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Expert response to the report by the Joint Research Centre entitled "Technical assessment of nuclear energy with respect to the 'Do No Significant Harm' criteria in Regulation (EU) 2020/852, the 'Taxonomy Regulation'"

Particularly considering the suitability of criteria for including nuclear energy in EU taxonomy

The Federal Office for the Safety of Nuclear Waste Management (BASE)

with support from the Federal Office for Radiation Protection (BfS)

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Summary

The Federal Office for the Safety of Nuclear Waste Management (BASE) with support from the Federal Office for Radiation Protection (BfS), acting on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), has examined the report by the Joint Research Centre (JRC) of the European Union (EU) entitled "Technical assessment of nuclear energy with respect to the 'Do No Significant Harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation')" to see whether the JRC has used expertise that is complete and comprehensible when determining whether the use of nuclear fission to generate energy can be included in the taxonomy register.

The Taxonomy Regulation defines criteria that determine whether an economic activity (and therefore investments in this activity) can be viewed as ecologically sustainable. The JRC, the EU's research centre, concludes in its report dated March 2021 that the conditions for including nuclear energy in EU taxonomy are met in terms of the "Do No Significant Harm" criteria (DNSH). Prior to this, the Technical Expert Group (TEG) had not yet recommended the inclusion of nuclear energy in EU taxonomy and advised the EU Commission to review the DNSH criteria more closely.

This expert response finds that the JRC has drawn conclusions that are hard to deduce at numerous points. Subject areas that are very relevant to the environment have also only been presented very briefly or have been ignored. For example, the effects of severe accidents on the environment are not included when assessing whether to include nuclear energy in the taxonomy register – yet they have occurred several times over the last few decades. This raises the question of whether the JRC has selected too narrow a framework of observation. The aspects mentioned and others listed in this expert response suggest that this is true.

This expert response also points out that the JRC mentions topics, but then fails to consider them further or in more detail, although they must be included in any assessment of the sustainability of using nuclear energy. The need to consider them is partly based on the fact that certain effects on the other environmental objectives in the Taxonomy Regulation must be expected if the matter is viewed more closely or at least cannot be excluded. In other cases, this need results from the fact that the Taxonomy Regulation refers to the UN approach in its 2030 Agenda in its understanding of sustainability – and the latter, for example, contains the goals of "considering future generations" and "participative decision-making". Any sustainability, particularly for future generations, can only be guaranteed if attempts are made at an early stage to achieve acceptance in the population, enable future generations to handle the use of nuclear energy and its legacy or waste appropriately and ensure that information and knowledge are maintained in the long term. Generally speaking, it should be noted that the problem of disposing of radioactive waste has already been postponed by previous generations to today's and it will 'remain' a problem for many future generations. The principle of "no undue burdens for future generations" (pp. 250ff) has therefore already been (irrevocably) infringed, while the DNSH-hurdle "significant[ly] harm" has also been infringed.

Generating huge quantities of dangerous waste is being continued for decades without any effective disposal solution being available. The JRC itself says that the primary and best waste management strategy is not to generate any radioactive waste in the first place. However, this assessment is not consistently applied within the report.

The JRC Report only provides an incomplete view of the consequences and risks of using nuclear energy for people and the environment or for future generations or does not even mention them in its assessment. Where it does mention them, some of the principles of scientific work are not correctly considered at some points. The JRC Report is therefore incomplete and therefore fails to comprehensively assess the sustainability of using nuclear energy.

1 Reason and background, goal, approach and structure of the expert response

1.1 Reason for and background to the expert response

The Joint Research Centre (JRC) of the European Union (EU) submitted its report entitled "Technical assessment of nuclear energy with respect to the 'Do No Significant Harm' criteria of Regulation (EU) 2020/852 ('Taxonomy Regulation')" in March 2021. The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) asked the Federal Office for the Safety of Nuclear Waste Management (BASE) on 20 April 2021 to scientifically review the JRC Report, taking into consideration the "Do No Significant Harm" (DNSH) criteria in the Taxonomy Regulation. The Ministry particularly asked for an expert response to review whether the JRC made use of complete, comprehensible and independent technical expertise in examining whether to possibly include nuclear energy in the taxonomy register for the EU Commission. This expert response summarises the results of the review. BASE consulted the Federal Office for Radiation Protection (BfS) on individual issues.

The BMU in Germany is the ministry responsible for issues related to climate protection, environmental protection and nuclear safety. BASE and BfS are scientific, technical authorities, which conduct research work as part of their statutory tasks. BASE is also responsible for surveying and licensing repositories and supervising the site selection procedure for a repository site for highlevel radioactive waste (HLW), a process that is taking place in Germany at this time. It is responsible for public participation in the site selection procedure too. In addition, BASE is the licensing authority for storing and transporting high-level radioactive waste.

The starting point for the expert response from BASE and BfS is Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (OJ L 198/13) – known as the Taxonomy Regulation. The latter defines criteria to determine whether an economic activity (and therefore investments in this activity) can be viewed as ecologically sustainable. These criteria mean that an economic activity must make a contribution to one of the environmental objectives mentioned in Article 9 of the Taxonomy Regulation – i.e. climate change mitigation, climate change adaption, sustainable use and protection of water and marine resources, transition towards a circular economy, pollution prevention and control or protection and restoration of biodiversity and ecosystems without significantly harming one of the other environmental objectives at the same time; cf. Article 17 of the Taxonomy Regulation ("Do No Significant Harm" - DNSH).

The Regulation is made more specific by delegated legal acts by the European Commission (EU Commission). The EU Commission determines so-called technical screening criteria in these delegated legal acts, which break down the criteria in the Taxonomy Regulation to individual economic activities. An economic activity can only be viewed as ecologically sustainable if it meets the technical screening criteria relevant to it.

The EU Commission submitted the draft of a delegated legal act on 21 April 2021 and it lists the economic activities that are viewed as sustainable because of their contribution to the objectives climate change mitigation and climate change adaptation. Nuclear energy has not yet been included as an ecologically sustainable economic activity.

The draft of the delegated legal act is based on the recommendations of the so-called Technical Expert Group (TEG). The Commission launched this group to obtain advice about implementing the "Action Plan: Financing Sustainable Growth" dated 8 March 2018 – partly to draw up the Taxonomy Regulation. In its report dated 9 March 2020 on "Taxonomy: Final Report of the TEG on Sustainable Finance" or in its annex, the TEG concludes that nuclear energy may make a contribution to the environmental objective of climate change mitigation, but significant adverse effects on other environmental objectives cannot be ruled out. The reasons for this are mainly the unresolved issues of disposing of radioactive waste, particularly the lack of any empirical data about safe disposal. The TEG therefore did not recommend that nuclear energy should be included in the EU taxonomy register at that time and recommended an in-depth study of the DNSH criteria (TEG, 2020b).

The discussions taking place at a European level at this time on whether nuclear energy should be included in the taxonomy register must be viewed in this light. It is particularly unclear whether using nuclear energy meets the DNSH criteria. Following up on the issues left unresolved by the TEG, the European Commission asked the EU's Joint Research Centre or JRC to review whether nuclear energy meets the conditions for inclusion in the taxonomy register and which technical screening criteria should be used. The JRC presented its report in March 2021 and concludes that the conditions for including nuclear energy in EU taxonomy are met.

1.2 Goal of the expert response

The goal of the review of the JRC Report by BASE and BfS is to establish whether the JRC completely and comprehensibly assesses whether using nuclear energy is suitable for inclusion in the taxonomy register in its arguments – particularly with regard to the DNSH criteria in the Taxonomy Regulation. The BMU also asked for a review of the independence of the expertise provided by the JRC. Whether the JRC worked independently is determined in this expert response by checking to see whether the JRC's arguments are complete and comprehensible. The review focuses on the topics of nuclear safety, radiation protection and nuclear disposal issues. The fundamental key questions were whether the JRC's approach meets good scientific practice and whether the JRC submitted a complete and comprehensible basis for making a decision to the EU Commission.

This review of the JRC report is necessary for several reasons:

- Viable classification is only possible if the factual basis, particularly about possible significant adverse effects on environmental objectives caused by an economic activity (the DNSH criteria), has been examined completely and comprehensibly (cf. also JRC Report, Part A 1.3.2.3, p. 22 and 5.3, p. 192).
- Article 19 Para. 1 f of the Taxonomy Regulation itself calls for the EU Commission to lay down technical screening criteria that are based on conclusive scientific evidence. Recital

(40) states that the technical screening criteria (and therefore the risk assessment of an economic activity) must be based on conclusive scientific evidence. The criteria must consider the environmental impact of the complete life cycle of an economic activity, according to Article 19 Para. 1 g of the Taxonomy Regulation.

This expert response designed to assess the JRC Report therefore forms a basis for the upcoming expert discussions with the EU Commission on the procedure for appraising and passing the delegated legal acts.

1.3 Approach and structure of the expert response

The expert response has been prepared by a working group at BASE and BfS consisting of experts from different departments. BfS was responsible for the aspects of radiation protection. BASE handled the topics of nuclear safety and disposal. During this work, it became clear that the JRC Report also correctly refers to some topic areas that could not be treated in great detail in BASE's expert response, as responsibility for them in Germany lies with other public authorities. This was particularly true of the following sections in the JRC Report:

- A 3.2.3 DNSH to the sustainable use and protection of water and marine resources
- A 3.2.5 DNSH to pollution prevention and control
- A 3.2.6 DNSH to the protection and restoration of biodiversity and ecosystems

The responsible authority for questions about environmental resources is the Federal Environmental Agency (Umweltbundesamt).

Tabulated review and text section

The text section of the expert response is based on comparing statements made in the JRC Report with a review of these statements in tabular form to see whether they are complete and comprehensible. The tabulated review of the gaps or weak points identified by BASE and BfS in the JRC Report has been separated from this final version of the experts` response text section and will be published on the BASE website. It has not yet been attached to this text for editorial reasons. However, the bibliography of the tabulated review is already listed at the end of this document.

The main statements about whether the JRC Report is complete and comprehensible, which can be derived from the form of assessment that was selected, are summarised in the following sections of this expert response. The expert response has been drawn up as an independent document, which stands alone. The tabulated review already mentioned will further underline the arguments and make clear the approach adopted by BASE.

Main statements in the assessment of the JRC report in tabulated form

It is clear that the JRC barely touched on some environment-related aspects of using nuclear energy or did not consider them in its assessment at all. The JRC does not explicitly state whether and how this procedure is supported by the Taxonomy Regulation. Ultimately, this raises the question of whether the JRC selected too narrow a framework for its observations.

The assessment also shows that the expert rigour and sense of balance used in the JRC's approach to the DNSH criteria must be questioned. Individual content items or stages in the life cycle for using nuclear energy have not been completely and adequately assessed.

Structure of the text section of the expert response

The text section starts with a critical analysis of the topics not covered or only barely covered in the JRC Report in line with the results of this review. Other general methodical issues for checking the DNSH criteria used by the JRC are tackled (cf. section 2 of this expert response). This is followed by a critical appraisal of the JRC Report, particularly with regard to the DNSH criteria – however, not without briefly assessing the JRC's statements about nuclear energy's contribution towards climate protection (cf. section 3). Based on the JRC Report in Part A 3.3 and Part B, the presentation of the DNSH criteria follows the life cycle phases of using nuclear energy; one section is devoted to the phases of generating energy and operating power plants, including dismantling them (cf. section 4) and one section to the problems of disposal (cf. section 5).

Sections 3 – 5 of this expert response are primarily dedicated to analysing whether the scientific principles used by the JRC in relation to the criteria in the Taxonomy Regulation are complete and comprehensible. When reviewing the JRC Report, principles of good scientific practice, e.g. as defined by the German Research Foundation (DFG) in its "Guidelines for Safeguarding Good Research Practice" (DFG, 2019), have been used as the basis for the scientific assessment. The JRC's conclusions arising from the scientific principles for the technical screening criteria or TSCs are also examined if they appeared to be problematic.

Sub-headlines have been used to link the subsections. Where necessary, bold, underlined subheadlines denote the statements about the scientific statements made by the JRC Report or the TSCs developed by the JRC. Underlined headlines in normal print are used for individual subtopics – as in this subsection.

Chapter 6 finally provides an outlook for aspects of using nuclear energy, which may not have been relevant as part of JRC's assessment, but are relevant for the minimum safeguards in Article 18 of the Taxonomy Regulation or other sustainability goals (to be defined in future) and are therefore relevant for a comprehensive review of sustainability.

2 A critical review of the JRC's methodology – the DNSH criteria for the use of nuclear energy

In its assessment of whether to add nuclear energy to the taxonomy register (cf. section 2.2 of this expert response below), the JRC Report does not include aspects of using nuclear energy, which could create considerable adverse effects on environmental objectives or could help prevent these effects. The reason for this is not directly clear, because the JRC does not appropriately consider the review or analysis framework for assessing the DNSH criteria. It is therefore uncertain whether the JRC selected too narrow a framework of observation or whether the non-inclusion of other aspects is supported by the Taxonomy Regulation (cf. 2.1). In other respects, the JRC's methodology does not completely match the requirements for a scientific analysis, as required by the Taxonomy Regulation. Questions must also be asked about the report's professional robustness and the selection of sources (cf. 2.3).

2.1 The JRC's review standards in assessing the DNSH criteria

The JRC's review standards

The JRC deals with some major topics related to using nuclear energy. Severe accidents when operating nuclear power plants (JRC report, Part A 3.5, p. 175ff) definitely have a major impact on the

environment. Disruptive action or other intervention of third parties (JRC report, Part A 3.3.5.1.5, p. 109) can also create environmental effects. Maintaining information and knowledge in the long term (JRC Report, Part B 1.2, p. 205ff) is necessary to inform subsequent generations about the repository and protect people from the damage caused by ionising radiation. Research and development (JRC Report, Part B 6) are essential in the light of the issues that are still unresolved, mainly related to disposal. The JRC Report does discuss these topics, but not with the necessary expert depth. The JRC does not include these topics in its assessment of the DNSH criteria or create any link with the Taxonomy Regulation.

What is necessary to technically and scientifically examine whether nuclear energy can be added to the taxonomy register would be to develop an investigative framework or review standards based on the Taxonomy Regulation to decide which aspects of using nuclear energy should be included in the review of the DNSH criteria. The JRC does not adequately do this. The aforementioned topics are not sufficiently examined and their assessment relevance is not clear.

