficiently justified.

A.7.1 Inappropriate Evaluation of the Operational Experience and the State of the Art

The JRC was asked to include information on treatment and disposal (in particular geological disposal facilities in European countries, i.e. Finland, France or Sweden). Specifically, this should provide an assessment of the operational experience and future outlook in safe disposal of all radioactive waste and spent fuel.

The JRC Report wrongly presents the disposal of high-level radioactive waste as a completely resolved problem by citing the example of the disposal projects in Finland and France. This largely ignores the fact that the Finnish repository is still under construction and in France the licence application from the operational company has already been delayed on several occasions. Both countries are still years away from starting to operate the facilities.

The JRC Report does not evaluate the problems that arise. JRC Report offers a very short overview of the development of the Swedish final repository, giving the impression that this project is about to receive the final permits needed that is still not such clear.

The research on the method with copper as canister material started as early as 1975. The scientific hypothesis was that oxygen-free water does not corrode copper in a repository where there is no oxygen after closure. This assumption ruled out to be false. In 2011, SKB submitted a licence application for its spent fuel repository system. It was placed under review by the regulator, the Swedish Radiation Safety Authority (SSM). During the review, problems with the copper canisters were revealed. In December 2020 the issue of corrosion was still under investigation and could derail the entire project in Sweden and Finland. SKB refuses to make available test reports on copper corrosion – even to the regulator SSM.

Based on selected results from safety assessments of repositories in Finland, Sweden and France, the JRC Report (Part B 5.2, p. 249ff) draws a assessment of radiological safety at a deep geological repository. These countries have the technical and financial resources to complete the disposal of high-level radioactive waste in geological repositories. The capabilities and the needs of smaller countries, which possibly depend on outside help to resolve their repository issue, are not mentioned.

The JRC Report also restricts itself to only two potential host rocks (crystalline in Finland and Sweden and clay in France). Other possible host rocks like salt are missing.

The JRC Report does not adequately consider the fact that no successful, deep geological disposal of high-level radioactive waste, including the permanent seal, has yet been introduced anywhere in the world. It should also be noted that only one repository for HLW is currently being built around the world.

The JRC Report sketches a simplified and very optimistic picture of the process of introducing a national Deep Geological Repository **(DGR)** in Part B 5.2.3. The examples of programmes that have failed or been halted in the past (e.g. in Great Britain, Germany, Switzerland and the USA) are not mentioned. The JRC Report should also discuss that there are inherent risks that a disposal programme may completely fail because of social, technological, political or economic problems or can be greatly delayed.

The JRC Report is also incomplete in the sense that, it only considers the time after the repository has been sealed, i. e. **there is no discussion about assessing radiological safety during the operational phase**. The safety criteria discussed only represent a selection of general requirements. Other potentially relevant requirements are not discussed.

There is no successful operating experience for a repository for high-level radioactive waste anywhere. On the contrary, many countries have had experience with failed repository projects.

The **role of unexpected events** is restricted in the JRC Report and not fully discussed.

The JRC Report does not provide any analysis of consequences from potential accidents, particularly for the operating phase of geological disposal. However, when analysing the life cycle, one major aspect is whether an activity creates any threats that can be prevented or mitigated**. This omission is viewed as an important shortcoming, as unexpected events cannot by definition be completely prevented and if they occur, accidents or incidents can trigger considerable radioactive contamination.**

The JRC Report particularly states with regard to radioactive discharge that the release calculated during the containment phase is far below the permissible thresholds. This is a statement that is not backed up by adequate arguments in the report. The statement does not consider the influence of the major inherent uncertainties when assessing the long-term safety or the potential risks in conjunction with operational accidents.

The topic of **unintentional human intrusion** is not appropriately discussed in the JRC Report. The likelihood for this kind of event, which cannot be ruled out, and associated radiological consequences in the light of the long isolation periods that are required for the radioactive waste are neither treated nor appropriately considered when assessing the TSCs and the DNSH criteria. However, the topic is not adequately treated with regard to the DNSH criteria.

The discussion of **potentially damaging, non-radiological effects** of geological disposal of spent fuel elements and HLW (JRC Report, Part A 3.3.8.6, p. 162f) is conducted on the basis of a selection of results from the Swedish environmental impact assessment. It is implicitly assumed that this document contains an assessment that is generally representative for each kind of repository at each place (e.g. climate, geography, biosphere etc.). No reason for this assumption is provided.

The JRC provides a confusing comparison between carbon (dioxide) capture and storage (CCS) and disposing of radioactive waste in Part B 5, p. 336ff of the JRC Report. The comparison between CCS and disposing of radioactive material is only possible to a certain extent, as a different risk is caused by disposing of CO_2 at a great depth. In other respects, the technical concepts for both types of disposal are completely different and are associated with very specific requirements and risks. The safety provisions for both types of disposals are therefore different too.

The JRC Report contains oversimplified statements about the **reliability of the barrier system**, which can lead to fundamental misunderstandings, as complex expert knowledge is necessary to assess them. A multi-barrier concept forms the basis for disposal in most of the safety concepts. This concept consists of a number of technical, geotechnical and geological barriers. The functionality of the individual barriers has to be demonstrated and proven for the envisaged periods of time in each case. The evidence that the technical (e.g. containers) and geotechnical barriers (e.g. closure of the shaft) function and transferring this capacity to long periods of time represent an enormous challenge.

Imprecise statements are made about the **possible discharge of radionuclides** from the repository into the biosphere. Lower doses than 0.3 mS/y (cf. e.g. Section 99 Para. 1 of the Radiation Protection Ordinance) can still cause damage to people's health. The statement in the JRC Report "*and will never exceed the limit below which they can cause no harm*" is therefore contradictory. The impact of low doses of radiation is already discussed in chapter A.4. The arguments should be presented in a more careful manner. Damage to people's health cannot be absolutely excluded (ICRP, 2013; DoReMi, 2016).

Part B 5 of the JRC Report states, "[…] *the safety of disposal during the* ***post-closure*** *phase is demonstrated by a robust and reliable process which confirms that dose or risk to the public are kept under all circumstances below the required limits*." As there is still no repository with an operational license for HLW, the use of the word "is" here is incorrect.

A summary is provided in Part A 3.3.8.9, p. 167 of the JRC Report, "*In the light of the above analysis it can be concluded that activities related to the storage & disposal of technological & radioactive waste, as well as spent nuclear fuel do not pose significant harm to human health or to the environment*." It is unclear which analysis is meant in the context of the post-closure phase of repositories. It is therefore not possible to clearly follow the conclusion mentioned here. In addition, the comments on the possibility of unintentional human intrusion, which cannot be ruled out, and the associated possible effects on people and the environment and other uncertainties regarding the development of repositories in the post-closure phase make it impossible to reach this kind of firm conclusion.

A.7.2 Not completed Technical Screening Criteria

The process of developing the technical screening criteria (TSCs) has not been completed. Any use of the TSCs for a final assessment of taxonomy criteria is not possible, or at least problematic.

Exemplary arguments and evidence from safety cases in specific projects are used to assess the long-term consequences of disposal of HLW and this is consistent with the state-of-the-art of science and technology. However, the assumptions and requirements for the system associated with this are presumed to have been implicitly met, although uncertainties exist in their implementation and their long-term effect. Despite their central significance for the method, the TSCs are only presented in a very general way and require further specification (e.g. dose criteria for radiological assessment).

A.7.3 No Compliance with Current Nuclear Waste Legislation

The JRC Report listed the current legislation but failed to mention the deficiencies in implementing some of this legislation. This is especially important with to regard to the implementation of the first Nuclear Waste Directive (Directive 2011/70/Euratom) in the EU Member States. Directive 2011/70/Euratom tried to force EU Member States to address the issue of solving the nuclear waste problem seriously, after this had been neglected for decades – thus immediately proving that nuclear waste has never been effectively dealt with. The Member States were asked to present a national waste management programme that fulfils the conditions of the Nuclear Waste Directive. The first national programmes had to be submitted in 2015, followed by two national reports describing the progress of implementation in 2018 and 2021.

Almost no EU Member State has fulfilled this task within the timeframe set by the directive. Firstly, most Member States failed to communicate or notify their transposition of the Nuclear Waste Directive into national law in time. Secondly, most Member States did not notify their national waste management programmes to the EC in time. And thirdly, a set of infringement procedures was initiated in 2018, as all Member States apart from five had been unable to transpose all the aspects of the Nuclear Waste Directive in a correct manner.

The EC conducted two reviews of the submitted national waste management programmes. In its second report from late 2019, the EC presented a long list of necessary remedies to be delivered by the Member States.

Moreover, in most countries, an assessment of environmental impacts of the nuclear waste management programmes is missing. This should have been carried out as part of a Strategic Environmental Assessment (SEA) for the national programmes, but because most countries have not undertaken a SEA, no environmental impacts have been assessed and taken into account.

When financing, regulatory structures, inventory data and transparency regimes are not available, or in a poor status, decades of improvement must follow before a sufficiently or acceptably safe nuclear waste management programme can result.

A.7.4 Insufficient Evaluation of the topic “Research and Development”

A number of statements and facts about research and development are mentioned in the JRC Report, but they cannot be followed, or their derivation cannot be shared from an expert point of view. (BASE 2022)

Various text passages in the JRC Report make it clear (e.g. JRC Report, Part B 6.2, p. 278 and Part B 6.4.1, p. 283) that no consistent distinction is made between:

- research and development
- state-of-the-art of science and technology.

The scope of basic research shown in the JRC Report only mentions examples that relate to the inventory. The aspect of basic research that deals with host rocks is completely missing. As a result of the brief description, major topics are not mentioned or only mentioned in passing (e.g. uncertainties, human activities including human intrusion, and long-term documentation). Furthermore, Part B 6 of the JRC Report entitled “Research and Development” only deals with research programmes centred on Europe.

A.7.5 Uncertainties not taken in Account

The issue of uncertainties plays a major role in conjunction with the safety statements about repositories. However, the JRC Report does not adequately cover this topic, e.g. in Part B 6, p. 277ff. There are a number of uncertainties that cannot be further reduced or resolved. One example here is the effects of further ice ages, which may be viewed as certain in Germany within the next one million years, but an ‘exact’ prediction with its precise location of the possible formation of glaciers inland cannot be provided (GRS, 2018).

Alongside the uncertainties e.g. about future climate developments, the uncertainties associated with future human actions and society and social behaviour must be mentioned here too.

The view adopted by the JRC – i. e. that the safety of repositories is generally ensured without any restrictions for the underlying periods of isolating the waste from the environment (JRC Report, Part B 5.1, p. 244, p. 246 and p. 247 and Part B 5.2.2, p. 250 and Part B 5.2.4, p. 260) – also neglects to mention the fact that there are different disposal concepts, sites with different topographical and geological conditions, safety and assessment concepts and national regulatory safety requirements within and outside the countries that are planning to have one or more repositories for radioactive waste (Charlier, 2019).

The reference to regulatory requirements does not rule out some uncertainties either. Therefore, the approach of providing a general statement that the question of safe disposal for high-level radioactive waste has been resolved in terms of sustainability if the relevant, underlying national and international regulatory safety provisions are followed and that this will continue to be valid in future is not supported by the necessary scientific diligence.

A.7.6 Opposing Opinion of the Article 31 Group of Experts

Also, the opposing opinion of the Article 31 Group of Experts points to the existing uncertainties: “*According to current knowledge, deep geological repositories are considered appropriate and safe for depositing high-level radioactive waste for very long periods. However, the necessary large time spans leave room for uncertainties. Aside from the lack of practical experience, uncertainties exist among other things with regard to future changes in the climate, future societal developments (e.g. human intrusion), social behaviour as well as long-term information and knowledge retention. Furthermore, implementation requires a social consensus that must be maintained over a longer period of time.*”[10]

A.7.7 Comments by the SCHEER

The SCHEER provided a review of specific assessment on the current status and perspectives of long-term management and disposal of radioactive waste (Part B of the JRC Report). It is explained: “Given the SCHEER expertise (which does not include expertise on management and disposal of radioactive waste), the SCHEER has provided only general comments on Chapters 1, 5 and 6 of Part B.” However, the SCHEER points to four gaps/shortcomings of the JRC Report that is not taken in account by the EC:

- The SCHEER notes that risk assessment to environment and human health of long-term disposal of radioactive waste is based solely on modelling, and over very long timescales thus increasing the uncertainties around any modelled impacts.

[10] https://ec.europa.eu/info/sites/default/files/business_economy_euro/banking_and_finance/documents/210630-nuclear-energy-jrc-review-article-31-report_en.pdf

- The SCHEER is of the view that high-level waste storage remains an open research question, with considerable uncertainties.
- Within the JRC report the definition of accessible biosphere seems to exclude deep biosphere: deep sea environments and deep subsurface. The SCHEER is of the opinion given the timescales of storage that this definition needs to be reconsidered.
- The SCHEER is also of the view that Chapter 5 is too focused on humans, with other organisms not explicitly protected.

A.8 Ignoring the sustainability goals

The JRC Report deals with other aspects that are important for sustainable development in conjunction with disposing of high-level radioactive waste, in addition to the ecological criteria. The JRC Report particularly highlights consideration for future generations (JRC Report, Part B 5.2.3.3, p. 258) and the importance of participative decision-making (JRC Report, Part B 5.2.3.1, p. 254) when searching for a repository site. The JRC Report formulates both aspects as important requirements when searching for a repository site.

However, the JRC Report does not provide any detailed treatment of the two aspects of “considering future generations” and “participative decision-making”. It is important, however, to consider both aspects in order to assess the sustainability of the disposal of radioactive waste. Both aspects represent sustainability goals in the United Nations’ 2030 Agenda (UN, 2015).

The JRC was possibly not commissioned to perform a review of sustainability beyond the DNSH criteria in relation to environmental objectives. However, it should be pointed out that the TEG definitely sees the possibility of including the aspect of intergenerational risks in the development of TSC or the DNSH criteria as regards the environmental objectives (TEG 2020b, p. 33).

The Taxonomy Regulation, which forms the basis for the JRC’s analysis, views the United Nations’ 2030 Agenda as a goal for the European Union to implement this view of sustainability and it aims to include further criteria for sustainability from the 2030 Agenda in the Taxonomy Regulation beyond the ecological criteria in future. The recent decision by Germany’s Federal Constitutional Court on climate protection also illustrates the need to assess technological risks with a view to future generations.

The Taxonomy Regulation is based on this broad approach. It therefore makes sense to already analyse the use of nuclear energy and the disposal of radioactive waste specifically now – and in the context of other sustainability goals like considering future generations and participative involvement in societies.

The Taxonomy Regulation (recital 2) refers to the UN’s approach in its 2030 Agenda in its interpretation of sustainability. The two sustainability goals, i. e. “considering future generations” and “participative decision-making” are not listed in the EU’s Taxonomy Regulation. Article 26 Para. 2 b of the Taxonomy Regulation, however, considers that the scope of the Taxonomy Regulation will be expanded in future. More sustainability goals are to be included in future, for example.

Considering future generations and participative decision-making in any society represent individual sustainability goals in the United Nations’ 2030 Agenda for Sustainable Development (UN, 2015).

- Goal no. 7 in the 2030 Agenda formulates access for all (i. e. for future generations too) to affordable energy supplies on the basis of its goal of social sustainability and places its confidence in renewable energies and energy efficiency.
- Goal no. 16 in the 2030 Agenda 2030 formulates the importance of a peaceful and inclusive society for sustainable development. This includes effective, accountable and transparent institutions and the need to ensure, as formulated in a sub-goal, that decision-making at all levels takes place in a demand-oriented, inclusive, participatory and representative manner.

These two sustainability goals are not adequately considered in the JRC Report with a view to nuclear disposal but are important for assessing the fundamental issue of sustainability, which is also part of the Taxonomy Regulation.

A.8.1 Insufficient Consideration of the sustainability goal considering future generations

Developing and introducing a geological disposal programme/disposal system takes decades and is associated with costs that are hard to calculate. Monitoring after the closure of the repository will also continue for at least another 100 years. During this long period, following generations will have to deal with problems that have been caused by previous generations.

The risk of long-term financial burdens that are hard to calculate (as the example of the Asse II mine illustrates) and the risks caused by geological disposal for several generations are not adequately treated in the JRC Report. The report states that it is necessary to prevent placing any inappropriate burdens on future generations (e.g. JRC Report, Part B 1.1, p. 201). In the light of the requirement formulated in Section 1 Para. 2 Sentence 3 of the Site Selection Act to “minimise the need for resources, costs and the burden of risk, which are passed on to future generations”, it can be assumed that the challenges associated with geological disposal have already infringed the principle of equality between generations. The development and implementation costs for deep geological repositories in particular are generally hard to forecast over long periods of time (BMU, 2015).

The JRC Report fails to provide any in-depth analysis of this aspect and provides a distorted picture, particularly with a view to the aspect of sustainability and intergenerational justice, by ignoring the negative consequences of using nuclear energy.

Preservation of records, knowledge and memory (RK&M) regarding radioactive waste repositories is only mentioned once as a quotation from Article 17 of the Joint Convention (JRC Report, Part B 1.2, p. 206) and once rudimentarily in Part B 5.2.3.3, p. 259f. This does not do justice to its importance for future generations. (ICRP, 2013). An international understanding of this has been developed in the so-called RK&M Initiative at the OECD/NEA about what maintaining information and knowledge for future generations might involve for future generations and how it could be handled. A research project undertaken by the NEA concluded that no single mechanism or technique exists which by itself is likely to achieve RK&M over all timescales.

Spent fuel and other highly radioactive nuclear waste must remain isolated from the environment for a million years or longer ‑ an unimaginably long period. The human species might not even exist for this long. Nuclear authorities and states will have ceased to exist much earlier during this time span. This burdens authorities and civil society alike in taking responsibility for the long term.

Also, in the case of severe nuclear power plant accidents, where large amounts of radioactive substances are discharged into the environment, generational justice is an important aspect of sustainability. The example of Chernobyl shows that coping with the consequences of an accident is also at the expense of future generations – ranging from restrictions or non-usage possibilities in the affected areas and even the planned dismantling of the damaged reactor block and disposing of the retrieved nuclear fuel.

