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CRITICAL REVIEW

TAXONOMY
AND NUCLEAR ENERGY

Critical Review of the Joint Research Centre's Assessment for the EU Taxonomy Regulation

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http://www.ecology.at/taxonomie_atom_2021.htm

Vienna, June 2021

Content

1 Summary

This Critical Review of the Joint Research Centre's Assessment for the EU Taxonomy Regulation points out those facts put forward by the Joint Research Centre's (JRC) which are factually wrong or so incomplete that they misrepresent reality.

The other part of this review is identifying issues which the JRC was asked to cover when given this task (Terms of Reference) but decided not to, mostly relating to negative environmental impacts of nuclear power.

After a short introduction in **Chapter 2**, the requirements of the Taxonomy Regulation (EU) 2020/852, the Terms of Reference the European Commission has tasked the Joint Research Centre with (JRC Mandate), and what the JRC Report actually delivered will be compared in **Chapter 3** which introduces a comprehensive table.

The following section summarizes the essential findings and points of critic of **Chapter 4:**

Impacts of Ionizing Radiation on Human Health

The JRC Report argues that the dose for members of the public attributable to nuclear energy production is 10 thousand times less than the dose from natural background.

The JRC Report argues that the doses of nuclear workers are minimized by radiation protection measures.

BUT: 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.**

Nuclear energy does significantly harm human health, even in the low dose range resulting from normal NPP operation and nuclear workplaces (see in detail chapter 4.1)

- 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.

The comparison of radiation due to normal operation of NPPs with natural background radiation is misleading: If people receive not only background doses but also doses from nuclear energy production, their risk will increase. Any additional radiation doses should be minimised or avoided, particularly in areas with high background radiation.

Impacts of Severe Accidents in NPP

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. These risks are by no means negligible, especially in the light of the Wheatley et al. (2016) study which assessed a 50% chance of a severe nuclear accident occurring every 60-150 years.

Following severe accidents, for decades the situation has been anything but under control: Mayak in Russia is still one of the most contaminated places on earth; in the Chernobyl sarcophagus surprising reactions in the corium are starting after 35 years; and at Fukushima, tritium-contaminated water has become an immense problem. These are proof that significant harm to the environment can be expected for decades after a severe accident has occurred.

Human Fatalities Resulting from Severe Accidents

The JRC report argues that the Generation II reactors have a very low fatality rate.

BUT: A little trick made this possible: Both major accidents - Chernobyl and Fukushima - were not taken into account in assessing the fatality rate for nuclear. Therefore the resulting low fatality rate has a credibility problem. 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 recognized 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 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.

Do Newer Reactors (Generation III) Have Lower Risk?

The JRC Report argues that accidents in a Generation III NPP will lead only to impacts in a few kilometres distance to the site.

BUT: It should also be noted that Gen III technology is not radically different to that of Generation II reactors which were also licensed under the condition that the possibility of severe accidents is excluded. Fukushima Daichi was deemed safe by all the authorities involved until the very day of the disaster. Residual risk with potential human fatalities in such reactors is not excluded. Newer reactor designs can also have severe impacts at long distances from the site. An example: The EPR in Olkiluoto-3 is expected to start operating in 2022. Dispersion calculations were made for an accident with early containment failure: **The consequences were not limited to a few kilometres around the site, but could even impact Austria** (in a distance of around 1,600 km). (See in detail chapter 4.2.2)

The JRC Report argues that Generation III reactors have even lower fatality risk than Gen II reactors.

BUT: Gen III reactors like the EPR developed under European nuclear safety standards are not yet in operation in Europe. Only in China are the two EPRs in operation at Taishan (operation started in 2018/2019 respectively). 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.

The JRC Report argues that now practically only Gen III reactors are constructed and commissioned.

BUT: In June 2021, in the heart of Europe, a reactor of a standard far less than Gen III is about to receive an operational license – Mochovce Unit 3 in Slovakia. Unit 3 and 4 are VVER-440/213 reactors without containments. The fleet however which industry intends to keep online will consist of almost 98% old life-extended reactors, because only new reactors are under construction (Finland, France, EPR).

Effects of Severe Accidents Besides 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. In the JRC Report, no such indicator was introduced to measure the consequences of nuclear accidents.

Radioactive pollution following the accident at Chernobyl has led to **permanent loss of large agricultural and forestry areas**. This has not been mentioned in the JRC Report.

Nuclear Safety and Security

Nuclear Safety

The JRC Report argues that operating NPP are subject to continuous improvement, and that the most important safety improvement have already been made.

BUT: 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.

Many national nuclear regulators delayed implementing the recommendations made by the EU stress tests: e. g., in France the '*hardened core'* was decided for all NPPs in France**. 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.

The JRC Report argues that appropriate measures to prevent the occurrence of the potentially harmful impacts or mitigate their consequences can be implemented using existing technology at reasonable costs.

BUT: If this argument relates to safety measures and post-accident measures, it is worth pointing out that the costs and consequences of **Fukushima** are staggering, and far from having been solved at reasonable costs. Only last week, Japan announced that the decommissioning process was still unclear, would not be finalised before 2050, and that costs were constantly increasing.

Safety of Lifetime Extension of NPP

The JRC Report argues that lifetime extensions of operating reactors up to 60 or 80 years can be achieved.

BUT: Perfectly aware of the dire situation with respect to new nuclear capacity, the industry needs to keep old reactors on the grid as long as possible.

The JRC Report did not hesitate in using the term "*experience*" in a world in which the oldest reactor is around 51 years old (Beznau 1/Switzerland). In assessing the likelihood of reactors being able to operate for 50 or 60 years, it is useful to compare the age distribution of reactors that are currently in operation with those that have already closed. The age structure of the 181 units already closed (eight more than one year ago) completes the picture. In total, 66 of these units operated for 31 years or more, and of those, 24 reactors operated for 41 years or more. Many units of the first-generation designs only operated for a few years. Considering that the **mean age of the closed units is 25.8 years,** plans to stretch the operational lifetime of large numbers of units to 40 years and far beyond seems rather optimistic.

The INRAG Report on Ageing NPPs (INRAG 2021) finding is that especially due to the interaction of different ageing phenomena, the additional risks of NPP due to ageing becomes incalculable and increases the risk of severe nuclear accidents. Not all design deficits can be eliminated by retrofitting: A considerable part of the safety standard is already determined by the design of the NPP. **Despite extensive retrofitting, current safety standards are not achieved in old nuclear power plants.**

Climate Change Impacts on Nuclear Safety

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. NPP are extremely dependent on a steady supply of cooling water. The 2020 study[1] "*Impacts of climate change on nuclear risk and supply security*" examined the consequences at a general level and presented case studies, and concluded that: "*The efficiency of nuclear power plants decreases with increasing temperature, some sites may lose safety, with sea-level rise being of particular importance and extreme weather events threaten the safety of NPPs additionally* (...) *Cold and heat waves represent a significant problem for the electricity generation sector. Unplanned outages of NPP due to excessively high-temperature water constitute clear examples of this.* ***Reports showed that 40% of the NPPs in Europe have already experienced cooling problems because of high temperatures*****.** The study also reported that for NPP Beznau in Switzerland, the oldest plant in Europe, the authorities tried to update the permit because of water temperature increases in the

[1] http://www.joint-project.org/upload/file/Joint_Project_Working_Paper_Climate_Change_Impacts_final.pdf

Aare River, but encountered resistance from the operator who has to reduce the output of generated electricity. **This could be one of many cases in future, in which the use of less water will lead to severe conflicts**.

Nuclear Security and Terrorism

The 2020 NTI Nuclear Security Index (NTI Index) assessed the security of some of the deadliest materials in the world—highly enriched uranium (HEU) and plutonium—against theft and the security of nuclear facilities against sabotage. Stolen HEU or plutonium could be used to build a nuclear bomb; the sabotage of a nuclear facility could result in a dangerous release of radiation. NTI came to the following conclusion

"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."

Nuclear Weapons and Non-Proliferation

Also rather underrepresented in the discussion, but made relevant by the 2014 IPCC 1.5 degree report, is the issue of nuclear proliferation as a consequence of nuclear energy use. The Taxonomy Regulation and the TOR by the European Commission also failed to mention the issue, and the (unknown) authors of the JRC Report professed ignorance of this well-known situation.

The Iran crisis is a current reminder of this unique and massive problem that only nuclear energy threatens the world with:

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 IPCC report: *Nuclear energy, the share of which increases in most of the 1.5ºC-compatible pathways (see Chapter 2, Section 2.4.2.1), can increase the risks of proliferation (SDG 16), and have negative environmental effects.*

Radioactive Waste and Spent Fuel Management – unsolved, even on paper

According to the Terms of Reference (TOP) used the basis for its report, 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 storage and disposal of all radioactive waste and spent fuel.

With respect to nuclear waste, Chapter 4 of the JRC Report includes many images of colorful and clean drums in interim storage and similar facilities. But the references listed at the end of Chapter 5 make clear that this does not reflect the reality but exist only in theory, since mostly OECD/Nuclear Energy Agency (NEA), some IAEA papers were quoted, which consist of plans, concepts and research tasks published regularly.

Everything Under Control? The Current Nuclear Waste Legislation

The Nuclear Waste Directive 2011/70/Euratom tried to force EU Member States to start taking the problem of nuclear waste seriously, after this had been neglected for decades – thus already proving that nuclear waste has never been managed effectively. The European Commission's own report on the implementation of the Nuclear Waste Directive (EC Report 2019) found that Member States are far from achieving the goals that are defined in the Directive. The EC conducted two reviews of the submitted national waste management programmes. In its second report from late 2019, the EC stated that progress has been made, but **"[H]owever, more needs to be done" (EC Report 2019, p. 17).**

But without a clear idea of how to deal with nuclear waste, progress cannot be expected soon. When financing, regulatory structures, inventory data and transparency regimes are unavailable or in a poor state, decades of improvement must follow before a sufficiently or acceptably safe nuclear waste management programme can result.

State-of-the-art Technologies and Operational Experience

The only final disposal facility in operation for nuclear high level waste is the **WIPP (Waste Isolation Pilot Project)** in the USA, but its operational experience is not even mentioned in the JRC Report, nor is the operational experience from the **Asse final repository** in Germany. **The most likely reason for this omission is the fact that both storages have experience massive technical problems and enormous clean up costs.**

The situation has not changed significantly over the past 70 years since the first nuclear reactors started operating: there is no solution for nuclear waste, only the nuclear industry's public relations have improved when claiming they are very close to finding a solution. The much-hailed repositories in Sweden, Finland and France are far from ready to receive spent fuel, instead increasingly there are problems, such as finding an appropriate material for the storage canisters.

The first three final repository projects in Europe are already delayed, and the other Member States seem to have taken refuge in postponing their plans for as long as possible, to avoid early failures. It is clear that future delays can be expected.

Copper Dreams Not Coming True and Other Corrosion Problems

One of the key safety features for the final repositories are the canisters needed to keep the spent fuel waste from leaking into the surrounding host rock. However, over the past 50 years **no materials sufficiently resistant to radiation, toxic impacts, involved heat production, etc., have been identified**. The material the industry has placed its biggest hopes in for use in a granite-based deep geological disposal is copper – or rather it was.

The scientific hypothesis was that oxygen-free water does not corrode copper in a repository where there is no oxygen after closure. 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**. This means that copper in a KBS-repository may corrode at much faster rates than acceptable, and **release radioactivity from the canisters after only around 1,000 years of storage time**.