The JRC believes that the DNSH criteria have been met for activities related to nuclear power, if the regulatory requirements – particularly the safety case and environmental compatibility – are satisfied. This is clear from the JRC Report at several points (cf. JRC Report, Executive Summary, p. 7, first and second indents; p. 8, first, eighth and tenth indents; Part A 1.3.2.3, p. 22f and Part A 5.1, p. 190f; Annex 1) without any appropriate development of review standards.

The JRC's approach means that the evidence for ecological sustainability is or should ultimately be provided through the licensing or approval procedure for the activity in question or should be. Case examples are cited for disposal (Finland, Sweden, France), according to which safe disposal seems possible if the aforementioned conditions are met. The TSCs are therefore based on whether the regulatory framework exists and has been worked through during the approval and licensing procedure (cf. JRC Report Part A 5.2, p. 191). If this is the case, using nuclear energy and disposal is compatible with the DNSH criteria as part of the nuclear energy life cycle, according to the JRC.

Provisions in the Taxonomy Regulation and the TEG's approach

The JRC follows the TEG in adopting this approach. The TEG states that an economic activity must at least be compatible with the environmental law provisions in the EU (TEG 2020b, p. 33).

The Taxonomy Regulation itself may support this approach adopted by the TEG and the JRC procedure based on it. Based on recitals (26) – (30) and (40) in the Taxonomy Regulation, it is clear that the environmental objectives must be interpreted in the light of the relevant stipulations in EU law and compliance with EU law represents the minimum requirement for DNSH conformity in any economic activity. In addition, recital (40) refers to Article 191 of the Treaty on the Function of the European Union and states that the precautionary principle should apply "where scientific evaluation does not allow for a risk to be determined with sufficient certainty".

The Taxonomy Regulation therefore urges that all the risks of an economic activity require thorough, scientific consideration; uncertainties must be clearly stated and any non-consideration of risks when assessing an economic activity using the DNSH criteria require in-depth justification – not least to satisfy the precautionary principle. The JRC does not reflect these requirements. The JRC therefore does not engage in any discussion about whether an adequate review and analysis framework, which goes beyond the statutory requirements, for assessing the DNSH criteria is advisable when using nuclear energy. The result is, firstly, that aspects of using nuclear energy, which are relevant to the environment, are not included in the analysis. Secondly, the JRC does not recognise that the reference to the regulatory requirements alone is inadequate to be able to assess the DNSH criteria in terms of environmental objectives.

Some of the aspects considered by the JRC, such as protecting future generations, may go beyond the environmental objectives of the Taxonomy Regulation. However, the JRC Report does not consider whether and to what degree this (and other) aspect(s) should be included in any review of the DNSH hurdle that needs to be understood in a broader light. This expert report considers these kinds of aspects in section 6.

Other reasons for an expanded framework of observation

The macrosocial implications and consequences of using nuclear energy suggest that the regulatory requirements may not be the only framework of observation or review standards for the DNSH criteria.

The indirect consequences of using nuclear technology, which cannot be quantified by the effective dose or the activity concentration of radon 222 (Rn-222) in the air that people breathe (or quantities derived from these), are missing in the JRC Report in relation to planned activities. They particularly include the effort and expense created by the lack of individual and social acceptance and the associated costs of using nuclear technology and the nuclear fuel cycle within society. The spectrum in Germany here ranges from planning and licensing nuclear facilities and installations (e.g. exploring the salt mine in Gorleben, planning the reprocessing facility in Wackersdorf) to operating nuclear facilities and installations (e.g. nuclear power plants) and even releasing very low level radioactive material, which occurs, for instance, when dismantling nuclear power plants, from regulatory control (clearance).

The JRC study also falls short of the mark when it comes to the harmful consequences of a severe nuclear accident, because it ignores all the ensuing non-radiological effects. They not only involve psycho-social secondary illnesses, which are clearly verifiable (Hayakawa, 2016) – in the numbers of fatalities too – but also the social impact such as the massive loss in the quality of life, social cohesion and economic prosperity – and the lack of prospects of a return to normal in the affected regions within the near future. (Bromet und Havenaar, 2007; Hawegawa et al., 2015; Shigemura et al., 2020)

Overall, the social costs, for instance in Germany, arising from the intense social discussions about the risks of nuclear technology and the risks associated with storing and disposing of radioactive waste in comparison with other energy generation technologies have been high – and the JRC Report fails to mention them. These social costs occur if nuclear energy does not "smoothly" fit into the social context, but has been the subject of controversial discussions for decades, as in Germany, if it triggers resistance and protest activities and destroys confidence in the state in general, in politics and in the authorities taking action – and leads to delays in planning and implementing projects.

It is often necessary to use huge amounts of effort and expenditure to make nuclear energy "socially acceptable" as a high-risk technology in order to increase social confidence and acceptance. This effort and the economic consequences should be included as inherent costs when making comparisons with other energy sources.

Consequences of the narrow view adopted by the JRC

The fact that the JRC devotes too little attention to the issue of its review standards means that environmentally-related aspects of using nuclear energy are discussed, but are not included in the assessment and the JRC does not consider whether the Taxonomy Regulation supports this process (cf. section 2.2 of this expert response below). Other sustainability aspects like considering future generations are not adequately considered either, although the Taxonomy Regulation recommends this (cf. section 6 of this expert response). Reference will also be made to these findings below, if the review standards appear to be problematic.

2.2 Environmental aspects of nuclear energy use and radioactive waste disposal that are omitted in JRC's assessment of the the DNSH criteria

2.2.1 Accidents

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

At best, the JRC implicitly derives this approach from the Taxonomy Regulation and the work performed by the TEG (TEG, 2020a) and its technical screening criteria (TEG, 2020a). The work performed by the TEG and the technical screening criteria based on this do not envisage any consideration of severe accidents in the other economic activities assessed so far. On this basis, the statements by the JRC about accidents represent an extra element added to the overall summary of the consequences of using nuclear power, but are not taken into account in JRC'S assessment.

However, it is questionable whether the assessment of the ecological sustainability of energy sources may ignore aspects related to beyond design basis events. When operating nuclear power plants, for example, severe accidents with far greater effects on the environment can occur; they can go beyond the potential environmental impact described in the JRC Report through the approved discharge of radioactive materials or using cooling water, particularly if there is any uncontrolled release of radioactive substances. It is true that the nuclear regulations envisage a defence-in-depth concept to prevent this kind of discharge caused by incidents (WENRA, 2014; BMUB, 2015). However, in principle substances may be released because of accidents (cf. section 4.4 of this expert response) and this has already occurred several times during the last few decades.

The JRC Report does not consider the environmental effects associated with this in any greater detail because of the JRC's basis for its assessments. When presenting the consequences of accidents, the JRC largely restricts itself to considering the numbers of human fatalities. It does not take into account the consequences of severe accidents on people's health, climate protection, biodiversity, protecting soil and water supplies etc. The incidents that go beyond design problems are adressed by the so-called 4th safety level by stipulating measures to reduce the risk of accidents. However, the JRC does not examine how the possible release of pollutants caused by an accident would affect the environmental objectives beyond human fatalaties.

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

The lethal effects practically occur continually with fossil fuel energy generation. Beyond that, there is an additional component geared towards the future by the contribution made by fossil energy generation to climate change. In contrast, accidents may occur rarely when using nuclear energy but with severe consequences. In addition, the production of radioactive waste causes a risk, which far exceeds the service life of a nuclear power plant itself, in terms of the time involved. The report does not mention psycho-social secondary diseases caused by accidents, which have a veryfiable impact on the numbers of fatalities either (Hayakawa, 2016) (cf. section 2.1 above). The consequences of accidents therefore are different, depending on the various forms of energy generation. In other respects, it must be remembered that events that release pollutants can also take place during the decommissioning and dismantling phase for nuclear power plants and during the much longer periods involved for disposing of radioactive material. This is not mentioned in detail in the JRC Report.

The basis for discussing severe accidents in the JRC Report is the probabilistic stage 3 safety analysis, which not only involves the probability of occurrence of an accident and the associated release of radionuclides, but also environmental impacts. It should be noted that, in contrast to the incidence of damage occurring with other forms of energy, the probability levels assumed or estimated for nuclear accidents are discussed by the international experts in emergency preparedness and response.

As a result, probabilities are compared to frequency levels, which is questionable in conceptual terms. The problem in assessing the risk in terms of the number of deaths per GWh for severe nuclear accidents is their infrequency, whereas the associated consequences are severe. The comparison in Figure 3.5-1 in the JRC Report is therefore misleading, as a comparative figure involving the product of two numbers, which – as a limiting case of the respective model - are extremely low and extremely high. The product of an (uncertain) extremely low number and an (uncertain) extremely high number does provide only very limited information.

The frequency of damage only considers well-known risks, not unknown ones ("known unknowns" versus "unknown unknowns"). Following the disaster in Fukushima, any justification for continuing to use nuclear energy on the basis of a low probability level ("residual risk") in Germany is not an opinion that attracts a consensus; a large majority in politics, society and the scientific world rejects such a justification, as the risk assessment itself is clouded by a degree of uncertainty that cannot be quantified.

As a consequence, all the scenarios that are physically possible have explicitly been included for example in Germany, when extending the planning radii for radiological emergency response. "We have to prepare for what is conceivable" is the motto (in line with (SSK, 2015)). The relevant recommendations from the Radiation Protection Committee (SSK) follow this logic too. Ultimately, the German government's fast-track decision to abandon nuclear power in the summer of 2011 was precisely based on this point of view. This line of argument is ignored in the JRC Report.

There is no doubt that severe accidents at nuclear power plants can lead to considerable adverse effects on environmental objectives; the damage caused by accidents can be particularly serious when compared to other economic activities and extend far beyond national borders.

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

Whether the framework of observation selected by the JRC is derived from the Taxonomy Regulation or whether the Regulation allows or requires a different framework of observation is not clear from the JRC Report. The reference in the Taxonomy Regulation to the precautionary principle and the consequential need to look at all the environmental risks tend to support a more comprehensive framework of observation (cf. section 2.1 of this expert response).

The current Taxonomy Regulation demands a more comprehensive framework of observation, which considers the environmental impact of accidents. It is also necessary to emphasise the following: discussions about the need to determine activities that must be largely excluded in the

Taxonomy Regulation, as they do fundamentally fail to meet the DNSH criteria, are already being conducted in various organisations; the discussions underline the fundamental significance of this question (cf. e.g. (NABU, 2021)).

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

2.2.2 Uncertainties

Due to the review standards of the JRC in assessing the DNSH-criteria, uncertainties which cannot be eliminated even in view of the specified regulatory requirements - i.e. the legal and sub-statutory regulations, are not taken into account.

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

Alongside the uncertainties e.g. about future climate developments, the uncertainties associated with future human actions and society and social behaviour must be mentioned here too. The possibility of unintentional human intrusion into a repository, which cannot be ruled out, illustrates the limits of any safety assessment over long periods of time (cf. the remarks about maintaining information and knowledge in the long term below, particularly with a view to human intrusion). Uncertainties also relate to the possible adverse effects on environmental objectives, e.g. in the context of to disposal, when it comes to the robustness of barriers (for more details, see section 5.3 of this expert response).

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

In principle, each repository is unique and requires an individual safety assessment because of the different conditions already mentioned. The safety assessment is the responsibility of each country where the repository is being constructed. The country's regulations and the substatutory rules form the basis for the safety assessment. There are certainly differences between the individual countries in terms of the legal framework (GRS, 20019). Ultimately, this will lead to a different safety level that will not be fundamentally different, but its details will vary.

In addition, the individual countries do not have the same geological conditions (Charlier, 2019; GRS, 2009). There are countries, for example, which have varied geology in their territory, and other countries where the choice of a host rock to accommodate the repository, for example, is more or less inherent (cf. the BASE information platform here: https://www.endlagersuche-infoplattform.de/webs/Endlagersuche/DE/Radioaktiver- Abfall/Loesungen-anderer-

Laender/loesungen-anderer-laender_node.html). The selection of host rock, however, plays a major role in helping to organise and draw up plans for the repositoryand the underlying safety concept. As a result, interest may switch to just focusing on certain topics related to the local conditions for safe disposal. Even if all the aspects are examined in the end and the disposal system is viewed as suitable for a licence, some uncertainties, which cannot be resolved, will still remain.

The reasons cited here make it clear that the issue of providing safe disposal for high-level radioactive waste may be a common European topic, but implementing it and the pathway towards its implementation can be very complex in the member states. The reference to regulatory requirements does not rule out some uncertainties either. Therefore, the approach of providing a general statement that the question of safe disposal for high-level radioactive waste has been resolved in terms of sustainability if the relevant, underlying national and international regulatory safety provisions are followed and that this will continue to be valid in future is not supported by the necessary scientific diligence.

2.2.3 Research and development

The enormous effort and expenditure incurred for research in the past, present and future illustrates the complexity of the issue related to the safety of any repository. A large number of conceptual questions and technical details still have to be clarified. It is possible that some issues will not be completely resolved and remain fraught with uncertainties.

It is noticeable that the JRC report deals with the subject of research and development, but does not make an explicit link to the Taxonomy Regulation. Research and development projects are crucially important to shed light on imprecise circumstances and unresolved questions. This particularly affects issues related to disposal. This last part of the life cycle when using nuclear energy has not yet been fully completed – and this is clear simply from the fact that no repository for high-level radioactive waste is operating anywhere in the world, seven decades after the start of using nuclear energy. In contrast with other technologies, research and development here are not used to improve technologies that already exist, but to develop the last stage of the life cycle of a technology. This is not explicitly stated in the JRC Report. If it was, it would also be necessary to mention that this part of the life cycle of using nuclear energy is not yet completely known and is therefore hard to analyse or evaluate too. As a result of this, a DNSH analysis here is associated with special challenges (cf. also TEG 2020b, p. 210). It would therefore be even more important to include research and development in the assessment here. Research and development describe measures, with which possible significant adverse effects on environmental objectives can be better evaluated or even prevented in the sense of the Taxonomy Regulation. One conceivable option would be to develop technical screening criteria for what is required for research programmes to answer unanswered questions and resolve issues that are still unclear.

The statements made by the JRC on the topic of research and development are also critically evaluated in section 5.5 of this expert response.