A.8.2 Insufficient Consideration of the sustainability goal participative decision-making

The involvement of stakeholders is greatly oversimplified in the JRC Report and is described in very optimistic terms. This also oversimplifies the problem of searching for a site and presents it in a one-sided way. There is no discussion either that – where no social consensus on using nuclear energy exists – its use itself can represent a blockage factor for solving the repository issue – experience for example in Germany illustrates this.

There is no assessment/evaluation about whether the requirements formulated here for participative decision-making are being met by the three country examples of Finland, Sweden and France, which, according to the report, have made great progress in their search for a repository site. However, it would be important to assess the progress of these three countries in relation to the issue of participative decision-making too.

Participative procedures would also be necessary in process stages upstream like uranium mining or if indigenous peoples are affected. Article 18 of the Taxonomy Regulation about minimum safeguards (**in this case regarding human rights**) should have been more clearly directed towards uranium mining too.

Also, uranium mining call for a separate consideration of the issues of intergenerational justice and participation in terms of the sustainability of using nuclear energy.

Overall, it is necessary to state that the consideration of sustainability in the JRC Report is incomplete and needs to be complemented in terms of the minimum objectives and other sustainability goals. The broad sustainability approach adopted by the United Nations is not picked up.

A.8.3 Opposing Opinion of the Article 31 Group of Experts

Also opposing opinion of the Article 31 Group pf Experts criticized the lack of appropriate considering undue burden for future generations.

“The mandate of the Article 31 Group of Experts (GoE) reviewing the JRC report is rather narrow. The review of the JRC report was carried out in accordance with the request of the European Commission and the general mandate and competence of the GoE. Further environmental aspects such as the *polluter pays principle*, the *principle of not imposing an undue burden on future generations*, costs as well as proliferation and (nuclear) security were not covered by the review of the GoE. In order to give a serious answer to the question of whether nuclear energy is environmentally sustainable, these other aspects have to be taken into account.”

A.9 Ignoring the Risk of Terrorism and War

The JRC Report restricts itself to a very brief statement about the topic of physical protection (disruptive action or other intervention of third parties) and it only refers to a few particular aspects (e.g. JRC Report, Part A 3.3.5.1.5, p. 109). Simply referring to the regulatory requirements falls short of the mark in terms of the nuclear security regime too.

This is inadequate for an overall description in the light of the significance of this subject area. Any unauthorised and improper intervention by third parties to a nuclear facility or material can create significant adverse effects for people and the environment and therefore for the environmental objectives too.

One should keep in mind that any estimate of the risk of disruptive action or other effects caused by third parties largely depends on the will of the third parties and their criminal energy. This element of deliberate action creates a situation where determining the risk to the population from disruptive action or other interventions caused by third parties is fundamentally different from the procedures regarding safety. While technical scientific findings form the basis for any supposed disruption scenarios in the field of safety, the definition of design basis scenarios for physical protection cannot be deduced scientifically. The relevant scenarios are identified by expert judgement of the competent authorities based on objective findings. These relevant observations are translated into continuously updated assessments of the current hazard situation (BMU, 2012).

The 2020 NTI Nuclear Security Index (NTI Index) assesses the security of weapon grade nuclear material against theft and the security of nuclear facilities against sabotage. Stolen weapon grade nuclear material could be used to build a nuclear bomb; the sabotage of a nuclear facility could result in a dangerous release of radiation.

For 2020 it made the following conclusions: "*The 2020 NTI Nuclear Security Index finds that progress on protecting nuclear materials against theft and nuclear facilities against acts of sabotage has slowed significantly over the past two years, despite ongoing, major security gaps. An alarming development at a time of growing global disorder and disruption, the decline in the rate of improvement to national regulatory structures and the global nuclear security architecture reverses a trend of substantial improvements between 2012 and 2018*."

A.9.1 Ignoring the Risk of Terror Attacks

Worldwide, there is the risk of an attack against a nuclear facility. Since September 11, 2001, the potential terror threat NPPs are exposed to, received considerable public attention. For obvious reasons, this attention is mainly focusing on the hazard of the deliberate crash of a large airliner.

However, those threats are much more diverse and complex. There are numerous potential targets for terrorist attacks. However, what makes an attack on a NPP very "attractive" for a terrorist group is the global attention this would generate. In recent years, the rise of terrorist groups who have sufficient resources placed nuclear security high on the political agenda.

Nuclear power plants are designed with safety provisions such as thick concrete walls and diverse systems providing multiple backups in case of an emergency. These provide some protection against attacks. However, about 85% of the about 450 reactors around the world were built before the 9/11 attacks and were not designed to withstand potential acts of sabotage. Old NPPs have numerous known design flaws which make them vulnerable to attacks. At the same time, it is known that they lack sufficient measures to manage a severe accident.

Furthermore, in old plants, unexpected multiple failures of structures or components cannot be excluded in case of a terror attack; in particular, common cause failures of safety relevant systems cause concern. Reactor cores of old reactors are surrounded by a relatively thin-walled **reactor building** (less than 1 m). This design does not reflect current standards in science and technology. A thickness of about 2 m is applied for new NPPs.

If the reactor building is destroyed by an attack, it has to be assumed that the reactor's cooling circuit will be damaged. Because of debris and fire, safety and control systems will also suffer major damage. (If the pipelines of the cooling system are damaged, it would be irrelevant if the emergency cooling system still functioned, since it would no longer be able to be effectively fed in.)

The **spent fuel pool** is another vulnerable component of NPPs with considerable radioactive inventory. If an attack causes a breach of the concrete walls of a spent fuel pool, the cooling water will pour out. In case sufficient refilling is not possible, the fuel will heat up due to the decay heat. Once the fuel reaches the temperatures of 900 °C, the zirconium cladding of the fuel starts to burn in air. The resulting spent fuel fire would release a significant fraction of the cesium-137 from the fuel into the atmosphere. A recent study calculates a fraction of 75% (10-90%) of the cesium inventory. (The possible release depends on the density of the stored fuel.) (BECKER 2017)

A.9.2 Ignoring the Risk of Military Actions

Military actions against nuclear facilities, such as the Russian attacks on the Ukrainian nuclear facilities, represent another danger that deserves special attention in the current global situation. A new risk assessment would have to consider whether such scenarios should be included to consider nuclear energy in the frame of the Taxonomy.

With the targeted terrorist attack on 11 September 2001, it has become clear that extreme terrorist activities can also represent concrete threat situations, which led to a strengthening of security requirements for nuclear facilities. With Russia's attack on Ukraine, however, scenarios have occurred that were previously considered hardly realistic.

With the war in Ukraine, civilian nuclear facilities have for the first time become an indirect target of armed conflict. Nuclear facilities cannot be designed against this form of threat. Russia has made it clear that international rules prohibiting acts of war around nuclear power plants can only last as long as all actors feel bound by them. Nuclear plants become a particular threat in such cases. In many nuclear states, their use is also closely linked to military use. Military use, whether by nuclear weapons or even indirectly by shelling a facility, represents an increase in risks for a society. (BASE 2022b)

In the current military conflict in Ukraine, nuclear power plants are located in the war zone. This poses a threat of radioactive contamination for the whole of Europe. The Zaporozhye Nuclear Power Plant, the largest nuclear power plants in Europe. It was seized by Russian forces in early March 2022. However, the Ukrainian staff continuing to operate the plant.

Over the past month, Russia has repeatedly accused Ukrainian forces of shelling the nuclear power plant, damaging some of the equipment and buildings. Ukraine, in turn, strongly denies its military is targeting the facility, and accuses Russian troops of deliberately shelling the plant. Moreover, Ukrainian officials claim that Russia is using the plant as a military base, hiding its personnel and hardware on its grounds.

A.9.3 Opposing Opinion of the Article 31 Group of Experts

Also opposing opinion of the Article 31 Group pf Experts criticized the lack of appropriate considering nuclear security.

“The mandate of the Article 31 Group of Experts (GoE) reviewing the JRC report is rather narrow. The review of the JRC report was carried out in accordance with the request of the European Commission and the general mandate and competence of the GoE. Further environmental aspects such as the *polluter pays principle*, the *principle of not imposing an undue burden on future generations*, costs as well as proliferation and (nuclear) security were not covered by the review of the GoE. In order to give a serious answer to the question of whether nuclear energy is environmentally sustainable, these other aspects have to be taken into account.”

A.10 Ignoring the Risk of Proliferation

Nuclear proliferation, the spreading of nuclear weapons, fissionable material and weapons applicable nuclear technology and information is often ignored, because the debate usually centres on energy production. However, proliferation was brought back into the discussion by the authors of a task similar to the Taxonomy effort ‑ the 2018 Intergovernmental Panel on Climate Change (IPCC) report: **Nuclear energy, the share of which increases in most of the 1.5°C-compatible pathways, can increase the risks of proliferation, and have negative environmental effects**. The IPCC conclude, with “*robust evidence and high agreement*” that nuclear weapons proliferation concern is a barrier and risk to the increasing development of nuclear energy.

The growth of nuclear energy has historically increased the ability of nations to obtain plutonium or enrich uranium to manufacture nuclear weapons. Peaceful nuclear cooperation and nuclear weapons are related in two key respects. First, all technology and materials related to a nuclear weapons program have legitimate civilian applications. Second, civilian nuclear cooperation builds-up a knowledge-base in nuclear matters.

The building of a nuclear reactor for energy in a country that does not have a reactor increases the risk of nuclear weapons development in that country. Specifically, it allows the country to import uranium for use in the nuclear energy facility. If the country so chooses, it can secretly enrich the uranium to create weapons grade uranium as well as harvest plutonium from uranium fuel rods used in a nuclear reactor, for nuclear weapons. This does not mean any or every country will do this, but historically some have, and the risk is high. If a weapon is used, it may kill 2 to 20 million people and burn down a megacity, releasing substantial emissions. (JACOBSEN 2019)

The military and civil use of nuclear energy have been closely connected to each other historically. The technologies for their use are often dual-use items, i. e. they can in principle be used for both civil and military purposes. In the course of using nuclear energy and the supply and disposal of fuels associated with it, an elaborate network of international controls has therefore been created to minimise the risk of military misuse by state or non-state players. This particularly applies to fissionable material like uranium-235 and plutonium-239, which are used when generating nuclear energy or produced in power reactors. In addition to this, significant risks are also created by other radioactive substances if they are stolen and used in an improper manner ("dirty bombs").

Processes that are particularly important for proliferation are created when manufacturing nuclear fuel (uranium enrichment) and reprocessing spent nuclear fuel materials: the technologies for uranium enrichment can be used with modifications to produce highly enriched uranium to build a nuclear weapon. During reprocessing, plutonium is separated, and it can be used for nuclear weapons. (Mark, 1993; US DoE, 1994).

Using nuclear energy to generate electricity is therefore associated with specific risks of proliferation. As nuclear weapons have unique destructive potential in many respects (Eisenbart, 2012), the issue of sustainability for this type of energy generation should not ignore this aspect.

The authors of the 2012 study Global Energy Assessment – Toward a Sustainable Future summarized the situation as follows: "*An important societal debate is still ongoing. Do the potential environmental benefits from low-carbon nuclear power outweigh the risks inherent in the technology? These risks occur in reactor operation and possibly in disposal facilities, but, in the view of the authors of this chapter, the most important risk from nuclear power is that its technology or materials may be used to make nuclear weapons. [...]That nuclear weapons may spread with nuclear power technology is therefore a danger that must be taken seriously*."

The German government's "Safe energy supplies" ethics committee stated in 2011: "*Proliferation […] is a largely unresolved problem when using nuclear energy. Due to the large number of reactors and the quantity of fissionable material, the risk of criminal or even terrorist misuse has multiplied. Attempts within international law to curb or control proliferation have only been effective to a limited degree in the past. Proliferation has proved very hard to regulate. We must assume that any successful and complete prevention of the spread of fissionable material will only succeed if the sources themselves are ultimately discontinued and replaced by other energy sources.*" (Ethics committee, 2011).

The argument that EU Member States in which the Taxonomy will be implemented are highly unlikely to be typical proliferators or try to acquire nuclear weapons is not valid, as the EU hopes to 'export' the Taxonomy to countries which trade with EU Member States. It would be difficult to stop NPP sales to countries outside the EU by insisting that they are suspected of acquiring civil nuclear technology with the hidden agenda of preparing a nuclear weapon programme.

The JRC Report only mentions the risk of proliferation very briefly in conjunction with the civil use of nuclear power. This analysis is inadequate to do justice to proliferation in the light of the DNSH criteria related to the environmental objectives, as it represents a considerable risk for almost all sustainability goals. (BASE 2022)

The Taxonomy Regulation and the Terms of Reference (TOR) of the European Commission for the JRC failed to mention the issue.

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European Commission and the general mandate and competence of the GoE. Further environmental aspects such as the *polluter pays principle*, the *principle of not imposing an undue burden on future generations*, costs as well as proliferation and (nuclear) security were not covered by the review of the GoE. In order to give a serious answer to the question of whether nuclear energy is environmentally sustainable, these other aspects have to be taken into account."

A.11 Ignored of Risk Lifetime Extension of operating NPPs

The International Nuclear Risk Assessment Group (INRAG) is an interdisciplinary expertise network. Members are academics, former members and heads of nuclear authorities, members of technical support organizations, independent scientists and experts, from Austria, Bulgaria, France, Germany, Sweden, the UK and the USA. They provide international independent expertise in the nuclear field. INRAG perform analyses, based on scientific and technically sound knowledge and expertise to make international expert knowledge available to the public and decision-makers.

INRAG published in 2021 the comprehensive study "The Risks of Life-time Extension of Ageing Nuclear Power Plants" This Study concludes: **Life-time extensions and the operation of ageing nuclear power plants increase nuclear risks in Europe.**

A look at the age structure of existing nuclear power plants shows the importance of analysing risks of life-time extension and long-term operation. Some of the world's oldest plants are located in Europe. Of the 141 reactors in Europe, only one reactor came into operation in the last decade, and more than 80 percent of the reactors have been running for more than 30 years (see Figure 3). Nuclear power plants were originally designed to operate for 30 to 40 years. Thus, the operating life-time of many plants are approaching this limit, or has already exceeded it.

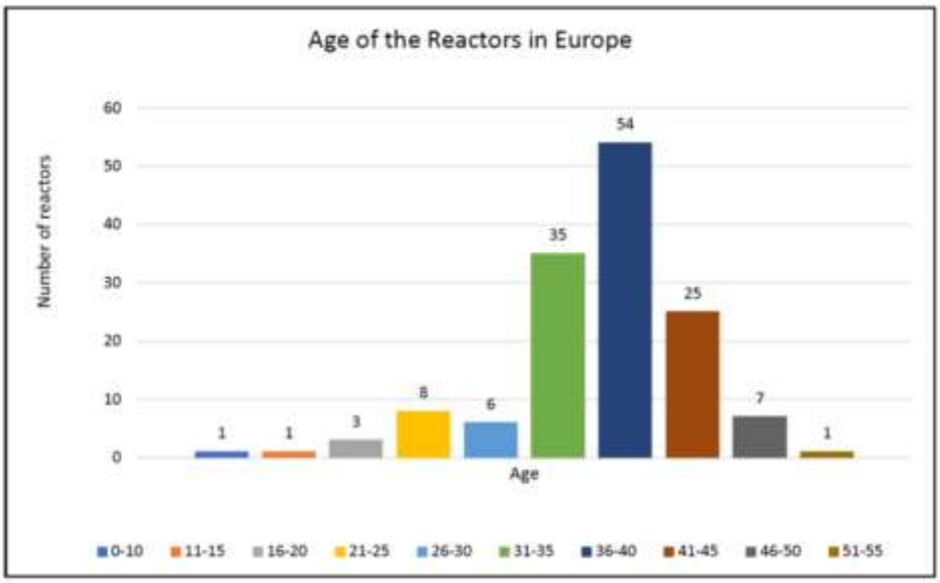

Figure 3: Age of European reactors Status 2020 (INRAG 2021, IAEA PRIS 2021)

A.11.1 Summary of the Findings of the INRAG Study

The ageing of nuclear power plants leads to a significantly increased risk of severe accidents and radioactive releases. The risk of continued operation of old plants is further significantly increased due to their further life-time extension and power increase. Partial retrofits can, in practice, do little to change this. The age structure of operating nuclear power plants in Europe shows that many plants are already approaching or have already exceeded the age of their original technical design. However, they are expected to continue operating beyond this point.

Ageing processes increase the risk of transients and accidents. The cause of many safety-relevant events can be traced back to ageing processes. This is shown by operating experience. Ageing processes such as corrosion, abrasion or embrittlement reduce the quality of systems, structures and components to the point of failure. Safety reserves vanish, the effectiveness and reliability of safety functions and thus also the potential for controlling accidents are limited as a result.

In the early years of nuclear power plant development and construction, the materials, manufacturing processes and test methods used were of lower quality than today. Similarly, knowledge of the nature and extent of age-related damage to the materials used was limited compared to today. Therefore, ageing processes are a particular problem for old nuclear power plants.

All power plant concepts are, in practice, outdated in terms of safety. Most power plant concepts date back to the 1970s and 1980s. The construction and operating licenses of many nuclear power plants are already 30 years old and more. At that time, they were approved for operation as “safe” after licensing reviews. Essential safety principles (such as diversity, spatial separation and protection against external impacts) were not used or were used only to a limited extent; in this respect, from today's perspective, old nuclear power plants have numerous design weaknesses.

Structural separation of safety areas, redundancy, independence of the levels of the staggered safety concept, the installation of diversified technologies, were all implemented far less consistently than would be required according to today's knowledge and standards. With the increasing age of the plants, these conceptual deviations from the safety level required today for new plants become bigger and bigger.

Many nuclear power plants are operated beyond the limit of the original technical design and at an outdated technical level. The technical license review of nuclear power plants was carried out within the framework of the original licensing with regard to an operating time of 30-40 years. Nevertheless, today nuclear power plant life-times are to be extended to 60 or more years without a new license review and without fundamental modernization. The even older underlying concepts of these nuclear power plants would then, at decommissioning, be up to 100 years old.

New threats have emerged. Terrorist attacks, airplane crashes and other disruptive actions as well as extreme natural events as a result of ramping climate change, can no longer be neglected, and represent risks. As such, they require special protective measures which were not foreseen in the design of the existing plants and can only implemented to a very limited extent. Compliance with today’s safety standards would practically require the development and construction of a completely new nuclear power plant.