What is important to understand: **The Onkalo final repository in Finland which, according to some industry organisations, would be only months away from being granted an operational licence, is supposed to use the very same Swedish copper canister system.** However, the current status of research and licensing in Sweden makes such fast procedures impossible. Even if Finland could manage a granite/copper system, this has no real value for other countries who would need to locate their own sites, start investigations of site-specific geological conditions in their own host rock, and design and approve their own appropriate container system and ensure local acceptance at the chosen repository site. Summing up: **"*We need to develop a new model for storing nuclear waste*":** This was the alarming message from the most recent corrosion research at Ohio State University. Corrosion is increasingly becoming a serious problem, also at the French repository site, Cigeo in Bure**. This leads to the conclusion that current planned methods for storing high level nuclear waste are seriously unsafe and could result in radioactive materials being released into the environment.**

Current EU Joint Research into Waste Management

Another sign that not everything is not yet on track are the large amounts being spent on research on EU level, e. g. in the **EURAD Project - European Joint Programme on Radioactive Waste Management.** This five-year research project started in 2019 and gives an idea of the issues in the field of waste management which have yet to be resolved. EURAD is not at the laboratory research stage: **It was designed to identify the most important topics for research**.

Transmutation & Partitioning

Transmutation and Partitioning is supposed to transform high-level waste into short-lived products (i.e. 'transmutation') would generate waste that decays over much shorter timeframes thus making final disposal easier. This T&P would be done by adapted fast neutron reactors or in dedicated waste burning reactors.

The JRC Report presented the Transmutation and Partitioning as an upcoming technology for reducing the nuclear waste burden. However, after decades of research the development of any Transmutation and Partitioning system will still require several more decades. Therefore, it is wishful thinking to assume that Transmutation and Partitioning will be able to solve the nuclear waste problem any time soon. Development of partitioning and transmutation is currently only at an experimental scale.

Creating Unmanageable Risks for Future Generations – Unsolved Long-term Transgenerational Aspects of Final Disposals

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. Such a responsibility means maximal avoidance of further production of radioactive wastes.

The safety of future generations is at stake. Decisions must be taken on how long nuclear waste can be recovered after a final repository has been sealed – an important criterion for choosing geology and technology, and not just a simple question to be decided at some point in the future.

The means of preserving knowledge, data and memory on nuclear waste burials are not solved, needing much and continuous effort, also long after nuclear power production is over. This is another clearly unsustainable aspect of nuclear energy.

Uranium mining and milling

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.

BUT: Uranium mining is being infamous for its environmental consequences. While the JRC Report refers to control and prevention measures that are regulated in several Euratom and EU Directives, it has to be kept in mind that 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. Clearly the safe storage of tailings over hundreds or thousands of years cannot be assumed, as shown by the example of dam failures.

Reprocessing spent fuel

The JRC Report chose to present reprocessing as any other technology when saying that reprocessing is part of the "closed" nuclear life cycle, however, careful reading shows that 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 (p.111) but without noting that **reprocessing is still one of the riskiest technologies in terms of weapons proliferation.** Despite the JRC Report pointing out that IAEA – worldwide – and Euratom for the EU are running a tight ship on non-proliferation, China simply refuses to be subject to those controls. Nor does France take non-proliferation seriously, because Paris has been negotiating the export of a reprocessing plant to China for a decade.

Finally, in **Chapter 5**, we draw conclusions.

To keep this paper short, the overall highly pro-nuclear spin with dozens of pages of textbook description of how nuclear technologies from uranium mining all the way to final disposal should work are mostly not discussed or commented on.

Among those are severe accidents with catastrophic and long-term consequences which the (unknown) authors of the JRC chose to gloss over quickly. Part of this approach is also the (unknown) authors' approach of suppressing information on the unique environmental damages and risks caused by nuclear energy and instead focusing on 1. the steps from mining to final disposal based on theory and 2. proving nuclear safety by quoting legal provisions and international conventions and monitoring and safety upgrades which ensure safety. Risks and hazards specific to nuclear energy are

downplayed systematically, many areas of danger and hazards left out, the residual risk of severe accidents at actually every plant any time are ignored, even though mankind already had to make this experience. This is not only a serious mistake, but also non-fulfilment of the task the JRC was asked to fulfil in the TOR (See List of issues the EC TOR tasked the JRC but were not delivered.)

As an example of the arguments combining a certain spin ("other technologies are not that different from nuclear after all") and omission of exactly those facts which make nuclear energy use so uniquely risky serves the following quote from the JRC Report „[…], *it is important to note that very severe nuclear accidents, as well as non-nuclear severe accidents, can lead to other direct and indirect impacts that might be more difficult to assess. Evaluating the effects of such impacts is not in the scope of the present JRC Report, although they can be important for understanding the broader health implications of an accident*" (JRC, page 178). And finally, the chapter on *Evaluation and Summary* concludes that "…*nuclear power plants (NPP) operation activities <u>do not represent unavertable harm to human health or to the environment</u>. They do not represent significant harm to any of the technical expert group (TEG) objectives, provided that the associated industrial activities satisfy appropriate technical screening criteria*."

The (unknown) authors of the JRC assessment chose the same path when discussing the decades old problem nuclear energy – waste: Ignoring the experiences made with nuclear waste disposals and fully relying on regulations, existing once such as EU directives or IAEA Convention or future once (Technical Screening Criteria of the EU Taxonomy) – but there is only paper, no final wastedisposal.

The JRC experts try hard to give the impression that nuclear energy is technology like any other, a "mature" technology. Therefore the JRC Report did not even mention that the molten reactor cores from the Fukushima accident 2011 have not even been found yet and there is no method yet how to stop constant radioactive contamination by the still necessary cooling (!). Meanwhile at Chernobyl, 35 years after the accident there, fission reaction seems to picking up again under two shelter constructions in inaccessible rooms - a fully unexpected phenomena which can cause very serious consequences.

We call upon the European Commission and both the tasked Committees Euratom Art. 31 Group and SCHEER to evaluate the JRC Report in a well-balanced, evidence and fact-based approach. The JRC assessment is an insufficient basis for decision-taking. Our Critical Review provides facts on consequences of nuclear energy use that need to be recognized. It is not acceptable to leave out undesired facts about nuclear energy.

2 Introduction

The European Commission is currently setting up an EU-wide classification system, the so-called Taxonomy, which will be used in the future to classify economic activities on the basis of their ecological sustainability. Within this framework, the question of whether an investment in nuclear power can be classified as sustainable is being debated. The final report of the TEG of March 2020 contains the following nuclear energy assessment in the Annex: **"[…] it was not possible for TEG, nor its members, to conclude that the nuclear energy value chain does not cause significant harm to other environmental objectives on the time scales in question. The TEG has therefore not recommended the inclusion of nuclear energy in the Taxonomy at this stage."**(TEG Report Annex 2020, p. 211) Among other issues, the unsolved nuclear waste issue was cited by the TEG as a reason for this assessment.

After the TEG's statement clarified that nuclear energy was not assessed as a sustainable activity in the sense of the Taxonomy, it is the declared aim of some Member States and lobby organisations to have this science-based decision revised. Despite intense lobbying, the first delegated act was decided by the EU Commission without including nuclear energy and gas on April 21, 2021. Decisions on both highly contentious issues were postponed until the end of the year.

According to the plan, two committees were mandated to perform a review of the JRC Report. The so-called Art. 31 expert group is named after the respective article of the Euratom Treaty, which is tasked to ensure compliance of specific projects and to act in complete secrecy; its members act in complete secrecy and are nominated by their respective governments.

However, they are certainly not experts on life cycle analysis or nuclear waste management. The other group is similarly secretive and unknown: SCHEER (Scientific Committee on Health, Environmental and Emerging Risks) at the DG SANTE (the European Commission's Directorate-General for Health and Food Safety). Their expertise seems to be even more remote from the topic at hand than the Art. 31 group's qualifications. They will assess the JRC Report (they have started already), ask questions and finally make a statement of their own. The SCHEER mandate is to assess the Taxonomy Regulation's articles 17 and 19 that set the legal framework for the 'do no significant harm' principle: "(iii) the long-term disposal of waste may cause significant and long-term harm to the environment; and (e) pollution prevention and control, where that activity leads to a significant increase in emissions of pollutants into air, water or land, compared with the situation before the activity started; and Article 19: (f) be based on conclusive scientific evidence and the precautionary principle enshrined in Article 191 TFEU; (g) take into account the life cycle, including evidence from existing life cycle assessments, by considering both the environmental impact of the economic activity itself and the environmental impact of the products and services provided by that economic activity, in particular by considering the production, use and end of life of those products and services; the EC said those committees' reviews will be for internal purposes only. A complementary delegated act will be developed and decided soon after the review of the two committees is finished.

By end of **June 2021,** both should have completed their task. In **September** the European Commission is expected to present the **draft specific (complementary) delegated act on nuclear energy and gas** as announced on April 21.

3 Comparing the JRC Report with the Taxonomy Regulation and the JRC Mandate – an overview

This table compares the requirements of the Taxonomy Regulation (EU) 2020/852, the Terms of Reference the European Commission has tasked the Joint Research Centre with (JRC Mandate), and what the JRC Report actually delivered.

Taxonomy Regulation (EU) 2020/852	**JRC Mandate**	**JRC Report**
Substantial contribution to climate change mitigation (Art. 10)		GHG emissions (in t CO2-eq/GWh)
Substantial contribution to climate change adaptation (Art. 11)	Not included	Not mentioned
Substantial contribution to sustainable use and protection of water and marine resources	Not included	Not mentioned
Substantial contribution to the transition to a circular economy	Not included	Not mentioned
Substantial contribution to pollution prevention and control	Not included	Not mentioned
Substantial contribution to protection and restoration of biodiversity and ecosystems	Not included	Not mentioned
DNSH Climate change mitigation	DNSH Climate change mitigation	Not assessed
DNSH Climate change adaptation	DNSH Climate change adaptation	Not assessed
DNSH Sustainable use and protection of water and marine resources	DNSH Sustainable use and protection of water and marine resources	Acidification (in g SO2-eq/kWhe): assessed Eutrophication (in g PO_4^{3-} -eq/kWhe): assessed Loss of species (in PDFm2a): assessed Ecotoxicity (in g 1.4-DCB-eq/kWh): assessed Water withdrawal Water consumption: assessed Chemical pollution (nitrous oxides - NOx, sulfur dioxide - SO2): assessed Thermal pollution Radioactive pollution

Taxonomy Regulation (EU) 2020/852	JRC Mandate	JRC Report
		Missing: radioactive **contamination** of water and marine resources Missing: Potential cause of water conflicts Missing: decreased cooling water availability due to climate change
DNSH Transition to a circular economy	DNSH Transition to a circular economy	Abiotic Depletion Potential (g Sb-eq/GWh, or g Fe-eq/GWh): assessed Use of Fossil Fuels: assessed Potential material recyclability Land occupation Chemical Waste Volumes Radioactive Waste: assessed, but with many aspects missing – see below Misleading: Significance of reprocessing spent fuel
DNSH Pollution prevention and control	DNSH Pollution prevention and control	Particulate Matter (PM): assessed Non-methane volatile organic compounds (NMVOC): assessed Ozone depletion potential (µg CFC-11-eq/kWh): assessed Photochemical Oxidant Creation Potential (POCP) (g C2H4 eq/kWh): assessed Human toxicity potential (HTP) (1.4-dichlorobenzene equivalent/kWh) Human health and mortality impacts (DALY/GWh, YOLL/GWh) Missing: consequences of low radiation in normal operation (living near NPPs, nuclear workers) Missing: probability of severe accidents, increased accident risk in old NPP with lifetime extension Missing: evaluation of long-term consequences of nuclear waste repositories
DNSH Protection and restoration of biodiversity and ecosystems	DNSH Protection and restoration of biodiversity and ecosystems	Terrestrial ecotoxicity potential (TETP) (g DCB-eq/kWh) Ecotoxicity (PDFm2a/kWh)