2.2.4 Nuclear Security

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

This is inadequate for an overall description in the light of the significance of this subject area. Any unauthorised and improper intervention by third parties to a nuclear facility or material can create

significant adverse effects for people and the environment and therefore for the environmental objectives too.

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

These observations here must be transferred into continuing updates of the current threat assessment (BMU, 2012).

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

In the light of this, any brief treatment, as in the chapter of the JRC Report mentioned above, is inadequate to do full justice to the varied and complex scenarios and the associated risks caused by any improper use of radioactive material.

2.2.5 Preservation of records, knowledge and memory regarding radioactive waste repositories with a view to human intrusion

The importance of maintaining information and knowledge in the long term – referred to as preservation of records, knowledge and memory (RK&M) regarding radioactive waste repositories - is not given any prominence or recognised in the JRC Report. Even if the preservation of records is mentioned as a quotation from Article 17 of the Joint Convention (IAEA, 1997) in the JRC Report (Part B 1.2, p. 206), the topic otherwise remains largely overlooked. It is particularly missing in conjunction with the basic principles of geological disposal – a connection that is established by the ICRP (ICRP, 2013) and the OECD/NEA (OECD, 2014).

Its relevance for assessment is clear, however, from a closer look. In general, it is impossible to predict how people will behave and act in future (NAS, 1995; Seitz et al., 2016). For this reason, unintentional human intrusion into a repository, if the information about the repository is lost, cannot be ruled out either (ICRP, 2013). If human intrusion takes place, the risk of exposure to radiation for people and contamination for the environment cannot be excluded, despite the use of technical measures. Other future human activities at the site must be considered in addition to human intrusion, too. These activities are different from human intrusion because they are not associated with any direct intrusion, but a possible indirect effect caused by, for example, changing the groundwater situation at the repository site. A number of measures have been drawn up and discussed as part of the HIDRA IAEA project (Seitz et al., 2016).

It is therefore necessary to adopt measures to preserve record, knowledge and memory. They help prevent exposure to radiation, which may, for example, be caused by human intrusion (cf. ICRP,

2013, p. 6f; OECD, 2014), for as long as possible. As a result, these measures should be included in the technical screening criteria – and should also guarantee the prevention and reduction of effects on the environment (cf. JRC Report, Part A 1.3.2.2, p. 22). This has been omitted, although the JRC has recognised that human intrusion must be prevented (JRC Report Part B 5.1, p. 246, 5.2.1, final paragraph on p. 250).

However, even if measures are included in the TSCs to preserve record, knowledge and memory, a certain risk, which, in the final analysis, is hard to reduce, still remains. Ultimately, it is impossible to make any reliable forecasts about whether the envisaged measures to prevent human intrusion or messages can be appropriately noted and understood if knowledge about the repository lost. Archiving and the installation of markers are being hotly disputed internationally, for example. This illustrates the danger that future generations might hereby be attracted to the site and encouraged to make their way into it (NEA, 1995; Seitz et al., 2016). The remaining uncertainties are not considered in the JRC Report.

The OECD/NEA also underlines another goal of maintaining information and knowledge in the long term – enabling future generations to make informed decisions – and describes this as part of responsible, ethically sound and sustainable radioactive waste management (OECD, 2014). This topic will be treated in greater detail in section 6.2 of this expert response.

2.3 The JRC's methodology

What is also striking when reviewing the JRC Report is the fact that the JRC's approach is not always rigorous and comprehensible – and is also unbalanced at times.

2.3.1 Approach and structure of the JRC Report

The approach described in Part A 1.2, p. 17 and 1.3, p. 18 of the JRC Report covers three stages:

1) Assessing the contribution to climate protection (cf. JRC Report, Part A 3.2.1, p. 35ff and 3.2.2., p. 39ff)

2) Life cycle analysis and determining the environmental effects of using nuclear energy (cf. JRC Report, Part A 2, 3.2.3 – 3.2.6, and 3.3) combined with an overall assessment of whether the sustainability objectives are being threatened (with a focus on environmental objectives, cf. JRC Report, Part A, p. 181ff and Part B with Annexes 2, 5 and 6) and

3) Development of TSCs where the activity is viewed to be sustainable if met (JRC Report, Part A 5, p. 190ff with Annexes 3 and 4).

Stages 1 and 2 are described in detail in the JRC Report. The JRC views stage 2 as the basis for assessing the DNSH criteria. It expresses this as follows: "The criteria applied in the DNSH assessment must be based on an adequate and thorough analysis of the potential environmental impacts of the economic activity under investigation, in order to ensure that the conditions for its acceptance/rejection will be defined appropriately." (JRC Report, Part A 1.3.2.3., p. 22; cf. also Part A 5.3., p. 192). In terms of this standard, it is striking that some aspects relevant to the environment have not been considered (cf. section 2.2 above). The aspects treated by the JRC do not fully stand up to an examination of whether they are complete and comprehensible either (cf. sections 3 – 5).

The TSCs developed in stage 3 are still a draft document. TSCs are only offered for selected phases of the life cycle (cf. JRC Report, Part A 5.1, p. 190f). The method for disposal has deliberately not been fully developed. The TSCs available are also too general.

The JRC does not provide any sources for the TSCs and ignores uncertainties about their implementation and any long-term effects (more on this in section 5.3 of this expert response under the sub-headline "Technical screening criteria"). The approach adopted by the JRC therefore does not allow any full assessment of the ecological sustainability of nuclear energy generation. If TSCs have been drawn up, the TSCs developed for the disposal of high-level radioactive waste are viewed as sufficient for low- and intermediate-level radioactive waste. However, very low-level waste and long-lived low- and intermediate-level radioactive waste are not considered and the different requirements for surface and deep geological disposal are ignored (more details in section 5.2 of this expert response, under the sub-headline "Technical screening criteria").

The JRC Report has been structured in such a way that Part B is supposed to provide the basis for the assessments conducted in Part A 3.3.8 about the environmental effects of storage and disposal. Part B, however, largely stands on its own and there are only a few actual references in Part A to Part B. It is therefore not clear which statements in Part A should be supported by the findings presented in Part B.

It is particularly striking that there is no section that draws conclusions, particularly with regard to the conclusions in Part B for Part A of the JRC Report. Such a section should contain the main points that have been found in the study, i.e. which questions/topics remain unresolved and what recommendations can be made for the main points identified in retrospect. The JRC should also critically examine in such a section whether the report has met the terms of reference or whether the terms of reference could be met. As a result, the study seems incomplete.

The key findings in the "Executive Summary" only partially relate to the analyses and assessments in Part A and the knowledge base in Part B. It is therefore not possible to trace their source and they appear as a collection of isolated statements without adequate links to the report.

2.3.2 Balance of presentation, data and source selection

The aspects brought together in the JRC Report are only suitable as an adequate basis for making decisions about taxonomy in their presented form to a limited degree. In many parts, they are factually comprehensible, but the selection of the individual facts favours a positive view of the sustainability of using nuclear energy and disposal of radioactive waste. The selection almost completely fails to include any balanced contrast involving critical arguments and to deal with them. This incompleteness and one-sidedness runs through the entire report and can be observed not only in some detailsFor example, the JRC Report quotes some classic examples of handling the problematic consequences of economic activities in the nuclear energy life cycle, but fails to state that these consequences have not been be completely overcome – or only with delays (cf. section 4.1 on uranium mining, section 5.2 on Asse in this expert response).

The report also contains unfounded generalisations in many places. For example, quotations or sources are often cited for fairly long paragraphs or whole pages in summarised form (cf. JRC Report, Part B 6.2, p. 277ff). This gives the impression that the original sources were not consulted to back up the statements that have been made. This would contradict common standards of good scientific practice (DFG, 2019). Conclusions are drawn from individual, selected examples, implying their global validity. This is done implicitly and is therefore hard for readers to recognise. For example, parallels are drawn between handling the disposal of other "waste" (CO₂) in deep geological formations and disposal of high-level radioactive waste in the Executive Summary of the JRC Report (JRC Report, Executive Summary, p. 8, third indent). However, the report lacks a corresponding analysis, so the transferability is not examined, contrary to the impression given in the summary. There is only a comparison of the legal requirements for disposing of CO₂ or radioactive waste in

Annex 1. There is no mention of the completely different risk potential, particularly over very long periods of time. Another example involves the comments about new-generation power plants. They overlook the fact that almost exclusively fairly old reactors are in service in Europe and will continue to dominate the power-generating reactor fleets for at least the next few decades.

It is also striking that the selection of sources is not always balanced. The report uses a broad knowledge base, as is outlined in the IAEA and OECD/NEA documents. Laws, guidelines, but also research strategies (EURAD) are listed. A large number of reports from operators or project developers are used to underpin and illustrate the latest science and technology and are complemented by comments from regulators and governments. However, the report only draws on very few published assessments from peer-reviewed journals. Arguments from scientific work that tends to be critical or NGOs are not mentioned or discussed.

Overall, the data or reference basis used in the JRC Report seems unbalanced. For example, the share of nuclear energy in electricity generation within the EU, which is used as the starting point for analysis by the JRC, both for the taxonomy criterion of contributing to climate protection and the DNSH criteria, is overestimated (cf. section 3.1.2 of this expert response). Normal operations for nuclear plants and radioactive waste management activities are also used as the basis for assessing the DNSH criteria. The report does not mention the environmental impact of beyond design basis events (cf. sections 2.1, 2.2.1, 4.4, 5.3). Near surface disposal of low-level waste is also viewed as the standard option for disposal. The report ignores the fact that a number of countries are exclusively envisaging deep geological disposal for low-level waste or even all other kinds of radioactive waste (cf. section 5.2). The focus is also exclusively on countries with large-scale nuclear energy programmes. No consideration has been given to countries that are far less developed economically (cf. section 5.3).

The examples quoted here and others forming the basis for the criticism expressed here will be picked up and formulated in greater detail below.

3 Criterion 1 in the Taxonomy Regulation – making a contribution to climate change mitigation

This section examines the contribution made to climate protection by nuclear energy (objectives 1 and 2 in the Taxonomy Regulation). It involves a critical review of the expert statements in the JRC Report with regard to electricity generation at nuclear power plants (cf. section 3.1) and when using technologies that are being developed like small modular reactors (cf. section 3.2).

It should be noted, inter alia, that the JRC Report presents the contribution of nuclear power plants to greenhouse gas emissions in a very positive light. The forecast for the ongoing development of using nuclear energy for power generation in the EU, as presented in the JRC Report, is also clearly far too optimistic.

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

3.1 Nuclear power plants

An assessment of using nuclear energy in terms of its contribution to climate protection takes place in Part A 3.2.1, p. 35ff and 3.2.2, p. 39ff of the JRC Report according to Article 10 Para. 1 of the Taxonomy Regulation. The JRC Report compares the contribution made to climate protection by generating nuclear energy and other energy generation options in Part A 3.2.3, p. 39ff (cf. section 3.1.1. of this expert response below). It is based on a very optimistic forecast about using nuclear energy in the EU in Part A 3.2.1, p. 35ff of the JRC Report (cf. section 3.1.2).

3.1.1 The contribution of nuclear power plants to climate change mitigation in the JRC Report

Part A 3.2.2 of the JRC Report provides an assessment of the contribution made to climate protection by using nuclear energy. Many special cases are presented to back up the statements made about low greenhouse gas emissions when generating electricity with nuclear energy and this creates a distorted view. The JRC Report is imprecise at many points and abbreviates or omits statements that are made in the sources used. As a result, the contribution to greenhouse gas emissions made by using nuclear energy is presented in a very favourable light, particularly in relation to the threshold value that is currently set at 100 g of CO_2eg/kWh by the Technical Expert Group (TEG) in the Taxonomy Report Technical Annex (TEG, 2020b). However, the TEG clearly indicates, in contrast to the JRC Report, that this threshold value will be reduced every five years to achieve net zero emissions by 2050 – in accordance with the political goals to reach zweo net emission by 2050 (TEG, 2020b). The JRC Report conveys the impression that the threshold value of 100 g of CO_2eg/kWh will remain constant during the next 50 years (JRC Report, Part A 3.2.2, p. 40).

Another example of shortened statements in the JRC Report and the resultant optimistic presentation of the life-cycle-based greenhouse gas emissions when using nuclear energy is Figure 3.2-6 (JRC Report, Part A 3.2.2, p. 40). The JRC Report does not mention that the literature used for the figure (WNA, 2011) cites many factors that contribute to the discrepancies in the greenhouse gas emissions that are presented. One important factor according to WNA (WNA, 2011) is the different definition of "life cycle" in the publications consulted. Some of the publications included waste management and waste treatment in the life cycle, while others did not (WNA, 2011). In addition the WNA publication that is cited dates back to 2011 and is therefore already relatively old. It points out, for example, that the great discrepancies in greenhouse gas emissions with solar energy are based on the rapid developments in solar panel units, which have already taken place, and further increases in efficiency can be expected.

3.1.2 Forecast about using nuclear energy in the JRC Report

Part A 3.2.1, p. 35ff in the JRC Report contains an estimate of the proportion of electricity generated using nuclear energy globally and in the EU in order to underline the great importance of using nuclear energy in Europe, which is expected in future too.

It should be noted that, while the impression is created in other subject areas (cf. sections 2.1 and 2.2), that the JRC has unnecessarily selected too narrow a framework of observation, the JRC goes far beyond this for the aspects that are necessary to assess the taxonomy criteria. The forecast about the share of nuclear energy in Europe is not necessary to assess the taxonomy criteria.

In summarising, it can be stated that the statements in Part A 3.2.1 of the JRC Report about the further development of nuclear power for the electricity generation in the EU are presented in a far too optimistic way. The forecast is largely founded on the article written by Capros et al. (2018) (Capros et al. 2018), which is based on a model calculation. This model calculation is taken over without any classification and without specifying any uncertainties. The forecast that the share of

nuclear energy of 22% will continue until the year 2050, while overall electricity production increases, presupposes a massive expansion of nuclear power plants in Europe. This expected massive expansion cannot be deduced given that just four nuclear power plants are being built in the EU and it normally takes more than 10 years to construct a new nuclear power plant (IAEA, 2020, p. 13).