To justify life-time extensions original safety margins are reduced. In order to reduce the risk of operating nuclear power plants, safety margins are introduced in the design of individual systems and components in accordance with deterministic safety philosophy. These safety margins are used to compensate for unforeseen errors in the material, in the mode of operation, in the design, or in the safety-related calculations as a precaution. These safety margins are reduced or are no longer present in ageing nuclear plants. In addition, safety calculations carried out today utilze safety margins in order to be able to show that the corresponding safety limit has not yet been reached. The risk of failure increases accordingly.

The old plants cannot be licensed according to today's standards. The severe accidents at Three Mile Island, Chernobyl and Fukushima have each shown that nuclear power plants are not as safe as had been claimed and assumed. This means that the risk of the old plants was underestimated at the time they were licensed. As a result of these accidents in particular, the state of the art in science and technology was expanded and the requirements for new plants were tightened. However, these new requirements cannot be sufficiently implemented in old plants.

This means at the old plants a risk is accepted that would not be acceptable for new projects. No EU member state would grant a new construction permit to any of the ageing nuclear power plants currently in operation.

The statement that the safety of old nuclear power plants has been continuously improved by retrofitting is misleading. Retrofits often serve to reduce deficiencies in the plant or to protect against risks that had been accepted or not recognized at the time of licensing. Thus, retrofits often serve to establish the "safe" condition that was assumed at the time of approval, but not for the present.

There are limits to retrofitting on principle. Major conceptual weaknesses of old nuclear power plants remain. Safety requirements according to the current state of science and technology cannot be fully implemented in the design of old nuclear power plants. Elementary weaknesses of the outdated safety concepts cannot be eliminated. A significant part of the safety standard is already determined in the design of the nuclear power plant. The state of the art in science and technology has evolved. Reactor safety research has gained new insights into previously unrecognized risks. Added to this is the accumulated experience from incidents, accidents and even severe accidents. This has resulted in extended requirements for systems, structures and components, which have grown over decades, in order to eliminate previously unrecognized weaknesses.

When comparing the design concepts of existing plants with the concepts of new-builds, there are striking differences, for example, in the degree of redundancy, the independence of safety systems, protection against external events and the design features against severe accidents. New, advanced requirements that affect the fundamentals of the safety concept and the basic design of large structures (e.g. core catcher) cannot be retrofitted in existing plants, partly because of spatial constraints. For certain accident sequences, attempts are made to compensate for design deficits with additional mobile equipment kept on standby. This is not equivalent to safety provisions in the basic design. Additional measures taken by the operator can not achieve the same level of safety as structural measures (e.g. fire protection).

The possibilities of ageing management are limited. Repair and replacement of components affected by ageing, if possible at all, can only eliminate deficiencies locally. Damage in structures, systems and components that cannot or should not be replaced (such as the reactor pressure vessel) means a permanent and (as ageing processes progress) increasing reduction in originally installed safety margins. Measures such as additional inspections or tests, which are often introduced as a substitute for remedying the identified deviations, can at best observe the damage progression, but cannot compensate for the loss of safety. This continued operation at lower safety levels is justified by the competent authorities by allowing substitute measures instead of requiring to restore an acceptable condition.

Retrofitting and repairs in old plants lead to additional risks. By interfering with the safety technology of the existing plant, new risks can be created - for example through unforeseen interactions. New technical solutions may show incompatibilities with the existing technology. In the case of ageing components, the problem of procuring spare parts increases if they are taken out of the delivery program or no longer developed further. Changes (design, material, manufacturing process) in the supply chain can lead to unexpected failures. Sufficient quality, a prerequisite for safe operation, can then often no longer be demonstrated.

A.12 Incorrect Assessment of the Contribution of the new NPPs

The JRC Report stated that the deployment of various Gen III plant designs started in the last 15 years worldwide and now practically only Gen III reactors are constructed and commissioned. (JRC Report Chapter 4.3) Even this statement is almost right, it ignored the reality that shows a lot of problems and delays in construction times.

A.12.1 Long “Plan to Operation” Time

In March 2007, the United States Nuclear Regulatory Commission (NRC) approved the first request for a site permit in 30 years. This process took 3.5 years. The time to review and approve a construction permit is another 2 years and the time between the construction permit approval and issue is about 0.5 years. Thus, the minimum time for preconstruction approvals (and financing) in the United States (US) is 6 years. An estimated maximum time is 10 years. The time to construct a reactor depends significantly on regulatory requirements and costs. Although reactor construction times worldwide are often shorter than the 9-year median construction times in the US since 1970, they averaged 7.4 years worldwide in 2015. As such, a reasonable estimated range for construction time is 4 to 9 years, bringing the overall time between planning and operation of a nuclear power plant worldwide to 10 to 19 years. (JACOBSEN 2019)

To build new nuclear power plants is impractical as a short-term response to climate change. Planning and approvals can take a decade (particularly for nuclear ‘newcomer’ countries), and construction another decade. The time lag between planning and operation of a nuclear power plant includes the times to obtain a construction site, a construction permit, an operating permit, financing, and insurance; the time between construction permit approval and issue; and the construction time of the plant.

Examples:

- The Vogtle 3 and 4 reactors in US were first proposed in August 2006 to be added to an existing site. The current date for start of operation is 2023, given them PTO times of 17 years. Their construction times will be about 10 years, respectively.
- Plans for the Haiyang 1 and 2 in China were starting in 2005. Construction started in 2009 and 2010, respectively. Haiyang 1 began commercial operation on October 2022, 2018. Haiyang 2 began operation on January 9, 2019, giving them construction times of 9 years and PTO times of 13 and 14 years, respectively.

- The Taishan 1 and 2 reactors in China were bid in 2006. Construction began in 2008. Taishan 1 began commercial operation on December 13, 2018, Taishan 2 on September 7, 2019, giving them construction times of 10 and 11 years and PTO times of 12 and 13 years, respectively. (JACOBSEN 2019)

An examination of some recent nuclear plant developments confirms that this range is not only reasonable, but an underestimate for Europe:

- The Olkiluoto 3 reactor in Finland was proposed to the Finnish cabinet in December 2000 to be added to an existing nuclear power plant. Its latest estimated completion date is 2022, giving a planning-to-operation (PTO) time of 22 years.
- The plan of Hinkley Point C in UK was starting in 2008. Construction began only on December 11, 2019. (JACOBSEN 2019) In 2022 the start of electricity generation for unit 1 of the Hinkley Point C plant is now expected in June 2027 giving it a PTO time of 19 years.

According to the World Nuclear Industry Status Report (WNSIR) 2019, the mean construction time for the nine reactors started up in 2018 was 10.9 years. The report states: **According to a recent assessment, new nuclear plants take 5–17 years longer to build than utility-scale solar or onshore wind power, so existing fossil-fueled plants emit far more CO_2 while awaiting substitution by the nuclear option. In 2018, non-hydro renewables outpaced the nuclear program in China, by a factor of two, in India by a factor of three.** (WNISR 2019)

Stabilizing the climate is urgent, nuclear power is slow. (WNISR 2019) It meets no technical or operational need that renewables cannot meet better, cheaper, and faster. The longer the time lag between the planning and operation of an energy facility, the more the air pollution and climate relevant emissions from the electric power grid. (JACOBSEN 2019)

A.12.2 Problems with new power plants project

The contribution of new nuclear power plants (NPP) to energy security is very limited for two main reasons: significant delays between planning and operation of NPPs and the comparatively high cost of energy production from NPPs.

The current new built projects listed by reactor type below show considerable cost and construction time increases:

EPR (AREVA)

EPR with two reactors completed in China, two reactors under construction in Finland, and France and two reactors just starting construction in UK (THOMAS 2019):

- In 2002, EPR in Olkiluoto (Finland) was approved with cost of €2.5bn. In 2005 the construction started with estimated cost already €3bn, the completion was expected in 2009. But in 2019, costs were €11.4bn and the completion expected later than 2020. Grid connection was done in March 2022.[11] Commercial operation is now projected to begin December 2022.[12]

- In 2005, the EPR in Flamanville (France) was approved with cost of €3bn. In 2007, construction started with cost of €3.3bn, completion was expected in 2012. In 2019, costs were increased to €10.9bn, commercial operation is now expected in 2024.

[11] https://www.world-nuclear-news.org/Articles/Finnish-EPR-starts-supplying-electricity
[12] https://www.ans.org/news/article-4070/olkiluoto3-start-pushed-to-end-of-year/

- In 2008, for the two EPRs in Hinkley Point C (UK), the costs were expected to be £ 4bn. In 2010, completion was expected in 2017. In 2013, costs were increased to £ 14bn. In 2022 the start of electricity generation for unit 1 of the Hinkley Point C plant is expected in June 2027 and the project completion costs are now estimated in the range of £25 to 26 14bn (in 2015 price).[13] Note: Hinkley Power contracted on a 35-year contract at £92.5/MWh, latest UK off-shore wind prices, <£40/MWh (both 2012 money).

2016, Areva collapsed in large part due to Olkiluoto losses, now owned by EDF and likely to be nationalized.

AP1000 (Westinghouse)

Four AP1000 reactors completed in China, two reactors under construction in US and two reactors abandoned in US.

- In 2012, the cost for the two reactors in Summer (US) was $9.8bn. Construction started 2013 with expected completion 2017-18. Early 2017, completion was expected in 2020. Late 2017, project was abandoned, because costs were estimated up to $25bn.
- In 2008, estimated costs for the two reactors in Vogtle (US) were $14.2bn. Construction start was in 2013. In 2016, $8.3bn loan guarantees and in 2017, $3.7bn additional loan guarantees were given. 2019, construction cost was $23-27bn. Start is now expected for 2023.[14]

In 2017, Westinghouse files for bankruptcy due to losses on new build projects Vogtle & Summer. Now owned by Canadian company but unlikely to pursue new orders.

APR1400 (KEPCO)

Two APR1400 reactors completed and four reactors under construction in South Korea, four reactors under construction in the UAE. The APR1400 is seen as a cheaper, easier to build option than EPR or AP1000 on basis of rapid construction in Korea and low bid for UAE. APR1400 design was approved by NRC in 2019, but there were no US customers. 2010, KEPCO bid $3600/kW for four reactors for UAE, 30% lower than the EPR. KEPCO acknowledges design for Korea & UAE lacks safety features required for Europe, notably a core-catcher and a reactor building able to withstand an aircraft impact.

- The APR1400 reactors Shin Kori 3, 4 were completed in 2016 and 2019 respectively in South Korea after 8-10 years construction.
- Shin Hanul 1,2 are under construction for 7-9 years, Shin Kori 5,6 started construction in 2017/18. Delays due to discovery in 2012 of large-scale falsification of documents (thousands of parts) requiring affected components to be replaced & problems with pilot operated safety relief valves (POSRVs).
- The construction of the four reactors at Barakah (UAE) started 2012-15, expected completion was 2017-20. Delays initially claimed due to lack of operators, now clear

[13] https://www.world-nuclear-news.org/Articles/EDF-revises-Hinkley-Point-C-schedule-and-costs
[14] https://world-nuclear-news.org/Articles/Vogtle-3-approved-to-load-fuel

also quality problems. POSRV & cracks in all containment buildings. Commercial operation of unit 1 started in April 2021, of unit 2 in March 2022.[15]

Costs of NPPs have increased 90-500% from project agreement to completion. All European & US NPPs projects have been built on the basis of sovereign loan guarantees and/or promises of full cost recovery from consumers. Losses essentially bankrupted the world's largest reactor vendors, Areva & Westinghouse. (THOMAS 2019)

Investing in a new NPP leads to average losses of around five billion euros. The lack of economic efficiency goes hand in hand with a high risk with regard to the proliferation of weapons-grade materials and the release of radioactivity, as shown by the accidents in Chernobyl (1986) and Fukushima (2011). For all these reasons, nuclear energy is not a relevant option for supplying economical, climate-friendly, and sustainable energy in the future. (DIW 2019)

A.12.3 Energy payback time

Additionally, to land and water, there is also the inefficient use of energy. It can take five years or more to repay the energy debt expended in the construction of the reactor. A University of Sydney report states: "*The energy payback time of nuclear energy is around 6.5 years for light water reactors, and 7 years for heavy water reactors, ranging within 5.6–14.1 years, and 6.4–12.4 years, respectively*." (FoE 2019)

A.13 Incorrect Assessment of the Contribution of Small Medium Reactors

SMR concepts ("Small Modular Reactors") date back to developments in the 1950s, in particular the attempt to use nuclear power as a propulsion technology for military submarines. Today, a wide variety of concepts and developments for SMRs exist worldwide, however the vast majority are only at the conceptual level. In the context of discussions about the use of future nuclear reactors, in particular also as a measure against climate change, the concept of SMRs has been receiving renewed attention for some time.[16]

The statement about many countries' growing interest in SMRs is mentioned in the JRC Report (Part A 3.2.1, p. 38) without any further classification. In particular, there is no information about the current state of development and the lack of marketability of SMRs.

Reactors with an electric power output of up to 300 MWe are normally classified as SMRs. Most of the extremely varied SMR concepts found around the world have not yet got past the conceptual level. Many unresolved questions still need to be clarified before SMRs can be technically constructed in a country within the EU and put into operation. They range from issues about safety, transportation and dismantling to matters related to interim storage and final disposal and even new problems for the responsible licensing and supervisory authorities.

[15] https://www.world-nuclear-news.org/Articles/Second-Barakah-unit-begins-commercial-operation

[16] In this context, the German Federal Office for the Safety of Nuclear Waste Management (BASE) commissioned the Öko-Institut to prepare an expert report to provide an overview of reactor concepts currently being pursued internationally under the term SMR, a scientific assessment of possible areas of application, and the associated safety issues and risks. This report was prepared in cooperation with the Workgroup for Infrastructure Policy (WIP) at Berlin Institute of Technology (TU Berlin) and the Physikerbüro Bremen (PhB).

A compilation made as part of the report (BASE 2021) includes 136 different historical as well as current reactors or SMR concepts. Of these, 31 concepts were considered in greater detail. Some of these SMR concepts already have a very long history of development. For example, the development of Argentina's CAREM dates back to the 1970s. Other SMR concepts are more recent and therefore still in an earlier phase of concept development. Further SMR concepts are discussed as current concepts whose development is effectively interrupted (such as the South African PBMR-400). There are several start-up designs, including from Bill Gates' Terrapower, NuScale and Rolls Royce.

SMR concepts differ in important technical characteristics, especially the coolant used. Mostly water-cooled and non-water cooled SMR concepts are distinguished. The latter can be assigned to High- Temperature Reactors (HTR), reactors with a fast neutron spectrum or Molten Salt Reactors (MSR).[17]

Today, water-cooled reactors represent the vast majority of nuclear power plants in operation worldwide. This means that, in principle, extensive operational experience and a broadly developed infrastructure are available for such reactors. The majority of the SMR concepts currently being pursued or at an advanced stage of development can also be classified as light water reactors. Such concepts therefore have the lowest development risks.

Non-water cooled SMR concepts include fundamental innovations compared with today's nuclear power plants. Many of these concepts aim at a so called closed fuel cycle, with associated high technological risks in the field of fuel development and reprocessing technologies. Significantly less operating experience, mainly from prototype and demonstration reactors, as well as the planned use of novel technological solutions and new materials, lead to the expectation of significantly longer development periods as well as higher technological development risks compared to water-cooled SMR concepts.

A variety of motivations intermingle in technology and innovation policy, including industrial and economic development and geopolitical influence. Industrial and geopolitical motivations, as well as military interests, also play a role in SMR development. The majority of countries pursuing SMR activities maintain nuclear weapons programs and build nuclear submarines and/or already have a large commercial nuclear program. Of particular importance are the development activities in the USA.

In Canada SMRs are being discussed primarily as an alternative power supply option for remote mining projects and communities that currently rely on diesel generators. In Russia, so-called floating nuclear power plants (Akademik Lomonosov, KLT-40S) are being used to supply remote regions

A.13.1 High costs and long construction time

Today`s new nuclear power plants have electrical output in the range of 1000–1600 MWe. SMR concepts, in contrast, envisage planned electrical outputs of 1.5–300 MWe. In order to provide the same electrical power capacity, the number of units would need to be increased by a factor of 3–1000. Instead of having about 400 reactors with large capacity today, it would be necessary to construct many thousands or even tens of thousands of SMRs (BASE, 2021; BMK, 2020).

[17] For some years, concepts with particularly low power have also been discussed as so-called Micro- Reactors (MR), although these can also be generally categorized as non-water cooled SMR concepts.

Due to the low electrical capacity, the specific construction costs are higher for SMRs than for large nuclear power plants due to the loss of economies of scale. However, the hypothesis is formulated that the modular, standardized, factory production of SMRs should be able to reduce both the total construction costs and the construction times of such systems.

A current production cost calculation, which consider scale, mass and learning effects from the nuclear industry, concludes that more than 1,000 SMRs would need to be produced before SMR production was cost-effective. It cannot therefore be expected that the structural cost disadvantages of reactors with low capacity can be compensated for by learning or mass effects in the foreseeable future (BASE, 2021).

Another important reason stated for the development of SMR concepts is the expectation of shorter time horizons, in particular shorter construction times, and possibly also uncomplicated dismantling. An evaluation of plants currently planned, under construction or in operation does not confirm this assumption. On the contrary: planning, development and construction times usually exceed the original time horizons many times over.

In 2020, two SMR pilot plants based on the KLT-40S concept (so-called floating nuclear power plants) were commissioned in Russia. Russia realised these floating reactor in 2020 after 13 years of construction.

The costs of SMRs are not lower than reactors of the GW size, but higher. That is why in the past people started to build large reactors instead of small ones. Reactors can only be built with subsidies or government money. In the periods that are particularly important for climate protection, the next two to three decades, SMR concepts are irrelevant.

Over the past few years in the UK, and in a number of other countries with nuclear power programmes, there has been a growing clamour of support within government and from the nuclear industry to develop a programme of SMRs. This has been part of a wider attempt to make nuclear power part of the 'low carbon' energy solution and stabilise the nuclear sector from an apparently terminal decline.

A report has been initiated and developed by the Nuclear Consulting Group (NCG) to provide a rational, technical and independent analysis of the prospects for SMRs being developed in the UK and around the world. The authors conclude that it remains likely that no substantive deployment of the technology will be realised, with just a very few reactors built, at most. This will be the case despite large amounts of public money being invested in these projects and, worse, the neglect of other more viable non-nuclear options.