Taxonomy Regulation (EU) 2020/852	JRC Mandate	JRC Report
		Biodiversity impact of land use (PDFm2a/kWh) Missing: genetic changes in wildlife after radioactive contamination over generations
Minimum safeguards (Art. 18)	Not included	Missing
Compliance with technical screening criteria (Art. 10)		Proposal for TSC Missing: How will the compliance of such TSC be guaranteed, esp. in non-EU countries with other legislation?
Special focus on radioactive waste: Not included	Current status and perspectives of long-term management and disposal of nuclear waste: • legal framework • technologies with focus on recycle and reuse • research and prospects compare to carbon capture and sequestration (CCS)	Missing: non-existence of positive experiences with DGR for HLW Missing: non-compliance with the EU Nuclear Waste Directive Misleading: presenting the nuclear waste problem as solved Misleading: description of Partitioning & Transmutation as solutions for the nuclear waste problem
Missing in both the TOR und the JRC Report		Missing: Nuclear material security Missing: Terrorism along the entire nuclear energy chain Missing: Nuclear weapons production Missing: Non-proliferation Missing: DNSH by nuclear weapons and proliferation due to the inextricable linking of civil and military use

In the next chapter we will analyse the delivered arguments and add missing information to complete the picture.

4 The JRC Report in Detail: Missing Answers and Misleading Arguments

In this chapter, we assess key conclusions of the JRC Report on the contribution of nuclear energy to the goal of climate mitigation, and especially to the 'do no significant harm' criteria of the other environmental goals.

4.1 Impacts of Ionising Radiation on Human Health

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. Low doses result from nuclear installations during normal operation, from accident situations in nuclear facilities impacting workers and the public, from the nuclear bombs on Hiroshima and Nagasaki and thousands of nuclear weapon tests in the atmosphere, under sea and underground, as well as from medical exposure and natural background radiation.

4.1.1 Radiation Health Effects Due to Normal Operation

> *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 problematic.

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

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 census-based cohort study was conducted for children < 16 years in 1990 and 2000, with follow-up until 2008.[2] 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). The increased risk among children exposed to dose rates ≥200 nSv/h compared to those exposed to <100 nSv/h for leukaemia was hazard ratio (HR) = 2.04[3].

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. The mean cumulative red bone marrow (RBM) equivalent

[2] On average, natural terrestrial radiation contributed 54 nSv/h, cosmic radiation 45 nSv/h and artificial terrestrial radiation 8 nSv/h.
[3] (95% CI: 1.11, 3.74)

dose from gamma-rays and radon[4] combined over the period from birth to diagnosis for the first controls is 4.0 mSv, with a range from zero (for those diagnosed at birth) up to about 31 mSv.[5] There was 12% excess relative risk (ERR)[6] 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.

Secondly, even extremely 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[7] 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

[4] On average, radon contributed about 10% of the RBM equivalent dose, although contributions were highly variable, ranging from 1% to 80%.

[5] To compare the risk estimates from this study with published estimates, it was necessary to calculate doses to the target tissue in question, and if the risks from gamma-rays and radon are to be examined together, doses from both sources must be calculated on the same basis. This could be done only for leukaemia, for which the relevant quantity is the (RBM) equivalent dose.

[6] (95% CI 3, 22), two-sided P=0.01

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

newborn babies.[8] The product of possible increased doses and possible increased risk per dose may provide an explanation. (Fairlie 2014)

4.1.2 Health Effects for Nuclear Workers

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)

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 protracted 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. The estimated ERR of mortality from all cancers was calculated as 0.51 per Gy[9], for solid cancers 0.47 per Gy[10]. Smoking can be a confounder for lung cancer, therefore the study authors also estimated ERR for solid cancers deaths without lung cancer deaths: the ERR was 0.46 per Gy[11] which was similar to the ERR for all solid cancer deaths.

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.

The INWORKS study also analysed mortality associated with leukaemia and lymphoma. (Leuraud et al. 2015) The association between bone marrow doses and mortality due to leukaemia and lymphoma was studied. The ERR of leukaemia mortality (without CLL) was 2.96 per Gy, mostly attributed to chronic myeloid leukaemia. As the authors state, this study provides strong evidence of positive associations between protracted low dose radiation exposure and leukaemia.

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).

Busby and de Messieres (2014) examined descendants (children and grandchildren) of members of the British Nuclear Test Veteran Association (BNTVA). Based on 605 veteran children and 749 grandchildren, compared with 311 control children and 408 control grandchildren, there were significant excess levels of miscarriages, stillbirths, infant mortality and congenital illnesses in the

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[8] Fairlie derived his explanation from observation of the KIKK study: the increased solid cancers were mostly "embryonal", i.e. babies were born either with solid cancers or with pre-cancerous tissues which, after birth, developed into full-blown tumours: this also happens with leukaemia. (Fairlie 2014)
[9] (90% CI: 0.23, 0.82), lagged by 10 years
[10] (90% CI: 0.18, 0.79)
[11] (90% CI: 0.11, 0.85)

veterans' children relative both to control children and expected numbers. There were 105 miscarriages in veteran's wives compared with 18 in controls (OR 2.75[12]). There were 16 stillbirths; three in controls (OR 2.70[13]). Perinatal mortality OR was 4.3[14] on 25 deaths in veteran children. 75 veteran children had congenital conditions vs three control children (OR 9.77[15]) – these rates are also around eight times those expected based on the UK EUROCAT data for 1980 to 2000. For grandchildren, similar levels of congenital illness were reported, with 46 veteran grandchildren compared with three controls (OR 8.35[16]).

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. And what is additionally very problematic is the genetic and teratogenic risk to their children and grandchildren.

4.1.3 Conclusions

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.

The comparison of radiation due to normal operation of NPPs with natural background radiation is misleading: If people receive not only background doses but also doses from nuclear energy production, their risk will increase. Any additional radiation doses should be minimised or avoided, particularly in areas with high background radiation.

Nuclear energy does significantly harm human health, even in the low dose range resulting from normal NPP operation and nuclear workplaces.

4.2 Impacts of Severe Accidents in NPP

4.2.1 Human Fatalities Resulting from Severe Accidents

If severe accident fatality rates are compared, then the current Western Gen II NPPs have a very low fatality rate (≈5·10^{-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). (JRC Report Chapter 4.3)

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[12] (95% CI: 1.56, 4.91), p<0.001
[13] (95% CI: 0.73, 11.72), p=0.13
[14] (95% CI: 1.22, 17.9), p=0.01
[15] (95% CI: 2.92, 39.3), p<0.001
[16] 95% CI,:2.48, 33.8), p<0.001

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 [114], an approach based on the use of a simplified, site-specific, Level 3 Probabilistic Safety Assessment (PSA115) 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, 2010). 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. [3.5-1], 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. Therefore the resulting low fatality rate has a credibility problem.

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.

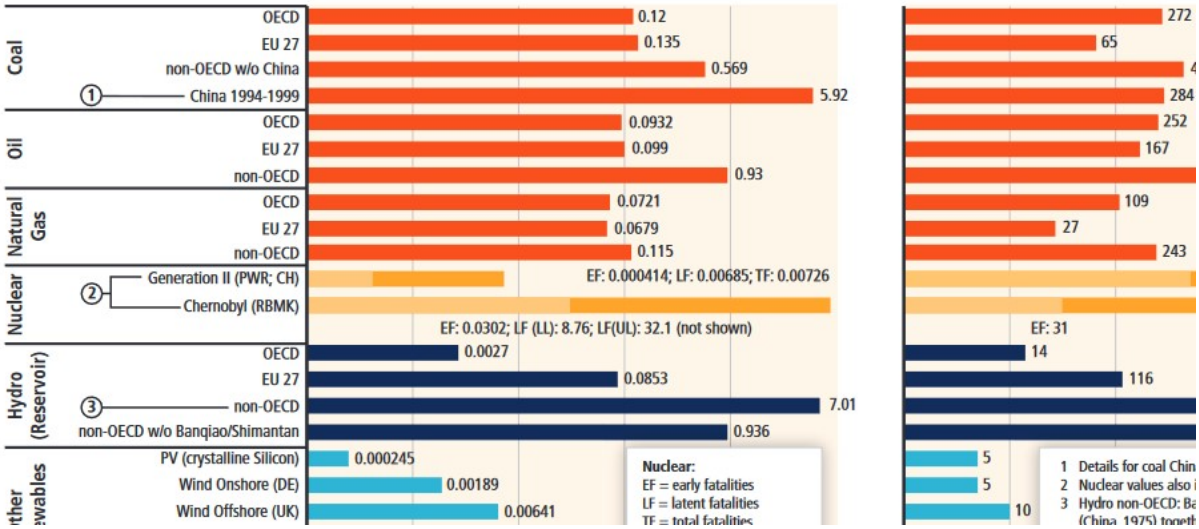

Figure 1: Comparison of fatality rates and maximum consequences of operating large energy technologies, including accidents in the fuel chain; the accident at Fukushima is not included. (IPCC 2012, p. 746)

The fatalities per GWeyr (sum of immediately and latently) in OECD countries are lowest for PV, geothermal, onshore wind and hydro, followed by offshore wind and after that nuclear Gen II.

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.

Comparing the results of such probabilistic assessments of human fatalities to numbers of people who are affected by severe nuclear accidents show that the upper limit was exceeded by reality.

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.[17] 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.[18]

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.

4.2.2 Do Newer Reactors (Generation III) Have Lower Risk?

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)

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. The following figure 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.

[17] https://www.ippnw.de/atomenergie/themen-projekte.html
[18] https://cordis.europa.eu/article/id/25525-effects-of-chernobyl-worse-than-expected

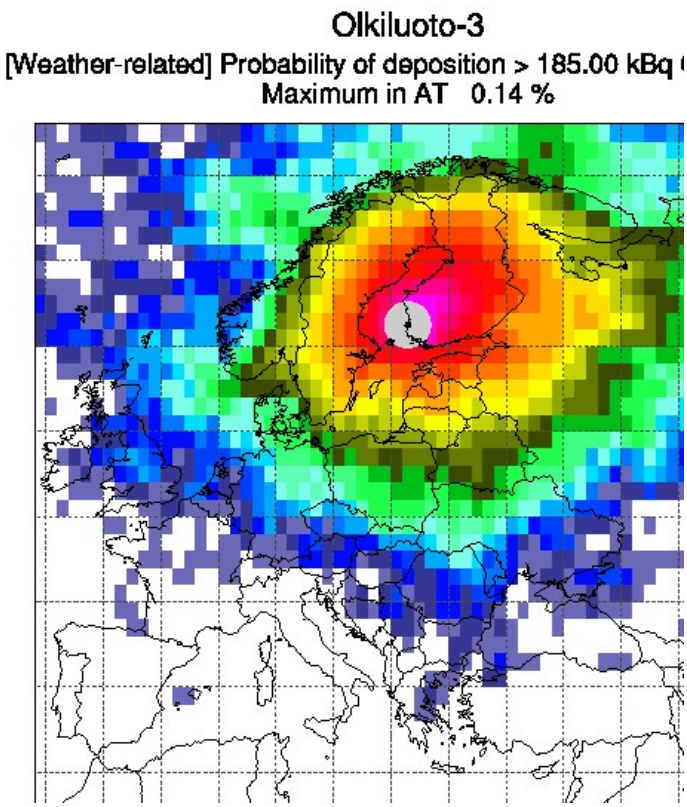

Figure 2: Weather-related probability of a deposition of more than 185 kBq Cs-137/m^2 due to a severe accident in Olkiluoto-3 with a source term of 173.7 PBq Cs-137

These latest technology developments are reflected in the very low fatality rate for the Gen III EPR design (≈8·10^{-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.