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

The forecast presented in the JRC Report not only presupposes new construction of nuclear power plants, but also extensive retrofitting of the ageing nuclear power plants in the EU: the first cases of decommissioning of nuclear power plants in Figure 2.3-4 of the JRC Report are not envisaged until the year 2040. This would imply a lifetime for all the nuclear power plants within the EU of about 60 years, although this is unlikely because of shut-downs that have already been announced, including those in Germany. Figure 2.3-4, p. 38 of the JRC Report, which shows the evolution of nuclear power in the EU based on new structures and extensions to operating terms, cannot be found in the source that is cited (Capros, 2018).

Most of the nuclear power plants currently operating in the EU are more than 30 years old, 66 of the 106 currently in service in the EU are between 30 and 40 years old and 26 are actually more than 40 years old. Only two new nuclear power plants have been connected to the grid during the last 20 years (IAEA, 2021).

The nuclear power plants were originally designed for a lifetime between 30 and 40 years. The degree to which national authorities will actually approve a lifetime extension to the service life of old units in accordance with the current safety requirements is uncertain – as is required for the forecast in the JRC Report – and will depend on the status of the unit concerned and the respective national regulatory framework. Retrofitting units with additional safety systems is only possible to a limited degree because of the structural conditions (INRAG, 2021, p. 181). Questions must also be raised about the ageing process and the brittleness of materials and therefore the long-term behaviour of nuclear power plants beyond the original design period.

This very positive presentation of future prospects for nuclear energy, which is shown in the JRC Report, must be viewed critically. Even if these forecasts cannot play a role when assessing nuclear energy according to the specific environmental objectives of the EU taxonomy, this presentation by the JRC is suspect from a professional point of view and possibly indicates a lack of adequate independence. Large parts of society struggle to accept nuclear energy and it is accompanied by long development periods (10-19 years for each power plant in democratic societies) (BMK, 2020, p. 4). Any major expansion of nuclear energy would delay the decommissioning of fossil-fired power plants, as the latter would have to remain in operation during this period and therefore make it hard to achieve the climate change mitigation objective. It is even possible to argue that nuclear energy hinders the use of other alternatives with low CO₂ emissions because of its high capital intensity. Otherwise this capital could be used to expand alternative energy sources like sun, wind and water (BMK, 2020, p. 4-5). While nuclear power generation in the electricity generation phase has been associated with relatively low greenhouse gas emissions from a historical perspective, the lions' share of greenhouse gas emissions in the nuclear fuel cycle is caused by the front-end and back-end processing stages. Based on estimates, the CO₂ emissions can be broken down into the construction of nuclear power plants (18%), uranium mining and enrichment (38%), operations (17%), processing and storing nuclear fuel (15%) and decommissioning activities at the power plant (18%) (BMK, 2020, p. 6).

3.2 Analysing the contribution made by small modular reactors (SMRs) to climate change mitigation in the JRC Report

The statement about many countries' growing interest in SMRs is mentioned in the JRC Report (Part A 3.2.1, p. 38) without any further classification. In particular, there is no information about the current state of development and the lack of marketability of SMRs. Reactors with an electric power output of up to 300 MWe are normally classified as SMRs. Most of the extremely varied SMR concepts found around the world have not yet got past the conceptual level. Many unresolved questions still need to be clarified before SMRs can be technically constructed in a country within the EU and put into operation. They range from issues about safety, transportation and dismantling to matters related to interim storage and final disposal and even new problems for the responsible licensing and supervisory authorities. The many theories frequently postulated for SMRs – their contribution to combating the risks of climate change and their lower costs and shorter construction periods - must be attributed to particular economic interests, especially those of manufacturers, and therefore viewed in a very critical light. Today's new new nuclear power plants have electrical output in the range of 1000-1600 MWe. SMR concepts, in contrast, envisage planned electrical outputs of $1.5 - 300 \text{ MW}_{e}$. In order to provide the same electrical power capacity, the number of units would need to be increased by a factor of 3-1000. Instead of having about 400 reactors with large capacity today, it would be necessary to construct many thousands or even tens of thousands of SMRs (BASE, 2021; BMK, 2020). A current production cost calculation, which consider scale, mass and learning effects from the nuclear industry, concludes that more than 1,000 SMRs would need to be produced before SMR production was cost-effective. It cannot therefore be expected that the structural cost disadvantages of reactors with low capacity can be compensated for by learning or mass effects in the foreseeable future (BASE, 2021).

There is no classification in the JRC Report (Part A 3.2.1, p. 38) regarding the frequently asserted statement that SMRs are safer than traditional nuclear power plants with a large capacity, as they have a lower radioactive inventory and make greater use of passive safety systems. In the light of this, various SMR concepts suggest the need for reduced safety requirements, e.g. regarding the degree of redundancy or diversity. Some SMR concepts even consider refraining from normal provisions for accident management both internal and external – for example, smaller planning zones for emergency protection and even the complete disappearance of any off-site emergency zones. The theory that an SMR automatically has an increased safety level is not proven. The safety of a specific reactor unit depends on the safety related properties of the individual reactor and its functional effectiveness and must be carefully analysed – taking into account the possible range of events or incidents. This kind of analysis will raise additional questions, particularly about the external events if SMRs are located in remote regions, if SMRs are used to supply industrial plants or if they are sea-based SMRs (BASE, 2021). In regard to external emergency planning, the working group for the planning zones at the SMR Regulators' Forum has requested, among other things, that planning zones may need to be set for facilities used to handle and store fuel outside an SMR site. Special consideration is also necessary if the planning zones for SMRs are close to densely populated centres (SMR Regulators' Forum, 2018). The working group also pointed out that possible source terms are hard to forecast, especially in the case of new technical designs, and new methods would need to be developed for them. The design and safety analysis working group at the SMR Regulators' Forum also emphasises that challenges would need to be

identified if an accident takes place at an SMR site with several modules/units and evidence would have to be provided about the availability of appropriate resources (personnel and equipment) and

emergency strategies (SMR Regulators' Forum, 2019). It can therefore be assumed that – in contrast to what is stated by some SMR developers – planning zones are necessary for emergency protection outside the SMR and they need to go beyond the unit's site. The responsible nuclear regulatory authorities must ultimately decide how the emergency measures touted by SMR developers have to be actually implemented (BASE, 2021).

Responsible regulatory authorities, but also potential SMR producers and SMR operators face new challenges if there is a global spread of SMRs. No specific national or international safety standards have yet been drawn up for SMRs. International safety standards would particularly be required, if an SMR was delivered by one country, where the SMR was manufactured, will be used in a different country. This will be particularly important if the "user country" is a newcomer in nuclear terms. When drawing up or adapting the regulations, it is not only necessary to cover the central issues of the design and safe operations for an SMR, but also the regulatory approach to manufacturing and transporting SMRs, to the assembly of modular systems, to the handling and transporting fuels and other materials as well as to the handling and transporting the spent fuel and nuclear waste. Questions of security and protection against disruptive action and other effects caused by third parties also need to be clarified. This will particularly be necessary for transportable nuclear power plants (BASE, 2021).

In addition to clarifying the regulatory issues, the liability of operators or manufacturers in case of an accident must also be considered if SMRs are going to be used worldwide. The International Expert Group on Nuclear Liability – INLEX – is dealing with this topic at the IAEA and has already issued statements about the special case of a floating nuclear power plant (IAEA, 2020c). Liability issues related to SMRs, however, are continuing to be discussed internationally (BASE, 2021).

If SMRs are used, this not least raises questions about proliferation, i.e. the possible spread of nuclear weapons as well as the necessary nuclear technologies or fissionable materials for their production. In order to halt the spread of nuclear weapons, promote disarmament and ensure greater global security, member states, which have signed the Nuclear Non-Proliferation Treaty, obligate themselves to accept special monitoring measures (IAEA safeguards). The risks of proliferation increase too against a background of a theoretically higher number of SMRs at various sites, some of them very remote, as already mentioned, and the use of fuels with greater levels of enrichment. At the same time the time and effort for the monitoring measures increases if there is a need to monitor a large number of SMRs, special designs and regular transport operations of complete nuclear power plants or replaceable reactor cores. Many of the standard methods for monitoring fissionable material do not directly match the special features of SMR concepts (BASE, 2021).

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

4 Criterion 2 in the Taxonomy Regulation – the DNSH criteria: from uranium mining to operating and dismantling power plants

This section deals with the production stages ranging from mining uranium to the decommissioning

and dismantling of nuclear power plants. The technical and scientific statements made by the JRC are examined to see whether they are complete and comprehensible. Sub-headlines have been used to link the subsections. Underlined headlines in normal print are used for individual subtopics.

The text particularly deals with the problems associated with uranium mining for people and the environment (cf. section 4.1 of this expert response below). The statements in the JRC Report about uranium enrichment, fuel element production and reprocessing are also examined critically (cf. section 4.3).

The JRC Report focuses on normal operations at nuclear power plants and particularly refers to the new generations of power stations (cf. section 4.4). This ignores the fact that almost all the reactors serving the grid in Europe are already more than 30 years old and their safety facilities therefore do not match those of third-generation reactors. The decommissioning and the dismantling of nuclear power plants, on the other hand, are treated too superficially in the JRC Report (cf. section 4.5).

4.1 Uranium mining and processing

Measures to reduce the environmental impact

The JRC Report is contradictory when it comes to the environmental impact of uranium mining: it certainly mentions the environmental risks of uranium mining (particularly in JRC Report, Part A 3.3.1.2, p. 67ff), but finally states that they can be contained by suitable measures (particularly JRC Report, Part A 3.3.1.5, p. 77ff). However, suitable measures are not discussed in the depth required in this context nor when assessing the DNSH criteria (JRC Report, Part A 4.2 p. 182ff) nor for developing TSCs (JRC Report, Part A 5.5, p. 195f with Annex 4.2) – and there is no explanation of how they should be implemented. The report does not indicate either how state institutions and regulatory authorities could exercise some influence on the uranium mining industry to ensure that the aforementioned suitable measures (which are not defined in any detail) achieve the environmental objectives in the EU's Taxonomy Regulation. The fact that most uranium mines are located outside the EU plays an important role here - uranium ore is only extracted within the EU at the Crucea mine in Romania.

A comparison between coal and uranium mining

The JRC Report compares uranium and coal mining and concludes that uranium mining is much more effective and "more environmentally-friendly" than coal mining (JRC Report, Part A 3.3.1.1, p. 64ff). While about 50,000 t of uranium are enough to operate all the nuclear power plants around the globe every year, a single 1-GW coal-fired power plants requires 9,000 t of coal every day. However this argument has not been thoroughly thought through: neither coal mining nor uranium mining can be viewed as sustainable – irrespective of the amounts involved in each case. The JRC Report wrongly confuses the comparison levels here: coal mining involves mining hydrocarbons, while uranium mining means extracting ore. The mining and processing techniques for both minerals are very different. Uranium mining principally creates radioactive waste and requires significantly more expensive waste management than coal mining – regardless of whether black coal or lignite are used in the comparison. In the past, handling the legacy of mining was left to the community at large. The old sites in the uranium mining areas in Thuringia are one example of this. The most viable uranium deposit sites have now been fully exploited and opening up new mines is becoming more expensive, as the ore that is mined contains less material that is suitable for fission (cf. Uranium Atlas, 2019; OECD/NEA, 2020).

In-situ leaching

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

The dam breach at Church Rock

Another example of the imprecise and unclear treatment of environmental risks continues with the description of the dam breach at Church Rock (JRC Report, Part A 3.3.1.2.2, p. 70, lines 1 ff). This is the only time that the JRC Report mentions a mining accident and it is only described very briefly. The dam of a mining sludge pond (SRIC, 2007) burst at Church Rock in New Mexico, USA (on the territory of the Navajo Nation) on 16 July 1979. More than 1,000 t of radioactive mining sludge and about 360,000 m³ of radioactively contaminated water escaped into the Puerco River in this tailings pond accident. The Church Rock disaster released the largest amounts of radioactivity ever in the USA. The surrounding area and its residents are still suffering from the consequences of the accident (Knutson, 2021). The impact of the disaster, which is still continuing today, and the intensive uranium mining around Church Rock, i.e. serious environmental and health problems, are described in the Report of the Church Rock disaster released released the long-term, negative consequences of the Church Rock disaster are not even mentioned in the JRC Report.

Cleaning up uranium mining sites - the example of Wismut

The JRC Report describes how abandoned uranium mining sites are decontaminated, waste and processing tips are removed and opencast mining pits are filled. Cleaning up the SDAG Wismut sites in Saxony and Thuringia after the demise of East Germany in 1990 are mentioned as a classic example here (JRC Report, Part A 3.3.1.2.1, p. 67, lines 7ff). However, the history of Wismut recultivation and decontamination is more complicated. Wismut GmbH (the legal successor of SDAG Wismut) was obliged after reunification to clean up the mining sites that were owned by SDAG Wismut on 30 May 1990. Most old sites in Thuringia were therefore not cleaned up (Uranium Atlas, 2019). The storage structures in decontaminated areas and their radioactive content will require constant monitoring for many years to come. Rivers and groundwater in Eastern Thuringia are exposed to risks of contamination. The JRC Report seems to suggest that even massive, polluted areas like these, which involve decades of decontamination work, do not lead to environmental objectives not being met.

Conclusion

To conclude, when it comes to describing and assessing uranium mining and uranium processing, the JRC Report mentions the risks associated with uranium mining and uranium ore processing, but only describes the risk-filled reality of extracting uranium ore and its processing to an inadequate degree.

4.2 Conversion into uranium hexafluoride

Front-end, fuel element production

Reference is constantly made to contamination with short-lived radionuclides in the context of producing fuel elements and processing natural uranium (JRC Report, Part A 3.3.2.2.2, p. 85f and 3.3.5 p. 105ff). No mention is made of the importance of the radionuclides formed in the uranium actinium or uranium radium decay chain with long half-lives (Pa-231: half-life of ~ 32,000 years; Th-230: half-life of ~ 75,000 years and Ra-226: half-life of ~ 1,600 years). The daughter nuclide Ra-226 in particular is largely responsible for all the gaseous radioactivity emissions from all the uranium processing facilities through its decay into the daughter Rn-222.

Radioactive inventory

The report argues that large amounts of VLLW or LLW have been properly disposed of without specifying the actual disposal method in any greater detail. Implicitly, this might possibly refer to the reclassification of depleted uranium hexafluoride from enrichment, which is formally viewed as an educt for the synthesis of hydrofluoric acid (cf. JRC Report, Part A 3.3.3.3, p. 99), but this is not consistent with any material recycling in the narrower circular economy sense, as the quantity of radioactive heavy metal requiring disposal remains the same. This would simply be "disposal" in line with an individual definition in the JRC Report. Unfortunately, the report leaves readers in the dark at this point.