The report also outlines in some detail UK Government policy on SMRs. It notes that after some considerable early promotion of the technology, interest has markedly cooled. At a global level, the report concludes that SMRs will not be built in any significant scale. Indeed, many of the features of the SMRs being developed are the same ones that underpinned the latest, failed generation of large reactors. Reactor cost estimates will remain with a large degree of uncertainty until a comprehensive review by national nuclear regulators is completed, the design features are finalised and demonstration plants are built.

A.13.2 Unclear or Reduced Safety features

The theory that a SMR automatically has an increased safety level is not proven. The safety of a specific reactor unit depends on the safety related properties of the individual reactor and its functional effectiveness and must be carefully analysed – taking into account the possible range of events or incidents. (BASE, 2021).

Several sequential barriers are usually used to confine the radioactive materials, in today's nuclear power plants typically including the fuel rod cladding, the reactor coolant pressure boundary and a reactor containment. For water-cooled SMR concepts, containment concepts comparable to those for today's light-water reactors are pursued. However, some SMR concepts do not see the need for a reactor containment, as credited special containment properties already exist in the fuel.

These liquid salt reactors (Molten Salt Reactor and its further development Molten Salt Fast Reactor) work with thorium as fuel. The claim that this type of reactor is particularly safe due to its design only refers to the technical plant safety. The threat of natural disasters, terrorist attacks, plane crashes, human error and so on remains. In addition, there is the great risk of proliferation of weapons-grade uranium. In the case of the thorium liquid salt reactor, the feeding and removal of material by means of a built-in reprocessing plant is an integral part of the reactor. This so-called fourth reactor generation simplifies the construction of nuclear weapons considerably, as it does not require complex enrichment. And it is not suitable for solving the climate crisis either: According to the assessment of the Scientific Services of the German Bundestag, "a commercial reactor is not to be expected before 2060".

The safety-related properties of the reactor must also be analyzed, taking into account the possible spectrum of events. Internal events such as pump failure, power supply loss in the equipment, pipeline leaks or hazards such as internal fires can play a significant role. In addition, external hazards such as earthquakes, external flooding or extreme weather conditions must be considered. Furthermore, human-induced external hazards such as an accidental or terrorist-motivated aircraft crash as well as malevolent disruptive acts or other third-party interventions must be considered. In some cases, SMR concepts are intended for use in remote regions or to supply industrial plants. In these cases, sites cannot be freely selected. Especially for sea-based SMR concepts, further questions may arise with regard to natural hazards.

With respect to measures and equipment for internal accident management, similar measures to those for today's nuclear power plants are discussed in principle for SMR concepts. However, it cannot be conclusively determined at present whether such measures are going to be implemented in all SMR concepts, or whether some will not be implemented due to an expected higher reliability of other safety measures. Questions regarding the necessity and sizing of the planning zones (areas, for which radiological contamination must be assumed in case of severe accidents) for off-site emergency protection in SMR concepts remain open. So far, in contrast to what is sometimes stated by SMR-developers, a need for planning zones that extend significantly beyond the plant site must be assumed for off-site emergency protection in SMRs. Special consideration is also necessary if the planning zones for SMRs are close to densely populated centres (SMR Regulators' Forum, 2018).

Overall, SMRs could potentially achieve safety advantages compared to power plants with a larger power output, as they have a lower radioactive inventory per reactor and aim for a higher safety level especially through simplifications and an increased use of passive systems. In contrast, however, various SMR concepts also favour reduced regulatory requirements, for example, with regard to the required degree of redundancy or diversity in safety systems. Some developers even demand that current requirements be waived, for example in the area of internal accident management or with reduced planning zones, or even a complete waiver of external emergency protection planning. **Since the safety of a reactor plant depends on all of these factors, based on the current state of knowledge it is not possible to state, that a higher safety level is achieved by SMR concepts in principle.**

No specific national or international **safety standards** have yet been drawn up for SMRs. International safety standards would particularly be required, if an SMR was delivered by one country, where the SMR was manufactured, to another country, where it will be used. This will be particularly important if the "user country" is a newcomer in nuclear terms. Questions of security and protection against disruptive action and other effects caused by third parties also need to be clarified. This will particularly be necessary for transportable nuclear power plants. Liability issues related to SMRs are continuing to be discussed internationally (BASE, 2021).

Various non-water cooled SMR concepts envisage the use of higher uranium enrichments, plutonium as fuel as well as reprocessing of spent fuel. **This is fundamentally detrimental to proliferation resistance**. In order to halt the spread of nuclear weapons, promote disarmament and ensure greater global security, member states, which have signed the Nuclear Non-Proliferation Treaty, agree to accept special monitoring measures (IAEA safeguards). The risks of proliferation increase too against a background of a theoretically higher number of SMRs at various sites, some of them very remote, as already mentioned, and the use of fuels with greater levels of enrichment. At the same time, the time and effort for the monitoring measures increases if there is a need to monitor a large number of SMRs, special designs and regular transport operations of complete nuclear power plants or replaceable reactor cores. Many of the standard methods for monitoring fissionable material do not directly match the special features of SMR concepts (BASE, 2021).

Today's regulations are generally based on water-cooled reactor concepts. For new manufacturing processes, novel materials or new technological solutions for safety functions, as discussed for SMR concepts, new regulatory approaches may be required. This is especially true for non-water cooled concepts and may involve a potentially significant lead time before such SMR concepts are approved.

In some cases, technologies are to be used in SMRs for which there is little or no corresponding operating experience. In many cases, suitable verification methods must still be developed and validated for these technologies. This may also require new calculation methods, new measurement procedures or new inspection technologies.

It is important to state that many questions are still unresolved with regard to any widespread use of SMRs – and this would be necessary to make a significant contribution to climate protection – and they are not addressed in the JRC Report. These issues are not just technical matters that have not yet been clarified, but primarily questions of safety, proliferation and liability, which require international coordination and regulations.

A.13.3 More Waste and incompatible for current final disposal plans

A recent published study has assessed the implications of SMRs for the back end of the nuclear fuel cycle. The low-, intermediate-, and high-level waste stream characterization reveals that SMRs will produce more voluminous and chemically/physically reactive waste than LWRs, which will impact options for the management and disposal of this waste. Although the analysis focuses on only three of dozens of proposed SMR designs, the intrinsically higher neutron leakage associated with SMRs suggests that most designs are inferior to LWRs with respect to the generation, management, and final disposal of key radionuclides in nuclear waste. **Results reveal that water-, molten salt–, and sodium-cooled SMR designs will increase the volume of nuclear waste in need of management and disposal by factors of 2 to 30.**

The analysis of three distinct SMR designs shows that, relative to a gigawatt-scale PWR, these reactors will increase the energy equivalent volumes of spent fuel, long-lived LILW, and short-lived LILW by factors of up to 5.5, 30, and 35, respectively. These findings stand in contrast to the waste reduction benefits that advocates have claimed for advanced nuclear technologies. More importantly, SMR waste streams will bear significant (radio-)chemical differences from those of existing reactors.

The excess waste volume is attributed to the use of neutron reflectors and/or of chemically reactive fuels and coolants in SMR designs. That said, volume is not the most important evaluation metric; rather, geologic repository performance is driven by the decay heat power and the (radio-)chemistry of spent nuclear fuel benefit. SMRs will not reduce the generation of geochemically mobile fission products (129I, 99Tc, and 79Se), which are important dose contributors for most repository designs. In addition, SMR spent fuel will contain relatively high concentrations of fissile nuclides, which will demand novel approaches to evaluating criticality during storage and disposal.

SMR waste streams that are susceptible to exothermic chemical reactions or nuclear criticality when in contact with water or other repository materials are unsuitable for direct geologic disposal. Hence, the large volumes of reactive SMR waste will need to be treated, conditioned, and appropriately packaged prior to geological disposal. These processes will introduce significant costs—and likely, radiation exposure and fissile material proliferation pathways—to the back end of the nuclear fuel cycle and entail no apparent benefit for long-term safety. The **SMRs are incompatible with existing nuclear waste disposal technologies and concepts**.[18]

A.14 Ignored impact of the climate change on NPPs

With our climate-impacted world now highly prone to fires, extreme storms and sea-level rise, nuclear energy is touted as a possible replacement for the burning of fossil fuels for energy – the leading cause of climate change. Yet scientific evidence and recent catastrophes call into question whether nuclear power could function safely in our warming world. NPP were built and developed decades ago and are not designed to withstand the major climate change phenomena we are currently witnessing. The sites were not chosen with this factor in mind.

Extreme weather events, fires, rising sea levels and warming water temperatures all increase the risk of nuclear accidents, while the lack of safe, long-term storage for radioactive waste remains a persistent danger. (HUTNER 2019)

The climate change affects nuclear energy production in several ways, including

(1) The efficiency of nuclear power plants decreases with increasing temperature.

(2) Some sites may lose safety, with sea-level rise being of particular importance.

[18] PNAS: Nuclear waste from small modular reactors: Lindsay M. Kralla,1,2 , Allison M. Macfarlaneb , and Rodney C. Ewinga Edited by Eric J. Schelter, University of Pennsylvania, Philadelphia, PA; received June 26, 2021; accepted March 17, 2022 by Editorial Board Member Peter J. Rossky

(3) Extreme weather events threaten the safety of NPPs additionally.

The IAEA distinguish climate change related phenomena between Gradual Climate Changes (GCC) and Extreme Weather Events (EWE).

Regarding 1) and 2) loss of efficiency of nuclear power plants as well as location issues are primarily associated with gradual climate changes (e.g. gradual warming), while safety issues are rather linked to extreme events. However, gradual climate change and extreme events are linked – rising sea levels, for example, also lead to extreme water levels during storms.

Heavy precipitation (rain or snow), high or particularly gusty winds, snowstorms, freezing rain, thunderstorms, lightning, hail with particularly large grains and tornadoes are also among the potential hazards. In areas with more winter precipitation, snowstorms and ice build-up can blockcooling water inlets and outlets, especially when wind is blowing at the same time. A special safety problem is the so-called biofouling, i.e. the disturbance by plants or animals that can settle at the inlets and outlets of the cooling water under appropriate conditions.

Extreme weather events and climate-related hazards may directly affect NPPs, but may also be relevant to safety through indirect effects in the surrounding area, because they limit accessibility (e.g. forest fires or floods), are associated with cascade problems (e.g. a dam burst upstream) or because they affect the power grid (e.g. disturbance by falling trees) with consequences for the availability of off-site energy. (INRAG 2020)

A.14.1 Impact of flooding und storm

Flooding is a symptom of our warming world that could lead to nuclear disaster. Many nuclear plants are built on coastlines where seawater is easily used as a coolant. Sea-level rise, shoreline erosion, coastal storms and heat waves – all potentially catastrophic phenomena associated with climate change – are expected to get more frequent as the Earth continues to warm, threatening greater damage to coastal nuclear power plants. (HUTNER 2019)

Local high precipitation events can cause floods directly at the site of power plants and can damage buildings, equipment and downstream fuel cycle components, such as spent fuel storage (e.g. on-site dry casks). Floods upstream in the river basin may carry large amounts of debris and items accumulated on the riverbank, which would necessitate precautionary measures to be taken to protect cooling water intake.

Cooling needs of nuclear reactors dictate a location at the sea or at a large river. Flooding due to one or more natural causes such as runoff resulting from precipitation or snow melt, high tide, storm surge, seiche and wind waves that may affect the safety of the nuclear installation are possible.

Extreme winds and storms (tornadoes and other rare events) can damage buildings, cooling towers and storage tanks. Upgrading construction standards can reduce the risk of structural damage. Storm surges, superimposed on sea level rise, increase the flood risk for all facilities in low lying coastal areas.

High winds and lightning have always been a threat to nuclear plants, and the threat will rise as these EWEs become more intense with climate change. Typically, the greatest threat from wind is its ability to disrupt power from the grid system, either off the site or via the plant’s internal power connections. Without connection to the grid system for any length of time, a nuclear plant’s reactors must sometimes be tripped to stop generating electricity.

A.14.2 Impact of heat and cold waves

Of relevance for the safety of nuclear power plants can be particularly high or low temperatures, prolonged heat or cold episodes as well as dry phases, and particularly high or low humidity values. (INRAG 2020)

Extreme weather events are related to the extreme values of environmental variables. One of these variables is temperature and, when such extreme values persist across several days, a cold or heat wave takes place for low and high values of temperature, respectively.[19]

During **heat waves** high temperatures affect the generation capacity of NPPs due to increased air and water temperature. During droughts and heat waves, the loss of electricity production may exceed 2% per degree Celsius given that cooling systems of power plants are limited by physical laws, regulations and access to cold water. It has been reported that near to 40% of the NPPs in Europe have already experienced cooling problems because of high temperatures.

Transmission and distribution systems lose efficiency at high temperatures because they limit the power of the transformers and lines and expand the resistance of electric transmission in networks, thereby increasing energy losses. The capacity of transformers decreases by 1% for each °C; in copper lines the temperature of the resistance increases by 0.4% for each °C. Hence, total network losses increase 1% for every 3 °C.

Wildfires are strongly influenced by weather and climate phenomena. Drought substantially increases the risk of wildfire in most forest regions, with a particularly strong influence on long-lived fires. There were a massive forest fires in Canada and Sweden in 2018. (WMO 2019)

As a secondary impact, heat can foster the rapid growth of **biological material**, which can clog cooling water intake, leading to reduced generation or shutdown. Indirect biological impacts are simple to manage by increasing the maintenance of screens to ensure that biological matter does not clog water intake systems.

The effects of **cold waves** on the energy sector include breakdowns in power plants. They could also cause failures in airlines and towers, since ice and snow may accumulate in the insulation under freezing conditions, bridge them and cause a flashover.

The safety impacts of **long-lasting droughts or of low temperatures** and issues should be clarified in safety analysis. (RSK 2013)

- It should be shown that in case of a prolonged drought, a loss of water supply via the receiving water is either not to be postulated or that under such conditions the alternate heat sink cannot be affected in addition to the primary heat sink at the same time.
- For plants with emergency cooling system cooled via cells, clarification is needed as to whether these coolers can freeze.
- It should be shown that the formation of ice barriers at the site is either not to be postulated or that there are sufficiently effective and robust precautions in place for prevention, removal or for the management of the related effects.

[19] The World Meteorological Organization (WMO) proposes the following definition for a heat wave and cold wave respectively (ATMOSPHERE 2017):"*A marked unusual hot weather (Max, Min and daily average) over a region persisting at least two consecutive days during the hot period of the year based on local climatological conditions, with thermal conditions recorded above given thresholds*" and, in a similar way, it defines a cold wave.

- Operating experience shows that for air temperature extremely low e.g., pipes may freeze. Appropriate measures are to be provided by which the vital safety functions will also be maintained under these conditions.

A.14.3 Vulnerability of Nuclear Power Plants in the Case of Grid Failure

Extreme Weather Events can cause a failure of the electric power supply. Nuclear power plants generate electric power and supply it to the offsite grid. On the other hand, the plants themselves are dependent on a continuous electric power supply to operate, particularly for the instrumentation and safety systems, even when they are shut down. A typical nuclear power plant is connected to the electric grid through three or more transmission lines.

Heavy storms can lead to multiple damage of the transmission lines, and hence to loss of off-site power. Also, there can be grid failures even if transmission lines in the vicinity of the NPP remain intact. Should the power lines to the NPP be cut-off or a regional electrical grid collapse occur, onsite emergency generators are designed to automatically start. Every NPP has emergency power supplies, which are often diesel-driven. These generators provide power to special electrical safety distribution panels. If the emergency diesel generators (EDG) fail, the situation at the plant becomes critical ("station blackout"). A natural disaster that disables the incoming power lines to a nuclear power station coupled with the failure of on-site emergency generators can result in severe accident.

Apart from the diesel generators, there are also batteries that supply direct current in case of an emergency; however, the batteries cannot provide electricity for large components such as pumps and have only very limited capacity. Without electricity the operator loses instrumentation and control power leading to an inability to cool the reactor core. Counter measures (accident management) are practically impossible. If the blackout lasts for a long time, not only the reactor, but also the fuel in the spent fuel pool can overheat, contributing to radioactive releases.

After the Fukushima accident, measures to cope with Station Blackout situations are improved. However, these measures are mostly the use of mobile systems, which would be difficult to use in an accident situation and need actions by the staff.

A.14.4 Unjustified assumption that the 1.5°C will be met

One problem especially for new NPPs is that for scenarios for flooding or other climate change effects, it is assumed that the goal of 1.5 °C degree will be met. This is not assured at all. For example: The low-lying marshlands that surround the proposed Sizewell C in the UK could certainly be affected by a climate change scenario that fails to limit global warming to 1.5 degrees. Furthermore, there is no plausible mechanism that could justify the assumption for the maintenance and preservation of the unconsolidated Dunwich bank over the next two 100-year episodes of coastal processes.[20]

A.14.5 Insufficient adaptation measures to reduce the Risks of Climate Change

Nuclear power plant structures, systems, and components (SSCs) important to safety are to be designed to withstand the external effects of natural phenomena such as tornadoes, hurricanes, or floods without loss of capability to perform their safety functions. Extreme values for wind, precipitation, snow, temperature and storm surges, based on empirical data from the weather

[20] https://www.umweltbundesamt.at/fileadmin/site/publikationen/rep0812.pdf

statistics, are used for calculating the design parameters and estimating the impact load from severe weather conditions.

The apparent increase of frequency and intensity of extreme weather conditions in the past few years has resulted partially in a re-assessment of potential consequences of such effects and heightening of the standards for NPP design.

The estimation of probabilities for extreme events resulting from climate change, however, is extremely difficult due to fact that there is no sufficient database for such estimates. Furthermore, because the situation is constantly evolving, any data that can be acquired may be outdated by the time their evaluation is concluded. **The time lag is still more drastic for the drafting of new rules and regulations by the authorities, and their implementation by the NPP operators**. **It seems hardly possible to win this race against time – particularly in the face of economic pressure that might lead to the result that only low-cost measures are realized.**

NPPs are designed to withstand very rare events. The probabilities of occurrence for licenses are usually derived from past data series using statistical methods. In a phase of climate change, however, these data series are no longer relevant, and the derivation procedures are no longer valid. It is a matter of forecasting the frequency of very rare events at certain locations, which must be derived from model calculations. Models, however, reflect the mean ratios much more reliably than extremes. Apart from a few special cases, science is overwhelmed with precise statements on the probability of occurrence of rare events. In flood protection and the construction industry, which would need similar statements, safety factors are sometimes added whose scientific validation is questionable. In the case of nuclear energy, this route is not recommended because the risk is too great in the case of under-dimensioning. (INRAG 2020)

In spite of the fact that the hazards of climate change are becoming more and more obvious, safety reassessments and improvements generally are only implemented – if at all – after an event occurred. This practice is aggravated by the fact that an event in one NPP does not necessarily lead to backfits in another plant.