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)

In June 2021, in the heart of Europe, a reactor of a standard far less than Gen III is about to receive an operational licence – Mochovce Unit 3 in Slovakia. Unit 3 and 4 are VVER-440/213 reactors without containments.

4.2.3 Effects of Severe Accidents the JRC Report Chose to Leave Out

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[19]. A quarter of Belarus timber was too contaminated fur further use; the same also applied to some of the country's minerals and sand[20]. 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).[21] The well-known fact that entire regions have become inhabitable for decades following the accidents at Chernobyl and Fukushima is not even mentioned.

The consequences of historical severe nuclear accidents are part of the everyday business of nuclear generation. The situation in the Chernobyl region is far from safe. **Forest fires** in spring 2020 unleashed radionuclides that were bound in timber, resulting in possible further contamination.

In addition, the 2011 **Fukushima** accident is still out of control, not even robots can work in this environment to start clean up. 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. This water was used for cooling the as yet unfound molten cores from the three reactors. 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.

Only a few days after the international row which broke out following Japan's announcement that it would discharge the tritium-contaminated water, Chernobyl is back in the news after 35 years with an unexpected phenomenon: As reported in the *Science* Journal in May 2021[22], inside the shelter "*fission reactions are smouldering again in uranium fuel masses buried deep inside a mangled reactor hall. (…) Now Ukrainian scientists are scrambling to determine whether the reactions will wink out on their own—or require extraordinary interventions to avert another accident."* **New chain reactions in the molten corium** may start.

4.2.4 The Risk of Future Severe Accidents

The risk of another severe nuclear accident like Chernobyl or Fukushima has been recently 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.

4.2.5 Conclusions

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

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[19] IAEA (1996a): One Decade after Chernobyl: environmental impact and prospects for the future - working material.

[20] Ministry for Emergencies and Population Protection from the Chernobyl NPP Catastrophe Consequences, Academy of Sciences of Belarus (1996): The Chernobyl Catastrophe. Consequences in the Republic of Belarus - National Report.

[21] IAEA (1996b): Social, Economic, Institutional and Political Impacts. Report for Ukraine

[22] https://www.sciencemag.org/news/2021/05/nuclear-reactions-reawaken-chernobyl-reactor

contaminated territories. These risks are by no means negligible, especially in light of the Wheatley et al. (2016) study which assessed a 50% chance of a severe nuclear accident occurring every 60-150 years.

Following severe accidents, for decades the situation has been anything but under control: Mayak is still one of the most contaminated places on earth (Bellona 2018); in the Chernobyl sarcophagus surprising reactions in the corium are starting after 35 years; and at Fukushima, tritium-contaminated water has become an immense problem. These are proof that significant harm to the environment can be expected for decades after a severe accident has occurred.

The existing nuclear Gen II reactor fleet is by no means the best in class with respect to the human fatality rate per GWyear. Gen III reactors require very long construction times – the decision to build Olkiluoto-3 in Finland (EPR/Gen III) was taken in 2000; it is not yet operational. It should also be noted that its technology is not radically different to that of Generation II reactors which were also licensed under the condition that the possibility of severe accidents is excluded. Fukushima Daichi was deemed safe by all the authorities involved until the very day of the disaster. Residual risk with potential human fatalities in such reactors is not excluded. The research flexRISK project demonstrated what consequences can be expected following a severe beyond-design base accident. These consequences are not limited to an area of just a few kilometres around the site.

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. In the JRC Report, no such indicator was introduced to measure the consequences of nuclear accidents.

4.3 Nuclear Safety and Security

4.3.1 Nuclear Safety

> "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 by the German nuclear reactor expert Oda Becker revealed that the EU nuclear safety stress test recommendations have not been implemented, and the 'Lessons from Fukushima not Learned'[23]. The Fukushima disaster in 2011 shed light on serious deficits in the nuclear safety concepts and plant safety levels, also in Europe:

- NPP' vulnerability to natural hazards is much higher than assumed prior to 2011, e.g. they are not able to withstand the seismic events which are likely at their site;

[23] https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/20210303-greenpeace-akw-europa-fukushima.pdf

- Power supply for the plant and heat removal are not robust, which can lead to extremely severe accidents;
- Possibilities for preventing radioactive releases during a severe accident with meltdown are actually very limited.

The study is based on the official reports made by the individual national regulators. None of the 11 NPP in the EU which were evaluated in 2021 have implemented all the measures which the EU expert peer review teams - not independent experts, but representatives from the very same nuclear safety authorities that licensed these plants in the first place - recommended after the stress tests. In many cases, even the key measure will never be implemented. One example is the Czech NPP Temelin which was advised by the ENSREG stress test Peer Review Team to ensure the availability of another ultimate heat sink for cooling during loss of power. But this recommendation was not adequately acted upon, and only mobile measures were introduced.

The JRC Report tries to make believe that Regulation scare severe nuclear accidents away by explaining (key conclusions, p. 9):

> *"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. The achievement and maintenance of a high level of safety during the lifetime of nuclear facilities and the duration of related activities requires a sound governmental, legal and regulatory framework, which includes regular safety reviews and strict monitoring and reporting." (JRC Report, p. 9)*

The truth is, however, that nuclear regulators never insist on the implementation of state-of-the-art safety measures. Some of their announcements seemed very sound, but remained only announcements. Many national nuclear regulators delayed implementing the recommendations made by the EU stress tests: e. g., in France the '*hardened core'* was decided for all NPPs in France**.** **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.

The JRC Report continues by stating in its key conclusions (p. 8):

> *"Related analyses demonstrate that appropriate measures to prevent the occurrence of the potentially harmful impacts or mitigate their consequences can be implemented using existing technology at reasonable costs."*

Reality: If this statement relates to safety measures and post-accident measures, it is worth pointing out that the costs and consequences of **Fukushima** are staggering, and far from having been solved at reasonable costs. Only last week, Japan announced that the decommissioning process was still unclear, would not be finalised before 2050, and that costs were constantly increasing. Decontamination is not progressing, contrary to government claims. 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[24]:

"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

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

community. Over 160.000 people evacuated, but fewer than 35 per cent of them have returned. The fishing industry remains devastated. Agricultural industry is 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."

4.3.2 Safety of Lifetime Extension of NPP

This current fleet of old NPP are the ones the industry will use for another 20 years – almost no plants are under construction, and each takes an average of 20 years to construct. The JRC Report quotes enormous volumes of new NPP capacities (100 GW in 2050) which is certainly overstated, just as they have been in past decades. Regarding small modular reactors (SMR) there is not a single operating yet and the arguments why they should be deployed easier do not really hold up. This however not being a DNSH issue, we would like to refer to existing literature debunking the forecasts myths: *Role of nuclear and climate goals in IEA, IAEA, IPCC scenarios. Critical look at forecasts – Overestimated for nuclear and underestimated for renewables? Nuclear generation increases, on average by around 2.5 times by 2050 in the 89 mitigation scenarios considered by the IPCC.* (Günsberg 2019).

Perfectly aware of the dire situation with respect to new nuclear capacity, the industry needs to keep old reactors on the grid as long as possible. The (unknown) authors of the JRC Report claim:

> *"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 did not hesitate in using the term "*experience*" in a world in which the oldest reactor is around 51 years old (Beznau 1/Switzerland). That this is factually wrong was also pointed out by the Chairwoman of the Czech nuclear regulator SUJB, who added that "*Europe has relatively little experience with reactors operating for more than 50 years* (…) *lifetime extensions of more than 50 years will likely face mounting security and regulatory demands*"[25]. Researchers showed this already, for example, in the World Nuclear Industry Status Report (WNISR 2019). As Chairwoman Dana Drábová noted, the issue of security and safety is unknown at this point and can change at any time under new conditions, new insights or accidents such as Fukushima in 2011.

The INRAG Report on Ageing NPPs (INRAG 2021) distinguished between three main ageing phenomena: physical ageing (changes in properties of structures, systems and components), non-physical ageing (obsolescence, conceptual and technological ageing), and competence or loss of know-how due to ageing and retirement of those with experience. Their study's finding is that especially due to the interaction of these three ageing phenomena, the additional risks of NPP due to ageing becomes incalculable and increases the risk of severe nuclear accidents. Not all design deficits can be eliminated by retrofitting: A considerable part of the safety standard is already determined by the design of the NPP. Retrofitting of additional safety systems is only possible to a limited extent due to the structural conditions**. Despite extensive retrofitting, current safety standards are not achieved in old nuclear power plants.**

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[25] Platts Nuclear News Flashes 21 05 03:Czech nuclear regulator cautions against reliance on lifetime extensions

In assessing the likelihood of reactors being able to operate for 50 or 60 years, it is useful to compare the age distribution of reactors that are currently in operation with those that have already closed (see Figure 3 and 4). The age structure of the 181 units already closed (eight more than one year ago) completes the picture. In total, 66 of these units operated for 31 years or more, and of those, 24 reactors operated for 41 years or more. Many units of the first-generation designs only operated for a few years. Considering that the mean age of the closed units is 25.8 years, plans to stretch the operational lifetime of large numbers of units to 40 years and far beyond seems rather optimistic.

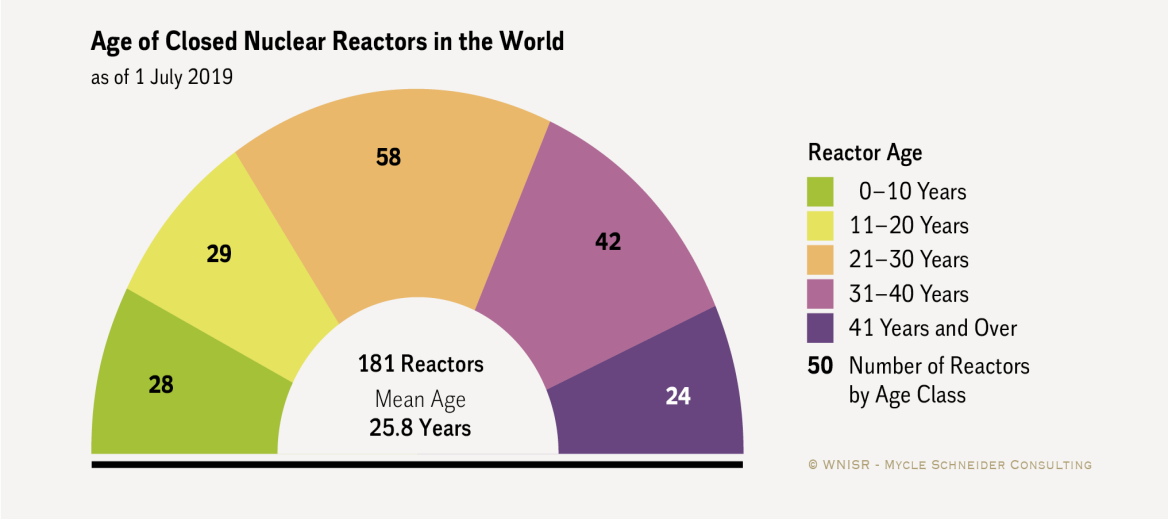

Figure 3: Age distribution of closed NPPs. Sources: WNISR 2019, with IAEA-PRIS, 2019

It is correct to say that the operating time prior to closure has increased continuously, but while the average age worldwide of reactors closed in a given year is now close to 40 years, it has passed this marker only twice so far: in 2016, with two reactors shutting down at ages 43 (Fort Calhoun, US) and 45 (Novovoronezh, Russia) respectively, and in 2018 with Oyster Creek, the oldest US reactor closing at 49 years, Leningrad-1 at 45 and Bilibino at 44 in Russia (see Figure 4).