The report also argues that large amounts of liquid radioactive waste outside the EU come from military programmes (Russia, USA) and are not further considered within the report. This fails to mention the fact that Slovakia, for example, transported spent fuel elements from power reactors to the USSR or Russian Federation for reprocessing in the past (SLOV, 2017). These exports naturally only include fairly low volumes of heavy metal (cf. JRC Report, Part B 2.3, Figure 2.3-2., p. 218), but produce radioactive waste water outside the EU. The JRC Report should have extended its "waste balance area" to the recipient countries, if it knew about the export of waste outside the EU.

4.3 Uranium enrichment, fabrication of UO_2 fuel, reprocessing, fabrication of MOX fuel

The process stages for uranium enrichment, the fabrication of uranium dioxide (UO_2) fuel – manufacturing fuel rods and fuel assemblies, the reprocessing of spent nuclear fuel and the fabrication of mixed oxide (MOX) fuel elements are examined in the JRC Report Part A 3.3.3 - 3.3.6 with regard to their influence on the DNSH criteria in the Taxonomy Regulation. These processes are completed in so-called fuel cycle facilities. The review of the JRC Report has given rise to similar remarks on the chapters mentioned. As a result, a summarised view of the process stages follows below.

General results of the review

In general, it is possible to state that the four chapters merely take into account the technical process stages, but safety aspects are not adequately considered in their scope or suitable depth.

The report describes the necessary technical processes for manufacturing and reprocessing fuel elements and examines the effects on the DNSH criteria. No consideration is given to any other process stages, such as transportation (cf. section 5.4 too) between the facilities. The discharge of radioactive substances cannot be fully excluded by incidents during transportation, even if the current requirements in hazardous goods law are followed. As severe accidents are not considered

beyond the design requirements in the methodology used by the JRC, this has no influence on the assessment of the DNSH criteria by the JRC. The importance of this fundamental issue has been explained above (cf. section 2.1 and 2.2.1 of this expert response).

The report does not examine the necessary decommissioning measures for facilities either. Decommissioning and dismantling not only place special requirements on the interplay between people, technology and organisation, but also for the later storage and disposal of the radioactive substances that accrue.

The effects of possible beyond design basis events have not been covered in the JRC Report (cf. sections 2.1 and 2.2.1 of this expert response). As the consequences of a severe accident in one of the types of units mentioned can have a far-reaching impact on people and the environment, this aspect should be included in the sustainability considerations to a greater degree.

Reprocessing of spent nuclear fuel

The reprocessing of spent nuclear fuel (JRC Report, Part A 3.3.5, p. 105ff) is presented in the report as an opportunity for achieving a so-called closed fuel cycle. Part A 3.3.5, p. 105ff and 5.6, p. 196 and Part B 6.3, p. 280ff of the JRC Report discuss to what degree using a closed fuel cycle could create the conditions for making the size of a repository for high-level radioactive waste smaller.

Using the "twice through cycle" (described in the JRC Report as the "partially closed fuel cycle"), uranium oxide fuel elements from light water reactors are reprocessed once. This involves using the plutonium and some of the uranium to produce mixed oxide (MOX) fuel elements. This is fed into light water reactors again. After having been used once in a light water reactor, no further reprocessing of the MOX fuel elements in the "twice through cycle" is envisaged because of technical problems (an unfavourable shift in the plutonium nuclide vector). In the case of a "fully closed cycle", fuel elements, which come from the reprocessing, could also be reprocessed (repeated reprocessing). A "fully closed cycle" requires the use of fast reactors.

The JRC Report itself does not elaborate on how a "fully closed cycle" can be implemented. However, it has to be noted that the fuel cycle is not fully closed, as waste accrues here too and has to be removed from the cycle and taken to a repository. New fuel also has to be added to the cycle (but less than in an open or "partially closed" fuel cycle).

The report provides a comparison of simple reprocessing ("twice through cycle") and not using any reprocessing (open fuel cycle). The report specifies that the disposal volume can be reduced by a factor of 3.4 (JRC Report, Part A 3.3.5, p. 113). This reduction can only be achieved in the underlying source by the fact that fairly large parts of the waste are not considered (the JRC Report presents this in a footnote.).

The report explains at a different point (JRC Report, Part A 3.3.5, p. 107) that the disposal volume would be reduced by 40% in a fully closed fuel cycle. According to the explanation given above, however, larger reductions can be expected in a fully closed fuel cycle than with single reprocessing. In this sense, these statements seem to contradict each other. To what degree the size of a possible repository is relevant for assessment in the sense of EU taxonomy also requires further examination.

4.4 Operating nuclear power plants

The JRC Report only considers normal operations at many points; accident scenarios are only studied in the relatively short Part A 3.5 (cf. sections 2.1 and 2.2.1 of this expert response). They are

only considered in terms of their lethality and this is compared to other energy sources, but the report does not mention the other aspects of accident risks, which are relevant for taxonomy. Incidents and accidents, particularly when operating nuclear power plants, can lead to the uncontrolled discharge of radioactive substances and therefore cause considerable environmental effects. A holistic assessment of the use of nuclear energy must therefore include a risk assessment related to all the environmental objectives that are relevant to EU taxonomy and set them against the risks emerging from other energy sources during any events that go beyond design basis events.

Current rules were reworked after the accident in Fukushima; the EU Directive 2009/71/EURATOM in particular was strengthened in terms of the safety objectives needing to be achieved and especially the requirements for the design of nuclear power plants that are newly built in 2014/87/EURATOM. However, this does not mean that accidents that discharge substances at nuclear power plants can be categorically ruled out. The member states are obliged to design, build and operate nuclear power plants with the goal of preventing accidents and, if an accident occurs, mitigate its effects. The fundamental possibility that an accident might occur, however, still exists (EURATOM, 2014).

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

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

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

The wording has not been adopted in the EU Directive (EURATOM, 2014) either. The safety objectives mentioned there only apply to existing nuclear power plants as a reference value for the timely implementation of safety improvements (EURATOM, 2014) that can be reasonably achieved at the facilities.

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

Even if upgrades are repeatedly performed across Europe with the aim of increasing safety levels – this took place most recently after the accident in Fukushima on a large scale, the design philosophies of the generations of nuclear power plants differ greatly, particularly when it comes to classifying accidents with a meltdown. Depending on the design of the power plants, there are limits to the possibility of introducing "safety improvements that can be reasonably achieved" (EURATOM, 2014).

4.5 Dismantling nuclear power plants

It should be generally noted that comparatively little space is dedicated to the topic of decommissioning and dismantling in the JRC Report. This involves a very complex, challenging and long process; this applies to both dismantling nuclear power plants and also nuclear fuel cycle facilities. A more detailed and differentiated consideration would be advisable here.

So far, some power plants have been fully dismantled and released from nuclear regulatory control (the report talks about "green fields", JRC Report, Part A 3.3.7.1.4, p. 129). The report correctly states that the strategy of immediate dismantling is the preferred method around the world when selecting the dismantling strategy (IAEA, 2014). The second possible dismantling strategy deferred dismantling after safe enclosure (for a restricted time) is given less prominence because of various imponderables (IAEA, 2018). However, the IAEA does not view permanent containment (entombment), which is specified in the report as the third strategy, as a dismantling strategy at all and it is only acceptable in extraordinary circumstances (e.g. severe accidents). Entombment basically implicates the permanent local disposal of radioactive waste.

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

One major element when dismantling a nuclear power plant is the waste balance sheet, particularly with a view to the amount of radioactive waste. The JRC Report in Part B 2.1, p. 210 takes over a table (Table 2.1-1) from the IAEA document entitled TECDOC 1817 (IAEA, 2017), which illustrates typical annual waste generation rates. The figure quoted for decommissioning power plants has a footnote in the JRC Report, which does not exist in the IAEA source. The footnote in the JRC Report states that the unit is [m³ per plant (1 GW)], while in the IAEA source it is specified as [m³/GW x year], i.e. an annual waste generation rate. While the JRC Report mentions a waste volume arising from the decommissioning of a nuclear power plant of "375 m³ per plant (1 GW)" in Part B 2.1, the associated IAEA source refers to an annual waste generation rate. The volume of waste arising from decommissioning a power plant would therefore be significantly higher than specified in the JRC Report in Part B 2.1, depending on the time required to dismantle it.

A further inaccuracy arises from the later statement about disposing of radioactive waste with low levels of radioactivity. In contrast to the practice mentioned in the report in other countries, Germany, for example does not operate a near surface repository. Low-level and intermediate-level radioactive waste, which are not subject to clearance, will be permanently taken to a deep geological repository in Germany too (cf. section 5.2 of this expert response too).

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

4.6 Ionising radiation and its impacts on people's health and the environment during all the life cycle phases (apart from disposal and transportation)

The JRC Report largely restricts itself in Part A 3.4 to the "impact of ionizing radiation on human health" (JRC Report, Part A 3.4.1, p. 167ff) and the environment (JRC Report, Part A 3.4.2, p. 173ff). The impact of emissions of non-radioactive substances is only considered at one point (publication [3.4-1]).

The quantities used to assess the impact of ionising radiation on human beings in Part A 3.4 of the JRC Report range from "Disability Adjusted Life Years" (DALY) to total emissions in becquerels (Bq) and the effective dose in millisieverts (mSv) or microsieverts (μ Sv). From a scientific point of view, the impact of radionuclides on human beings with low exposure to radiation can only be quantified by the effective dose or in terms of radon-222 (Rn-222) and its decay products by the activity concentration of Rn-222 in the air that people breathe (or quantities derived from these). Information on the total activity released into the environment is not suitable for quantifying the impact on human beings, as the dynamics in the environment and the dose coefficients for internal exposure and the dose rate coefficients for external exposure depend on the radionuclide in question.

The figures quoted for the radiation exposure of human beings in Part A 3.4.1 of the JRC Report are plausible. It is correct that human exposure to radiation as a result of the civil use of radioactive materials and ionising radiation is low in comparison with radiation exposure from natural sources and its range of variation. However, the report does not match the latest findings in radiation protection when specifying average effective doses per head of the population for nuclear facilities and installations. According to the latest recommendations of the International Commission on Radiological Protection (ICRP), the so-called "representative person" in the sense of the ICRP has to be considered an individual in the population, who is exposed to higher levels of radiation because of his or her lifestyle habits.

5 Criterion 2 in the Taxonomy Regulation – the DNSH criteria: disposal of radioactive waste, transportation, research and development

The subject of disposing of radioactive waste is considered in this section. It professionally examines the scientific statements in the JRC Report about the topics of storage (section 5.1 of this expert response), disposing of low- and intermediate-level radioactive waste (section 5.2), disposing of high-level radioactive waste (section 5.3), transportation (section 5.4) and research and development (section 5.5). Sub-headlines have been used to interconnect the subsections.

The text section deals with the problem that only normal operations for power plants and activities in the disposal field are discussed as the basis for assessing the DNSH criteria. The incidents needing to be considered according to relevant laws and sub-statutory rules and beyond design basis accidents and their possible influence on the DNSH criteria are, however, not included in the assessment in the JRC Report. The JRC Report also assumes that LLW stored at near surface repositories is the standard option, but does not consider that a number of countries have exclusively earmarked geological disposal for LLW and all other kinds of radioactive waste too. The JRC Report does not discuss whether any possible discharge of radionuclides at the end of the observation period for repositoriesbelow the (national) statutory minimum threshold conforms to the DNSH criteria either.

The JRC Report does not adequately consider the fact that no successful, deep geological disposal of high-level radioactive waste, including the permanent seal, has yet been introduced anywhere in the world.

5.1 Interim storage of radioactive waste

The JRC Report generally fails to provide any basis for the findings that are listed in the Executive Summary of the report related to storing radioactive waste. As a result, questions must be raised about the transparency of the conclusions that are drawn.

The presentation in the JRC Report related to storing high-level radioactive waste is restricted to a brief description of the most common types of storage. However, only the storage of high-level radioactive waste is dealt with in Part A 3.3.8.3, p. 156ff of the JRC Report and its discussion gives rise to the impression that only normal operations are relevant for assessing storage.

Only after considering the technical screening criteria developed by the JRC and presented in the JRC Report in Part A, Annex 4, No. 4, p. 366ff, it (implicitly) becomes clear that the design-basis accidents as defined in the relevant regulations and beyond-design accidents must also be included in the assessment of any storage of radioactive waste.

As a result, the assessment of interim storage consistently takes place according to the standard adopted by the JRC, which, however, is inadequate from an expert point of view. For beyond design basis events it is impossible to exclude that uncontrolled discharges of radioactive substances and therefore considerable effects on the environment may occur through incidents and accidents or by some other intrusion involving third parties (e.g. terrorist attacks) when operating storage facilities; a risk therefore remains. A holistic assessment of using nuclear energy must therefore include a risk assessment related to these events too (cf. section 2.1 and 2.2.1 of this expert response).

The JRC Report briefly mentions dry and wet storage as storage options for high-level radioactive waste. Whereas Germany is exclusively using dry storage for the purpose of storage of waste until it is taken to a repository, a large proportion of the spent fuel worldwide is stored in wet storage facilities (IAEA, 1999). However, the report fails to provide any detailed discussion of the specific safety features of these technologies. Wet storage facilities, for example, require active cooling systems. If any external factors influence the building structures, the safety level provided by the cask barrier is missing in external wet storage facilities when compared to dry storage. This applies not least to the wet storage of spent MOX fuel elements mentioned in the JRC Report which might be stored waiting for further developed reactor systems, the implementation of the so-called closed fuel cycle and transmutation. As the successful introduction of these technologies is uncertain, however, (cf. section 3.1.1. and 5.5), questions must be asked about the permanent storage of these high-level radioactive substances too.

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

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

The JRC Report deals with long-term or extended interim storage without, however, discussing whether the DNSH criteria have been met in line with the standards applied in the JRC Report (cf. section 2.1). Even if there is currently no information available that extended storage is not possible from a safety point of view – particularly in relation to the dry storage of high-level radioactive

waste in dual purpose cask for transport and storage – consideration of this issue has a crucial influence on the disposal pathway, as storage must safely provide an interim solution until the disposal of the material.