The situation is more difficult because of the costs of climate change adaption measures. Even there are available, they could try to be avoid because of the high costs or if they will be done the high costs of energy production from NPPS will further increase. A study by the Electric Power Research Institute (EPRI) estimated the costs of replacing once through cooling with wet recirculating retrofits at plants in the US. The study found that the average cost calculated at net present value for a nuclear plant (average size 1538 MW) would be US $1.9 billion or US $1239/kW, including capital costs, extended outage revenue losses, and heat rate and energy penalties. The need for larger cooling towers translates into much higher construction costs. Dry cooling retrofits would approach the (theoretical) cost of building an entirely new nuclear plant.

A.15 Ignoring the Link between Civilian and Military Nuclear Energy

Nuclear weapon states remain the main proponents of nuclear power programs. The World Nuclear Industry Status Report (WNISR) 2018 offers a first look into the question whether military interests serve as one of the drivers for plant-life extension and new-build in some countries. Why is it that nuclear power is proving surprisingly resistant in particular places around the world, to dramatically changing global energy market conditions and structures for electricity supply? Against a backdrop of decline in the worldwide nuclear industry as a whole, plans for plant life-extension and nuclear new-build remain major areas of investment in a few specific countries. Intense attachments persist to projects like Hinkley Point C in the U.K., despite costs multiplying fivefold over original estimates, a series of still-unresolved technical difficulties and demands for escalating government financial concessions and guarantees.

In several countries, it may be that military drivers play a significant role in the persistence of what is otherwise increasingly recognized to be the growing obsolescence of nuclear power as a low-carbon electricity generating technology.

Technologies with such strikingly cumulative comparative disadvantages as nuclear would be abandoned in most other sectors. Therefore, serious questions arise as to why the declared commitments of some governments should remain so oddly intense around a nuclear option that under-performs so obviously across so many energy policy criteria.

A.15.1 Neglected military dimension of nuclear power

Nuclear reactors, whether small or commercial-size, are the only effective means to produce crucial fissile materials for nuclear weapons, like plutonium-239. The fuel supply chain for nuclear power, and uranium enrichment in particular, is the source for high-enriched uranium, the other main strategic, weapons-usable fissile material. All these ‘material links’ have been acknowledged for many years and described in great detail. But less well appreciated in public debate, are a set of ‘industrial interdependencies’—involving the wider nuclear skills, education, research, design, engineering and industrial capabilities associated with civil nuclear industries, that are also essential in many ways to the sustaining or introduction of nuclear weapons programs or their associated platforms and infrastructures.

Heavy water reactors and graphite-moderated designs like the Chernobyl-style RBMK or the French and U.K. natural uranium gas-graphite reactors were based on principles originally chosen to facilitate on-load refueling for production of plutonium required in nuclear weapons manufacture. Likewise, even the most modern variants of light water reactors are still built around basic engineering principles originally optimized for the confined spaces of nuclear-propelled submarines. Yet, even after many decades of opportunities to establish entirely new designs dedicated to civilian power production, these military-derived variants still account for almost all of the global civil nuclear power capacity worldwide. In fact, there exists no major commercial reactor design, whose basic configuration was optimized from first principles solely for safe or economic civilian power. A high proportion of leading designs for a currently much-vaunted ‘new generation’ of Small Modular Reactors or SMRs relate even more closely to contemporary nuclear submarine propulsion reactors.

An additional dimension to civil-military nuclear interdependencies has only come to light over recent years. This is the importance to government support of nuclear power in some countries of continuing commitments to build and maintain military, nuclear-propelled submarines. These machines are often identified as being among the most complex and demanding manufactured artefacts ever conceived. Security concerns are seen to require the sustaining of the entire range of necessary industrial capacities within a single country. Only in the last couple of years, are inside sources beginning to acknowledge that (even in large economies like that of the U.S.), it is difficult to sustain this military capability without a parallel civil nuclear power industry. High profile documents by industry bodies and senior policy figures openly urge that perceived needs to maintain the naval nuclear propulsion industry is a major reason to continue with otherwise-declining civil nuclear power.

There are, around the world, then, many major connections between civil and military nuclear industrial capabilities, skills, expertise and infrastructures. Thus, if civilian nuclear power and its associated specialist practices are to be allowed (like many earlier technologies) to go obsolete, then the nuclear establishments of a small number of countries that maintain *military* nuclear ambitions that would disproportionately be the losers.[21]

According to the positions asserted in national data published by the World Nuclear Association (WNA), the five largest-scale prospective nuclear new-build programs in the world are in four of the five 'official' nuclear weapons states. India is also pursuing an ambitious nuclear new-build program. And France is an illuminating exception, in that the scale of its existing reliance on nuclear power in itself militates against further large-scale national expansion. So large is the existing French civil nuclear fleet, that the associated national engineering base also required for military purposes, is much less under threat from nuclear decline than in other countries. But the *Le Monde* newspaper nonetheless does still highlight "the ultimate question an expert dares asking": "What would become of the credibility of our nuclear weapons program and our position at the UN [Security Council], if France were to renounce its [nuclear power] plants?"

The major state-held Russian nuclear construction and services company Rosatom is clear that the "[r]eliable provision of Russia's defense capability is the main priority of the nuclear industry". And in the U.S., the Nuclear Energy Institute, now strongly lobbies for subsidies for failing nuclear developments, on the grounds that abandonment of these will "stunt development of the nation's defense nuclear complex". Perhaps most significantly, former U.S. Energy Secretary Ernest Moniz, launched a report in 2017, which stated that "a strong domestic supply chain is needed to provide for nuclear Navy requirements. This supply chain has an inherent and very strong overlap with the commercial nuclear energy".

Accordingly, a memorandum leaked under the Trump administration in June 2018, reveals that recent regulatory measures to protect nuclear power reflect high-level perceptions that the civil nuclear industry is essential to national security, specifically including naval propulsion. Also in June 2018, "several dozen retired generals and admirals, former State, Defense and Energy Department officials, three former chairmen of the Nuclear Regulatory Commission, and a sprinkling of former senators, governors, industrialists and other worthies" wrote a letter to U.S. Energy Secretary Rick Perry[22], to commend him "for recognizing the important role our civil nuclear energy sector plays in bolstering America's national security" and to urge him "to continue to take concrete steps to ensure the national security attributes of U.S. nuclear power plants are properly recognized by policymakers and are valued in U.S. electricity markets".

The U.K. was one of the first developers of both nuclear weapons and commercial nuclear power. With early civil nuclear facilities documented to have been central to military plutonium production, joint civil-military nuclear ambitions are especially relevant in the U.K. Military nuclear standing is frequently emphasized as being central to elite British political identities on

[21] Conversely, for those hoping for long-stalled reversal in either horizontal or vertical nuclear weapons proliferation, it is possible that obsolescence of civil nuclear power as an energy source forms a potentially major global opportunity.

[22]

the world stage. So, it is no surprise that the U.K. should currently be pursuing declared nuclear new-build commitments that are exceptional in Europe.

Submarine reactor manufacturer Rolls Royce recently dedicated a major report in large part to the argument that a program of submarine-derived small modular reactors should be adopted in U.K. energy policy in order to “relieve the Ministry of Defence of the burden of developing and retaining skills and capability” on the military side.

These civil-military links are also highly visible in U.K. industrial strategy, with priority given to a nuclear ‘sector deal’ spanning both sectors together and with many new agencies and programs openly dedicated to achieving synergies between U.K. submarine and civil nuclear programs. The nuclear sector deal is particularly focused on facilitating ‘mobility’ between the civil and defense nuclear workforce as a key strategy to manage the skills challenge. It is stated in “The Nuclear Sector Deal ”that “the sector is committed to increasing the opportunities for transferability between civil and defense industries and generally increasing mobility to ensure resources are positioned at required locations” and that 18 percent of projected skills gaps can be met by ‘transferability and mobility’.

A.15.2 Example for Misuse of civilian technology for nuclear weapon

Urenco (short for Uranium Enrichment Company) emerged from a project 50 years ago in which Germany, Great Britain and the Netherlands wanted to develop the then novel centrifuge technology for uranium enrichment and bring it to application maturity.

Today, Urenco is the second largest uranium enrichment company in the world. The company is owned one-third each by Great Britain and the Netherlands, and one-sixth each by EON and RWE, albeit under the supervision of the German government. The corporation has four branches: Capenhurst in England, Almelo in the Netherlands, Eunice in the US state of New Mexico and Gronau in North Rhine-Westphalia. In Gronau, uranium hexafluoride (UF6) has been enriched in gas centrifuges since 1985 and then exported. The new type of process was much more energy-efficient, but had one major disadvantage: highly enriched uranium capable of producing nuclear weapons can also be produced in the gas centrifuges. For this reason, the Treaty of Almelo on 4 March 1970 stipulated that Urenco could only enrich uranium for civilian purposes and was subject to strict controls. However, this did not prevent blueprints from being stolen from the Almelo plant as early as 1975 and used for the nuclear weapons programme in Pakistan. This was also sold to North Korea, Libya and Iran in the 1980s.[23]

This incident in Urenco's past shows how difficult it is to ensure that the technologies are only available for civilian use. It is impossible, even in today's world, to protect the know-how of civilian technologies from unwanted access. It is even possible that digitalisation has made unauthorised theft easier.

A.15.3 Modernising the Arsenals

The fact that the nuclear threat is increasing is made clear by current developments: at the beginning of 2021, there are a total of 13,081 nuclear bombs, according to the Peace Research Institute SIPRI. That is 320 warheads fewer than in the previous year, but the reduction in nuclear potential is not a sign of disarmament. "It is primarily due to the US and Russia

[23] Deutschen Welle: Urenco: Der Atomkonzern und das Problem mit den Uranabfällen; Anika Limbach; 04.03.2020; https://www.dw.com/de/almelo-atomm%C3%BCll-urenco-atomanlage-uran/a-52578312 eingesehen 18.04.2020

dismantling retired warheads," SIPRI notes in its annual report. "The global dismantling of operational warheads appears to have stalled, and their numbers may be on the rise again."

In 2009, US President Barack Obama spoke of a vision of a world free of nuclear weapons. But instead of building on this, the nuclear power states are modernising their arsenals. Under Donald Trump, the development of new, especially smaller "tactical" nuclear weapons has been accelerated. Yet most of the "small nukes" still have the same destructive power of the Hiroshima bomb. Along with the USA, Russia is also in the process of modernising its entire arsenal and is expected to have completed this process by the mid or late 2020s. Already, a large part of the strategic arsenal has been renewed. The modernisation programmes of both states concern not only nuclear warheads, but also missile and aircraft systems. Russia has newly developed and stationed carrier systems both in the long-range range and in the medium-range range, which is particularly threatening for Europe. The other nuclear-armed states are also developing or deploying new weapon systems, according to the SIPRI report. China is in the process of significantly expanding its nuclear arsenal, and India and Pakistan also appear to be increasing their nuclear stockpiles.

“The Russian threat in the Ukraine war breaks a taboo and shows how far this development can lead. The increasing dissolution of the boundaries of possible deployment scenarios must be reversed as a matter of urgency.”

Part B – Contribution to Climate Mitigation

B.1 Unjustified Positive Light about the possible Climate mitigation of NPPs

B.1.1 Unrealistic Forecast about using nuclear energy

The JRC Report (Part A 3.2.1, p. 35ff and 3.2.2, p. 39ff) presents an assessment of using nuclear energy in terms of its contribution to climate protection according to Article 10 Para. 1 of the Taxonomy Regulation. The JRC Report compares the contribution made to climate protection by generating nuclear energy and other energy generation options in Part A 3.2.2, p. 39ff. **It is based on a very optimistic forecast about using nuclear energy in the EU in Part A 3.2.1, p. 35ff of the JRC Report.** (BASE 2021)

The JRC Report (Part A 3.2.1, p. 35ff) contains an estimate of the proportion of electricity generated using nuclear energy globally and in the EU in order to underline the great importance of using nuclear energy in Europe.

The JRC Report presents the contribution of nuclear power plants to greenhouse gas emissions in a very positive light. The forecast for the ongoing development of using nuclear energy for power generation in the EU, as presented in the JRC Report, is also clearly far too optimistic. The JRC Report quotes enormous volumes of new NPP capacities von 100 GW in 2050 (Figure 3.2-4), which is certainly overstated. A new capacity of 100 GW would correspond to the installation of around 60 to 80 new nuclear power plants.

With regards to the contribution to climate protection that could be made by the small modular reactors (SMR), the JRC Report does not discuss the fact that they are not yet ready for market introduction – nor does it cover the unresolved issues about safety, transportation, dismantling and disposal connected with this type of reactor. (See chapter A.13)

The JRC Report is too optimistic about the "substantial contribution" of nuclear energy, because building of nuclear power plants is too slow and too expensive. Many examples can be given. Poland started nuclear program in 1974, until now there is no NPP. Result of the “nuclear program” is that there is little development of renewables and coal plants are the main contributor to the energy supply. In the UK, M. Thacher called for more nuclear already in 1989, no new NPP is realized only two reactors are under construction today.

All in all, it can be stated that the statements in Part A 3.2.1 of the JRC Report about the further development of nuclear power for the electricity generation in the EU are presented in a far too optimistic way. The forecast is largely founded on one article, which is based on a model calculation. **This model calculation is taken over without any classification and without specifying any uncertainties.** The forecast that the share of nuclear energy of 22% will continue until the year 2050, while overall electricity production increases, presupposes a massive expansion of nuclear power plants in Europe. This expected massive expansion cannot be deduced given that just four nuclear power plants are being built in the EU right now and the “plan to operation time” NPPs is 10 to 19 years. (MRAZ et al. 2021)

Moreover, the JRC Report still uses the database of EU28, i. e. including Great Britain. Great Britain left the European Union on 31 January 2020 and made a major contribution to the installed capacity in the EU with its 15 reactors that are currently in service (8.9 GWe of installed capacity). (MRAZ et al. 2021)

The forecast presented in the JRC Report not only presupposes new construction of nuclear power plants, but also extensive retrofitting of the ageing nuclear power plants in the EU: the first cases of decommissioning of nuclear power plants in the JRC Report (Figure 2.3–4) are not envisaged until the year 2040. This would imply a lifetime for all the nuclear power plants within the EU of about 60 years, although this is unlikely because of shut-downs that have already been announced, including those in Germany. (BASE 2021)

Most of the nuclear power plants currently operating in the EU are more than 30 years old, 66 of the 106 currently in service in the EU are between 30 and 40 years old and 26 are actually more than 40 years old. (BASE 2021)

The nuclear power plants were originally designed for a lifetime between 30 and 40 years. The degree to which national authorities will actually approve a lifetime extension to the service life of old units in accordance with the current safety requirements is uncertain – as is required for the forecast in the JRC Report – and will depend on the status of the reactors concerned and the respective national regulatory framework. The problems with ageing related effects show that the lifetime extension is not always possible or only possible when a higher risk for the population is accepted and/or with high investments.

This very positive presentation of future prospects for nuclear energy, which is shown in the JRC Report, must be viewed critically. **Even if these forecasts cannot play a role when assessing nuclear energy according to the specific environmental objectives of the EU taxonomy, this presentation by the JRC is suspect from a professional point of view and possibly indicates a lack of adequate independence.**

Large parts of society struggle to accept nuclear energy. Moreover, development periods are rather long – 10–19 years for each power plant in democratic societies. (STAGL 2020)

Any major expansion of nuclear energy would delay the decommissioning of fossil-fired power plants, as the latter would have to remain in operation during this period and therefore make it hard to achieve the climate change mitigation objective. It is even possible to argue that nuclear energy hinders the use of other alternatives with low CO_2 emissions because of its high capital intensity. Otherwise, this capital could be used to expand alternative energy sources like sun, wind and water (STAGL 2020).

B.1.2 Incorrect calculation of the CO_2 emission from NPPs

The JRC Report (Part A 3.2.2) provides an assessment of the contribution made to climate protection by using nuclear energy. The contribution to greenhouse gas emissions made by using nuclear energy is presented in a very favourable light, particularly in relation to the threshold value that is currently set at 100 g of CO_2 g/kWh by the Technical Expert Group (TEG) in the Taxonomy Report Technical Annex[24]. However, the TEG clearly indicates, in contrast to the JRC Report, that this threshold value will be reduced every five years to achieve net zero emissions by 2050 – in line with the political goals to reach zero net emission by 2050. The JRC Report conveys the impression that the threshold value of 100 g of CO_2 g/kWh will remain constant during the next 50 years. (BASE 2021)

Another example of shortened statements in the JRC Report and the resultant optimistic presentation of the life-cycle-based greenhouse gas emissions when using nuclear energy is

[24] EU Technical Expert Group on Sustainable Finance (TEG): Taxonomy report: Technical Annex, Updated Methodology & Updated Technical Screening Criteria, March 2020.

Figure 3.2–6 (JRC Report, Part A 3.2.2, p. 40). The JRC Report does not mention that the literature of the World Nuclear Association (WNA, 2011)[25] used for the figure cites many factors that contribute to the discrepancies in the greenhouse gas emissions that are presented. One important factor according to WNA is the different definition of "life cycle" in the publications consulted. Some of the publications included waste management and waste treatment in the life cycle, while others did not. (BASE 2021)

Several calculations of the CO_2g/kWh emission of nuclear energy calculate higher values than 100 gCO_2 /kWh than calculated at the JRC Report.

A nuclear power plant is not a stand-alone system. The nuclear chain is comprised of three sections (STORM 2017):

- The front end of the nuclear chain comprises five processes (mining, milling, refining and conversion, enrichment, fuel fabrication) to produce nuclear fuel from uranium ore.
- The midsection encompasses the construction of the NPP plus operating, maintenance and refurbishment during its operational lifetime.
- The back end comprises the 12 processes needed to manage the radioactive waste, including dismantling of the radioactive parts of the power plant after final shutdown, and to isolate the radioactive waste permanently from the human environment.