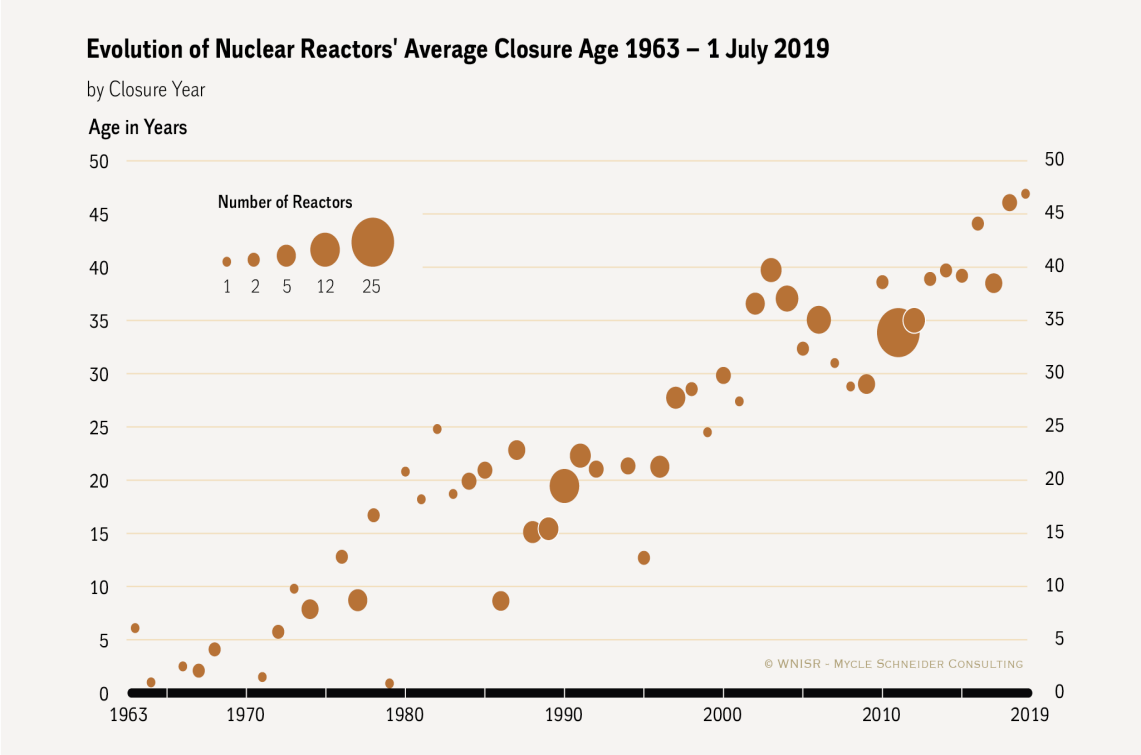

Figure 4: Nuclear Reactor Closure Age 1963 – 1 July 2019. Sources: WNISR, with IAEA-PRIS, 2019

4.3.3 Climate Change Impacts on Nuclear Safety

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.

NPP are extremely dependent on a steady supply of cooling water. The 2020 study "*Impacts of climate change on nuclear risk and supply security*" (Becker et al. 2020) examined the consequences at a general level and presented case studies, and concluded that: "*With our climate-impacted world now highly prone to fires, extreme storms and sea-level rises, nuclear energy is touted as a possible replacement for the burning of fossil fuels for energy. Yet scientific evidence and recent catastrophes call into question whether nuclear power could function safely in our warming world. Extreme weather events, fires, rising sea levels and warming water temperatures all increase the risk of nuclear accidents* (...)." The consequences included: *The efficiency of nuclear power plants decreases with increasing temperature, some sites may lose safety, with sea-level rise being of particular importance and extreme weather events threaten the safety of NPPs additionally* (...) *Cold and heat waves represent a significant problem for the electricity generation sector. Unplanned outages of NPP due to excessively high-temperature water constitute clear examples of this. Reports showed that 40% of the NPPs in Europe have already experienced cooling problems because of high temperatures*." The study also reported that for NPP Beznau in Switzerland, the oldest plant in Europe, the authorities tried to update the permit because of water temperature increases in the Aare River, but encountered resistance from the operator who has to reduce the output of generated electricity. This could be one of many cases in future, in which the use of less water will lead to severe conflicts.

4.3.4 Nuclear Security and Terrorism

Again, this report cannot discuss in depth all the topics not covered in the JRC Report, however, we would like to refer to the 2020 Nuclear Threat Initiative (NTI) Nuclear Security Index[26]. It describes its tasks:

The 2020 NTI Nuclear Security Index (NTI Index) assesses the security of some of the ***deadliest materials in the world—highly enriched uranium (HEU) and plutonium****—against theft and the security of nuclear facilities against sabotage. Stolen HEU or plutonium 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."

4.3.5 Conclusions

The JRC report claims that the most important safety improvements have probably been made already, including those following the EU nuclear stress tests, but the truth is that the EU nuclear safety stress test recommendations have not been implemented, some not even started ("hardened core"). Concerning severe nuclear accidents the JRC tries to make believe that Regulation can prevent them from now on from happening. The JRC stated that "*experience*" showed that an operating time of 60-80 years for nuclear power plant is possible – however, the oldest reactor is around 51 years old (Beznau 1/Switzerland); the mean age of closed units is 25.8 years. Concerning climate change impacts on nuclear power plants, research showed that sites were chosen without assuming the new higher risks such as extreme storms and sea-level rises. NPP operation will be hit by scarcer water supply, because reports showed that 40% of the NPPs in Europe have already experienced cooling problems because of high temperatures. Nuclear terrorism was ignored by the JRC Report, however, it has to be taken seriously and included in any assessment of nuclear energy's role in the future.

4.4 Nuclear Weapons and Non-proliferation

Also rather underrepresented in the discussion, but made relevant by the 2014 IPCC 1.5 degree report, is the issue of nuclear proliferation as a consequence of nuclear energy use. The Taxonomy Regulation and the TOR by the European Commission also failed to mention the issue, and the (unknown) authors of the JRC Report professed ignorance of this well-known situation.

The Iran crisis is a current reminder of this unique and massive problem that only nuclear energy threatens the world with:

[26] https://www.nti.org/analysis/reports/2020-nti-nuclear-security-index/

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 IPCC report: *Nuclear energy, the share of which increases in most of the 1.5ºC-compatible pathways (see Chapter 2, Section 2.4.2.1), can increase the risks of proliferation (SDG 16), and have negative environmental effects.*

The authors of the 2012 study Global Energy Assessment – Toward a Sustainable Future summarised 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 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.
- When looking at the IAEA list of countries considering starting nuclear programmes, the so-called newcomers are, in general, not the safest and politically most stable countries (IAEA 2017): "*Since the last report in 2014, Belarus and the United Arab Emirates (UAE) have progressed in building their first NPPs and four countries have decided to postpone or scrap their plans for nuclear power. Several countries in Africa have moved forward with their plans after hosting Integrated Nuclear Infrastructure Review (INIR) missions conducted by the Agency. Some, such as Bangladesh and Turkey, have ordered their first NPP and have initiated the site and construction licence processes. Others, such as Egypt and Jordan, are in the contractual negotiation phase, or are about to take a knowledgeable decision or prepare for contracting, such as Ghana, Kenya, Nigeria, Poland, Saudi Arabia and the Sudan, although national decisions reflecting broad political support are still pending in some cases."*

At this point, the international non-proliferation regime comes into focus. The key piece is the **NPT, the Non-proliferation Treaty** of 1968 which gives the IAEA the authority to watch its Member States, ensuring they do not acquire nuclear weapons, except for those who already (officially) own them.

Some doubt the efficacy of this concept, as the NPT is not a solution to proliferation, rather an effect of it. Sagan refers to countries such as South Africa and Israel who simply failed to sign up to the NPT while they had nuclear weapon programmes, and Iraq or North Korea who joined the NPT but secretly continued their nuclear weapon programmes.

However, the question for the Taxonomy discussion is whether civil nuclear programmes also pose a proliferation risk, considering that only 10 states have the necessary uranium enrichment facilities (as of 2010). More recently, leading experts in the field of non-proliferation have highlighted "*that the spread of all types of peaceful nuclear technology, not just "sensitive" nuclear technology, increases the likelihood of proliferation." (Sagan 2011)*

Scott D. Sagan gives an interesting insight into this discussion, as the following quote from his paper The Causes of Nuclear Proliferation (2011) shows: "*The conventional wisdom is wrong—and dangerous. All types of civilian nuclear assistance raise the risks of proliferation. Peaceful nuclear*

cooperation and proliferation are causally connected because of the dual-use nature of nuclear technology and know-how. Fuhrmann acknowledges that the vast majority of states that have received civil nuclear assistance agreements have not acquired weapons (in 99.77% of country-year observations, states receiving civilian nuclear assistance did not acquire the bomb), but he also insists that there is a strong statistical and causal link between the number of nuclear cooperation agreements (NCAs) and the likelihood that a country will initiate a nuclear weapons programme and eventually acquire the bomb. Fuhrmann asserts that 'nuclear cooperation strongly influences whether a country goes down the nuclear [weapons] path. Participation in at least one nuclear cooperation agreement increases the likelihood of beginning a bomb program by about 500%' ".

Fuhrmann is also quoted with his central insight "that a state may acquire dual-use technology with only peaceful intent, but then succumb to the temptation to initiate weapons research when international threats emerge."

Non-proliferation is a risk which the NPT has not been able, and will not become able, to constrain. The NPT regime itself is under increasing pressure. The 10th NPT Review Conference was scheduled for April 27 to May 22, 2020, but was postponed due to the corona pandemic. As the much-respected Pugwash experts put it in their May 2020 statement: "The risks for the Conference and, ultimately, for the Treaty itself, have been multiplying. There is a large list of serious worries and problems: the renewal of the nuclear arms race; the crisis in the architecture of nuclear arms control treaties; the crisis in the relations among nuclear weapon powers; new setbacks relating to the Iranian nuclear deal and the proliferation crisis in North-East Asia; and growing antagonisms between nuclear-weapon-possessor and non-possessor states."[27]

The following reflection in the Bulletin[28] on the Turkish President's speech in which he stated that "Nuclear [military] power should be forbidden for all, or should be permissible for all" serves as the conclusion for this chapter: "Over the years, the Nuclear NPT has been subject to heavy fire, both from enemies and friends, but recently there has been nothing so sharp as the criticism that Turkish President Recep Erdogan delivered on September 24 in a UN General Assembly speech. It deserves much more attention than it got because it reflects a continued loss of respect amongst key NPT-Member States for the Treaty's no-nuclear-weapons pledge (…) Of course, Turkey is only just constructing its first nuclear power reactors—but we should not underestimate Turkey's industrial abilities once engaged. And we should not take Erdogan's criticism of the NPT arrangement as idle talk."