Based on the legal and the practical fact that storage sites can only exist in their initially licensed form for a restricted period, implications arise for other nuclear waste management acitvities, which may be similar to those that become necessary for conditioning for disposal. The time periods over which this will become relevant, are an important question for research and development. This too is completely missing from the JRC Report.

5.2 Disposing of low- and intermediate-level radioactive waste

With regard to the final disposal of low and intermediate level radioactive waste, incomprehensible or incomplete technical statements by the JRC were noticed. The same applies to the technical evaluation criteria developed by the JRC. Bold, underlined headings are therefore used to break up the chapter to examine the statements made by the JRC, on the one hand, and the consequences for the TSCs, on the other hand. Underlined headings in normal print subdivide the text within these parts, according to sub-topics.

Expert appraisal

A number of statements are made in the JRC Report with regard to disposing of low- and intermediate-level radioactive waste; they cannot be understood in specialist terms or are very hard to follow. Reference is made to these statements below.

Focus on disposal of low-level radioactive waste at near surface repositories

There are statements at various points in the JRC Report (e.g. Part B 5, p. 242) that low-level waste (LLW) is disposed in near surface repositories.

This statement gives the impression that the disposal of LLW in facilities in near surface repositories is the common approach of disposal. There are certainly a number of countries that have exclusively envisaged deep geological disposal for LLW and all other kinds of radioactive waste (e.g. Switzerland, Finland, Sweden and Germany) (KOM, 2015).

Period of time and material behaviour

With regard to the isolation period, the JRC Report states (Part B 5.1, p. 244) that the typical period for isolating LLW in near surface repositories 300 years. It also asserts that the material behaviour of the technical barriers is well-known during this period and it is therefore possible to predict that the barriers will be sufficiently reliable.

The JRC Report comprehensively states that near surface repositories involve a number of different storage concepts and different technical facilities and components. The requirements placed on the materials being used must be adapted, taking into consideration e.g. the specific site conditions, the spectrum of waste requiring disposal, the climatic conditions and other general circumstances.

This statement about the isolation period of 300 years is not explained in any greater detail and/or supported by references. Overall, it is necessary to view the details about the aspects mentioned here as a generalisation. After all, the isolation period depends on the disposal concept in question, technical facilities and the components used.

The need for deep geological repositories for LLW and institutional checks

The statement (JRC Report, Part B 5.1, p. 244) that there is no need to emplace LLW in deep geological disposal facilities is incrompehensible. Near surface repositories are believed to be more susceptible to human intrusion than deep geological repositories (IAEA, 2012). Aspects like robustness, accessibility, protection, loss of knowledge etc. must also be taken into account when judging their safety. The institutional checks that are normally envisaged for near surface repositories for a period of 300 years cannot be generally guaranteed either. The reason for this is that no scientific basis exists to forecast human behaviour and social actions (NAS, 1995: AKS, 2008; Seitz et al., 2016).

The "Storage of High-Level Radioactive Waste" committee has concluded with regard to the disposal of this waste that long-term storage near surface disposal is not an acceptable option for handling radioactive waste in a verifiably safe manner in the long term because of the unreliable prediciton regarding social and political developments, the danger of accidents (e.g. caused by a lack of maintenance), and attacks caused by war or terrorism, the risk of proliferation, the huge organisational effort and financial expenditure for future generations and climate uncertainties (KOM, 2016). This conclusion on the long-term interim storage of high-level radioactive waste at or near the surface can in principle also be transferred to near surface repositories for low- and intermediate level waste with regard to the predictability of the development of a facility.

The need to act in case of complications

The JRC Report mentions the Asse II mine, which is located in the Federal Republic of Germany, in relation to the statements about the content of periodical safety checks, their reliability and their contribution towards the safety of facilities near the surface (JRC Report, Part B 5.1, p. 249). The mine was operated on the basis of German mining law and was originally set to be decommissioned according to this. A long-term safety analysis or a safety case under German atomic energy law was not performed for Asse II. The JRC Report mentions the salt mine, which was used to dispose of low-and intermediate-level radioactive waste between 1967 and 1978, as an example of the fact that a renewed safety review on the basis of the Atomic Energy Act, which has applied since 2009, has led to the decision to remove the stored waste, recondition it and dispose of it at another facility.

The Asse II mine can rightly be viewed as an example of the dubious robustness of safety mechanisms and processes - it is, however, a deep geological disposal facility. In this connection, it seems important to point out that there is no close temporal link between recognising the safety problems and the decision to remove the waste. It is actually possible to see that the shortcomings of the old extraction mine had already been recognised in the 1960s and had become clear to a broader circle of state and non-state players by the end of the 1970s/beginning of the 1980s (Möller, 2016). Hydro-geological interrelationships and issues in particular, which concerned the longer term site safety, were initially only processed as a side issue in the form of estimates and generally with less intensity (Möller, 2016). The example of Asse II cannot illustrate the way to deal with uncertainties and reservations, as this procedure is no longer permissible today (cf. section 2.2.2 of this expert response). A deeper analysis of the decision processes, which led to using the Asse II mine as a repository for low- and intermediate-level waste, show that several reasons initially supported the idea of including the mine in the nuclear disposal plans - and they were not necessarily geared towards safety. The key issues were rather its low price, immediate availability, the ability to meet all the existing disposal wishes, the ability to conduct various experiments and the possibility of gaining time for further planning work. It also becomes clear that economic aspects carried more weight than safety aspects in the efforts to help nuclear energy achieve an economic breakthrough (Möller, 2009). Disposal and budgetary considerations and the conflict potential in this field of activity

effected that state players tended to deal with the safety shortfalls at the mine with greater restraint in later years. Viewed from this perspective, Asse II is perhaps not a special German case, and the situation could possibly be transferred to other facilities that were created and licensed in times when cost-effective usage was the primary factor.

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

Measures against human intrusion (HI)

We can largely support the statements in the JRC Report about the measures to counter human intrusion into an enclosed repository (JRC Report, Part B 5.1, p. 246). However, the topic is not adequately treated with regard to the DNSH criteria (cf. section 2.2.5).

Technical screening criteria

Gap for VLLW and long-lived LLW and ILW

The JRC Report (Part A 5.7, p. 197) states that disposing of LLW and short-lived intermediate-level waste (ILW) is less demanding compared to high-level waste (HLW) and therefore the TSCs developed for storing and disposing of HLW and spent fuel elements are covering for the disposal of LLW and short-lived ILW too.

The short-lived LLW and ILW only contain small amounts of long-lived radionuclides. The waste must meet the following three criteria to be viewed as short-lived (IAEA, 2009: GRS, 2004):

- the waste's half-life is less than 30 years,
- the specific activity of the α radiation in the waste is lower than 400 Bq/g at the entire repository and
- the specific activity of the α radiation in individual containers is lower than 4,000 Bq/g.

The long-lived LLW and ILW includes waste that exceeds the aforementioned criteria and does not produce any significant heat. The JRC Report does not explicitly deal with this waste. This involves waste that does not accrue from energy production (i.e. in industry, research, medicine). A large proportion of isotopes, which are relevant for nuclear medicine, have very long half-lives (e.g. Tc-99, Se-79). By ignoring the issue of waste with a fairly long active life from the LLW or LLW, a major part of the potential negative influence on the environment is not considered. This once again leads to a systematic underestimate of the negative effects of using nuclear energy on the DNSH criteria in the direct comparison with other forms of energy generation.

This raises the following question: which TSCs apply to or should be used for low- and intermediatelevel waste, which is not included in the aforementioned waste classes? This involves, for example, very low-level waste (VLLW) and long-lived LLW and ILW. The JRC Report contains a gap in the TSCs for these waste classes.

Differences between deep geological and near surface repositories

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

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

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

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

Compatibility of the TSCs for HLW with those for LLW

The JRC Report (Part A 3.3.8.9, p. 165ff) states that activities, including those related to disposing of radioactive waste, do not cause any significant damage to people's health or the environment. This is true, provided that the industrial activities associated with it meet the TSCs.

The TSCs for storing and disposing of HLW and spent fuel elements are outlined in Annex 4 of the JRC Report. The DNSH-related TSCs state, among other things, that the repository facility must guarantee that the waste is contained and isolated from the biosphere. This also applies if extreme natural phenomena occur such as earthquakes, tornadoes, floods or the loss of technical barriers.

The JRC Report does not list any special TSCs for LLW and ILW and states that the TSCs developed for HLW and spent fuel elements are believed to be satisfactory (cf. JRC Report, Part A 5.7, p. 196f). The reasoning leading to this conclusion is not mentioned in the JRC Report and the statement is generally incorrect. If the TSCs for HLW are also used for LLW, there are doubts whether the aforementioned condition for complying with the TSCs, e.g. when considering extreme natural phenomena, is comprehensively met. The reason for this exists in possible differences about the robustness of the deep geological repositories envisaged for HLW and LLW in near surface repositories.

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

5.3 Disposing of high-level radioactive waste

Incomprehensible or incomplete statements made by the JRC regarding the disposal or low- and intermediatelevel radioactive waste are striking. The same applies to the technical assessment criteria developed by the JRC. Bold, underlined headings are therefore used to break up the chapter to examine the expert statements made by the JRC, on the one hand, and the consequences for the TSCs, on the other hand. Underlined headings in normal print subdivide the text within these parts, according to sub-topics.

This must be prefixed by the fact that nuclear energy has been used for several decades, but there is still no repository for high-level radioactive waste operating anywhere in the world. Responsibilities are therefore passed on to following generations and they are restricted in their freedom of choice. Section 6 of this expert response will deal with this matter in greater detail.

Expert appraisal

General results of the review

The JRC Report contains unfounded generalisations at many points. Conclusions are drawn from individual, selected examples and their global validity is assumed. Readers without any detailed specialist expertise will find it hard or impossible to recognise this. For example, the feasibility of disposing of other "waste" (CO₂) in deep geological formations is transferred to the disposal of HLW in the report. However, the report does not mention the completely different risk potential, particularly over very long periods of time (more details available below).

The conclusions in Part A 3.3.8.9, p. 165 of the JRC Report, e.g. "The disposal (...) does not contribute (the results are zero or negligible) to those indicators representative of the impacts to the Taxonomy Regulation objectives", are only inadequately supported by the analyses and discussions that are presented. Based on the information in Part A 3 of the JRC Report, this statement is premature and insufficiently justified. The results of the analyses described in Part A 3 of the JRC Report are only discussed in the following chapter (JRC Report, Part A 4) in the light of the basic principles and objectives of taxonomy (more details available below).

As for citing sources, there are some striking examples of incompletely described references for information that has been presented – for example, in the text on page 217, Part B 2.3 of the JRC Report on the inventory of spent fuel elements in the EU, on page 244, Part B 5.1, Figure 5.1.-1 on the period mentioned for isolating low-level radioactive waste from the biosphere and the general public (300 years) and on page 161, Part A 3.3.8, Figure 3.3.8-9 regarding the details of constructing the Finnish repository.

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

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

Assessing the safety of a repository

Based on selected results from safety assessments of repositories in Finland, Sweden and France, the JRC documents in Part B 5.2, p. 249ff of its report a fragmentary assessment of radiological safety at a deep geological repository. These countries have the technical and financial resources to complete the disposal of high-level radioactive waste in geological repositories. The capabilities and the needs of smaller countries, which possibly depend on outside help to resolve their repository issue, are not mentioned. The report also restricts itself to only two potential host rocks

(crystalline in Finland and Sweden and clay in France). Other possible host rocks like salt are missing. The report is also incomplete in the sense that, in contrast to storage, it only considers the time after the repository has been sealed: i.e. there is no discussion about assessing radiological safety during the operational phase. The safety criteria discussed only represent a selection of general requirements. Other potentially relevant requirements are not discussed.

A lack of empirical data

The JRC Report correctly states on page 243, Part B 5 that "...there is no empirical evidence generated by a radioactive waste disposal facility that has gone through all the three stages (preoperational, operational, and post-closure) for the entire time frame foreseen (up to a hundred thousand years for a deep geological repository)". It should also be noted that only one repository for HLW is currently being built around the world.

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

Part B 5 of the JRC Report states, "...the safety of disposal during the post-closure phase is demonstrated by a robust and reliable process which confirms that dose or risk to the public are kept under all circumstances below the required limits". As there is still no repository with an operational license for HLW, the use of the word "is" here is incorrect. The relevant assessments in the context of a safety case are currently still involved in various licensing processes, depending on the national regulations, even for the HLW repository projects that are more advanced (in Finland, Sweden and France).

A focus on normal operations of disposal facilites and ignoring uncertainties

The role of unexpected events is restricted in the JRC Report and not fully discussed. The report does not provide any analysis of consequences from potential accidents, particularly for the operating phase of geological disposal. This is surprising, since, when analysing the life cycle, one major aspect is whether an activity creates any threats that can be prevented or mitigated. This omission is viewed as an important shortcoming, as unexpected events cannot by definition be completely prevented and if they occur, accidents or incidents can trigger considerable radioactive contamination (cf. sections 2.1 and 2.2.1).

The significance of the effects of disposing of radioactive waste on the environmental objectives according to the TEG is qualitatively assessed in Table 3.3.8.3, p. 166 of the JRC Report. The lowest possible significance is attributed to all three radiological effects (producing solid radioactive waste, the discharge of gaseous radionuclides and the discharge of liquid radionuclides). The report particularly states with regard to radioactive discharge that the release calculated during the containment phase is far below the permissible thresholds ("Calculated releases during the closure phase well below authorised limits"). This is a statement that is not backed up by adequate arguments in the report.

The statement does not consider the influence of the major inherent uncertainties when assessing the long-term safety or the potential risks in conjunction with operational accidents.

Unintentional human intrusion

The topic of unintentional human intrusion is not appropriately discussed in the JRC Report. The likelihood for this kind of event, which cannot be ruled out, and associated radiological consequences in the light of the long isolation periods that are required for the radioactive waste are neither treated nor appropriately considered when assessing the TSCs and the DNSH criteria. Cf. sections 2.2.2 and 2.2.5 of this expert response.