Each process of the nuclear chain consumes thermal energy, provided by fossil fuels, and electricity: the direct energy input. In addition, all processes consume materials, the production of which also consumed thermal energy and electricity: the indirect energy input. By means of an energy analysis the direct and indirect energy input of the full nuclear system can be quantified. The figures of the specific CO_2 emission of the full nuclear energy system found by a detailed analysis are summarized to 117 ± 29 gCO_2/kWh.

JACOBSEN (2019) presented emissions from new nuclear of 78 to 178 g-CO_2/kWh, which is also more than stated in the JRC Report. For comparison, the comparable CO_2/kWh emission of energy production from wind (onshore) is 4.8-8.6 gCO_2/kWh.

B.2 Lock-in Effect of Nuclear Energy

Article 16 lit. (a) TR excludes activities that "*lead to a lock-in of assets that undermine long-term environmental goals, considering the economic lifetime of those assets*".

Definition: Lock-in describes the phenomenon that a technical and political system is difficult to bring onto a new path once it has developed a momentum of its own and is thus 'fixed or locked' on a certain path. With regard to long-term environmental goals, various lock-ins can be relevant, especially technological and economic lock-ins that are interconnected.

All in all, it is to conclude that use of nuclear energy leads to a considerable lock-in of assets.

[25] World Nuclear Association (WNA) (2011): Comparison of Lifecycle Greenhouse Gas Emissions of Various Electricity Generation Sources, July 2011, URL: *http://www.world-nuclear.org/uploadedFiles/org/WNA/Publications/Working_Group_Reports/comparison_of_lifecycle.pdf*, last consulted on 27 May 2021.

B.2.1 Economic 'lock-in'

Due to the very high initial costs of building nuclear power plants, amortisation of these costs is only possible if the plants have a long operation time. For this reason, the most licence holders of NPPs applied for a lifetime of old nuclear power plants beyond the planned lifetime of 30 to 40 years to 50, 60 or even 80 years. However, this will increase the risks. (see chapter A. 11) Furthermore, the backfitting measures required for license extensions to meet higher regulatory standards make considerable investments necessary.

Nuclear power is also highly capital-intensive. Nuclear power plants take almost ten years to build, and in the average about 20 years for the decommission.[26] The area will then lie fallow for a considerable period of time and cannot be used further. In addition, there are costs for decades (according to current estimates 100 years) of interim storage of radioactive waste and spent fuel elements, as well as for final storage for several 100,000 years. The costs for future taxpayers cannot yet be calculated because of the uncertainties that still exist and the problems that have arisen in the past.

Technology and market lock-ins can result from subsidised technologies with long lifetimes. If other technologies become more cost-efficient during the lifetime of a power plant, the market remains distorted for a considerable period of time. (STA GL 2020) This is already the case for nuclear power plants. The costs of renewable energy are already significantly lower than the cost of nuclear energy. Projections show a further increase in the cost of NPPs and a further decrease in the cost of renewables.

Nuclear power plants take a considerable time to build and have an economic lifetime of several decades. Nuclear power is also highly capital-intensive. The cost per kWh for small modular reactors (SMRs) will be even more expensive.

B.2.2 Technological 'lock-in'

Nuclear power plants can work in certain power range of about 50 to 100% of full power. They normally keep running on 100% power, because in the grid system it is easier to reduce wind power. The "must run" of nuclear power, limits the option for RE.

There are limits for NPPs in regulating energy output in lower electricity production (lower than 30%); and to shut down a NPP and just restart it again is not possible. In the low power range, more fission products accumulate, which absorb neutrons. This can lead to dangerous reactor conditions (neutron poisoning), the missing neutrons lead to a reduction in power, which is compensated by removing control rods. In the case of neutron poisoning, a reactor must be shut down until these fission products have sufficiently disappeared through radioactive decay. This is to be avoided and it is best not to let the reactor go below a certain power limit or to shut it down completely, but then it cannot be started up again immediately.

On top is the problem, that nuclear is the most expensive electricity production and reducing the full power hours will further increase the cost per kWh and the total system cost.

More details see in the chapter B.3.2 problematic load follow operation.

[26] The average worldwide duration of the decommissioning process, independent of the chosen strategy, has been around 20 years, with a very high variance: the minimum of six years for the 22-MW Elk River plant, and the maximum of 42 years for the 17-MW CVTR (Carolinas-Virginia Tube Reactor), both small reactors, both in the U.S. (WNISR 2021)

B.2.3 Ecological 'lock-in’

Environmental lock-in refers to the self-perpetuating inertia created by nature-consuming energy systems that inhibits public and private efforts to adopt alternative energy technologies. There can be numerous environmental constraints associated with nuclear energy. The first is finding suitable sites for nuclear power plants: A difficult task, as a suitable site requires low population density, exclusion of natural disaster areas and access to massive water resources (ABBOTT 2011; STAGL 2020).

After 70 years of using nuclear energy, the issue of storing highly radioactive waste with its very long-term consequences is still being not solved, mainly because of uncertainties due to unforeseen geological conditions and radioactive leakage into groundwater. (STEGL 2020)

Furthermore, the clean-up of uranium mines remains an unresolved issue, as thousands of abandoned uranium mines exist in different parts of the world, the land that cannot be used for other purposes for a long time. (see chapter A.2)

B.2.4 Military-driven ‘lock-in’

A recent published paper focuses on the causal determinants of the accumulation of nuclear weapons, also known as vertical nuclear proliferation, in China, France, India, Pakistan, Russia, UK, and the US. It empirically analyzes the causal relationships between the civilian uses of nuclear energy, military expenditures, trade openness, and the stockpiling of nuclear warheads. It is stated: “*A potential nuclear power lock-in into their energy systems induced by vertical proliferation aspirations is also plausible for some of the states*.” The authors suggest that military nuclear relationships affect energy system developments and impede a nuclear phase-out in the seven states. Emphasizing the mutually beneficial relationship between a state’s nuclear warhead stockpiles and its civil nuclear capabilities helps to explain nuclear incumbency and the future use of nuclear power in nuclear armed states.[27]

B.3 Inflexible NPPs cause “System conflict”

B.3.1 System conflict versus “bridge technology”

The Institute for Advanced Sustainability Studies (IASS) in Potsdam published a study evaluate the question ”*Is a decarbonized electricity system with a mix of fluctuating renewables and nuclear reasonable*?” in January 2018. It is explained that the Germans have known about the “Systemkonflikt” (system conflict) between nuclear and wind & solar for a decade. The English-speaking world continues to debate what “dispatchable” means, whether wind and solar are “intermittent” or “variable”. The German debate knows no such confusion. Gas turbines are quickly dispatchable; inflexible baseload is not. Inflexible baseload (like nuclear power plants) is incompatible with fluctuating wind and solar. (IASS 2018)

Claims about nuclear being necessary towards “deep decarbonization” are often based on misunderstandings about Germany, specifically claims that Germany has needed coal to replace nuclear. In fact, Germany replaced the power from the eight reactors closed in 2011 with new renewables in only three years and had less coal power in 2016 than in 2010.

All talk of nuclear as a possible “friend” of wind and solar or as a “bridge technology” stems from a wish to make everyone happy. This approach overlooks technical conflicts. Germany

[27] Warheads of Energy: Exploring the Linkages between Civilian Nuclear Power and Nuclear Weapons in Seven Countries: Lars Sorge, Anne Neumann, In: *Energy Research & Social Science 81 (2021), 102213, 17 S.*

has moved beyond such political compromises and accepts physical realities in energy policy. The so called “Energiewende” identifies enemies: if significant shares of fluctuating wind and solar are the goal, inflexible baseload must go, and nuclear is the least flexible source of baseload power. (IASS 2018)

The term “bridge technology” for nuclear power was probably first used in 1996 by the Commission of German Bishops[28]. The idea was that renewables needed time to grow, and nuclear would give them the time needed. The label was intended to placate both camps in the debate: nuclear could stay on for now, but renewables would eventually push it out. Its coinage was not based on any scientific findings showing that nuclear would be a good – or perhaps even the best – bridge for renewables; rather, the term stemmed from a political desire to please everyone. (IASS 2018)

In April 2009, the Environmental Ministry published a paper entitled, “Nuclear power as an obstacle.” (BMUB 2009). It argued: A power supply based largely on renewables does not need baseload power plants, but flexible backup capacity (specifically, combined-cycle gas turbines, even though open-cycle turbines ramp the best). It depicted nuclear reactors as the least flexible facilities in the traditional power plant fleet.

The German Advisory Council on the Environment (SRU) followed up with another study in May 2009.[29] It found that:

- 100% renewable electricity is possible and preferable to other options;
- and a large fleet of baseload power plants is incompatible with further renewable energy growth.

The study included a chart showing what became known as the “residual load” (power demand minus renewable power generation), which conventional plants would have to cover.

In 2010, the BEE produced its own idealized version, clearly showing that the residual load would completely disappear over the course of a week – only to come roaring back a day or so later. (see Figure 4) Whatever backed up renewables would need to disappear from the grid entirely for hours at a time, then remain online at a very low level for additional hours, and then ramp up significantly. (IASS 2018)

[28] Vogt, Prof. Markus. "Wissenschaftliche und technische Aspekte einer sicheren Energieversorgung aus der Sicht Christlicher Sozialethik Statement zur Öffentlichen Tagung der Ethikkommission." 1996. www.kaththeol.uni-muenchen.de/lehrstuehle/christl_sozialethik/personen/1vogt/texte_vogt/vogt_sichere_energie.pdf

[29] SRU “Weichenstellungen für eine nachhaltige Stromversorgung.” Press release from 28 May 2009. www.umweltrat.de/SharedDocs/Pressemitteilungen/DE/2009/2009_04_pressemitteilung.html?nn=9732658.

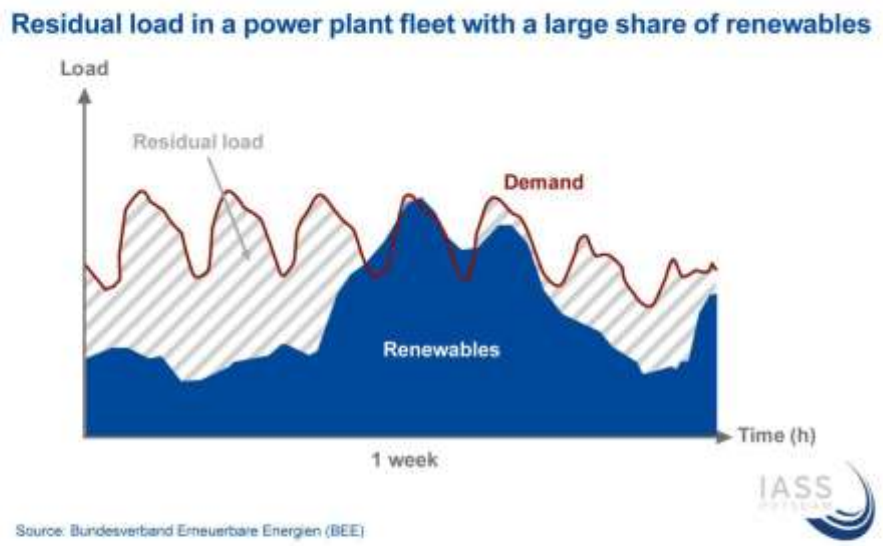

Figure 4: Residual load power plant fleet with a large share of renewables (Source: IASS based on data provided by the Bundesverband Erneuerbare Energien (BEE)). (IASS 2018)

To conclude: Germany's nuclear phaseout is partly based on an understanding that baseload cannot flexibly accommodate fluctuating wind and solar, with nuclear being the least flexible of all conventional options. A discussion about this "inherent conflict" (Systemkonflikt) took place roughly from 2008-2011; the second phaseout of 2011 put an end to the debate. That phaseout also marked the point when Germany became the focus of international attention; the previous discussion in Germany about the flexibility of nuclear thus went largely unnoticed abroad. (IASS 2018)

Those calling for a "balanced" mix of nuclear, wind, and solar assume that nuclear reactors can ramp up and down sufficiently to back up wind and solar. Experts in Germany argued a decade ago that baseload is synonymous with inflexibility, which in turn is incompatible with fluctuating wind and solar power. The Germans coined the term "Systemkonflikt" (system conflict) for the incompatibility of nuclear with wind and solar. This German insight has entered the international debate quite strongly in the past few years as criticism of the need for baseload.[30] (IASS 2018)

B.3.2 Problematic Load-Following-operation of NPPs

A nuclear power plant is a thermal power plant. The difference to fossil fueled power plants consists of the fact, that steam is produced by nuclear fission. Nuclear fission takes place inside the reactor vessel in the reactor core. The thermal energy (thermal power) generated by the nuclear fuel is transferred to the coolant. The coolant can be used to produce steam directly (BWR) or via the steam generator and heat exchanger (PWR). Like in other thermal power plants the steam drives the turbine and after the generator.

Mostly NPP are operated as base-load plants at a steady power level of 100%. Startup, shutdown and load changes are very infrequent. Pressurized water reactors (PWR) can rebalance small disturbances by inherent self-regulation. Thus, nuclear plants can contribute to

[30] Most notably, the 2017 edition of REN21's Global Status Report contains a chapter on "Deconstructing baseload." Global Status Report 2017. http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf

the stabilization of the grid frequency. Operating NPP in Europe are mainly working in base load. Their flexibility is limited a few two percent of nominal power.

Operating NPP in load following mode causes technical disadvantages, because plant components are exposed to numerous thermal stress cycles; this leads to faster aging and requires more sophisticated systems for reactor monitoring and control. An economic disadvantage of load following operation of NPP in a larger power range occurs if the plants are operated on reduced power.

For new plants (under construction and planned) load following suggested to be fully implemented. But there is not much experience from operation practice. Investigations into the possible impacts of load following operation are limited and do not allow conclusions on the impacts in future.

Due to economic aspects the new nuclear plants currently under construction or planned in Europe have a high capacity of 1200 to 1700 MW. Even if a high flexibility is promised for the new reactors, some more research will be necessary until load following with the necessary capability can be implemented. However, until now no Generation III reactor is operating in Europe. Controlling the reactor core during load following is challenging and difficult also for advanced reactors, in particular for reactors with large cores.

With respect to nuclear power plants, responsiveness of currently available light water reactors (LWR) is challenged by neutron poisons – in particular the isotope xenon-135 (xenon). Xenon is a powerful thermal neutron absorber (poison) and will capture neutrons otherwise available for fission of the reactor fuel. It is produced directly and indirectly from fission in all reactors.

The time periods, frequency of adjustment and response time required in load following are in direct conflict with the nature of xenon transients at NPP. For this reason, most NPP operators choose not to subject their facilities to load following operating modes.

Withdrawing control rods increases core reactivity. As a poison, xenon absorbs neutrons and therefore reduces core reactivity with increasing concentration. The time periods, frequency of adjustment and response time required in load following are in direct conflict with the nature of xenon transients at NPP. For this reason, most NPP operators choose not to subject their facilities to load following operating modes. (NUTTAL 2009)

B.3.2.1 Aspects of Load-following Constraints in Germany and France

In the above mentioned IASS study a deeper view in the load following activities in France is presented. It is explained that a look at the data by generation unit during a day reveals that five reactors adjusted their output, each quite dramatically, on that day (with one replacing another during the course of the day). If 40 of France's 58 reactors are indeed capable of following load, they obviously take turns. They do not all adjust output slightly; rather, as few of them as possible adjust output as much as possible so that as many reactors as possible do not have to change output at all. It is also clear, that countries with do not have a large fleet cannot cover this approach. (IASS 2018)

In a paper investigating power generation and wholesale prices, Fraunhofer ISE found that German nuclear reactors never fell below 70% of output regardless of how low prices got. Indeed, on several days one finds the nuclear fleet running closer to 80% of rated output even though the spot price has fallen below **minus 50 €/MWh** – easily 80 €/MWh below the marginal operating cost of nuclear. (IASS 2018)

These two short examples demonstrate the difficulties of load-following operation. In France, the operator avoids actual load-following operation of the entire fleet but shuts down some reactors for a longer period of time. In Germany, the operator also avoids load-following operation, accepting negative prices for the energy generated.

Note: In recent years, increased oxide-thickness on the fuel rods has been detected at several nuclear power plants in Germany. To limit the corrosion mechanism, among other measures a restriction on load-following operation has also been established.[31]

B.3.3 NPPs operator Call for Limits of the Energy Share

EDF and EON call in 2009 for a limit on the share of renewables so that NPPs are not hindered, this clearly proves that investment in nuclear energy hampers investments in renewables energies.

The Eon Group wants to put the brakes on the development of renewable energies. Together with its French competitor Électricité de France (EdF), Germany's leading electricity supplier is sounding the alarm: the more wind, hydro or solar power is developed, the more the nuclear industry will fall behind.

In its statement for the current British hearing, Eon stresses that renewable energies should not be promoted "indefinitely". The government must set a maximum limit for their share of total electricity generation. Eon recommends a maximum of 33 percent; EdF demands an even lower threshold of 20 to 25 percent of electricity production.