4.4.1 Conclusions

The atom bomb, nuclear proliferation, the spreading of nuclear weapons, fissionable **material and weapons-applicable nuclear technology and information is often ignored, because the debate about nuclear power usually centres on energy production. However, proliferation has been brought back into the discussion by the authors of a task similar to the Taxonomy effort – the 2018 IPCC report: *Nuclear energy, the share of which increases in most of the 1.5ºC-compatible pathways (see Chapter 2, Section 2.4.2.1), can increase the risks of proliferation (SDG 16), has negative environmental effects.*** The end of the bipolar world order and the rise of regional powers

[27] https://thebulletin.org/2020/05/the-postponement-of-the-npt-review-conference-antagonisms-conflicts-and-nuclear-risks-after-the-pandemic/
[28] https://thebulletin.org/2019/11/taking-erdogans-critique-of-the-nuclear-non-proliferation-treaty-seriously/

leads to states such as Turkey starting a nuclear power programme, without excluding their possible interest in acquiring nuclear weapons.

4.5 Radioactive waste and spent fuel management – unsolved, even on paper

The JRC Mandate includes a special section (part B) on nuclear waste. Their task was to **conduct a specific assessment of the current status and perspectives of long-term management and disposal of nuclear waste**. Reminder: The final comments of the TEG were based on the claim that there is no robust evidence regarding DNSH criteria with respect to high level radioactive waste.

The research of the JRC was required to include:

- An analysis of the current legal framework.
- An analysis of the state-of-the-art technologies, focusing on recycling and reuse, 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 storage and disposal of all radioactive waste and spent fuel.
- A review of the scientific research and prospects for the treatment and management of radioactive waste.

4.5.1 Everything Under Control? The 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**. When presented with the directive by the European Commission, every Member State was forced to produce 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 2015 and 2018.

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 European Commission's own report on the implementation of the waste directive (EC Report 2019) found that Member States are far from achieving this goal. The EC conducted two reviews of the submitted national waste management programmes. In its second report from late 2019, the EC stated that progress has been made, but **"[H]owever, more needs to be done" (EC Report 2019, p. 17).** The EC presented a long list of necessary remedies to be delivered by the Member States:

- Swift decisions on national policies, concepts and plans should be taken, especially for intermediate level waste and high level waste.
- Member States that consider shared solutions should cluster up and take practical measures, including on site-specific matters.
- Member States must ensure sufficient funding for the costs of the national programmes.
- Classification schemes must be harmonised.
- Many countries report delays in the implementation of the programmes. Clear key performance indicators are needed for monitoring progress to avoid further delays.
- The inventory projections must be improved.
- The independence of the nuclear waste regulator must be demonstrated or established in the first place, including allocating sufficient financial and human resources.
- Outcomes of peer reviews and self-assessments should be shared, and a transparent dialogue with stakeholders is necessary.
- Research, development and training also remain important in delivering long-term solutions for high level and intermediate level waste and spent fuel management.
- Many Member States need to improve the quality of their national reports; and.
- The EC will follow up the work of the Member States and take legal action if necessary.

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.

This list of conclusions from the 2019 EC Report shows the overall poor status of the Member States national nuclear waste management programmes. But without a clear concept of how to deal with nuclear waste, progress cannot be expected soon. 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.

The JRC Report mentioned the ARTEMIS peer reviews, but ignored other reviews with worrying results such as the mission to Bulgaria in 2018.[29] Recommendation No. 4 made clear that **Bulgaria does not have the means to finance a final repository at all**: *"The Government should ensure that financial provisions for geological disposal are made."* This recommendation was made because the Peer Review Team was informed that the cost for geological disposal was not included in the activities covered by the RAW fund.

4.5.2 State-of-the-art Technologies and Operational Experience

According to the TOR used the basis for its report, 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 storage and disposal of all radioactive waste and spent fuel.

With respect to nuclear waste, Chapter 4 of the JRC Report includes many images of colourful and clean drums in interim storage and similar facilities. But the references listed at the end of Chapter 5 make clear that this does not reflect the reality but exist only in theory, since mostly OECD/Nuclear

[29] https://www.iaea.org/node/41657

Energy Agency (NEA), some IAEA papers were quoted, which consist of plans, concepts and research tasks published regularly.

The only final disposal facility in operation for nuclear high level waste is the **WIPP (Waste Isolation Pilot Project)** in the USA, but its operational experience is not even mentioned in the JRC Report, and nor is the operational experience from the **Asse final repository** in Germany. The most likely reason for this omission is the fact that both storages have experience massive technical problems and enormous clean up costs.

WIPP/USA is currently the only underground nuclear waste storage site for high level waste disposal. The basic concept is the internationally-favoured combination of barriers to store transuranic waste from the US' nuclear weapons programme, and later also to receive nuclear waste from commercial power-generating plants. Instead of proving to be safe for 10.000 years, there was already a radiation leak in 2014, and in another accident a truck inside the underground facility caught fire. The cause was confirmed in a recent study as "*Heat and pressure had built up in the drum due to chemical reactions with an organic kitty litter, Sweat Scoop, which had been mistakenly added to it at Los Alamos National Laboratory, the birthplace of the atomic bomb*." (Ialenti 2021) The study is also valuable because it identifies causes for safety violations connected with packaging, transport and storage of nuclear waste, which can be transposed to other waste management programmes. Several sources report that the costs of clean up were USD 1 – 2 billion, after the facility had to be shut down for years, re-opening only recently.

The rest of Chapter 5 in Part B of the JRC Report presents only ideas and potentials, but tries to give the impression of challenges already met, e.g. *"This goal is technically achieved by interposing a series of barriers between the waste and the environment. Figure 5-1 schematically illustrates the multi-barrier concept. Some of the barriers are engineered and some are provided by the natural properties of the host rock of the repository."* None of this exists in practice, and the materials for the multi-barrier concepts have not been yet determined (see the arguments below).

As a consequence, the interim storage facilities – often located at the nuclear power plant site – keep filling up, leading to new and unexpected problems requiring new research. What are the **implications of extended interim storages**?

> *"(…) spent fuel storage containers are designed for storage and are not suitable for disposal. (…)Therefore, at the end of the interim storage stage, spent fuel needs to be retrieved and encapsulated in a different (smaller) container suitable for disposal. 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)*

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 need to be upgraded, e.g. with thicker walls to withstand terror attacks and airplane crashes. Interim storage for spent fuel rods turning into long-term interim storage with unexpected problems are another example of a non-mature technology, as described by the JRC Report (page 242): "*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 goal is to confirm that spent fuel assemblies and containers will retain their integrity and functionality, allowing repackaging and transportation after extended storage in excess of one century, and/or to define preventing or mitigating measures potentially necessary to cope with significant degradation of any containment system (**cladding, canister, cask, welds/sealing**, etc.)".*

The JRC Report offers a very short overview of the development of the Swedish final repository (page 267), giving the impression that this project is about to receive the final permits needed, and ending the paragraph with the sentence: "*This, together with approval from SSM and MMB[30], allows the government to approve the licence so the construction of the repository and the encapsulation plants can be implemented.*"

Outlook on the timetable for deep geological repositories

A timeline for planned operation of a deep geological disposal is presented in the figure below. The first three projects are already delayed, and the other Member States seem to have taken refuge in postponing their plans for as long as possible, to avoid early failures.

Figure 5: Timeline for the development of deep geological repositories, and their delay. Source: Presentation by Manuel Martin Ramos, EC JRC, at the EURAD Introductory Course on 14 Sept 2020

It is clear that future delays can be expected.

4.5.3 Copper Dreams Not Coming True and Other Corrosion Problems

One of the key safety features for the final repositories are the canisters needed to keep the spent fuel waste from leaking into the surrounding host rock. However, over the past 50 years no materials sufficiently resistant to radiation, toxic impacts, involved heat production, etc., have been identified. The material the industry has placed its biggest hopes in for use in a granite-based deep geological disposal is copper – or rather it was.

An overview of the Swedish/Finnish spent fuel repository situation[31]: The research on the KBS(-3) 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. SKB, the private Swedish company responsible for finding a solution to nuclear spent fuel, kept

[30] SSM is the Swedish Nuclear Regulator and the competent court is MMB.

[31] http://www.nuklearsymposium.at/images/2020/2020_wns_Swahn_MKG.pdf, http://mkg.se/en/scientifically-inferior-skb-report-on-copper-corrosion-in-lot-project-shows-that-copper-is-not

presenting this concept as the much-needed solution. 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 2017, the Swedish Environmental Court refused to accept the regulator's (!) attempt to postpone the copper corrosion issue until after a government permission for the repository. During the court proceedings, leaks to media showed that even the regulator own SSM's experts had doubts, with their own corrosion expert against the go-ahead for copper because the science has now shown that water can directly corrode copper even in the absence of oxygen. This means that copper in a KBS-repository may corrode at much faster rates than acceptable, and release radioactivity from the canisters after only around 1,000 years of storage time.

On January 23, 2018, the Environmental Court made its recommendation to the government and did not support the application, primarily because of uncertainties regarding the long-term safety of the planned repository due to possible problems with copper canisters. The Swedish NGO MKG said in October 2019[32]: *"The two test packages were secretly taken up by the nuclear waste company in the autumn of 2019. It was then revealed that the company did not want to report any copper corrosion results until after the government had approved the licence to start building the repository for spent nuclear fuel in Forsmark. The company then changed its mind, and said that copper corrosion results would be reported both for the copper pieces (coupons) that were in the test packages, but also for the central copper tube that has been heated to significantly higher temperatures. The Swedish Radiation Safety Authority SSM then decided to start a project to ensure that the copper corrosion results that the company reports will be quality assured."*

Finally, the regulator SSM took this issue up and started a quality assurance programme.[33] It should be understood that the very basis of the repository project is at stake here: SKB's claim that the corrosion is caused by trapped air and thus will not proceed over the next years during storage has not been proven to date. SKB also is an example – together with the State's regulator SSM – of safety not being the first priority. The scientific community is worried about SSM's attitude: the KTH Royal Institute of Technology listed several serious problems with the SKB report on the 20-year copper corrosion test[34] saying that, '*SKB has excluded scientific facts concerning microbial activity in the ground water and used flawed thermodynamics (…) omitted to study the most corroded parts of the central copper tubes and the bottom plates'* and concluded with a short statement, *'This LOT-study shows, under all circumstances, that the anoxic* ***copper corrosion rate in Swedish groundwater is catastrophic with respect to the KBS-3 model****,'* going on to explain that the catastrophic copper corrosion rates resulted from circumstances with additional stress under real repository conditions consisting of *'radiation induced corrosion (radiolysis), stress corrosion cracking and hydrogen embrittlement.*'

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. SSM will deliver a report on the repository to the Swedish government in March 2021. With a view to more scientific insecurities, the government is advised by several

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[32]http://mkg.se/en/scientifically-inferior-skb-report-on-copper-corrosion-in-lot-project-shows-that-copper-is-not

[33]https://www.stralsakerhetsmyndigheten.se/contentassets/b8881783acf14def9409d9d48789a0e2/201922-technical-note-ssms-external-experts-reviews-of-skbs-report-on-supplementary-information-on-canister-integrity-issues.pdf

[34]http://mkg.se/uploads/Appendix_3_Szakalos_&_Leygraf_The_most_important_comments_to_the_SKB_LOT-report%20_TR-20-14_201123.pdf

stakeholders (including academic and from civil society) and could refuse the go-ahead for this repository project.