Non-radiological effects

The discussion of potentially damaging, non-radiological effects of geological disposal of spent fuel elements and HLW (JRC Report, Part A 3.3.8.6, p. 162f) is conducted on the basis of a selection of results from the Swedish environmental impact assessment. It is implicitly assumed that this document contains an assessment that is generally representative for each kind of repository at each place (e.g. climate, geography, biosphere etc.). No reason for this assumption is provided. For example, the possible effects on water resources also depend on the specific climate, land use and hydrological conditions (Öko, 2015). This is related to the problem that has already been described above – i.e. restricted practical experience in relation to operating a deep geological repository.

The JRC provides a confusing comparison between carbon (dioxide) capture and storage (CCS) and disposing of radioactive waste in Part B 5, p. 336ff of the JRC Report. The comparison between CCS and disposing of radioactive material is only possible to a certain extent, as a different risk is caused by disposing of CO_2 at a great depth. In other respects, the technical concepts for both types of disposal are completely different and are associated with very specific requirements and risks. The safety provisions for both types of disposal are therefore different too (cf. JRC Report, Executive Summary, p. 8, third indent).

Barrier system

The JRC Report contains oversimplified statements about the reliability of the barrier system, which can lead to fundamental misunderstandings, as complex expert knowledge is necessary to assess them. For example, Part B 5.2.2, p. 250 of the JRC Report simply states the following, "Chemical and mechanical interactions between natural and engineered barriers will occur", while not explaining in greater detail the form that this interaction will take. The Executive Summary also contains a similarly simplified and significant statement, "The multi-barrier configuration of the repository prevents radioactive species from reaching the biosphere over the time span required. In the absence of releases of radioactive species to the accessible biosphere, there is neither radiological pollution nor degradation of healthy ecosystems, including water and marine environments." This is an oversimplified and generalised description. The maximum spread of radionuclides must be restricted to an expected degree, which is determined in advance (cf. Section 26 Para. 2 of the Site Selection Act). However, a potential discharge, at a level below this regulatory standard, cannot be excluded, ("Negligibility criterion", Section 4 of the Order for Safety Requirements for Disposing of High-Level Radioactive Waste), but must be assessed with a view to the expected effects on people and the environment according to current standards. It is all the more important to convincingly show in the safety case for the repository that these kinds of possible discharges are below the statutory thresholds and therefore do not represent an unacceptable risk for future generations. The JRC Report does not discuss whether these (national) statutory thresholds match the DNSH criteria either.

Part A, 3.3.8.5, p. 162 of the JRC Report makes an oversimplified and final statement about the long-term reliability of the barrier system, "Long term post-closure safety will be achieved by means of a system of passive barriers...". Statements about the long-term safety in the post-closure phase are made here without describing or questioning possible relevant developments, which have an effect

on the reliability of a repository. As for the long-term safety of a repository, appropriate statements must always be considered in relation to the regulatory requirements and general conditions underlying them. It should be noted that, even in very favourable geological situations, uncertainties still exist and cannot be completely ruled out (NEA, 1995 and 2012).

Discharge of radionuclides

Imprecise statements are made about the possible discharge of radionuclides from the repository into the biosphere. For example, "No radiologically relevant release or impact to the public is expected..." (JRC Report, Part A 3.3.8.5, p. 161 – operating phase) or "and [radionuclides] will never exceed the limit below which they can cause no harm" (JRC Report, Part B 5, p. 241 - phase after the closure of the repository). The first statement is incomplete and oversimplified – the risks associated with potential accidents (e.g. a canister drop, fire, criticality) or improper use of the fissionable material (e.g. a terror attack, theft etc.) – are not assessed or not finally assessed. The risk assessment here also seems to have been taken out of context, but the conclusions are included in the overall assessment. The reasoning here is not underpinned by references to sources either.

As for the second statement, the national and international rules cited in the report related to the repercussions of disposal activities when disposing of HLW do not assume a "zero criterion", but a "negligibility criterion". Lower doses than 0.3 mS/y (cf. e.g. Section 99 Para. 1 of the Order to Protect Against the Damaging Effects of Ionising Radiation) can still cause damage to people's health.

The statement in the JRC Report "and will never exceed the limit below which they can cause no harm" is therefore contradictory. The report at least discusses the impacts of low doses of radiation. However, the arguments should therefore be presented in a more careful manner. Damage to people's health cannot be absolutely excluded (ICRP, 2013; DoReMi, 2016).

An imprecise and incorrect statement is made in Part A, 3.3.8. p. 165 of the JRC Report. "The deep geological disposal facility aims at isolating and containing the radioactive waste until its radioactivity decays to harmless levels." According to the relevant period in the rules in Sweden (100,000 years), the waste is still harmful (JRC Report, Figure 2.4-1). The report contradicts itself here.

Disposing of radioactive waste through dilution and discharge

Part B 3, p. 224 of the JRC Report states, "For certain types of waste with a low concentration of activity, typically gaseous and liquid effluents the management strategy is its dilution and release to the environment". The JRC Report does not deal with the subject matter any further and justifies this as follows: "This is carried out under regulatory control following strict procedures ensuring that releases are below authorised limits, and it is outside the scope of this section." (JRC Report, Part B 3, p. 224). The JRC overlooks the fact that this disposal method is excluded by law in Germany, for example. Section 61 Para. 3 of the Radiation Protection Act forbids the deliberate dilution of any radioactive waste.

Post-closure phase

A summary is provided in Part A 3.3.8.9, p. 167 of the JRC Report, "In the light of the above analysis it can be concluded that activities related to the storage & disposal of technological & radioactive waste, as well as spent nuclear fuel do not pose significant harm to human health or to the environment." This statement is not supported by the discussions presented in Part A 3 of the JRC Report (or the following chapters). The results of the analyses described in Part A 3 are discussed in the following chapter (Part A 4) using the basic principles and objectives of taxonomy. The report states that it is possible to conclude, in the light of an analysis, that activities related to storing and disposing of conventional and radioactive waste and spent fuel elements do not imply any significant risk to people's health or the environment. It is unclear which analysis is meant in the context of the post-closure phase of repositories. Quoting the examples of procedures in different countries and presenting general results is therefore inadequate, apart from other things, because of the different site situations, specific general conditions like the waste characeristics, the repository concept, the safety concept or the regulatory requirements.

It is therefore not possible to clearly follow the conclusion mentioned here. In addition, the comments on the possibility of unintentional human intrusion, which cannot be ruled out, and the associated possible effects on people and the environment and other uncertainties regarding the development of repositoriess in the post-closure phase make it impossible to reach this kind of firm conclusion.

Technical screening criteria

The process of developing the technical screening criteria (TSCs) has not been completed. Part A 5.1, p. 190f of the JRC Report, however, argues as if they were complete, but the relevant sources are missing, including those related to international experience. Any use of the TSCs for a final assessment of taxonomy criteria is not possible, or at least problematic.

Exemplary arguments and evidence from safety cases in specific projects are used to assess the longterm consequences of disposal of HLW and this is consistent with the state-of-the-art of science and technology. However, the assumptions and requirements for the system associated with this are presumed to have been implicitly met, although uncertainties exist in their implementation and their long-term effect.

Despite their central significance for the method, the TSCs are only presented in a very general way and require further specification (e.g. dose criteria for radiological assessment). Annex 1, Appendix E, page 369f of the JRC Report mentions other requirements for the DNSH criteria, particularly funding aspects. The report fails to mention them. This is consistent with the inner logic of the JRC Report, but is lacking in any overall discussion of sustainability.

5.4 Transportation

The JRC Report does not mention the aspect of transportation in its presentation of the life cycle analysis. This would have been necessary for a conclusive overall presentation of all the aspects of nuclear power.

All the shipments of radioactive materials are conducted on the basis of internationally agreed rules and also require an appropriate licence. According to the underlying review standards set by the JRC for the DNSH criteria (cf. critical comments in sections 2.1 and 2.2 of this expert response), the DNSH criteria should therefore not be problematic. However, this narrow analysis fails to do justice to the subject, as has been pointed out on several occasions above. Beyond design basis accidents or beyond-design threat interventions by third parties during transport cannot be completely ruled our; thus the corresponding risks cannot be excluded neither, even if international rules are followed.

5.5 Research and development

A number of statements and facts about research and development are mentioned in the JRC Report, but they cannot be followed or their derivation cannot be shared from an expert point of view. However, general information, which is definitely related to research & development and taxonomy, can be deduced from the text. The following text deals with this general information and the aforementioned statements.

General results of the review

The JRC Report only contains a few cross-references to Part B 6 "Research and Development" and conversely from Part B 6 to other chapters in the JRC Report (cf. also section 2.3.1 of this expert response). The reference to Part A in particular is not presented. An explicit connection with taxonomy has not been provided or shown (cf. section 2.1). The JRC Report does not consider either that the enormous expenditure on research in the field of disposal underlines the associated uncertainties and casts doubt on whether using nuclear energy meets the taxonomy criteria (cf. section 2.2.3).

Connection between storage, the operating phase and the post-closure phase

The JRC Report fails to deal with one aspect that plays an important role in current research: the connection between storage, the operating phase and the post-closure phase ("integrated safety case") and the relevance of this connection for safety within the time scale in question (IAEA, 2016a; IAEA 2016b; IGSC, 2008; NEA, 2016; GRS, 2020).

Transferability of the functionality of the barriers to long periods of time

A multi-barrier concept forms the basis for disposal in most of the safety concepts. This concept consists of a more or less nested number of technical, geotechnical and geological barriers. The functionality of the individual barriers has to be demonstrated and proven for the envisaged periods of time in each case. The effectiveness of the overall system must be proven, even if one or several individual barriers fail. The evidence that the technical (e.g. containers) and geotechnical barriers (e.g. closure of the shaft) function and transferring this capacity to long periods of time represent an enormous challenge. However, this aspect is sometimes viewed critically in the case of technical barriers compared to geological barriers, some of which are linked to natural analogues that underpin the barrier effectiveness over very long periods of time (AkEnd, 2002; cf. KOM, 2015).

Scope of the research programme and pure research

The scope of basic research shown in the JRC report only mentions examples that relate to the inventory. The aspect of basic research that deals with host rocks is completely missing at this point. Of course, it is impossible to mention all the aspects of basic research. As a result, major topics are not mentioned or casually by means of a brief description (e.g. uncertainties, human activities including human intrusion, and long-term documentation).

This generally raises the question why Part B 6 of the JRC Report entitled "Research and Development" only deals with research programmes centred on Europe. We might have at least expected a more detailed critical assessment of activities outside Europe with the major priorities pursued there in Part B 6.1, p. 277 "Introduction". Solely mentioning some countries by name (e.g. JRC Report, Part B 6.4.2, p. 286 "Such global partnerships with, e.g. with USA and Japan have been in existence for a long time.") without specifying other sources seems inadequate.

Uncertainties

Uncertainties are addressed in relation to the current focus of research and development. It should be pointed out in this connection that there will be a number of uncertainties that cannot be reduced or completely resolved (GRS, 2018). Research and development work needs to start at an early stage on how to handle these uncertainties or take them into account (cf. sections 2.2.2 and

2.2.3 of this expert response).

Research and development, the state-of-the-art of science and technology

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

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

The latest science and technology is crucial for disposal, e.g. Section 19 Para. 1 Sentence 3 of the Site Selection Act. Research and development can move these findings forward.

P&T and the so-called "closed fuel cycle"

Research has been conducted for a long time on how to separate the existing and accruing radioactive waste into various waste streams using suitable procedures and transfer them to less long-lived radionuclides through nuclear physics conversion processes. This approach, which is called partitioning and transmutation (P&T), provides a number of benefits, according to the JRC Report. However, the underlying technologies still do not exist. Whether and when they could be available for use on a large scale is completely unknown. Giving less priority to disposal and transporting the waste to long-term storage sites near the surface until the P&T technology has developed far enough for large-scale use would be necessary for this.

The German "Commission on Storage of High-Level Radioactive Waste" discussed this topic thoroughly and overall reached the following conclusion about the issue of long-term storage on or near the earth's surface (cf. also section 5.2 of this expert response):

"The committee does not believe that permanent, monitored storage is a realistic option for handling radioactive waste in a verifiably safe and long-term manner. The committee therefore rejects any active pursuit of this kind of strategy." (KOM, 2016).

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

- According to the state-of-the-art of science and technology, P&T programmes only seem practicable for treating spent fuel rods from power reactors, but not for waste that has already been vitrified.
- A P&T concept requires a large number of nuclear facilities and long-term operations there. The safety risks caused by operating nuclear facilities in the long term would have to be accommodated in a P&T programme.
- The nuclear facilities required for P&T are not available on such a large technical scale.
- Many decades of research and development work would be necessary before introducing any P&T programme.
- It is still unclear whether it will be possible to achieve the necessary technical development stage for implementing a P&T programme on a large scale.
- Whatever happens, a repository for high-level radioactive waste will still be needed.

• Operating nuclear facilities within a P&T programme in the long term would give rise to proliferation risks.

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

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

The contribution played by minor actinides to the long-term radiotoxicity of spent fuel elements is also presented in the JRC Report in Figure 6.3-1, p. 281. The figure shows that the transmutation of plutonium and americium would lead to a significant reduction in the dose. The diagram does not show the fission products, which initially dominate the radiation, at least with thermal reactors (Schwenk-Ferrero, 2013). Studies in Switzerland on clay rock have also shown that long-lived fission products in clay have a high degree of mobility in the earth and therefore account for the lion's share of the dose that is discharged into the biosphere (NAGRA, 2002, p. 203).

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

6 Future and further criteria in the Taxonomy Regulation – other sustainability goals and minimum standards

The JRC Report deals with other aspects that are important for sustainable development in conjunction with disposing of high-level radioactive waste, in addition to the ecological criteria. The JRC Report particularly highlights consideration for future generations (JRC Report, Part B 5.2.3.3, p. 258) and the importance of participative decision-making (JRC Report, Part B 5.2.3.1, p. 254) when searching for a repository site. The JRC Report formulates both aspects as important requirements when searching for a repository site. The two requirements of "considering future generations" and "participative decision-making", however, are not considered in any further depth – e.g. mentioning the challenges associated with these requirements when searching for a repository site for radioactive waste. The report emphasises that there is still no repository for high-level radioactive waste in operation anywhere in the world (JRC Report, Part A 1.1.1, p. 17), but leaves open the question of whether there is any connection here with the challenges of "considering future generations" and "participative decision-making".