The electricity giants' braking manoeuvre is justified in this way: Wind and solar power are subject to strong "fluctuations", which means they require very flexible market mechanisms. However, this is precisely what so-called base-load power plants do not offer. Lignite-fired and especially nuclear power plants operate quite cheaply, but their ramp-up and ramp-down is costly. The more wind and solar power are taken into account in the energy mix, the more flexibly power plants have to react and the more their profitability is affected, argues Eon.[32]

B.3.3.1 EDF was spying Greenpeace

EDF as the operator of the nuclear power plants supply in France, spied Greenpeace, which means promoting RE is a danger for EDF. In November 2011, France's state energy firm EDF has been fined €1.5m by a Paris court for spying on Greenpeace. Its head of nuclear production security in 2006 was given a three-year sentence with two years suspended, and a €10,000 fine for commissioning the spying. The Nanterre court also sentenced the security No 2 in 2006 to three years, 30 months suspended. EDF has also been ordered to pay €500,000 in damages to Greenpeace. In 2006, EDF hired a detective agency, Kargus Consultants, run by a former member of France's secret services, to find out about Greenpeace France's intentions and its plan to block new nuclear plants in the UK. The agency hacked the computer of Greenpeace's then campaigns director, taking 1,400 documents.[33]

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[31] Reaktor-Sicherheitskommission (RSK): Erhöhte Oxidschichtdicken im oberen Bereich von Brennstäben mit M5-Hüllrohren; Empfehlung der Reaktor-Sicherheitskommission (RSK) am 12.02.2020

[32] Frankfurter Rundschau: Stromriesen contra Windkraft; 25.03.2009 https://www.fr.de/wirtschaft/stromriesen-contra-windkraft-11479534.html

[33] The Guardian: EDF fined €1.5m for spying on Greenpeace, 10. November 2011; https://www.theguardian.com/environment/2011/nov/10/edf-spying-greenpeace

B.3.4 Outdated Arguments for the need of NPPs

Stabilizing the climate is urgent, but nuclear power is slow. It meets no technical or operational need that these low-carbon competitors cannot meet better, cheaper, and faster. Even sustaining economically distressed reactors saves less carbon per dollar and per year than reinvesting its avoidable operating cost (let alone its avoidable new subsidies) into cheaper efficiency and renewables. (WNISR 2019)

Whatever the rationales for continuing and expanding nuclear power, for climate protection it has become counterproductive, and the new subsidies and decision rules its owners demand would dramatically slow this decade's encouraging progress toward cheaper, faster options, more climate-effective solutions of renewables. (WNSIR 2019)

Worldwide, nuclear is already significantly more expensive than major alternatives like solar photovoltaics (PV) and wind power and the disadvantage is growing fast. Available cost-effective energy resources from these renewables are huge, and their modularity, small unit size and short lead times typically make them a more rapid means to carbon emissions abatement. Where once nuclear advocates claimed that 'firm' (inflexibly-steady) nuclear output is an advantage, grid operators now recognize that new network technologies render the underlying idea of 'base load' power to be "*outdated*".

Objections to renewables other than cost-effectiveness are often raised, whether expressed as technical issues or as hidden costs. These become ever less convincing as experience gives grid operators comfort with new ways of operating power systems, and as major heavy-electricals firms like General Electric, Siemens, Schneider and Asea Brown Boveri (ABB) refocus their skills from nuclear power to distributed and renewable energy systems. (WNSIR 2019)

There is the discussion of the main arguments:

Baseload: The "baseload" concept that grid stability needs gigawatt-scale, steadily operating thermal (steam-raising) power plants reflects the valid economic practice of dispatching power at least operating cost, so resources with lowest operating costs are run most. This traditional role of giant thermal plants led many people to suppose that such plants are always needed. But now that renewables with no fuel cost are taking over the "baseload" role of being dispatched whenever available, those big thermal plants are relegated to fewer operating hours, making the term "baseload" an obsolete honorific. Thermal plants must now adapt to follow the net load left after cost-effective efficiency, demand response, and real-time "base-cost" renewable supply have been dispatched. Nuclear power's limited flexibility, and its technical and economic challenges when cycled, have thus become a handicap, complicating least-cost and stable grid operation with a rising share of zero-carbon, least-cost variable renewables.[34] That is why Pacific Gas and Electric Company (PG&E) in the United States found that early closure of its well running Diablo Canyon reactors would save customers money and, by making the grid more flexible, raise renewables' share. (WNISR 2019)

Storage: Keeping the grid reliable as solar photovoltaics and wind power (both with accurately forecastable but large variations in output) come to dominate electric generation requires changes in markets, institutions, operations, habits, and mental models. This has proven feasible

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[34] Amory B. Lovins, "Do coal and nuclear generation deserve above-market prices?", *The Electricity Journal*, Vol.30, Issue 6, July 2017, see https://doi.org/10.1016/j.tej.2017.06.002 , notes 58–68; and C. Morris, "Backing up Wind and Nuclear Power", 2015, see www.renewablesinternational.net/backing-up-wind-and-nuclear-power/150/537/86412/..

in both theory and practice, as illustrated by national statistics' reports of 75 percent renewable coverage of annual electricity consumption in Scotland (2018), 72 percent in Denmark (2017, domestic production only), 67 percent in Portugal (2018), 40 percent in peninsular Spain (2018). Solar and wind power don't need massive batteries so they can produce power steadily like big thermal plants; rather, at least eight classes of grid flexibility resources exist[35] besides bulk electrical storage and fossil-fueled backup are proven, available, cost-effective, and sufficient.[36] (WNISR 2019)

Backup: An argument often claims that more renewables mean steeply rising grid integration costs. But such effects would be worse for nuclear-dominated grids because nuclear plants are bigger, more transmission-dependent, and more prone to sudden, lengthy, unpredictable failures (see for example Belgium and France). No kind of plant is running 24/7/365, but failure is more consequential in big units. Variable renewables' "firming costs"—the cost of diversification (which may include network expansions), backup, storage, or other ways to ensure reliability standards remain low even at high renewable fractions. Either way, renewables generally have lower backup needs and costs than nuclear plants, despite solar and wind power's much lower capacity factors. (WNISR 2019)

B.4 Alternatives for Energy supply available

B.4.1 Feasibility of highly Renewable Scenarios

In the scientific magazine "Renewable and Sustainable Energy Reviews" a comprehensive article was recently published. It was the answer to an article that called into question the feasibility of highly renewable scenarios.[37] **As a result, Brown et al. (2018) conclude that the 100% renewable energy scenarios proposed in the literature are not just feasible, but also viable**. **100% renewable systems that meet the energy needs of all citizens at all times are cost-competitive with fossil fuel-based systems, even before externalities such as global warming, water usage and environmental pollution are taken into account**.

The authors of "burden of proof..."claim that a 100% renewable world will require a 'reinvention' of the power system. However, Brown et al. (2018) have shown that this claim is exaggerated: only a directed evolution of the current system is required to guarantee affordability, reliability and sustainability.

B.4.2 Energy production from Biomass supporting energy production from VRE

In Germany, about 50.4 billion kWh (11 %) of electricity was provided from biomass and biogenic waste in 2021. The installed capacity increased by about one percent to 10,431 MW

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[35] 1. Efficient use; 2. unobtrusively flexible demand; 3. modern forecasting of variable renewables' output (often more accurately than demand); 4. diversifying those variable renewables—wind and solar PV—by type and location; 5. dispatchability—integrating wind and solar PV portfolios with the other renewables (not counting big hydropower, which could also be integrated more effectively than now and with cogeneration that must run anyhow to satisfy its thermal loads; 6. distributed thermal storage worth buying anyway, or managed thermal storage in buildings' existing thermal mass; 7. distributed electrical storage worth buying anyway (e.g. smart charging and discharging of electric vehicles bought to provide mobility); 8. hydrogen, now most likely from renewable electricity

[36] Amory B. Lovins, "Reliably integrating variable renewables: Moving grid flexibility resources from models to results", *The Electricity Journal*, Volume 30, Issue 10, December 2017, see https://doi.org/10.1016/j.tej.2017./11.006.

[37] Heard B, Brook B, Wigley T, Bradshaw C. Burden of proof: a comprehensive review of the feasibility of 100% renewable-electricity systems. Renew Sustain Energy Rev 2017; 76:1122–33. http://dx.doi.org/10.1016/j.rser.2017.03.114.

in 2021. Compared to 2016, the increase in installed capacity is about 20 percent. However, the expansion of biomass plant capacity in recent years has primarily served to make electricity generation more flexible. This so-called "overbuilding" has hardly led to an increase in the amount of electricity generated annually in recent years, but it does ensure that renewable electricity can be provided more flexibly in line with demand (i.e. for example in times of low wind and PV electricity (VRE) generation).[38]

B.4.3 Example Switzerland - PV as Alternative to Nuclear Energy

A recent published report suggests that nuclear power is by no means the best option for ensuring security of supply in Switzerland: The Swiss Energy Foundation (SES) commissioned the Berlin-based economic research institute DIW to conduct a study on the effects of extending the operating times of the Swiss nuclear power plants compared to an increased expansion of solar energy. (DIW 2022) The experts clearly came to the conclusion that solar is the better choice. Switzerland currently has a total of four active nuclear power plant units, of which the two oldest (Beznau 1 and Beznau 2) are to be taken off the grid by 2035 at the latest. The study, led by Christian von Hirschhausen, uses four modelled scenarios to shed light on how different measures for supply security could develop. The measures include, on the one hand, extending the operating times of the two newer reactors, Gösgen and Leibstadt, but also the alternative of driving forward the expansion of solar energy more quickly and to a greater extent.

Scientists confirm that the Swiss nuclear power plants have relatively high production values in international comparison. But in the event of unplanned outages, safety-related rapid shutdowns and prolonged repair times, there is a considerable supply risk in the event of a lifetime extension, according to the experts. Especially in the months of March and April, supply security is critical, the report continues. This is mainly due to the high share of storage hydropower plants, as the reservoir level is usually very low during this period. If additional power reserves, for example, in the form of gas-fired power plants or a strategic energy reserve through hydropower were not taken into account, the generation capacity would already be too low at the beginning of March to guarantee security of supply in the event of a nuclear power plant outage.

The scientists base their assessment that the expansion of solar energy will lead to improved security of supply compared to a nuclear power plant lifetime extension on the fact that PV-based energy systems are less susceptible to large-scale unplanned outages, as is the case with nuclear power. Therefore, in the PV scenario, gas-fired power plants can be completely dispensed with and the purchase of expensive storage water reserves can be minimised, the report concluded.[39]

B.4.4 Visegrád countries - Controllable renewable energies as an Alternative to NPPs

In the next decade, the need for investment in controllable power generation in Europe will grow strongly. Meanwhile, photovoltaic (PV) and wind plants have very favourable power generation costs, but their power generation is not controllable. Their integration into the electricity grids increases the flexibility requirements for other grid users. A controllable renewable energy power plant (seE power plant) consisting of photovoltaic (PV) and wind

[38] Umweltbundesamt: Erneuerbare Energien in Zahlen; https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-in-zahlen?sprungmarke=strom#strom

[39] Efahrer.com: Mehr Versorgungssicherheit als mit Atomkraft: Studie sieht Solarstrom vorne; 17. Juli 2022 https://efahrer.chip.de/news/strom-studie-testiert-solarausbau-sichert-versorgung-besser-als-atomkraftwerke_108536

plants for cheap primary energy use and electrolysers with gas-fired power plants for controllability and thus security of supply is a technically conceivable solution. (ENERGY BRAINPOOL 2018)

When there is strong solar radiation and high wind speeds, surpluses occur; at other times, the demand for electricity cannot be fully met. If the electricity that cannot be used directly is used for the process of electrolysis, oxygen and hydrogen are produced from water. The latter is now enriched with carbon dioxide, and methane is produced in this methanisation process with the use of energy. Methane and to some extent hydrogen can be fed into the gas grid and stored in gas storage facilities. Various gas power plant technologies can use methane and in part also hydrogen to provide electricity according to demand; the controllability of the system is guaranteed. (ENERGY BRAINPOOL 2018)

The Visegrád countries are planning to build nuclear power plants with a total net capacity of 15.6 GW. An alternative is a controllable renewable energy power plant consisting of fluctuating generation on the one hand and electrolysers with methanisation and gas-fired power plants for controllability on the other. It produces electricity at comparable costs with consistent supply security, high energy independence and minimal climate impact. The average LCOE for such a power plant system that converts surplus electricity into electrolysis gas across the Visegrád states and distributes it via the European gas grid in the states according to demand, the costs are 120 EUR_{2016}/MWh in 2027 and 100 EUR_{2016}/MWh in 2035. (ENERGY BRAINPOOL 2018)

A profitability calculation based on the electricity production costs of nuclear power plants shows that planned values and literature values of 55 to 89 EUR_{2016}/MWh are often significantly exceeded in the more recent projects. For Flamanville, electricity production costs of 87 to 126 EUR_{2016}/MWh are to be expected due to high cost increases, Hinkley Point C receives financial support of 119 EUR_{2016}/MWh. (ENERGY BRAINPOOL 2018)

B.5 Investing in Renewables Save More Carbon per Year and Dollar

The foregoing evidence suggests that closing many, perhaps most, operating nuclear units will not directly save CO_2, but can indirectly save more CO_2 than closing a coal-fired plant, if the nuclear plant's larger saved operating costs are reinvested in efficiency or cheap modern renewables that in turn displace more fossil-fueled generation. Therefore, closing both coal plants and costly-to-run nuclear plants (with reinvestment of avoided operating costs and subsidies) makes sense—the former to save carbon directly, and the latter to save money whose climate-effective reinvestment can then save more carbon. So can the billions of dollars' new subsidies to induce those plants' owners to keep them running, such as US$16.5/MWh in Illinois. Those avoided costs can then be reallocated, voluntarily by the owner or compulsorily by regulators, to more climate-effective investments that cost less and hence save more carbon per dollar. (WNISR 2019)

Deployment speed depends on both installation rate and project lead time. (WNISR 2019) An assessment finds that new nuclear plants take 5–17 years longer to build than utility-scale solar or onshore wind power[40], so existing fossil-fueled plants emit far more CO_2 while awaiting substitution (for example 62–102 gCO_2/kWh more, equivalent to 11–18 percent of average U.S. grid carbon intensity). (WNISR 2019)

The National Renewable Energy Laboratory (NREL) expected in 2018 that onshore wind power would get 27 percent cheaper during 2016–2050 and photovoltaics 60 percent, so by 2050 they should cost respectively around US$27/MWh and US$18/MWh in good sites. **Nuclear new-build thus costs many times more per kWh, so it buys many times less climate solution per dollar, than these major low-carbon competitors**. **That reality could usefully guide policy and investment decisions if the objective is to save money or the climate or both. This gap is widening as nuclear costs keep rising and renewable costs falling.**

The International Energy Agency (IEA) agrees that Solar PV costs fell by 65 percent between 2012 and 2017, and are projected to fall by a further 50% by 2040; onshore wind costs fell by 15% over the same period and are projected to fall by another 10–20% to 2040.[41] (WNISR 2019)

B.5.1 Development of energy production from nuclear energy and Renewables

Through 2015, modern renewable energy globally was growing faster than nuclear power ever had; through 2018. The world's most aggressive nuclear program (in China) has been outgenerated by China's wind power since 2013, and 2.2:1 by China's non–hydro renewable portfolio in 2018. The corresponding Indian factor is 3.1-fold. (WNISR 2019)

The pace of wind deployment has picked up again and, despite the difficult conditions during the COVID-19 pandemic, the deployment of wind power was thriving in 2020 with a net increase in global capacity of 111 GW a near doubling of the 58 GW addition in 2019. Solar PV increased by 127 GW, a 22.5 percent increase over the 97.6 GW expansion in 2019. (WNISR 2021)

Figure 5 illustrates the extent to which renewables have been deployed at scale since 1997, an increase in capacity of 716 GW for wind and of 707 GW for solar.

[40] Mark Z. Jacobson, "Evaluation of Nuclear Power as a Proposed Solution to Global Warming, Air Pollution, and Energy Security", *Cambridge University Press*, 15 June 2019, see https://web.stanford.edu/group/efmh/jacobson/WWSBook/WWSBook./html.

[41] International Energy Agency (IEA): "Nuclear Power in a Clean Energy System", May 2019, see https://webstore.iea.org/download/direct/2779?fileName=Nuclear_Power_in_a_Clean_Energy_System.pdf

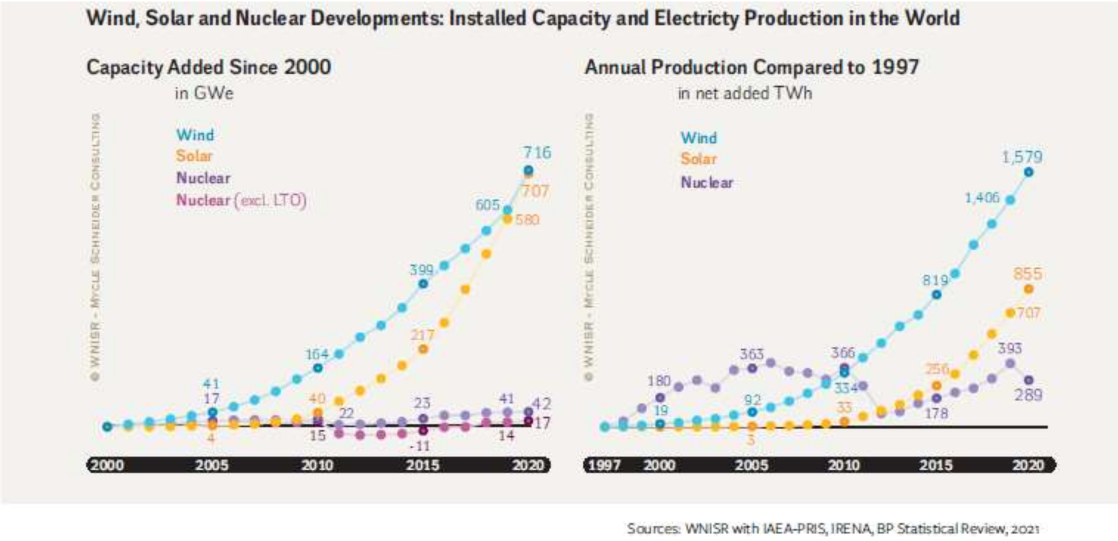

Figure 5: Wind, Solar and Nuclear Development: Installed Capacity and Electricity in the world (WNSIR 2021)

In 2019, for the first time, non-hydro renewables (solar, wind, and mainly biomass) generated more power than nuclear plants. In 2020, with the significant drop of nuclear output, the gap widened, and renewables generated globally 16.5 percent more electricity than nuclear reactors. (WNISR 2019)

The International Energy Agency (IEA) is struggling to improve its renewables forecasting: since 2002, it has raised wind power forecasts sixfold and solar forecasts 23-fold without ever catching up with reality, so installed solar capacity is now over 50 times the 2002 forecast. That's because IEA's renewable cost projections lag the market, and because its forecasting model, like other conventional economic models, is structurally unable to handle increasing returns. (WNISR 2021)

In preparation for COP26, the IEA published a report outlining a strategy for the energy sector to meet the temperature targets of the Paris Agreement, and concluded that in their scenario "*by 2050, almost 90% of electricity generation comes from renewable sources, with wind and solar PV together accounting for nearly 70%*".[42] This is a remarkable perspective from the IEA, which in its scenarios has so long underestimated and downplayed the role for renewable energy. (WNISR 2021)

B.5.1.1 Development of energy production from nuclear energy and Renewables in EU

In the European Union (EU), renewables, including hydro, continue to grow and for the first time they overtook fossil fuels to become the primary source of power in 2020. Renewables rose to generate 38 percent of Europe's electricity in 2020 (compared to 34.6 percent in 2019), with fossil fuels falling to 37 percent. Coal fell by 20 percent in the year, halved its production from 2015, and gas-produced electricity decreased by 4 percent. Nuclear generation fell by 11 percent, its largest fall since 1990. Wind generation rose 9 percent in 2020 and solar production rose 15 percent, together generating a fifth of Europe's electricity in 2020 (wind 14 percent, solar 5 percent). (WNISR 2021)

2020 is the first time that non-hydro renewables generate with 702 TWh more power than nuclear reactors with 652 TWh (688 TWh gross) in the EU27 (see Figure 6).