What is important to understand: The Onkalo final repository in Finland which, according to some industry organisations, would be only months away from being granted an operational licence, is supposed to use the very same Swedish copper canister system. However, the current status of research and licensing in Sweden makes such fast procedures impossible. Even if Finland could manage a granite/copper system, this has no real value for other countries who would need to locate their own sites, start investigations of site-specific geological conditions in their own host rock, and design and approve their own appropriate container system and ensure local acceptance at the chosen repository site.

"We need to develop a new model for storing nuclear waste"[35]**:** This was the alarming message from the most recent corrosion research by Xiaolei Guo et al., a Deputy Director at Ohio State University. Their study (Guo et al. 2020) researched the corrosion of glass or ceramic waste forms in stainless-steel canisters for HLW. Results showed that, *"under simulated repository conditions, corrosion could be significantly accelerated at the interfaces of different barrier materials, which has not been considered in the current safety and performance assessment models*." This leads to the conclusion that current planned methods for storing high level nuclear waste are seriously unsafe and could result in radioactive materials being released into the environment.

Corrosion is increasingly becoming a serious problem, also at the French repository site, Cigeo in Bure. The site, with clay as a host rock, poses an additional problem, because "*Radiation will break down water in the rock and cause corrosion of metal structures, leading to the release of explosive hydrogen gas, says biologist and engineer Bertrand Thuillier, an associate professor at the University of Lille. ANDRA plans to ventilate the tunnels, but that could exacerbate fires by providing oxygen, he says. A failure could be catastrophic, Thuillier warns: The area around Bure helps provide eastern Paris with water and is close to one of the world's most cherished wine regions, Champagne"*[36].

4.5.4 Current EU Joint Research into Waste Management

Another sign that not everything is not yet on track are the large amounts being spent on research on EU level, e.g. in the **EURAD Project - European Joint Programme on Radioactive Waste Management.** This five-year research project started in 2019 and gives an idea of the issues in the field of waste management which have yet to be resolved. EURAD is not at the laboratory research stage: It was designed to identify the most important topics for research. The European Commission sees the EURAD project's goals as a way of finding answers to "*the challenges in the field of radioactive waste management*" in Europe. One question EURAD considers is how to manage uncertainties – based on the insight that nuclear waste management can never be free of uncertainties. In an Introductory Course held in September 2020[37] the key importance of uncertainty management was highlighted, research needs to be done to reduce, avoid or mitigate uncertainties.

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[35] https://www.independent.co.uk/news/science/nuclear-waste-storage-safety-weapons-environment-a9303971.html, Accessed on December 15 2020

[36] https://www.thefreelibrary.com/Reports+raise+concerns+about+France%27s+nuclear+waste+tomb.-a0506829286.

[37] https://www.ejp-eurad.eu/events/one-day-course-introductory-course-eurad-and-radioactive-waste-management

In consequence, it is clear that the notion of "safe" will have to be switched to "as safe as possible," which is, in the end, the result of negotiations between different stakeholders. Moreover, in this Introductory Course it became clear that the Safety Case concept has been not defined in the Nuclear Waste Directive, because all countries apply it differently.

Research questions dealt with in the EURAD project include: Will the interaction between materials have an impact on the integrity of the waste package, for example? What will happen to the organics in the waste package, and to their degradation forms? How can the chemical evolution in large structures and over long times be assessed, not only in laboratories? What research results can be upscaled from waste packages to disposal cell scale? Is adsorption a reversible process? In reality, many components will simultaneously compete for adsorption, but in studies usually only one component is researched at a time.

This shows that a vast amount of research is still necessary and may take decades. Large-scale experiments are needed, but not even within the framework of the large EURAD research project can the EU or the Member States provide sufficient funding for these experiments and tests.

4.5.5 Transmutation & Partitioning

The JRC Report described a process which has been researched for several decades already – **Transmutation and Partitioning**: A process complementary to the fully closed cycle is 'partitioning and transmutation' 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 (i.e. 'partitioning'). Their transformation into short-lived products (i.e. 'transmutation') 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 partitioning and transmutation is currently **only at an experimental scale**.

Or as SKB (Swedish Nuclear Fuel and Waste Management Co) put it: "Research on P&T started in the 1950s when development of nuclear power gained momentum. In subsequent years it was mainly tied to the development of the breeder reactor. As the development of breeder reactors slowed down to a very low level in the early 1980s, **interest in P&T more or less disappeared**."[38] The report mentions a certain renewed interest in the 1990s, however, and also concludes that "a successful development of P&T will not eliminate the need for deep geologic repositories for high level waste and for long-lived waste. The complex processes will unavoidably create waste streams containing small quantities of long-lived radionuclides. The development **may**, however, decrease the demands on engineered barriers. It may also decrease the required volumes of high level waste in the repositories (volumes of low and intermediate level waste will, on the other hand, tend to increase as a result of the partitioning processes)".

The "experimental scale" has been the status of Transmutation and Partitioning for 50 years. According to the SKB study "the development of any P&T-system will require several decades."

[38] SKB 2017. Partitioning and transmutation Current developments – 2013 A report from the Swedish reference group for P&T-research

4.5.6 Creating Unmanageable Risks for Future Generations – Unsolved Long-term Transgenerational Aspects of Final Disposals

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. Such a responsibility means maximal avoidance of further production of radioactive wastes.

The Nuclear Waste Directive 2011/70/Euratom Art. 12 (1) (e) specifies that EU countries must include concepts in their waste management programmes on how to ensure the safety of their repositories, also after end of operation. Only a few countries are engaged in research on knowledge preservation, while most countries neglect the topic altogether.

Currently, most scientists and politicians promote a concept of passive safety – sealing the final repository, dismantling the above ground facility (resulting in a so-called green field) and relying on the technological and geological safety barriers, without any need for human action. But such a passive safety concept is not helpful in view of unintended intrusions such as potential drilling activities. An example: In the region of the WIPP[39]/USA New Mexico, a drilling rate of 148 boreholes per square kilometre over a 10.000 year period is predicted; drilling into the repository and after that into a brine pocket could result in the mobilisation of radionuclides due to the brine reacting with the radioactive waste; radioactive fluid could spread through the borehole into the groundwater and above ground level [40].

To preserve memory over generations, all types of warning mechanisms need to be updated regularly. The US Department of Energy created the so-called Human Interference Task Force (HITF) in 1980 with the aim of developing a method to warn future generations for up to 10.000 years not to intrude in a nuclear waste site. In 1984, HITF published its results in a technical report[41]. The risks of war or terrorism were also included in this HITF assessment, resulting in the recommendation that "[r]epositories should, therefore, be unattractive targets for war, sabotage or terrorism." With the terrorism experiences of today, this recommendation sounds very outdated.

What has been proposed since the 1980s to warn and inform future generations[42]? Warning signs, warning messages and symbols, building immense markers and dangerous looking monuments, creating an artificial moon, engineering mathematical code on biological matter based on the assumption that only biology but not culture will survive, genetically manipulated cats which change their skin colour when coming into contact with radioactivity, dissemination of myths, fairy tales and legends, a nuclear priesthood and artificially created rituals and legends, to be renewed from time to time and passed on between endless new generations of these priests….

A research project undertaken by the NEA concluded that no single mechanism or technique exists which by itself is likely to achieve Preservation of Records, Knowledge and Memory (RK&M) over all timescales. The project therefore created a toolbox which consists of a set of nine approaches,

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[39] WIPP = Waste Isolation Pilot Plant. The WIPP is located in New Mexico, USA. It is a repository in a salt bed for military transuranic waste like Plutonium. In 2014, an accident occurred at WIPP (the so-called cat-litter accident). The WIPP was planned to be closed in the early 2030ies, which was postponed to 2050 or even beyond.

[40] Tracy, Cameron L.; Dustin, Megan K.; Ewing, Rodney C. (2016): Policy: Reassess New Mexico's nuclear-waste repository. Comment. In: Nature 529, 149-151 (14 Jan 2016).

[41] HITF (1984): https://www.osti.gov/servlets/purl/6799619

[42] Read more: http://www.ecology.at/wua_endlager_wissenserhalt.htm

comprised of a set of 35 mechanisms. Two of these mechanisms are called novel concepts: 1) the key information file, designed to be a summary file (about 40 pages) for wide dissemination and use; and 2) a set of essential records (SER), with the selection based on anticipated future needs.

The European EURAD mega-research project is focusing its research only up to the closure phase of a deep geological disposal. But after closure, the risk of environmental contamination or security breaches will not have vanished. The difficult question of how to protect future generations over the very long term is not tackled at all in this flagship nuclear waste research project.

End of nation states – a reminder:

It should not be forgotten that all the possible routes to take rely on the existence of a state with strong legal and financial continuity. Otherwise nuclear knowledge will disappear in a very short time, which will be a problem when ensuring the safety and security of waste repositories over thousands of years and keeping the memory alive over hundreds of thousands of years.

The issue of a state needed to look after the waste for one million of years cannot be considered solved. It is clearly not possible to claim that the continuation of states or similar entities can be seen as guaranteed for tens of thousands of years, when it is almost impossible to imagine what Europe will look like in only 150 years. Who will be legally and financially forced to look after the toxic legacy?

Around only one hundred years ago, many European states did not exist and were founded in the years after the end of the First World War. They include the Czechoslovak Republic (now two states), Hungary, Poland, the Kingdom of Serbs, Croats and Slovenes, Romania, Austria, not to mention countless territories which became parts of other states as the result of various treaties.

Former Yugoslavia alone has now been replaced by eight countries, the most recent being Montenegro, created in 2006:

The present-day states which succeeded Yugoslavia are still today sometimes collectively referred to as the **former Yugoslavia**. These countries are, listed chronologically:

- Slovenia (since 1991)
- Croatia (since 1991)
- North Macedonia (formerly Republic of Macedonia) (since 1991)
- Bosnia and Herzegovina (since 1992)
- Federal Republic of Yugoslavia (Serbia and Montenegro) (1992–2006)
  - Serbia (since 2006)

2008 map of the former Yu

Figure 6: Post-Yugloslavian states. Source: wikipedia

In the early 1990s the break-up of the UdSSR and its rule over satellite states resulted in the creation of 15 new states (Wikipedia):

Figure 7: Post-Soviet states after 1990, Source: wikipedia

The geopolitical developments point towards the creation not only of an increasing number of new states, but also of regional powers. The assumed statical political situation is wishful thinking only.

Instead of the former superpowers and the US refusing to play the role of the world's police, more states will project their power on other states, creating a more volatile geopolitical situation.

4.5.7 Conclusions

The JRC Report listed current legislation but did not mention the deficiencies in implementation of some of this legislation, especially the first Nuclear Waste Directive (Directive 2011/70/Euratom), in the EU Member States. The Nuclear Waste Directive tried to force EU Member States to start taking the problem of nuclear waste seriously, after this had been neglected for decades – thus already proving that nuclear waste has never been managed effectively. In its second report in late 2019, the EC stated that progress has been made, but *"[H]owever, more needs to be done"* (EC Report 2019, p. 17). The conclusion of the EC Report from 2019 shows the overall poor status of the Member States national nuclear waste management programmes.