The JRC was possibly not commissioned to perform a review of sustainability beyond the DNSH criteria in relation to environmental objectives. However, it should be pointed out that the TEG

definitely sees the possibility of including the aspect of intergenerational risks in the development of TSC or the DNSH criteria as regards the environmental objectives (TEG 2020b, p. 33). The JRC Report also refers to the approach adopted by the TEG (JRC Report, Part A 1.3.2.4, p. 23). However, the JRC Report does not provide any detailed treatment of the two aspects of "considering future generations" and "participative decision-making". However, it is important to consider both aspects in order to assess the sustainability of the disposal of radioactive waste. Both aspects represent sustainability goals in the United Nations' 2030 Agenda (UN, 2015). The Taxonomy Regulation, which forms the basis for the JRC's analysis, views the United Nations' 2030 Agenda as a goal for the European Union to implement this view of sustainability and it aims to include further criteria for sustainability from the 2030 Agenda in the Taxonomy Regulation beyond the ecological criteria in future (more on this in section 6.1 of this expert response). The recent decision by Germany's Federal Constitutional Court on climate protection also illustrates the need to assess technological risks with a view to future generations (Federal Constitutional Court, Decision on 24 March 2021, file no. 1 BvR 2656/18, 1 BvR 96/20, 1 BvR 78/20, 1 BvR 288/20, 1 BvR 96/20, 1 BvR 78/20).

The major topic in this section about maintaining information and knowledge about disposal in the long term from one generation to another also affects the interests of following generations and must be considered from sustainability points of view (cf. section 6.2).

Regardless of disposal, the problem of proliferation (cf. section 6.3), which is only mentioned in a very rudimentary manner in relation to reprocessing in the JRC Report, and uranium mining (cf. section 6.4) mean that it is necessary to treat the topics of intergenerational justice and participation separately in terms of the sustainability of using nuclear energy.

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

6.1 "Considering future generations" and "participative decision-making" in conjunction with disposal

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

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

- Goal no. 7 in the 2030 Agenda formulates access for all (i.e. for future generations too) to affordable energy supplies on the basis of its goal of social sustainability and places its confidence in renewable energies and energy efficiency.
- Goal no. 16 in the 2030 Agenda 2030 formulates the importance of a peaceful and inclusive society for sustainable development. This includes effective, accountable and transparent

institutions and the need to ensure, as formulated in a sub-goal, that decision-making at all levels takes place in a demand-oriented, inclusive, participatory and representative manner.

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

Consideration of sustainability aspects and future generations in the JRC Report

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

The risk of long-term financial burdens that are hard to calculate (as the example of the Asse II mine illustrates) and the risks caused by geological disposal for several generations are not adequately treated in the JRC Report. The report states that it is necessary to prevent placing any inappropriate burdens on future generations (e.g. JRC Report, Part B 1.1, p. 201). Geological disposal, however, continues to depend on whether the generations not responsible for the problem, e.g. in the case of cost risks and associated additional funding resources, will be prepared to share the costs – and what happens, for example, if this readiness or the possibility for it no longer exists? How should expenditure be prioritised during crisis times (e.g. a global health or environmental crisis)? What happens if the funding is interrupted? In the light of the requirement formulated in Section 1 Para. 2 Sentence 3 of the Site Selection Act to "minimise the need for resources, costs and the burden of risk, which are passed on to future generations", it can be assumed that the challenges associated with geological disposal have already infringed the principle of equality between generations. The development and implementation costs for deep geological repositories in particular are generally hard to forecast over long periods of time (BMU, 2015).

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

Consideration of participative decision-making in societies in the JRC Report

The involvement of stakeholders is greatly oversimplified in the JRC Report and is described in very optimistic terms. For example, NGOs are not considered in the description of interest groups and their role in developing a programme for deep geological repository sites (JRC Report, Part B 5.2.3.1, p. 253-254). Part B 5.2.3.1, p. 254 of the JRC Report ignores the fact that it may not be possible to reach consensus among the stakeholders. This also oversimplifies the problem of searching for a site and presents it in a one-sided way. There is no discussion either that – where no social consensus on using nuclear energy exists – its use itself can represent a blockage factor for solving the repository issue – at least experience in Germany illustrates this. Abandoning nuclear power and therefore resolving a social field of conflict, which had continued for decades, was a central factor in ensuring that discussions were relaunched about a site election procedure and led to a broad consensus.

As far as using participative decision-making in a society is concerned, the report mentions various requirements when searching for a repository site (clarity about the roles of those involved, i.e. particularly politicians, supervisory bodies and operators, transparent and trustworthy

involvement of all the relevant stakeholders through open dialogue, a broad consensus among all the stakeholders and the general public etc.). However, these requirements for a participative process are not further specified at any point in the report or analysed with a view to disposal.

Participative procedures would also be necessary in process stages upstream like uranium mining or if indigenous peoples are affected (c.f. section 6.4 of this expert response). Article 18 of the Taxonomy Regulation about minimum safeguards (in this case regarding human rights) should have been more clearly directed towards uranium mining too.

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

This gap in the report is particularly underlined by the fact that the scientific and technical requirements for a repository are presented and assessed in detail.

Conclusion

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

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

6.2 Preservation of records, knowledge and memory regarding radioactive waste repositories

Preservation of records, knowledge and memory (RK&M) regarding radioactive waste repositories is only mentioned once as a quotation from Article 17 of the Joint Convention (JRC Report, Part B 1.2, p. 206) and once rudimentarily in Part B 5.2.3.3, p. 259f. This does not do justice to its importance for future generations (cf. sections 2.1 and 6.1 of this expert response).

The approach was pursued up to the 1970s of using passive technical means to prevent any unintentional intrusion into a repository for radioactive waste after it had been sealed and its integrity and protective function from being damaged. This view has been increasingly developed during the past few decades and the international discussions can now be summarised by saying that the fundamental conditions are to be passed on to future generations - by preserving records, knowledge and memory regarding the repository (in very different formats and degrees of detail) - to reduce the risk of any inadvertent human intrusion and enable independent decisions about how to go ahead with the radioactive waste. Preservation of records, knowledge and memory regarding radioactive waste repositories also includes the question of using signs and symbols to communicate information over very long periods; research in this area has been conducted since the 1980s primarily in Germany using the term "nuclear semiotics". And it also includes the internationally discussed possibilities of marking repositoriess and the pros and cons of various storage media under discussion.

Preservation of records, knowledge and memory regarding radioactive waste repositories is an important additional component with regard to the long-term safety of a repository (ICRP, 2013) and it already requires in-depth information management during the construction and operating

phases. An international understanding of this has been developed in the so-called RK&M Initiative ("Records, Knowledge and Memory") at the OECD/NEA about what maintaining information and knowledge for future generations might involve for future generations and how it could be handled. A toolbox involving 35 "mechanisms" for preservation of records, knowledge and memory preservation about maintaining information is presented in the final report of the initiative (OECD, 2019) – including well-known concepts like markings and archives, but also new concepts like the SER (Set of Essential Records) and the KIF (Key Information File) – which help to develop an extensive strategy in the national and site specific context. The OECD/NEA recommends making preparations for long-term preservation of RK&M while there is still recognition of the importance of dealing with the radioactive waste and therefore the resources necessary for this purpose are available (OECD, 2014). Requirements like these are not taken into account in the JRC Report.

6.3 Proliferation

The JRC Report only mentions the risk of proliferation – i.e. the spread or transfer of fissionable material, mass weapons of destruction, their design plans or launching systems – very briefly in conjunction with the civil use of nuclear power. This analysis is inadequate to do justice to proliferation in the light of the DNSH criteria related to the environmental objectives, as it represents a considerable risk for almost all sustainability goals.

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

Processes that are particularly important for proliferation are created when manufacturing nuclear fuel (uranium enrichment) and reprocessing spent nuclear fuel materials: the technologies for uranium enrichment can be used with modifications to produce highly enriched uranium to build a nuclear weapon. During reprocessing, plutonium is separated and it can be used for nuclear weapons. Even if the plutonium vector, which is produced in power reactors, does not have the ideal properties for military use from a physics point of view, it is still basically suitable for making weapons (Mark, 1993; US DOE, 1994).

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

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

6.4 Uranium mining - specific requirements for sustainable mining

The term sustainability, which actually has its roots in forestry and therefore relates to the renewable resource of wood, is now being discussed in mining too, although the latter involves extracting minerals, which cannot grow again. In the light of this fact, sustainability in mining needs to be defined differently. The discussion about defining sustainable or eco-friendly mining is still continuing (e.g. Gorman & Dzombak, 2018; Lahiry, 2017; Tyson, 2020). Gorman & Dzombak (2018) focus on the need to view sustainability throughout the usage cycle of a mining operation and apply existing environmental rules for sustainability. The taxonomy environmental objective no. 4 "Moving towards a circular economy, preventing waste and recycling" is relevant here. Lahiry (2017) calls for strong supervision through government authorities to enforce sustainability and reliable environmental standards. Tyson (2020) emphasises that a specific form of sustainability can be achieved in mining if all the stakeholders are involved in defining sustainability (and its implementation) on an equal footing and fairly.

There is no real discussion of the term "sustainable mining" in the JRC Report (cf. particularly JRC Report Part A 3.3.1.4, p. 76 at the bottom). The report does not examine the discussion about sustainable mining has any repercussions for investigating the environmental effects of uranium mining. However, it is important in terms of other sustainability goals or the minimum safeguards laid down in Article 18 of the Taxonomy Regulation (cf. BMK, 2020, p. 22 too).

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

Abbreviations

Abbreviation	Explanation
AkEnd	Arbeitskreis Endlagerung (Disposal Working Group)
ALARA	As low as reasonably achievable
BASE	Bundesamt für die Sicherheit der nuklearen Entsorgung (Federal Office for the Safety of Nuclear Waste Management)
BfS	Bundesamt für Strahlenschutz (Federal Office for Radiation Protection)
BMU BMUB	Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) Bundesministerium für Bundesministerium für Umwelt,
	Naturschutz, Bau und Reaktorsicherheit (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)
CCPNM	Convention on the Physical Protection of Nuclear Material
CO ₂	Carbon dioxide
CSS	Carbon Capture & Storage
DFG	German Research Foundation
DGR	Deep Geological Repository
DNSH	Do No Significant Harm
EU	European Union
EURAD	European Joint Programme on Radioactive Waste Management
Gen I, II, III	Generations of nuclear power plants
GRS	Gesellschaft für Anlagen- und Reaktorsichereit (Society for Plant and Reactor Safety)
н	Human intrusion
HLW	High-level waste
HAW	High active waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection

ILW	Intermediate-level waste
INRAG	International Risk Assessment Group
ISL	In situ leaching
JRC	Joint Research Centre
KKW	nuclear power plants
КОМ	EU Commission
kWh	Kilowatt hour
LCA	Life cycle analysis
LLW	Low-level waste
МТО	Human-technical organisation
MWe	Megawatt electric
NEA	Nuclear Energy Agency
NGO	Non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
OECD-NEA	Organisation for Economic Co-operation and Development –
OECD-NEA P&T	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutation
OECD-NEA P&T SDAG Wismut	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutation Wismut Soviet/German joint stock company
OECD-NEA P&T SDAG Wismut SEWD	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutation Wismut Soviet/German joint stock company Disruptive action or other effects caused by third parties
OECD-NEA P&T SDAG Wismut SEWD SMA	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutation Wismut Soviet/German joint stock company Disruptive action or other effects caused by third parties Low- and intermediate-level radioactive waste
OECD-NEA P&T SDAG Wismut SEWD SMA SMR	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutation Wismut Soviet/German joint stock company Disruptive action or other effects caused by third parties Low- and intermediate-level radioactive waste Small modular reactors
OECD-NEA P&T SDAG Wismut SEWD SMA SMR StandAG	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutationWismut Soviet/German joint stock companyDisruptive action or other effects caused by third partiesLow- and intermediate-level radioactive wasteSmall modular reactorsSite Selection Act
OECD-NEA P&T SDAG Wismut SEWD SMA SMR StandAG StrlSchV	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutationWismut Soviet/German joint stock companyDisruptive action or other effects caused by third partiesLow- and intermediate-level radioactive wasteSmall modular reactorsSite Selection ActRadiation Protection Order
OECD-NEA P&T SDAG Wismut SEWD SMA SMR StandAG StrlSchV TEG	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutationWismut Soviet/German joint stock companyDisruptive action or other effects caused by third partiesLow- and intermediate-level radioactive wasteSmall modular reactorsSite Selection ActRadiation Protection OrderTechnical Expert Group on Sustainable Finance
OECD-NEA P&T SDAG Wismut SEWD SMA SMR StandAG StrlSchV TEG	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutationWismut Soviet/German joint stock companyDisruptive action or other effects caused by third partiesLow- and intermediate-level radioactive wasteSmall modular reactorsSite Selection ActRadiation Protection OrderTechnical Expert Group on Sustainable FinanceTechnical screening criteria
OECD-NEA P&T SDAG Wismut SEWD SMA SMR StandAG StrlSchV TEG TSCs	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutationWismut Soviet/German joint stock companyDisruptive action or other effects caused by third partiesLow- and intermediate-level radioactive wasteSmall modular reactorsSite Selection ActRadiation Protection OrderTechnical Expert Group on Sustainable FinanceTechnical screening criteriaTerawatt hour
OECD-NEA P&T SDAG Wismut SEWD SMA SMR SMR StandAG StrlSchV TEG TSCs TWh	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutationWismut Soviet/German joint stock companyDisruptive action or other effects caused by third partiesLow- and intermediate-level radioactive wasteSmall modular reactorsSite Selection ActRadiation Protection OrderTechnical Expert Group on Sustainable FinanceTerawatt hourGerman Environment Agency
OECD-NEA P&T SDAG Wismut SEWD SMA SMR SMR StandAG StrlSchV TEG TSCs TWh UBA	Organisation for Economic Co-operation and Development – Nuclear Energy Agency Partitioning und transmutationWismut Soviet/German joint stock companyDisruptive action or other effects caused by third partiesLow- and intermediate-level radioactive wasteSmall modular reactorsSite Selection ActRadiation Protection OrderTechnical Expert Group on Sustainable FinanceTerawatt hourGerman Environment AgencyUnited Nations

VLLW	Very low-level waste
W&T	Science and technology
WAA	Reprocessing plant
WENRA	Western European Nuclear Regulators Association

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