[42] IEA, "Net Zero by 2050 – A Roadmap for the Global Energy Sector", International Energy Agency, May 2021, see https://www.iea.org/reports/net-zero-by-2050, accessed 28 Auguste 2022.

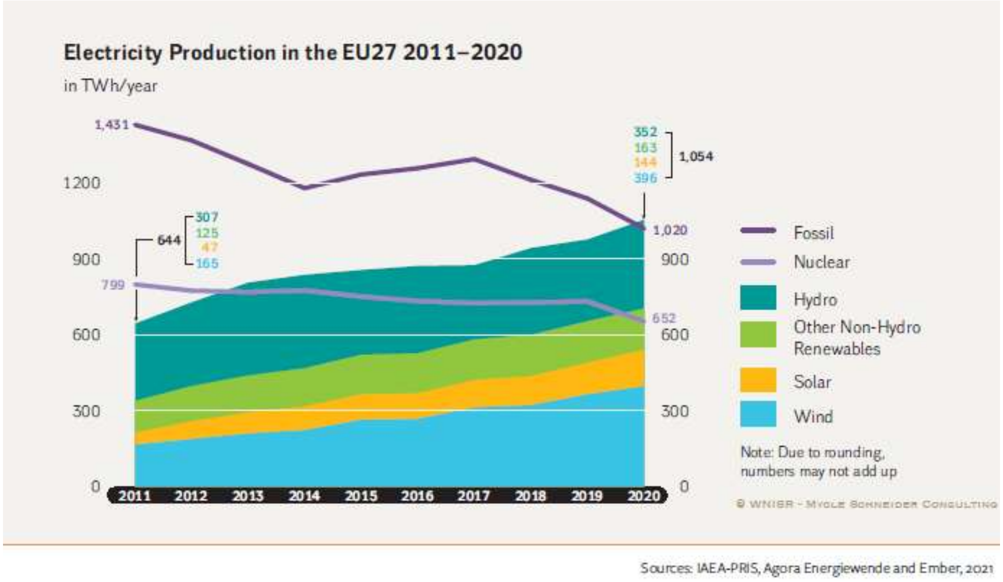

Figure 6: Electricity Generation in the EU27 by Fuel 2011-2020 (WNISR 2021)

B.5.2 Cost Advantage of Renewables Energies compared to NPPs

B.5.2.1 Levelized Cost of Energy 2020 (LCOE)

The annual Levelized Cost of Energy (LCOE) analysis for the U.S. last updated by Lazard, one of the oldest banks in the world, in October 2020([43], suggests that unsubsidized average electricity generating costs declined between 2015 and 2020 in the case of solar PV (crystalline, utility-scale) from US$64 to US$37 per MWh, and for onshore wind from US$55 to US$40 per MWh, while nuclear power costs went up from US$117 to US$163 per MWh. **Over the past five years alone, the LCOE of nuclear electricity has risen by 39 percent, while renewables have now become the cheapest of any type of power generation. (WNISR 2021)**

Since 2009, when Lazard started publishing its LCOE estimates in the current format, solar PV costs dropped by 90 percent, onshore wind by 70 percent, while nuclear power increased by one third. (WNISR 2021)

In their annual review of renewable energy costs, the International Renewable Energy Agency (IRENA) concludes: "*In 2020, the global weighted-average levelized cost of electricity (LCOE) from new capacity additions of onshore wind declined by 13%, compared to 2019. Over the same period, the LCOE of offshore wind fell by 9% and that of utility-scale photovoltaics (PV) by 7%.*"[44]

As the share of variable renewables (VRE), such as solar and wind, increases there will be challenges for grid management. System flexibility will be key, with a variety of solutions available, such as energy storage in various forms, demand side management, interconnection, and backup generation. Even with relatively high levels of VRE the technologies and costs are widely known. An assessment undertaken by the UK Energy Research Center found that median values for operating reserve costs were less than €5/MWh (US$6/MWh) when VRE

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[43] Lazard, "Levelized Cost of Energy and of Storage – 2020", 19 October 2020, see http://www.lazard.com/perspective/levelized-cost-of-energy-and-levelized-cost-of-storage-2020/ , accessed 6 June 2021

[44] IRENA, "Renewable Power Generation Costs in 2020", June 2021, see https://www.irena.org/publications/2021/Jun/Renewable-Power-Costs-in-2020, accessed 26 June 2021.

contributed up to 35 percent of annual electricity production, and less than €10/MWh (US$12/MWh) when VRE contribution is up to 45 percent.[45]

Storage costs are falling rapidly. Lithium-ion batteries, which are both used in electric vehicles and for short term grid balancing, were above US$1,100/kWh in 2010 and have fallen 89 percent in real terms to US$137/kWh in 2020. By 2023, average prices are expected to be close to US$100/kWh according to BNEF.[46]

The International Energy Agency (IEA, World Energy Outlook 2020) goes beyond LCOE when comparing the cost prices. The "Value-adjusted Levelised Costs of Energy" (VALCOE) take into account the factors of flexibility, operating characteristics and base-load capability versus volatility (summarised under "system serviceability") in addition to the conventional LCOE. For the EU in 2019, VALCOE are given as US$145/MWh for nuclear, US$60/MWh for solar PV, US$55/MWh for onshore wind and US$80/MWh for offshore wind. By 2040, the VALCOE for nuclear power is expected to be 115 US$/MWh, for PV US$65/MWh, for wind onshore US$60/MWh and for offshore wind only US$50/MWh. (IAE 2020)

B.6 No Security of Energy Supply through NPPs

Nuclear power is not a secure source of energy, as there are various outages during operation. Moreover, there are already enough flexibility options for a secure power supply. Those who think of digitalisation and climate protection together combine energy and load management, flexible demand and, in the medium term, electricity storage systems that compensate for fluctuations in the shortest possible time.

- The contribution of new nuclear power plants (NPP) to energy security is very limited due to significant time between planning and operation of NPPs.
- The contribution of SMRs to energy security is even more limited, as it will take decades before they can be used commercially.
- The contribution of the ageing nuclear power plants to energy supply security is limited. This is mostly because of the ageing related outages. In addition, there are some climate change related outages.

B.6.1 Examples for ageing related outages of NPPs in France and Belgium

Proponents of nuclear power say that the reactors' relative reliability and capacity make this a much clearer choice than other non-fossil-fuel sources of energy, such as wind and solar, which are sometimes brought offline by fluctuations in natural resource availability. However, older nuclear plants are extremely inefficient and run a higher risk of disaster. (BECKER et al. 2020) Examples for ageing related outages in France and Belgium are described below.

B.6.1.1 Ageing related outages of the French NPPs

The average age of the 58 reactors is 36 years (end of 2020). (WNISR 2021) In 2018, the French nuclear power plants provided 71.7 percent of the country's electricity. The annual load factor

[45] Philip J. Heptonstall and Robert J. K. Gross, "A systematic review of the costs and impacts of integrating variable renewables into power grids", *Nature Energy*, January 2021.
[46] BloombergNEF, "Battery Pack Prices Cited Below $100/kWh for the First Time in 2020, While Market Average Sits at $137/kWh", 16 December 2020, see https://about.bnef.com/blog/battery-pack-prices-cited-below-100-kwh-for-the-first-time-in-2020-while-market-average-sits-at-137-kwh/, accessed 19 December 2020.

at 69.6 percent was still poor in 2018 but improved since a record low of 55.6 percent in 2016. The lifetime load factor remains constant below 70 percent (69.3 percent). (WNISR 2019)

In 2018, generation performance was affected by exceptional damages and large generation incidents (costing around 12.5 TWh), longer-than-expected outages (costing around 5 TWh) and environmental constraints (costing around 2 TWh). The outage extensions experienced in 2018 were caused in equal measure by maintenance and operational quality issues, technical failures and project management deficiencies. Performance losses related to unplanned outages rose from a rate of 3.26% in 2017 to 3.7% in 2018 because of several exceptional incidents. (WNISR 2019)

Additionally, the finding of carbon segregations in the pressure vessel of new build reactor Flamanville 3 had raised concerns about the possibility that other components could have been fabricated below technical specifications due to poor quality processes at Creosote Forge. On 25 April 2016, AREVA informed ASN that irregularities in the manufacturing checks, the quality-control procedures, were detected at about 400 pieces fabricated since 1969, about 50 of which would be installed in the French currently operating reactor fleet. The irregularities included inconsistencies, modifications or omissions in the production files, concerning manufacturing parameters or test results. According to EDF, in total, it has detected 1,775 anomalies in parts that were integrated into 46 reactors. (WNISR 2019)

In summer 2022, only half of the 56 reactors in France were operating. Only some reactors were shut-down because of planned outages, but several because of unexpected ageing failures: Between mid-2021 and early 2022, inspections by EDF revealed corrosion and cracks in key pipes at five reactors, prompting lengthy checks and repairs. In mid-April, the company reported ultrasound inspection results suggesting that at least four additional reactors could be affected by similar problems.[47]

B.6.1.2 Ageing related outages in the Belgians NPPs

In 2020, the average age of the seven reactors in Belgium is 41 years. (WNISR 2021) Due to continuous technical issues and extended outages, the average load factor of the Belgian fleet plunged to 48.6 percent in 2018. On average, the units were down half of the year and in October 2018 power prices reached record levels (€205/MWh). (WNISR 2019)

In summer 2012, the operator identified an unprecedented number of hydrogen-induced crack indications in the reactor pressure vessels of Doel-3 and Tihange-2, with respectively over 8,000 and 2,000 – which later increased to over 13,000 and over 3,000 respectively – previously undetected defects. In spite of widespread concerns, and although no failsafe explanation about the negative initial fracture-toughness test results was given, on 17 November 2015, the Federal Agency for Nuclear Control (FANC) authorized the restart of Doel-3 and Tihange-2. (WNISR 2019)

The technical assessment of the safety implications of the flaw indications remains the subject of intense controversy. Several independent safety analysis reports are highly critical of the restart authorizations. In April 2018, the International Nuclear Risk Assessment Group (INRAG) stated on Tihange-2 that “the risk of failure of the reactor pressure vessel is not

[47]NuclearNewswire: France’s energy woes worsened by inspection-related nuclear power plants shutdowns; 6 May 2022; https://www.ans.org/news/article-3939/frances-energy-woes-worsened-by-inspectionrelated-nuclear-power-plant-shutdowns/

practically excluded" and requested that "the reactor must therefore be temporarily shut down".[48]

Additionally, in October 2017, the operator Electrabel identified serious flaws in the concrete of a building adjacent to the reactor buildings of Doel-3. These bunkered buildings contain backup systems for the safety of the facilities and are supposed to withstand impact from outside like an airplane crash. Some of these anomalies at the reinforcements of the reinforced concrete were present since the construction of the building. Doel-3 was originally expected to be off-line for scheduled maintenance for 45 days, however, the outage lasted 302 days. Similar problems, to varying degrees, have been identified at Tihange-2 and -3, as well as Doel-4. Tihange-3, which was shut down on 30 March 2018 for planned maintenance and refueling, suffered subsequent delays. (WNISR 2019)

The cumulation of planned outages that were extended repeatedly, plus unexpected outages, led to an unprecedented annual record. In 2018, the seven Belgian nuclear reactors cumulated a total of 1,265 outage days, representing an average of six months (181 days) per reactor. All of the seven units were offline at some point, with cumulated outages reaching between 31 days (Tihange-1) and 276 days (Tihange-3) per reactor. (WNISR 2019)

B.6.2 Examples for weather-related events in NPPs affecting the energy supply

When thinking of possible climatic effects on the resilience of the nuclear power plants, heat waves are particularly concerning due to their impact on the temperature of the reactor's cooling water. A heat wave could increase the number of shutdowns. In 2003, for example, a heat wave forced the shutdown of more than thirty nuclear power plants in Europe. A similar event took place in 2018 when numerous nuclear power plants all over the world, from France to South Korea, had to cease their operations due to abnormally high temperatures. These events resulted in substantial economic losses. (CAIRO 2019)

A heat wave has consequences on the operation of nuclear reactors: Reactors must be permanently cooled to ensure their safety. For this purpose, water is taken from a river or sea. The water taken to cool the reactor is, in general, discharged at a higher temperature, either directly or after cooling in cooling towers allowing a partial evacuation of heat in the reactor. In order to preserve the environment, especially the ecosystem, the heating of the watercourse due to the operation of the NPP as well as the temperature of the water downstream are framed by limit values. NPPs are required to curtail operation or shut down completely when discharge water exceeds such a heat threshold. Continuing operation of NPPs would result in "cooking" the river biosystems locally. Regulations exist in France (and elsewhere) preventing this effect. (KRAFT 2017)

It should be noted that nuclear power plants located on seacoasts can also be vulnerable to higher than usual temperatures. In 2018, nuclear reactors in Sweden and Finland were forced to shut down or reduce their power due to temperatures 6–10°C higher than the seasonal average. In Sweden, a 900-MW reactor at the Ringhals plant was shut down as sea-water temperatures exceeded 25°C. (WNISR 2021)

48 INRAG, "Evaluation of the nuclear risks of the Tihange nuclear power plant 2 — Statement by the international group of experts 'INRAG'", April 2018 (in German and English), see http://www.inrag.org/wp-content/uploads/2018/04/01_INRAG-Statement-Tihange_2018_04_10-ST_ff_final.pdf.

B.6.2.1 Weather-related events in the French NPPs affecting the energy supply

France and also Germany, Spain and other European nations are hit with extraordinary heat wave and drought – ultimately killing over 30,000 people in Summer 2003. France, Germany and Spain are confronted with the dilemma of allowing reactors to exceed design standards and thermal discharge regulations. Spain shuts theirs down; France and Germany allow some of theirs to exceed standards and thermal discharge regulations, while shutting others. In France local firefighters are actually called out to hose down overheating reactor containments (at Fessenheim). In the course of the summer the French nuclear reactors at Blayais on the Gironda River estuary are alone allowed to exceed thermal discharge limits 50 times. (BECKER et al. 2020)

A 500 million Euro plan called "Grands Chauds" (great heat) was started following the 2003 and 2006 heat waves to prepare French plants for hotter temperatures. The plan included nuclear safety modifications including increasing the capacity of units to handle hotter temperatures, including through the addition of heat exchangers, air conditioning in certain plant areas. However, in 2009 again, France faced a river water crisis that forced the shutdown of one-third of its entire nuclear power fleet. Due to serious drought conditions, maintenance issues, and a worker strike, France had to import electricity from England to meet power demand. Fourteen of France's 19 nuclear power plants are sited on rivers. (NW2019b)

The heat wave in the summer of 2019 led again to the closure or output reduction of several reactors, including the two Golfech units and the two Saint Alban units. Environmental constraints refer to operating restrictions for several nuclear plants because of lack of cooling water or excess water temperatures. (NW2019b)

In 2022, as a large part of the nuclear power plants has already been shut down for technical reasons, France cannot afford a failure of further power plants. In view of the heat wave, the environmental regulations for the discharge of cooling water were f "temporarily" eased to allow the continued operation of nuclear power plants.

Now, more and more power plants are being allowed to exceed even the already raised limits in order to only have to regulate the nuclear power plants down, but not shut them down. They are to continue operating at a minimum power level, according to a decree published in the law gazette. The reactors at Bugey can now continue to draw cooling water and discharge it warmed up, as long as the heating does not exceed 3° C on a daily average after the discharge water is mixed in the Rhone, the decree says. The nuclear regulator (ASN) had requested this exemption for a period until 8 August 2022 for the Golfech (Tarn-et-Garonne), Blayais (Gironde) and Saint-Alban (Isère) power plants. These exceptions are authorised "*if necessary for the smooth functioning of the electricity grid*", underlines EDF.[49]

For river-cooled reactors, the heating of the river water caused by the plant is normally less than 0.3 C downstream of the plant. Thermal discharge to a river causes a gradual mixing of the relatively warmer water over several miles, avoiding the creation of a "thermal wall" that could block fish migration. (BECKER et al. 2020)

B.6.2.2 Weather-related events in the Swiss NPPs affecting the energy supply

In Switzerland, the Beznau nuclear plant reduced its output by 50% on several days in July 2019 as the temperature of the Aare River, which supplies its cooling water, reached 24 °C.

[49] Telepolis: „Frankreichs Atomkraftwerke: Probleme wegen Hitze", 18. Juli 2022, https://www.heise.de/tp/features/Frankreichs-Atomkraftwerke-Probleme-wegen-Hitze-7181896.html?seite=all

With the aim that the Aare temperature does not exceed 25 degrees at the power plant. The move is in compliance with an interim ruling of the Swiss Federal Office of Energy, issued in early July, requiring the plant to reduce its output when the temperature of the river reaches unusually high levels. Operator Axpo protests and argues that it has made substantial investments in the plant in reliance on the permanent permit. (AZ 2019)

The heat wave in Summer 2022 is also affecting electricity production in Switzerland. For example, the Beznau nuclear power plant has reduced its output. It uses water from the Aare River for cooling. To prevent the water in the river from getting too warm, less electricity is now being produced. This is intended to protect river life, which is already suffering from the already warm water of the Aare.[50]

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[50] Zentralplus: „*Hitze: AKW Beznau drosselt Leistung*", 18.07.2022, https://www.zentralplus.ch/news/hitze-akw-beznau-drosselt-leistung-2410781/

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