But without a clear idea of how to deal with nuclear waste, progress cannot be expected soon. When financing, regulatory structures, inventory data and transparency regimes are unavailable or in a poor state, decades of improvement must follow before a sufficiently or acceptably safe nuclear waste management programme can result.

The situation has not changed significantly over the past 70 years since the first nuclear reactors started operating: there is no solution for nuclear waste, only the nuclear industry's public relations have improved when claiming they are very close to finding a solution. The much-hailed repositories in Sweden, Finland and France are far from ready to receive spent fuel, instead increasingly there are problems, such as finding an appropriate material for the storage canisters.

Corrosion of containers is a huge problem. Copper canisters were believed not to corrode – the scientific hypothesis was that oxygen-free water does not corrode copper in a repository where there

is no oxygen after closure. But experiments have shown that this is not true. The issue of corrosion is still under investigation and could derail the entire repository project in Sweden and Finland.

Research questions that are dealt with in the most recent joint research project on the deep geological repository (EURAD project, 2019 – 2024) include: Will the interaction between materials have an impact, for example on the integrity of the waste package? What will happen to the organics in the waste package, and to their degradation forms? How can the chemical evolution in large structures and over long times be assessed, not only in laboratories? What research results can be upscaled from waste packages to disposal cell scale? Is adsorption a reversible process? In reality, many components will compete for adsorption simultaneously, but in studies usually only one component is researched. This shows that a vast amount of research is still needed and may take decades. Large-scale experiments are required, but not even within the framework of this large EURAD project can the EC or the Member States provide sufficient funding for such experiments.

The JRC Report presented the Transmutation and Partitioning as an upcoming technology for reducing the nuclear waste burden. However, after decades of research the development of any P&T-system will still require several more decades. Therefore, it is wishful thinking to assume that Transmutation and Partitioning will be able to solve the nuclear waste problem any time soon.

The safety of future generations is at stake. Decisions must be taken on how long nuclear waste can be recovered after a final repository has been sealed – an important criterion for choosing geology and technology, and not just a simple question to be decided at some point in the future.

The means of preserving knowledge, data and memory on nuclear waste burials are not solved, needing much and continuous effort, also long after nuclear power production is over. This is another clearly unsustainable aspect of nuclear energy.

4.6 Uranium Mining and Milling

"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)

"However, they [uranium mining and milling activities] can significantly challenge the four remaining environmental objectives, as most of the LCA indicators can exert "high" or "critical" impacts on all these four objectives. These challenges can be averted, as there are appropriate measures – using existing technology at reasonable costs – to prevent the occurrence of the potentially harmful impacts or mitigate their consequences (see the "appropriate measures" column in Table 3.3.1-2)." (JRC Report, p. 79ff.)

All three 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.

Clearly 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 report notes that "abandoned or improperly constructed uranium mill tailings" cause enormous problems.

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. 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) or another overview including smaller dam failures to 2017: http://www.wise-uranium.org/mdafu.html) The UNEP, the UN Environmental Program, has also listed such accidents and commissioned major studies. (UNEP 2017)

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. Measurements at the MAPE mine near Mydlovary in Czechia in 1990 showed radium contamination up to 800 kBq/kg soil material, and external dose rates up to 200 times the natural background at locations that could be easily accessed by the public. A non-occupational additional exposure due to MAPE was assessed at several 100 µSv/a. (Bossew 1990) Seventeen years later, in 2007, the remediation of the area was still not finished. (Švehla 2006)

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[43]. The radiation level was 20 times the background level.

4.6.1 Conclusions

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. Therefore, the JRC argument that if measures and standards are kept, contamination can be held at bay, is weak.

[43] http://urlz.fr/fNan

4.7 Reprocessing Spent Fuel

"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 certainly 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.

"Techniques for reprocessing of irradiated uranium were developed in the 1940s for military purposes. 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)

The JRC Centre chose to present reprocessing as any other technology when saying that reprocessing is part of the "closed" nuclear life cycle, however, careful reading shows that 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 (p.111) but without noting that reprocessing is still one of the riskiest technologies in terms of weapons proliferation. The NPEC report (NPEC 2021) tries to alert the world to China's intention to increase its reprocessing capacities, saying "*This raises another problem with China's "peaceful" plutonium programme. 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. As explained in the two appended studies, the history of safeguarding reprocessing, in particular, has been punctuated with disturbing failures, which do not lend themselves to technical fixes."* Despite the JRC Report pointing out that IAEA – worldwide – and Euratom for the EU are running a tight ship on non-proliferation, China simply refuses to be subject to those controls. Nor does France take non-proliferation seriously, because Paris has been negotiating the export of a reprocessing plant to China for a decade, according to the NPEC report: "*China has pursued the purchase of an 800 tHM/y civil reprocessing plant from France. If a plant of this size is built and operated at an average 75 per cent capacity factor, it could recover on the order of 6 t/y of plutonium (or 1.200 bombs' worth of Reactor Grade Plutonium assuming 5 kgs per warhead and that the SF processed contains approximately one per cent plutonium)."* Appendix 1 of this study provides an overview of safeguarding failures both by Euratom and the IAEA.

The JRC also chose to ignore the environmental impact of this technology. As part of the reprocessing process, plutonium is separated from the uranium in the SF: *"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."[44]

The JRC Report explains that this recycled fuel is used in advanced reactors operating with a fast neutron spectrum (fast neutron reactors or fast reactors)(p.108) with a footnote pointing out that in Europe, prototype and commercial scale demonstration fast neutron reactors have been developed, built and operated, but fast reactors are not yet commercially available. They remain under development for future deployment.

4.7.1 Conclusions

The nuclear chain will in large parts never be a cycle.

Reprocessing has practically no impact and has been abandoned as a technology. Moreover, it is one of the riskiest technologies with respect to proliferation and nuclear weapons development. In essence, the associated technology – so-called fast reactors – does not exist either.

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

5 Overall Conclusions: Can Nuclear Energy Fulfil the Taxonomy Criteria?

The Taxonomy Regulation recognises as green, or 'environmentally sustainable', economic activities that make a substantial contribution to at least one of the EU's climate and environmental objectives, while at the same time not significantly harming any of these objectives and meeting minimum social safeguards.

What can nuclear energy contribute to the six environmental objectives, and where does it significant harm?

1. Climate change mitigation

Under certain circumstances, nuclear power can produce electricity with low greenhouse gas emissions compared to fossil fuels. However, taking into the account the long list of highly problematic issues this paper listed (from uranium mining to the unsolved waste disposal problem), nuclear energy does not fulfill the 'best-in-class approach' in the energy sector, since there are electricity generation sources with even lower greenhouse gas emissions and no comparable "side effects".

2. Climate change adaptation

For nuclear this could be understood as nuclear power generation's resilience against impacts of climate change. NPP are dependent on a continuous supply of cooling water, while at the same time they heat up rivers by releasing hot water from operating the reactors.

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.

NPP are extremely dependent on a steady supply of cooling water. The 2020 study "*Impacts of climate change on nuclear risk and supply security*" [45] examined the consequences at a general level and presented case studies, and concluded that: "*With our climate-impacted world now highly prone to fires, extreme storms and sea-level rises, nuclear energy is touted as a possible replacement for the burning of fossil fuels for energy. Yet scientific evidence and recent catastrophes call into question whether nuclear power could function safely in our warming world. Extreme weather events, fires, rising sea levels and warming water temperatures all increase the risk of nuclear accidents* (...)." The consequences included: *The efficiency of nuclear power plants decreases with increasing temperature, some sites may lose safety, with sea-level rise being of particular importance and extreme weather events threaten the safety of NPPs additionally* (...) *Cold and heat waves represent a significant problem for the electricity generation sector. Unplanned outages of NPP due to excessively high-temperature water constitute clear examples of this. Reports showed that 40% of the NPPs in Europe have already experienced cooling problems because of high temperatures*."

3. The transition to a circular economy

The Taxonomy defines 'circular economy' as an economic system whereby the value of products, materials and other resources in the economy is maintained for as long as possible, enhancing their

[45] http://www.joint-project.org/upload/file/Joint_Project_Working_Paper_Climate_Change_Impacts_final.pdf

efficient use in production and consumption, thereby reducing the environmental impact of their use, prevents or reduces waste generation and of hazardous substances at all stages of their life cycle, including through the application of the waste hierarchy (waste prevention, reuse and recycling).

A circular economy is characterised as an efficient use of resources followed by recycling or reuse; waste is minimised. None of this is true for the nuclear energy sector: from the very beginning of uranium mining, enormous quantities of all types of nuclear wastes are produced and have to be stored and disposed of for up to a million years, despite efforts of reprocessing spent fuel, which is being abandoned for lack of efficiency and cost. **A safe solution for radioactive waste has not been found during the 70 years of existence of nuclear power.**

4. Sustainable use and protection of water and marine resources

Top attention should be drawn to ongoing dispute around the planned release of tritium contaminated water from the Fukushima accident into the Pacific Ocean, where the neighbouring countries are fighting this desperate post-Fukushima disaster measure undertaken by the Japanese authorities.

And this is not the only radioactive waste that enters the global water resources. Especially problematic are discharges from nuclear facilities like the reprocessing plant Sellafield to the Sea, but also historical nuclear waste dumping.

5. Pollution prevention and control

In legal texts, often limits and thresholds are fixed. If these were 100% met, it would be a step towards lower risk due to nuclear energy use and a step away from doing significant harm. But legal requirements often are only existing on paper. In reality, states chose to ignore requirements (see high number of infringement procedures among EU Member States), or use them to “prove” that the safety of their nuclear installations is high enough. It cannot be said often enough: If a legal text requires that in case of a severe accident in a NPP no consequences in more than a few kilometres distance will occur, then this does not mean that severe consequences really can be ruled out. **No nuclear facility is 100% safe and secure.** Even if new reactor technologies have to comply to the concept of practical elimination of early and large releases in case of a severe accident, this does not mean they will always be able to fulfil this requirement in reality, nor does it mean that the existing old NPP fleet of Europe can fulfil requirements of practical elimination.

From the very beginning, nuclear energy use has created **nuclear legacies having done and still are doing significant harm to humans and environment**. These legacies are:

- Dumping of nuclear waste into the Sea, or into regions of the Global South. For many of these dumped waste containers there is no knowledge available where they have been dumped and if they are still intact, if they can and should be recovered.
- Heavily polluted areas by atomic weapons tests and nuclear bombs.
- Heavily contaminated areas due to severe accidents in nuclear facilities.

- Abandoned uranium mines with huge tailings.
- Former nuclear waste disposals causing environmental problems (like the Asse in Germany).

All of these legacies are here to stay. Either there are no remediation measures available (how to decontaminate a forest or large soil areal effectively?), or there is no interest in remediation (no plans for recovering the dumped nuclear waste containers from the Sea), or there is no money available for actions like uranium tailings remediation. If a technology and its industry want to be labelled sustainable, more efforts should be undertaken to clean up the historical mess.

6. The protection and restoration of biodiversity and ecosystems

Like on humans, radiation also has effects on flora and fauna. the genetic consequences are of special importance.

Nuclear energy has done and does significant harm to environmental objectives.

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